DESIGN OF A HIGH-PERFORMANCE CONCRETE MIX FOR USE IN DOWEL BAR RETROFIT

A Research Report

By

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Prepared For
The North Dakota Department of Transportation
2003

RCS HHO-30-19

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

EXPERIMENTAL PROJECT REPORT

EXPERIMENTAL PROJECT	EXPERIMENTAL PROJECT NO. 1 STATE: NDSU; YEAR: 2000 - NUMBER: 01; SURF:	CONSTRUCTION PROJ NO 8	LOCATION 28
	EVALUATION FUNDING 48 1 X HP&R; 2 CONSTRUCTION; 3 DEMONSTRATION; 4 IMPLEMENTATION	NEEP NO. 49	PROPRIETARY FEATURE? 51 Yes; No X
SHORT TITLE	TITLE 52: Design of a High-Performance Concrete Mix for use in Dowel Bar Retrofit		
THIS FORM	DATE 140 MO. -- YR.	REPORTING: 1 INITIAL; 2 ANNUAL; 3 FINAL X	
KEY WORDS	KEY WORD 1 (145): Dowel Bars	KEY WORD 2 (167): Concrete	
	KEY WORD 3 (189): Load Transfer	KEY WORD 4 (211): Durability, Shrinkage	
	UNIQUE WORD (233):	PROPRIETARY FEATURE NAME (255):	

CHRONOLOGY	Date Work Plan Approved (277)	Date Feature Constructed: (281)	Evaluation Scheduled Until: (285)	Evaluation Extended Until: (289)	Date Evaluation Terminated: (293)
	12-2000				2003

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

AVAILABLE EVALUATION REPORTS	CONSTRUCTION	PERFORMANCE	FINAL
	315		X

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

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

REMARKS 321

Trial concrete mixes were made using local aggregates, an air entraining admixture, a water reducing (superpasticizer) admixture, and an accelerating admixture. The final mix design had high early strength (greater than 4,000 psi in 6-hours), 9-inch slump, and 5.75% air content. The final mix design was placed in Styrofoam molds that had the same dimensions as the dowel bar slots in the field. The final mix design showed no signs of debonding or shrinkage. The estimated cost for materials (concrete patch mix only and no labor costs) per slot is approximately $1.83 to $2.06. These costs will vary depending on the supplier or manufacturer of each material used.

Form FHWA 1461

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EXECUTIVE SUMMARY

Dowel bar retrofit is a method of restoring load transfer at faulted joints in concrete pavement by using smooth dowel bars placed in slots cut at the joint. The North Dakota Department of Transportation has experimented with this method for repairing some of the state's concrete highways. Although this method has proven to be effective in restoring load transfer, some of the sites have experienced distress associated with the commercially available concrete mixes used for patching the slots. These mixes have shown problems with durability and shrinkage as well as being expensive.

The objective of this research was to develop a high-performance patch mix using locally available materials. The concrete mix should exhibit several important properties including high early strength, good workability, low shrinkage, and good durability.

In this research, laboratory tests were performed with different percentages of admixtures, cement, and water/cement ratios. Various combinations of ingredients were tested until an optimum mix exhibiting that produced a mix with all the targeted properties was reached.

The report contains five chapters, including an introduction to the field and review of existing methods and applications. The final targeted mix is presented in chapter IV under the designation trial mix 3-12 (Table 4.5). The strength achievement of this mix was independently confirmed by an outside testing laboratory. Chapter V summarizes the research effort and provides a cost breakdown of different concrete ingredients in producing the concrete patch mix. Future research recommendations are also provided.

ACKNOWLEDGMENTS

We would like to express our gratitude to Mr. Clayton Schumaker, Mr. Tom Bold, Mr. Bryon Fuchs, and the Division of Research and Materials of the North Dakota Department of Transportation (NDDOT) for funding and supporting this research.

We would also like to thank Mr. Hank Hauge and Master Builders Industries for providing the admixtures for our research and the invaluable advice and information regarding concrete technology. We are very grateful to Mr. David Sethre of the North Dakota Ready Mix and Concrete Products Association for the useful information and encouragement he provided us on dowel bar retrofit.

We appreciate the assistance of Mr. Earl Nelson from the North Dakota DOT, Fargo District, for helping us visit several sites in the Fargo District and see the dowel bar retrofit process during construction.

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I. INTRODUCTION

1.1. Background

Concrete pavements are constructed with transverse joints to accommodate the expansion and contraction of the concrete slabs. Many of the interstate highways were constructed using plain concrete pavements with no dowels at the joints. The design of these pavements relies on the aggregate interlock to provide for the transfer of load from one side of the joint to the other. Load transfer is the ability of a joint or a crack to transfer load from the slab on one side of the joint to the other through shear action. The effectiveness of aggregate interlock in providing load transfer decreases with long-term heavy loading and environmental changes. Cold weather and heavy loads increase the rate of aggregate wear at the joint, and eventually, the load transfer is completely lost. Jointed reinforced concrete pavements (JRCP) that develop mid-panel working cracks due to reinforcing steel rupture or corrosion also rely on aggregate interlock and may eventually exhibit poor load transfer. Load transfer is very important since it affects the magnitude of the slab deflection and the stress distribution. Poor load transfer causes increased concentrated stresses at the joint, leading to pumping and faulting at the joint.

Load transfer is usually measured by determining the load transfer efficiency of the joint. Load transfer efficiency is defined as the ratio of the deflection of the unloaded slab to the deflection of the loaded slab as shown in Figure 1-1 (Pierce, 1994). The test used to measure the deflections of the slabs is called the Falling Weight Deflectometer (FWD), where the slab on one side of the joint is loaded and the deflections of both the loaded and adjacent slabs are measured at the joint. Some DOTs specify that, when the load transfer efficiency drops below 60%, there is a need for load transfer restoration (Federal Highway Administration [FHWA], 1997).

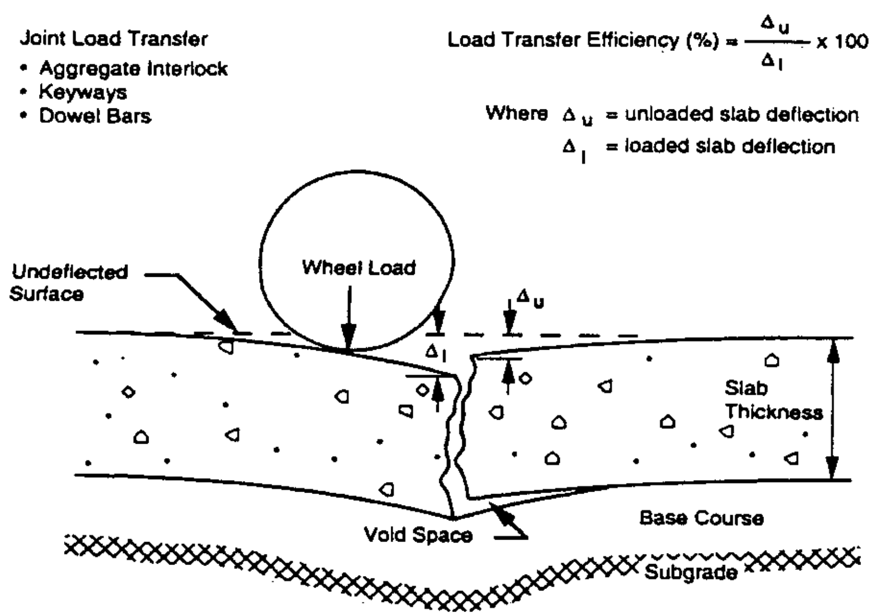


Figure 1-1. Concept of joint load transfer efficiency (Pierce, 1994).

Load transfer restoration is achieved by placing a mechanical device across the joint or crack. Several types of mechanical devices have been used, but the most effective one is the use of smooth dowel bars placed in slots cut in the pavement at the joint or crack. This method is called dowel bar retrofit. Generally, three to four bars are placed in each wheel path. The dowels used are usually 1.25" or 1.5" in diameter, and the bar length is at least 7 inches on each side of the joint. A typical layout of the dowels is shown in Figure 1-2.

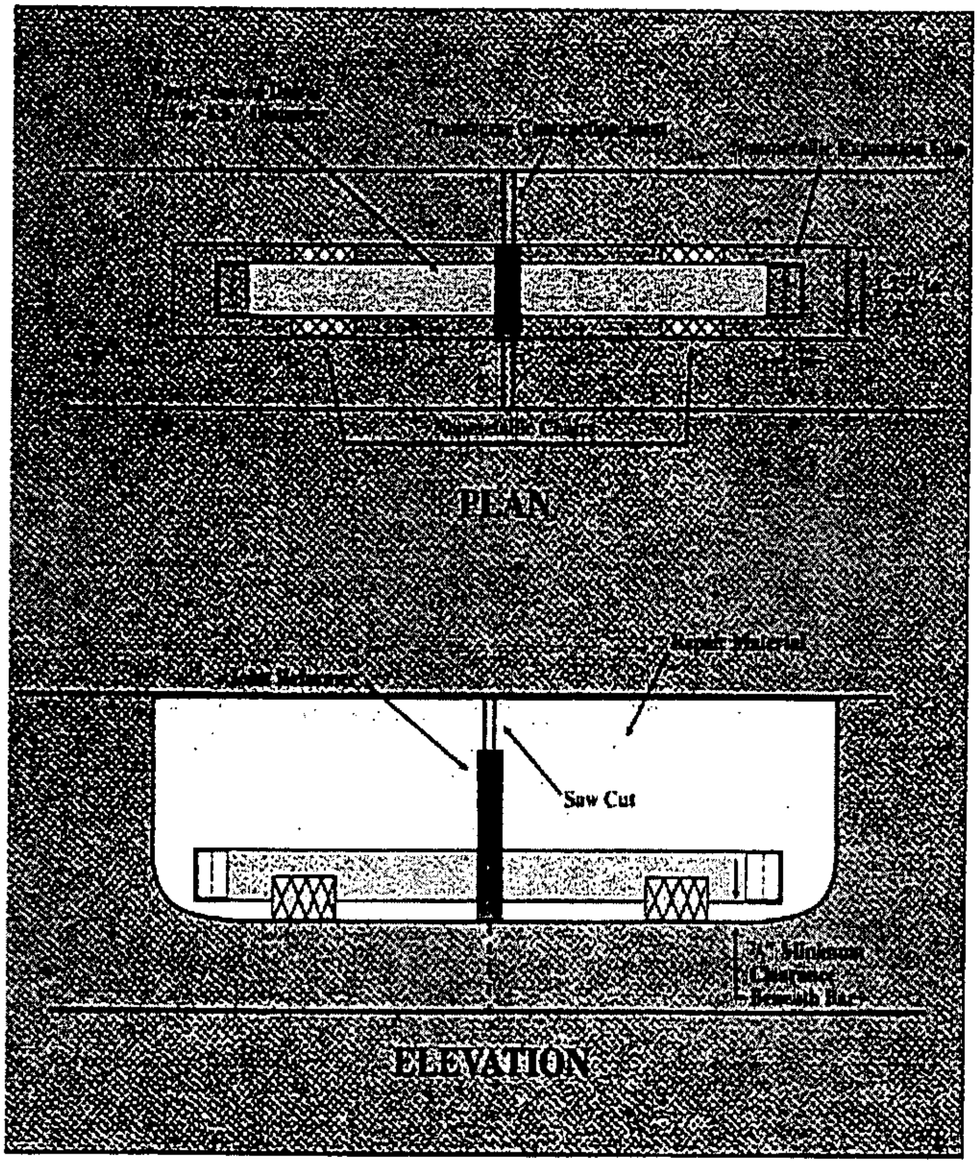


Figure 1-2. Typical dowel bar retrofit detail (Dunn, 1998).

The North Dakota Department of Transportation (NDDOT) has experimented with dowel bar retrofit as a technique for rehabilitation of some concrete pavement roadways. Some problems were encountered with the patch mixes used to fill the slots after placing the dowel bars. The problems encountered with these test sections were mainly durability and shrinkage issues. Most of the patch mixes used were proprietary mixes, which generally have high costs. Deterioration (i.e. any loss of the integrity and/or strength) of the patch concrete can render the dowel bar retrofit ineffective in transferring the load at the joint or crack. Therefore, it is important to use a patch mix with properties specifically tailored for this application. The patch mix must satisfy the specifications for dowel bar retrofit provided by the NDDOT and achieve the properties for a concrete mix needed in such an application. It is also important to use a patch mix composed of known materials to be able to adapt the mix to any future changes in the properties needed for this application.

1.2. Objective of Study

The main objective of this study is to develop a high performance concrete patch mix that has a low cost and uses locally available materials. A high performance mix is defined, in this study, as a mix that would attain high early strength in a short period of time (4000 psi in 6 hours), while maintaining a good workability during its placement and exhibiting good durability during its life cycle. In order to achieve these objectives, several issues were covered in detail. First, different types of materials used in concrete production available locally were considered. Second, the dowel bar retrofit technique with respect to its installation method was studied. Third, the types of distress encountered in patch mixes used in previous dowel bar retrofit projects were analyzed in detail, and finally, the properties of the concrete mix needed for this specific application were identified.

1.3. Methodology

The methodology used to achieve the objectives of this study included a Literature Review, discussions with field engineers and concrete manufacturers, field visits, and laboratory experiments. The Literature Review covers the dowel bar retrofit technique, and properties and materials used for high performance concrete.

Information about locally available concrete materials was obtained by discussions with field engineers and concrete manufacturers. Field visits were made to observe the installation method for dowel bar retrofit and to study the types of distress encountered in previous projects. Finally, developing the concrete mix with the specified properties using trial mixes was achieved by laboratory testing.

1.4. Report Outline

This report is comprised of five chapters including the Introduction. The second chapter deals with the Literature Review. The third chapter includes a discussion of the materials chosen for testing in the trial batches and the testing procedure used. The fourth chapter contains the results and discussion of the different phases of experimentation. The fifth and last chapter is a conclusion of this study's results and recommendations for future work. The report also includes appendices and references.

II. LITERATURE REVIEW

2.1. Load Transfer Restoration

A considerable portion of the highway system in the United States consists of jointed concrete pavements. When pavements are subjected to heavy truck traffic and severe climatic conditions, various types of pavement deterioration occur. A major part of this deterioration occurs at the joints and intermediate cracks. Loss of load transfer at a joint or crack is one of the types of distress that results in high deflections (Darter et al., 1985). This problem causes increased pumping which is the displacement of fines from under the slab on one side of the joint to the other, resulting in voids forming under the slab which becomes unsupported and generally leads to faulting at the joint.

In order to retard further deterioration of the pavement, restoration of load transfer across a transverse joint or crack is used. If overlays are placed over joints or cracks with poor load transfer, reflective cracks that will spall and deterioration will soon develop (Darter et al., 1985).

Several types of mechanical devices have been used for restoration of load transfer at joints and cracks in concrete pavements. To evaluate the effectiveness of the restoration methods, Gulden and Brown (1985) experimented with various load transfer devices that were placed in 28 test sections. The devices included split pipes, figure-eight, vee, double-vee, and dowel bars. The short-term performance data indicated that the dowel bars were performing well and were not restricting the horizontal joint movement.

2.1.1. Repair Using Dowel Bar Retrofit

Reiter et al. (1988) conducted a study to test the field performance of four load transfer restoration devices. Round steel dowels, double-vee, figure-eight, and miniature I beam shear devices were tested. Thirteen uniform test sections located in nine states were chosen. The performance of dowel bar retrofit was evaluated by faulting and visual inspection. After an average of 3.8 years of service and 2.62 million equivalent single axle loads (ESALs), the mean faulting value was only 0.04 inch, and 98% of the devices were in good condition. Compared to the other devices, the retrofit dowel bars were the most effective in the reduction of faulting. It was reported that the critical factor for the device performance was the performance of the backfill material.

It was also pointed out that the application of this technique reduces the cost of repairing faulted joints and cracks by one-half compared to the cost of full-depth pavement repair and reduces the time of repair by one-third. It was reported that, in the fall of 1997, the Kansas Department of Transportation repaired 18.75 miles of State Highway K-10. The pavement was constructed originally as an undoweled JPCP and was faulting at the transverse joints.

The Kansas DOT estimated a savings of $10 million compared to a total reconstruction of the pavement and expected a 10- to 20-year extension of the pavement's service life (Larson et al., 1998). In the state of North Dakota, the reconstruction cost of 11 miles of I-29 was estimated at $1 million/mile. The cost of the dowel bar retrofit technique was under $200,000/mile.

To place the dowel bars, slots are cut in the pavement at the joints or crack. It is a current practice to place three dowels in each wheel path. In a study by Tayabji and Colley (1983), the stresses and deflections for 6 dowels spaced nonuniformly in a joint (3 in each wheel path) were similar to those of 12 uniformly spaced dowels. Therefore, they concluded that placing the dowels in the wheel path should be more cost-effective. The slots are normally cut perpendicular to the joint, and the dowel bars are placed in the slots at the center of the pavement cross-section.

It is recommended to use dowel bars with diameters of at least 1.25 inches to 1.5 inches for heavy traffic pavements (Reiter et al, 1988). The repair projects visited in this study in North Dakota used 18-inch long dowel bars that were 1.5 inches in diameter with a slot length of 35 to 36 inches as shown in Figure 2-1.

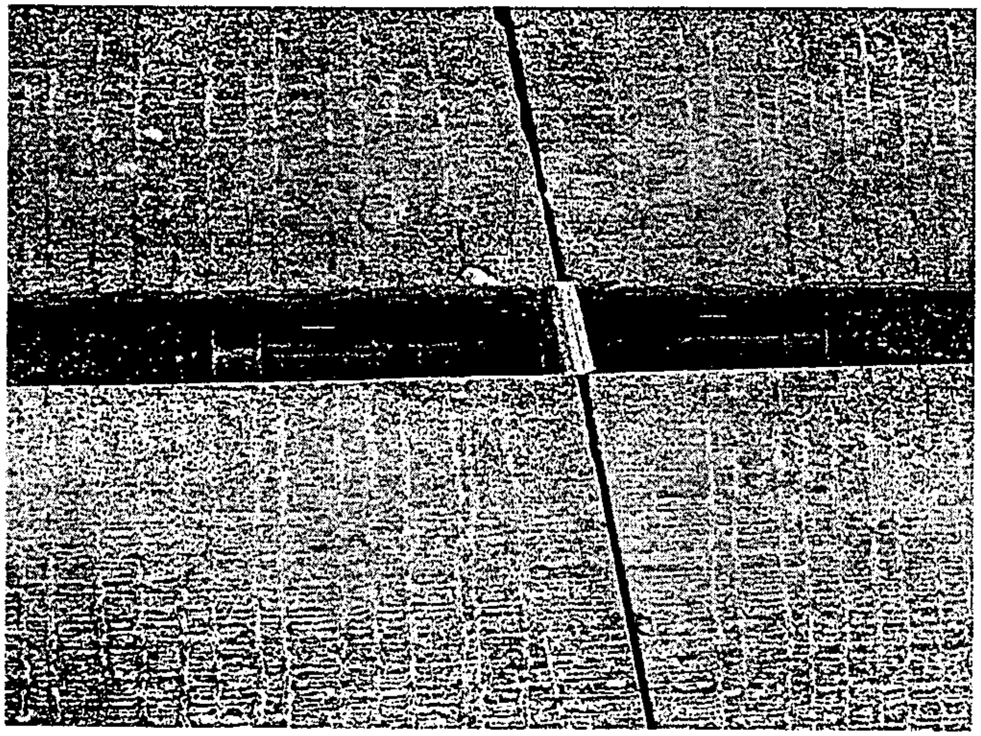


Figure 2-1. Dowel bar placed in the slot.

2.2. Installation Method for Dowel Bar Retrofit

Proper installation of the dowel bar retrofit system is critical for the success of this method in improving load transfer, and care must be taken during construction. The *Concrete Pavement Rehabilitation Guide for Load Transfer Restoration* (FHWA, 1997) provides details of the installation method which will be summarized in this section. There are five main steps for proper installation of the dowel bars.

2.2.1. Cutting the Slots

Two different types of equipment are available for cutting slots in existing pavements: diamond saw cutters and milling machines. Diamond saw cutters make two parallel cuts (Figure 2-2a) for each dowel slot while milling machines cut the entire slot at once (Figure 2-2b). The slots must be aligned parallel to the centerline of the pavement. These machines are capable of cutting several slots at the same time in one wheel path or in both.

