USE OF STABILIZER AGENTS IN MIXER DRUM WASH WATER

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BY

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EXECUTIVE SUMMARY

It is common practice in the ready-mixed concrete industry to thoroughly clean the inside of a concrete truck's drum at the end of each day using approximately 150-300 gallons of water. According to the Water Quality Act (part 116), truck wash water is a hazardous substance (it contains caustic soda and potash) and its disposal is regulated by the Environmental Protection Agency (EPA). In addition, a high pH makes truck wash water hazardous under EPA definition of corrosivity. These regulations require concrete producers to contain truck wash water on-site and prohibit its discharge off-site.

One alternative to disposal of concrete wash water in the usual way is the use of chemical stabilizing systems. The use of these admixtures circumvents the necessity to remove any wash water from concrete truck drums, and allows wash water to be reused for mixing more concrete. The admixture is added in a dosage dependent on the amount of waste water present in the drum of the concrete truck, and on the time span desired for the reuse of the water. These admixtures momentarily stop the hydration process, literally putting the cement present in a "dormant" state. Because the hydration process is interrupted, the cement in the wash water will not harden into concrete, nor will it adhere to the inside of concrete truck drums. The stabilized water is calculated into the next mix of concrete and more concrete can then be mixed in the concrete trucks.

Though preliminary studies have shown that concrete stabilized wash water can produce acceptable concrete, the main concern to FDOT is the state and type of admixture residues in the wash water, the effects of these residues on the concrete properties, and the percentage range over which these derivatives have detrimental effect

on concrete performance. Suspicion of detrimental effects on concrete durability is sufficient cause to deny use of stabilizer agents.

The FDOT sponsored this research project in fiscal year 1998-99 to develop water quality standards, which address use of stabilized mixer drum wash water in the production of fresh concrete. In order to meet this objective, a state-of-the-art review of work conducted in the use of stabilized/activated wash water in the production of fresh concrete was performed and the effects of stabilized wash water on the properties of plastic and hardened concrete were evaluated.

The following is a summary of the work done in the execution of this research project:

1. Information obtained from the literature illustrate that the properties of concrete made from stabilized wash water and/or stabilized waste concrete ranged at comparable levels to the control mixtures. Literature showed there were no significant differences in compressive strength, flexural strength, or modulus of elasticity. However, stabilized mixtures had slightly higher drying shrinkage values, especially if an accelerating admixture was used. Also, set times were reduced by about 20% when using the stabilizer/activator systems. Set times were found to be controlled by the dosage of stabilizer admixture applied or the dosage of activator if used. Set times decreased with increased dosages of activator; therefore this difference in set times can be controlled. (see Chapter 2).
2. A test program was designed and conducted to investigate the effects of stabilized wash water in concrete production. The work was divided into several phases to evaluate the effects of stabilizer for overnight applications using different Florida

aggregates, different admixture, normal and high concrete placement temperature, and different classes of concrete. In addition, the effect of stabilized wash water on early strength gain and thermal properties of concrete was evaluated. The results of each phase are summarized here:

a. Properties of stabilized concrete and their control mixtures were evaluated using a number of fresh and hardened concrete tests (temperature, slump, unit weight, air content, set time, compressive strength, flexural strength, drying shrinkage, resistance to chloride ion penetration, and sulfate expansion). FDOT Class I concrete mixtures (2500 psi) made with different Florida aggregates were evaluated in the laboratory under conditions that simulated overnight stabilization of their wash water to determine how the fresh and hardened properties changed. The results of Phase I tests (see Section 4.1) indicated that stabilizer used without addition of a retardant admixture produced concrete which performed equal to or better than its control mixture. However, stabilizer used in combination with a retardant admixture (Type D) produced concrete mixtures with higher slump, higher set time, and lower strength than their control mixtures.

b. In Phase II tests, new mixes (FDOT Class I) were made to check the effect the air-entraining admixture may have had in the development of the above results. In addition, the dosage rate of the stabilizer and the retardant admixture were changed to find an appropriate dosage rate that will not cause the above reported behavior. The results of Phase II tests indicated that elimination of air entraining admixture makes the concrete very harsh and non-workable (less than 1 in slump with the maximum allowable water/cement ratio). Reducing the dosage of retardant admixture from 14 oz to 7 oz per 100 lb of cement (switching from Type D, water reducer- retarder to Type A, water reducer) improved setting time, but continued to produce a concrete mixture with lower strength than its control mixture (see Section 4.2).

c. In Phase III, the last two mixtures of Phase II (STB –005 B and STB-005 BII) were repeated to confirm the results obtained in Phases I and II. In addition, another Type A water reducer admixture (Polyheed 997) was used in combination with the stabilizer to examine if it also causes the above reported behavior (lower strength compared to control mixture). The results of Phase III study showed that combination of stabilizer and Type A water reducer did not reduce the compressive strength, flexural strength, and modulus of elasticity. Use of Polyheed 997 water reducer in combination with stabilizer also produced concrete with properties equivalent to control mixture (see Section 4.2).

d. In Phase IV, A Class II-Bridge Deck (4500 psi) hot concrete trial mix was prepared and fresh properties of concrete were measured. The dosage of air entraining agent, Type A water reducer, and stabilizer admixtures were adjusted to obtain the desired fresh properties for concrete. Four hot concrete mixtures were then prepared and their properties were measured (temperature, slump, unit weight, air content, set time, compressive strength, flexural strength, drying shrinkage, resistance to chloride ion penetration, and time-to-corrosion). Early strength gain of concrete made from stabilized wash water was comparable to those of untreated control mixtures. Compared to control concrete samples, the compressive and flexural strengths of the stabilized concrete were acceptable. The difference between stabilized mixtures and their control mixtures was in set times. Set times for the stabilized mixtures were greater than those of their control mixtures. The test results also showed that use of stabilized wash water when concrete placement temperature is within 90-100 degree F is not affecting concrete properties. It also showed that stabilized wash water could be used with structural concrete (see Section 4.3).

e. To determine the effect of stabilized wash water on thermal properties of concrete and to collect more data on the effects of stabilized wash water on the properties of structural concrete, four Class II - Bridge Deck concrete mixtures were prepared and their properties were measured (temperature, slump, unit weight, air content, compressive strength, flexural strength, drying shrinkage, resistance to chloride ion penetration, and time-to-corrosion, and adiabatic temperature rise). The temperature rise of concrete in an adiabatic condition due to hydration of the cement was measured by using a computer -controlled adiabatic calorimeter, which maintained conditions such that no heat was lost during the test. Monitoring of adiabatic temperature rise continued for 14 days. The results show that stabilized wash water does not appear to have any effect on the thermal properties of concrete.

The objectives of this FDOT project were to verify the performance test results reported by Master Builders for concrete produced with Florida aggregates and DELVO Stabilized wash water. Through this supporting data perhaps FDOT will develop the use of DELVO technology in the reuse of mixer wash water in order to reduce concrete mixture costs, increase concrete construction productivity, and reduce the adverse environmental impact associated with the disposal of mixer wash water.

The results of this study confirmed that the use of DELVO Stabilizer in overnight applications is a viable means of reducing the disposal of wash water for concrete. Allowing reuse of stabilized wash water in production of fresh concrete reduces the cost of disposing wastewater by the concrete producers, which in turn decreases the concrete production cost. FDOT as a concrete consumer will benefit from reduction of concrete production cost. Finding environmentally friendly solutions for the use of wash water from ready mixed concrete operations will also add to the image of FDOT as one of the most progressive agencies in recycling efforts.

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CHAPTER 1 INTRODUCTION

1.1 Background

It is common practice in the ready-mixed concrete industry to thoroughly clean the inside of a concrete truck's drum at the end of each day using approximately 150-300 gallons of water. Disposal of wash water is often accomplished by discharging it into a wash water pit at the ready-mix plant or dumping it into a landfill. Both waste concrete and mixer wash water are classified by the Environmental Protection Agency as hazardous material (U.S. EPA, 1992). The disposal of these materials is highly regulated by such legislation as the Resource Conservation and Recovery Act, the Water Quality Act, and the Superfund Amendments and Reauthorization Act. As a result, the availability of landfills authorized for disposal of waste fresh concrete and wash water has been significantly reduced for the past ten years. Likewise, the effect of these environmental regulations on concrete producers and users has led to a slight increase in costs.

Most concrete producers have developed a variety of operational configurations to manage their own wash water. Alternatives include settling ponds; storm water detention/retention facilities and water reuse systems. Recognizing that a typical batch plant generates an average of 20 gallons of wash water discharge per cubic yard of ready-mixed concrete and that the average concrete production rate for a batch plant is 250 cubic yards per day, the proper disposition of the wash water presents an important issue.

In order to overcome the potential problems of recycled wash water and plastic concrete in new concrete, stabilizing admixture systems were introduced in 1988. They are now primarily marketed by Master Builders Technologies under the trademark DELVO, by Grace Concrete Products under the trademark Recovery and by Fritz Industries under the trademark Fritz-Pak Mini Delayed Set. The use of these admixtures circumvents the necessity to remove any wash water from concrete truck drums, and allows wash water to be reused for mixing new concrete. These systems consist of two phases: stabilization and activation. The stabilization phase slows or stops the hydration of the individual cement grains. The activation phase allows the hydration process to proceed normally. The activating admixture acts as an antidote for the stabilizing admixture and neutralizes the retarding effect. The dosage of stabilizer and activator depend on several factors, including the type of application, the desired length of stabilization, the age of the concrete, the cement content in the concrete, the desired set time after activation, other admixtures in the concrete, and concrete temperature (Borger, et al, 1994).

There are many applications for stabilizing admixtures. The system was originally developed for overnight and weekend stabilization of returned plastic concrete, but many new applications, including stabilization of ready-mix truck wash water, have also been developed. When a ready-mix truck delivers a load, wash water is created inside the drum from cleaning. By utilizing stabilizing admixtures, this wash water can be held overnight without setting of any of the concrete residue (butter) and then reused in the next day’s batch. In the morning, the activating admixture may be added to restore the stabilized wash water before any fresh concrete is batched using this wash water.

Often, the activating admixture is not even required because the stabilized wash water represents such a small percentage of the new batch of concrete.

Although these stabilizing admixtures have been commercially available for several years, their novelty and perceived difficulties have limited the general acceptance of the product in the ready-mixed concrete industry. In addition, only a handful of independent investigations of concrete containing these admixtures (discussed in Chapter 2) have been conducted to confirm performance results reported by their developers. All the preliminary studies have shown that stabilized waste fresh concrete and wash water can produce acceptable concrete in a new mix. In fact, ASTM C 94-94, *Standard Specification for Ready-Mixed Concrete*, and AASHTO T 26-79, *Standard Specification for Quality of Water to be Used in Concrete*, permit the use of water from mixer washout operations as mix water in subsequent batches. ASTM C 94 and AASHTO T 26 place certain criteria on the quality of wash water that can be used as concrete mix water. The levels of impurities permitted in the wash water should be below the maximum concentration criteria as follows: sulfate as SO4 (3000 parts per million), alkalies as Na2O equivalent (600 ppm), and total solids (50,000 ppm). ASTM C 94 and AASHTO T 26 only differ in the amount of chloride ion allowed. ASTM C 94 allows 500 ppm, while AASHTO T 26 allows 1000 ppm. The Portland Cement Association (PCA) also permits the use of wash water for mixing concrete with a tolerance of up to 50,000 ppm of total solids. ASTM C 94 requires that age of 28-day mortar strengths made with test water to be a minimum of 90% of the strength of cubes made with distilled water. Also, the time of setting in the test mortar should not be more than 1 hour quicker nor more than 1-1/2 hour later than the time of setting when distilled water is used.

Despite the above permitted levels of impurities in concrete batch plants' wash water, some concrete consumers do not accept its use in making concrete. In Florida, for example, the Department of Transportation (FDOT) requires that water for mixing concrete should not contain impurities in excess of the following: acidity or alkalinity calculated in terms of calcium carbonate (500 ppm), total organic solids (500 ppm), total inorganic solids (800 ppm), and total chloride as sodium chloride (500 ppm). However, even if wash water of a batch plant or truck mixer would meet these requirements, still FDOT does not allow its use as mixing water due to existence of other impurities derived from concrete admixtures. The main concern to agencies such as FDOT is the state and type of admixture residues in the wash water, the effects of these residues on the concrete properties, and the percentage range over which these derivatives have detrimental effect on concrete performance.

If authorized by FDOT, ready-mix producers could stabilize small amounts of sand and rock from a previous concrete mix and utilize the wash water (usually 30 to 50 gallons) as free water in the next day's mix. The benefits to the ready mix producer are summarized below:

- Reduces the amount of water needed to clean ready-mix truck drums.
- Reduces labor costs pertaining to washing out trucks.
- Eliminates wash water disposal.
- Eliminates the need for settling ponds/slurry pits and disposal costs.
- Reduces EPA concerns pertaining to wash water.

Concrete producers encounter a significant problem when faced with the prospect of disposal of thousands of gallons of process water daily in an environmentally acceptable manner. Ideally this water would be reusable, avoiding the environmental issues and the expense of disposal. Allowing the use of stabilized/activated wash water that meets certain physical and chemical requirements in production of fresh concrete reduces the cost of disposing wash water by the concrete producers, which in turn decreases the concrete production cost. Finding environmentally friendly solutions for the use of wash water from ready mixed concrete operations would also add to the image of FDOT as one of the most progressive agencies in sustainable development.

1.2 Objective

The objectives of this study were (a) to verify the performance test results reported by Master Builders for concrete produced with Florida aggregates and wash water containing the DELVO Stabilizer; (b) to provide supporting data and suggest key points to be considered by FDOT engineers in the development of guidelines for the use of stabilizer/activator systems; and (c) to develop the use of DELVO technology in the reuse of mixer wash water in order to reduce concrete mixture costs, increase concrete construction productivity, and reduce the adverse environmental impact associated with the disposal of mixer wash water.

1.3 Scope

The scope included FDOT and the University of Florida conducting a joint investigation in order to meet the study objectives. Attention was focused on evaluating DELVO Stabilizer for overnight stabilization of simulated truck and central mixer wash water. This investigation was patterned somewhat after the admixture evaluation procedures described in ASTM C 494-92, *Standard Specification for Chemical Admixtures for Concrete,* in that control mixtures containing no DELVO were batched and tested along with those including wash water treated with DELVO. In fact, the mixer wash water created from the control mixtures was the very wash water treated with DELVO. The work was divided into several phases to evaluate the effects of stabilizer for overnight applications using different Florida aggregates, different admixtures, normal and high concrete placement temperature, and different classes of concrete. Each control mix utilized a coarse aggregate representative of a specific Florida region in order to cover the array of physical and chemical properties induced into the mixture by the various coarse aggregates. Tests conducted on the fresh and hardened concrete included temperature, slump, air content, time of setting, compressive strength, flexural strength, dry shrinkage, rapid chloride permeability, sulfate resistance, and time to corrosion.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of literature on various aspects of applying chemical stabilizing systems to waste concrete and wash water. Topics presented deal with properties of mortar or concrete made in part from stabilized waste concrete or wash water. Also presented is review guidelines and specifications developed for use of stabilized waste concrete and wash water. The information covered includes both laboratory and field studies.

2.2 Poole (1990)

This report describes the evaluation of the DELVO System by the California Department of Transportation. The report concluded that DELVO has merit and if used it would greatly reduce the need for: (1) expensive aggregate recycling units and/or (2) hauling and dumping of hardened concrete from ready mix plants. Also, it would minimize environmental concerns. The study included two lab tests and a field test. For best results, DELVO representatives recommended that one part stabilized/activated concrete be blended with two or more parts of fresh concrete. Therefore, concrete quantities mixed one part stabilized/activated concrete to two parts fresh concrete, by volume were evaluated. It was difficult to determine exact quantities of DELVO for small concrete batches mixed in the laboratory, and several trial batches were needed to achieve acceptable stabilized/activated concrete.

Lab Test I. Ingredients were mixed in a Lancaster mixer (2 cubic foot capacity) in accordance with ASTM C 192. At the 2-hour period DELVO Stabilizer was added to the concrete. Two 5-gallon buckets stored the stabilized concrete. When the stabilized concrete was 19 hours old, DELVO Activator was added to the mix. Two 5-gallon buckets then stored the activated concrete. The mixer was cleaned and a one cubic foot sample of fresh concrete was mixed. A 0.5 cubic foot sample of the activated concrete was then added to the one cubic foot of fresh concrete. Immediately after final mixing, slump, unit weight, and air content tests were performed. When the concrete test specimens were 7 days to 6 months old, other tests were performed.

Field Test. At a ready-mix plant, two cubic yards of PCC were mixed and placed in a transit-mix truck (9 yard capacity). The 6-sack mix was continuously agitated at low speed for 2.5 hours. Then 3 gallons of water were added to produce a 3 in slump. After mixing for 5 min DELVO Stabilizer was added and mixed for 7 minutes. After mixing the concrete appeared to have a slump of about 8 inches. The truck was left alone with a plastic sheet over the drum opening to avoid contamination of the stabilized concrete. The next morning at approximately 19 hours after stabilization, the plastic was removed and the concrete mixed for about 5 minutes (16 rev/min). It had a slump of 7 to 8 inches. DELVO Activator was added. The drum was then rotated for 7 min. At the batch plant, 4 cubic yards of fresh concrete were added to the 2 cubic yard mixture in the truck. The blended concrete was then mixed for 5 minutes. Approximately 30 minutes later the truck arrived at the lab. It looked stiff so 4 gallons of water was added and then it was mixed for 5 minutes. The concrete was then placed into a 23’long x 9”wide and 9” deep form. The second lab test was simply the control mix performed similar to lab test 1. All the same tests were performed.

Compressive strength testing. The concrete specimens from the DELVO Lab Mix did not perform as well as concrete specimens from the Control Lab Mix. The average compressive strength for DELVO Lab Mix was 98, 82, 91 and 87 percent of the Control Lab Mix at 7 days, 28 days, 2 months and 6 months, respectively. The DELVO Truck Mix however outperformed the Control Lab Mix.

Flexural strength testing. Concrete from the DELVO Lab Mix generally had a lower flexural strength at all ages compared to the Control Lab Mix. The flexural strength of concrete from the DELVO Lab Mix was 94, 74, 104 and 90 percent of Control Lab Mix concrete at 7 days, 28 days, 2 months and 6 months, respectively. The flexural strength testing for the Truck Mix was performed in a different manner and was not comparable to the above.

Modulus of elasticity testing. At 7 days, the modulus of elasticity of concrete specimens from the DELVO Truck Mix and the DELVO Lab Mix test specimens was significantly higher than that of the concrete specimens from the Control Lab Mix, 51 and 28 percent respectively. But then from 28 days to 6 months, they are more or less the same.

Abrasion resistance testing. At 6 months, abrasion loss values for all three mixes averaged about 14 grams (1.5%).

Drying shrinkage testing. At 7 days the DELVO Truck Mix drying shrinkage was 65% higher than the Control Lab Mix. But at the 2- and 6-month period, it was only 8 and 2 percent higher than that of the Control Lab Mix. Average drying shrinkage values of concrete specimens from the DELVO Lab Mix were within +/-16% of concrete specimens from the Control Lab Mix throughout the evaluation period.

Set-time testing. Set times for the DELVO Lab Mix compared to the Control Lab Mix were somewhat shorter. 1 hour 55 min compared to 2 hour 30 min initial set. 3 hours compared to 3 hours 45 min final set.

Chemical testing revealed that DELVO is fully compatible with steel reinforcement in PCC. The DELVO Truck Mix revealed water-soluble chlorides of less than 0.001% and water-soluble sulfates of 0.016%. When PCC contains steel rebar without an epoxy coating, Caltrans limits maximum level of water soluble chlorides and water soluble sulfates to 0.05 percent and 0.25 percent, respectively.

Summary of conclusions. (1) There were no significant differences in flexural strength, modulus of elasticity and abrasion resistance for test specimens evaluated from the DELVO Truck Mix, DELVO Lab Mix and Control Lab Mix. (2) For the first 21 days, concrete specimens from the DELVO Truck Mix and the DELVO Lab Mix had slightly higher drying shrinkage values than concrete specimens from the Control Lab Mix. However, from one to six months, drying shrinkage values of concrete specimens from the DELVO Truck Mix and DELVO Lab Mix approached drying shrinkage values of concrete specimens from the Control Lab Mix. (3) The DELVO System does not adversely affect the set time of PCC. However, laboratory tests indicated that set times were reduced about 20% when using the DELVO System (one part stabilized/activated PCC to two parts fresh PCC).

2.3 Borger, et al, (1994)

In a research work by Borger, et al, the effects of stabilizer systems on the properties of mortar were examined. Half of this test program dealt with stabilizing and activating admixtures and their use in controlling the hydration dynamics of a mortar. Depending on the dosage of stabilizer, the mortar was kept from setting for any desired period of time. However, above a certain dosage of stabilizing admixture the mortar did not set at all. In general the mortars that were allowed to sit for a longer period of time before being dosed needed more stabilizer than the mortars that were dosed immediately upon batching. This was explained by the more advanced degree of hydration of the older mortars.

When the mortar was activated, there was a general trend that the set times decreased with increased dosages of activator. In all tests, the strength of the stabilized/activated mortars equaled or exceeded the strength of the control batch. In fact, the use of stabilizer alone, without any activator was shown to increase the compressive strength. There were no adverse effects of high dosages of activator on compressive strength.

In all cases, the resulting mortar had a similar flow to the original mortar, indicating that the workability was not affected by the stabilization/activation process. The flow for mortars containing higher activator dosages was larger than for mortars containing lower activator dosages.

2.4 Lobo, et al, (1995)

In a research work by Lobo, et al, the use of stabilized waste concrete in fresh concrete production was examined. In this report, the term “blended concrete” was used for a mixture of stabilized or treated plastic concrete with fresh concrete ingredients. The study evaluated some of the processing conditions and the resulting properties of blended concrete containing plastic concrete treated with extended set-retarding admixtures. The response of a cement and admixture combination is unique, so the conclusions are specific, to a certain extent, to the brands of cement and admixture, as well as the operating conditions.

The study looked at four processing factors that need to be considered when stabilizing concrete is mixed with fresh materials to produce a blended concrete batch.

1. (SAT) stabilizer addition time – the age of concrete when the admixture was added.

Low – 45 min, represented the earliest time a producer might decide to use a stabilizer.

High – 180 min, represented the latest time this particular concrete mixture could be stabilized.

2. (SD) stabilizer dose – amount used to keep the treated concrete from setting for the desired period. The selected stabilizer dosage depended on the age of concrete at the time it was treated (SAT), and the duration for which the concrete had to be held prior to batching fresh material (CAT).

3. (PTC) percent of treated concrete – the percent (by mass) of treated concrete in a blended concrete batch.

Low – 5% - The mortar fraction, or “butter,” that sticks to the walls of a concrete truck mixture generally constitute about 1% of a full load of concrete, or about 270 kg (600 lb) of cement, fine aggregate, and water. 5% represented this situation of recycling truck wash water.

High – 50% - This represented an upper practical limit of recycling returned concrete.

4. (CAT) concrete addition time – the duration for which the stabilized concrete was held prior to the addition of fresh material.

Low – 45 min – represented recycling wash water or plastic concrete on the same day.

High – 20 hrs – represented the case when stabilized concrete would be held in a truck overnight and batched with fresh materials the next day.

Batching fresh materials in a mixer containing 90 min old butter is regularly done and does not typically need the use of a stabilizer. Also, holding treated concrete overnight and combining it with 50% or less fresh material was not recommended by the admixture suppliers. Constant factors were temperature, ingredients (cement, admixture brands, aggregates), concrete mixture proportions for original and blended batches, and concrete slump was held relatively constant by retempering as required. Response variables evaluated were setting time of blended concrete, compressive strength at 28 days, and drying shrinkage of 28 days moist-cured specimens after 91 days in air.

Concrete that was stabilized for the purpose of recycling on the next day was typically over-dosed, to prevent it from setting up in the mixer drum. Prior to batching fresh material, an activator was added to counteract the effect of the stabilizer. In this study, CaCl2, in flake form, was used as the activator. Samples were obtained from the original and blended concrete batches at ages of 8 min, 45 min, and 180 min.

<u>Setting time</u>. Two opposing mechanisms were at work: the accelerating effect of older concrete, and the retarding effect of the admixture. For a particular set of stabilizing conditions, the admixture dosage was optimized to produce a blended batch with the same setting characteristics as that of a control batch. At this optimum dosage, the accelerating and retarding effects were shown to cancel out.

Compressive strength. For concrete recycled on the same day, the strength of the blended concretes was essentially similar to that of the control concrete. For the concrete recycled on the next day, blended and control were similar except for the case of insufficient admixture. Strength of later age samples was essentially controlled by water addition requirements resulting from a modified setting time. Longer setting times of blended batches resulted in lower water contents and higher strengths.

Shrinkage. Shrinkage increased as SAT increased when looking at the 8 min samples, which have similar water contents. Shrinkage increased as PTC increased. For concrete recycled at 20 hrs, no significant difference between the recycled batches and the control was evident. The data did not indicate any conclusive effect of SAT, SD, or PTC in the recycled batch. Calcium chloride had an overwhelming effect on shrinkage and probably clouded any effect of the admixture and stabilization conditions. At later ages, the shrinkage was controlled by recycling conditions that increased or decreased the setting time with respect to the control batches, which in turn determined the water content in the batch at that age.

Later age properties. Job site properties are controlled by the haul time of the concrete, which in turn controls the amount of retempering water required to discharge workable concrete. Concrete temperature also has a significant effect on water demand, but in this study it was kept constant. Also, the original and blended concretes were periodically agitated and retempered to maintain a 3 in slump. A rapid setting concrete required a higher rate of water addition to maintain slump. The properties of the delivered concrete were a function of the amount of retempering water needed to discharge concrete at the desired slump, which was shown to be a function of the initial setting characteristics of the batch. The set time of blended concrete was controlled by the stabilization conditions or factors. Data also showed the well-known effect that increasing water content result in decreased strength.

Conclusions. For the case of recycling stabilized truck-mixer wash water (PCT=5%) as batch water in a subsequent concrete batch, the compressive strength and drying shrinkage of the resulting concrete was not significantly affected.

A calibrated curve that determines admixture dosage for different holding times was suggested to be developed for a particular cement and admixture combination for various concrete ages and temperatures.

2.5 Ragan, et al, (1995)

In a report by Ragan, et al, of the U.S. Army Corps of Engineers, DELVO technology was evaluated for several applications. Both laboratory and field tests were performed on same-day, overnight, long haul and elevated-temperature stabilized mixtures. Also, the use of DELVO in lean mass concrete and in mass roller-compacted concrete was examined.

To address questions and concerns in the industry, Master Builders and U.S. Army Engineer Waterways Experiment Station (WES) entered into a Cooperative Research and Development Agreement (CRDA) under the Construction Productivity Advancement Research (CPAR) Program. The CPAR Program is a cost-shared research and development program aimed at assisting the U.S. construction industry in improving productivity by facilitating development and application of advanced technologies. As the productivity and competitiveness of the U.S. construction industry is advanced, savings will be realized for the Government, and the U.S. economy will be boosted. This document is the final report of the work undertaken.

The objectives of this study were (a) to verify the performance test results reported by Master Builders for concrete containing the DELVO Stabilizer and Activator and (b) to develop new applications for DELVO technology in order to reduce concrete mixture costs, increase concrete construction productivity, and reduce the adverse environmental impact associated with the disposal of waste fresh concrete.

The scope included WES and Master Builders conducting separate investigations in order to meet the study objectives. WES focused attention on evaluating DELVO Stabilizer and Activator for standard ready-mixed concrete applications as defined by Master Builders, Inc. These applications included long haul, same-day, and overnight stabilization. This investigation was patterned somewhat after the admixture evaluation procedures described in ASTM C 494 (1991i) in that control mixtures containing no DELVO were batched and tested along with those for each DELVO application. Tests conducted on the fresh and hardened concrete included temperature, slump, air content, time of setting, compressive strength, flexural strength, resistance to rapid freezing and thawing, length change, rapid chloride-ion penetration, and parameters of air-void system.

A major focus for Master Builders in the study was the development of simplification procedures for generating DELVO Stabilizer dosage charts for the same-day stabilization application. A computer model based upon a database of field dosage data was developed and will enable Master Builders' representatives to generate DELVO Stabilizer dosage charts for customers in a shorter period than was previously possible.

