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RECYCLING PROCESS WATER IN READY-MIXED CONCRETE OPERATIONS

Final Report

Submitted to

Florida Department of Transportation
(Contract No. BB 258)

BY

Abdol R. Chini, Larry C. Muszynski, and Brian S. Ellis

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16. Abstract

Wastewater produced at ready-mixed concrete plants from the cleaning of the concrete truck's drum has recently been banned from direct disposal to ground or surface waters. Recent environmental regulations require ready-mixed concrete plants to manage and contain wastewater by the use of a reclamation system until it is environmentally acceptable for discharge. There is an interest in the ready-mixed concrete industry for the recycling of concrete wastewater, however current Florida Department of Transportation (FDOT) specifications concerning the quality of water in concrete limit recycling possibilities. The objective of this study was to investigate water quality standards and the possibility of reusing concrete wastewater as aggregate irrigation and/or batch mixing water in the production of fresh concrete.

The project included the following:

1. Surveys of state highway agencies and Florida ready-mixed concrete producers to determine national and state regulations and practices concerning wastewater reuse.
2. A water analysis of Type I and Type II wastewater produced at ready-mixed concrete plants in Florida to determine chemical and physical properties considered to be problematic.
3. A two phase fresh and hardened concrete test program to determine the effects of Type II wastewater on concrete properties when used as 1) aggregate irrigation water and 2) as aggregate irrigation water and batch water.

The results indicates that Type II wastewaters used in this study, which did not meet FDOT water quality specifications (Section 923 - Water for Concrete), but did comply with the water quality standards of AASHTO M 157 (Standard Specification for Ready-Mixed Concrete), had no detrimental effects on concrete properties. Based on the data produced during this project, it is recommended that the FDOT water quality specification be supplemented to address the use of Type II wastewater as aggregate irrigation and/or batch mixing water in the production of fresh concrete. Type II wastewater shall be tested for compliance with the requirements established by AASHTO M 157 which sets limits on the amount of sulfate, chloride ion, total solids, and total alkalies, as Na_2O equivalent, for water used in concrete.

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RECYCLING PROCESS WATER
IN READY-MIXED CONCRETE OPERATIONS

This report is prepared in cooperation with the State of Florida Department of Transportation and the U.S. Department of Transportation.

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.

The current practices for the disposal of concrete wash water include dumping at a landfill or dumping into a concrete wash water pit at the ready-mix plant. The availability of landfill sites for the disposal of truck wash water has been drastically reduced for the past ten years. In 1981, there were approximately 50,000 such sites in the United States; today, there are only about 5,000. In response to this reduction, most ready-mix batch plants have developed a variety of operational configurations to manage their own wash water. The alternatives include settling ponds, storm water detention/retention facilities and water reuse systems. Accumulated wastewater flows into holding ponds, which drain by evaporation or percolation. Often accumulation exceeds dissipation, and un-intentional run-off is generated. Recognizing that a typical batch plant generates an average of 20 gallons of wastewater discharge per cubic yard of ready-mixed production and that the average concrete production rate for a batch

plant is 250 cubic yards per day, the proper disposition of the wastewater presents an important issue. 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 recyclable, avoiding the environmental issues and the expense of disposal.

Two primary examples of potential reuse option are: 1) aggregate irrigation and 2) batch mixing water. Though preliminary studies have shown that concrete 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 batch plant wastewater as mixing water for FDOT.

The FDOT sponsored this research project in fiscal year 1997-98 to develop water quality standards which address reuse of batch plant wastewater in the production of fresh concrete (aggregate irrigation, batch mixing water, etc.). The objective was to provide specification limits of chemical constituents that would affect concrete durability or other physical/chemical properties.

In order to meet this objective, several goals were established: literature review, survey of State Highway Agencies, survey of Florida ready-mix concrete plants, water sampling and analysis, concrete testing using wastewater saturated aggregate, and concrete testing using wastewater as batch mixing water.

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

1. A literature search was conducted to review previous research done in the area of wastewater reuse in the production of concrete. Studies conducted on concrete wastewater reuse as well as other types of wastewater reuse were included in this search. Studies done on the environmental impacts of wastewater were also examined. The literature search indicated that concrete wastewater (Type II wastewater) has no detrimental effect on concrete properties when used in the production of concrete. Several studies did however indicate that an extremely high amount of solids may lead to a decrease in compressive strength and increased shrinkage (see Chapter 2).

2. A survey of State Highway Agencies throughout the United States was conducted. The objective of this survey was to examine current policy and practice around the country concerning the reuse of Type II wastewater in ready-mixed concrete operations. Surveys were distributed to the Department of Transportation's Materials Engineer for all 50 states plus Puerto Rico. The survey indicated that the majority of agencies do not allow the reuse of Type II wastewater in the production of concrete. Variability in chemical content and effect on quality control are influential factors in the agencies' decisions (see Chapter 3).