(a)

(b)

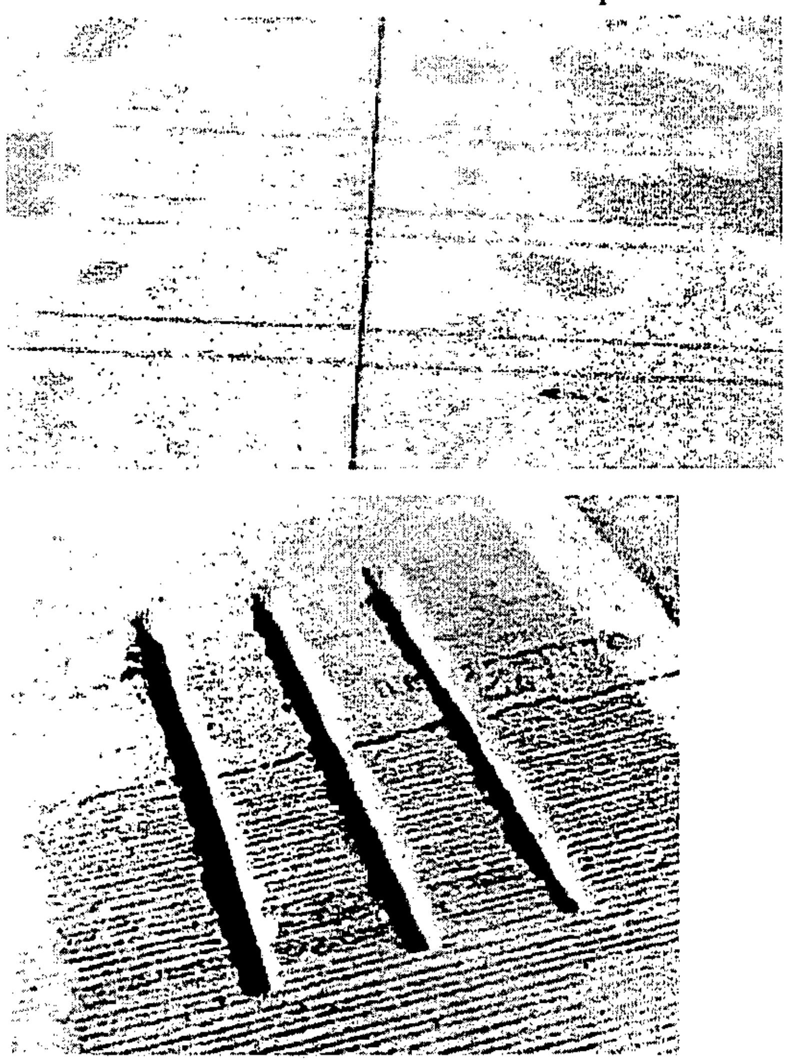


Figure 2-2. Cutting the slots for dowel bar retrofit (Pierce, 1994).

2.2.2. Preparation of the Slots

In case of diamond saw cutters, the concrete fins left between the cuts must be removed using small handheld jackhammers (Figure 2-3) and the bottom of the slots must be flattened using a small hammerhead. The slot is then cleaned by sandblasting and air blasting to remove any loose debris (Figure 2-4). When milling machines are used, the slot must also be cleaned. Caulking material is then applied to the side and bottom of the slot at the joint to prevent the patching material from flowing down into the joint (Figure 2-5).

Figure 2-3. Removing the fines (Pierce, 1994).

Figure 2-4. Flattening the bottom
of the slot (Pierce, 1994).

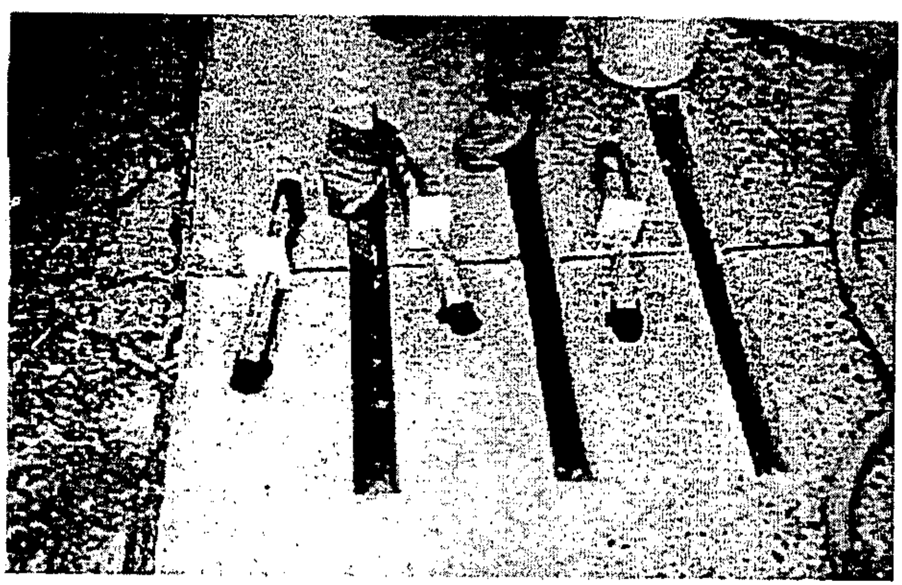


Figure 2-5. Applying the caulk material (Pierce, 1994).

2.2.3. Placing the Dowel Bars

Before the dowels are placed in the slots, they are fitted with expansion caps, foam core board, and chairs (Figure 2-6). The dowel bar must be coated with a debonding agent to allow for the expansion and contraction of the pavement segment. Dowels are placed in the slot and must be aligned parallel to the road centerline and surface (Figure 2-7). The sides of the slots are wetted (Figure 2-8) for good adhesion between the grout and the pavement.

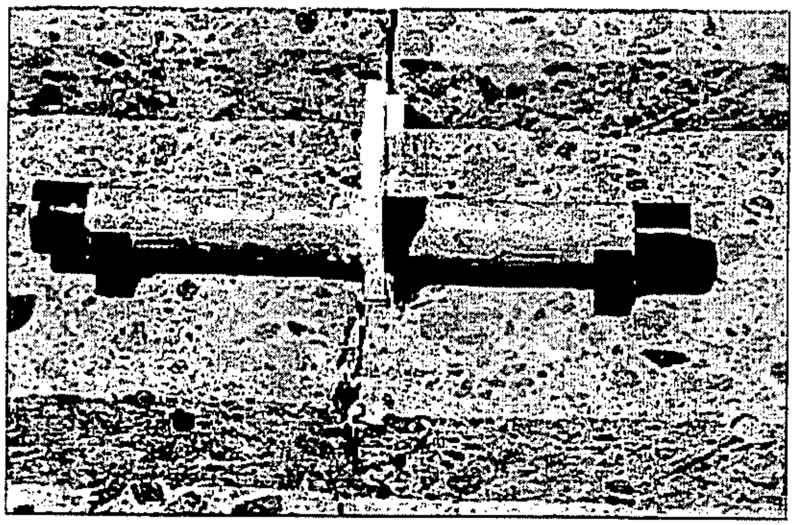


Figure 2-6. Dowel bar fitted with board, expansion caps, and chairs (Pierce, 1994).

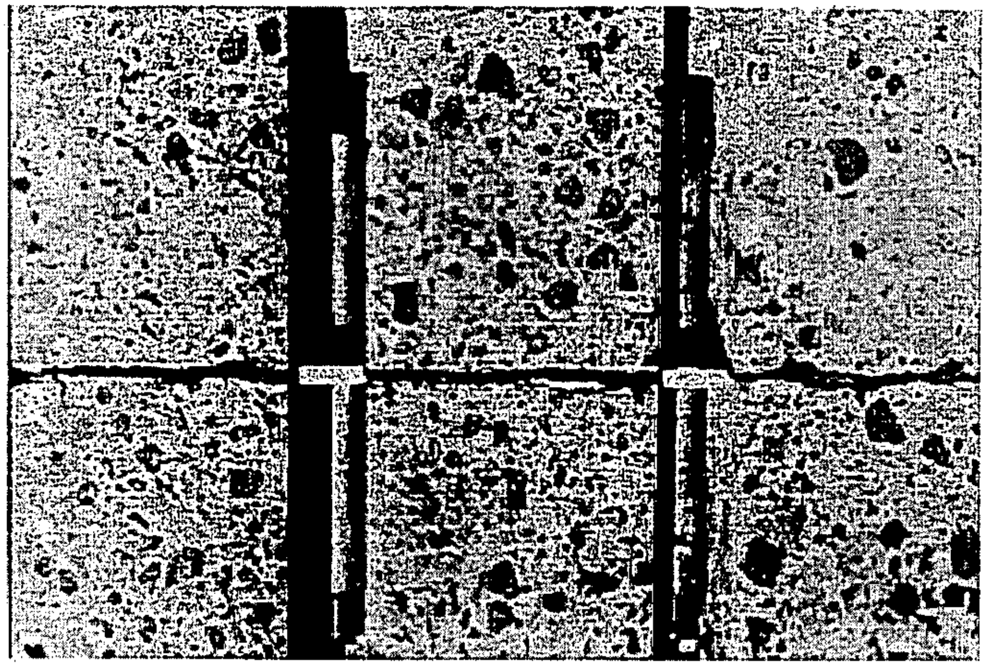


Figure 2-7. Dowels placed in the slot (Pierce, 1994).

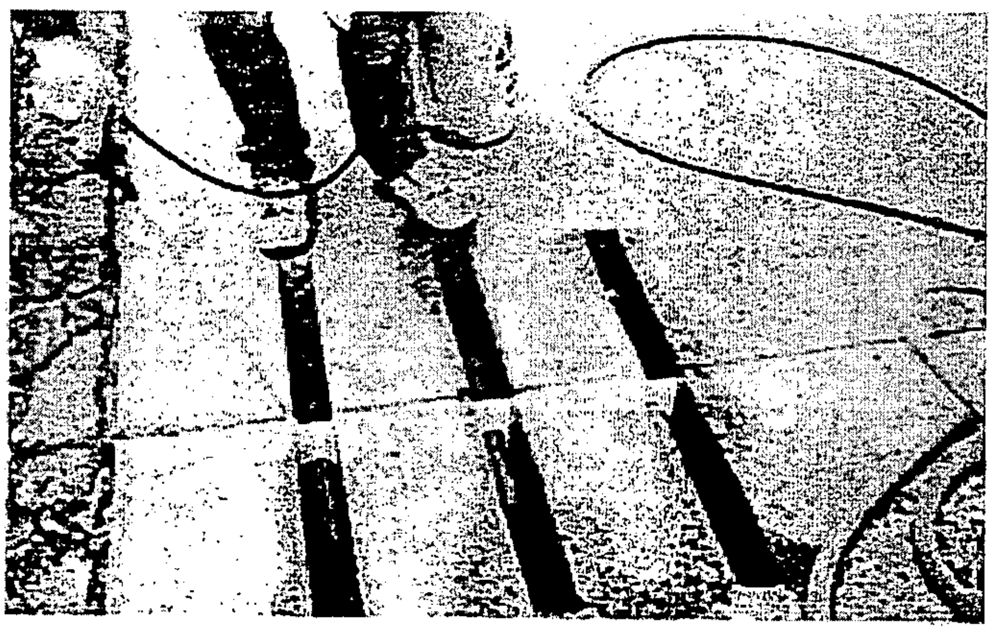


Figure 2-8. Wetting the sides of the slot
(Pierce, 1994).

2.2.4. Grouting the Slots

The patch material is placed in the slot and consolidated with a small vibrator (Figures 2-9 and 2-10).

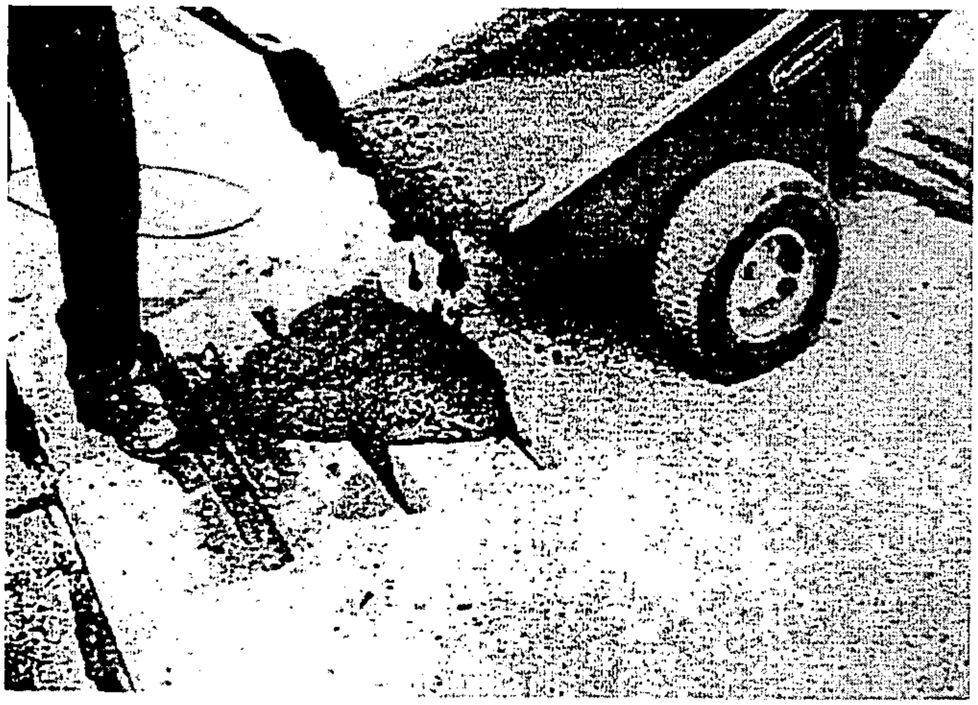


Figure 2-9. Placing the patch concrete (Pierce, 1994).

Figure 2-10. Mix is vibrated (Pierce, 1994).

2.2.5. Curing

After consolidation, a curing compound is applied to the patch material to decrease shrinkage.

2.3. Use of Dowel Bar Retrofit in North Dakota

2.3.1. Background

In the state of North Dakota, the Department of Transportation has recently started using this technique for rehabilitation of the state's faulted pavements. A study was performed by the NDDOT to test the effectiveness of this method in improving the load transfer and decreasing the faults in jointed concrete pavements. This study was initiated in 1995 when test sections were incorporated in projects IM-8-029(003)022 and IM-6-029(022)186. The Materials and Research Division of the NDDOT has been monitoring and evaluating the performance of the retrofitted sections, and has issued an annual report to this effect.

Several problems have been observed in the test sections. Some types of distresses were found to be due to construction problems while others were due to the inadequacy of the patch mix used to grout the slots. In the next section, a brief account of the types of patch material used and the mix design will be presented, and the types of distress observed will be outlined.

2.3.2. Patch Mix Used in NDDOT Projects

Two types of patch materials were used in the test sections. One was a mix designed using locally available materials and was obtained from the Minnesota Department of Transportation (MnDOT), which identifies the mix as 3U18. The other one was a commercial mix (Patchroc 10-60) produced by FOSROC.

2.3.2.1. Specifications of the 3U18 Mix

The following mix design was used for 1 cubic yard:

Cement	850 lbs
Water	295 lbs
Sand	1318 lbs
Coarse Aggregate	1341 lbs
w/c ratio	0.35

The cement specified was of type I, IA, II, or IIA, meeting the requirements of Section 804.01 of the NDDOT *Standard Specifications for Road and Bridge Construction* (1992) stating that Portland cement should meet the requirements of AASHTO M-85. Air-entraining admixtures were proportioned according to the requirements of Section 808.01 of the NDDOT *Standard Specifications for Road and Bridge Construction* (1992), which states that air-entraining admixtures should meet the requirements of

AASHTO M-154. The air content of the mix was required to be maintained at 5.5% ± 1.5%

Fine aggregates met the requirements of Section 816.01 of the North Dakota specifications which states that fine aggregates should meet the requirements of AASHTO M-6 but with some changes as stated in NDDOT *Standard Specifications for Road and Bridge Construction (1992)* (Refer to the NDDOT special provision SP-141-1992). The following list was the specification for the sand gradation:

Sieve	%Passing
#4	95-100
#8	80-100
#16	55-85
#30	30-60
#50	5-30
#100	0-10

Coarse aggregate also met the requirements of Section 816.02 of the NDDOT *Standard Specifications for Road and Bridge Construction (1992), Special Provision, SP-141-1992*. The gradation of the coarse aggregate was

Sieve	%Passing
3/8"	100
#4	70-95

2.3.3. Types of Distress Observed in Some of the NDDOT Projects

According to the evaluation performed on the two previously mentioned projects, several types of distress were found in the dowel bar retrofit. In the IM-6-029(022)186 project, which was constructed in the Grand Forks District, both types of patching material were used. The average load transfer efficiency before installing the dowel bars was between 20 and 30%. After installation, the average load transfer was 76%. The areas with load transfer of less than 50% were located in the areas where the Patchroc 10-60 was used.

One problem that was encountered during construction was the existence of voids under the dowels in some of the slots due to insufficient vibration of the mix. This problem was discovered when several cores were taken after the test sections were constructed as seen in Figure 2-11. This problem caused the type of distress shown in Figures 2-12 and 2-13 where the mix has become loose and severe cracking is evident. The material has disintegrated.

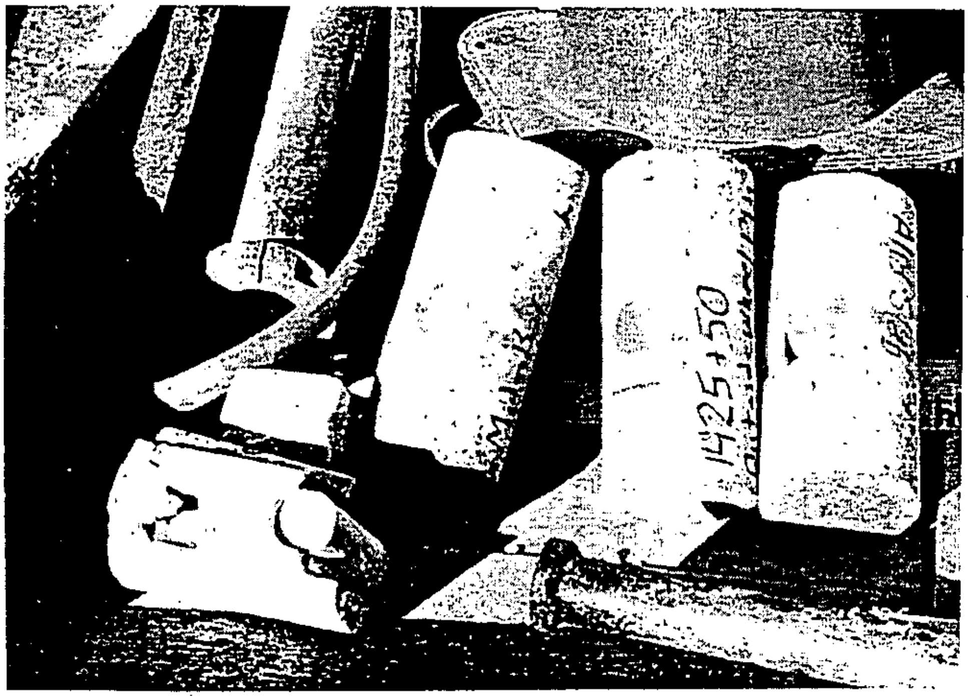


Figure 2-11. Several cores taken from the test sections (Dunn, 1998).

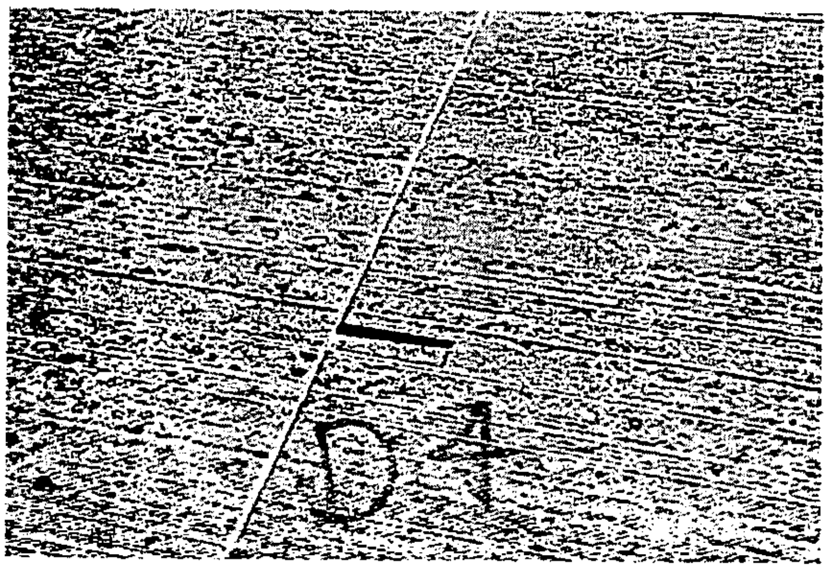


Figure 2-12. Distress due to insufficient mix vibration (Dunn, 1998).