The same-day stabilization of returned fresh concrete allows concrete producers to stabilize the concrete either immediately upon return to the plant so that new concrete may be batched on top of the stabilized concrete and immediately used, or to stabilize returned fresh concrete for a short period until the producer is able to locate a site where it may be used. When fresh concrete is returned to the concrete plant, water may need to be added to bring the concrete slump to approximately 4 to 6 in. DELVO Stabilizer is added, and then new concrete is batched either immediately or at some later time on top of the stabilized concrete. In most cases, the DELVO Activator is not needed for this application. As with the overnight stabilization application, any water added to the stabilized concrete must be deducted from the total mixing water added to the newly batched concrete.

Other current commercial applications of the DELVO system include overnight and weekend stabilization of truck and central mixer wash water, same-day stabilization of concrete during truck breakdowns assuming the mixer drum can be turned to achieve sufficient mixing action, and same-day and overnight stabilization of leftover concrete from pumping operations. The applications evaluated in this investigation included same-day stabilization of fresh concrete, overnight stabilization of fresh concrete, and simulated long-haul application.

Four reference mixtures were proportioned and evaluated using a number of fresh and hardened concrete tests. Each of the four mixtures was then evaluated in the laboratory under conditions that simulated same-day, overnight, and long-haul stabilization of fresh concrete to determine how the fresh and hardened properties changed. Two of the reference mixtures contained Lonestar cement, and two contained Capitol cement. Three replicates were made for each mixture, which resulted in a total production of 48 trial batches of concrete.

Same-day stabilized mixtures. Time zero for purposes of determining initial time of setting was defined as the time when the concrete reached 2.5-hr age, rather than the time it was initially discharged from the mixer. This simulated 2.5-hr-old concrete that might be returned to the concrete plant. The temperatures and initial times of setting of the stabilized batches were then compared to those of the reference mixtures with no DELVO Stabilizer. The dosages selected for use were those that retarded the time of initial setting to approximately 2 hours beyond that of the reference mixtures.

Master Builders recommends that when returned fresh concrete is to be reused the same day, it should first be stabilized with DELVO; then approximately twice that volume of concrete having the same mixture proportions, as the original batch should be added to it. Once same-day DELVO Stabilizer dosage rates were determined for the reference mixtures, the same-day stabilized trial batches were mixed in two stages to simulate reuse of returned concrete. First, 1.25 cu-ft of a particular reference mixture was batched and mixed in accordance with ASTM C 192 (ASTM 1991d). The concrete remained in the mixer for 2.5 hrs to simulate concrete that was sent out from a plant and then later returned. The mixer remained covered during this time to minimize evaporation of mixing water, and it was rotated 5 to 10 revolutions every 15 min to simulate agitation. DELVO Stabilizer was added to the batch at the end of the 2.5-hr aging period, and the concrete was remixed for 4 min. Then 2.55 cu-ft of the same reference mixture was batched on top of the stabilized concrete, and the entire batch was again mixed in accordance with ASTM C 192. After completion of the mixing, the batch was discharged from the mixer so that fresh concrete tests could be conducted and hardened concrete specimens could be molded.

Overnight stabilized mixtures. In accordance with recommendations by Master Builders' staff, the Stabilizer dosages were determined for each reference mixture such that time of initial setting was not achieved until approximately 30 to 36 hr after mixing. This would comfortably permit stabilization of the concrete for 12 to 20 hr, which is the typical duration of interest for ready-mixed concrete producers. The overnight-stabilized mixtures were mixed in two stages to simulate concrete that was returned and then reused the following day. Following the same-day stabilization format, 1.25 cu-ft, of a particular reference mixture was batched and mixed. However, after the 2.5-hr aging period, water was added to the concrete to raise the slump to an estimated value of 8 to 10 in. The DELVO Stabilizer was then added, and the concrete was remixed for 7 min to ensure uniform distribution of the Stabilizer. The stabilized concrete was then discharged into a container and covered to prevent evaporation of mixing water. No additional agitation of the concrete occurred after discharge. 17 hrs after addition of the Stabilizer, the concrete was prepared for reuse by returning it to the laboratory mixer and adding a predetermined dosage of Master Builders' Pozzutec 20, an ASTM C 494 (ASTM 1991i) Type C accelerating admixture. The concrete was then mixed continuously for 7 min, after which time 2.75 cu-ft of concrete was batched onto the stabilized concrete. This concrete had proportions similar to those of the concrete originally batched, except water was withheld to compensate for that added during the stabilization process. The total trial batch was then mixed in accordance with ASTM C 192 and discharged so that tests could be performed. For overnight-stabilized mixtures, fresh tests were conducted on samples before the addition of DELVO Stabilizer and on samples taken 18 hr after Stabilizer addition.

Compressive strength. Within each of the four mixtures evaluated, each stabilization application resulted in compressive strengths comparable to the reference mixture.

Flexural strength. The average flexural strengths of the overnight-stabilized mixtures are generally at least 90% of those of the reference mixtures.

Resistance to rapid freezing and thawing. The average durability factors of overnight-stabilized mixtures relative to the reference mixtures ranged from 78 to 107. A relative durability factor of 80 seems a useful benchmark to use for evaluating the resistance of freezing and thawing of the stabilized mixture.

Length change. In general, accelerated mixtures are expected to exhibit greater shrinkage than mixtures that are not treated with accelerating admixtures.

Resistance to chloride-ion penetration. Both the reference and stabilized mixtures had moderate-to-high chloride-ion penetrability and were comparable.

Parameters of air-void system. Some of the mixtures have relatively low entrained-air contents and yet still have small spacing factors.

Recommendations. The objectives of this CPAR project were to verify the performance test results reported by Master Builders for some of the current standard applications of DELVO technology and to develop new applications for the technology which might reduce concrete mixture costs, increase concrete productivity, improve infrastructure durability, and reduce the adverse environmental impact associated with the disposal of waste concrete. The use of DELVO Stabilizer in the same-day, overnight, and long-haul applications is a viable means of reducing the disposal of waste concrete. Additional research is recommended to confirm the length-change results reported herein for these applications. If drying shrinkage is notably increased when DELVO Stabilizer is used for overnight stabilization, then changes in the procedures followed for this application, or in the product formulation itself, may be warranted. Additional research is also recommended to evaluate the use of DELVO on concrete containing additional materials such as ground slag, pozzolans, and chemical admixtures, since DELVO is routinely used to stabilize mixtures containing these materials.

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents the materials, mixtures, and test methods used to evaluate the performance of DELVO Stabilizer applied to the overnight stabilization of mixer wash water. The work was divided into five phases as follows:

a. Phase I. In phase I of this study, six FDOT Class I concrete mixtures were made with three groups of coarse aggregate representative of those available in different regions of Florida. Brookesville Limestone (005) and Calera Limestone (351) aggregates represented Central and North Florida respectively. Oolitic Limestone (090) aggregate represented the South Florida region. This allowed comparison between a stabilized mixture and its control mixture of the same aggregate type. Differing proportions of chemical admixtures used amongst the three groups permitted the examination of the effects dosage rates have on mixtures. All other variables were held constant.

b. Phase II. In phase II tests, four FDOT Class I concrete mixtures were made to check the effects dosage rates of air-entraining and water reducer/retarder admixtures have on concrete made with stabilized wash water. Brooksville limestone coarse aggregate was used for all mixtures and all other variables were held constant.

c. Phase III. In Phase III, four FDOT Class I concrete mixtures were made. The first two were similar to phase II mixtures to confirm the results obtained previously. A different type A water reducer was used in the last two mixtures to examine the effect of type of water reducer on properties of stabilized mix.

d. Phase IV. Four FDOT Class II- Bridge Deck hot concrete mixtures were made to examine the effect of stabilized wash water on early strength gain and form removal of concrete in Florida environment.

e. Phase V. Four FDOT Class II - Bridge Deck concrete mixtures were made to determine the effect of stabilized wash water on thermal properties of concrete.

3.2 Materials

Water-Reducing and Retarding Admixtures

One drum of the DELVO Stabilizer was received by FDOT from Master Builders in August 1998. Master Builders informed FDOT that the DELVO Stabilizer met the requirements of ASTM C 494 Type B, Retarding Admixture, when used at a dosage rate of approximately 4 fluid ounces per 100 pounds of cement. A subsequent evaluation by FDOT indicated that this assertion was correct. Appendix A-1 provides the manufacturer's information on the DELVO system.

One drum of Pozzolith 220-N water reducer/retardant admixture was received from Master Builders in September 1998. Pozzolith 220-N is an aqueous solution of a complex mixture of organic acid salts containing a catalyst for the more complete and rapid hydration of Portland cement. Master Builders provided independent certification demonstrating that the admixture met ASTM C 494 Type A, Water-Reducing Admixture, (dosage rate of approximately 2 fluid ounces per 100 pounds of cement) and Type D, Water-Reducing and Retarding Admixtures, (dosage rate of approximately 4 fluid ounces per100 pounds of cement). Previous tests performed by FDOT verify this. The manufacturer's information on this product is provided in Appendix A-2.

Air-Entraining Admixture

The air-entraining admixture (AEA), MB-VR by Master Builders, was used in the investigation. Air entraining admixtures increase the air content of concrete resulting in increased workability and durability. It is an aqueous solution containing surface-active agents consisting of fatty acids and salts of sulfonic acids, which produce a concrete with a lower water content (typically an 8% to 10% reduction), greater plasticity, and greater strength. Typical addition rates for MB-VR range from 3 to 6 fluid ounces per 100 pounds of cement. Testing conducted in a previous FDOT investigation indicated that this AEA met the requirements of ASTM C 260-94, *Standard Specification for Air-Entraining Admixtures for Concrete*. Appendix A-3 provides the manufacturer's information concerning MB-VR.

Cement

One general purpose AASHTO Type I Portland cement as defined in AASHTO M 85-96, *Standard Specification for Portland Cement*, was supplied by Southdown and used in this investigation. Table 3-1 gives a summary of the chemical analysis and Table 3-2 summarizes the physical analysis performed on the cement. Appendix B-1 provides FDOT tests of Portland cement.

Table 3-1 Cement Chemical Analysis

Analysis	Percent (%)
Max. Loss of Ignition	1.6
Insoluble Residue	0.31
Sulfur Trioxide	3.0
Magnesium Oxide	0.8
Tricalcium Aluminate	6.7
Total Alkali as Na_2O	0.48
Silicon Dioxide	-
Aluminum Oxide	-
Ferric Oxide	-
Tricalcium Silicate	-

Table 3-2 Cement Physical Analysis

Analysis	
3 Day Strength	3350 psi
7 Day Strength	4720 psi
Fineness	208 sq-yd/lb
Initial Set Time	170 minutes
Final Set Time	245 minutes
Autoclave Soundness	-0.10

Fly Ash

A Class F fly ash finely divided mineral admixture was used in the mix design to replace 20 percent by weight of the Portland cement, which is common for FDOT projects. The fly ash was provided by Boral Technologies and Crystal River Power Plant was the source. Table 3-3 summarizes the test report for the fly ash used in this investigation. Appendix B-2 contains the FDOT test report for fly ash.

Table 3-3 Fly Ash Test Report

Property	Result
Oxides of Silicon, Iron & Aluminum	85.14%
Sulfur Trioxide	0.3%
Moisture Content	0.7%
Loss of Ignition	3.7%
Specific Gravity	2.02
Autoclave Expansion	-0.03
% Passing 325 Sieve	30%
Strength Activity Index-28 days	80%

Fine Aggregate

A natural siliceous sand, Keuka Silicia Sand, provided by Florida Rock Industries was used as fine aggregate. The fineness modulus was run in accordance with ASTM C 136-84a, *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates*, and determined to be 2.33. This is in the acceptable range of 2.3 to 3.1 designated by ASTM C 136. The absorption and specific gravity of the fine aggregate were determined in accordance with ASTM C 128, *Standard Test Method for Specific Gravity and Absorption of Fine Aggregate*, to be 0.24% and 2.64, respectively. Table 3-4 summarizes the grading results for the fine aggregate. The complete FDOT report for the fine aggregate is given in Appendix B-3.

Table 3-4 Grading Characteristics of Fine Aggregate

Sieve Size	Percent Passing	ASTM Specification	Cumulative % Retained by Weight
0.375 in	100%	100%	0
No. 4	100%	95% to 100%	0
No. 8	99%	80% to 100%	1
No. 16	90%	50% to 85%	11
No. 30	62%	25% to 60%	49
No. 50	15%	10% to 30%	134
No. 100	1%	2% to 10%	233*
No. 200	0%	-	
* 233/100 = 2.33 (fineness modulus)			

Coarse Aggregates

Three separate no. 57 (max. nominal size 1.5 in) coarse aggregates were used representative of those available in different regions of Florida. Brookesville Limestone and Calera Limestone aggregates were supplied by Vulcan Industries to represent Central and North Florida respectively. Oolitic Limestone aggregate was supplied by Rinker CSR to represent South Florida. The coarse aggregates were used in three separate control mixtures. Table 3-5 summarizes the grading characteristics of these aggregates and gives a comparison to the ASTM C 33, *Specification for Concrete Aggregates*. Appendices B-4, B-5, and B-6 contain the FDOT coarse aggregate test results for Brookesville, Calera, and Oolitic respectively.

Table 3-5 Grading Characteristics of Coarse Aggregates

Sieve Size	Percent Passing			ASTM C 33 Specification
	Brookesville	Calera	Oolitic	
1.5 in	100%	100%	100%	100%
1 in	99%	99%	100%	95% to 100%
0.5 in	30%	44%	31%	25% to 60%
No. 4	4%	3%	5%	0% to 10%
No. 8	3%	2%	4%	0% to 5%
No. 200	1.4%	0.5%	-	-

The specific gravity and absorption of the coarse aggregates were determined in accordance with ASTM C 127, *Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate*. Table 3-6 gives a summary of the results.

Table 3-6 Specific Gravity and Absorption of Coarse Aggregate

Coarse Aggregate	Specific Gravity	Absorption
Brookesville	2.42	2.60%
Calera	2.73	0.40%
Oolitic	2.39	3.70%

3.3 Concrete Mixtures

Control mixtures

a. FDOT Class I. Seven control mixtures were proportioned and evaluated using a number of fresh and hardened concrete tests (temperature, slump, unit weight, air content, set time, compressive strength, flexural strength, drying shrinkage, resistance to chloride-ion penetration, and sulfate expansion). Each of the seven mixtures was then evaluated in the laboratory under conditions that simulated overnight stabilization of their wash water to determine how the fresh and hardened properties changed. Two replicates were made for each mixture, which resulted in a total production of 14 trial batches of concrete. Each mixture was designed as FDOT Class I (nonstructural) Concrete having a 28-day compressive strength of 2,500 psi. They were designed to produce 6 cubic feet of concrete and proportioned to achieve a slump of 2 $\pm$ 2 inches. The mixture proportions are given in Table 3-7.

b. FDOT Class II - Bridge Deck. Four control mixtures were proportioned and evaluated using a number of fresh and hardened concrete tests.. Each of the four mixtures was then evaluated in the laboratory under conditions that simulated overnight stabilization of their wash water to determine how the fresh and hardened properties changed. Two replicates were made for each mixture, which resulted in a total production of eight trial batches of concrete. Each mixture was designed as FDOT Class II Bridge-Deck Concrete having a 28-day compressive strength of 4,500 psi. They were designed to produce 6 cubic feet of concrete and proportioned to achieve a slump of 3 $\pm$ 1.5 inches. The mixture proportions are given in Table 3-8.

Table 3-7 Mixture Proportions for FDOT Class I (nonstructural) Concrete

Mixture	Saturated Surface-Dry Weights, lb/batch (Batch 6.0 cu ft)								
	Cement	Flyash	Fine Aggregate	Coarse Aggregate	Air Entrainer	Pozz220N Retardant	DELVO Stabilizer	Water	w/c Ratio
STB005	83.5	20.9	293.0	375.2	46.0 ml	91.9 ml	0.0 ml	51.4	0.49
STB005 II	83.5	20.9	293.0	375.2	46.0 ml	0.0 ml	88.7 ml	57.3	0.55
STB351	83.5	20.9	293.0	424.7	46.0 ml	91.9 ml	0.0 ml	54.0	0.52
STB351 II	83.5	20.9	293.0	424.7	46.0 ml	91.9 ml	73.9 ml	51.8	0.50
STB090	83.5	20.9	293.0	372.1	46.0 ml	46.0 ml	0.0 ml	50.4	0.48
STB090 II	83.5	20.9	293.0	372.1	46.0 ml	46.0 ml	59.1 ml	50.1	0.48
Delvo I	83.5	20.9	293.0	372.1	0 ml	91.9 ml	0 ml	57.3	0.55
Delvo II	83.5	20.9	293.0	372.1	0 ml	91.9 ml	47.3 ml	57.3	0.55
Delvo III	83.5	20.9	293.0	372.1	46.0 ml	46.0 ml	0 ml	55.3	0.53
Delvo IV	83.5	20.9	293.0	372.1	46.0 ml	46.0 ml	47.3 ml	55.3	0.53
Delvo V	83.5	20.9	293.0	372.1	46.0 ml	46.0 ml	0 ml	54.3	0.52
Delvo VI	83.5	20.9	293.0	372.1	46.0 ml	46.0 ml	47.3 ml	55.3	0.53
Delvo VII	83.5	20.9	293.0	372.1	46.0 ml	46* ml	0 ml	54.3	0.52
Delvo VIII	83.5	20.9	293.0	372.1	46.0 ml	46* ml	47.3 ml	54.3	0.52

* Polyheed 997 admixture Type A was used

Overnight stabilized mixtures

Each of the control-mixtures' wash water was evaluated in the laboratory for overnight stabilization. In accordance with recommendations by Master Builders' staff, the Stabilizer dosage was determined for the control mixture such that time of initial setting was not achieved until approximately 24 to 30 hours after mixing. This would comfortably permit stabilization of the concrete wash water for 12 to 20 hours, which is the typical duration of interest for ready-mixed concrete producers. The DELVO Stabilizer dosage rate for the overnight-stabilized wash water was given as 32 oz (946 ml) DELVO:400 lb concrete:50 gallons (415 lb) of water. This 400 pounds of concrete represents the amount normally remaining in a mixer truck after the discharge of a delivery. When a new batch is mixed with this, the 400 pounds of concrete represents 1.5% of the new mix. Therefore, if the material is overdosed with DELVO Stabilizer, it is considered negligible due to the small percentage of the new mix it effects.

Table 3-8 Mixture Proportions for FDOT Class II – Bridge Deck Concrete

Mixture	Saturated Surface-Dry Weights, lb/batch (Batch 6.0 cu ft)								
	Cement	Fly ash	Fine Aggregate	Coarse Aggregate	Air Entrainer	Pozz220N Retardant	DELVO Stabilizer	Water	(w/c) Ratio
Delvo IX	118	27	260.0	371	65.6 ml	65.6 ml	0 ml	60.9	0.42
Delvo X	118	27	260.0	371	65.6 ml	65.6 ml	50 ml	63.8	0.44
Delvo XI	118	27	260.0	371	65.6 ml	65.6 ml	0 ml	63.8	0.44
Delvo XII	118	27	260.0	371	65.6 ml	65.6 ml	50 ml	63.8	0.44
Delvo XIII	118	27	260.0	371	65.6 ml	65.6 ml	0 ml	55.1	0.38
Delvo XIV	118	27	260.0	371	65.6 ml	65.6 ml	50 ml	58.0	0.40
Delvo XV	118	27	260.0	371	65.6 ml	65.6 ml	0 ml	63.8	0.44
Delvo XVI	118	27	260.0	371	65.6 ml	65.6 ml	50 ml	58.0	0.40

Similarly, the laboratory mixer was found to retain approximately 30 pounds of concrete in the drum after discharging a batch. The calculated ratio for the laboratory mixer based on the manufacturer's recommendation was 2.4 oz (71 ml) DELVO: 30 lb concrete:32 lb of water. To remain more on the conservative side of this ratio, the investigation began with the addition of 3 ounces of DELVO and 25 pounds of water. In the laboratory a 6 cu ft batch was mixed, so the 30 pounds of cementitious material represented 3.5% of the new mix.

After a particular control mixture was batched and mixed in accordance with ASTM C 192-90a, *Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory*, it was discharged leaving only a butter, the 30 pounds of cementitious material, remaining in the mixer drum. Tap water was added to the mixer drum for cleaning and the amount was recorded. Fresh concrete tests were performed and hardened concrete specimens were molded from the discharged material. After two hours elapsed, the DELVO Stabilizer was then added to the drum, and the wash water mixture was mixed for 3 min to ensure uniform distribution of the Stabilizer. The laboratory mixer was then covered to prevent evaporation of the wash water. No additional agitation of the stabilized wash water occurred after covering. Twenty-two hours after addition of the DELVO Stabilizer, a batch of concrete similar to the control was batched into the stabilized wash water mixture. This concrete had proportions similar to those of the control, except water was withheld to compensate for that added to create the wash water. The total trial batch was then mixed in accordance with ASTM C 192 and discharged. Fresh concrete tests were performed and hardened concrete specimens were molded.

3.4 Test Methods

The conduct of fresh concrete tests and the preparation and testing of hardened concrete test specimens followed standard procedures of ASTM. The tests performed and applicable methods are given in Table 3-9. Test results and discussions are given in Chapter 4.

Table 3-9 Summary of Test Methods

Type Test	Test Method or Specification
Temperature of fresh concrete	ASTM C 1064 (ASTM 1993)
Slump of fresh concrete	ASTM C 143 (ASTM 1990a)
Unit weight of fresh concrete	ASTM C 138 (ASTM 1992)
Air content of fresh concrete	ASTM C 173 (ASTM 1993)
Time of setting	ASTM C 403 (ASTM 1992)
Compressive strength	ASTM C 39 (ASTM 1996)
Static modulus of elasticity	ASTM C 469 (ASTM 1994)
Flexural strength	ASTM C 78 (ASTM 1994)
Drying shrinkage	ASTM C 157 (ASTM 1993)
Chloride ion penetration	ASTM C 1202 (ASTM 1994)
Sulfate expansion	ASTM C 1012 (ASTM 1995a)
Time to corrosion	FM 5-522

Temperature

The temperature of fresh concrete is an important factor in determining and evaluating the correct dosage of DELVO Stabilizer for any application. Therefore, fresh concrete temperature measurements were made according with ASTM C 1064-93, *Standard Test Method for Temperature of Freshly Mixed Portland Cement Concrete*, on all batches in order to examine the effects temperature may have on the properties of the concrete mixtures and their particular mixture proportions.

Slump, unit weight, and air content

Slump tests were performed in accordance with ASTM C 143-90a, *Standard Test Method for Slump of Hydraulic Cement Concrete*, on samples of concrete batched with tap water or with overnight-stabilized wash water. Unit weight tests were conducted according to ASTM C 138-92, *Standard Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete*. Air content tests were performed in accordance with

ASTM C 173-93, *Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method* on the two types of samples described above.

Time of setting

Since a primary function of DELVO Stabilizer is to extend the time of setting of concrete for various applications, actual knowledge of the concrete time of setting was critical. Time-of-setting tests were conducted in accordance with ASTM C 403-92, *Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance*, on control batches and concrete batches mixed with stabilized wash water.

Compressive strength

The unconfined compressive strengths of specimens representing the replicate batches of each mixture were determined according to ASTM C 39-93a, *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*, by the University of Florida's Civil Engineering Department. Nine standard 6" diameter x 12" cylinders were molded from each batch, and three each were tested at 7-, 14-, and 28-days age.

Static modulus of elasticity

Modulus of elasticity tests was performed by the University of Florida's Civil Engineering Department. The modulus of elasticity is defined as the ratio of stress to strain in the elastic range of a stress-strain curve. Two 6" diameter x 12" cylinders, which later were tested for compressive strengths at 28-days age, were first tested using Linear Variable-Differential Transformers (LVDTs). Vertical strains were measured and the chord modulus of elasticity determined according to ASTM C 469-94, *Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression*.

Flexural strength

The flexural strengths of specimens representing the replicate batches of each mixture were determined according to ASTM C 78-94, *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)*, to determine the modulus of rupture. Two 6" x 6" x 30" beams were cast from each batch, and two each were tested at 28-days age.

Drying shrinkage (length change)

Three prisms measuring 3" x 3" x 11-1/4" were molded from each batch in accordance with ASTM C 157-93, *Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete*, to determine the length change of concrete due to causes other than externally applied forces and temperature changes. Each prism was demolded after 24 hours of curing, and an initial comparator reading was taken. Later, after the prisms were stored for 28 days in lime-saturated water at 73 degrees F, a second length reading was taken. The prisms were then stored in air at 50% relative humidity and 73 degrees F for the remainder of the test period. The prisms' lengths were than measured 1, 2, and 4 weeks after initial air storage.

Resistance to chloride-ion penetration

The rapid chloride permeability of a specimen representing each batch was estimated following ASTM C 1202-94, *Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride-Ion Penetration*. In this test, the chloride-ion penetrability is determined on a preconditioned specimen by measuring the number of coulombs that can pass through a sample in 6 hrs. This provides an accelerated indication of the concrete's resistance to the penetration of chloride-ions, which may corrode steel reinforcement or prestressed strands. Two 4" diameter x 8" cylinders were molded from each batch and moist cured for 28 days. A 2" long sample was then sawed from the top of the cylinders and used as the test specimen. It has been determined that the total charge passed is related to the resistance of the specimen to chloride-ion penetration.

Sulfate expansion

The sulfate resistance of a specimen representing each batch was estimated following ASTM C 1012-95a, *Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution*. In this test the specimens are immersed in a sulfate solution and their change in length determines the effect of sulfate. Six 3" x 3" x 11-1/4" prisms were molded from each batch. After 24 hours of curing, the prisms were demolded and placed in a saturated limewater-curing tank for 28 days. After 28 days, the prisms were removed from the lime-saturated water and an initial comparator length change reading was taken. The prisms were then placed in a sulfate solution consisting of 50 grams of sodium sulfate per 900 milliliters of water (5.5% solution rate) for the remainder of the testing period. Length readings were taken 1, 2, 3, and 4 weeks after the initial length reading.

Time to Corrosion

The time to corrosion test determines the duration of time for reinforcing within a sample to corrode. Three samples were prepared in cylinders measuring 4-inches by 6-inches. Each sample contained a #4 reinforcing bar, 12 inches long. The bottom of the reinforcing bar was required to be elevated by .75” from the bottom of the mold. Fresh concrete was placed in each of the three molds and each mold was overfilled. The apparatus that had the reinforcing bars attached to it was placed over the three cylinders. The apparatus was then placed on an external vibrator that caused the reinforcing bars to submerge into the overfilled fresh concrete when the vibrator was turned on. When the vibrator was turned off, a trowel was used to slope the overfilled top of the mold at a 15-degree angle from the outer rim of the sample to the center of the sample. The samples were removed from their molds the next day and were taken to the Florida Department of Transportation Corrosion Laboratory. After 28 days of curing the samples in lime water and an additional 28 days of curing them in a solution of 3% NaCl, the laboratory performed time to corrosion tests on the samples. The results of these tests are provided in Chapter 4.

CHAPTER 4 TEST RESULTS AND DISCUSSION

4.1 Phase I

4.1.1 Introduction

Results of Phase I have been divided into groups of coarse aggregate type as mentioned in Chapter 3. The data are also distinguished by whether stabilized wash water was used in the mix. Mixture designations are STB-005 (Brookesville Control Mix), STB-005-II (Brookesville Stabilized Mix), STB-351 (Calera Control Mix), STB-351-II (Calera Stabilized Mix), STB-090 (Oolitic Control Mix), and STB-090-II (Oolitic Stabilized Mix).

4.1.2 Fresh Concrete Tests

Table 4-1 provides a summary of the individual fresh concrete test results for temperature, slump, unit weight, air content, and time of setting. Fresh tests were conducted on samples before the addition of DELVO Stabilizer and on samples taken 22 hours after Stabilizer addition. For example, STB-005 represents the mixture before addition of DELVO Stabilizer, and STB-005-II represents the batch after the addition of DELVO Stabilizer and after new concrete was batched onto the stabilized wash water.