3. A survey of ready-mixed concrete production plants in Florida was conducted. The objective of this survey was to determine amount of Type II wastewater produced, uses for Type II wastewater, current methods of handling Type II wastewater, and

overall industry opinion concerning Type II wastewater. Thirteen surveys were returned representing 13 different ready-mixed concrete companies in Florida. The survey indicated that there is a high level of interest and involvement in the ready-mixed industry regarding the recycling of Type II wastewater. The average ready-mixed plant uses approximately 70 gallons of water per cubic yard of concrete produced. The amount of wastewater produced is small enough to be totally recycled into the production of fresh concrete (see Chapter 4).

4. A sampling and analysis test plan was designed and conducted to determine the properties of Type I and Type II wastewater produced at ready-mixed concrete plants in Florida. Only concrete plants currently using a Type II wastewater containment system were selected. Water samples were tested for alkalinity, alkali content, sulfate content, chloride content, total inorganic solids, total volatile solids, and total solids. The water sampling and analysis test program indicates that Type II wastewater meets ASTM C 94 (Standard Specifications for Ready-Mixed Concrete, 4.1.3) and AASHTO M 157 (Standard Specification for Ready-Mixed Concrete) specifications for quality of water in concrete including sulfate content, chloride content, alkali content, and total solids. Type II wastewater meets FDOT specifications pertaining to quality of water in concrete (Section 923, Water for Concrete) with regards to chloride content and volatile solids. However, Type II wastewater does not meet FDOT specifications with regards to total alkalinity and inorganic solids (see Chapter 5).

5. A test program was designed and conducted to investigate the reuse of Type II wastewater in the production of concrete. Phase 1 of this test program incorporated Type II wastewater for saturation of coarse aggregate in the production of concrete. Tap water was used for batch water in this phase. Phase II of the test program used Type II wastewater to saturate coarse aggregate and as batch water in the production of concrete. Variables in Phase 1 and 2 included wastewater from two different ready-mixed plants and coarse aggregate from 3 different areas of Florida. Control samples were made using tap water for saturating aggregate and as batch water. Concrete specimens were produced and tested for slump, set time, unit weight, air content, compressive strength, flexural strength, modulus of elasticity, rapid chloride permeability, drying shrinkage, sulfate expansion, corrosion of rebar in concrete, and impressed current.

Test results indicate that Type II wastewater has no statistically significant effect on the properties of plastic (set time, unit weight, and air content) and hardened (compressive strength, flexural strength, and modulus of elasticity) concrete when used as batch water and/or to saturate coarse aggregate in the production of concrete. In addition, the use of Type II wastewater as batch water and/or to saturate coarse aggregate in the production of concrete has no statistically significant effect on the propensity of concrete to shrink when exposed to air or expand when exposed to sulfate and has no statistically significant effect on chloride permeability and time-to-corrosion of reinforcing steel (see Chapters 6 and 7).

6. Results of the Type II wastewater analysis and Phase 1 and 2 concrete test results indicate that Type II wastewater with alkalinity and total inorganic solid content in excess of FDOT limitations may be used in the production of concrete with no detrimental effects to concrete properties. Therefore, it is recommended that the FDOT water quality specification, Section 923 entitled, "Water for Concrete" be supplemented to address the use of Type II wastewater as aggregate irrigation and/or batch mixing water in the production of fresh concrete. Type II wastewater shall be tested for compliance with the requirements established by AASHTO M 157 specification entitled, "Standard Specifications for Ready-Mixed Concrete." The AASHTO M 157 specification sets limits on the amount of sulfate, chloride ion, total solids, and total alkalies, as Na_2O equivalent, for water used in concrete (see Chapter 8).

Allowing reuse of wastewater that meets certain physical and chemical requirements 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 wastewater from ready mixed concrete operations will also add to the image of FDOT as one of the most progressive agencies in recycling efforts. In addition, adopting a more comprehensive specification for use of water for concrete will provide an incentive to concrete producers and encourage them to develop more advanced operational configurations to manage their wastewater.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Objective

The objective of this report is to investigate re-use of ready-mix concrete production plant wastewater as aggregate irrigation and/or batch mixing water in the production of fresh concrete.

Background

When a 10 cubic yard ready-mix truck returns from a construction site there is still approximately 600 pounds of concrete adhering to the inside of the drum and mixing blades. It takes between 150 to 300 gallons of water to wash this concrete out before it hardens inside the drum. On a national level, it is estimated that 247,000,000 cubic yards of concrete are produced annually, requiring 1,240,000,000 gallons of cleaning water (Borger et al., 1994). When this water is discharged it is classified as Type II wastewater. The Type II wastewater contains fine cement particles, sand, gravel, and chemical admixtures. This includes two hazardous substances, sodium hydroxide (NaOH) and Potassium Hydroxide (KOH) (Chini, 1996). The wastewater has a pH between 10 and 13 (neutral pH is 7), high enough to be considered hazardous under the Environmental Protection Agency's (EPA) definition of corrosivity (Master Builders Technologies Research and Development, 1988).