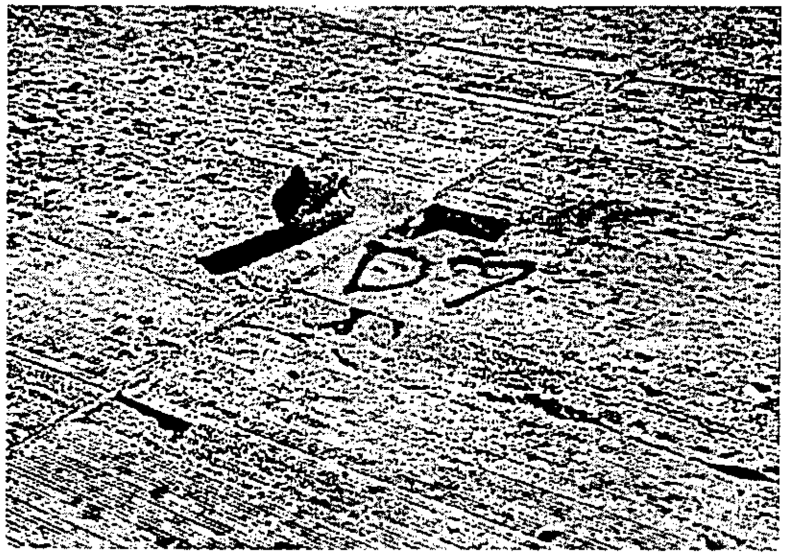


Figure 2-13. Similar distress: complete block of concrete has become loose (Dunn, 1998).

Another type of distress was caused by the failure of the core board to remain vertical during placement of the patching concrete. When the core board leaned on its side, concrete mix had lost its support. This area became unsupported and, therefore, unable to sustain the load from the traffic. This type of failure is shown in Figure 2-14. This problem was fixed in the following projects by changing the dimensions of the core board to prevent it from losing its stability.

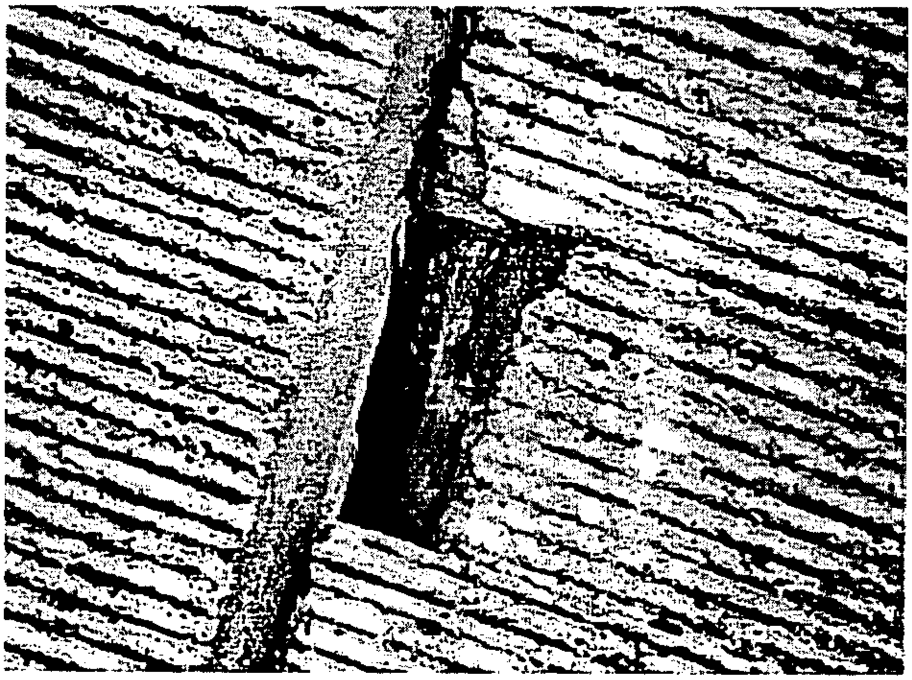


Figure 2-14. Distress caused by core board failure (Dunn, 1998).

Several of the problems encountered were caused by the mix itself. As seen in Figure 2-15, the patch concrete has completely deteriorated, especially closer to the joint where the stresses are higher. In some areas, the surface of the patch had worn away to the extent that it is no longer the same elevation as the pavement. This distress is shown in Figure 2-16.

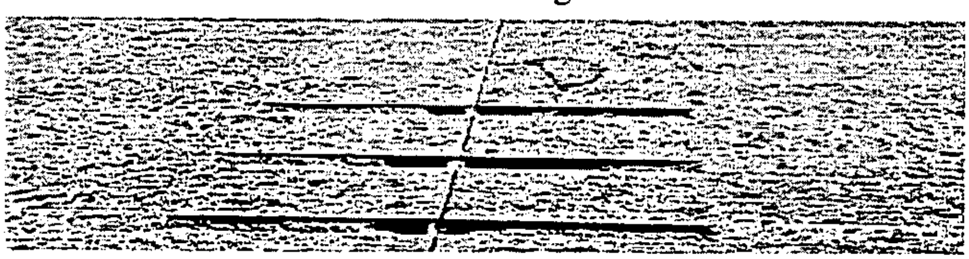


Figure 2-15. Patch concrete deterioration (Dunn, 1998).

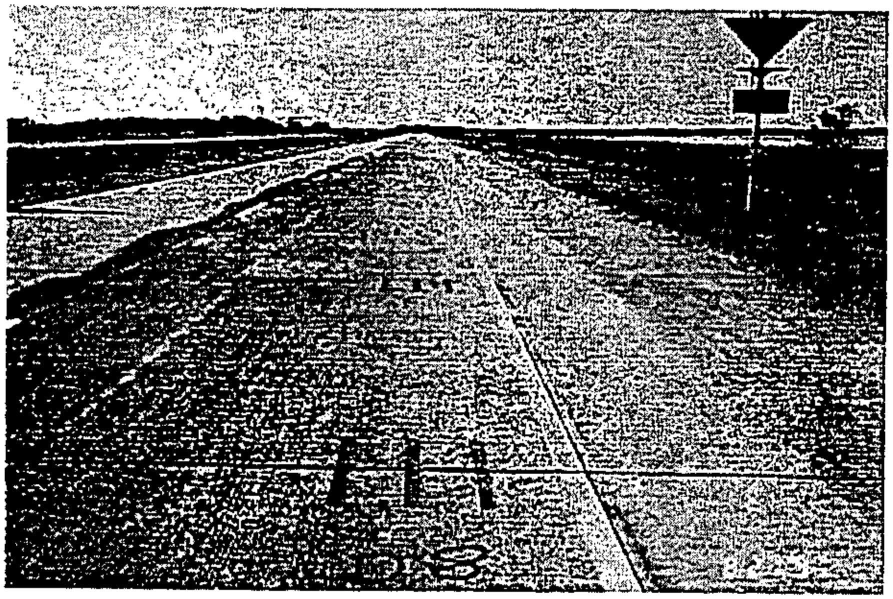
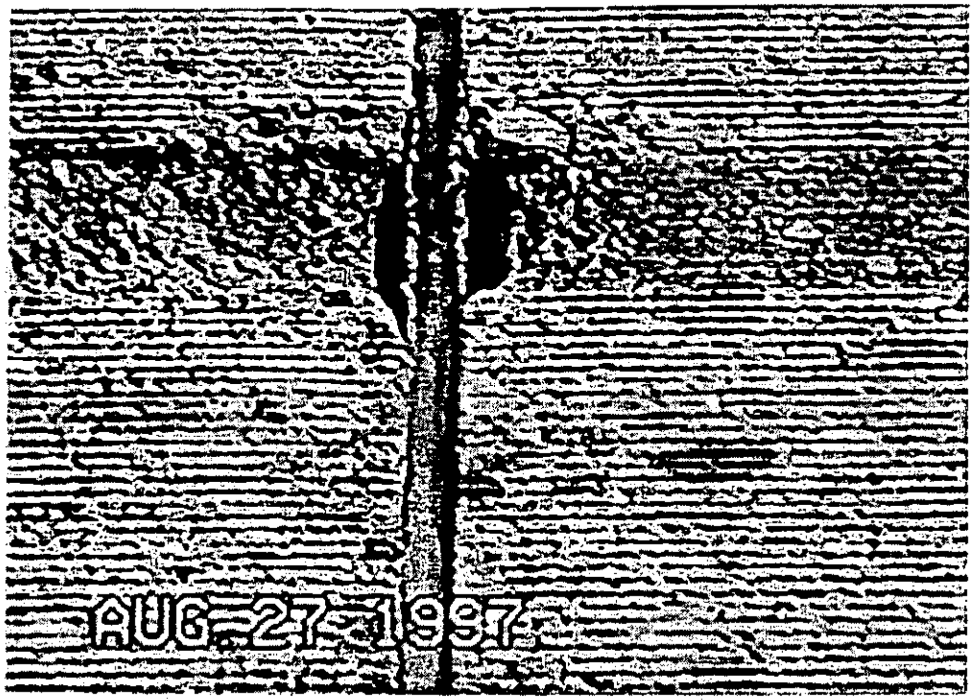


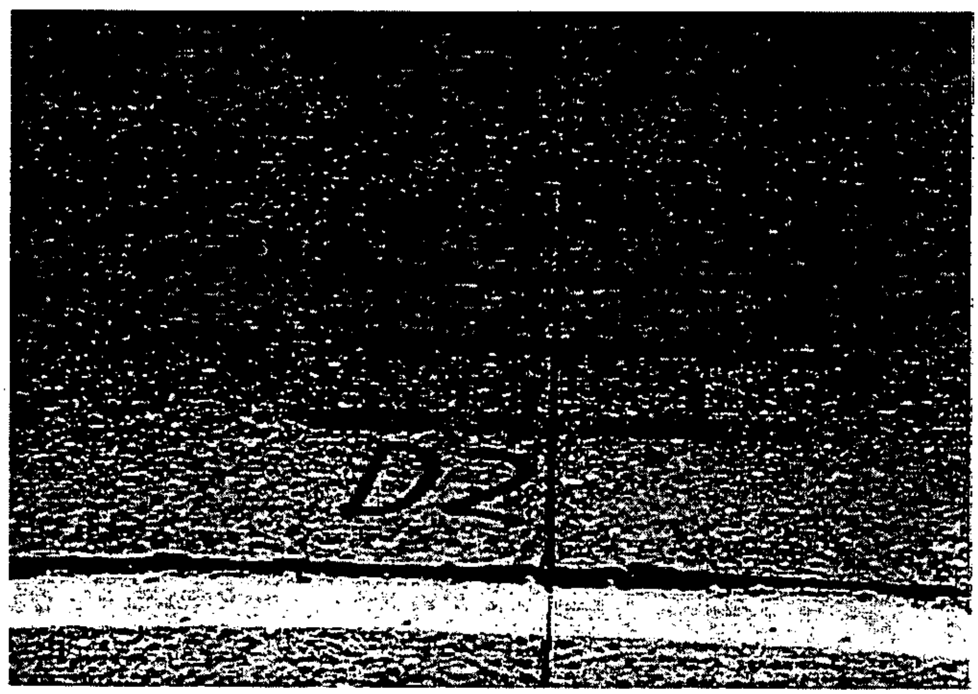
Figure 2-16. Wearing of the patch concrete Dunn, 1998).

Another problem was initiated by insufficient care taken during construction as seen in Figures 2-17a and 2-17b. Cracking on both sides of the joint is evident. On closer observation, it was discovered that the bonding problem between the patch mix and the existing concrete was caused by excess caulking material on the sides of the slots at the location of the joint.

In test sections where the 3U18 mix was used, additional types of distress (cracking) were noted. The cracking seen in Figures 2-18 and 2-19 running transverse and longitudinal to the dowel bar slots is due to shrinkage of the patch concrete.



(a)



(b)

Figure 2-17. Distress caused by excess caulk material (Dunn, 1998).

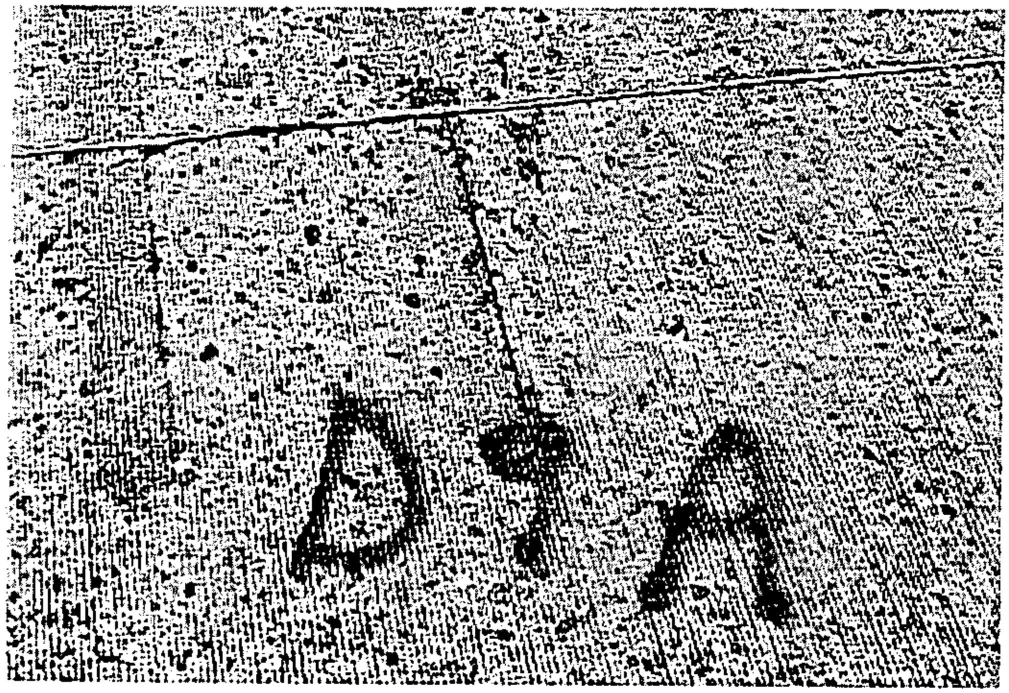


Figure 2-18. Longitudinal shrinkage cracks (Dunn, 1998).

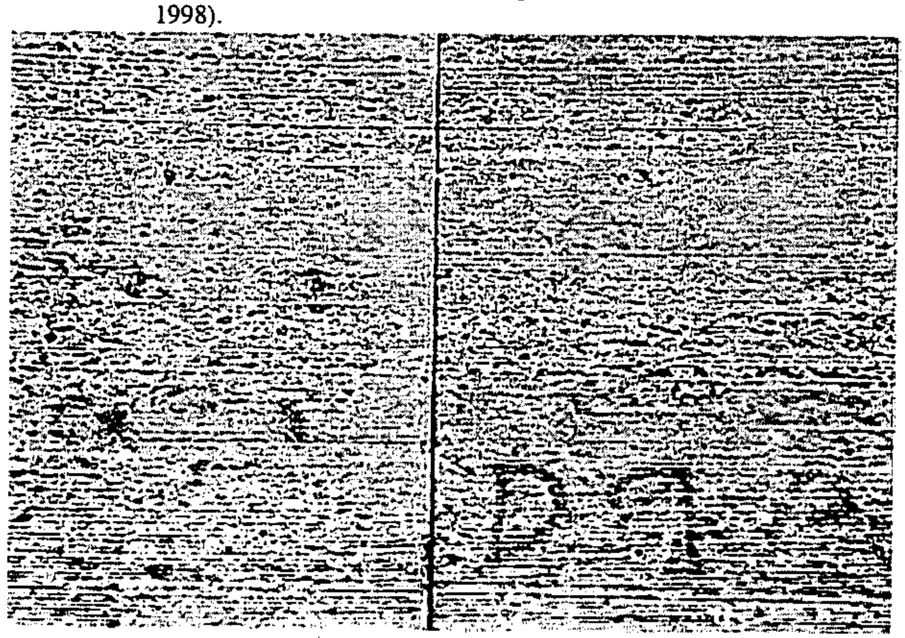


Figure 2-19. Transverse shrinkage cracks (Dunn, 1998).

The types of distress caused by problems in the construction procedure itself have been fixed in the new DOT projects, and provisions have been added to the NDDOT Dowel Bar Retrofit Specifications to prevent these problems from reoccurring. As for the performance of the patching concrete, it is clear that its performance must be improved for use in retrofitting the state's highways. Identifying the required properties of the patching concrete is an important step in developing a high-quality mix, and this issue will be discussed in the next section of the report.

2.4. Targeted Properties for Patch Concrete

The performance of the patching material used to grout the slots has an important role in the success of this method of rehabilitation. If the performance of the grout is inadequate and deterioration occurs, the load transfer at the joint can be affected, and failure of the dowel bar retrofit system becomes inevitable. Therefore, it is important to develop a high performance mix with specific properties for this special application. Identifying these properties and studying the methods for achieving these specific properties is an important step in developing this material. The most important of these properties are

- High early strength
- Little or no shrinkage
- Strong bond with existing concrete
- High durability, which includes
  - Freeze-thaw resistance

- Abrasion resistance

- Good workability and consistency
- Compatible thermal conductivity with existing concrete

2.4.1. High Early Strength

In this kind of application, it is important to use a mix that achieves high strength values at an early stage to minimize the time needed to close the road for repairs. Usually, there are only a few hours in the day between rush hours or during the night when the disruption to traffic is the least. During these hours, the processes of placing, consolidating, and curing need to be completed, and the concrete must reach a suitable strength that will sustain the traffic load. The NDDOT requires the patch mix for dowel bar retrofit to have a minimum compressive strength of 4,000 psi in 6 hours.

High early strength can be achieved using Type III cement or a rich mix of Type I. Type I cement is the regular cement used for most of the general construction applications. Type III cement is chemically similar to Type I cement except that its particles are ground finer (Kosmatka and Panarese, 1994). Also, there are special cements called Regulated-Set cements that produce concrete with fast setting properties and very high early strength.

Lowering the water to cement ratio as much as possible assists in achieving high early strength. In some cases, accelerating admixtures such as calcium chloride have been used to accelerate the strength gain of the concrete. Nevertheless, calcium chloride has some drawbacks. It causes an increase in drying shrinkage, possible reinforcement corrosion, and concrete discoloration.

2.4.2. Minimize Shrinkage of Concrete

As concrete hardens, it loses moisture, and its volume decreases. Concrete volume is also affected by temperature changes. Cracking can occur due to drying and thermal shrinkage if it causes tensile stresses larger than the tensile strength of the concrete. This type of distress has been shown in the previous section and must be avoided since it can cause deterioration of the mix and debonding from the existing concrete.

Minimizing shrinkage of concrete can be achieved by using non-shrinkage cement in the mix or by adding admixtures which will be discussed in more detail in the next section. Shrinkage can be minimized by keeping the water content as low as possible and keeping the total coarse aggregate content as high as possible. Also, proper curing of the concrete reduces shrinkage (Kosmatka and Panarese, 1994).

Use of hard and rigid aggregates decreases shrinkage of the mix because they are difficult to compress and provide more restraint to shrinkage of the cement paste. It is important to avoid aggregates containing excessive amounts of clay (Kosmatka and Panarese, 1994). It must be noted that shale is available in North Dakota, but it contains expansive clays that expand when exposed to moisture. This volume change should be avoided because it can cause cracking in the concrete.

It is important to note that the use of admixtures can affect shrinkage. Accelerators such as calcium chloride increase drying shrinkage. Many types of water-reducing admixtures also increase drying shrinkage substantially, despite the decrease in water content (Kosmatka and Panarese, 1994).

Shrinkage is also affected by the volume to surface area ratio of the concrete. As shown in Figure 2-20, shrinkage decreases as the volume to surface area ratio increases. Therefore, the samples that will be used for testing the concrete mix will be dimensioned so that they have the same volume/surface area ratio as the actual slots.

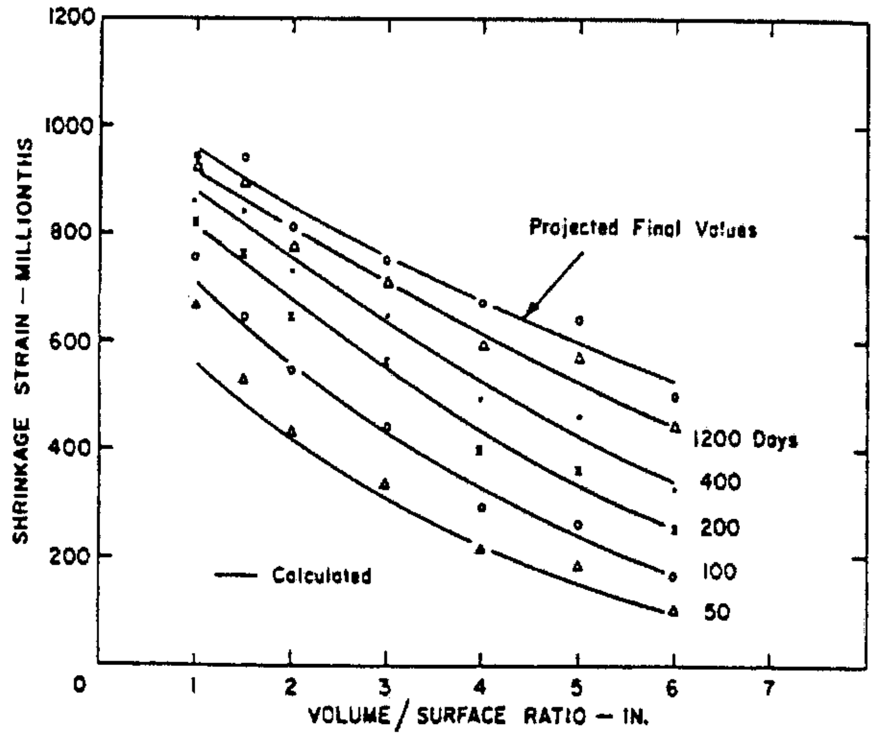


Figure 2-20. Effect of volume/surface area ratio on the shrinkage of concrete.