Table 4-1 Summary of Fresh Concrete Test Results

Mixture	Concrete Temperature degrees F	Slump, in.	Unit Wt, lb/cuft	Air Content, percent	Initial Time of Setting, hr:min	Final Time of Setting, hr:min	Water to Cement Ratio
STB005	75	1.75	138.4	4.6	11:05	13:35	0.49
STB005 II	73	1.75	140.2	4.6	8:20	10:30	0.55
STB351	95	1.75	145.0	4.2	10:25	12:50	0.52
STB351 II	96	4.75	140.8	5.9	>13:00	>13:00	0.50
STB090	73	2.00	146.4	5.1	6:40	8:15	0.48
STB090 II	72	4.75	133.0	6.7	11:30	13:55	0.48

Slump

The slump tests were run in accordance with ASTM C 143. The objective was to maintain the slump around 2", which allows the beam and prism samples to be vibrated rather than rodded. Water content was adjusted to achieve the desired slump. Generally the stabilized mixtures had slumps greater than the control samples, indicating that the DELVO Stabilizer has water-reducing capabilities, which should be considered during development of mixture proportions. Only the Brookesville mixtures had exactly the same slump. This is probably due to the fact that the retardant admixture was eliminated from the stabilized mix. However, all mixes were determined to have good workability with the exception of the Brookesville stabilized mix, which was harsh. Perhaps the addition of a Type A water reducer vise the Type D water reducer/retardant would better this condition.

Unit Weight

Unit weight tests were run in accordance with ASTM C 138. The unit weights of the mixtures ranged from 133.0 lb/cuft to 146.4 lb/cuft. Table 4-2 and Figure 4-1 summarize the results.

Brookesville: The control mix (STB-005) had a unit weight of 138.4 lb/cuft. The unit weight of the stabilized mix (STB-005-II) was determined to be greater than that of the control mix with a unit weight of 140.2 lb/cuft.

Calera: The control mix (STB-351) had a unit weight of 145.0 lb/cuft. The Calera coarse aggregate has a higher density than that of the Brookesville and Oolitic aggregates. The unit weight of the stabilized mix (STB-351-II) was determined to be lower than that of the control mix with a unit weight of 140.8 lb/cuft. This decrease in unit weight is most likely related to the 4.75" slump of the stabilized mix.

Oolitic: The greatest variance when comparing the unit weights of mixes using the same aggregate was observed in the mixes containing Oolitic coarse aggregate. The control mix (STB-090) had a unit weight of 146.4 lb/cuft. The unit weight of the stabilized mix (STB-090-II) was much lower than that of the control mix with a unit weight of 133.0 lb/cuft. The variance may be partially attributed to variances in water-cement ratio and air content.

Table 4-2 Unit Weight

Mixture	Unit Weight (lb/cuft)	Variance From Control
STB-005	138.4	-
STB-005-II	140.2	1.30%
STB-351	145.0	-
STB-351-II	140.8	-2.90%
STB-090	146.4	-
STB-090-II	133.0	-9.20%

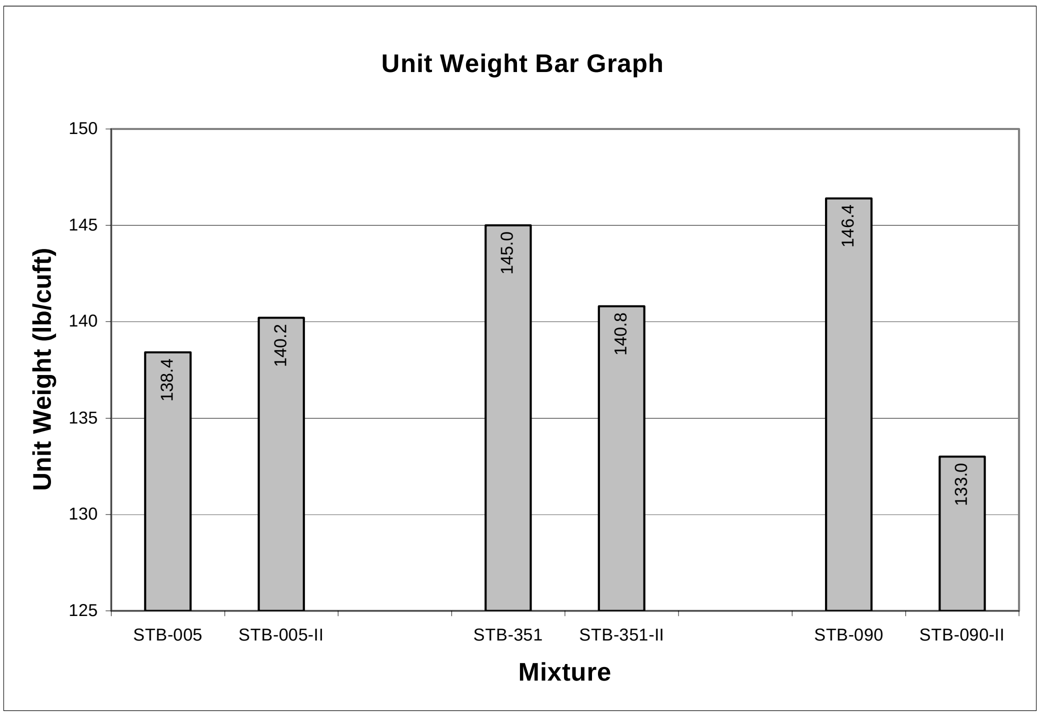

Figure 4-1 Unit weight bar graph

Air Content

Air content tests were performed in accordance with ASTM C 173. The values for this test varied from 4.2% to 6.7%. Table 4-3 and Figure 4-2 summarize the results for air content.

Brookesville: The control mix (STB-005) had an air content of 4.6%, and its stabilized mix (STB-005-II) also had an air content of 4.6%.

Calera: The control mix (STB-351) had an air content of 4.2%. The stabilized mix (STB-351-II) had a higher air content of 5.9%.

Oolitic: The control mix (STB-090) had an air content of 5.1%, and the stabilized mix (STB-090-II) also had a higher air content of 6.7%.

<u>Table 4-3 Air Content</u>

Mixture	Air Content (%)	Variance From Control
STB-005	4.6	-
STB-005-II	4.6	0%
STB-351	4.2	-
STB-351-II	5.9	40%
STB-090	5.1	-
STB-090-II	6.7	31%

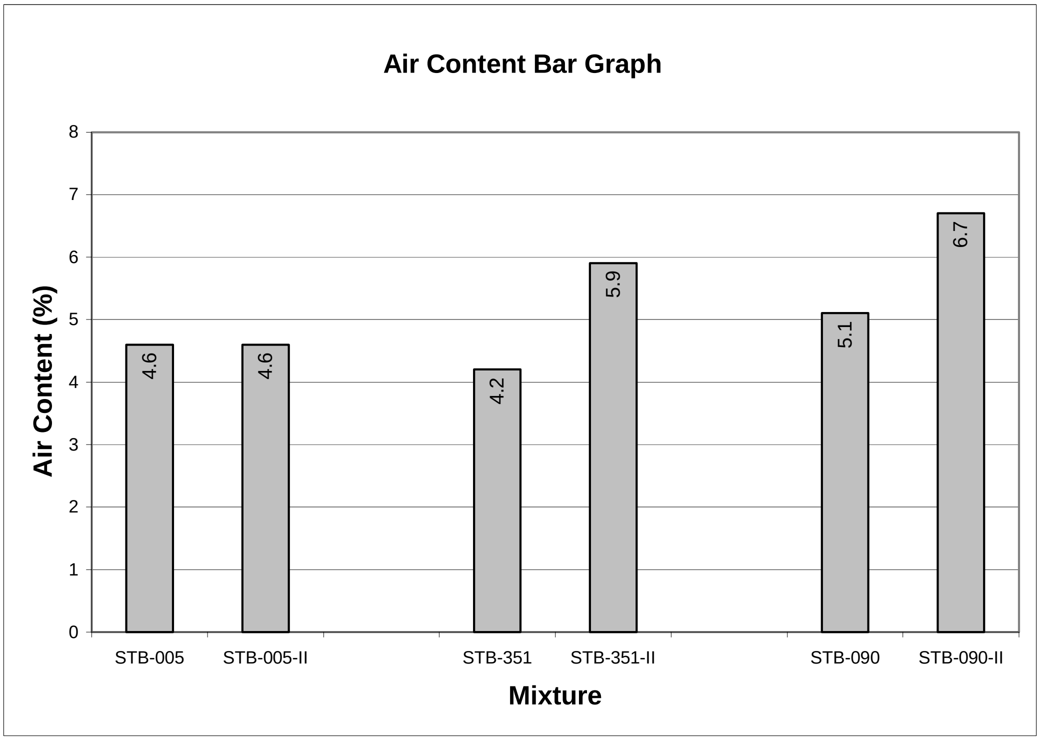

Figure 4-2 Air content bar graph

Time of Setting

The set time tests were performed in accordance with ASTM C 403. Overall long times of setting can be attributed to the tests being run in an air conditioned room with a constant temperature of approximately 72 degrees F, the use of a Type D water reducer/retardant, and/or the use of DELVO Stabilizer.

Brookesville: The control mix (STB-005) had an initial set time of 11 hours and 5 minutes and a final set time of 13 hours and 35 minutes. The stabilized mix (STB-005-II) had about a 3-hour variation from the control mix with initial and final set times of 2 hours and 45 minutes and 3 hours and 5 minutes less than the control mix, respectively. This variance is most likely due to the elimination of the water reducer/retardant admixture from the stabilized mix.

Calera: The control mix (STB-351) had an initial set time of 10 hours and 25 minutes and a final set time of 12 hours and 50 minutes. The times of setting for the stabilized mix (STB-351-II) occurred between 13 to 20 hours. The exact times could not be recorded due to the closure of the laboratory for the evening. As shown in Table 3-7, the control and stabilized mixture proportions contained the same amount of Type D water reducer/retardant. The stabilized mix of course contained DELVO. The extreme set times of the stabilized mix appears to be caused from the combination of DELVO Stabilizer and a Type D dose of the retardant.

Oolitic: In an attempt to lower the set times, the dosage rate of retardant was decreased to Type A for both the control and stabilized mixtures. The control mix (STB-090) had an initial set time of 6 hours and 40 minutes and a final set time of 8 hours and 15 minutes. These set times were significantly lower than all previous mixtures. The stabilized mix (STB-090-II) resulted in an initial set time of 11 hours and 30 minutes and a final set time of 13 hours and 55 minutes. Even though the dosages of DELVO Stabilizer and retardant admixture were both decreased, their combination again appears to prolong the times of setting.

In general, the times of setting for the stabilized mixtures indicate that DELVO alone can be used to effectively control time of setting of fresh concrete as the STB-005-II mix showed directly. Both the control and stabilized mixes had setting times 3 – 10 hours greater than normal (initial 4 to 5 hours, final 6 to 7 hours). From the comparably low setting times for STB-005-II, it appears that the retardant is suspect to delaying set time even further. When both DELVO and a Type D dose of retardant were combined in the STB-351-II mixture, the set times were extremely long even though the Calera mixtures were made with high temperature sand and concrete mixture temperature was 95-96 degree F. In an attempt to decrease the set time for the Oolitic mixtures, the retardant dose was halved. Now, with a Type A dosage of retardant, the Oolitic control mixture (STB-090) resulted in a more common initial set time of 6 hours and 40 minutes. But with the addition of DELVO in the STB-090-II mixture, the set times again increased significantly. Table 4-4 gives a summary of the set time results and Figures 4-3 and 4-4 give a graphical representation of the initial and final set time results, respectively. Figure 4-4a shows all set times for the six mixtures.

Table 4-4 Time of Setting

Mixture	Initial Time of Setting, hr:min	Variance From Control	Final Time of Setting, hr:min	Variance From Control	Air Temp. degrees F
STB-005	11:05	-	13:35	-	74
STB-005-II	8:20	(-)2hr 45 min	10:30	(-)3hr 5min	73
STB-351	10:25	-	12:50	-	74
STB-351-II	>13	3 - 10 hr	>13	3 - 10 hr	75
STB-090	6:40	-	8:15	-	72
STB-090-II	11:30	4hr 50min	13:55	5hr 40min	72

Note: Setting time tests were performed in a room with 72-75 degree F temperature.

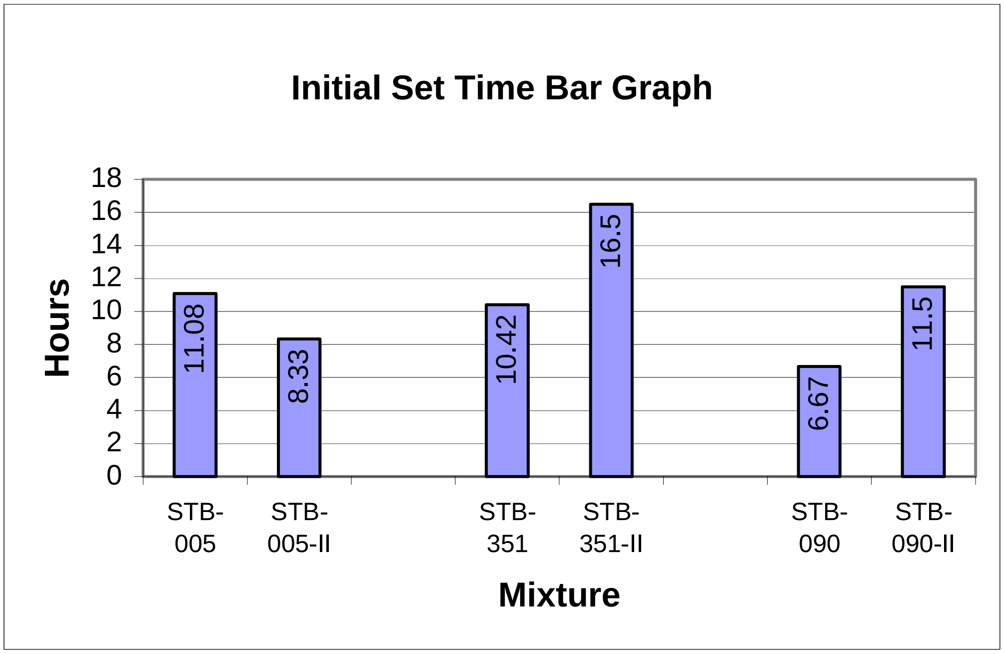

Figure 4-3 Initial set time bar graph

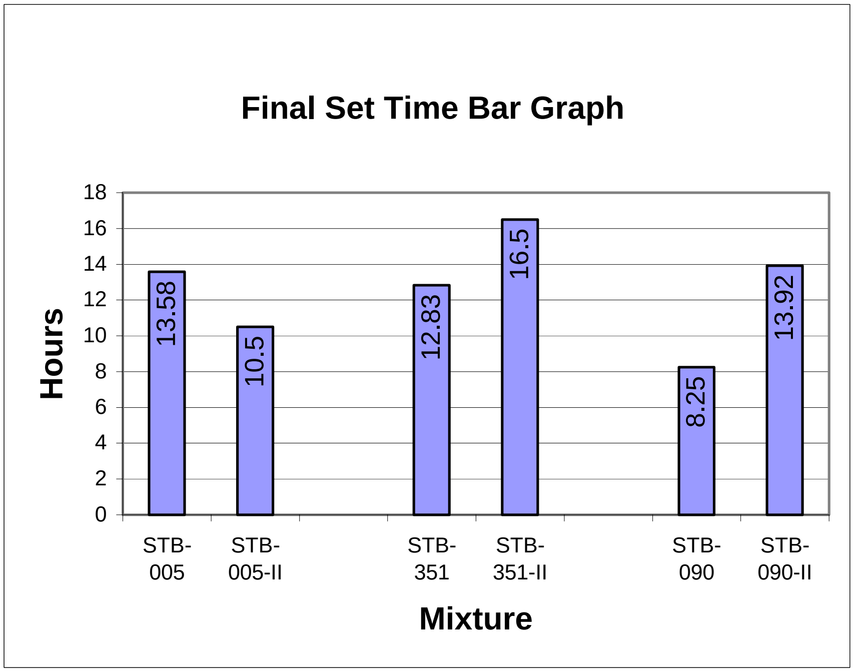

Figure 4-4 Final set time bar graph

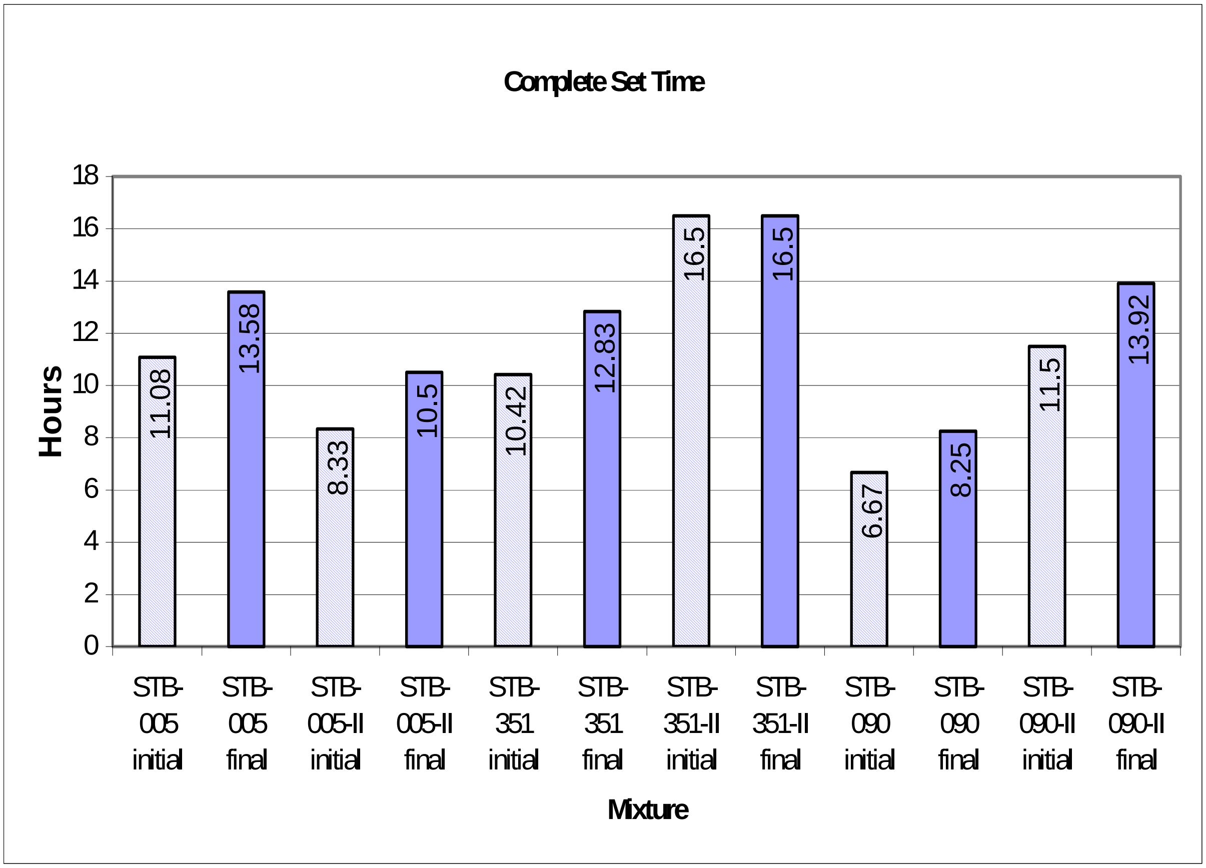

Figure 4.4a Complete set time bar graph

4.1.3 Hardened Concrete Tests

Table 4-5 is a summary of the averaged results of the compressive strength, flexural strength, and modulus-of-elasticity tests. The data are grouped by aggregate type, and whether stabilized wash water was used.

Table 4-5 Summary of Compressive-Strength, Flexural-Strength and Modulus-of-Elasticity Tests Results

Mixture	Average Compressive Strength, psi			Flexural Strength, psi	28-day Static Modulus of Elasticity, E + 06 psi
	7-day	14-day	28-day		
STB005	2530	3760	5570 (1.00)	770 (1.00)	3.028 (1.00)
STB005 II	2610	3700	5580 (1.00)	890 (1.16)	2.912 (0.96)
STB351	2680	3730	5420 (1.00)	820 (1.00)	3.545 (1.00)
STB351 II	2010	2810	4200 (0.77)	760 (0.92)	3.003 (0.85)
STB090	2570	3400	5310 (1.00)	930 (1.00)	2.657 (1.00)
STB090 II	2000	2740	4290 (0.81)	700 (0.76)	2.236 (0.84)

Compressive strength

Nine 6” diameter x 12” cylindrical compressive-strength test specimens were molded from each batch of concrete. Specimens were molded only from the final batch after all admixtures and new concrete, as applicable, were batched and mixed. Results for the compressive strength test are an average of three specimens tested at each interval of 7-, 14-, and 28-days age. The ASTM C 94 acceptance criterion for the compressive strength produced with a questionable water supply is at least 90% of the compressive strength of a sample incorporating potable water. Table 4-6 gives a summary of the water/cement ratio for each mixture, which is inversely related to the compressive strength.

Table 4-6 Water/Cement Ratio

Mixture	Water/Cement Ratio
STB-005	0.49
STB-005-II	0.55
STB-351	0.52
STB-351-II	0.50
STB-090	0.48
STB-090-II	0.48

Brookesville: The 7 day compressive strength for the stabilized mix (STB-005-II) was determined to be 2,607 psi, which is greater than the average strength of the control mix (STB-005), 2,526 psi. At 14 days the average compressive strength of the stabilized mix was lower, 3,704 psi, than the control mix, 3,755 psi. The 28-day compressive strength test determined the stabilized mix to have the highest compressive strength, 5,584 psi. Figure 4-5 gives a graphical representation of the results and Table 4-7 gives the complete results for the Brookesville mixtures.

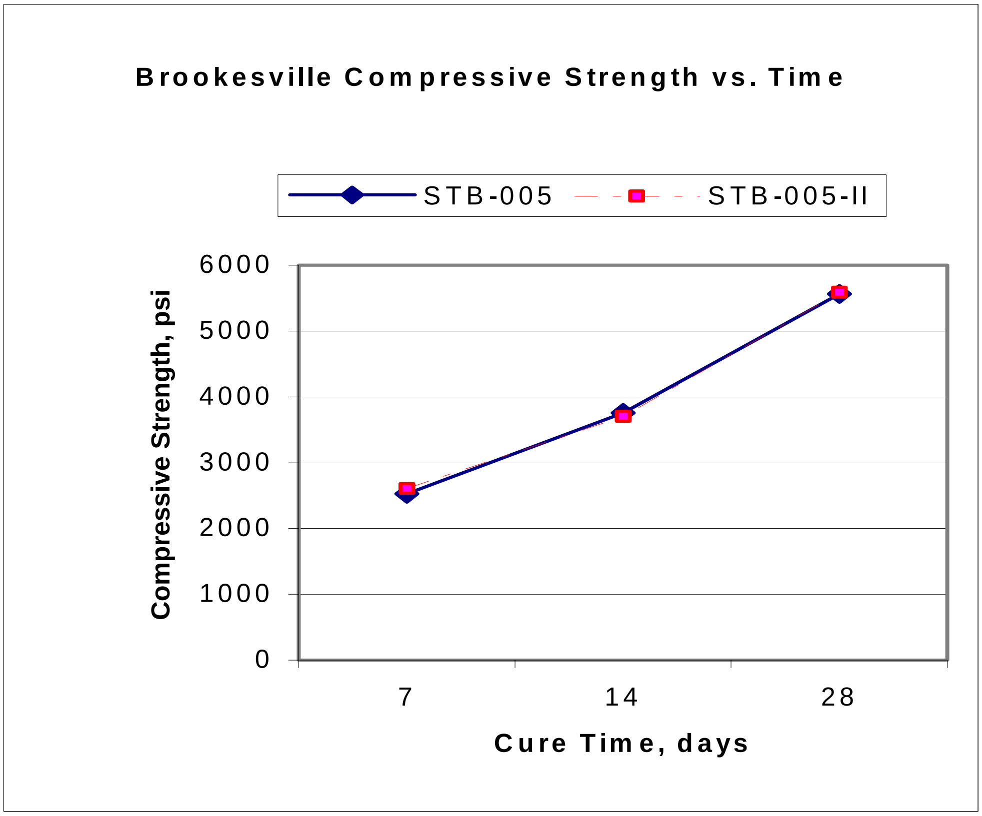

Figure 4-5 Brooksville aggregate compressive strength vs. time

Table 4-7 Brooksville Compressive Strengths

Mixture	STB-005	STB-005-II
7 DAY COMPRESSIVE STRENGTH (psi)	2499.823 2576.229 2503.007	2558.543 2793.774 2480.368
Average	**2526.353**	**2610.895**
STD. Deviation	43.223	163.130
14 DAY COMPRESSIVE STRENGTH (psi)	3559.250 3840.255 3867.704	3689.777 3653.696 3769.013
Average	**3755.736**	**3704.162**
STD. Deviation	170.715	58.989
28 DAY COMPRESSIVE STRENGTH (psi)	5714.892 5522.816 5456.666	5286.645 5567.386 5899.540
Average	**5564.791**	**5584.524**
STD. Deviation	134.133	306.807

Calera: The 7-day compressive strength of the control mix (STB-351-II) was 2,676 psi. The stabilized mix (STB-351-II) had a 7-day average lower than that of the control mix of 2,006 psi. At 14 days the compressive strength of the control mix increased at a faster rate than that of the stabilized mix. The control mix remained the strongest with a 14-day compressive strength of 3,727 psi with the stabilized mix coming in at 2,807 psi. The 28-day compressive tests showed the stabilized mix to be over 1,000 psi weaker than the control mix. The 28-day compressive strength of the control mix was 5,417 psi and that of the stabilized mix at 4,198 psi. This result determines the stabilized mix to have only 77% of the 28-day compressive strength of the control mix. Figure 4-6 gives a graphical representation of these results and Table 4-8 gives a complete listing of the results for the Calera mixtures.

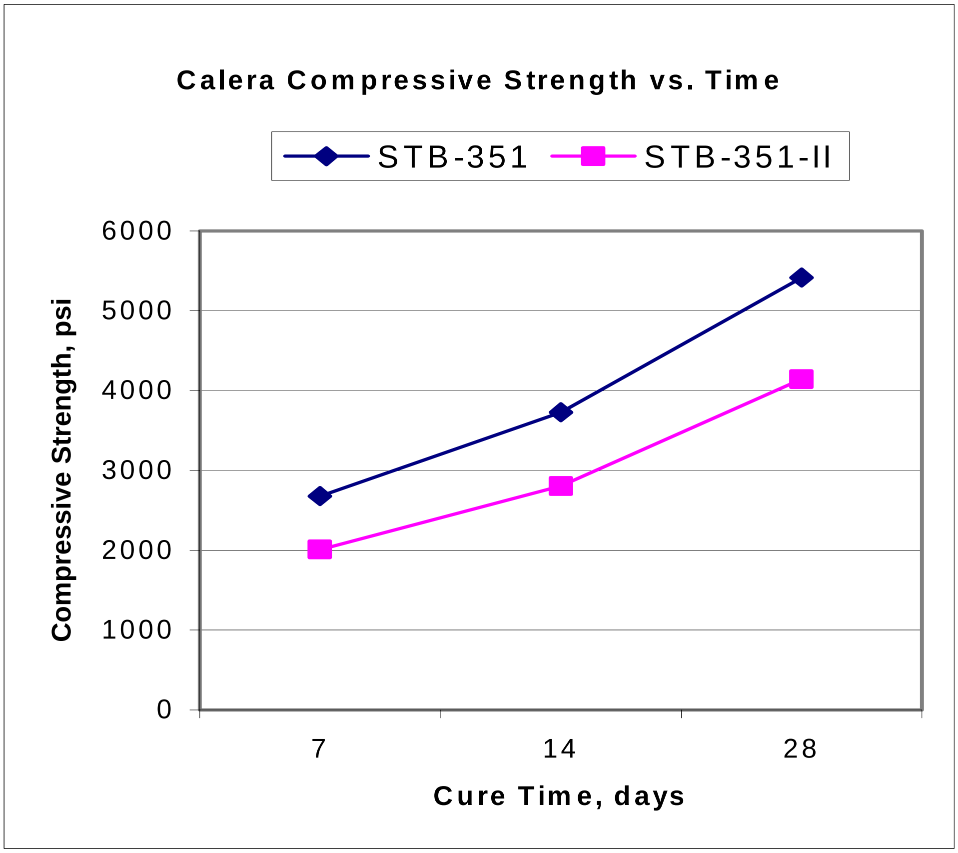

Figure 4-6 Calera aggregate compressive strength vs. time

Table 4-8 Calera Compressive Strengths

Mixture	STB-351	STB-351-II
7 DAY COMPRESSIVE STRENGTH (psi)	2764.415	2106.120
	2611.249	1978.069
	2653.343	1935.621
Average	**2676.336**	**2006.603**
STD. Deviation	79.129	88.759
14 DAY COMPRESSIVE STRENGTH (psi)	3567.388	2882.703
	3772.55	2717.722
	3841.628	2823.488
Average	**3727.189**	**2807.971**
STD. Deviation	142.636	83.578
28 DAY COMPRESSIVE STRENGTH (psi)	5439.689	4197.736
	5579.767	4028.652
	5234.878	4369.296
Average	**5418.111**	**4198.561**
STD. Deviation	173.454	170.323

Oolitic: The Oolitic mixtures generally had compressive strengths similar to that of the Calera mixtures. The control mix (STB-090) had the highest 7-day compressive strength, 2,569 psi. The stabilized mix (STB-090-II) had an average compressive strength of 1,997 psi. The control and stabilized mixes increased in strength at nearly the same rate from 7 to 14 days. The 14-day compressive strength for the control mix was 3,399 psi, and the average strength for the stabilized mix was 2,735 psi. The control mix had the greatest increase in compressive strength between the 14- and 28-day tests with a final 28-day average of 5,312 psi. The 28-day compressive strength of the stabilized mix was 4,288 psi. This result determined the stabilized mix to have only 81% of the 28-day compressive strength of the control mix. Figure 4-7 gives a graphical representation of these results and Table 4-9 gives a complete listing of the results for the Oolitic mixtures.