There are four basic options for disposing of wastewater from the concrete plants; 1) at the ready-mix plant, 2) at the construction site, 3) at a landfill, or 4) at a reclamation unit (Borger et al., 1994). The first two options have been limited by the 1987 revision to the Clean Water Act. Its objective: "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." With respect to the production of concrete in ready-mix plants, the EPA's concern is the contamination effect this toxic water will have on our ground water system. This problem is especially pertinent to Florida because the Florida Aquifer is relatively near the surface where the wastewater is disposed. If the wastewater was discharged directly into the ground it may be toxic to aquatic life and may pollute the water for drinking and recreation (U.S. Environmental Protection Agency, 1990). The development of environmental regulations and the increase in landfill demand have decreased the number of authorized disposal sites over the last 15 years. In 1981, there were about 50,000 landfill sites in the United States, today there are only approximately 5,000 (Chini, 1996). This decrease in the number of landfill sites has left the concrete industry with few options of what to do with their wastewater.

Presently the concrete industry in Florida is in the process of bringing all current plants up to code with new federal regulations that require new and existing facilities to obtain a generic permit to produce concrete in Florida. The majority of ready-mix concrete production facilities have begun to use retention ponds to collect and manage Type II wastewater. The following is a summary of the Memorandum of Agreement between the Florida Concrete and Products Association (FC&PA) and the Florida Department of Environmental Protection (DEP) regarding the new permit requirements and how it will be implemented. The Memorandum contains some key definitions pertaining to wastewater re-use, which are given below.

Definitions

Type I wastewater: wastewater generated during general industrial activities at a concrete batch plant including conveyor wash-down; spraying of water on aggregate piles, cleaning of the mixing plant and slump racks, and other similar sources of industrial activities; spraying of water for duct control; truck exterior washing; and contact stormwater runoff.

Type II wastewater: wastewater generated during the internal concrete truck wash-out activities associated with a concrete batch plant and any other water commingled with this wastewater, including rainfall that falls or drains directly into the Type II wastewater containment system.

Note: Type II wastewater in this report has been referred to as wash water in ASTM C 94, ***Standard Specification for Ready-Mixed Concrete*** and AASHTO M 157, ***Standard Specification for Ready-Mixed Concrete.***

Type II wastewater containment system: a concrete lined or other imperviously-lined structure of suitable dimensions that will allow all Type II wastewater generated at a concrete batch plant to be retained and separated from the Type I wastewater generated at a facility. The size of a Type II wastewater containment system for an individual facility will be determined in accordance with sound engineering practices and shall be sufficient in size to retain the entire volume of Type II wastewater generated by the facility on an average daily basis and the rainfall from a 25 year, 24 hour storm event that falls directly on or drains into the Type II wastewater containment system.

Summary of Memorandum of Agreement

During 1997, an agreement has been achieved between the State of Florida Department of Environmental Protection (DEP) *"Florida Wastewater Regulation Program"* (FWRP) and the Florida Concrete and Products Association (FC&PA).. The agreement was the result of a number of studies conducted by FC&PA and the DEP concerning wastewater handling at ready-mix concrete batch plants. The aim of the agreement was to act in partnership with the affected private sector interest groups and in this way move the industry to better practice concerning wastewater handling. Achievable levels of compliance with FWRP stipulations, to be met by the owners and operators of concrete batch plants, has been set forward. It was agreed that similarly situated ready-mix concrete batch plants be subjected to equivalent and consistent license and environmental permitting requirements. It has also been agreed that specific design and construction criteria for concrete batch plants will be promoted. The establishment of a *rule-based generic permit* incorporating all necessary approvals has been agreed upon. It has also been agreed that a transition period will be determined during which, an appropriate provision will be made for existing plant operations, before full implementation of the generic permit will be enforced. The ultimate goal of the agreement was to promote voluntary compliance with FWRP regulations within the ready-mix concrete industry. The two parties reached agreement on a series of steps that will lead to the promulgation of a generic permit by the DEP that should be sufficient to provide coverage for the vast majority of ready-mix concrete batch plants located in Florida.

Both parties have agreed to the following:

- FC&PA and the DEP will cooperate in their efforts and assist the industry to comply with FRWP regulations.
- FC&PA will publicize the agreement among its members and promote compliance with Florida law on a voluntary basis.
- FC&PA will provide written notification of the agreement to all known non-member concrete producers and encourage them to join this voluntary compliance initiative.
- FC&PA and the DEP will cooperate to identify and eliminate regulatory barriers that impede acceptance of the use of reclaimed wastewater in ready-mix concrete intended for use in transportation and other public infrastructure facilities.
- The DEP shall develop and promulgate by rule a generic permit and make it available to the industry as soon as possible.
- Concerning specific batch plant operations it was agreed that concrete batch plants be operated in such a way that Type I and Type II wastewater are treated separately.
- Type I wastewater shall be managed on site in such a way that it will meet quality standards prior to discharge to jurisdictional surface waters.