2.4.2.1. Shrinkage Compensating Cement (Expansive Cement)

There are three types of shrinkage compensating cements, identified as K, M, and S, and designated as E-1 in the ASTM C845. Type I cement can also be used by adding admixtures (Kosmatka and Panarese, 1994).

Expansive concrete is produced either by using expansive cement or by adding an admixture to the concrete mix. In both cases, the component that causes the expansion is calcium sulfoaluminate which forms ettringite when combined with calcium sulfate and lime during the hydration process (Womack, 1993). Special provisions must be taken when using expansive concrete. Proper curing is very important, and it is essential that enough water be provided throughout the curing process so that the ettringite can form. Ponding or continuous sprinklings are the preferred methods of curing (Womack, 1993).

Expansive concrete should not be placed in hot temperatures. In cold weather, proper cold weather concreting practices must be followed. It is recommended that the desired expansion of the concrete be specified. 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, might affect the expansion of the concrete (Womack, 1993).

However, according to the *Concrete Pavement Rehabilitation Guide for Load Transfer Restoration* (FHWA, 1997), it is not recommended to use high-alumina cement as it is susceptible to conversion of some of its calcium aluminate hydrate components, which may result in a significant strength loss.

2.4.3. Strong Bond Between Patch Concrete and Existing Concrete

To ensure proper load transfer, it is important to have a strong bond between the patching concrete and the existing concrete of the pavement slab. The objective of using dowel bars is to provide a means of transferring the load from one slab to the adjacent slab across the joint, and this load transfer will not be fulfilled if the bond between the old and new concrete is too weak.

The bond between the patch concrete and the old concrete depends on the physical and chemical properties of the interface. This bond can be enhanced by providing a clean and rough surface to the old concrete. Therefore, the walls of the slot are cleaned and sandblasted before placing the patch concrete. Using grout or epoxy to improve the bond has been successful in general concrete patching applications and could be applied in the case of dowel bar retrofit. In this case, the grout is applied to the sides of the existing concrete just before placement of the patch concrete (Patel et al., 1993). Also, bonding admixtures that improve the bonding properties of concrete exist (Kosmatka and Panarese, 1994). These admixtures are added to the concrete mix but have not been used in this application.

2.4.4. High Durability

2.4.4.1. High Freeze-Thaw Resistance

The patch concrete used in this application is exposed to severe temperature changes and environmental effects. In cold climates such as North Dakota, outdoor concrete applications should exhibit good freeze-thaw resistance. Using air-entrained concrete and a low water to cement ratio improves freeze-thaw resistance of concrete. Also, the use of a good quality aggregate, and proper finishing and curing techniques improves freeze-thaw resistance (Kosmatka and Panarese, 1994).

Air-entrained concrete can be produced by using either an air-entraining cement or adding an air-entraining agent that stabilizes bubbles formed during the mixing process. Air entrainment has an effect on a wide range of concrete properties (Kosmatka and Panarese, 1994):

- Freeze thaw resistance is improved.
- Workability is improved.
- Bleeding is reduced significantly.
- Sulfate resistance is significantly improved.
- Deicer scaling is significantly reduced.
- Scaling is significantly reduced.
- Resistance to alkali-silica reactivity is improved.
- Bond to steel decreases.
- Compressive strength is reduced approximately 2% to 6% per 1 percentage increase in air.
- Flexural strength is reduced approximately 2% to 4% per 1 percentage increase in air.
- Modulus of elasticity decreases with increased air approximately 105,000 to 200,000 psi per 1 percentage increase in air.
- Slump increases with increased air approximately 1 inch per ½ to 1 percentage increase in air.

- Thermal conductivity decreases 1% to 3% per 1 percentage increase in air.
- Unit weight decreases with increased air.
- Water demand of wet concrete for equal slump decreases with increased air.
- Permeability is reduced slightly due to the reduction of the water to cement ratio.
- Watertightness is increased slightly due to the reduction of the water to cement ratio.

According to the building code (ACI 318) requirements for reinforced concrete (ACI, 1999), concrete that will be subjected to moist freezing and thawing, and has a nominal maximum aggregate size of 3/8 inch should have an air content of $7^1/_2$% for severe exposure conditions and 6% for moderate exposure conditions.

2.4.4.2. High Abrasion Resistance

Wearing of the patch surface has caused problems in the previous projects constructed in North Dakota. As the patching concrete is exposed to traffic loads, the use of a high abrasion resistant material is required to resist erosion and wearing. Abrasion resistance increases with the increase of compressive strength, so a low w/c ratio and adequate curing will be beneficial. Also, hard aggregate should be used in the mix (Kosmatka and Panarese, 1994).

2.4.5. Good Workability and Consistency

The patch concrete in this application is placed in a slot that is not very wide and must completely surround the dowel bar so that no voids are formed under the bar. Therefore, the mix must have good workability, and the use of admixtures, such as superplasticizers, improves this property without unnecessary increase in the water to cement ratio. In addition, the use of air-entrained concrete improves workability and reduces bleeding (Kosmatka and Panarese, 1994).

It is clear from the previous discussion that several different properties of the patch concrete need to be addressed in order to develop a high-performance material. Enhancing one property might have an adverse effect on another; therefore, it is essential to consider the effect of each component and the interactions among components on the overall response of the mix material. This issue will be addressed during the experimental part of this research.

III. MATERIALS AND TESTING PROCEDURES

This chapter includes a brief description of the materials used for the trial mixes made in this study. In addition, a discussion of the tests performed on these trial mixes to evaluate their properties is presented in the following sections.

3.1. Materials Used in Testing

Different materials were used as ingredients for the trial mixes prepared in this research. These materials are discussed in the following sections.

3.1.1. Cement

Type III cement was chosen as the most appropriate cement for this application. Its chemical composition is similar to that of Type I cement, but its particles are ground much finer than that of Type I cement. Therefore, this cement gains strength faster than regular Type I cement. Cement from two different manufacturers was used: Holnam Type III cement and Lehigh Type III.

3.1.2. Aggregate

All of the aggregate used in the testing was supplied by Aggregate Industries, a regional aggregate supplier. The fine aggregate used was washed sand of nominal maximum aggregate size of 1/8" and was obtained from a pit in Rollag, Minnesota. The aggregate gradation of the sand is shown in Figure

3-1. Its specific gravity was 2.62, and its absorption was 1%. The coarse aggregate chosen was a granite aggregate of nominal maximum aggregate size of 3/8" as required by the North Dakota Department of Transportation specifications for dowel bar retrofit. From durability considerations, an aggregate from hard rock such as granite is preferred. The idea is to have an aggregate of high strength at low deformation and good abrasion resistance. In our study, the aggregate was obtained from a pit in Ortonville, Minnesota. Abrasion tests were not conducted on the aggregate. The aggregate gradation is shown in Figure 3-2. Its bulk specific gravity was 2.47, and absorption was 1.02%. Natural pea gravel was also tested with a nominal maximum size of 3/8" as it is currently being used in retrofit applications. The bulk specific gravity for pea gravel was 2.51, and absorption was 2.01%.

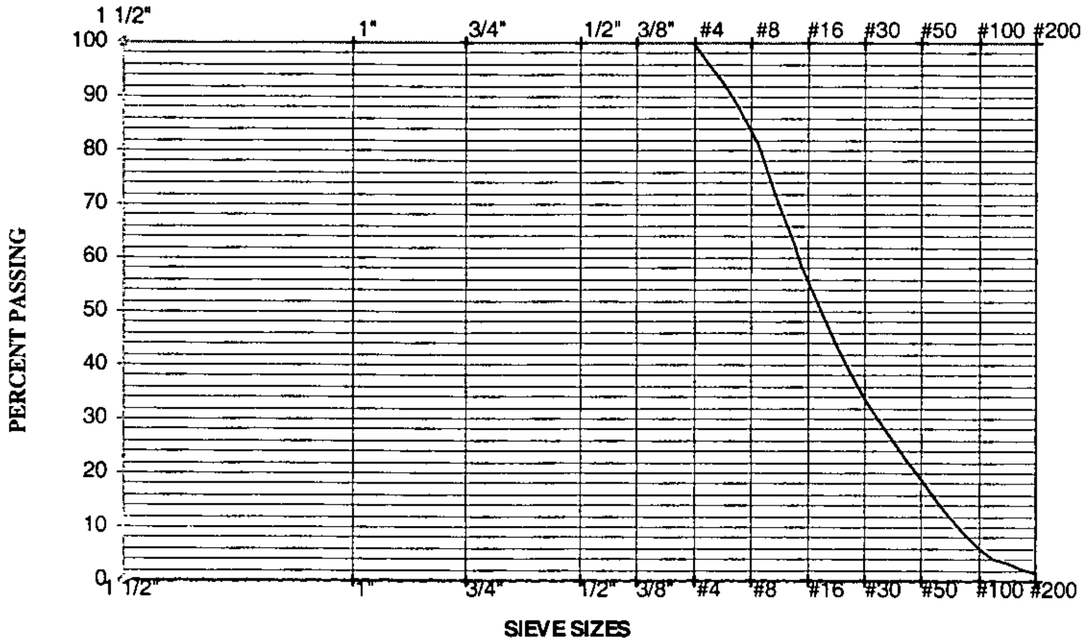


Figure 3-1. Gradation of fine aggregate.

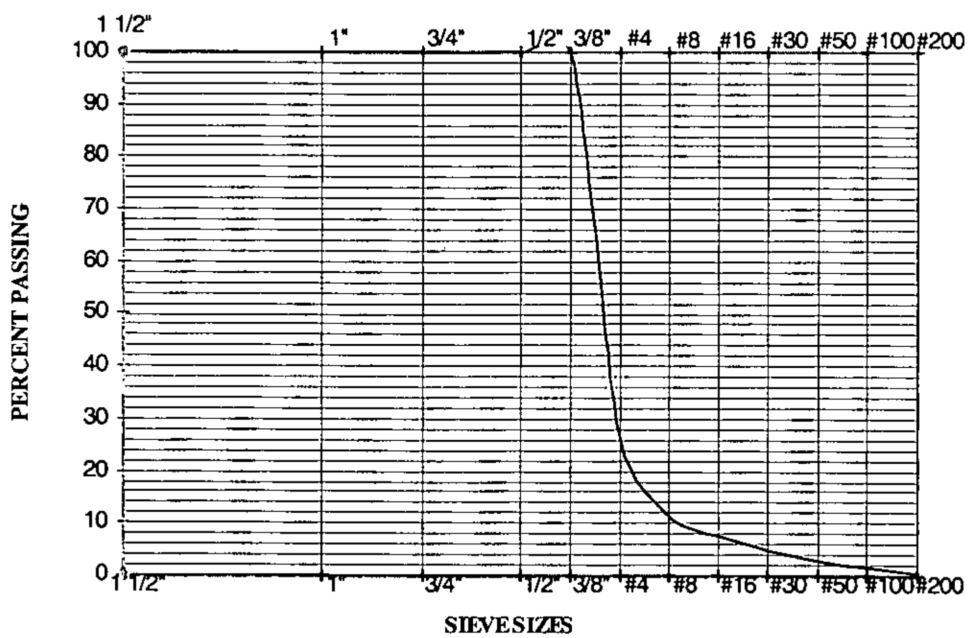


Figure 3-2. Gradation of coarse aggregate.

3.1.3. Admixtures

3.1.3.1. Air-Entraining Admixture

The air-entraining admixture used in the concrete mix was Pave-Air obtained from Master Builders Technologies. Pave-Air is designed for entraining air in paving concrete mixes. It meets the requirements of ASTM C 260, AASHTO M 154, CRD-C 13, and other federal and state specifications.

The advantages of using this admixture are (Master Builders, Inc., 1999)

- Improving freeze-thaw resistance
- Improving scaling resistance to deicing salts
- Reduces permeability
- Reducing segregation and bleeding
- Improving plasticity and workability

3.1.3.2. Accelerating Admixtures

Two types of accelerating admixture obtained from Master Builders Technologies were tested; the first was Pozzutec 20, which is a non-chloride, water-reducing and accelerating admixture formulated to accelerate concrete setting time and ultimate strength of concrete. The recommended dosage rate range for this admixture is 5 to 60 fl.oz./100lb of cement. The second accelerator was Pozzolith NC534, which is a ready-to-use, non-chloride admixture that complies with ASTM C 494 Type C accelerating admixture requirements. It is used to accelerate the setting time of concrete, and to increase its early and ultimate compressive strength. The recommended dosage rate ranges from 10 to 45 fl.oz./100lb of cement.

3.1.3.3. Water Reducing Admixture

A high-range, water-reducing admixture (superplasticizer) was chosen to reduce the water content of the concrete mix and keep the concrete flowing. The product used was Rheobuild 3000FC, which meets the ASTM C 494 requirements for Type A, water-reducing, and Type F, high-range water-reducing admixture. This type of admixture is recommended for use in concrete mixes with high early and ultimate strengths, and good durability. It produces a cohesive, non-segregating mix with reduced water content for a given slump.

3.2. Preliminary Phase

This phase of testing was designed to give a first indication for the suitability of the materials chosen and the testing procedure used. The results obtained from this phase indicated a need to change several elements of the testing. The mixing procedure was later altered in the following phases and some of the materials used. Therefore, an explanation of the steps used for mixing and the materials chosen in this phase is included in this section. Also, the reasons for changing some of the materials and the mixing procedure are presented.

A concrete mixer with a small capacity sufficient for mixing two cylinders was used, and the ingredients were added in the following order:

- Coarse and fine aggregate were weighed and put in the mixer.
- Air-entraining admixture was added.
- Half the quantity of water was added to the mixer.
- Accelerating admixture was added.
- Cement was added.
- The remaining quantity of water was added.
- Finally, the superplasticizer was added to the mix.

The total mixing time was five minutes.

In this phase, the Holnam Type III cement and the granite aggregate from Aggregate Industries were used. The natural gravel was also tested. The results of this phase are shown in Table 3-1. The first five mixes were made with the granite aggregate. Mix P6 was made with pea gravel and had the same exact proportions used for Mix P5. The compressive strength at six hours was tested. The granite aggregate preformed slightly better than the natural gravel obtained from Matson pit #103. Therefore, it was decided to use the granite due to its advantages in improving the shrinkage resistance properties and durability of concrete.

The air-entraining admixture and superplasticizer mentioned in Section 3.1.3 were used in this phase. The accelerating admixture used in this phase was the Pozzutec 20. The manufacturer recommended this type of admixture for our application and the dosages for the first trial mix (Mix P1).

In the first trial (Mix P1), the concrete was so stiff that it could not be consolidated properly. The concrete of these specimens was full of voids and, therefore, discarded; and was not tested for their compressive strength. Therefore, the accelerator and superplasticizer were increased, but there was no significant improvement in either the strength or consistency of the mix. The results of the trial mixes are given in Table 3-1. Although the maximum dosages recommended by the manufacturer for the accelerator and superplasticizer were reached, the mix was still quite stiff, and the strength was much less than the targeted value.

Table 3-1. Results of preliminary phase

Mix Number	P1	P2	P3	P4	P5	P6
Cement content (lb)	850	850	850	850	850	850
Water content (lb)	393	297.5	272	272	274.8	274.8
w/c ratio	0.38	0.35	0.32	0.32	0.323	0.323
Coarse Agg. (lb)	1518.5	1518.5	1518.5	1518.5	1482.9	1482.9
Fine Agg. (lb)	1074.7	1001.6	1071.2	958.6	958.6	958.6
Air Entraining dosage (fl.oz./100lb cement)	0.3	0.3	0.3	0.3	0.3	0.3
Accelerator dosage (fl.oz./100 lb cement)	15	15	50	90(max)	90	90
Superplasticizer dosage (fl.oz./100lb cement)	8	12 (max)	12	12	12	12
Compressive Strength at 6 hours (psi)	N/A	706	1713	1595	1197	944
Consistency	Very Stiff	Stiff	Stiff	Stiff	Stiff	Stiff

After discussions with the manufacturer, it was decided to change the mixing procedure. The superplasticizer was added with the mix water at the beginning of the mixing procedure, directly after the coarse aggregate. As a result of this modification, the consistency was greatly improved until the Pozzutec 20 was added, when the consistency of the mix became very stiff. This result showed that the Rheobuild 3000FC and the Pozzutec 20 were incompatible and should not be used together. Therefore, in the following phases of testing, another accelerator (Pozzolith NC534) was used, which proved to be compatible with the other admixtures.

Due to the manufacturer's recommendations, the mixing procedure was changed to add the superplasticizer earlier in the mixing procedure. This change provided sufficient time for the superplasticizer to be mixed and be well dispersed in the concrete. The final mixing procedure used is detailed in Section 3.3.

Another cement source (Lehigh Type III) was selected for testing, which gave better results with respect to high early strength. Therefore, it was used in the following phases of testing. In addition, a larger capacity mixer (3.5 cu. ft.) was used in the following phases, as the small mixer was not efficient in mixing the ingredients.

3.3. Preparation of Concrete Specimens

The concrete specimens used in the testing were prepared according to ASTM specification C 192[1]: Making and Curing Concrete Test Specimens in the Laboratory (ASTM, 1981). The temperature in the laboratory during the preparation of the concrete and storage of the cylinders was kept constant at 75°F.

The amount of water needed for the mix was weighed using an electronic scale of accuracy 0.1 grams. The other ingredients, cement, sand, and gravel,

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[1] AASHTO T126-93 is equivalent to ASTM C 192

were measured by weighing them on a scale with an accuracy of plus/minus 1 ounce.

All the chemical admixtures used were in liquid form. Therefore, they were measured volumetrically using graduated glass flasks and pipettes, which had an accuracy of 0.1 ml. The admixture dosages needed were calculated in fluid ounces and converted to milliliters to be measured and then added to the mix as shown in Figure 3-3.

Figure 3-3. Addition of the chemical admixtures to the mix.

The moisture content of the aggregate was measured before each trial mix to adjust the water content of the mix accordingly. A concrete mixer, of capacity 3.5 cu. ft., was used for mixing the concrete as shown in Figure 3-4. The mixer rotated at a rate of 30 revolutions/minute.

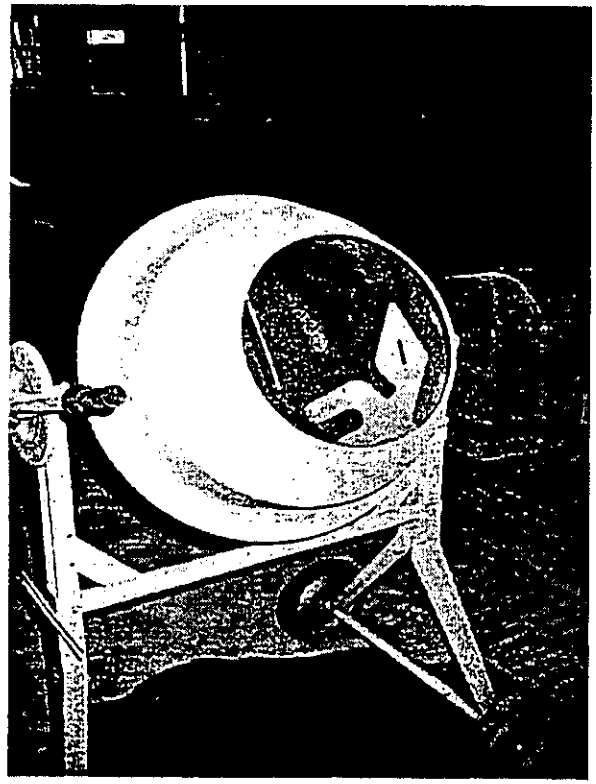

Figure 3-4. Mixer used in preparing the trial mixes.

The mixing procedure for the final trial mixes in phase III is described below. The ingredients were added using the following procedure.