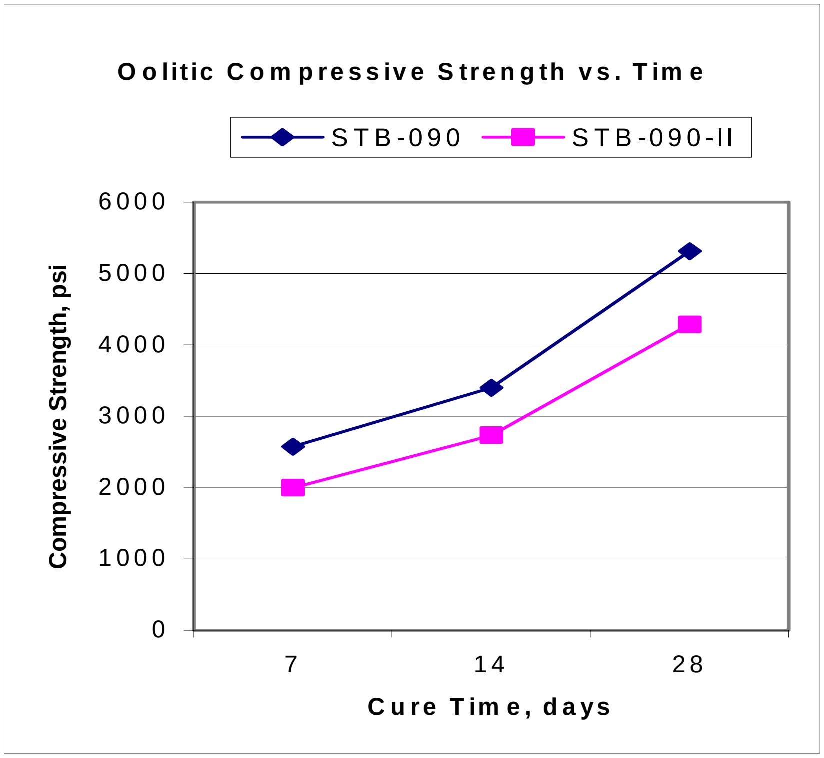

Figure 4-7 Oolitic aggregate compressive strength vs. time

Table 4-9 Oolitic Compressive Strengths

Mixture	STB-090	STB-090-II
7 DAY COMPRESSIVE STRENGTH (psi)	2637.779 2559.958 2511.143	1854.970 2073.788 2068.624
Average	**2569.627**	**1999.127**
STD. Deviation	63.869	124.871
14 DAY COMPRESSIVE STRENGTH (psi)	3829.855 3784.224 3562.434	2805.943 2613.371 2785.992
Average	**3725.504**	**2735.102**
STD. Deviation	143.054	105.893
28 DAY COMPRESSIVE STRENGTH (psi)	5314.821 5290.060 5333.569	4357.623 4190.661 4317.651
Average	**5312.817**	**4288.645**
STD. Deviation	21.824	87.178

In general the stabilized mixtures resulted in compressive strengths comparable to their respective control mixture. For all ages tested, the compressive strengths were not less than 75 percent of those of the control mixtures. In particular, the Brookesville stabilized mixture had compressive strengths greater than 100 percent of the control mixture for almost all ages tested. Since the total water contents in the Calera and Oolitic stabilized mixtures were the same as those used in the respective control mixtures, differences in compressive strength cannot be attributed to differences in w/c ratio. Strength differences for STB-351-II and STB-090-II may be attributed to the increased air content in these stabilized mixtures. However, an increase in only 1 – 2 % of air content cannot account for a 24% and 19% decrease in strength for STB-351-II and STB-090-II respectively. For the Brookesville mixtures, some strength increase in the stabilized mixture may be due to favorable modification of the cement hydration reaction and paste microstructure. Again, the most significant difference between the Brookesville stabilized mixture and the other stabilized mixtures was the combination of DELVO Stabilizer with the retardant. All mixtures did meet the Class I non-structural compressive strength requirement of 2,500 psi at 28-days age. However, the stabilized Calera and Oolitic mixtures did not fall within the 90% strength range designated by ASTM C 94.

Static modulus of elasticity

LVDT measurements were taken on two 28-day specimens from each mixture so that vertical strains could be measured and the chord modulus of elasticity calculated. The coefficients of variation of the moduli of elasticity are given in Table 4-10, and

Figure 4-8 presents a graphical representation. The moduli of elasticity are 15% or less when comparing the stabilized mixtures with their respective control mixtures. Again, the use of DELVO in combination with an additional retardant appears to effect the modulus of elasticity in the same way as it did the compressive strength. Appendices B-7 and B-8 provide samples of a stress/strain table and graph respectively.

Table 4-10 Modulus of Elasticity

Mixture	**STB-005**	**STB-005-II**	**STB-351**	**STB-351-II**	**STB-090**	**STB-090-II**
Modulus of Elasticity (psi)	3016140 3040639	2732793 3092016	3806574 3284118	3091928 2914944	2579556 2734229	2257583 2214245
STD. Deviation	17323	254009	369432	125147	109370	30645
Average	**3028390**	**2912405**	**3545346**	**3003436**	**2656893**	**2235914**
Variance from Control		(-)3.8%		(-)15.3%		(-)15.8%
Calculated E = 33(unit wt.)^1.5 (28-day avg. compressive strength)^0.5	4007851	4093630	4240776	3572227	4260441	3314505

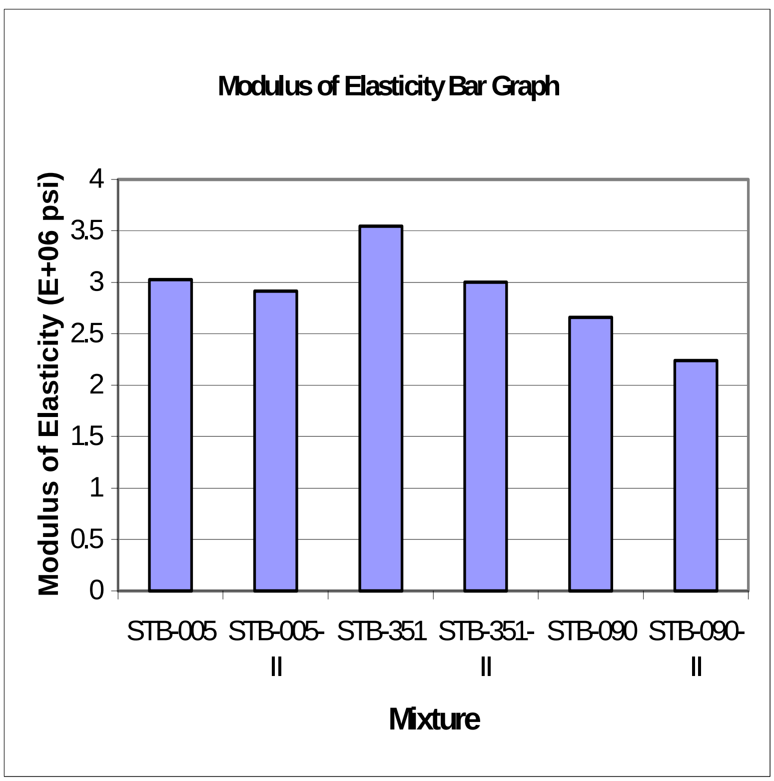

Figure 4-8 Modulus of elasticity bar graph

Flexural strength

Two beam specimens were molded from each batch. Beams were tested to determine flexural strength using third-point loading at the 28-day age in accordance with ASTM C 78. Results for each mixture are an average of their two specimens. Individual flexural strength test results are given in Table 4-11 and presented graphically in Figure 4-9.

Brookesville: The control mix (STB-005) had a flexural strength of 766 psi and the stabilized mix (STB-005-II) had a flexural strength of 887 psi.

Calera: The control mix (STB-351) had a flexural strength of 821 psi and the stabilized mix (STB-351-II) had a flexural strength of 755 psi.

Oolitic: The control mix (STB-090) had a flexural strength of 926 psi and the stabilized mix (STB-090-II) had a flexural strength of 702 psi.

Like the 28-day compressive strengths, the flexural strengths of the stabilized mixtures are at least 75 percent of those of the control mixtures. The Brookesville stabilized mixture produced a flexural strength, which exceeded its control mixture.

Table 4-11 Flexural Strength

Mixture	**STB-005**	**STB-005-II**	**STB-351**	**STB-351-II**	**STB-090**	**STB-090-II**
28-day Flex. Strength (psi)	786 746	915 859	840 801	792 718	877 975	685 719
STD. Deviation	28	40	28	52	69	24
Average	**766**	**887**	**821**	**755**	**926**	**702**
Variance from Control		(+)16%		(-)8%		(-)24%

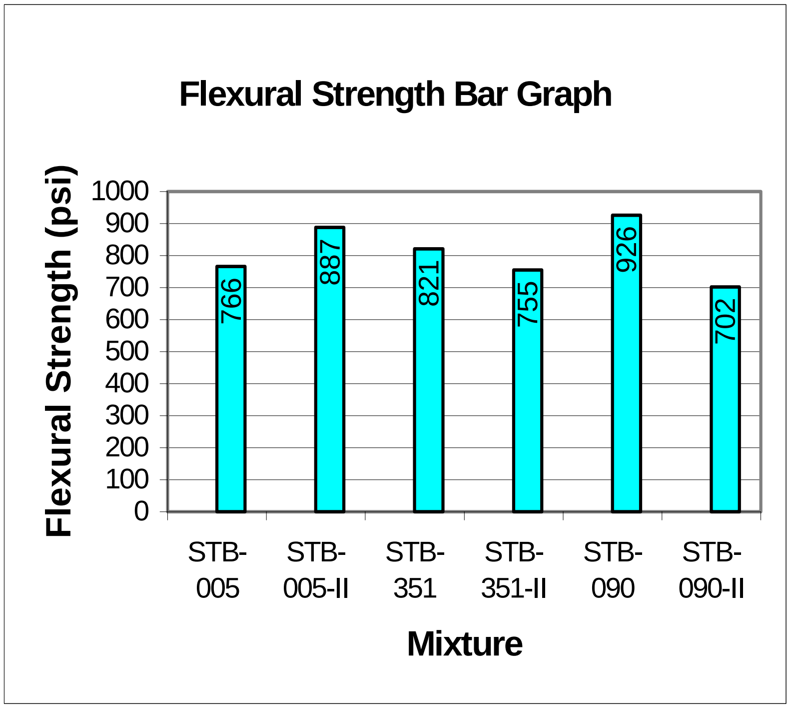

Figure 4-9 Flexural strength bar graph

Drying shrinkage (length change)

Three length-change prisms were molded from each batch. The prisms were cured in accordance with procedures described in ASTM C 157. ASTM C 157 requires the drying shrinkage to be reported as a percent increase or decrease in lineal dimension to the nearest 0.001% of the gage length based on the initial measurement made at the time of removal from the molds. The gage length in this test is standardized to be 10 inches. The results are calculated as follows:

$$\triangle L = \frac{Lx - Li}{Lg} \times 100$$

$\triangle$ L = change in length at x age, %
Lx= comparator reading of specimen at x age
Li= initial comparator reading of specimen
Lg= nominal gage length (10.0 inch)

The results represent an average of three test specimens when available. In some instances the test specimens were found to be too short in length to be measured by the comparator. In these cases, only the measurable specimens were considered. Figure 4-10 represents the percent of shrinkage graphically. The results are as of the 68th week of curing in air storage. All of the six mixes experienced an average decrease in length. All of the stabilized mixtures experienced less shrinkage than the control mixtures. Literature search showed that stabilized mixtures had slightly higher drying shrinkage values when an accelerating admixture was used. However, this study showed that without accelerator, the stabilized mixtures tend to have less drying shrinkage.

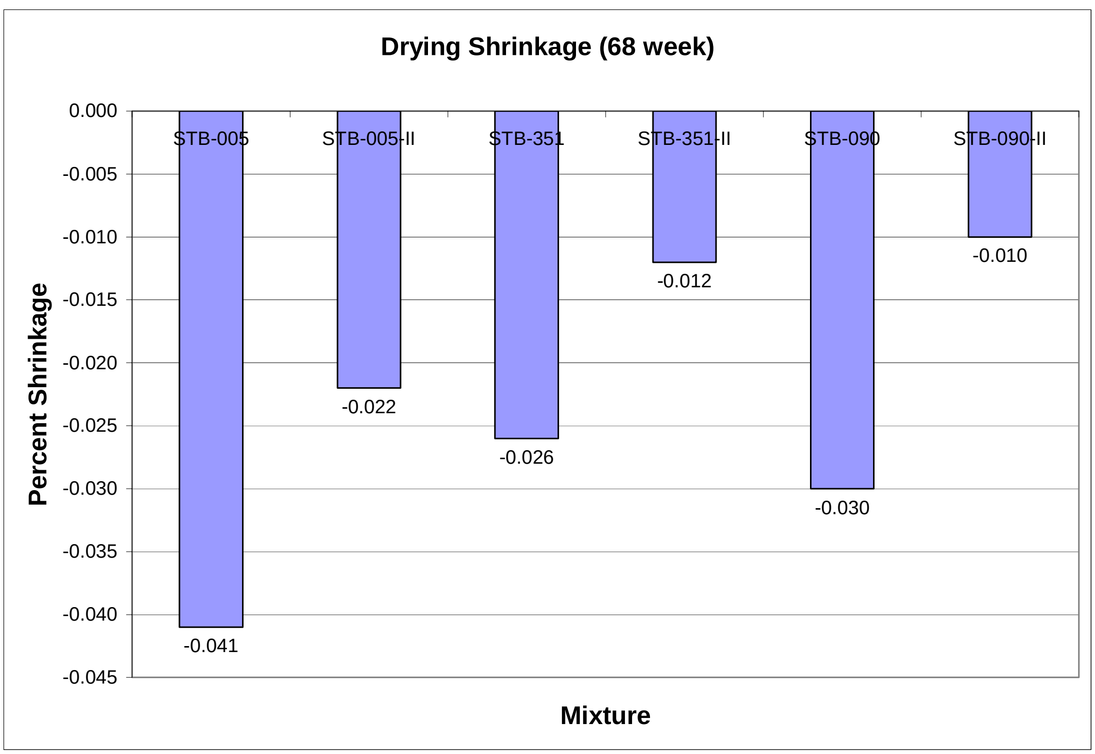

Figure 4-10 Drying shrinkage bar graph (68 weeks)

Resistance to chloride-ion penetration

Two 4” x 8” cylindrical specimens were molded from each batch. The averages of the individual test results for 28-days age, expressed as coulombs passed, are given in Table 4-12 and Appendix B-9, which is a sample RCP test result. Table 4-13 gives a summary of the rating system used for the rapid chloride permeability tests, and the results are expressed graphically in Figure 4-11. These results appear somewhat variable for some of the mixtures, although the precision statements given in ASTM C 1202 indicate indirectly that this test has a relatively high degree of variability associated with it. Consequently, caution is warranted in using the data to evaluate the performance of the concrete especially when this test is not a requirement for Class I non-structural concrete. Based upon qualitative estimates of chloride-ion penetrability given in ASTM C 1202, both the control and stabilized mixtures have high chloride-ion penetrability and were comparable.

Table 4-12 Chloride-Ion Penetration Tests (28-days age)

Mixture		**Average Charge Passed Coulombs**	**Rating**
Brookesville Control	STB-005	5905	HIGH
Brookesville Stabilized	STB-005-II	4707	HIGH
Calera Control	STB-351	5223	HIGH
Calera Stabilized	STB-351-II	4403	HIGH
Oolitic Control	STB-090	5763	HIGH
Oolitic Stabilized	STB-090-II	6448	HIGH

Table 4-13 Value Table for Coulomb Rating

Value	Rating
0 - 100	NEGLIGIBLE
101 - 1000	VERY LOW
1001 - 2000	LOW
2001 - 4000	MODERATE
4001 - up	HIGH

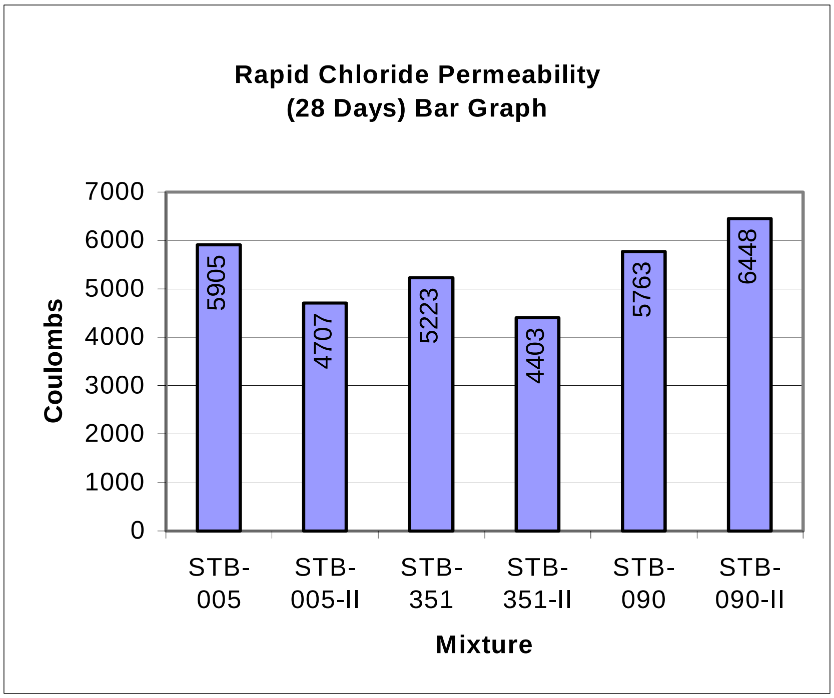

Figure 4-11 Rapid Chloride Permeability bar graph (28 days)

Sulfate expansion

Six length-change prisms were molded from each batch. Some prisms were too short to be measured in the laboratory comparator and were excluded. The average length changes after 12 months are shown in Figure 4-12. All of the mixes showed an increase in length when exposed to the sulfate solution. It does not appear that the addition of the DELVO Stabilizer increases the susceptibility of the concrete to sulfates.

Brookesville: The average length-change measurement for STB-005-II shows that the stabilized mixture experienced more expansion than its control mixture, STB-005.

Calera: The STB-351-II mixture only experienced an average 0.0006 inches less expansion than its control mixture, STB-351.

Oolitic: The average length-change measurement for STB-090-II shows that the stabilized mixture experienced more expansion than its control mixture, STB-090.

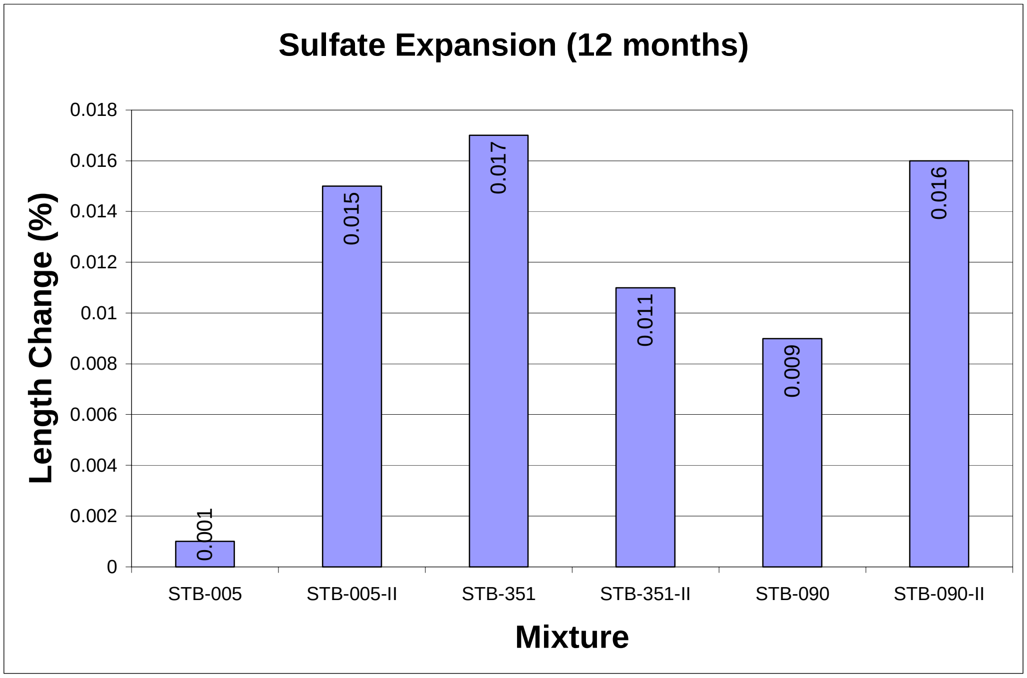

Figure 4-12 Sulfate expansion bar graph (12 months)

4.2 Phase II and III

4.2.1 Introduction

The objective of Phase II and III was to check the effects dosage rate of air-entraining and water reducer/retarder admixtures have on concrete made with stabilized wash water. The following section provides results from testing ten concrete mixes. The test results are divided based on varying type and quantities of admixtures used. Materials that remained constant were coarse aggregate, fine aggregate, fly ash, and Type I cement. The mixture designations are identified as control mixes with odd numbers such as STB 005, Delvo I, Delvo III, DelvoV, and Delvo VII. The differences between stabilized wash water mixes and control mixes are the addition of stabilizing admixture, and residual material from cleaning out the control mixer drum.

4.2.2 Fresh concrete Tests

Fresh concrete results include testing performed on concrete samples after thoroughly mixing all batch ingredients. Table 4.14 illustrates summary results for slump, temperature, unit weight, air content, and time of setting.

Slump

Slump testing was determined according to ASTM C 143. A two-inch slump or lower allowed external vibration of certain samples, such as prisms and beams. Four liters of water was withheld from the mix, and used to adjust the slump. Between control mixes and stabilized wash water mixes, slump values were within close proximity. Due to the stabilizer, control mixes had slightly greater slump values than stabilized wash water mixes in Delvo III through Delvo VI. The stabilizer has water-reducing capabilities that should be considered during mix design. The slump values for mixes mentioned above had a maximum range of three-quarters of an inch. The maximum range of all eight Delvo mixes was 1 ½" between high and low. The mean variation of slump between control mixes and stabilized wash water mixes was zero.

Table 4-14 Fresh Concrete Test Results

Mixture	Temp. Deg. F.	Slump Inches	U. W. lb/cuft	Air Content %	Initial Set Time	Final Set Time	W/C Ratio
STB 005	75	1.75	138.4	4.6	11:05	13 :35	0.49
STB 005 II	73	1.75	140.2	4.6	8 :20	10 :30	0.55
Delvo I	74	0.75	139.8	3.4	8 :00	10 :20	0.55
Delvo II	74	1	139.6	3.6	9 :05	11:05	0.55
Delvo III	72	2	135.8	6.6	6 :30	9 :00	0.53
Delvo IV	72	1.25	136.9	6.2	7 :55	10 :05	0.53
Delvo V	73	1.75	135.8	6.5	6 :30	8 :53	0.52
Delvo VI	74	1.25	138.6	5.6	8:15	10:42	0.53
Delvo VII	68	1.25	137.1	5.5	5:30	7 :32	0.52
Delvo VIII	71	2.25	135.4	6.9	7 :12	10 :00	0.52

Unit Weight

The unit weight was determined according to ASTM C-138. The unit weight test results for control mixes STB 005, Delvo I, Delvo III, Delvo V, and Delvo VII were compared to the Delvo wash water mixes STB 005 II, Delvo II, Delvo IV, Delvo VI, and Delvo VIII. There were minimal differences in unit weight, the largest being a two percent increase in the stabilized wash water mix Delvo VI. When compared to their stabilized wash water mixes, each control mix had a unit weight difference close to one percent or less. In most of these cases, slight weight variations may be attributed to air content differences within the mixes. Figure 4.13 and Table 4.15 show the unit weight results for the ten mixes.

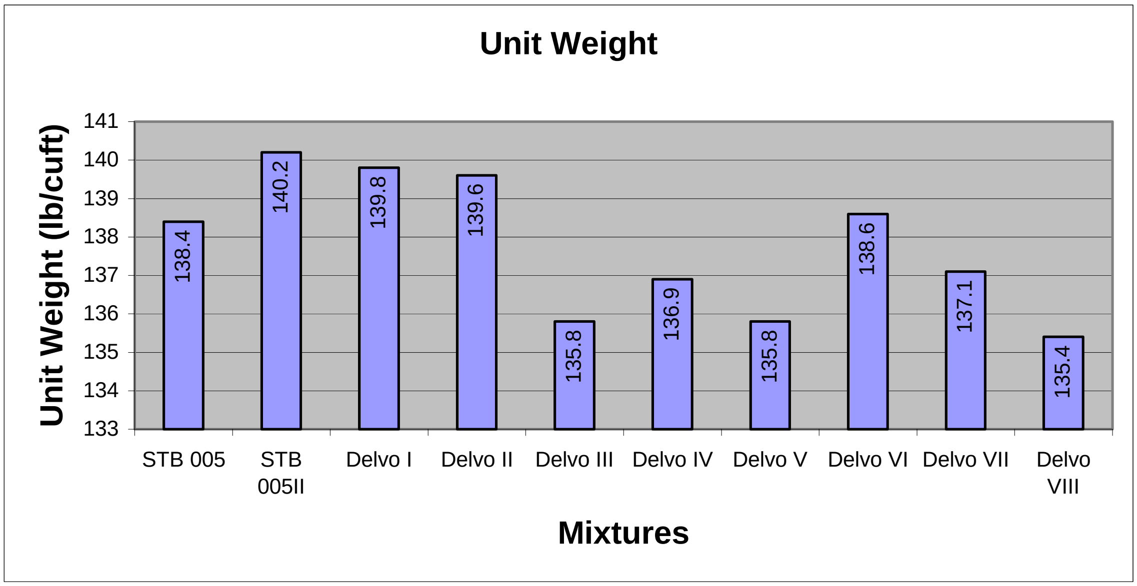

Figure 4-13 Unit Weight Results

Table 4-15 Unit Weight Test Results and Variance from Control Mix

Batch Sample	Unit Weight lb/cuft	Variance from Control
STB 005	138.4	
STB 005 II	140.2	1.30%
Delvo I	139.8	
Delvo II	139.6	-0.14%
Delvo III	135.8	
Delvo IV	136.9	0.81%
Delvo V	135.8	
Delvo VI	138.6	2.06%
Delvo VII	137.1	
Delvo VIII	135.4	-1.24%

Air Content

The air content was determined according to ASTM C-173 requirements. Air content percentages varied considerably, with a range between 3.4 percent and 6.9 percent. Delvo I and Delvo II did not contain MBVR air-entraining admixture, and displayed reductions in air content. Figure 4.14 shows the graphical test results for air content of each mix.