• It has been acknowledged by FC&PA and the DEP that a substantial number of ready-mix concrete batch plants may currently be operating without being in full compliance with FWRP. In order to facilitate such compliance, the parties agreed that a procedural vehicle is necessary to govern operations at these plants. It has been agreed that a DEP "*consent order*" is the appropriate way to establish compliance conditions for existing concrete batch plants. A model "consent order" has been developed for this purpose.

One option the concrete industry is presently considering is the re-use of wastewater in the production of concrete. Two primary examples of its potential re-use in concrete production are aggregate irrigation and batch mixing water. This study examines Type II wastewater in these applications in order to analyze current water quality specifications limiting its use.

Scope of Work

Literature Review

A state-of-the-art review of the research previously performed in the area of recycling wastewater from ready-mix concrete producers was undertaken.

Survey of State Highway Agencies

A survey was developed to determine current policy and practice of the State Highway Agencies concerning the reuse of Type II wastewater in ready-mixed concrete production operations. Surveys were distributed to the Department of Transportation's Material Engineer for all 50 states and Puerto Rico

Survey of Florida Ready-Mix Concrete Plants

With the cooperation of the FDOT and the Florida Concrete & Products Association, ready-mix concrete companies throughout Florida were surveyed to determine typical amounts and uses of wastewater produced, current methods being used to solve the wastewater problem, and industry opinion concerning wastewater.

Water Sampling and Analysis

Samples of wastewater were taken from ready-mix concrete plants throughout Florida to determine the typical chemical properties of Type I & II wastewater. Properties tested for include alkalinity, total alkali content, sulfate content, chloride content, and total inorganic solids, total volatile solids, and total solids.

Phase 1 Concrete Testing

Phase 1 testing was designed to determine if aggregate soaked in wastewater has any detrimental effects on both plastic and hardened concrete properties. Concrete samples were produced using wastewater to saturate the aggregate prior to mixing. The concrete was then batched using potable water. The mix design was a standard FDOT project mix design (see chapter 6). Three different coarse aggregates from North, Central, and South Florida were used. Properties of concrete samples made from coarse aggregates saturated with Type II wastewater were compared with those of control concrete samples made from aggregate saturated with potable water. Samples of concrete were tested for slump, set time, unit weight, air content, compressive strength, flexural strength, modulus of elasticity, rapid chloride permeability, drying shrinkage, sulfate expansion, corrosion of rebar in concrete, and time-to-corrosion.

Phase 2 Concrete Testing

Phase 2 testing was designed to determine if Type II wastewater used in place of potable batch water, has any detrimental effects on plastic and hardened concrete properties. In this phase, Type II wastewater was used both to saturate the coarse aggregate and as batch water. The test results were compared to those of the control mix from Phase 1. Samples were tested for slump, set time, unit weight, air content, compressive strength, flexural strength, modulus of elasticity, rapid chloride permeability, drying shrinkage, sulfate expansion, corrosion of rebar in concrete, and time-to-corrosion.

CHAPTER 2

LITERATURE REVIEW

Introduction

Water quality has been a matter of concern in the production of concrete since its early applications. Most specifications today require the use of potable water because its chemical content is known and well regulated. In this way properties of concrete can be controlled and the number of uncertainties would be limited. Since in some situations potable water is not readily available, a number of studies exist that examine the use of water coming from other sources (streams, lakes, etc.). Because of these studies current specifications regulate the use of water other than potable. Strict environmental regulations today force concrete producers to contain all of their wastewater on site. Because of these regulations, concrete producers would like to recycle these waters and reuse them in the production of fresh concrete. The effect on concrete properties when recycled wastewater is used as mixing water is not well known. This chapter summarizes some of the studies that examine these effects. Since water coming from streams or lakes has a much more uncertain chemical composition, several studies have been included that report on the use of waters coming from these and other sources. Two studies are included that examine the use of reclaimed sewage water for making concrete. Finally, two studies are included that describe the environmental impact of concrete batch plant operations and cement waste products.

Using Water from Streams, Rivers, Ponds, or Lakes for Making Concrete

Abrams, D.A., 1924

This early study examines the effect of impure waters when used for mixing concrete. Sixty-eight different kinds of water samples were tested. Among the waters tested were sea and alkali waters, bog waters, mine and mineral waters, waters containing sewage and industrial wastes, and solutions of common salt. Some of these waters contained up to 250,000 parts per million (ppm) of solids. Potable water was used as a reference. About 6,000 samples of mortar and concrete were tested for compressive strength, consistency, and time of set. Strength tests conducted for concrete of ages 3, 7, and 28 days, 3 months, 1 year, and 2 1/3 years. Concrete that gave strength ratios less than 85 percent compared to potable water were considered unsatisfactory for mixing concrete. In spite of the wide variation in the origin and type of waters used, most of the samples were found to give good results when used in making concrete. Acid waters, lime soak from tannery, refuse from paint factories, certain mineral waters, and waters containing over 5 percent of common salt were found to give unsatisfactory results for some of the samples. Time of set and consistency when impure waters were used was, with few exceptions, about the same as those samples made with fresh water. It was found that neither color nor odor were any indication of quality of water for mixing concrete.