- The coarse aggregate was weighed and put in the mixer.
- The superplasticizer was added to the water.
- Half the quantity of water was added to the coarse aggregate and mixed for two minutes.
- The air-entraining admixture was added directly on the fine aggregate, as shown in Figure 3-5, which was then added to the mix.
- The cement was added to the mix.

- The remaining quantity of water with the superplasticizer was then added to the mix.
- The last component to be added was the accelerating admixture.

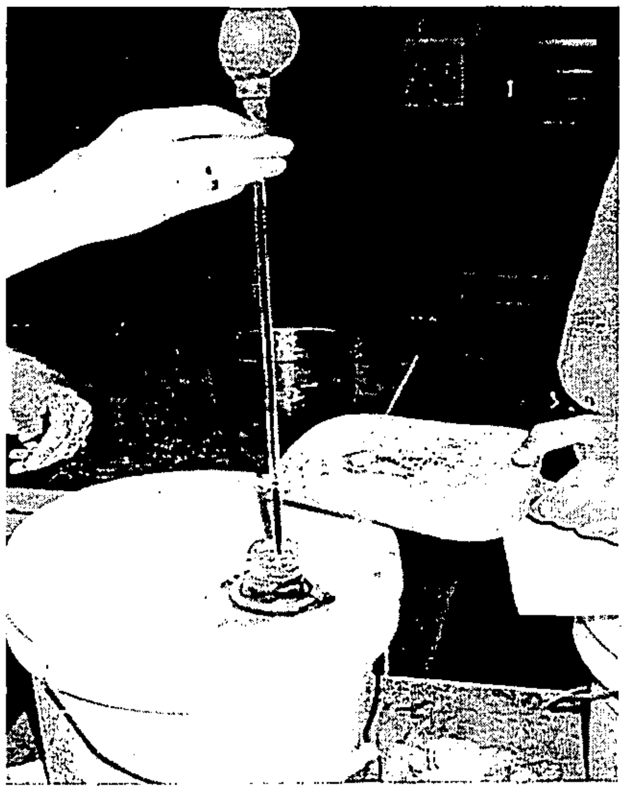

Figure 3-5. Addition of the air-entraining admixture to the sand.

The standard specifications require the concrete to be mixed three minutes after the last ingredient is placed in the mixer. This period was increased to five minutes to ensure that the effect of the superplasticizer would be retained. The mixer was then stopped for three minutes, and then, the mixing was resumed for an additional two minutes as required by the specifications.

The mixing procedure in phases I and II differed slightly from this procedure. This difference was due to the fact that, in phase I, the only admixture used was the accelerator and, in phase II, the accelerator and the superplasticizer were used together without any air-entraining agent.

Cylinders of standard size (6x12 inches) were prepared for the compressive strength testing. Single-use plastic molds obtained from Midwest Testing Laboratory, Inc. and conforming to ASTM specifications were used for the cylinders. After placing and consolidating the concrete in the cylinders, they were covered with plastic. The cylinders were then stored in the laboratory until the time of testing. Figure 3-6 shows the concrete being consolidated in the cylinder, and Figure 3-7 shows the cylinders after preparation.

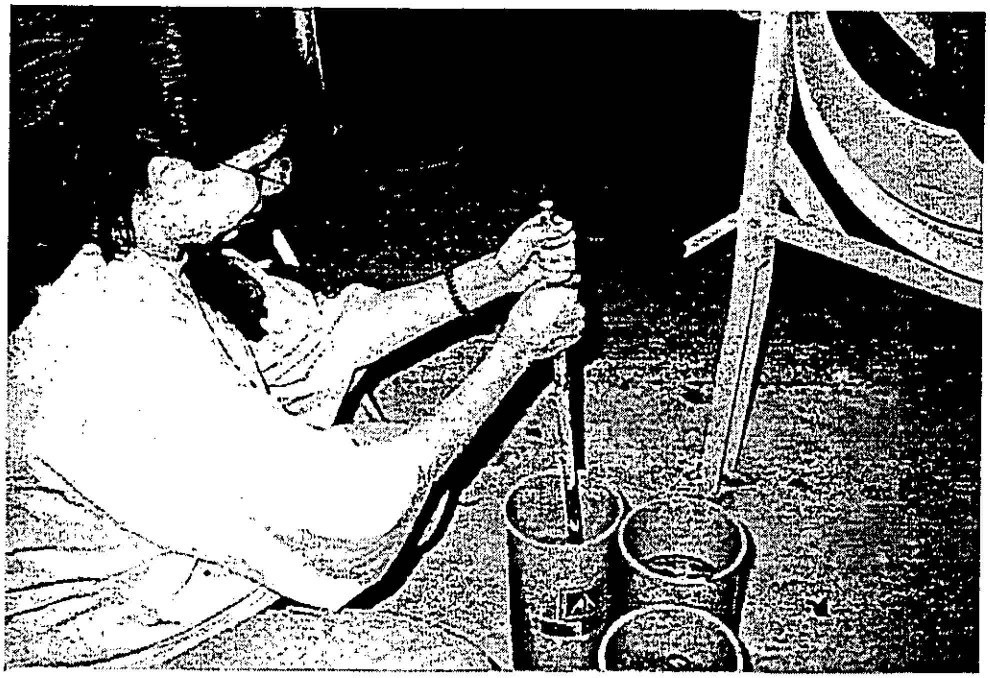

Figure 3-6. Consolidation of the cylinders.

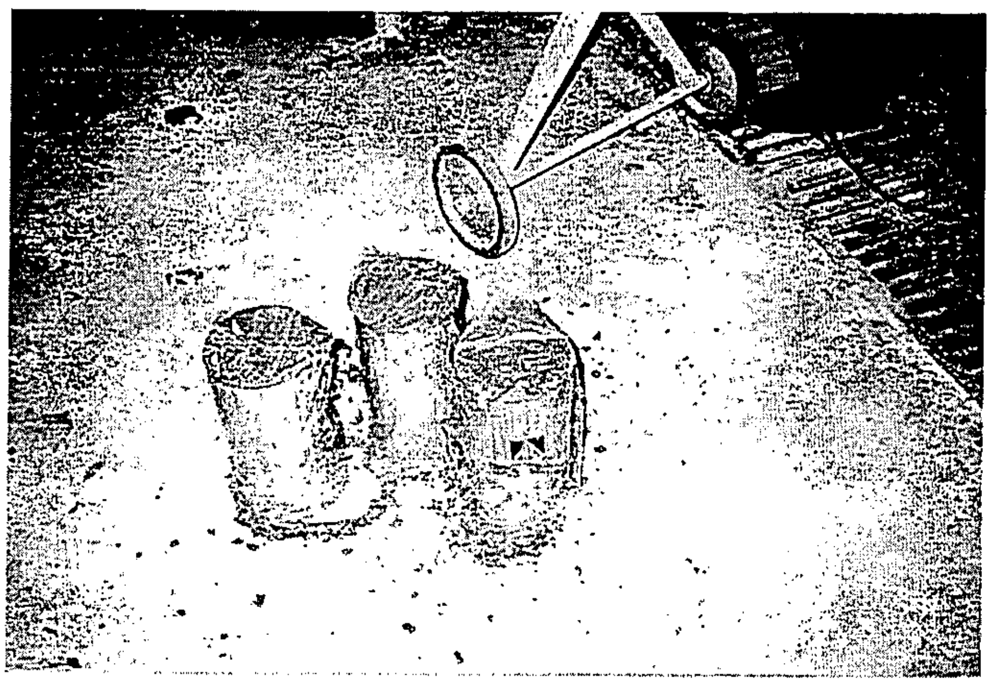

Figure 3-7. Cylinders after preparation.

3.4. Testing Procedure

The tests performed on the trial mixes to evaluate the properties of the concrete are discussed in the following sections.

3.4.1. Compressive Strength on Hardened Concrete at Six Hours

This test was performed according to ASTM specification C 39[1]: Standard Method of Test for Compressive Strength of Cylindrical Specimens (ASTM, 1983). The cylinders were removed from the molds after 6 hours of placement and then tested. The maximum compression load at failure was recorded for each trial mix. Three samples were prepared for each trial mix, and the average value for the three was calculated. The targeted compressive strength at 6 hours was 4000 psi. The testing machine used was a Satec compression-testing machine of maximum load capacity of 250,000 lbs and is shown in Figure 3-8.

[1] AASHTO T22-92 is equivalent to ASTM C 39

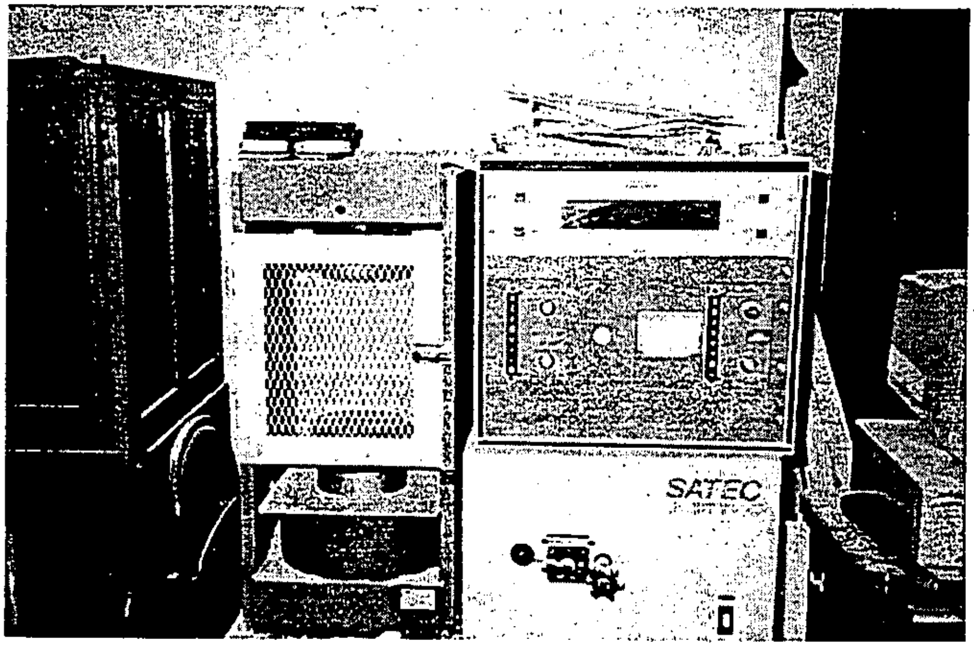

Figure 3-8. Compression-testing machine.

3.4.2. Slump

This test was performed according to ASTM specification C 143[1]: Standard Method of Test for Slump of Portland Cement Concrete (ASTM, 1978b). The target was to obtain a mix that had good workability and had a slump in the range of 7 to 9 inches, but had good consistency and did not show any segregation or bleeding.

3.4.3. Air Content

Measuring the air content of the trial mixes was performed according to ASTM specification C 173: Standard Method of Test for Air Content of

[1] AASHTO T119-93 is equivalent to ASTM C 143

Freshly Mixed Concrete by the Volumetric Method (ASTM, 1978a). Figure 3-9 shows the testing apparatus for this test. NDDOT specifes AASHTO T-52 for this particular test.

According to ACI (1999) specifications, the required air content for concrete which is exposed to moist freezing and thawing, or deicer chemicals, and contains aggregate of 3/8 inch maximum size is 7.5%. The NDDOT specifications for dowel bar retrofit require an air content of 5.5% plus or minus 1.5%. Figure 3-10 shows the improvement in durability of concrete with increase in air entrainment.

Figure 3-9. Air content test.

Kosmatka and Panarese (1994) discuss the effect of increasing the air content on reducing the expansion of concrete due to saturated freezing and thawing as shown in Figure 3-11. It is clear that the expansion decreases rapidly as the air content increases above 4%. Kosmatka and Panarese (1994) state, "Concrete mixtures with low water cement ratios may not require as much entrained air for durability as do concretes of lower quality." Therefore, in the trial mixes, it was decided that the targeted air content would be 6%.

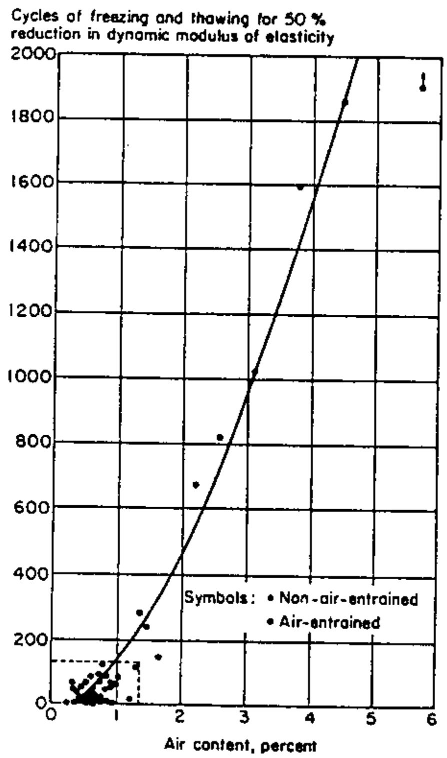

Figure 3-10. Effect of entrained air on the resistance of concrete to freezing and thawing (Kosmatka and Panarese, 1994).

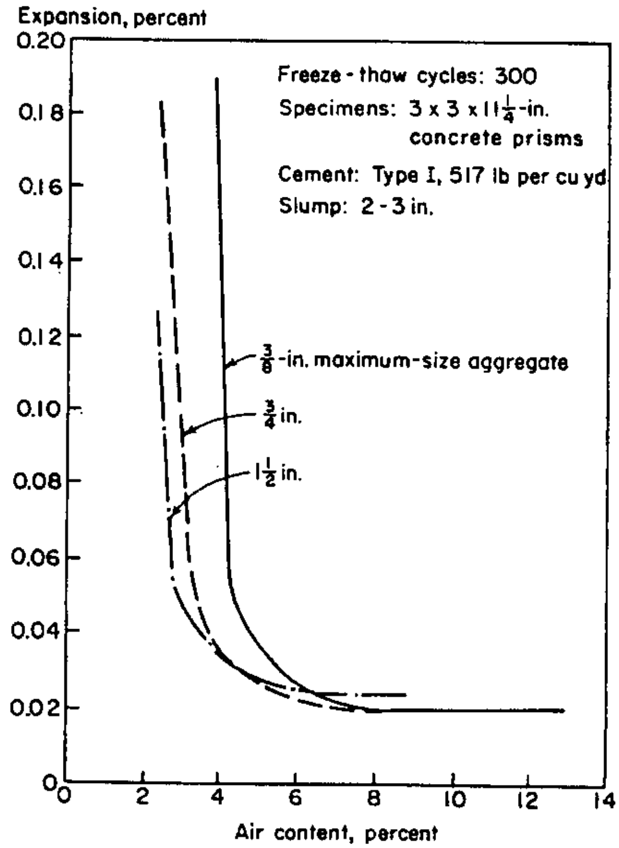

Figure 3-11. Relationship between air content and expansion of concrete specimens during 300 cycles of freezing and thawing for various maximum aggregate sizes (Kosmatka and Panarese, 1994).

3.4.4. Monitoring Shrinkage Cracks

To test the performance of the final mix for shrinkage, styrofoam molds were made to resemble the dowel bar retrofit slots. The dimensions of the laboratory slots (40" x 3" x 6" at the top and 38" x 2.5" x 6" at the bottom) were identical to the actual slots. These dimensions would ensure that the same volume to surface area ratio was maintained. A styrofoam insert was placed in the middle of the slot to simulate the core board foam placed at the joint. Styrofoam was chosen for its insulating characteristics to minimize the dissipation of heat from the sides and bottom of the slot, which resembles the actual conditions on site.

Figure 3-12 shows the empty molds prepared in the laboratory before concrete pouring. The final mix was tested in these molds and monitored for shrinkage cracks by visual inspection.

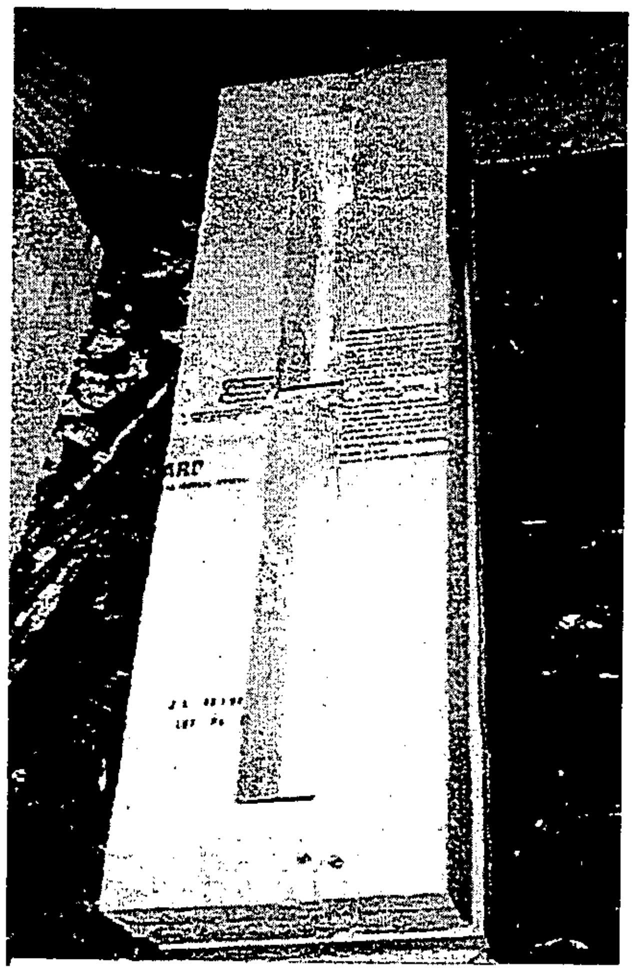

Figure 3-12. Molds for shrinkage testing.

The concrete was placed in the molds in three layers; each was rodded 60 times equally distributed on each side of the styrofoam insert. Figure 3-13 shows the slots after consolidation. Directly after consolidating the third layer, the surface of the concrete was sprayed with a white pigment 1600 curing compound as shown in Figure 3-14. This product is the same as that used by the NDDOT in pavement construction. Finally, the temperature and humidity were monitored and recorded throughout the observation period.

Figure 3-13. The molds after placing and consolidating the concrete.

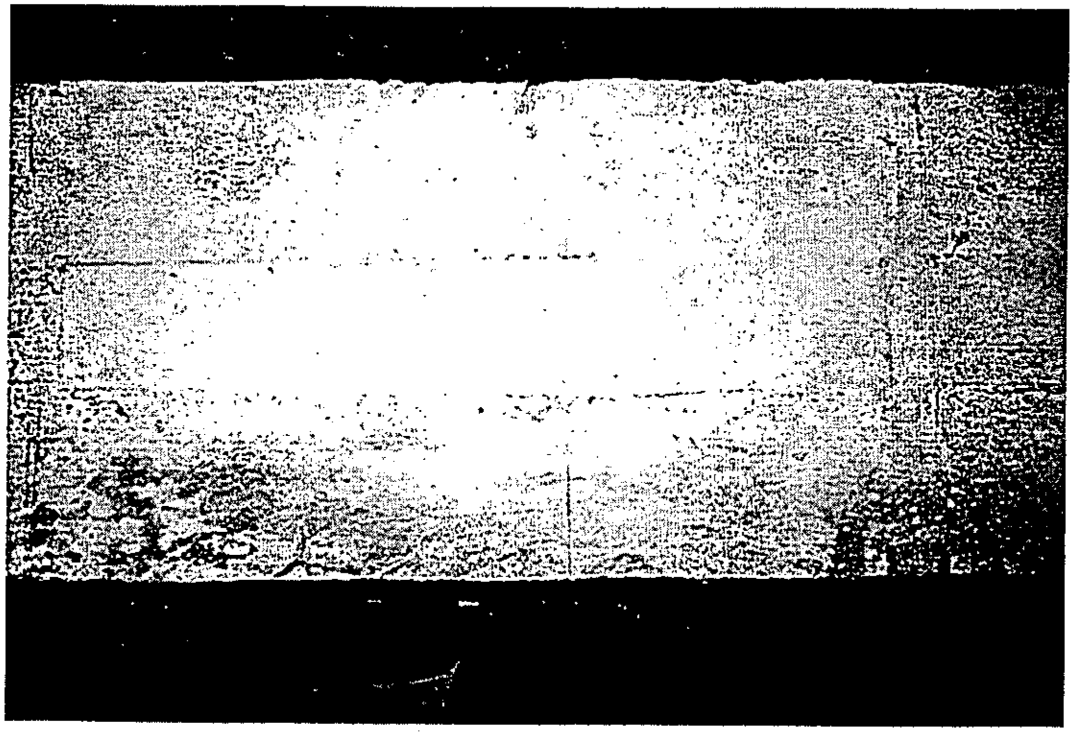

Figure 3-14. The slots sprayed with curing compound.