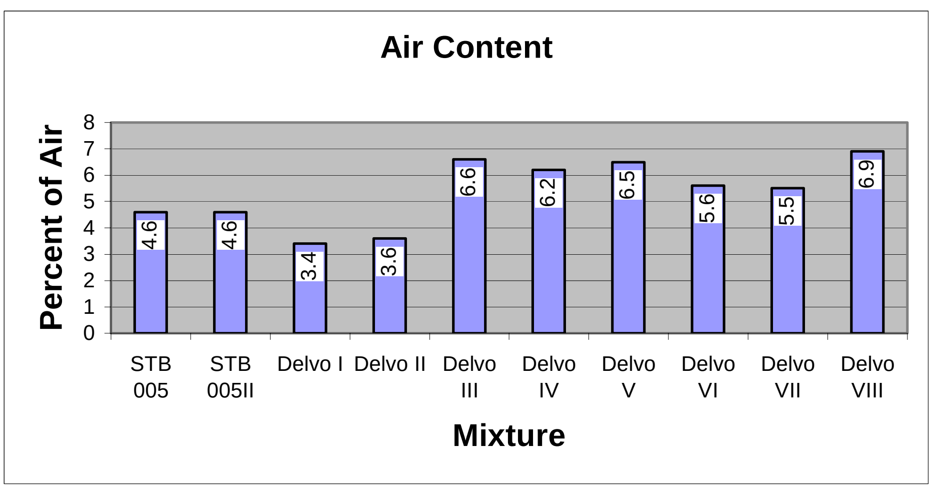

Figure 4-14 Air Content Test Results

The air contents of the control and stabilized mixes were comparable when using Pozzolith 220N. The results were, two groups of control mixes with higher air content percentages, two control mixes with lower air content percentages, and one group with control and stabilized mixes with identical air contents. Delvo VII and Delvo VIII produced the greatest variance in air contents between control mixes and stabilized wash water mixes. Table 4.16 shows variances between control mixes and their stabilized wash water mixes.

Table 4-16 Air Content Results with Variances from Control

Batch Sample	Air Content %	Difference from Control
STB 005	4.6	
STB 005 II	4.6	0.0
Delvo I	3.4	
Delvo II	3.6	0.2
Delvo III	6.6	
Delvo IV	6.2	-0.4
Delvo V	6.5	
Delvo VI	5.6	-0.9
Delvo VII	5.5	
Delvo VIII	6.9	1.4

In general terms, the air contents of the control and stabilized wash water mixes were quite comparable, and stabilized wash water mixes appear to have a minimal effect on the air content.

Time of Setting

Times of set readings were obtained according to procedures outlined in ASTM C-403. The room temperature was maintained within 68-74 degrees Fahrenheit. Initial times of set readings were recorded at 500 PSI, and final set readings were recorded at 4000 PSI. The comparative value of the time of set can indicate the effects of variables under investigation. Comparing the control mix and the resulting stabilized wash water mix can provide relevant information about the effects of alterations in admixture quantities. Figure 4.15 shows the comparison of control mix STB 005, and wash water mix STB 005II, both of which contained equivalent amounts of MBVR air-entraining admixture (46ml). The differences between the mixes were Pozzolith 220N and the Delvo Stabilizing admixture. The control mix contained enough Pozzolith 220N (91.9ml) to be considered a water reducing and set retarding admixture, and contained no Delvo Stabilizer. The wash water mix STB 005II contained Delvo Stabilizer (88.7ml) and no Pozzolith 220N.

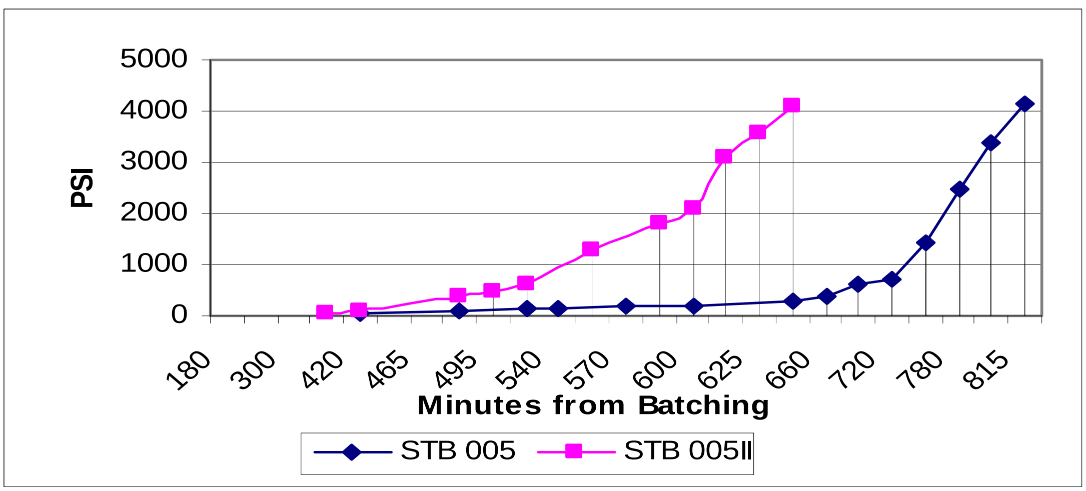

Figure 4-15 Time of Setting Comparison for STB 005 and STB 005II

It appears that the two variables had a significant effect on setting times. The control mix STB 005 had an initial set time of 11 hours and 5 minutes, and a final set time of 13 hours and 35 minutes. The stabilized wash water mix STB 005II set faster, with an initial set time of 8 hours and 20 minutes and a final set time of 10 hours and 30 minutes. The reason for these differences, are the elimination of Pozzolith 220N and its retarding effects on stabilized wash water batch STB 005II.

The Delvo I control mix and Delvo II wash water mix were initiated in an effort to identify characteristic effects of the Pozzolith 220N and Delvo Stabilizer admixtures. The amount of Pozzolith 220N admixture used (91.9 ml) per batch, and at this concentration is considered Type D water reducing and set retarding admixture. MBVR air-entraining admixture was removed from these mixes to focus on the effects of Pozzolith 220N. The addition of the Delvo Stabilizer admixture to wash water mix, Delvo II, was the only significant difference. Figure 4.16 graphs the time of setting for Delvo I and Delvo II.

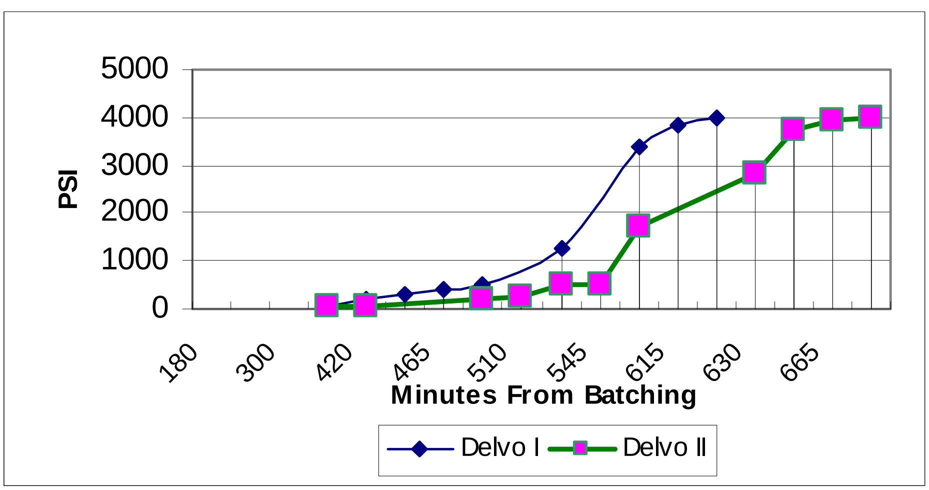

Figure 4-16 Time of Setting Comparison for Delvo I and Delvo II

Delvo Stabilized wash water tended to increase setting time durations. The initial set times were 8 hours for Delvo I, and 9 hours 5 minutes for Delvo II. The final set times for Delvo I and Delvo II mixes were 10 hours 20 minutes, and 11 hours 5 minutes respectively.

Delvo III through Delvo VI maintained similar mix designs for the control and stabilized wash water mixes. All four mixes utilized comparable raw materials. The admixture MBVR air entraining agent and Pozzolith 220N, were used in all four mixes at a concentration of 46 ml per batch. Pozzolith 220N admixture use at this concentration qualified it as a Type A water-reducing admixture, according to the manufacturer Master Builders Inc. Figure 4.17 shows the time of set plotted for mixes Delvo III through Delvo VI.

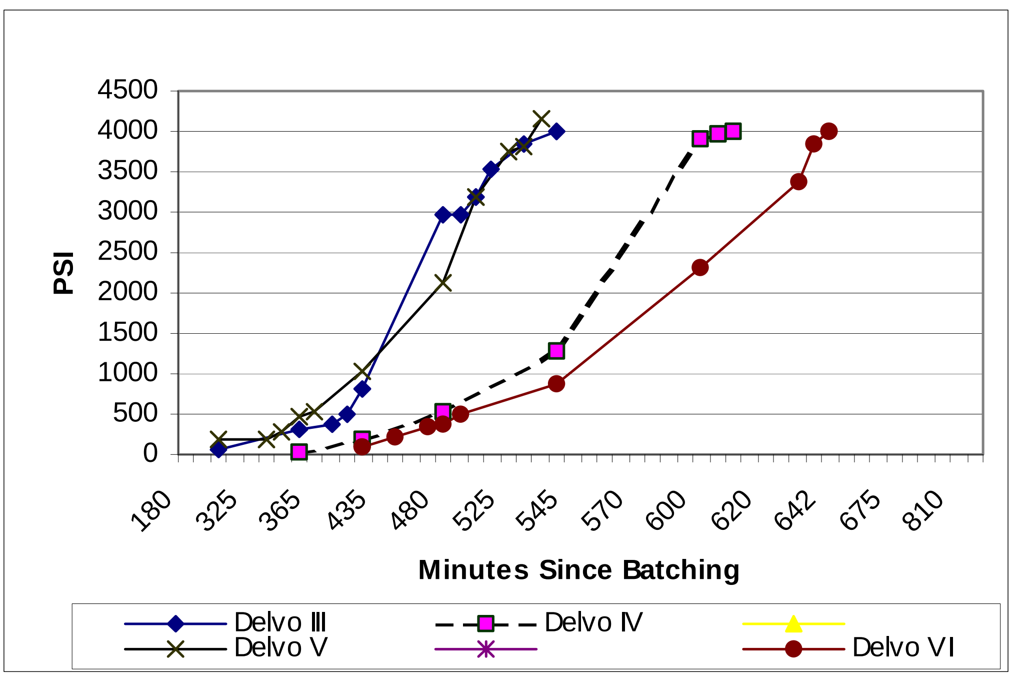

Figure 4-17 Time of Setting for Mixes Delvo III through Delvo VI.

The similarity between paired control mixes and paired stabilized mixes demonstrates the relative consistencies of setting times. The set times of stabilized wash water mixes increased in duration compared to their control mixes. Table 4.17 provides set times and time differences from control mixes for Delvo III through Delvo VI.

Table 4-17 Set Times and Time Difference from Control for Delvo III - Delvo VI

Mix Sample	Initial Set Time	Difference From Control	Final Set Time	Difference From Control
Delvo III	6:30		9:00	
Delvo IV	7:55	1:25	10:05	1:05
Delvo V	6:03		8:53	
Delvo VI	8:15	2:12	10:42	1:49

The control mix Delvo VII and wash water mix Delvo VIII were intended to test a different water-reducing admixture. MBVR air-entraining admixture and Polyheed 997, a Type A water-reducing admixture, were used at 46 ml in each mix, respectively. The initial set times for Delvo VII and Delvo VIII were 5 hours 30 minutes, and 7 hours 12 minutes. Their final set times were 7 hours 32 minutes and 10 hours, respectively. The following Figure 4.18 shows the graphical representation of the setting times for these mixtures. The times of setting for the other mixes using the Type A Pozzolith 220N admixture were marginally larger in all cases.

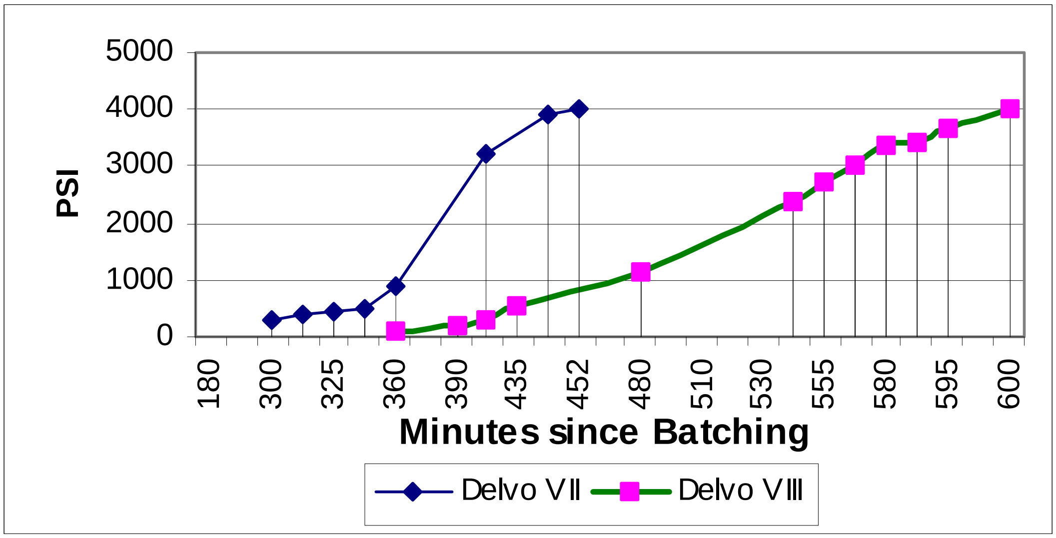

Figure 4-18 Time of Setting Comparison for Delvo VII and Delvo VIII

4.2.3 Properties of Hardened Concrete

The following test results pertain to concrete in hardened state. The hardened concrete tests performed, were compressive testing, modulus of elasticity, flexural strength, sulfate resistance, length change, time to corrosion, and rapid chloride permeability. The results are grouped comparatively between the control test mix and the stabilized wash water mix. Control mixes and stabilized wash water mixes of Delvo III through Delvo VI contained similar quantities of materials and admixtures. The comparisons are made in a group, with control mixes Delvo III and Delvo V compared directly to the wash water mixes Delvo IV and Delvo VI. A summary of the average compressive strengths, flexural strengths, and modulus of elasticity is provided in Table 4.18.

Table 4-18 Summary of Average Compressive Strengths, Flexural Strength, and Modulus of Elasticity

	Average Compression Results				Average		Mod of E	
	7 Day	14 Day	28 Day	%	Flexural	%	28 Day	%
				of Control	Strength	of Control	E + 06	of Control
Mixture	PSI	PSI	PSI		PSI		PSI	
STB 005	2526	3755	5564	100%	766	100%	3.028	100%
STB 005II	2607	3704	5584	100%	887	116%	2.912	96%
Delvo I	3262	4677	5400	100%	736	100%	2.796	100%
Delvo II	3317	4681	5476	101%	878	119%	2.834	101%
Delvo III	3317	3664	4513	100%	714	100%	2.645	100%
Delvo IV	3052	3411	4259	93%	679	95%	2.245	85%
Delvo V	2872	3450	4720	100%	731	100%	2.411	100%
Delvo VI	3126	3904	5051	109%	779	107%	2.551	106%
Delvo VII	2559	3092	4128	100%	723	100%	2.519	100%
Delvo VIII	2739	3282	4258	105%	689	95%	2.503	99%

Compressive Strength

The compressive strength tests were performed on nine different cylinders for each batch that was mixed. The compressive strength cylinders were tested at three different times (7,14 and 28 days) from the mixing date. The averaged compressive strength results are provided in Table 4.18. Wash water compressive strength deviations, as compared to control mixes made with potable water, are important. The minimum percentage of compressive strength for non-potable water concrete is 90 percent of the value for potable water concrete. This requirement is stated in ASTM C-94, and discusses the potential for reusing wash water. In order to make reasonable determinations, the effects of stabilized wash water on concrete properties requires minimal variables in order to identify cause-effect relationships. The correlation of the water / cement ratio is inversely related to the compressive strength of concrete when produced in a controlled environment. Table 4.19 provides the individual water / cement ratios.

Table 4-19 Water / Cement Ratios

Mixture	Water/Cement Ratio
STB 005	0.49
STB 005II	0.55
Delvo I	0.55
Delvo II	0.55
Delvo III	0.53
Delvo IV	0.53
Delvo V	0.52
Delvo VI	0.53
Delvo VII	0.52
Delvo VIII	0.52

The fact that the values are similar with minimum variance indicates that the water / cement ratio plays a minimum role in strength differences of potable water mixes, and stabilized wash water mixes. There is one exception with STB 005 and STB 005 II where the differences in values are significant. Figure 4.19 shows graphically the close proximity of the water / cement ratios.

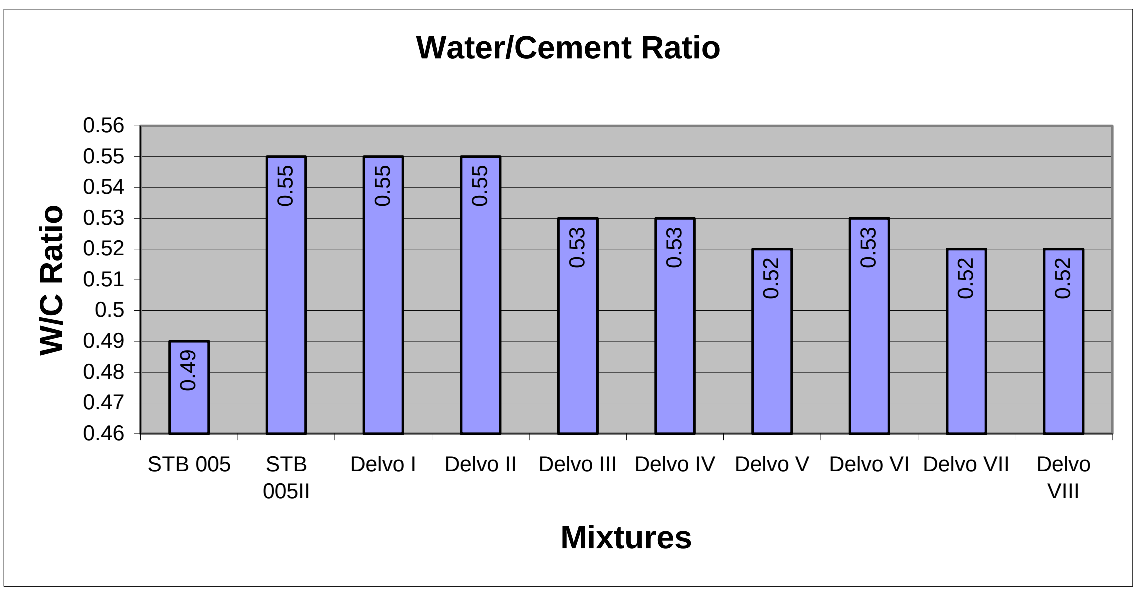

Figure 4-19 Water / Cement Ratios

The consistency of the water / cement ratios allows the comparison of multiple mixes, as the case of Delvo III through Delvo VI, where the water / cement ratios are an average 0.53. The compressive strength results facilitate the comparison of potable water control mixes and their counterpart stabilized wash water mixes. Table 4.20 provides the individual compressive strength values for each sample with average compressive strength values and standard deviations. The percentage of control indicates the compressive strength difference for the stabilized wash water mix and potable control mixes. It appears that the stabilized wash water, containing 88.7 ml of Delvo Stabilizer, had minimal effects on compressive strength. However, the other variable was the addition of Pozzolith 220N (91.9 ml) in the control mix, and it's exclusion in the stabilized wash water mix STB 005II. Figure 4.20 provides a graphical representation of the compressive test results for control mix STB 005 and wash water mix STB 005II at 7, 14, and 28 days.

Table 4-20 Individual Compressive Strength Results for STB 005 and STB 005II

Mixture	Age Tested	Sample 1	Sample 2	Sample 3	Average	STD Deviation	Percentage of Control
Unit	Days	PSI	PSI	PSI	PSI	PSI	%
STB 005	7	2500	2576	2503	2526	43	100%
STB 005 II	7	2559	2794	2480	2611	163	103%
STB 005	14	3559	3840	3868	3756	171	100%
STB 005 II	14	3690	3654	3769	3704	59	99%
STB 005	28	5715	5523	5457	5565	134	100%
STB 005 II	28	5287	5567	5900	5585	307	100%

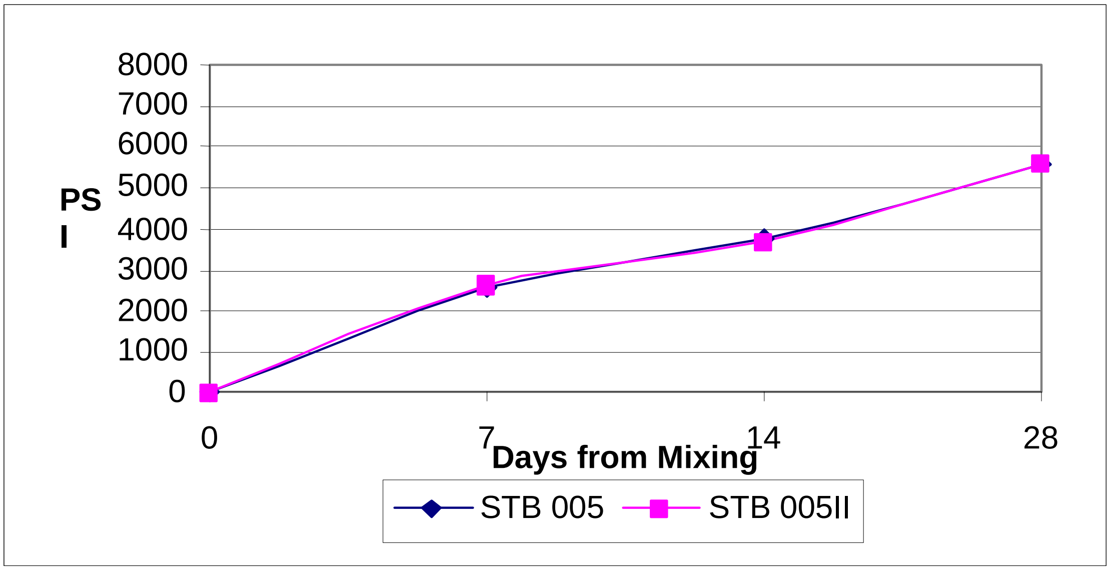

Figure 4-20 Compressive Strength for STB 005 and STB 005II

The first batch in phase II of this study focused on the effects of Pozzolith 220N as a Type D water-reducing and set retarding admixture. Pozzolith 220N was included in both Delvo I control mix and Delvo II stabilized wash water mix, at a rate of 91.9 ml per mix. Eliminating MBVR air-entraining admixture from both mixes illustrated the effects of Pozzolith 220N and Delvo (47.3ml) on compressive strengths. Table 4.21 provides the individual compressive strengths for mixes Delvo I and Delvo II, with standard deviations and percentage values of the control mix.

Table 4-21 Individual Compressive Strength Results for Delvo I and Delvo II

Mixture	Age Tested	Sample 1	Sample 2	Sample 3	Average	STD Deviation	Percentage of Control
Unit	Days	PSI	PSI	PSI	PSI	PSI	%
Delvo I	7	3213	3227	3347	3262	74	100%
Delvo II	7	3274	3354	3322	3317	40	102%
Delvo I	14	4650	4755	4628	4677	68	100%
Delvo II	14	4534	4889	4622	4681	185	100%
Delvo I	28	5271	5588	5341	5400	166	100%
Delvo II	28	5516	5498	5416	5476	53	101%

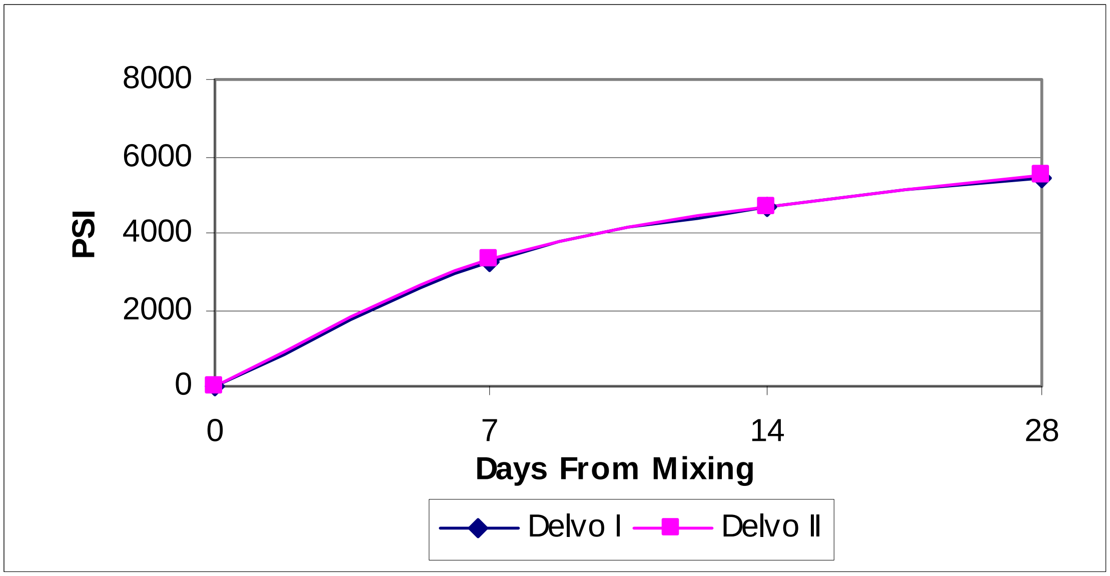

Figure 4-21 Compressive Strength for Delvo I and Delvo II

The compressive strength values have minimal variances at all testing ages (7, 14, and 28 days). Stabilized wash water appears to have negligible consequences on these compressive strength results. Figure 4.21 provides a graphical representation of the compressive strength test results for Delvo I and stabilized wash water mix Delvo II at 7, 14, and 28 days.

The stabilized wash water mix Delvo II exceeds compressive strength values of the control mix Delvo I at all ages. The compressive strength difference between MBVR air-entraining admixture in the control mix STB 005, and its exclusion in control mix Delvo I was only 3 percent. The minimal consequences of the MBVR air-entraining, and Pozzolith 220N admixtures may be disguised by the wide variations in water / cement ratios of these two mixes.

The compressive strength results of Delvo III through Delvo VI are reported in a group because of the similar mix designs and the consistencies of the water / cement ratios. There is one slight difference with the water / cement ratio for Delvo V (0.54 with the other three mixes at 0.53). The individual values of these mixes are given in Table 4.22, with the standard deviations and percentage of control.

Table 4-22 Individual Compressive Strength Results for Delvo III through Delvo VI

Mixture	Age Tested	Sample 1	Sample 2	Sample 3	Average	STD Deviation	Percentage of Control
Unit	Days	PSI	PSI	PSI	PSI	PSI	%
Delvo III	7	3082	3626	3342	3350	272	100%
Delvo IV	7	2954	3281	3213	3149	172	94%
Delvo III	14	3460	3528	3906	3631	240	100%
Delvo IV	14	3377	2989	3574	3313	298	91%
Delvo III	28	4245	4694	4600	4513	237	100%
Delvo IV	28	4323	4279	4174	4259	77	94%
Delvo V	7	2888	2822	2907	2872	45	100%
Delvo VI	7	3167	3394	2818	3126	290	109%
Delvo V	14	3484	3279	3588	3450	157	100%
Delvo VI	14	3926	3835	3950	3904	61	113%
Delvo V	28	4741	4673	4745	4720	41	100%
Delvo VI	28	4816	5017	5321	5051	254	107%

The differences in compressive strength between control mix Delvo III and stabilized wash water mix Delvo IV appear relatively consistent for 7, 14, and 28 day test results. The reduction of compressive strength for the stabilized wash water mix Delvo IV, compared to its control mix Delvo III at 28 days, is 6 percent. Delvo V and Delvo VI also show certain consistencies in compressive strength values, with stabilized wash water mix Delvo VI having greater values than the control mix. These compressive strength values appear relatively consistent for 7, 14, and 28-day test results. Compared to the control mix the average increase in compressive strength for stabilized wash water mix Delvo VI at 28 days is 7 percent. The combination of these four mixes into a control group (Delvo III and Delvo V) and stabilized wash water group (Delvo IV and Delvo VI) yields similar compressive strength values. The averaged stabilized wash water group shows slightly higher compressive strength values (101.44 percent) than the control group. Figure 4.22 provides a graphical representation of the compressive test results for mix Delvo III and Delvo V, and their wash water mixes Delvo IV and Delvo VI at 7, 14, and 28 days.