Steinour, 1960

Steinour presents a review of the literature concerning the amount of water impurities that can be accepted for use in concrete production. Based on the work of Abrams and others, he concluded that most water impurities have no adverse effect on concrete strength. He observed that in general no studies were performed that investigated the possible adverse effects of impure waters on reinforcing steel or other durability issues. He concluded that strength tests alone are not sufficient to allow higher concentrations of impurities in mixing water. He recommended making both set time and strength tests before using any water that lacks a service record, and that contains an exceptional amount of total dissolved solids in excess of 2000 ppm. Dissolved solids containing ions of calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, nitrate, and carbonate may also be detrimental in excess of 2000 ppm.

Reuse of Wastewater and Concrete Leftover in the Production of Fresh Concrete

Ullman, 1973

Ullman studied the reuse of wastewater as mixing water for fresh concrete. In this study, batches made with wastewater were compared with batches made with tap water. The wastewater used contained 4600 ppm of total solids and about 50 to 300 ppm of suspended solids. The aggregates used were natural quartz sand and gravel. The cement content was five sacks per cubic yard. An air-entraining admixture was batched on the sand. The study concluded that the reuse of wastewater had no detectable effect on strength, slump, air content, or mixing water requirement.

Meininger, 1973

Meininger conducted a study on the reuse of concrete truck or central mixer wastewater. He concluded that the reuse of clarified water had no significant effect on concrete properties. However, the reuse of agitated wastewater (which contains more solids) resulted in a compressive strength decrease of 10% and a shrinkage increase of 10%.

Kasai, 1979

Kasai summarized a report prepared by a committee established by the Japan Concrete Institute. The committee did research on the recycling of wastewater and cement slurry disposal at ready mixed concrete plants in Japan. Concrete was divided into 3 classes according to the type of water used (fresh water, clarified water, and slurry water). The effects of the different types of water on concrete properties were investigated. In their conclusions, they stated that clarified water could be used as mixing water for concrete without causing any problems. When slurry water is used, attention must be given to the amount of slurry, w/c ratio, percentage of fine aggregates and the amount of air entraining agents used.

C.U.R Report 93, 1979

The Civieltechnisch Centrum Uitvoering Research en Regelgeving in the Netherlands has studied the reuse of cement slurry as filler in concrete. The chemical composition of dried cement slurry was compared with that of pure cement and was found to be not significantly different. From the literature search, they concluded that when cement sludge was used this resulted in a) an increase in water demand for making a concrete having a particular consistency, b) a decrease in the bleeding of fresh concrete, c) a reduction in compressive strength, and d) an increase in shrinkage. Further research was performed to judge the results found in the literature. With regard to the addition of 1% cement slurry (referred to the mass of the aggregate in the mix) the following was found; a) for the mix designs studied, water demand increased about 7%, b) as a result, the water-cement ratio is increased by about 8 %, c) the factor water+air/cement is increased by about 6%, d) compressive strength is reduced by about 8%, e) shrinkage increased by about 14%, f) water tightness and frost resistance are not affected significantly, and g) in the accelerated carbonation test (84 days in CO_2 atmosphere) the depth of carbonation increased by 9mm, corresponding to a 42 % increase.

C.U.R Report 148, 1991

The same center in the Netherlands also studied the reuse of cement sludge and rinsing water of wet masonry mortar on concrete properties. Concrete was prepared with 1% (by weight) of sludge, this is 1 part of dry sludge material to 99 parts of the normal concrete solids. Mixes have been prepared using sludge from masonry mortars with a usual composition and with compositions containing triple dosages of admixtures. Setting times of concrete measured in accordance to ASTM C 403, *Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance,* were found to be not significantly different from those of the reference mix. From the results, it was concluded that setting times of cement paste in general were retarded, whereas setting times of concrete mixes in general were accelerated. Compressive strengths were found to be reduced to about 90 % of the reference mix at 7 and 28 days. At ages of 1 and 3 days, compressive strengths were higher than that of the reference mix. It was concluded from the study that the rinsing water coming from masonry mortar containing up to 1% of dry sludge and containing triple dosage of admixtures, is acceptable to be used in fresh concrete.

Woodward-Clyde Consultants, 1993

Woodward-Clyde conducted a study on the reuse of concrete wastewater (slurry) to replace a portion of the mixing water for ready-mixed concrete. The tests included 5 concrete batches with 0,3,5,6, and 7 percent total solids in the mixing water. Each batch was tested for slump, air content, initial set times, and compressive strength.

Woodward-Clyde concluded that the reuse of wastewater producing up to 7 percent total solids in the mixing water had little effect on the slump, initial set time, and compressive strength of each mix. They also concluded that there was a slight increase in air content.