IV. RESULTS, FINAL MIX, AND DISCUSSION

This chapter includes a discussion of the experimental stage of this research. A discussion of the results of different phases of testing is also included with the final mix chosen for use in the slots of the dowel bar retrofit.

4.1. Phase 1: Effect of Accelerating Admixture

Accelerating admixtures are used in concrete mixes to accelerate early gains in concrete strength and to quicken the setting time of the mix. The admixture used in this phase was the Pozzolith NC534 mentioned in Section 3.1.3.2. The purpose of this stage of testing was to obtain data about the effect of this admixture on the six-hour compressive strength of the mix. Therefore, four trial mixes that had the same cement content, water to cement ratio, and coarse to fine aggregate ratio were chosen. The accelerating admixture dosage was increased from a value of 10 to 40 fl.oz./100lb of cement as shown in Table 4-1. No other admixtures were used in order to isolate the effect of the accelerator on the compressive strength of concrete.

The cement content was chosen to be 850 lb/yd^3. This value was chosen as an appropriate value for high-strength concrete where the cement content is higher than in normal strength mixes. According to Mindess (1994), for high strength concrete, the cementitious material content ranges from 845 to

1090 lb/yd^3. The lower limit of this range was used to avoid the drawbacks of shrinkage cracks that could occur in high cement content mixes. The coarse to fine aggregate ratio was kept constant at 1.5. This value was chosen because, for high-strength concrete, the ratio of coarse to fine aggregate used in practice ranges from 1.5 to 1.8 (Mindess, 1994).

Table 4-1. Trial mixes of phase 1

Mix Number	1-1	1-2	1-3	1-4
Cement content (lb)	850	850	850	850
w/c ratio	0.42	0.42	0.42	0.42
Coarse aggregate content (lb)	1487	1479	1471	1463
Fine aggregate content (lb)	1064	1058	1052	1046
Accelerator dosage (floz/100 lb cement)	10	20	30	40
Accelerator quantity (floz)	85	170	255	340
6 hour compressive strength (psi)	2576	3104	3173	3732

All 4 mixes had a stiff consistency, although the water to cement ratio was kept at 0.42, which indicated the need for using a superplasticizer in the final mix. The six-hour compressive strength increased steadily with the increase of the accelerator dosage, and the relationship between both appeared to be linear as shown in Figure 4-1. Since there appeared to be no optimum value for the accelerator dosage, it was decided that using a moderate value for the accelerator while decreasing the water to cement ratio would be sufficient for reaching the required strength. A value of 20 fl.oz./100lb of cement was chosen to be used in the following stages and would be kept constant in the following trials for testing the superplasticizer dosage.

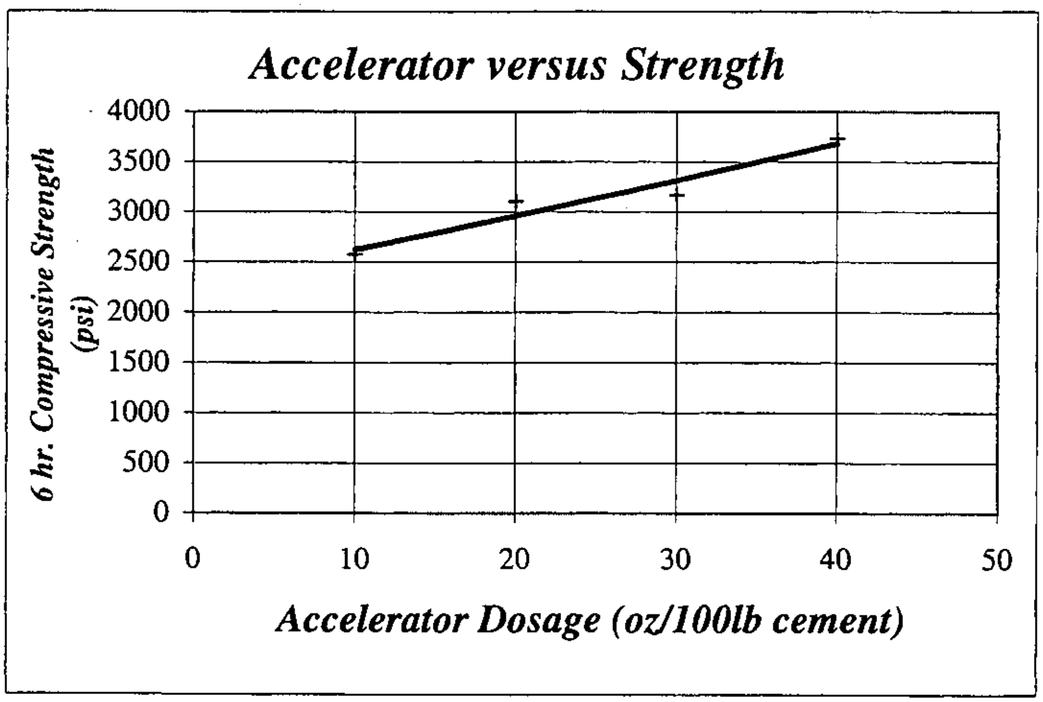

Figure 4-1. Effect of the accelerator dosage on the six-hour compressive strength of concrete.

4.2. Phase 2: Effect of Superplasticizer

The superplasticizer (high range water reducer) used in these trials was Rheobuild 3000FC that was mentioned previously in Section 3.1.3.3. The purpose of using such an admixture is to decrease the water content of the mix in order to gain high strengths while improving workability.

In order to understand the effect of this particular superplasticizer on the properties of the mix, four different dosages of this admixture were tried. Mindess (1994) stated that there is no specific method for determining the superplasticizer dosage and that it must be determined by trial and error. The dosages tested ranged from 8 to 14 fl.oz./100lb of cement, and the water to cement ratio was decreased linearly with the increase in the superplasticizer dosage from a value of 0.42 to 0.3, with 0.3 corresponding to the highest admixture dosage. The same accelerator dosage (20 fl.oz./100lb of cement) was used in the 4 mixes, and no air-entraining admixtures were used as shown in Table 4-2. For each mix, the slump was measured, and the compressive strength after six hours was tested. The relationship between the superplasticizer dosage and the six-hour compressive strength was plotted as shown in Figure 4-2. Also, the relationship between the superplasticizer dosage and slump is shown in Figure 4-3. During the preparation of higher superplasticizer dosage mixes, it was observed that the slump was very high, and the consistency of the mix started to disintegrate; i.e., the aggregate started to separate from the paste. This segregation was quite evident in Mix 2-5.

Table 4-2. Trial mixes of phase 2

Mix Number	2-1	2-2	2-3	2-4	2-5
Cement content (lb)	850	850	850	850	850
w/c ratio	0.42	0.353	0.337	0.32	0.303
Coarse aggregate content (lb)	1479	1554	1573	1593	1613
Fine aggregate content (lb)	1058	1099	1112	1126	1140
Accelerator dosage (floz/100 lb cement)	20	20	20	20	20
Accelerator quantity (floz)	170	170	170	170	170
Superplasticizer dosage (floz/100 lb cement)	0	8	10	12	14
Superplasticizer (floz)	0	68	85	102	119
6 hour compressive strength (psi)	3104	3911	3309	3621	3548
Slump (in)	1	2	8	9.5	10.25

It was also noticed that the effect of increasing the superplasticizer while decreasing the water to cement ratio did not have a great effect on the six-hour compressive strength for the range of water to cement ratio tested, but was very effective in improving the consistency as evidenced by a dramatic increase in the slump.

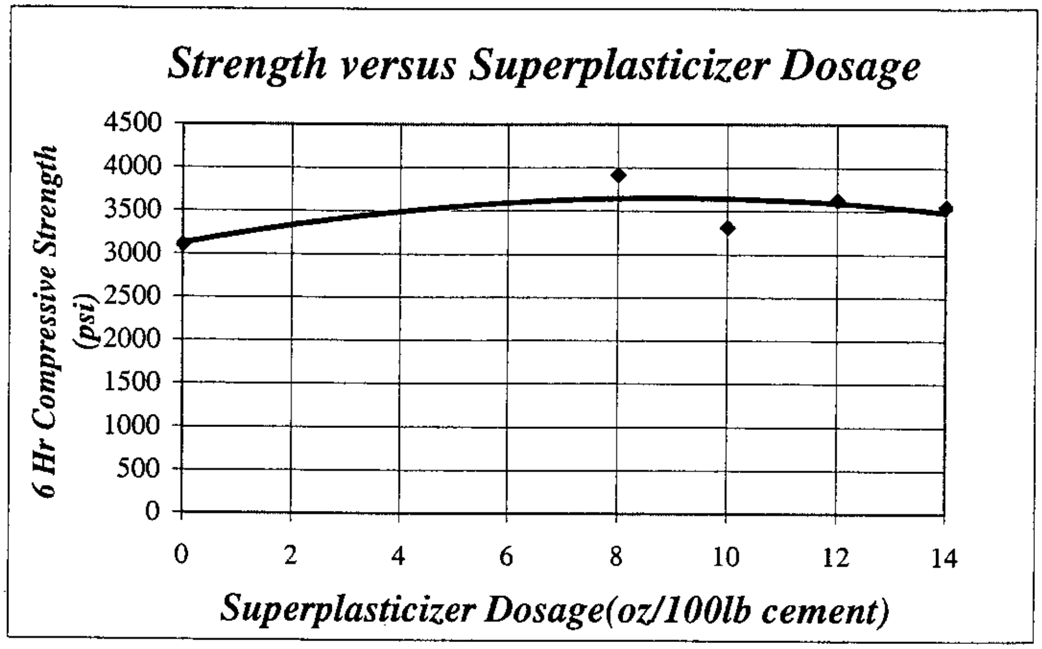

Figure 4-2. Effect of the superplasticizer dosage on the compressive strength of the concrete.

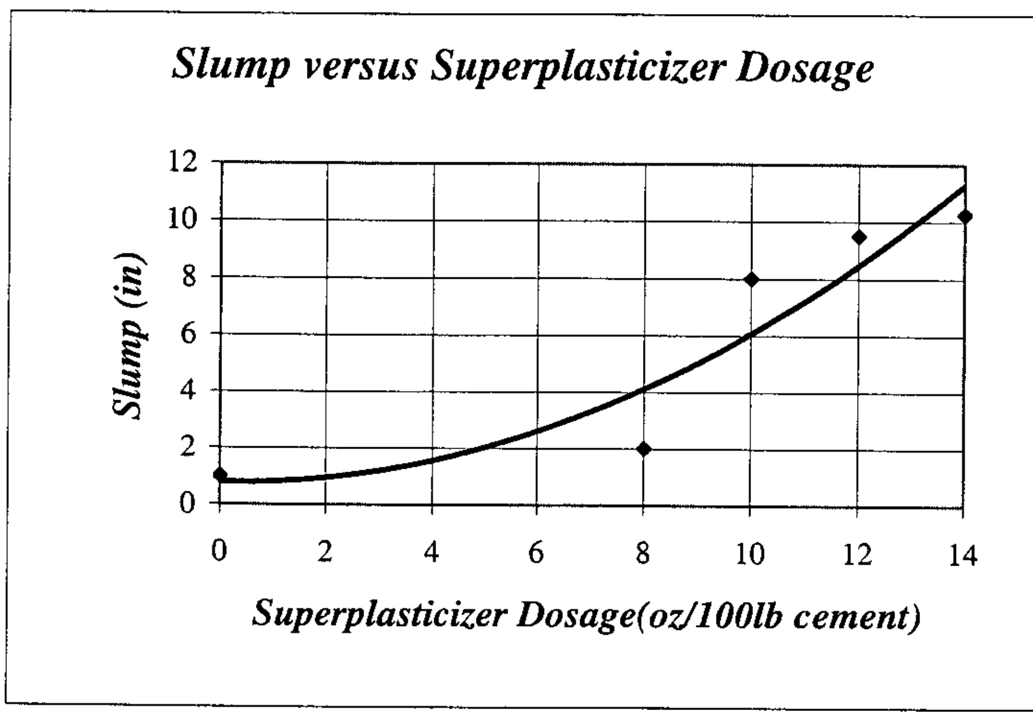

Figure 4-3. Effect of the superplasticizer dosage on the slump of the fresh concrete.

4.3. Phase 3: Final Adjustments

The purpose of this final stage was to achieve the required strength, workability, and air content of the mix guided by earlier trial phases. Balancing these three different properties proved to be quite a difficult task since an improvement in one of them could have an adverse effect on another.

Mix proportions of the first mix in this phase were chosen based on the data obtained from previous phases. Since the variation in strengths of the trial mixes of different superplasticizer dosages was not too great, it was decided to choose a trial dosage based on slump values. Therefore, a value of 10 fl.oz./100lb of cement was chosen with 30 fl.oz./100lb of cement for the accelerator dosage to increase the compressive strength since the required 4000 psi in 6 hours had not been reached yet. In this stage, the air-entraining admixture was added to obtain the targeted air content. An initial value of 0.1 fl.oz./100lb of cement was used.

The first mix (Mix 3-1) had quite a stiff consistency; its slump was only 4 inches; and the required air content was not attained. The compressive strength exceeded the requirements and was over 4700 psi in 6 hours. These results are shown in Table 4-3. It was decided that an increase in the air-entraining admixture was required, and the dosage was tripled for the next trial mix (Mix 3-2). This increase proved effective in increasing the air content to more than double the previous mix and also had a positive effect on the slump, which increased to 9.5 inches. The disadvantage was a noticeable decrease in the strength to 3758 psi as shown in Table 4-3.

Table 4-3. Trial mixes 1 to 6 of phase 3

Mix Number	3-1	3-2	3-3	3-4	3-5	3-6
Cement Content (lb)	850	850	850	850	900	900
w/c ratio	0.32	0.32	0.31	0.32	0.32	0.32
Air Entraining Dosage	0.1	0.3	0.3	0.3	0.3	0.2
Accelerator dosage (floz/100 lb cement)	30	30	30	30	30	30
Superplasticizer dosage (floz/100 lb cement)	10	10	10	10.5	10	10
Air Content%	2.8	6	4.5	7	5.5	4.5
6 hour Compressive Strength (psi)	4778	3758	4604	3106	4004	4557
Slump (in)	4	9.5	3.875	9.5	9	8

These observations agree with the available literature regarding concrete technology and mix design. It is reported that an increase in the air content of concrete causes a decrease in its compressive strength. The effect of the air content is significant in high-strength concrete (as in this case), and attaining high-strength concrete with air entrained is a difficult task as shown in Figure 4-4. Kosmatka and Panarese (1994) stated that "reductions in strength become significant in higher-strength (higher cement content) mixes" and that "attainment of high strength with air-entrained concrete may be difficult at times."

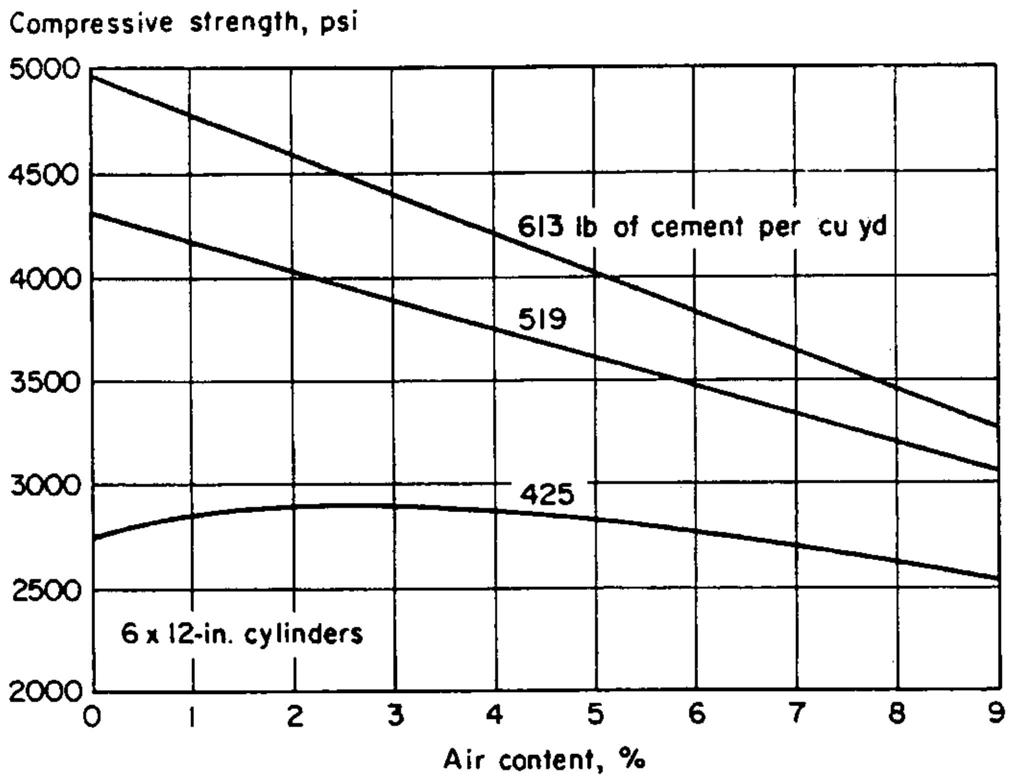

Figure 4-4. Relationship between air content and 28 day compressive strength for concrete at three constant cement contents (Kosmatka and Panarese, 1994).

The following step was to decrease the water to cement ratio in an attempt to increase the strength. A value of 0.3 was chosen initially for Mix 3-3, but during the actual mixing of this trial batch, it was observed that the mix was extremely stiff and would have a very low slump. Therefore, the w/c ratio was increased to 0.31. The workability improved slightly by increasing the water content, but the slump was still quite low at below 4 inches, which would not be sufficient for the patch concrete of the dowel bar retrofit. The air content and the slump of the mix decreased compared to Mix 3-2. The decrease in the water to cement ratio of the mix caused a decrease in the air content. This effect is supported by the information on concrete design in the literature. Kosmatka and Panarese (1994) mention that an increase in mixing water allows more water to be available for the generation of air bubbles. As the air content decreased to reach 4.5%, the compressive strength increased compared to Mix 3-2 and reached 4604 psi.

Mix 3-4 was tested to see the effect of the superplasticizer. All its proportions were the same as Mix 3-2 except that the superplasticizer dosage was increased to 10.5 fl.oz./100 lb of cement. This mix was workable. The air content increased to 7% compared to 6% for Mix 3-2, but the compressive strength decreased and was below the targeted value. Kosmatka and Panarese (1994) stated that, as the slump of a concrete mix increases, the air content increases.

Since Mix 3-2 had given good results, it was decided to use the same admixture dosages and w/c ratio, but increase the cement content slightly to improve the strength. As another option for improving the strength instead of lowering the w/c ratio, the cement content was increased by only 50 lb/yd^3 in Mix 3-5. It was noticed that the air content of the mix decreased to 5.5% when increasing the cement content. This effect is mentioned by Kosmatka and Panarese (1994), who state that the air content decreases with the increase of the cement content of the concrete mix. Trial Mix 3-6 had the same proportions as Mix 3-5 except that the air-entraining admixture was decreased. This mix was tested just to confirm the effect of the air content on the slump and compressive strength. The same observations were made as before where the air content and the slump decreased while the compressive strength increased. The results of Mix 3-5 were promising since it had properties close to the targeted values. However, it was decided to continue with the trials and try to achieve the same properties with a lower cement content.

The next trial mixes were an attempt to get the same or better results as Mix 3-5 but with an 850 lb/yd^3 cement content and 0.3 w/c ratio, expecting that they would perform better when tested in the slots for the shrinkage cracks. To compensate for the decrease in water, the superplasticizer dosage was increased to 11 fl.oz./100 lb of cement (Mix 3-7), and the air-entraining dosage was increased to 0.4 fl.oz./100 lb of cement because it was expected that a lower amount of water would decrease the air content. The results confirmed these expectations as seen in Table 4-4. Although the air-entraining admixture and superplasticizer were increased compared to Mix 3-2, the air content was decreased to 4.25% due to the reduction of the w/c ratio.

Table 4-4. Trial mixes 7 to 10 of phase 3

Mix Number	3-7	3-8	3-9	3-10
Cement Content (lb)	850	850	850	850
w/c ratio	0.3	0.3	0.3	0.3
Air Entraining Dosage	0.4	0.4	0.4	0.3
Accelerator dosage (floz/100 lb cement)	30	30	30	30
Superplasticizer dosage (floz/100 lb cement)	11	11.5	12	12
Air Content%	4.25	5	7.5	5.25
6 hour Compressive Strength (psi)	3810	3803	3771	3652
Slump (in)	8.75	7	9.5	9.25

The superplasticizer was increased again to 11.5 fl.oz./100 lb of cement for Mix 3-8. The slump for both Mixes 3-7 and 3-8 were acceptable, but the air content was still insufficient. The superplasticizer dosage was increased again to 12 fl.oz./100 lb of cement (Mix 3-9), and as a result, both the air content and the slump increased. Since the strength was a little below 4000 psi for the mix, the air-entraining dosage was reduced to 0.3 to decrease the air content slightly and improve the strength. The results of this trial are shown in Mix 3-10. The air content was 5.25%, and the slump was 9.25 inches. The consistency of the mix was also very good. Since the strength was still less than the targeted value, more trials were preformed.