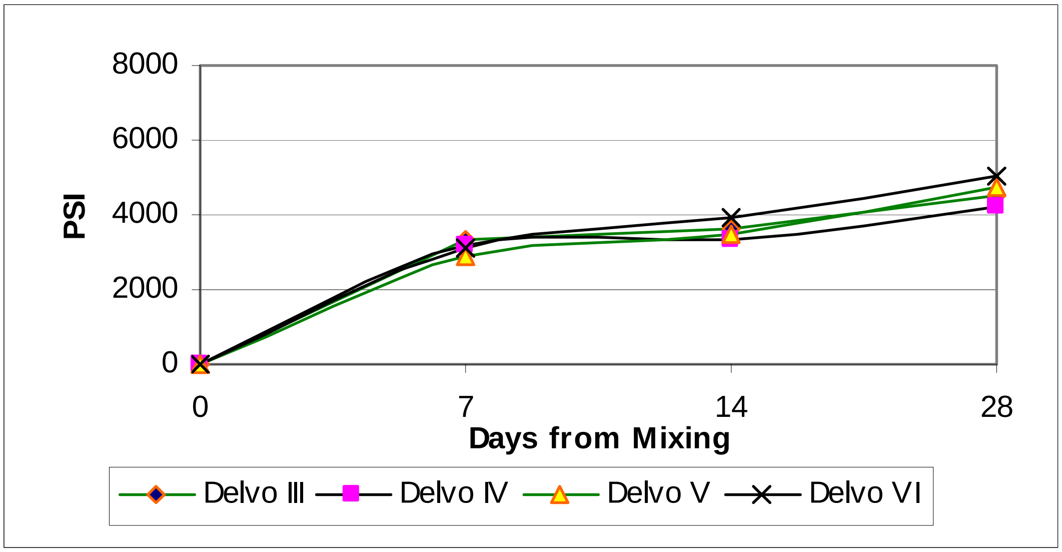

Figure 4-22 Compressive Strength for Delvo III, Delvo IV, Delvo V, and Delvo VI

The compressive strength results of Delvo VII and Delvo VIII are summarized in Table 4.23. These two mixes used a different Type A water-reducing admixture than the previous mixes. The dosage of Polyheed 997 (46 ml) was equivalent to the Pozzolith 220N (46 ml) in Delvo mixes III through VI.

Table 4-23 Individual Compressive Strength Results for Delvo VII and Delvo VIII

Mixture	Age Tested	Sample 1	Sample 2	Sample 3	Average	STD Deviation	Percentage of Control
Unit	Days	PSI	PSI	PSI	PSI	PSI	%
Delvo VII	7	2439	2569	2669	2559	115	100%
Delvo VIII	7	2574	2775	2868	2739	150	107%
Delvo VII	14	3147	2882	3248	3092	189	100%
Delvo VIII	14	3137	3287	3422	3282	142	106%
Delvo VII	28	4192	4044	4148	4128	76	100%
Delvo VIII	28	*	4258	*	4258	-	103%
* Damaged Cylinders							

The compressive strength values of Delvo VII and Delvo VIII are lower than the previous mixes. The compressive values of the stabilized wash water mixes appear less consistent than their predecessor, Delvo IV and Delvo VI. The stabilized wash water of Delvo VIII produced higher compressive values for 7 and 14-day results when compared to the control mix Delvo VII. Two of the cylinders intended to test Delvo VIII at 28 days were damaged. Figure 4.23 provides a graphical representation of the compressive test results for control mix Delvo VII and wash water mix Delvo VIII at 7, 14, and 28 days.

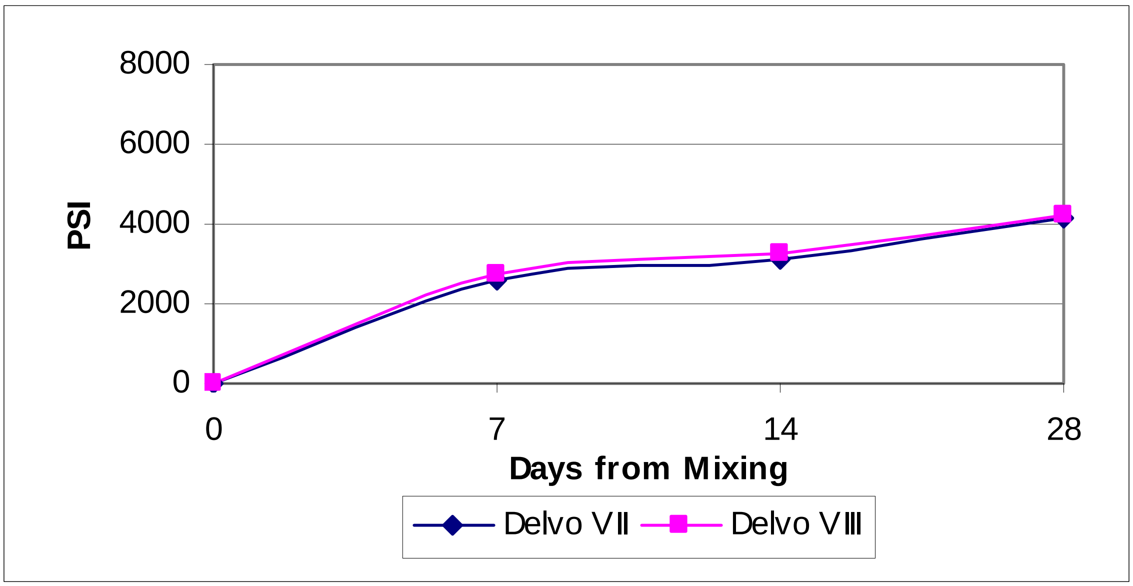

Figure 4-23 Compressive Strength for Delvo VII and Delvo VIII

Rapid Chloride Permeability

Four samples were tested for rapid chloride permeability at 28 and 70 days, two specimens were used for each testing date. This test has high variability and the results are not intended to be all-inclusive for permeability of concrete specimens**.** Table 4.24 provides the individual test results, standard deviations, and the percent changes from the control mixes. The error of the rapid chloride penetration testing can be as high as 30-35 percent, but comparisons between stabilized wash water and control mixes can provide information for generalizations. The general pattern for the 28-day samples indicates that the stabilized wash water samples perform better than the control mixes. The only exception for the five groups (28-day results) is Delvo VII and Delvo VIII, which used the Polyheed 997 admixture. The method for evaluating the rapid chloride permeability is based on a series of ranges provided in Table 4.25.

Table 4-24 Rapid Chloride Permeability Test Results

Mixture	Age of Testing	Sample 1	Sample 2	Average	STD Deviation	% Change From Control
	Days	Coulombs				
STB 005	28	5288	6521	5905	872	100%
STB 005II	28	4623	4791	4707	119	80%
Delvo I	28	8001	8025	8013	17	100%
Delvo II	30	7966	6414	7190	1097	90%
Delvo III	28	10650	8904	9777	1235	100%
Delvo IV	28	7792	5749	6771	1445	69%
Delvo V	28	6799	7671	7235	617	100%
Delvo VI	28	7494	6941	7218	391	100%
Delvo VII	28	4544	4827	4686	200	100%
Delvo VIII	28	6115	5796	5956	226	127%
Delvo I	70	4085	3537	3811	387	100%
Delvo II	70	4162	4773	4468	432	117%
Delvo III	70	7335	6917	7126	296	100%
Delvo IV	70	3862	3187	3525	477	49%

Table 4-25 Value Table for Coulomb Rating

0 -100	=	Negligible
101 -1000	=	Very Low
1001 - 2000	=	Low
2001 - 4000	=	Moderate
4001 - UP	=	High

All of the samples at 28 days had Coulomb values greater than 4001 and ranked high according to Table 4.25. The trend from the available samples tested at 70 days indicates an overall reduction in chloride permeability. The average reduction in Coulombs was 58 percent for Delvo I, II, III, and IV. The control samples Delvo I and Delvo III had an average reduction in Coulombs of 60 percent. The average reduction in Coulombs for stabilized wash water samples Delvo II and Delvo IV, was slightly less then that of the control samples and had a value of 57 percent. Delvo I and Delvo IV samples at 70 days moved from a high rating to moderate, with rapid chloride permeability values of 3511 and 3524 Coulombs, respectively.

Flexural Strength

The flexural strength results were obtained according to ASTM C-78-84 using third-point loading on two samples from each mix. The samples were moist cured for 28-days before testing. Table 4.26 provides the individual results for each sample (averaged value of the two samples, standard deviation, and the percentage change of the stabilized wash water mix compared to its control mix).

Table 4-26 Flexural Strength Results

Mixture	Sample 1 PSI	Sample 2 PSI	Average PSI	STD Deviation	Percentage of Control
STB 005	786	746	766	28	100%
STB 005II	915	859	887	40	116%
Delvo I	681	792	737	78	100%
Delvo II	944	812	878	93	119%
Delvo III	684	744	714	42	100%
Delvo IV	705	653	679	37	95%
Delvo V	759	703	731	40	100%
Delvo VI	765	794	780	21	107%
Delvo VII	692	754	723	44	100%
Delvo VIII	698	680	689	13	95%

All of the test results indicate that the flexural strength of stabilized wash water mixes is not significantly affected when compared to control mixes. The greatest reduction is 5 percent for stabilized wash mixes Delvo IV and Delvo VIII. The flexural strength of Delvo IV averaged with Delvo VI is equal to 101 percent of the averaged control mixes (Delvo III and Delvo V). The standard deviations of these mixtures are relatively low, indicating that repeatability is high. Delvo VIII was the only other case where stabilized wash water concrete produced lower flexural strength results than the control mix. The flexural strengths of this group were similar to the other mixes using Type A water reducing admixtures, and were within the range of 679-779 PSI. The use of Polyheed 997 admixture within this group may have caused the reduction in flexural strength. Further study may be warranted to develop the true significance and cause for this minimal flexural strength reduction. Figure 4.24 provides a graphical representation of the average individual flexural results.

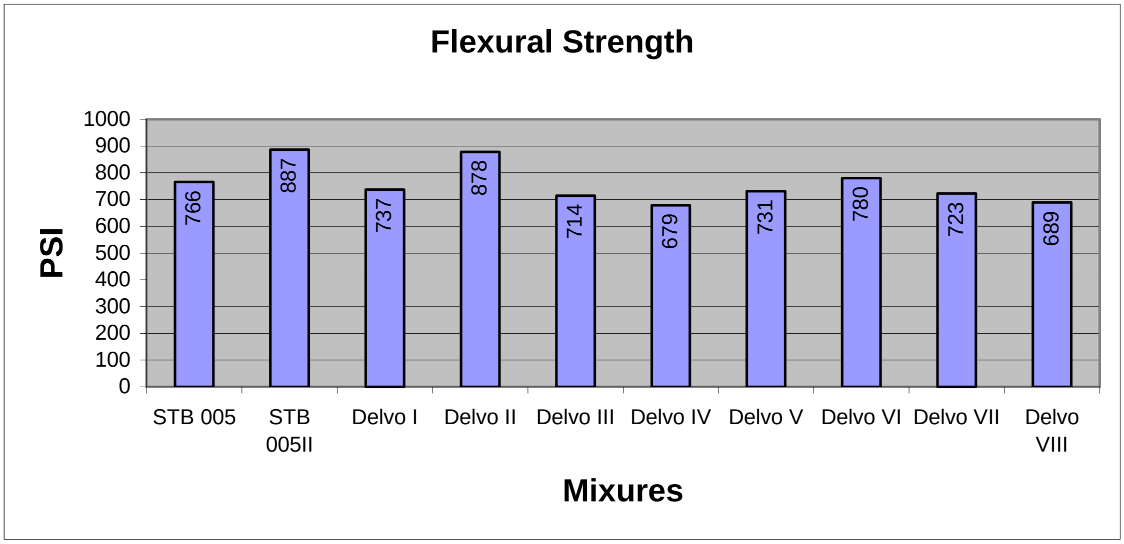

Figure 4-24 Average Flexural Strength Results

Overall, flexural strength results from stabilized wash water performed well when compared to their potable control mixes. The stabilized wash water mixes appear to have few negative characteristics in regards to flexural strength.

Length Change

The test results collected for the hardened hydraulic concrete prisms were determined according to ASTM C-157. The measurement of the linear dimension changes is reported as a percentage of the initial reading. The nominal gauge length used in all of the prisms was 10 inches. Three samples were produced for each batch, and the averaged results were used to develop the percentage length change to the nearest 0.001 percent. Figure 4.25 shows the averaged length change percentage of Delvo I through Delvo VIII mixtures after 68 weeks of curing in air storage.

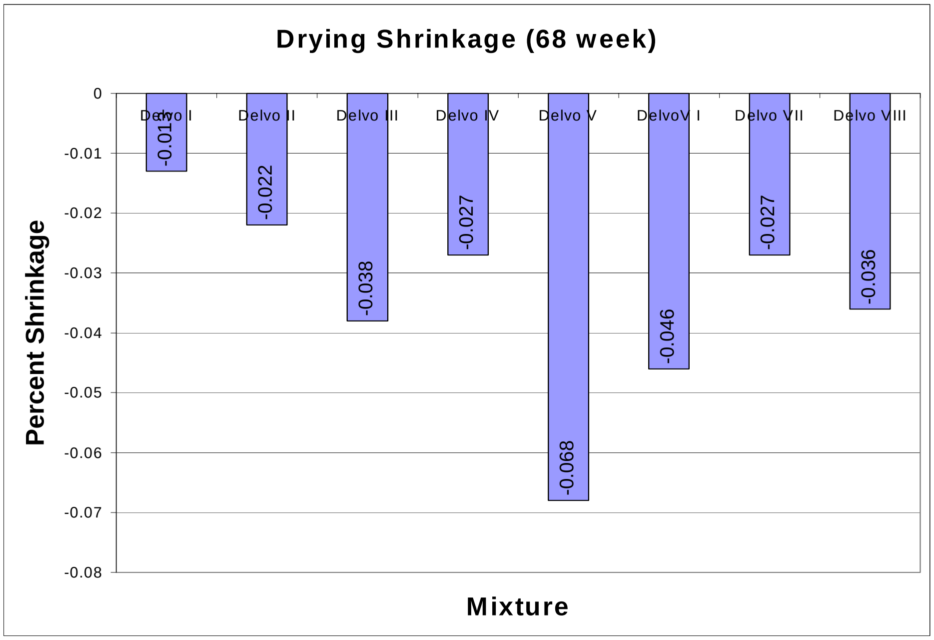

Figure 4-25 Drying shrinkage after 68 weeks air curing

All mixtures experienced an average decrease in length (shrinkage). The stabilized mixtures Delvo II and Delvo VIII experienced more shrinkage than their control mixtures, whereas Delvo IV and VI experienced less shrinkage than their control mixtures.

Sulfate Expansion

The length change of six sulfate-exposed prisms was measured and compared to their initial length. Figure 4.26 shows the average length changes after 12 months. All of the mixes except Delvo III and Delvo IV showed an increase in length when exposed to the sulfate solution. It does not appear that the addition of the DELVO Stabilizer increases the susceptibility of the concrete to sulfates.

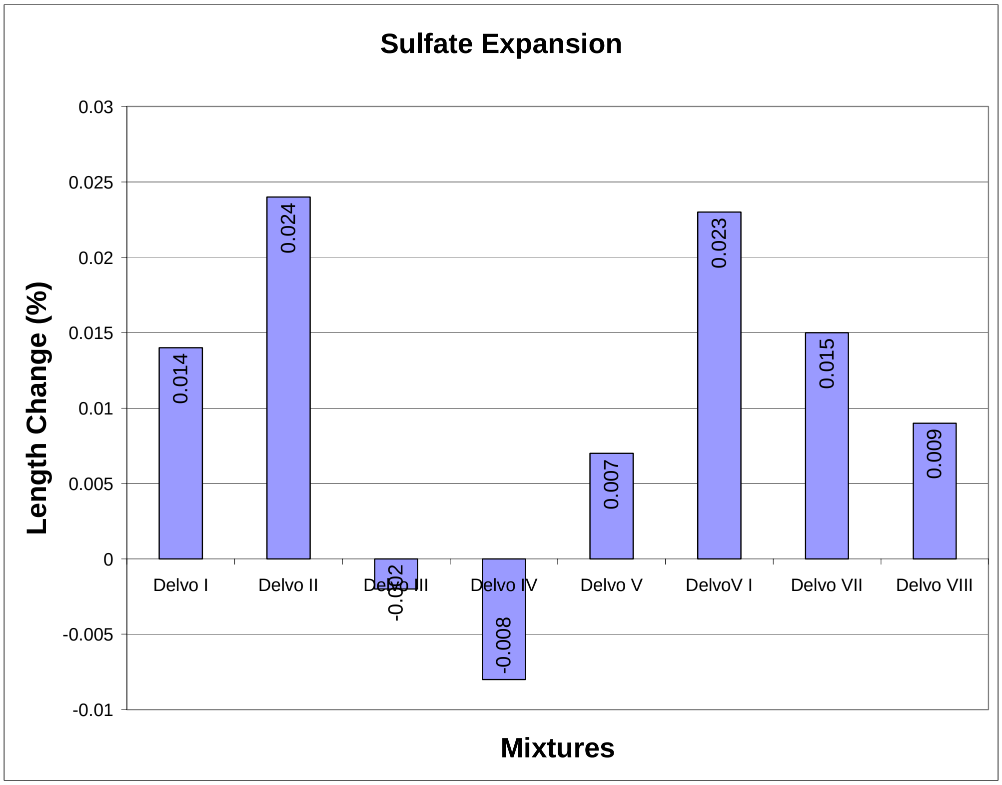

Figure 4-26 Sulfate expansion after 12 months for Delvo I through Delvo VIII

Corrosion Testing

The corrosion information for each sample is presented individually as an average of the three samples. The total results of the corrosion testing are presented in Table 4.27.

Table 4-27 Accelerated Corrosion Test Results

Mix	Sample 1 Days	Sample 2 Days	Sample 3 Days	Combined Averaged Days	Resistance Averaged Ohms	STD Deviation Ohms
STB 005	42	26	26	31	1045	9.24
STB 005 II	18	26	11	18	811	7.51
Delvo I	14	13	14	14	558	0.58
Delvo II	11	13	11	12	590	1.15
Delvo III	19	12	13	15	820	3.79
Delvo IV	18	17	14	16	706	2.08

The average days to failure for STB 005 was 31 days with an average resistance of 1045 Ohms. The wash water mix STB 005II had averaged days to failure of 18 days, and an averaged resistance of 811 Ohms. The stabilized wash water failed much earlier and also had a reduced resistance level of 234 Ohms compared with the control mix.

The Delvo I and Delvo II mixes had a reduced corrosion resistance compared with the prior two mixes. Delvo I failed at 14 days and had an average resistance level of 558 Ohms. Delvo II failed at 12 days with an average resistance level of 590 Ohms. The difference between the wash water mix and the control mixes were minimal. The stabilized wash water mix performed slightly poorer than the control mix. Figure 4.27 shows a graphical representation of the results.

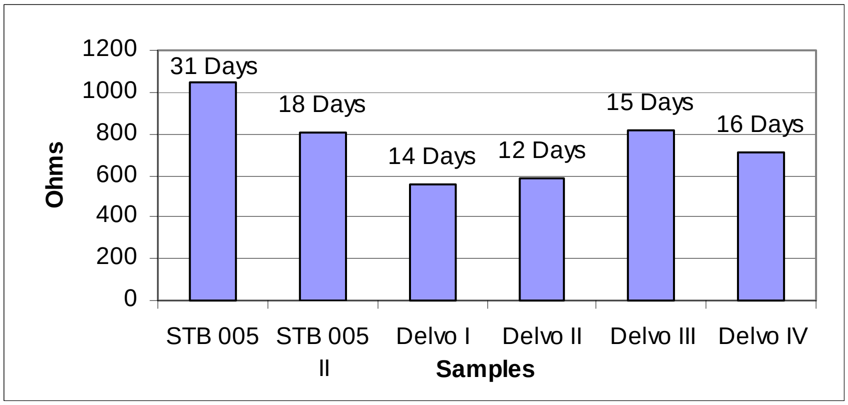

Figure 4-27 Days to Failure and Resistance Values

The Delvo III and Delvo IV mixes had results comparable to the STB 005II mix resistance levels and increased resistance to failure values when compared with Delvo I and Delvo II. Delvo III failed at 15 days and had an average resistance level of 820 Ohms. Delvo IV failed at 16 days with an average resistance level of 706 Ohms. The differences between the stabilized wash water mix and control mix appear to be minimal. The stabilized wash water mix performed slightly better than the control mix.

4.3 Phase IV and V

4.3.1 Introduction

The purpose of Phase IV study was to determine the effect of stabilized wash water in early strength gain and form removal of hot concrete mixtures. Delvo IX and XI were the control mixtures and had a concrete mix temperature of 99 and 98 degree Fahrenheit, respectively. Delvo X and Delvo XII contained the stabilized wash water and had a concrete mix temperature of 95 and 101, respectively.

The purpose of Phase V experiments was to investigate the effect of stabilized wash water on thermal properties of concrete by determining the magnitude and shape of the adiabatic temperature rise versus time. Delvo XIII and Delvo XV were the control mixtures for this phase and Delvo XIV and Delvo XVI contained the stabilized wash water.

4.3.2 Fresh Concrete Tests

Fresh concrete results include testing performed on concrete samples after thoroughly mixing all batch ingredients. Table 4.28 illustrates results for slump, temperature, unit weight, air content, concrete temperature, room temperature, and time of set for Delvo IX through Delvo XVI.

Table 4-28 Fresh Concrete Test Results

Mixture	Temp. Deg. F.	Temp. Deg. F.	Slump	Unit Weight	Air Content	Initial Set T.	Final Set T.	W/C Ratio	Work-ability
	Concrete	Room	Inches	lb./cuft	% by	Hrs:Min	Hrs:Min		
Delvo IX	99	82	2.0	144.4	2.5	4:05	5:10	0.42	Stiff
Delvo X	95	82	1.7	142.8	3.0	4:50	6:05	0.42	Okay
Delvo XI	98	86	1.0	143.2	2.7	4:20	5:35	0.44	Stiff
Delvo XII	101	86	1.0	144.4	2.9	6:10	7:30	0.44	Harsh
Delvo XIII	76	73	2.0	141.6	4.0	X	X	0.38	Okay
Delvo XIV	74	72	2.0	141.7	3.7	X	X	0.40	Okay
Delvo XV	70	68	3.5	140.0	4.5	X	X	0.44	Good
Delvo XVI	72	68	3.5	140.1	4.5	X	X	0.40	Good

- “X” Indicates item was not measured.

Slump Results

Slump testing was determined according to ASTM C 143. A three-inch slump or lower allowed external vibration of certain samples, such as for prism and beam molds. Four liters of water were withheld from the mix and used to adjust the slump. Between the control mixes and the stabilized wash water mixes, slump values were within close proximity. The maximum range of all eight mixes was between plus or minus 1” of the target range.

Unit Weight

The unit weight was determined according to ASTM C 138. The unit weight test results for the control mixes were compared to the unit weight test results for the experimental mixes. There were minimal differences in unit weight between the control mixes and the experimental mixes (close to one percent). The slight weight differences may be attributed to the different amount of entrained air contained in the mixes. Figure 4.28 and Table 4.29 show the unit weight results for the eight mixes.

Table 4-29 Unit Weight Results

Mixture	**Unit Wt. lb./cf.**
Delvo IX	**144.4**
Delvo X	142.8
Delvo XI	**143.2**
Delvo XII	144.4
Delvo XIII	**141.6**
Delvo XIV	141.7
Delvo XV	**140.0**
Delvo XVI	140.1

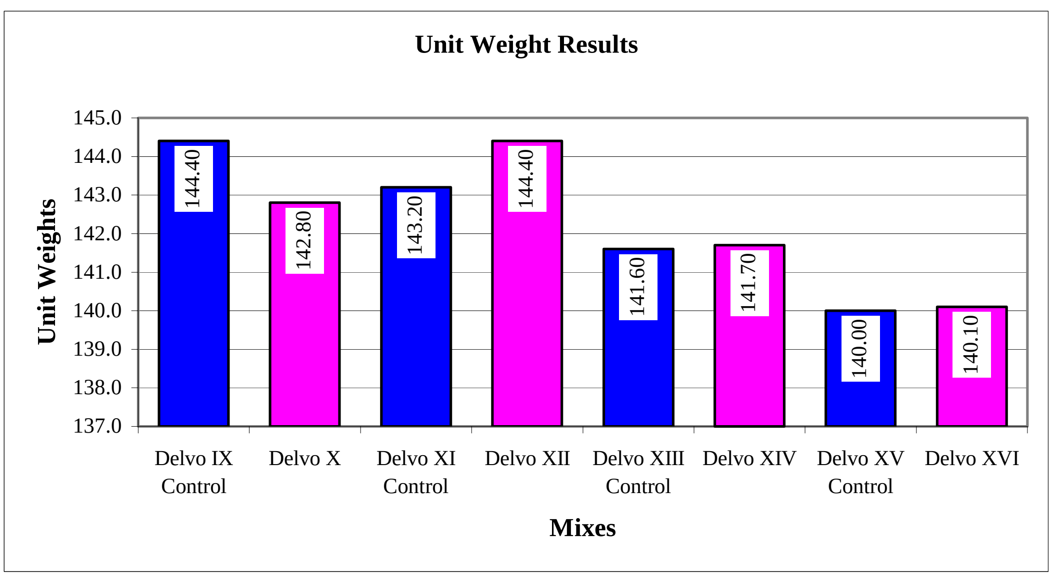

Figure 4-28 Unit Weight Results

Air Content Results

The air content was determined according to ASTM C-173 methods. Air content percentages ranged from 2.5% to 4.5%. Figure 4.29 shows the graphical test results for air content of each mix. The air contents of the control and stabilized mixes were comparable. Delvo IX and Delvo X produced the greatest variance in air contents between control mixes and stabilized wash water mixes. Table 4.30 shows the variances between control mixes and their stabilized wash water mixes. Stabilized wash water mixes had minimal effect on the air content.

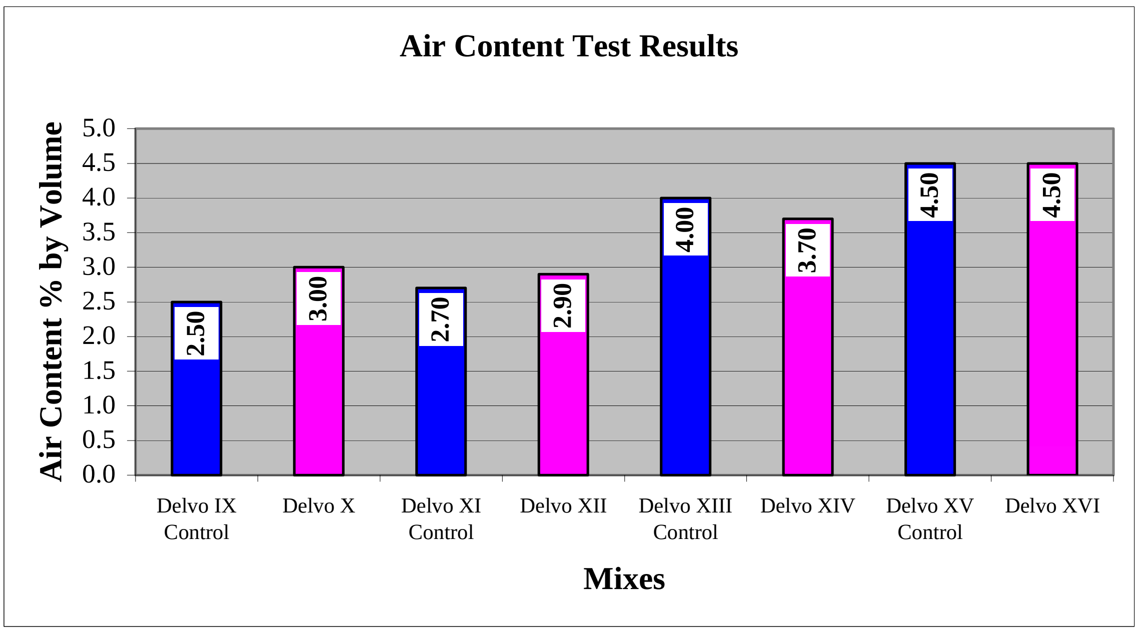

Figure 4-29 Air Content Results

Table 4-30 Air Content Results with Variances from Control

Mixture	Air Content (%)	Difference from Control
Delvo IX	2.50	
Delvo X	3.00	0.5
Delvo XI	2.70	
Delvo XII	2.90	0.2
Delvo XIII	4.00	
Delvo XIV	3.70	0.3
Delvo XV	4.50	
Delvo XVI	4.50	0

Time of Set Results

This test was done only on the samples that dealt with increased concrete temperature (Delvo IX through Delvo XII). The time of set were obtained according to procedures outlined in ASTM C-403. The room temperature was maintained at 82 degrees Fahrenheit for Delvo IX and Delvo X, and at 86 degrees Fahrenheit for Delvo XI and Delvo XII. Initial time of set readings were recorded at 500 PSI, and final time of set readings were recorded at 4,000 PSI. Comparison of the control mix and the stabilized wash water mix can provide relevant information about the effects of alterations in admixture quantities. Table 4.31 shows the time of set and the differences from the control mix for Delvo IX through Delvo XII.