Oregon Department of Transportation, 1993

A study to determine whether or not the use of recycled concrete wastewater would have any adverse effects on concrete properties was conducted. Wastewater coming from a plant in Portland, Oregon was used. This plant continuously agitates and circulates the wastewater after passing it through a settling basin. The water was further passed through a filter press and collected in a tank. The pH of the water was adjusted by the introduction of carbon dioxide (CO_2). Chemical tests on the wastewater gave values that were well within the limitations of ASTM C 94, *Standard Specification for Ready-Mixed Concrete*, and AASHTO T 26, *Quality of Water to be Used in Concrete*. Concrete samples used contained 80 % of wastewater and 20% of clear water as mixing water. Setting times of cubes were found to be well within the minimum and maximum ranges as determined in ASTM C94 and AASHTO T26. The average strength of concrete made with recycled wastewater was 98% of the strength of concrete made with fresh water. Slump and air loss increased when wastewater was used, but results were found to be acceptable. All data was found to be well within their respective limits. A recommendation was made stating that no significant problem exists when recycled water is used in structural concrete decks.

Borger, et al, 1994

The use of recycled wastewater and returned plastic concrete in the production of fresh concrete was investigated by Borger et al. Mortars with wastewater of different ages were tested. They concluded that wastewater can be successfully used for producing fresh concrete. When wastewater with an age of 8 hours or less was used, strength of the mortars increased. The use of wastewater increased the sulfate resistance and stiffness of the mortars. The use of wastewater accelerated setting times. They also tested mortars in which a stabilizer agent was used. They concluded that: a) compressive strength remained the same or was increased, b) high dosages of activators were required to achieve setting times similar to control mix, c) high dosages of activator did not affect strength, and d) the final workability was similar to that of normal mortars.

Lobo, et al, 1995

A study on the reuse of plastic concrete and wastewater using extended set-retarding admixtures was conducted by Lobo et al. Setting time, compressive strength and drying shrinkage were determined. They concluded that concrete containing stabilized concrete could be used for applications where setting time is less critical. When 5% treated wastewater was used in the mix, compressive strength and drying shrinkage was not significantly effected. When 50% recycled and stabilized concrete (3 hours old) was used in the mix, strength was reduced and shrinkage was increased.

Souwerbren C., 1996

This author gives an overview of the situation in the Netherlands concerning the recycling of wastewater based on the two studies mentioned above. The European standard CEN TC104 (draft) for mixing water and the reuse of wastewater as part of the mixing water is also discussed. According to the European standard the additional quantity of fines resulting from the use of wastewater should be less than 1% by weight of the total amount of aggregate present in the mix. It is also good practice to distribute solid material present in the water as evenly as possible by means of an agitator. When sedimentation basins are used, the water should be left in the basin for sufficient time to allow the solids to settle properly. The following requirements are set for wastewater:

a) Wastewater shall meet the requirements for mixing water for concrete

b) The wastewater in storage shall be adequately protected against contamination

c) Wastewater with a density greater than 63 lb/ft^3 shall be agitated in such a way that a uniform distribution of the solid material is ensured. Wastewater with a density less than or equal to 63 lb/ft^3 may be assumed to contain negligible amounts of solid materials.

Harr, et al, 1997

Harr's research dealt with the analysis and "rheological" effects of residual water from various ready mix plants which showed strong stiffening effects in ready mix concrete as well as a reduction of compressive strength in hardened concrete. The amount of solid material in residual water was determined and an analysis of solids and liquids was conducted. Results of the tests showed that these residual waters contained up to 300 grams of solids per liter. Solid materials detected were primarily cement particles. Tests also showed that higher temperatures combined with contaminated water result in a product that cannot be finished any longer. Harr recommended that solid material in residual water be limited to less than 100 grams per liter.

Reclaimed Sewage Water Used as Mixing Water for Fresh Concrete

Cebeci et al, 1989

The reuse of sewage water as mixing water in concrete was investigated by Cebeci et al. Raw and biological treated sewage water were obtained from a water treatment plant. Treatment of the sewage water consisted of screening and sedimentation followed by passing through different units such as aeration tanks (in which microorganisms are grown that consume soluble organics), and sedimentation tanks that settle and remove the microorganisms. Water analyses showed that suspended solids and organic content are substantially reduced by this treatment, dissolved solids were only marginally reduced. Mortars and concrete samples were made with treated and untreated sewage water, mortars and concrete made with distilled water was used as a reference. Results showed only a marginal increase in initial setting time when treated sewage water was used. When raw sewage water was used initial setting time increased 10 minutes. Air content and specific gravity of the mortars made with distilled water and treated wastewater were the same, the use of raw sewage water entrained 3 percent additional air. Distilled water and treated wastewater produced mortars with practically equal compressive and flexural strengths. When raw sewage water was used, the 3 day compressive strength was reduced by 9 percent. Strength tests performed on concrete confirmed these results. The use of treated sewage water did not affect the compressive strength of the concrete. When raw sewage water was used, the 28 day compressive strength was reduced by 9 percent. The authors concluded that treated sewage water could successfully be reused as mixing water for fresh concrete. Although properties of mortars and concrete made with untreated sewage water remained within acceptable limits (90%), the authors recommended not using untreated sewage water.