Since the required strength had not been achieved yet, in the next set of trials, the accelerator was increased to 40 fl.oz./100lb of cement. This change is shown in Mix 3-11 where the strength increased and was more than sufficient for the design requirements (4000 psi). These results are given in Table 4-5.

Table 4-5. Trial mixes 11 and 12 of phase 3

Mix Number	3-11	3-11(rep)	3-12	3-12(rep)	3-12(rep)
Cement Content (lb)	850	850	850	850	850
w/c ratio	0.3	0.3	0.3	0.3	0.3
Air Entraining Dosage	0.3	0.3	0.35	0.35	0.35
Accelerator dosage (floz/100 lb cement)	40	40	40	40	40
Superplasticizer dosage (floz/100 lb cement)	12	12	12	12	12
Air Content%	5.75	5.25	6.25	5.25	5.75
6 hour Compressive Strength (psi)	4883	4975	4755	4915	5064
Slump (in)	9.25	9	9.5	9	9

Mix 3-11 achieved an air content of 5.75% that was close to the targeted value with good workability, so this mix was repeated. The air content of the repeated mix (5.25%) was still lower than the required value. Therefore, to achieve a closer value for the air content to the targeted value of 6%, another trial mix was made (Mix 3-12), and the air-entraining admixture was increased to 0.35 fl.oz./100lb of cement instead of 0.3 fl.oz./100lb of cement. This mix proved to be successful with regards to the slump, air content, and compressive strength. Therefore, this mix was repeated two more times to confirm the results, and it proved to have properties sufficient for its intended application. In this mix, the dry weight of the coarse and fine aggregates was 1526 lb and 1079 lb, respectively The average air content for the 3 trials of Mix 3-12 was 5.75%. The consistency was very good, and the strength achieved at 6 hours was higher than the 4000 psi required by specifications.

The properties of Mix 3-12 satisfied the targeted properties with respect to high early strength, air content, and workability. Therefore, it was decided to test this mix in the next phase, and study its performance in the slots and its long-term compressive strength.

4.4. Phase 4: Testing for Shrinkage Cracks and Long-Term Compressive Strength

In this phase, the shrinkage properties of the final mix were tested by filling the molds previously prepared. The slots were filled with the concrete mix having the same proportions as Mix 3-12. The surface was sprayed with the curing compound directly after pouring the concrete mix. The concrete was then left to cure in the laboratory at room temperature. The slots were monitored by visual inspection over a period of two weeks to check for the appearance of shrinkage cracks or debonding from the sides of the mold. The temperature in the lab ranged from 64°F to 75°F, and the humidity ranged from 30% to 50%. No shrinkage cracking was detected at the interface with the sides of the mold or at the middle of the slot as seen from Figures 4-5 and 4-6. Fine hair-line cracks were observed on the surface of the slot, and it was noticed that they occurred only in the layer of the curing compound. It must be noted that the bond between the patch mix and the sides of the mold is not the same as between the patch mix and the sides of the slot of the concrete pavement on site. It is expected that the bond will be stronger between the two concrete surfaces and that no debonding will occur. However, the mix must be tested on the site to take the effect of temperature changes and humidity in the real-life conditions into consideration.

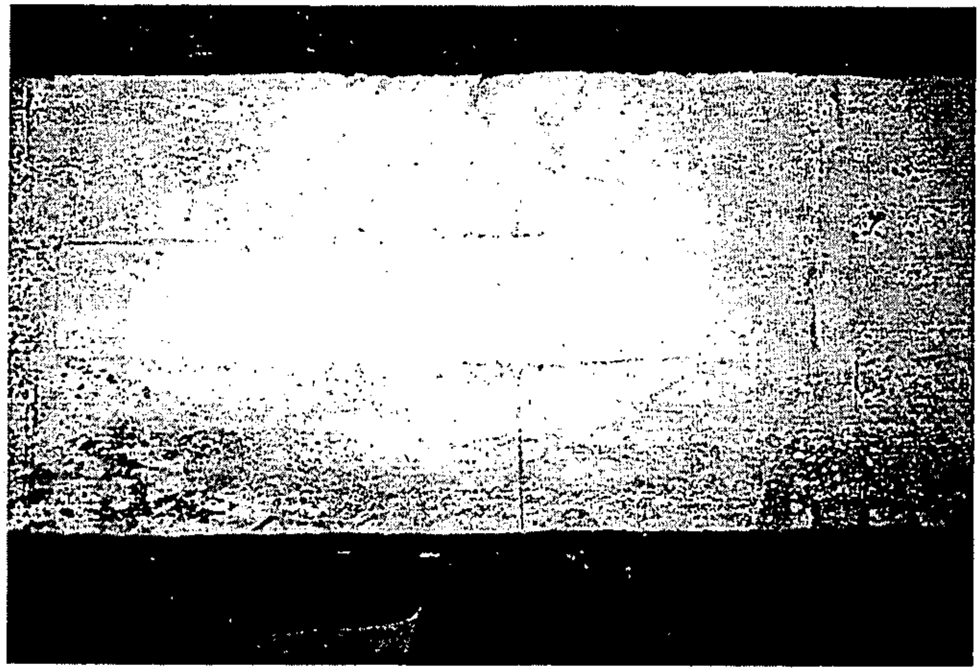

Figure 4-5. The surface of the concrete mix placed in the slots showing no signs of shrinkage.

Figure 4-6. A close-up of the slots showing no debonding at the interface between the sides of the mold and the patch concrete.

To check and confirm the results previously obtained and test the long-term compressive strength for the final mix, four batches of the final mix were tested at Midwest Testing Laboratory. Three cylinders were made from each batch, and the compressive strength was tested at 6 hours, 3 days, 7 days, and 28 days. All the concrete mixes were prepared in the university laboratory. The cylinders prepared for the 3-day, 7-day and 28-day compressive strength were left to harden for 24 hours. After this period, the cylinders were sent to the Midwest Testing Laboratory and stripped from the molds. The cylinders were then placed in curing tanks filled with saturated-lime water at a controlled temperature required by ASTM specifications until the time of testing.

Table 4-6 contains the results of these tests, and the values shown are the average values of the three cylinders. The results of these tests were plotted against the age of concrete at the time of testing and are shown in Figure 4-7. As seen from this figure, the compressive strength of this mix increases rapidly in the first few days of the age of the concrete, and then, the rate of strength increase drops and reaches a value of 11360 psi at 28 days.

Table 4-6. Results of the compressive strength tests from Midwest Testing

Age (days)	0.25	3	7	28
Compressive Strength (psi)	4500	9020	9557	11360

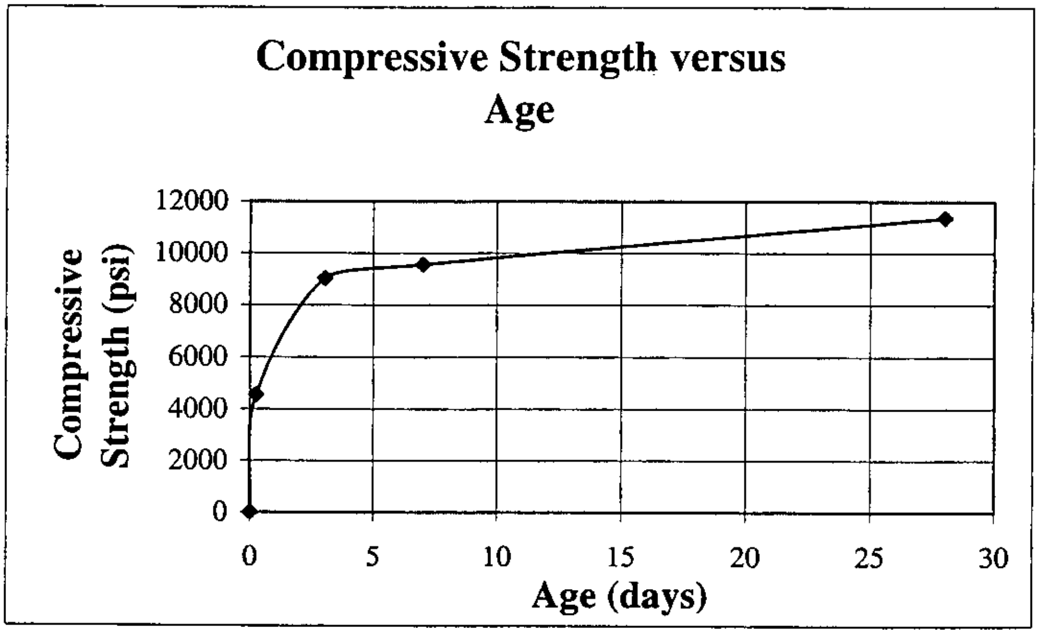

Figure 4- 7. Increase in compressive strength of the final mix with age.

4.5. Concluding Remarks

From the previous results, it can be concluded that the final mix achieved the targeted properties previously stated and has the advantages of gaining high early strength while being workable to fill the small spaces around the dowel bar in the slot. This mix also performed well in the slots, and no shrinkage cracks were detected. It also has high air content; therefore, it is expected to have good durability and freeze-thaw resistance.

V. CONCLUSIONS AND RECOMMENDATIONS

This chapter presents a summary of accomplishments during this study. The objectives and the results of the experimental work are provided. It also includes recommendations for future work in this field.

5.1. Summary

The objective of this research was to design a high-performance concrete mix for patching slots made for dowel bar retrofit utilizing locally available materials. This mix should have specific properties, including high early strength, good workability, and durability.

To achieve these objectives, a review of the available literature on the dowel bar retrofit practice and the design of concrete mixes were performed. Visits were made to the sites where dowel bar retrofit projects were under construction. The construction procedure was discussed with the engineers, contractors, and other experts. The problems encountered with the patch mixes in previous dowel bar retrofit projects were studied, and various difficulties and shortcomings along with the present procedure were presented in Chapter II.

To design a high-performance concrete mix, laboratory tests were performed on trial concrete mixes. Chapter III discussed the materials chosen for these trial mixes and the tests performed on them. It also described the preparation of the concrete specimens and the testing procedures used in the experiments.

Chapter IV presented the results of the experimental work of this research where several concrete trial mixes were tested. In these trial mixes, different combinations of the concrete mix proportions and admixtures were investigated. The problems encountered to achieve the targeted properties of the concrete mix were also discussed.

5.2. Results

The final concrete mix that was found suitable for the targeted properties of the dowel bar retrofit application was identified. The proportions of this mix are available in Table 4-5, page 63, of this report. This mix had high early strength (more than 4000 psi in 6 hours) and a high workability to facilitate pouring the mix in the tight area around the dowel bar (more than 9-inch slump). The suggested concrete mix was tested in molds having the same dimensions as the actual slots of dowel bar retrofit. No shrinkage cracks were observed on the surface of the patch mix, nor was there any debonding at the sides of the molds. The air content of the suggested concrete mix had an average value of 5.75%, which is appropriate for concrete that is exposed to outdoor weather conditions and must have good durability and freeze-thaw resistance.

One of the most significant advantages of the designed mix, compared to the proprietary mixes previously used in this application, is that it has known ingredients. These ingredients have specific and known proportions. Therefore, in case of any change in the requirements needed on site for the patch mix of this application, these proportions can be altered to adapt to the new requirements. Another advantage of the suggested concrete mix is that it is produced from locally available materials.

During the process of testing the trial mixes, several observations were noted concerning the effects of some of the concrete ingredients and admixtures on the mix properties:

- The same type of cement obtained from different manufacturers has different properties and develops mixes having different compressive strength values.
- Different concrete admixtures of the same type differ in their chemical composition and have different effects on concrete properties. Not all concrete admixtures are compatible together. If several different admixtures are added to the concrete, trial mixes must be tested before the final use on site.

- A slight change in the water/cement ratio of the mix has a great effect on the concrete properties, not only on the compressive strength of the mix, but also the air content.
- An increase in the cement content of the mix decreases its air content.
- An increase in the slump of the mix causes an increase in the air content of the concrete.

5.3. Cost Estimate for Patch Concrete:

The cost of the materials will be estimated for a hypothetical site in Bismarck. The cost of 1 metric ton of Lehigh type III cement is estimated at $101 in the Fargo and surrounding area. Lehigh cement is not available in Bismarck so it must be transported. The total cost of 1 metric ton including transportation to Bismarck is estimated at $150. Type III cement can also be obtained from local suppliers such as Lafarge which costs $100 for 1 ton. If another cement supplier is used the concrete mix must be tested to check its properties (Different suppliers use different units for bulk cement pricing. The differences has been taken into consideration).

The cost of 1 ton of granite is around $31.50 and to transport a legally loaded truck load (approximately 23 tons) of granite to Bismarck there is an additional cost of \$450. The cost of 1 ton of washed sand is about \$10.90 which is available all over the state and will not need transportation.

The cost of 1 gallon of each of the admixtures is as follows:

Cost of superplasticizer =\$20

Cost of accelerating admixture =\$8

Cost of air-entraining admixture =\$5

To produce a cubic yard of concrete, the following cost analysis is performed:

Cost of Lehigh cement =(850/2000) x 0.9071848 x 150 =\$57.83

Cost of Lafarage cement =(850/2000) x 100 =\$42.5

Cost of granite =(1526/2000) x 51.07 =\$38.97

Cost of sand =(1079/2000) x 10.9 =\$5.88

Cost of superplasticizer =(102/128) x 20 =\$15.94

Cost of accelerator =(340/128) x 8 =\$21.25

Cost of air-entraining admixture =(2.975/128) x 5 =\$0.12

Volume of 1 slot =3 x 6 x 38 =684 cu. in =0.0147 cu. yd.

Table 5-1. Cost estimate for the concrete mix[1].

Item	Cost using Lehigh Cement	Cost using Lafarage Cement
Cement	57.83	42.5
Gravel	38.97	38.97
Sand	5.88	5.88
Superplasticizer	15.94	15.94
Accelerator	21.25	21.25
Air-entrainer	0.12	0.12
Cost of 1cu.yd.	139.99	124.66
Cost of concrete 1 slot.	2.06	1.83

The volume of the dowel bar has not been deducted from the volume of the slot.

5.4. Recommendations and Future Research

It is important to note from the results of this research that any change in the types of admixtures, the mix ingredients, or their proportions will change the properties of the concrete mix. If any change is necessary, the new combination of ingredients must be tested before using it on site.

The suggested concrete mix has been tested according to ASTM specifications in the laboratory. In order to study the actual performance of the suggested concrete mix, an experimental test section using this mix on site should be undertaken. The reason is that the durability of the concrete mix and

[1] Based on a local contractor cost report, the cost of proprietary mix was about $3.50 per slot.

the effect of the weather conditions will be more clear under actual everyday loading and environmental conditions.

Several other combinations that could achieve comparable results with respect to the targeted properties can be tested; for example, the effect of changing the aggregate gradation can be studied in further research. As a result, several of these combinations could be developed and compared, targeting cost optimization of the developed mix.

REFERENCES

American Concrete Institute (ACI). (1999). *Building Code Requirements for Structural Concrete,* ACI 318-99, Farmington Hills, MI.

ASTM. (1978a). "Standard Method of Test for Air Content of Freshly Mixed Concrete by the Volumetric Method," C 173-78, West Conshohocken, PA.

ASTM. (1978b). "Standard Method of Test for Slump of Portland Cement Concrete," C 143-78, West Conshohocken, PA.

ASTM. (1981). "Standard Method of Test for Making and Curing Concrete Test Specimens in the Laboratory," C 192-81,West Conshohocken, PA.

ASTM. (1983). "Standard Method of Test for Compressive Strength of Cylindrical Concrete Specimens," C 39-83b, West Conshohocken, PA.

Darter, M. I., Barenberg E. J., and Yrjanson W. A. (1985). "Joint Repair Methods for Portland Cement Concrete Pavements," *National Cooperative Highway Research Program Report No. 281*, Transportation Research Board, Washington, D.C.

Dunn, C. (1998). "Dowel Bar Retrofit for Load Transfer Third Annual Report," North Dakota Department of Transportation, Materials and Research Division, Bismarck, ND.

Federal Highway Administration (FHWA). (1997). *Concrete Pavement Rehabilitation Guide for Load Transfer Restoration* Publication No. FHWA-SA-97-103, Washington, D.C.

Gulden, W., and Brown D. (1985). "Establishing Load Transfer in Existing Jointed Concrete Pavements," *Transportation Research Record No. 1043*, Transportation Research Board, Washington, D.C.

Kosmatka, S., and Panarese, W. (1994). *Design and Control of Concrete Mixtures*, Portland Cement Association, Skokie, IL.

Larson, R. M., Petersen D., and Correa A. (1998). *Retrofit Load Transfer Publication No. FHWA-SA-98-047*, Federal Highway Administration, Washington, D.C.

Master Builders, Inc. (1999). *Admixtures, Products for the Concrete Construction Industry*, Cleveland, OH.

Mindess, S. (1994). "Materials Selection, Proportioning and Quality Control," in *High Performance Concrete: Properties and Applications*, Shah, S.P. and Ahmad, S.H., eds., McGraw-Hill, NewYork, 1-24.

North Dakota Department of Transportation (NDDOT). (1997). *Standard Specifications for Road and Bridge Construction.* vol. 1, Bismarck, ND.

Patel, A. J., Mojab, C., and Romine, R. (1993). "Materials and Procedures for Rapid Repair of Partial-Depth Spalls in Concrete Pavements," *Concrete Pavement Repair Manuals of Practice SHRP-H-349*, Strategic Highway Research Program, Washington, D.C.

Pierce, L. M. (1994). "Portland Cement Concrete Pavement Rehabilitation in Washington State: Case Study," *Transportation Research Record No. 1449*, Transportation Research Board, Washington, D.C.

Reiter, M. J., Darter, M. I., and Carpenter S. H. (1988). "Restoration of Joint Load Transfer," *Transportation Research Record No. 1183*, Transportation Research Board, Washington, D.C.

Tayabji, S. D., and Colley, B. E. (1983). "Improved Rigid Pavement Joints," Construction Technology Laboratories-Presentation at Annual Meeting of Transportation Research Board, Washington, D.C.

Womack, K.C. (1993). Expansive Concrete: An Overview and Performance Comparison of Projects Using Type K Shrinkage Compensating Cement Mountain Plains Consortium Report No. 93-25, Utah Transportation Center, Logan, UT.

Appendix

APPENDIX A

SP-141(92)

NORTH DAKOTA DEPARTMENT OF TRANSPORTATION

SPECIAL PROVISION

DOWEL BAR RETROFIT

DESCRIPTION

This work consists of retrofitting epoxy-coated dowel bars into existing concrete pavement.

MATERIALS

1. Curing Compound. The curing compound shall be a liquid membrane-forming compound that conforms to the requirements of AASHTO M-148 (ASTM C 309) Type 1-D or 2, Class A or B.

2. Dowel Bars. The Dowel bars shall be plain, round bars fabricated from steel meeting AASHTO M-31, M-42, or M-53. Dowel bars shall be cut to the required length and cleaned to remove all cutting burrs, loose mill scale, rust, grease, and oil. The bars may be sheared providing the deformation of the bars from true round shape does not exceed 0.04 inch in diameter or thickness, and shall not extend more than 0.04 inch from the sheared end.

   Dowel bars shall be epoxy-coated 100% on all surfaces. The epoxy coating shall be in accordance with AASHTO M-284. The dowel bars shall also be shop coated with a bond breaking release agent. The bond breaking release agent shall be a black, non-diluted, Tectyl 164 as manufactured by Valvoline Oil Co. The dowel bars shall be installed and covered with patch material within 6 months of the delivery date.

   The dowel bars shall have tight fitting end caps made of nonmetallic materials that allow for 1/4 inch movement of the bar at each end. The Contractor shall submit sample end caps to the Engineer prior to use.

3. Caulk. The caulk for sealing the existing transverse joint crack at the bottom and sides of the slot shall be any commercial caulk designed as a concrete sealant that is compatible with the patch material being used.

4. Foam Core Board. The foam core board shall be 1/4 inch thick, constructed of closed cell foam, and be faced with poster board material on each side.

5. Patching Material. Two types of patch material will be used on this project. One-half of the project will be completed using a

patch mix made from local materials and the other half will be completed using a commercial patch mix.

a. "Concrete Patch Mix Type A" shall be a mix prepared using the following mix design:

Cement	850 lbs
Water	295 lbs
Sand	1318 lbs
Course Aggr.	1341 lbs.

The cement used shall be a Type I, IA, II, or IIA cement meeting the requirements of Section 804.01.