Table 4-31 Set Times and Difference from Control for Delvo IX-Delvo XII

Mixture	Initial Set Time	Difference	Final Set Time	Difference
Delvo IX	4:05		5:10	
Delvo X	4:50	:45	6:05	:55
Delvo XI	4:20		5:35	
Delvo XII	6:10	1:50	7:30	1:55

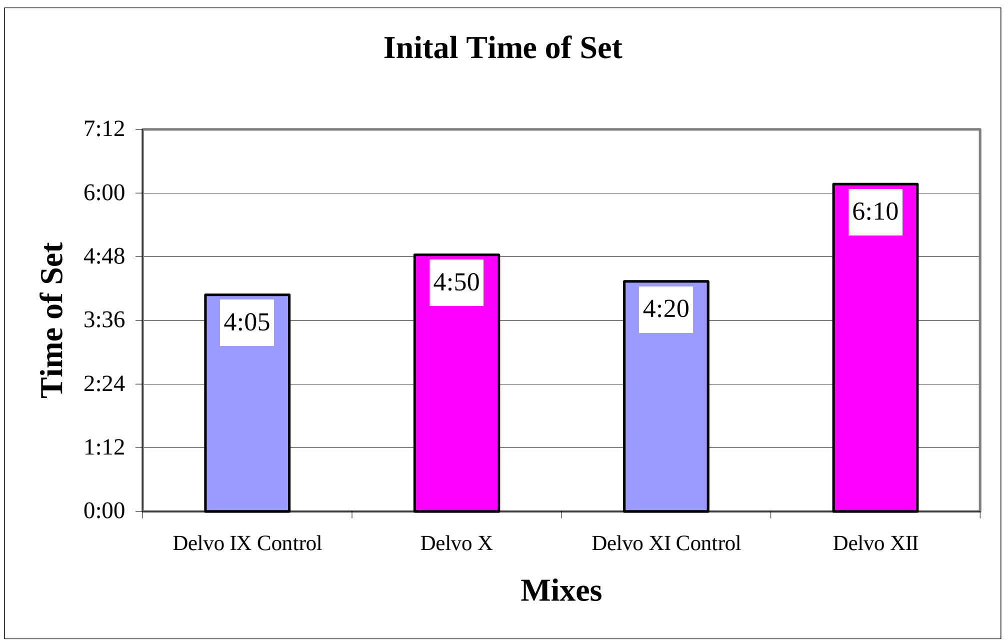

Figure 4-30 Initial Time of Set Result

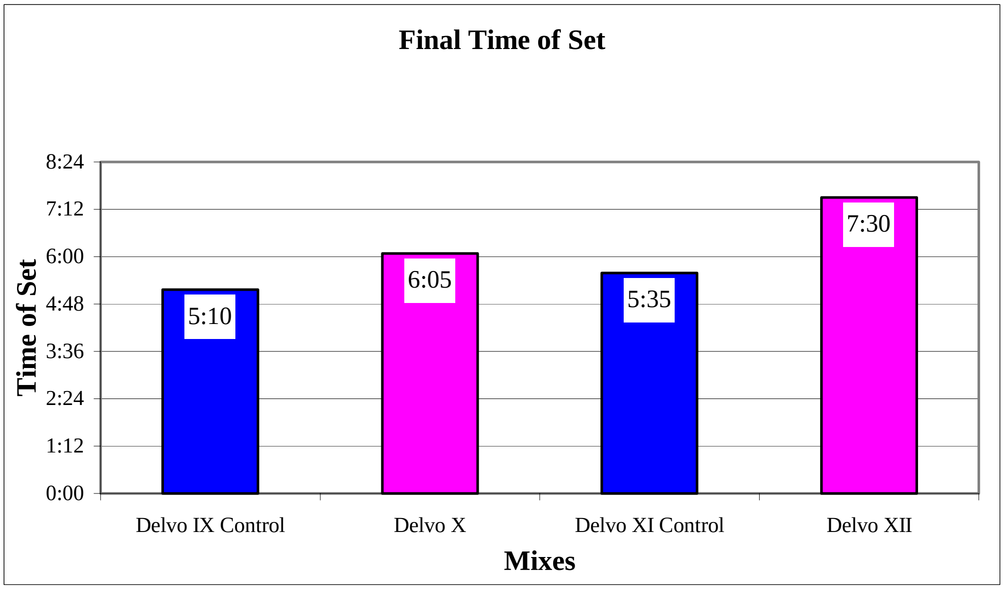

Figure 4-31 Final Time of Set Results

The stabilized mixtures took longer to set both in its initial and final times of set compared to control mixtures. Figures 4.30 and 4.31 show the time of set for these experiments.

4.3.3 Hardened Concrete Tests

The following test results pertain to the hardened state of concrete. The hardened concrete tests that were performed were compressive strength, flexural strength, length change, rapid chloride permeability, and adiabatic temperature. Delvo IX through Delvo XII studied the early strength gain of the samples based on their compressive strengths, where as Delvo XIII through Delvo XVI focused on adiabatic temperature rise.

Compressive Strength Results

The compressive strength cylinders were tested at five different times for Delvo IX through Delvo XII. This was done in order to find the early compressive strength of concrete made from stabilized wash water. Delvo XIII through Delvo XVI were tested on three different times at seven, fourteen, and twenty- eight day. The average compressive strength results are provided in Table 4.32.

Table 4-32 Average Compressive Strengths

Mix Delvo	**Comp. 1 psi**	**Comp. 2 psi**	**Comp. 3 psi**	**Comp 7 psi**	**Comp 14 psi**	**Comp. 28 psi**
IX	**2890**	**3450**	**3800**	**4470**	**X**	**5990**
X	2880	3710	4040	4930	X	6110
XI	**3030**	**4230**	**4230**	**5190**	**X**	**6140**
XII	3070	4050	4500	5240	X	6420
XIII	**X**	**X**	**X**	**4710**	**5380**	**5950**
XIV	X	X	X	5350	5800	6300
XV	**X**	**X**	**X**	**3970**	**4390**	**5010**
XVI	X	X	X	4590	5170	5770

ASTM C-94 standard requires concrete made from stabilized wash water to be 90 percent of the value of concrete made from potable water. The following graphs show the average compressive strengths for the mixtures made in this phase. Each graph shows the control mixture in blue and the stabilized mixture in red. For Delvo IX through Delvo XII mixtures the early strength results (1, 2,3, 7 and 28-day strengths) are shown, while for Delvo XIII through Delvo XVI mixtures show only compressive strengths at 7, 14, and 28-days are shown.

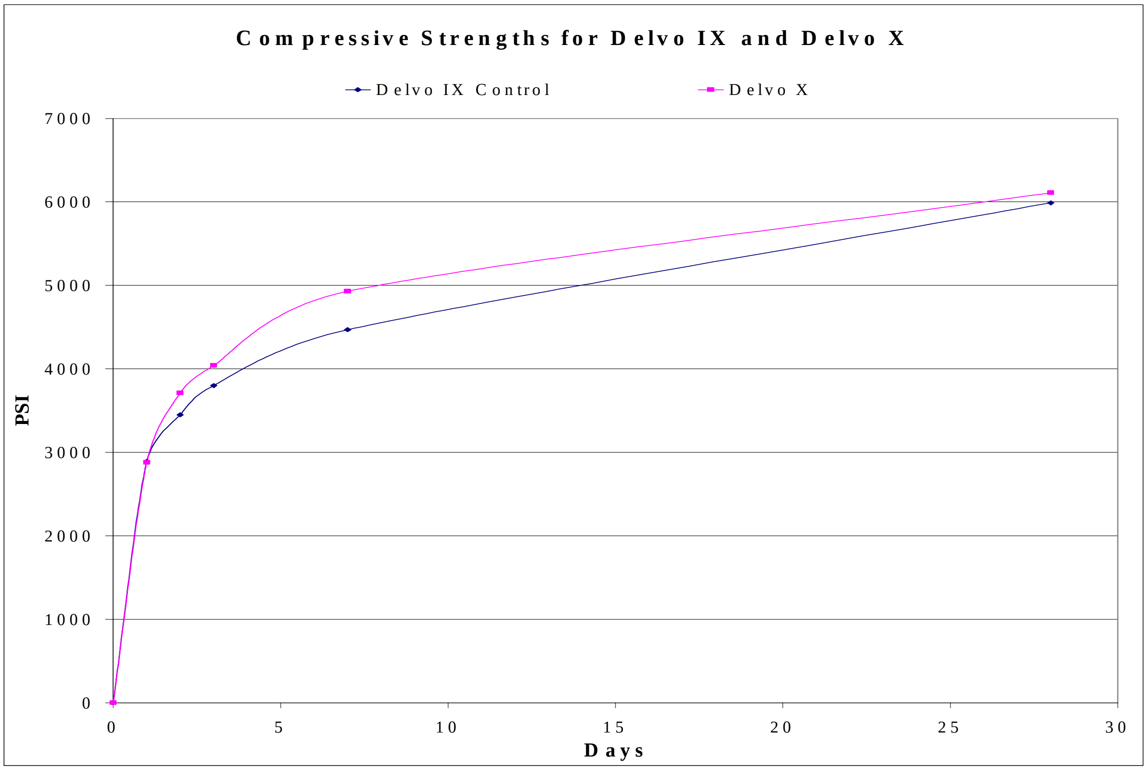

Figure 4-32 Compressive Strength Results for Delvo IX and Delvo X.

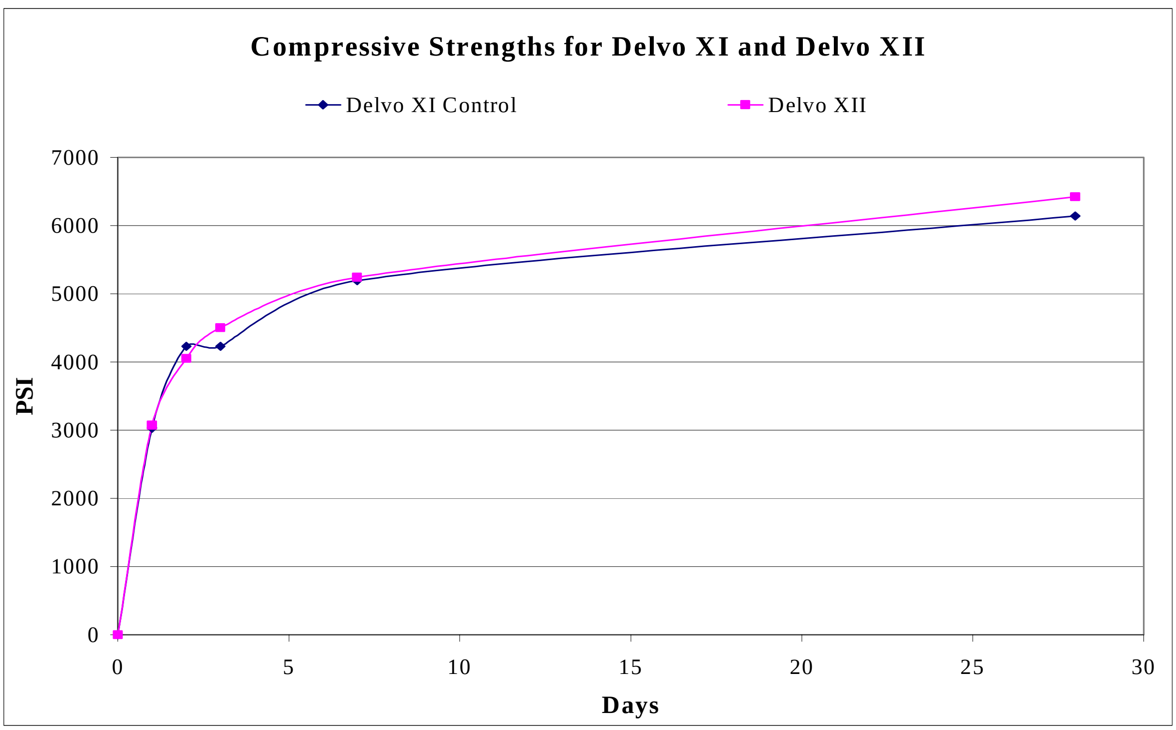

Figure 4-33 Compressive Strength Results for Delvo XI and Delvo XII.

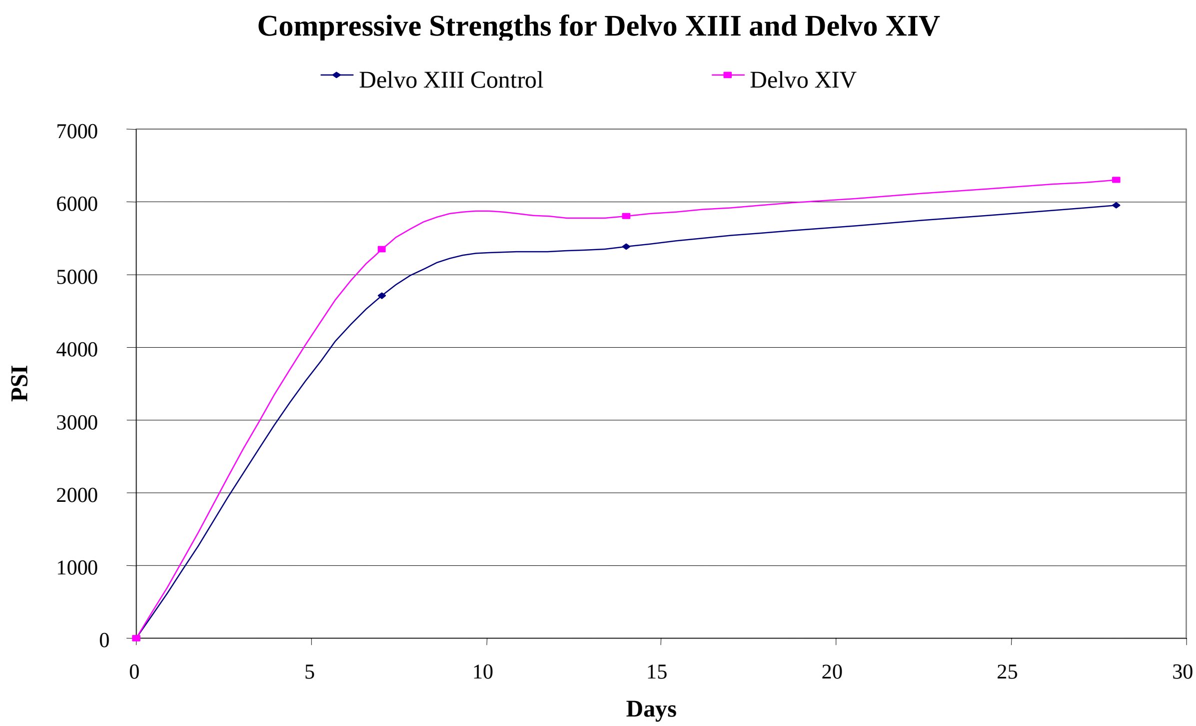

Figure 4-34 Compressive Strength Results for Delvo XIII and Delvo XIV

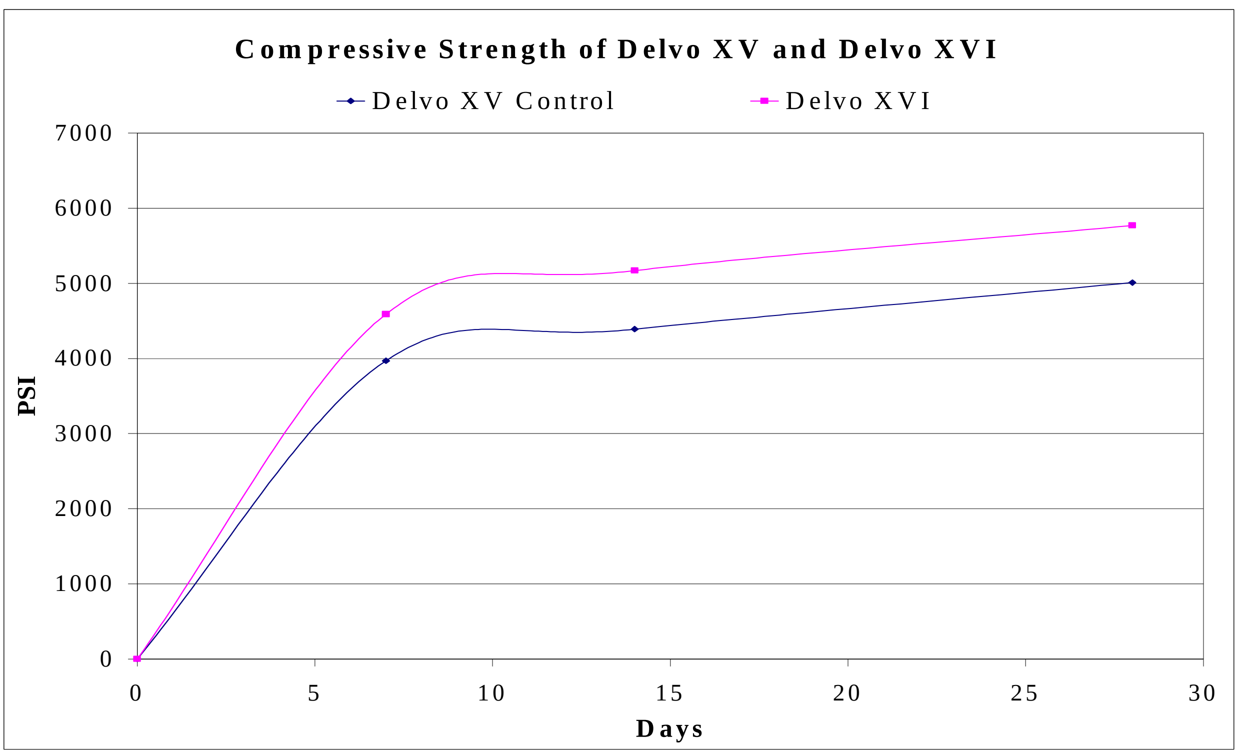

Figure 4-35 Compressive Strength Results for Delvo XV and Delvo XVI

Flexural Strength

The flexural strength results were obtained according to ASTM C-78-84 using three point loading on two samples from each mix. The samples were moisture cured for 28-days before they were tested. Table 4.33 provides the average flexural strength for each mix, and the percent change of the stabilized wash water mix compared to its control.

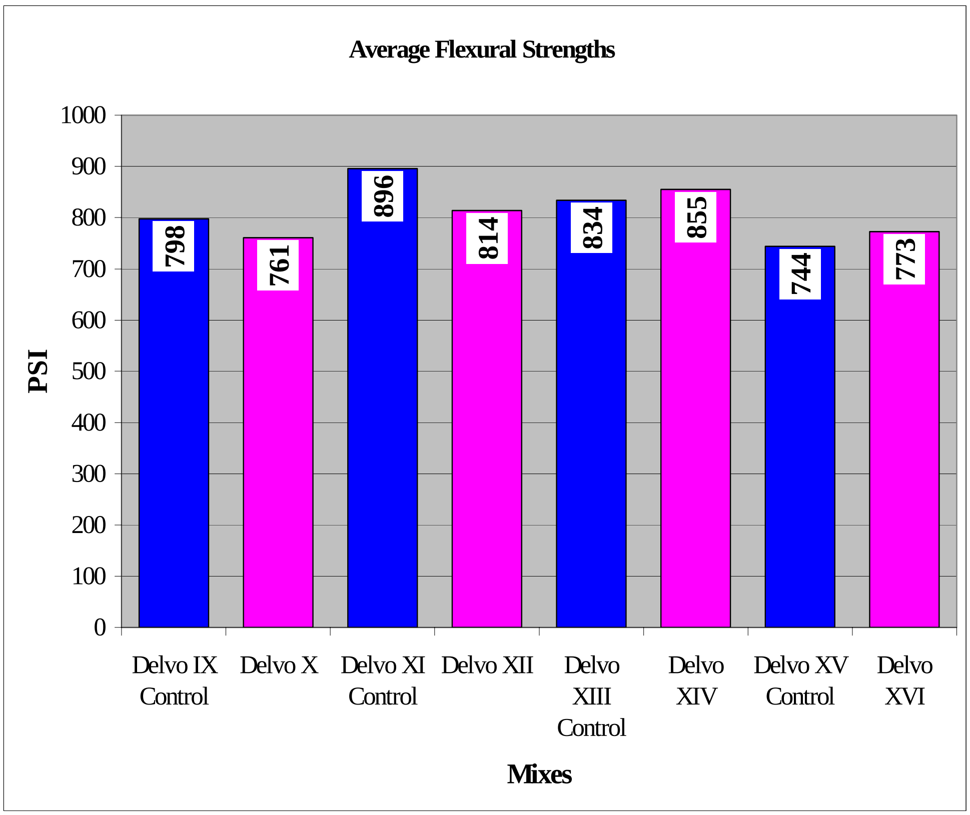

Figure 4-36 Average Flexural Strengths

Table 4-33 Average Flexural Strengths

Mix Type	Flexural (psi)	% of Control
Delvo IX	**798**	**100**
Delvo X	761	95.36
Delvo XI	**896**	**100**
Delvo XII	814	90.84
Delvo XIII	**834**	**100**
Delvo XIV	855	102.5
Delvo XV	**744**	**100**
Delvo XVI	773	103.89

All of the test results indicate that the flexural strength of the stabilized wash water mixes was not significantly affected as compared to its control. The greatest reduction is 10 percent for stabilized wash water mix Delvo XII. Delvo X is the only other mix where stabilized wash water concrete produced a lower flexural strength than the control. Both Delvo XIV and XVI were stronger than their respective controls. Figure 4.36 provides a graphical representation of the individual flexural results. The flexural strength results from stabilized wash water performed well when compared to their control mixes.

Dry Shrinkage

Table 4.34 shows the number of samples measured by using a comparator and the number of samples measured by using a strain gage. The table also shows the number of days readings were taken and the curing method.

Table 4-34 Type of measuring device and number of samples

	Strain Gage		Comparator		
Mix	Number of Samples	Days of Reading	Number of Samples	Days of Reading	
Delvo IX	**3**	**28**	**X**	**X**	^
Delvo X	3	28	X	X	^
Delvo XI	**2**	**28**	**X**	**X**	^
Delvo XII	2	28	X	X	^
Delvo XIII	**2**	**84**	**2**	**84**	*
Delvo XIV	2	84	2	84	*
Delvo XV	**3**	**84**	**X**	**X**	*
Delvo XVI	3	84	X	X	*

Notes:

* Samples stored in water for 3 days then air dried

^ Samples stored in water for all 28 days

For Delvo XIII and Delvo XIV mixtures, the length change for hardened concrete prisms were measured using a comparator according to ASTM C-157 Length change for Delvo IX through XII were measured using a strain gage. These samples were cured for three days in a limewater solution then air-dried for two weeks. Figure 4.37 shows the average percent change of the samples Delvo IX and Delvo X.

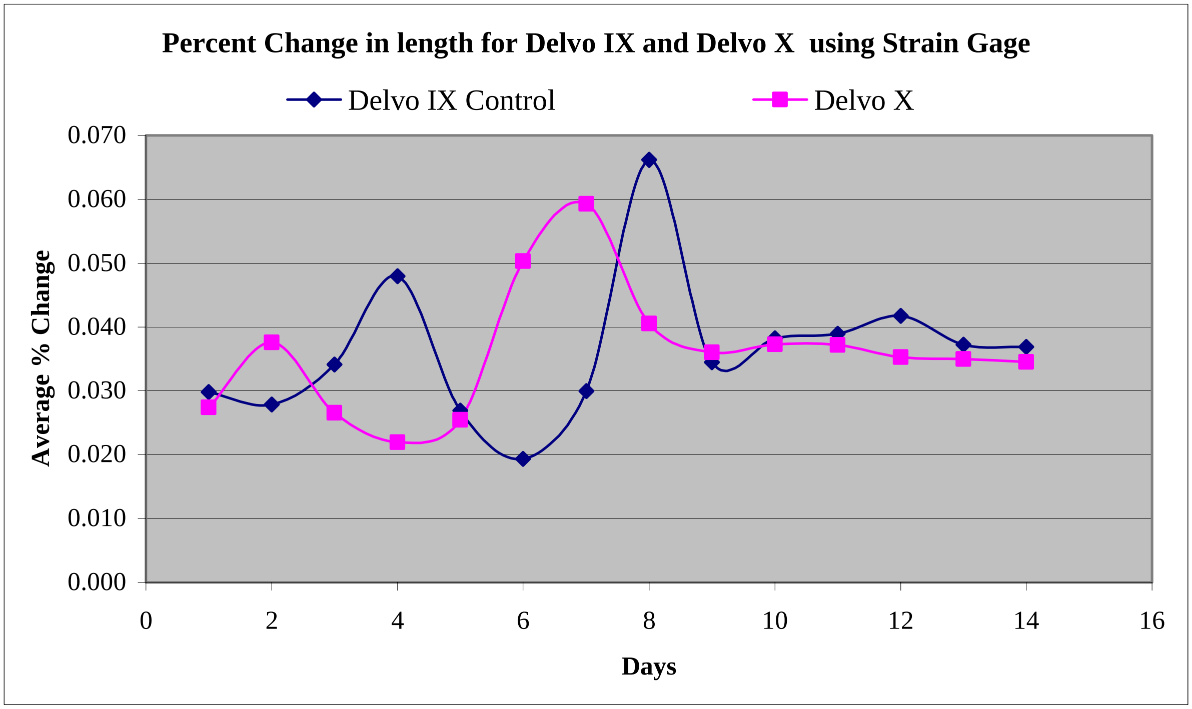

Figure 4-37 Percent change in length for Delvo IX and Delvo X using Srain Gage

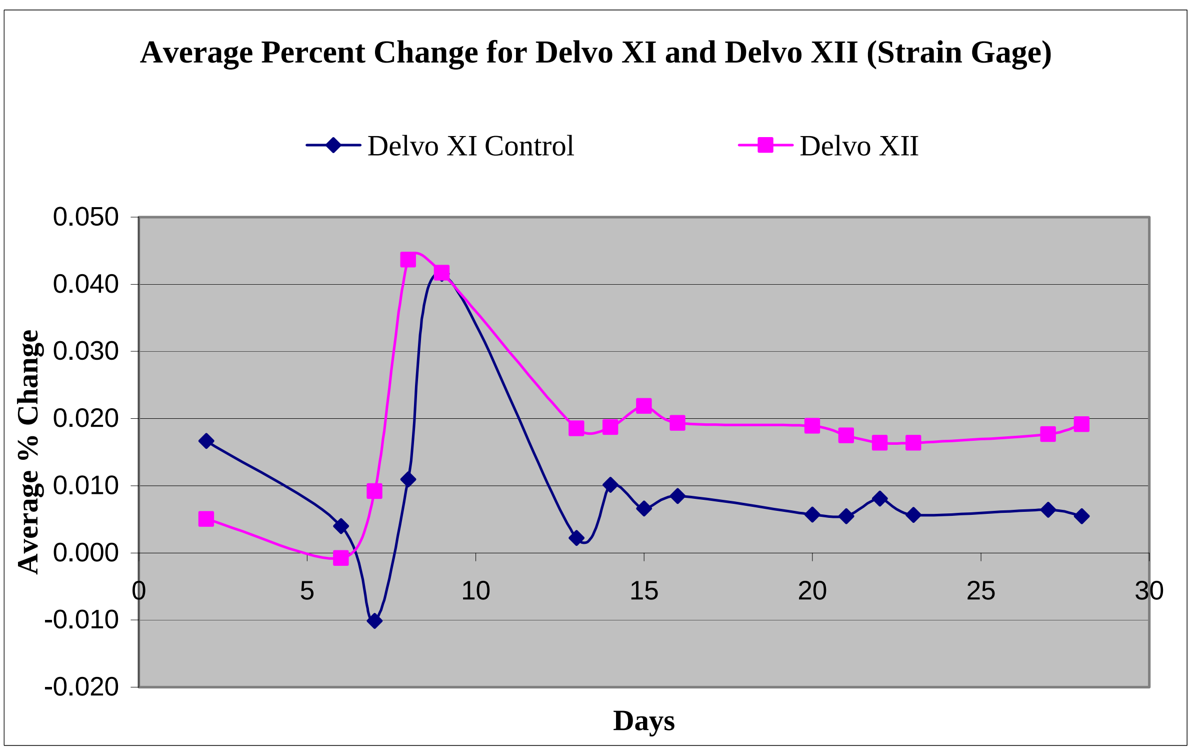

Figure 4-38 Percent change in length for Delvo XI and Delvo XII using strain gage