Tay et al. 1991

The effect of reusing reclaimed sewage water on concrete properties was investigated by Tay et al. Sewage waters coming from the sewer system in Singapore were treated in an industrial sewage wastewater treatment plant. The treatment consisted of coagulation, flocculation, sedimentation, filtration, aeration, and chlorination. Water analyses showed that these reclaimed waters are of lower quality than potable water. Concrete cubes of 100 mm were used to study the effect of these reclaimed waters on concrete strength. Several batches of concrete containing 25%, 50%, 75%, and 100% of reclaimed wastewater in the total mixing water were tested. A mix with 100% potable water was used as the reference. Compared with the reference, an increase of compressive strengths was observed for increasing percentages of reclaimed wastewater. The increase in compressive strength after 28 days was 8% and 17% for 25% and 100% reclaimed wastewater, respectively. For concrete of ages three months and beyond, the effect was found to be insignificant, yielding results similar to concrete made with potable water. The same study was repeated later, in 1991, showing the same results. In this second study, it was also reported that slump, initial, and final setting times of the concrete was not affected by the use of reclaimed sewage water.

Environmental Effects of Ready-Mixed Concrete Production

Environmental Science & Engineering, Inc., 1994

This firm analyzed wastewater at 10 concrete batch plants in Florida for the Florida Concrete & Products Association and Florida Department Of Environmental Protection. For these plants, surface water of retention ponds, and underground water were tested for bioassay, lead, sulfate, specific conductance, pH, chromium and formaldehyde. Underground water was tested using three wells per plant, one up gradient, one close to the wastewater pit and one down gradient to groundwater flow. The plants were selected such that they represent various plant configurations around the state. They had a variety of soil, hydrogeologic and climate conditions, and different concrete batch plant operational procedures. From the results of water tests, they concluded that neither underground water nor surface water are significantly impacted by batch plant operations.

Mathews, et al, 1996

The characteristics of road deicers produced from recycled water-plant residuals (coming from a sewage wastewater treatment plant) and cement waste products were examined by Mathews et al. Cement waste and water plant sludge were proposed as low cost sources for calcium and magnesium acetate. According to the study, deicers made from these products cause less damage to the environment and infrastructure than sodium chloride. They concluded that deicers made from water plant sludge have the highest potential in terms of ice melting rate and penetration. Cementitious waste products could also be used but larger quantities are required for the same results.

CHAPTER 3

A SURVEY OF STATE HIGHWAY AGENCIES

Introduction

A survey of state highway agencies (SHA) was performed to determine their policies toward the use of wastewater as mixing water, and to collect information on any existing standards or guidelines on this subject (see Appendix A for a sample of the questionnaire). The survey was distributed to the Department of Transportation's Materials Engineer for each state and Puerto Rico (51 total), of the 51 departments contacted, 42 responded (82% response rate).

Results of the Survey

Of the 42 state agencies that responded to the survey, ten states indicated that they allowed the reuse of wastewater in the production of fresh concrete. At the time of the survey, six state agencies were considering allowing the reuse of wastewater in the future. The remainder of the state agencies (26) did not allow the reuse of wastewater at that time. Table 3-1 presents the number of states that allow or do not allow the reuse of wastewater in the production of fresh concrete. It also indicates if any of these SHA currently have any standards to govern the reuse of wastewater.

Table 3-1. Results of SHA Regarding the Allowance and Associated Standards For the Reuse of Wastewater in the Production of Fresh Concrete

Question	Responses		
	Yes	**No**	**Under consideration**
Is the reuse of wastewater as mixing water in the production of new concrete allowed by your agency?	10	26	6
Does your agency currently have any standards for the reuse of wastewater as mixing water in new concrete?	9	33	-

Table 3-2 presents the reasons why the 26 state agencies responding did not allow the reuse of wastewater in the production of fresh concrete. The main reasons given by these SHA are:

- possible contamination and uncertainty about chemical content of the wastewater
- wastewater is not yet considered to be a problem
- conflict with current specifications
- variability of the wastewater

Table 3-2. Reasons Why SHA Do Not Allow Wastewater as Batch Water in Fresh Concrete

Reason	Responses
Concern about contaminants in the wastewater	7
Wastewater is not considered to be a problem yet	7
Conflict with current specification	4
Concern about variability of the water	3
Concern about alkalinity	2
Would not like to introduce extra uncertainty	1
More research on subject needs to be done.	1
No specific reason	1

The SHA that currently allow the reuse of wastewater all have different policies governing its reuse. Three of these policies allow the reuse of wastewater but have set some limitations on the percentage of wastewater that may be reused in the total mix. They also specified which applications wastewater may not be used for. Four SHA refer to their current specifications and say that wastewater can be reused as long as it meets these specifications. Two SHA currently allow the use of stabilizer agents to hold Type II wastewater overnight. Table 3-3 summarizes the specifications and comments of the SHA that allow reuse of wastewater.