Air-Entraining Admixture shall meet the requirements of Section 808.01. The air content of the mix shall be maintained at 5.5 percent, plus or minus 1.5 percent.

Fine aggregates shall meet the requirements of Section 816.01.

Course aggregate shall meet the requirements of Section 816.02. The gradation for the course aggregate shall be:

Sieve	% Passing
3/8"	100
#4	70-95

b. "Concrete Patch Mix Type B" shall be Patchroc 10-60, Five Star Highway Patch, Burke 928 Fast Patch or an approved equal.

6. Chairs. The chairs for supporting and holding the dowel bars in place shall be completely epoxy coated according to Section 836.02B, or made of nonmetallic material.

CONSTRUCTION REQUIREMENTS

The Contractor shall install the dowel bars in the existing concrete pavement as shown in the Plans and according to the following specifications:

1. Slots shall be saw cut in the pavement to the depth required to place the center of the dowel at mid-depth in the concrete slab. Multiple saw cuts parallel to the centerline may be required to properly remove material from the slot.
2. Jack hammers used to remove the concrete shall not be larger than the 30 pound class.

3. All exposed surfaces and cracks in the slot shall be sand blasted and cleaned of saw slurry and loose material before installing the dowel. All loose material will be disposed of by the Contractor off of the highway right-of-way.

4. Dowel bars shall be placed in a chair that will provide a minimum of 1/2 inch clearance between the bottom of the dowel and the bottom of the slot. The dowel bar shall be placed to the depth shown in the plans, parallel to the centerline, and parallel to pavement surface of the lower panel at the transverse joint, all to a tolerance of 1/4 inch. The chair design shall hold the dowel bar securely in place during the placement of the patch mix.

5. The contractor shall caulk the existing transverse joint crack at the bottom and sides of the slot as shown in the Plans. The transverse joint crack shall be caulked to provide a tight fit for the foam core board at the transverse joint and to prevent any of the patch mix from entering the crack at the bottom or the sides of the slot.

6. The dowel bar shall be placed through the foam core board at the specified location. The dowel bar shall be placed so a minimum of 7.0 inches is placed on either side of the transverse joint. The foam core board shall be capable of remaining in a vertical position and tight to all edges during the placement of the patch mix. If for any reason the foam core board shifts during the placement of the patch mix, the work shall be rejected and replaced at the Contractor's expense.

7. The existing concrete surfaces inside the slotted area shall be moistened with a hand sprayer immediately prior to placing the patch mix.

8. The patch mix shall be placed into the slot and vibrated with a small hand held vibrator to insure that the patch mix completely surrounds the dowel bar.

9. The surface of the filled area shall be cured using a curing compound that meets the requirements of AASHTO M-148.

10. The transverse joint shall be maintained by sawing the joint through the patched area within 24 hours after placement of the patch mix. The joint shall be sawed and sealed as shown in the plans

METHOD OF MEASUREMENT

Dowel Bars will be measured by each dowel bar installed and accepted by the Engineer.

APPENDIX B

Table B1. Sieve analysis of fine aggregate

Sieve sizes	Cumulative Wt. Retained	Wt. Retained on each sieve	% Retained on each sieve	% Passing
3/8in	0	0	0	100
#4	3.2	3.2	0	100
#8	223.7	220.5	16	84
#16	611.1	387.4	28	56
#30	915.4	304.3	22	34
#50	1117.7	202.3	15	19
#100	1296.8	179.1	13	6
#200	1359.6	62.8	5	1
200-	1373.6	14	1	0

Table B2. Sieve analysis of granite coarse aggregate

Sieve sizes	Cumulative Wt. Retained	Wt. Retained on each sieve	% Retained on each sieve	% Passing
3/8in	0	0	0	100
#4	1471.2	1471.2	74	26
#8	1769.8	298.6	15	12
#16	1843.8	74	4	8
#30	1901.8	58	3	5
#50	1941.1	39.3	2	3
#100	1967.4	26.3	1	2
#200	1988.3	20.9	1	1
200-	1998.1	9.8	0	0

Table B3. Sieve analysis of pea gravel

Sieve sizes	Cumulative Wt. Retained	Wt. Retained on each sieve	% Retained on each sieve	% Passing
3/8in	0	0	0	100
#4	1434.9	1214.6	72	28
#8	1857.9	423	25	3
#16	1890.8	32.9	2	1
#30	1899.1	8.3	0	1
#50	1901.8	2.7	0	0
#100	1903.2	1.4	0	0
#200	1904.3	1.1	0	0
200-	1907.1	2.8	0	0

APPENDIX C

Table C1. Compressive strength results

	Mix Number	Compressive Strength (psi)			
		Cylinder 1	Cylinder 2	Cylinder 3	Average
Preliminary Phase	P1	N/A	N/A	N/A	N/A
	P2	718	693	N/A	706
	P3	1803	1623	N/A	1713
	P4	1612	1577	N/A	1595
	P5	1174	1220	N/A	1197
	P6	926	962	N/A	944
Phase 1	1-1	2603.1	2528.8	2596	2576
	1-2	3108.9	3045.2	3165.5	3107
	1-3	2960.3	3151.3	3405.9	3173
	1-4	3851.6	3713.7	3642.9	3736
Phase 2	2-1	3108.9	3045.2	3165.5	3107
	2-2	3880.4	3838	4014.9	3911
	2-3	3130.5	3342.8	3452.4	3309
	2-4	3746	3463	3654	3621
	2-5	3395.8	3530.2	3717.7	3548
Phase 3	3-1	4602	4867.4	4863.8	4778
	3-2	3728.3	3714.2	3830.9	3758
	3-3	4446.4	4694	4672.8	4604
	3-4	2999.6	3035	3282.6	3106
	3-5	3983	4060.8	3968.9	4004
	3-6	4361.5	4715.2	4595	4557
	3-7	3339.2*	3788.5	3830.9	3810
	3-8	3413.5*	3746	3869.8	3808
	3-9	3399.4*	3770.8	3770.8	3771
	3-10	3569.1	3735.4	4166.9*	3652
	3-11	4701	4846.1	5100.8	4883
	3-11(rep)	4764.8	5086.7	5072.5	4975
	3-12	4449.9	4874.4	4941.6	4755
	3-12(rep)	4870.9	4828.4	5044.2	4915
	3-12(rep)	4991.2	5065.4	5136.2	5064

* The results of these cylinders have been discarded and the average of the other two were used.

APPENDIX D

COMPRESSIVE STRENGTH RESULTS FOR PHASE 4

MIDWEST TESTING LABORATORY

4102 - 7th Ave. N. / P.O. Box 3042 / Fargo, North Dakota 58108
Phone (701) 282-9633 / Fax (701) 282-9635

REPORT OF: TESTS OF CONCRETE CYLINDERS

PROJECT:	Plant Tests 2001 NDSU Civil Engineering	DATE:	October 24, 2001
REPORTED TO:	Attn: Marwa North Dakota State University Civil Engineering Department Room 201, CIE Building Fargo, ND 58102	COPIES:	
PROJECT NO:	10611		

GENERAL DATA

CYLINDER NUMBER	3A	3B	3C
DATE CAST	10-18-01		
CAST BY (ASTM C31)	NDSU		
CONCRETE TEMPERATURE (°F) (ASTM C1064)	N.G.		
SLUMP (") (ASTM C143)	N.G.		
AIR CONTENT (%) (ASTM C231)	N.G.		
UNIT WEIGHT (pcf) (ASTM C138)	N.G.		
SPECIFIED STRENGTH (At 28 days)	6000		
LOCATION:	Test		

MIX PROPORTIONS

CEMENT (Lbs.)	N.G.
FINE AGGREGATE (Lbs.)	N.G.
COARSE AGGREGATE (Lbs.)	N.G.
ADMIXTURE (oz./cwt)	N.G.
CONCRETE FURNISHED BY:	Not Given

COMPRESSIVE STRENGTH DATA (ASTM C39) (Dia = 6.0)

LABORATORY NUMBER	8840A	8840B	8840C
DAYS JOB CURED	6 hrs	6 hrs	6 hrs
DAYS OF LABORATORY CURED	0	0	0
AGE OF TEST (Days)	6 hrs	6 hrs	6 hrs
LOAD AT FAILURE (Lbs.)	128,640	130,980	126,380
STRENGTH (P.S.I.)	4550	4630	4470

REMARKS:

SIGNED

MIDWEST TESTING LABORATORY

4102 - 7th Ave. N. / P.O. Box 3042 / Fargo, North Dakota 58108
Phone (701) 282-9633 / Fax (701) 282-9635

REPORT OF: TESTS OF CONCRETE CYLINDERS

PROJECT:	Plant Tests 2001 NDSU Civil Engineering	DATE:	October 24, 2001
REPORTED TO:	Attn: Marwa North Dakota State University Civil Engineering Department Room 201, CIE Building Fargo, ND 58102	COPIES:	
PROJECT NO:	10611		

GENERAL DATA

CYLINDER NUMBER	1A	1B	1C
DATE CAST	10-16-01		
CAST BY (ASTM C31)	NDSU		
CONCRETE TEMPERATURE (°F) (ASTM C1064)	N.G.		
SLUMP (") (ASTM C143)	N.G.		
AIR CONTENT (%) (ASTM C231)	N.G.		
UNIT WEIGHT (pcf) (ASTM C138)	N.G.		
SPECIFIED STRENGTH (At 28 days)	6000		
LOCATION:	Test		

MIX PROPORTIONS

CEMENT (Lbs.)	N.G.
FINE AGGREGATE (Lbs.)	N.G.
COARSE AGGREGATE (Lbs.)	N.G.
ADMIXTURE (oz./cwt)	N.G.
CONCRETE FURNISHED BY:	Not Given

COMPRESSIVE STRENGTH DATA (ASTM C39) (Dia = 6.0)

LABORATORY NUMBER	8824A	8824B	8824C
DAYS JOB CURED	1	1	1
DAYS OF LABORATORY CURED	2	2	2
AGE OF TEST (Days)	3	3	3
LOAD AT FAILURE (Lbs.)	259,840	249,740	255,600
STRENGTH (P.S.I.)	9190	8830	9040

REMARKS:

SIGNED

MIDWEST TESTING LABORATORY
4102 - 7th Ave. N. / P.O. Box 3042 / Fargo, North Dakota 58108
Phone (701) 282-9633 / Fax (701) 282-9635

REPORT OF: TESTS OF CONCRETE CYLINDERS

PROJECT: Plant Tests 2001
NDSU
Civil Engineering

DATE: October 24, 2001

REPORTED TO: Attn: Marwa
North Dakota State University
Civil Engineering Department
Room 201, CIE Building
Fargo, ND 58102

COPIES:

PROJECT NO: 10611

GENERAL DATA

CYLINDER NUMBER	2A	2B	2C
DATE CAST	10-17-01		
CAST BY (ASTM C31)	NDSU		
CONCRETE TEMPERATURE (°F) (ASTM C1064)	N.G.		
SLUMP (") (ASTM C143)	N.G.		
AIR CONTENT (%) (ASTM C231)	N.G.		
UNIT WEIGHT (pcf) (ASTM C138)	N.G.		
SPECIFIED STRENGTH (At 28 days)	6000		
LOCATION:	Test		

MIX PROPORTIONS

CEMENT (Lbs.)	N.G.
FINE AGGREGATE (Lbs.)	N.G.
COARSE AGGREGATE (Lbs.)	N.G.
ADMIXTURE (oz./cwt)	N.G.
CONCRETE FURNISHED BY:	Not Given

COMPRESSIVE STRENGTH DATA (ASTM C39) (Dia = 6.0)

LABORATORY NUMBER	8841A	8841B	8841C
DAYS JOB CURED	1	1	1
DAYS OF LABORATORY CURED	6	6	6
AGE OF TEST (Days)	7	7	7
LOAD AT FAILURE (Lbs.)	267,140	274,660	268,960
STRENGTH (P.S.I.)	9450	9710	9510

REMARKS:

SIGNED Jeff Martin

MIDWEST TESTING LABORATORY

4102 - 7th Ave. N. / P.O. Box 3042 / Fargo, North Dakota 58108
Phone (701) 282-9633 / Fax (701) 282-9635

REPORT OF: TESTS OF CONCRETE CYLINDERS

PROJECT:	Plant Tests 2001 NDSU Civil Engineering	DATE:	November 8, 2001
REPORTED TO:	Attn: Marwa North Dakota State University Civil Engineering Department Room 201, CIE Building Fargo, ND 58102	COPIES:	
PROJECT NO:	10611		

GENERAL DATA

CYLINDER NUMBER	4A	4B	4C
DATE CAST	10-11-01		
CAST BY (ASTM C31)	NDSU		
CONCRETE TEMPERATURE (°F) (ASTM C1064)	N.G.		
SLUMP (") (ASTM C143)	N.G.		
AIR CONTENT (%) (ASTM C231)	N.G.		
UNIT WEIGHT (pcf) (ASTM C138)	N.G.		
SPECIFIED STRENGTH (At 28 days)	6000 +		
LOCATION:	Mix Design.		

MIX PROPORTIONS

CEMENT (Lbs.)	N.G.
FINE AGGREGATE (Lbs.)	N.G.
COARSE AGGREGATE (Lbs.)	N.G.
ADMIXTURE (oz./cwt)	N.G.
CONCRETE FURNISHED BY:	Not Given

COMPRESSIVE STRENGTH DATA (ASTM C39) (Dia = 6.0)

LABORATORY NUMBER	8789A	8789B	8789C
DAYS JOB CURED	1	1	1
DAYS OF LABORATORY CURED	27	27	27
AGE OF TEST (Days)	28	28	28
LOAD AT FAILURE (Lbs.)	322,000	317,640	323,880
STRENGTH (P.S.I.)	11390	11230	11460

REMARKS:

Time cast 6:00 p.m.

SIGNED Ted Englestt

Appendix E

Design Guidelines for the Dowel Bar Retrofit Projects

Dowel Bar Retrofit. This work consists of retrofitting epoxy-coated bars into existing concrete pavement.

1.**Materials.**

a. **Curing Compound**. The curing compound shall be a wax based liquid membrane –forming compound that conforms to the requirements of AASHTO M –148 (ASTM C 309) Type 1-D or 2,Class A or B.

b. **Dowel Bars.** The Dowel bars shall be plain, round bars fabricated from steel meeting AASHTO M –31,M-42, or M-53.Dowel bars shall be cut to the required length and cleaned to remove all cutting burrs, loose mill scale, rust, grease, and oil. The bars may be sheared providing the deformation of the bars from true round shape does not exceed 0.04 inch in diameter or thickness, and shall not extend more than 0.04 inch from the sheared end. Dowel bars shall be epoxy-coated 100 percent on all surfaces. The epoxy coating shall be in accordance with AASHTO M-284.The dowel bars shall also be shop coated with a bond breaking release agent. The bond breaking release agent shall be a curing compound meeting the requirements specified above. The dowel bars shall have tight fitting end caps made of nonmetallic materials that allow for 1/4 inch movement of the bar at each end. The Contractor shall submit sample end caps to the Engineer prior to use.

c. **Caulk.** The caulk for sealing the existing transverse joint crack at the bottom and sides of the slot shall be any commercial caulk designed as a concrete sealant that is compatible with the patch material being used.

d. **Foam Core Board.** The foam core board shall be constructed of closed cell foam and be faced with poster board material or laminate on each side.

e. **Patching Material**[1]. "Concrete Patch Mix " shall be a mix prepared using the following mix design:

Cement	850 lbs
Water	255 lbs
Fine Aggregate	1079 lbs
Coarse Aggregate	1526 lbs
Air –entraining Admixture (Pave-Air, Master Builders)	2.975 fl-oz
Accelerating Admixture(non chloride Pozzolith NC534)	340 fl-oz
Superplasticizer(Rheobuild 3000 FC)	102 fl-oz

The Recommended mixing procedure is as follows:

- Weigh the coarse aggregate and place it in the mixer.
- Add superplasticizer to water.
- Add half the quantity of water to the coarse aggregate and mix it for two minutes.
- Add air-entraining admixture directly on the fine aggregate, and then add to the mix.
- Add cement to the mix.
- Add the remaining quantity of water with superplasticizer to the mix.
- The last component to be added is the accelerating admixture.

The cement used shall be a Type III cement(Lehigh Type III) meeting the requirements of Section 804.01
The air-entraining admixture shall meet the requirements of Section 808.01
The other chemical admixtures shall meet the requirements of Section 808.02

[1] For the proprietary mix, see NDDoT special publication # 141-92.

The Contractor must test the compatibility of the different types of admixtures prior to their use in this mix.

Fine aggregates shall meet the requirements of Section 816.01

The Coarse aggregate shall be granite aggregate (Ortonville, Minnesota), or aggregate having similar high strength, low deformation and high abrasion resistance (LA abrasion loss 40% or less) , with a nominal maximum aggregate size of 3/8 inch and shall meet the requirements of Section 816.02 and follow the gradation requirements listed below:

Aggregate Gradation

Fine Aggregate

Sieve sizes	% Passing
3/8	100%
#4	95-100%
#8	45-65%
#50	10-30%
#100	0-10%
#200	0-3%

Coarse Aggregate

Sieve sizes	% Passing
3/8	100%
#4	25-30%
#8	10-20%
#200	1%

f. **Chairs.** The chairs for supporting and holding the dowel bars in place shall be completely epoxy-coated according to Section 836.02 B, or made of nonmetallic material.

2.**Construction Requirements.** The Contractor shall install the dowel bars in the existing concrete pavement as shown in the plans and according to the following specifications:

a. **Sawing.** Slots shall be cut in the pavement with a gang saw capable of cutting a minimum of three slots in the wheel path, at a time. The slots shall be cut to the depth required to place the center of the dowel at mid-depth in the concrete slab. Multiple saw cuts parallel to the centerline may be required to properly remove material from the slot.

b. **Jack Hammers.** Jack hammers used to remove the concrete shall not be larger than the 30-pound class.

c. **Cleaning.** All exposed surfaces and cracks in the slot shall be sandblasted and cleaned of saw slurry and loose material before installing the dowel. All loose material will be disposed of by the Contractor off of the highway right-of-way.

d. **Dowel Bar Chair Placement.** Dowel bars shall be placed in a chair that will provide a minimum of 1/4-inch clearance between the bottom of the dowel and the bottom of the slot. The dowel bar shall be placed to the depth shown in the plans, parallel to the centerline, and parallel to pavement surface of the lower panel at the transverse joint, all to a tolerance of 1/4 inch. The chair design shall hold the dowel bar securely in place during the placement of the patch mix.

e. **Joint Caulking.** Caulk the existing transverse joint crack at the bottom and sides of the slot as shown in the plans. The transverse joint crack shall be caulked to provide a tight fit for the foam core board at the transverse joint and to prevent any of the patch mix from entering the crack at the bottom or the sides of the slot. The sealant shall not extend beyond 3/8 inch of each side of the existing transverse joint crack.

f. **Dowel Bar Placement.** The dowel bar shall be placed through the foam core board at the specified location. The dowel bar shall be placed so a minimum of 7.0 inches is placed on either side of the transverse joint. The foam core board shall be capable of remaining in a vertical position and tight to all edges during the placement of the patch mix. If for any reason the foam core board shifts during the placement of the patch mix, the work shall be rejected and replaced at the Contractor 's expense.

g. **Mixing Patch Material.** The patch material shall be mixed with a hand mixer. A metering or measuring device for the water is required. The Contractor shall assure that a consistent batch of patch mix is being produced. A mobile mixer is not acceptable. The procedure for adding the chemical admixtures should follow the manufacturer's recommendations.

The patching material will be tested by the Engineer at a rate of 1 test for each 4 hours of production. A minimum compressive strength of 4,000 psi in 6 hours is required. If compressive strengths are not being met, production shall cease and the contractor shall resubmit a mix design correcting the strength problems.

The air content should also be tested and should be maintained at 6 percent, ± 1.0 percent. The associated slump requirement is 9 inches ± 1 inch.

h. **Existing Concrete Surface Preparation.** The existing concrete surfaces inside the slotted area shall be moistened with water, using a hand sprayer immediately prior to placing the patch mix.

i. **Placing Patch Mix.** The patch mix shall be placed into the slot and vibrated with a small hand-held vibrator to ensure that the patch mix completely surrounds the dowel bar.

j. **Curing.** The surface of the patched area shall be flushed with a curing compound that meets the requirements specified above. The curing compound shall be applied within 30 seconds after a set of three dowel bar patches has been finished.

k. **Spall Repairs.** Any spalling that occurs to the transverse joints shall be repaired at the Contractors expense. The joint shall be sawed and sealed as shown in the plans.

3.**Method of Measurement and Basis of Payment.** Installation of the dowel bars will be measured and paid for as "Dowel Bar Retrofit Type B or A " for each dowel bar installed and accepted by the Engineer. Payment shall be full compensation for all labor, equipment, and materials necessary to complete the work as specified.