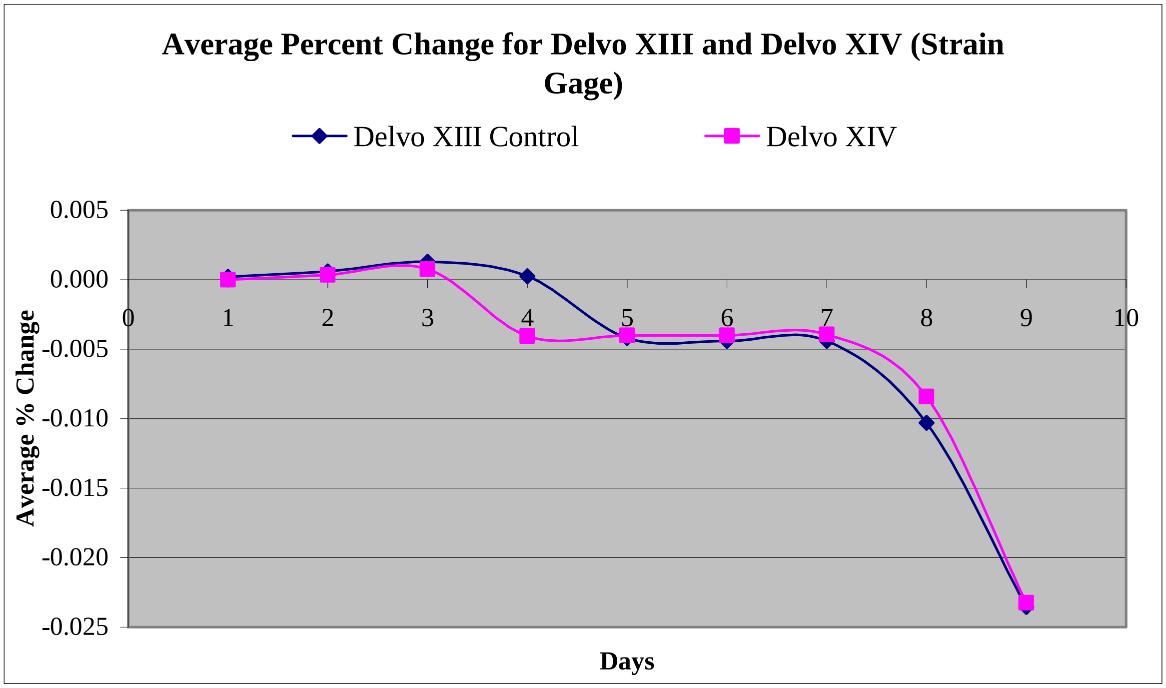

Figure 4-39 Percent Change in length for Delvo XIII and Delvo XIV using strain gage

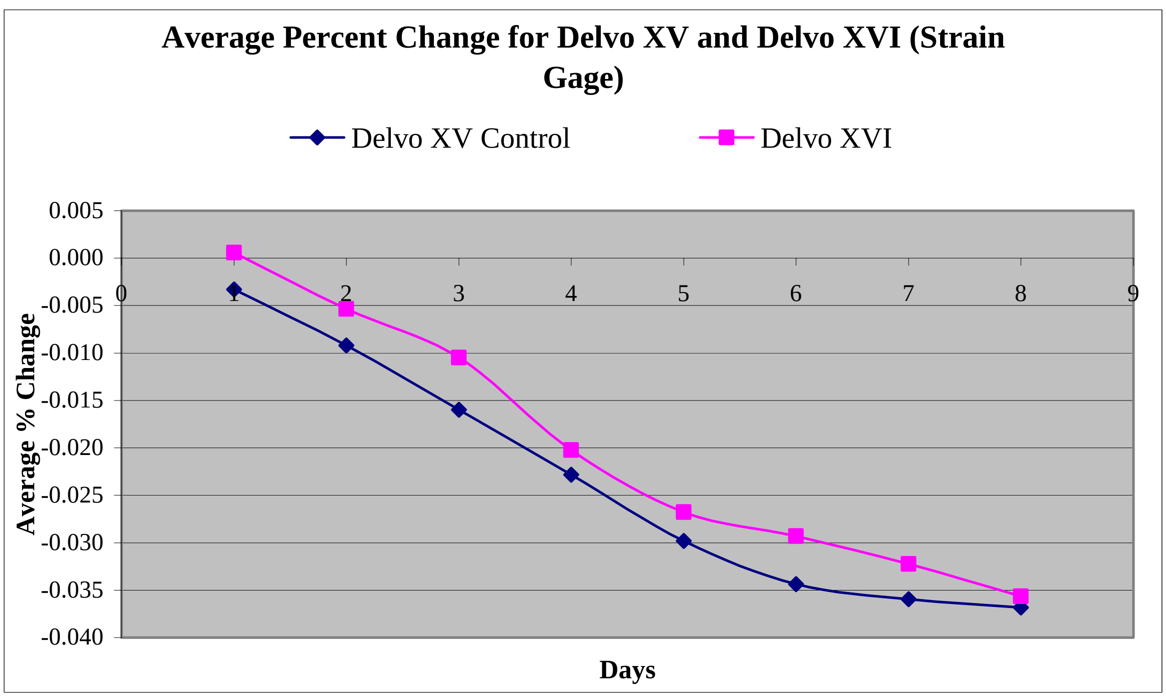

Figure 4-40 Percent Change in length for Delvo XV and Delvo XVI using strain gage

The following figures show the comparison between length change measurements taken by a comparator and those taken by a strain gage. These comparisons were made in order to check the feasibility of using strain gage in lieu of comparator for length change measurement.

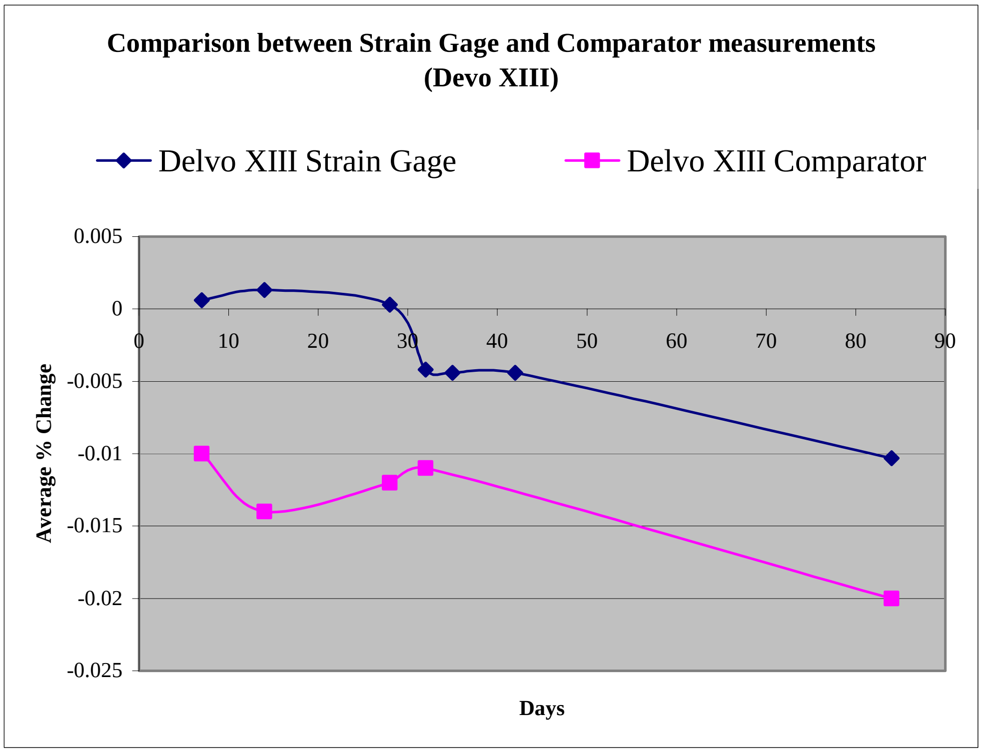

Figure 4-41 Percent change in length measured by the strain gage and with the comparator for Delvo XIII mixture

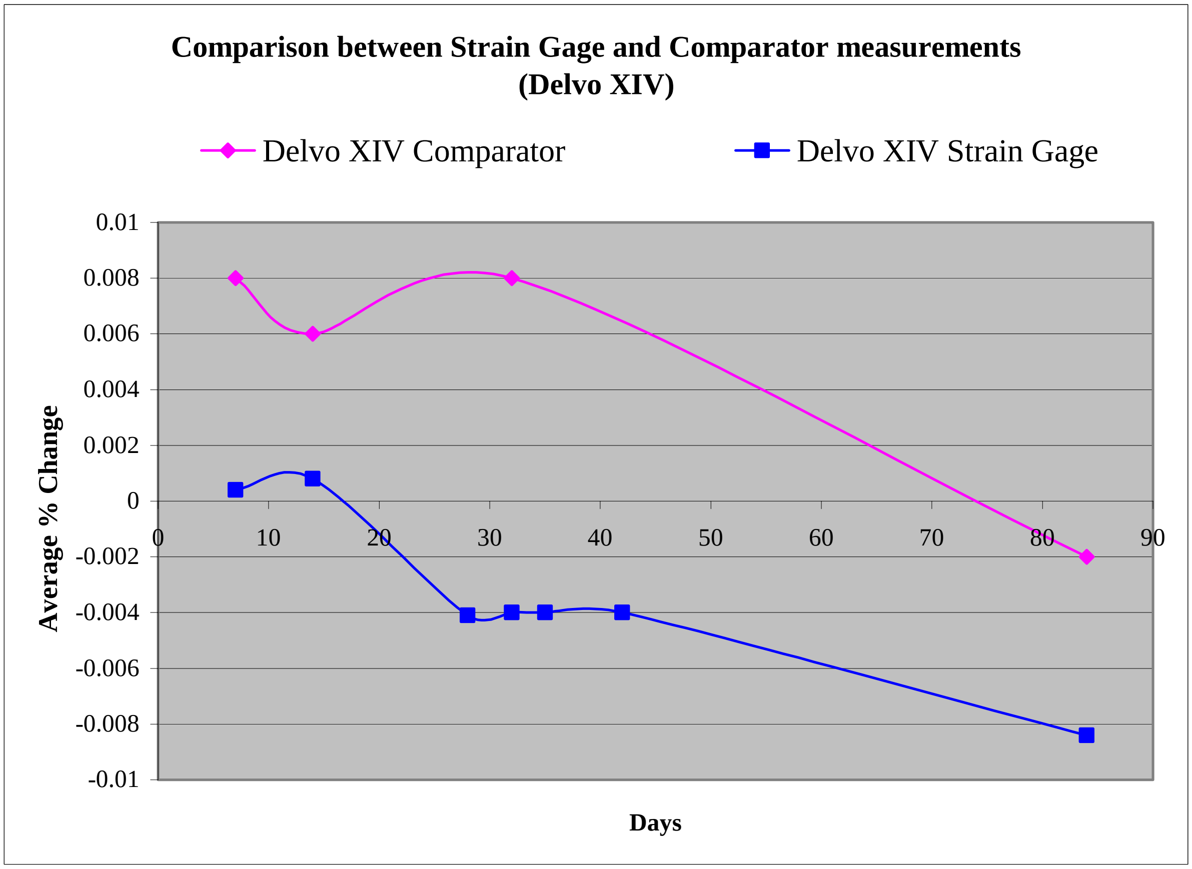

Figure 4-42 Percent change in length measured by the strain gage and with the comparator for Delvo XIV mixture

For experiments Delvo XIII and Delvo XIV a comparison was made in order to evaluate the effectiveness of measuring change in length using a strain gage. Dry shrinkage values are usually taken using a comparator. Using a comparator is not the most accurate measuring technology due to human error. The readings that are taken require human judgment and vary among individuals as to the exact measurement. For mixtures Delvo XIII and Delvo XIV both strain gage and comparators were used to measure change in length due to shrinkage.

Resistance to Chloride-ion Penetration

Two samples from each mix were tested at 28 days for rapid chloride permeability. Table 4.35 provides the individual and average test results for all the mixtures in this phase.

Table 4-35 Rapid Chloride Permeability Results (28-day)

Mix Type	Sample A	Sample B	Average
Delvo IX	**10112**	**9809**	**9961**
Delvo X	7115	9379	8247
Delvo XI	**5572**	**6135**	**5853**
Delvo XII	5652	4867	5259
Delvo XIII	**3785**	**4107**	**3946**
Delvo XIV	4797	5455	5126
Delvo XV	**4175**	**4387**	**4281**
Delvo XVI	4898	5114	5006
LEGEND	**0-100= Negligible** **101-1000= Very Low** **1001-2000= Low** **2001-4000= Moderate** **4001-UP= High**		

All samples except Delvo XIII had 28 days Coulomb values greater than 4001 and ranked high according to the grading criteria from ASTM C1202 provided at the bottom of the Table 4.35.

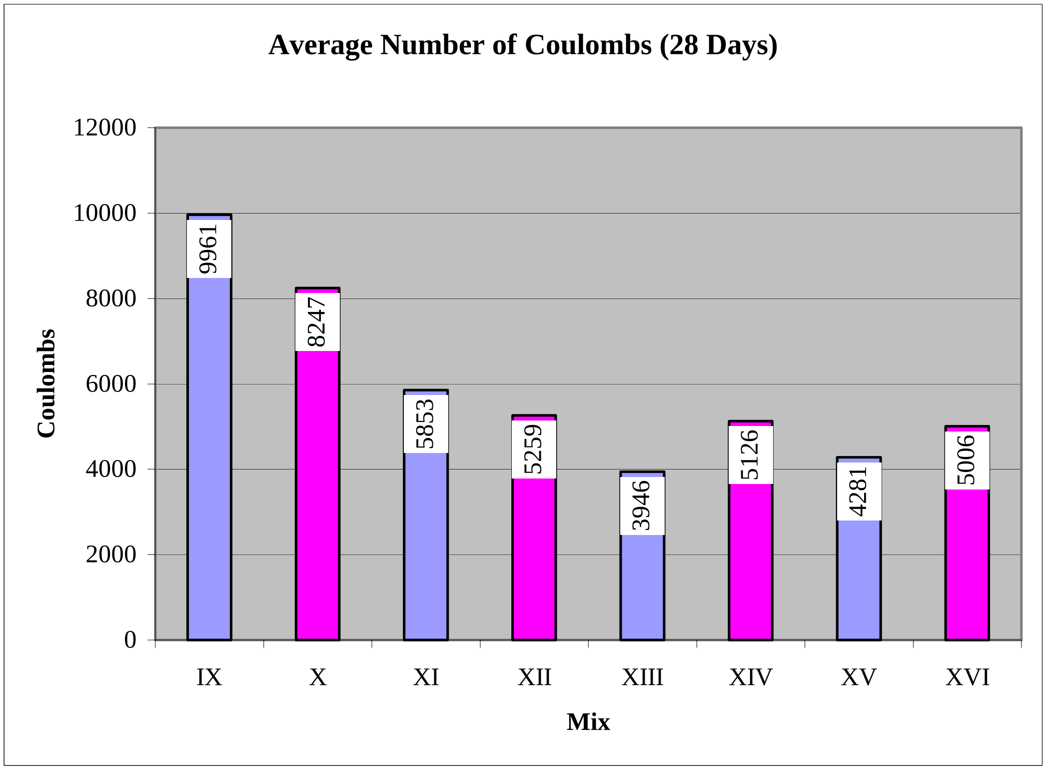

Figure 4-43 Rapid chloride permeability test results for 28-days

Adiabatic Temperature Rise

Adiabatic temperature rise is important in determining the thermal properties of concrete. Extreme differentials in thermal properties of concrete may cause excessive cracking in a structure using large quantities of concrete. Excessive cracking will cause the concrete to fail in its intended design use. Figure 4.44 shows the adiabatic temperature rise of concrete samples Delvo XIII though Delvo XVI. Delvo XIII and Delvo XV were the control group while Delvo XIV and XVI were the experimental group containing the Delvo admixture. The graph shows that Delvo does not have any effect on the thermal properties of concrete. Both stabilized mixtures were very close in comparison with their respective control samples. The sample groups were tested for fourteen days.

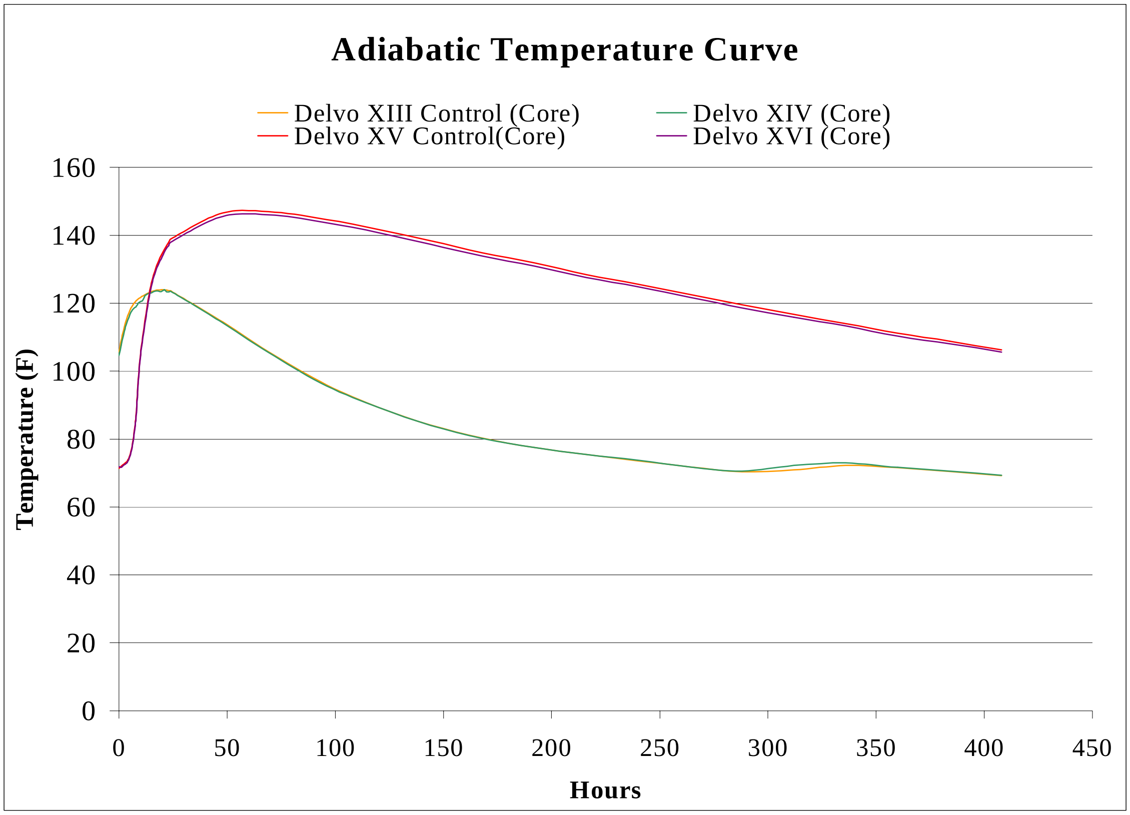

Figure 4-44 Adiabatic Temperature Rise for Delvo XIII through Delvo XVI

Time to Corrosion

The corrosion information for each sample is presented individually as an average of three samples. The total results of the corrosion testing are presented in Table 4.36. The average days to failure for each sample are shown including the average resistance in ohms.

The average days to failure for Delvo X was 43 days with an average resistance of 1157 ohms. Delvo XII had average days to failure of 39 and a resistance of 1499 ohms. Delvo XVI had average days to failure of 37 and a resistance of 1158 ohms. All of the Delvo samples except Delvo XIV did better than their respective controls.

Table 4-36 Average Days to Failure

	Days	Ohms
Delvo IX Control	**24**	**977**
Delvo X	43	1157
Delvo XI Control	**30**	**1147**
Delvo XII	**39**	1499
Delvo XIII Control	**42**	**1188**
Delvo XIV	29	1045
Delvo XV Control	**26**	**949**
Delvo XVI	37	1158

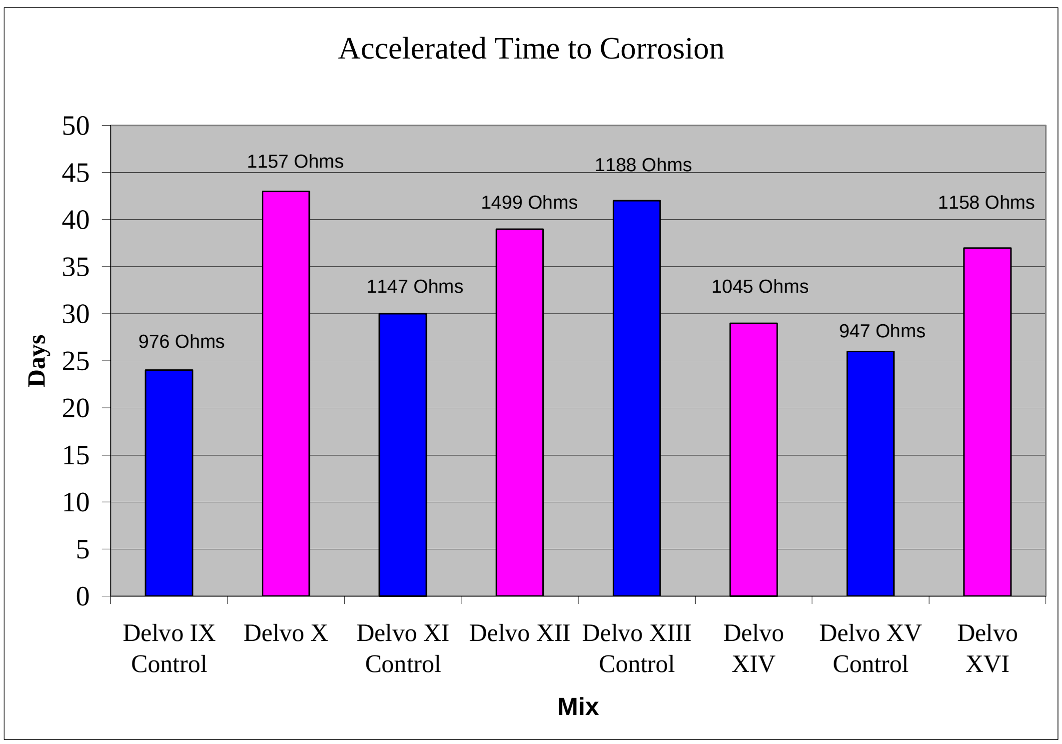

Figure 4-45 Accelerated Time to Corrosion Results

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

This project was undertaken to study the potential of using overnight-stabilized wash water in the production of fresh concrete. Main tasks of this study were: to review the literature on the use of stabilizer systems, determine the properties of concrete containing stabilized wash water, and evaluate stabilized mixture concrete compared with control mixtures not containing a chemical stabilizer.

Information from the literature review revealed that the properties of concrete made from stabilized wash water and/or stabilized waste concrete ranged at comparable levels to the control mixtures. Literature showed there were no significant differences in compressive strength, flexural strength, or modulus of elasticity. However, stabilized mixtures had slightly higher drying shrinkage values and reduced set times due to the use of an activator.

Properties of stabilized concrete and their control mixtures were evaluated using a number of fresh and hardened concrete tests (temperature, slump, unit weight, air content, set time, compressive strength, flexural strength, drying shrinkage, resistance to chloride-ion penetration, time to corrosion, and sulfate expansion). Mixtures were evaluated in the laboratory under conditions that simulated overnight stabilization of their wash water to determine how the fresh and hardened properties changed. Tests were conducted at the FDOT's State Materials Office in Gainesville and the University of Florida's Civil Engineering Department

5.1 Phase I, II, and III

The results of the investigation of Phase I, II, and III on the use of DELVO Stabilizer for overnight applications with Florida aggregates and Class I (non structural) concrete indicated the following:

1. DELVO used without the addition of a type D water reducer/retardant admixture (Pozzolith 220-N) produced concrete, which performed equal to or better than its control mixture. The only difference with the stabilized mixture was that in reaching the maximum water/cement ratio of 0.55, it had a slump of 1.75 inches and workability was harsh.
2. DELVO used in combination with a type D water reducer/retardant admixture (Pozzolith 220-N) produced concrete mixtures with:
   a. higher slump than their control mixtures.
   b. longer set times than their control mixtures.
   c. lower unit weights, compressive strengths, flexural strengths, and moduli of elasticity than that of their control mixtures.
3. Fresh concrete at normal and elevated temperatures with addition of type A water reducer and stabilized for overnight applications in accordance with the procedures recommended by Master Builders had all achieved at least 90 percent of the compressive and flexural strengths of the untreated control mixtures. In several cases the stabilized mixtures exhibited strengths greater than 100 percent of the unstabilized control mixture.

4. The overnight-stabilized mixtures experienced drying shrinkage within 0.0020 inch of that of the control mixtures. The general trend was that the stabilized mixtures sustained less shrinkage than that of the control mixtures.
5. The results of the chloride-ion permeability and time to corrosion tests were somewhat variable but indicated that the stabilized and control mixtures were of comparable quality with respect to chloride-ion penetrability and time to corrosion.
6. The fresh properties of concrete, such as setting time and workability, appeared to be affected by Delvo stabilizing admixture. Setting times were longer and workability appeared to be somewhat harsh.
7. Sulfate resistance of stabilized wash water mixtures was not adversely affected when compared to their control mixtures.

5.2 Phase IV and V

The results of the investigation of Phase IV and V on the use of DELVO Stabilizer for overnight applications with Class II - Bridge Deck concrete indicated the following:

1. Stabilized wash water concrete appeared to have minimal detrimental effects on concrete properties even at elevated temperatures (95-100 degrees Fahrenheit).
2. The mechanical properties of FDOT Class II Bridge Deck concrete were not adversely affected by stabilized wash water concrete in this study.
3. Use of stabilized wash water had no adverse effect on early strength gain of concrete and would not affect formwork removal time.

4. The final set time was longer for the stabilized mixes. Set times were found to be controlled by the dosage of stabilizer admixture applied (or the dosage of activator if used).
5. Stabilized wash water concrete exhibited similar adiabatic temperature results when compared to concrete made from potable water. It appeared that thermal properties of concrete were not affected by the use of stabilized wash water.

5.3 Recommendations

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The objectives of this FDOT project were to verify the performance test results reported by Master Builders for concrete produced with Florida aggregates and DELVO Stabilized wash water. Through this supporting data perhaps FDOT will develop the use of DELVO technology in the reuse of mixer wash water in order to reduce concrete mixture costs, increase concrete construction productivity, and reduce the adverse environmental impact associated with the disposal of mixer wash water.

The use of DELVO Stabilizer in overnight applications is a viable means of reducing the disposal of wash water for concrete. However, in order to be able to evaluate the quality of various mixtures, which incorporate DELVO, the following are recommended:

1. Additional research is recommended to evaluate the use of DELVO on concretes containing additional materials such as ground slag, pozzolans, and chemical admixtures, since DELVO is routinely used to stabilize mixtures containing these materials.

2. DELVO dosage rates should be developed further for particular cement and admixture combinations.
3. This study focused on FDOT Class I (non-structural) and Class II Bridge Deck concretes, further investigation into FDOT Class IV structural concrete utilizing stabilized wash water is suggested.
4. Rapid chloride permeability test is not accurate, especially when the readings are over 4000 Coulombs. Therefore, alternative testing methods need to be developed and assessed. For example the volume of permeable voids and/or Resistivity methods should be compared to the RCP test, for validity and accuracy.
5. Use of strain gage technology in this study to measure change in length of concrete prisms appears to be promising. More tests need to be performed in comparing strain gage readings with those of comparator to develop a revised specification for length change of hardened concrete. The revised specifications need to address the issue of water and air curing time to simulate curing of concrete in field more accurately.

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APPENDIX