Table 3-3. Specifications and Comments of the SHA That Allow Wastewater Reuse

Specification	**Responses**
Refer to existing specification	4
Not to be used in structural decks	2
Limitations on amount of wastewater used	2
Min. and Max. outdoor temperature of application	1
Stabilizers are allowed to hold the wastewater or concrete overnight	2

From the six SHA that currently are considering reuse of wastewater, four indicated that they have conducted studies to examine the effect of wastewater on concrete properties. Their major concern seems to be the variability in the chemical content of the wastewater and the effect this may have on quality control. Frequent testing, approval of specific plants and treatment of wastewater are among the solutions suggested by these agencies to deal with these uncertainties. Table 3-4 presents some of these comments.

Table 3-4. Comments of the SHA That Are Considering to Allow Wastewater Reuse

Comments	Responses
Will require frequent testing of the water	2
Will allow only after approval of specific plants	1
Recommend or require specific treatment of the water	2
Concern about variability of the water	1
Concern about alkalinity	1

Analysis of Survey Responses

The high response rate of 82 % indicates there is a broad interest in the issue of recycling wastewater in the production of fresh concrete. From the six SHA that currently are considering the reuse of wastewater, four indicated that they have conducted studies to examine the effect of wastewater on concrete properties. Their major concern seems to be the variability in the chemical content of the wastewater and the effect this may have on quality control. Frequent testing, approval of specific plants, and treatment of wastewater are among the solutions suggested by these agencies to deal with these uncertainties.

The SHA that currently allow the reuse of wastewater have different policies. Three of them allow the reuse of wastewater but have set some limitations on the percentage of water that may be reused in the total mix. They also specified which applications wastewater may not be used. Four SHA refer to their current specifications and say that wastewater can be reused as long as it meets these specifications. Two SHA currently allow the use of stabilizer agents to hold Type II wastewater overnight.

CHAPTER 4

A SURVEY OF FLORIDA READY-MIX CONCRETE PRODUCERS

Introduction

A survey was developed to collect data regarding source, quantity, quality, and handling of wastewater from ready-mix concrete facilities in Florida (see Appendix B for a sample of the questionnaire). The survey was distributed among ready-mix concrete production companies around the state that are members of the FC&PA. Each response represents the company's data for an average plant's concrete production. A total of 13 surveys were returned.

Survey Results

Table 4-1 represents the number of companies responding to the survey who currently recycle Type II wastewater. Of the 13 survey responses, 10 replied that they do recycle Type II wastewater in some manner. This number shows the level of interest of the ready-mixed concrete industry on the topic of wastewater and their dedication to dealing with it properly.

Table 4-1. Results of the Concrete Producers Survey Regarding the Recycling of Type II Wastewater

Question	Number of Responses	
	Yes	No
Does your company recycle type II wastewater?	10	3

Companies were questioned about how they recycle wastewater and were also asked to supply sketches and brief descriptions of their recycling systems. All companies responding claimed to use some type of closed loop multi-weir system where the wastewater was collected in a series of settling ponds to remove the suspended solids. See Appendix C for a typical concrete plant layout and recycling system design. A number of different methods for the water's reuse after the solids are removed were presented. Table 4-2 represents company applications for recycled wastewater. Some companies responded with more than one use for their recycled wastewater. Of the companies who do recycle wastewater, the most popular application mentioned for its reuse was to wash out the inside of the concrete mixer drums. Using recycled wastewater to spray on aggregate piles was the second most popular response. Batching concrete and cleaning the production plant and truck exterior were also mentioned as applications for the wastewater.

Table 4-2. Applications for Recycled Wastewater

Application	Number of Responses
Wash Out Inside of Concrete Mixer Drum	8
Aggregate Spray	6
Concrete Batch Water	4
Wash Plant and Truck Exterior	1

Companies were then questioned on whether or not they have performed any chemical or physical tests on their Type II wastewater to determine if it complies with the FDOT's specifications or ASTM C94, *Specification for Ready-Mixed Concrete*. They were also asked to provide a copy of these test results if possible. Four out of the thirteen companies responding said they have tested their water to see if it met specifications but none of them provided a copy of the results.

Table 4-3 represents suggestions, based on individual company experience, concerning the best way to handle the large amount of Type II wastewater. The majority of the concrete producers feel the best way to reuse wastewater is by batching fresh concrete with it and/or using it to spray aggregate piles. These results show the industry's concern for the reuse of wastewater and their desire to recycle it, to become a cost reducing resource and an environmentally safe solution. The most popular method mentioned to recycle the wastewater is the use of reclamation units or settling ponds. One interesting response for the use of recycled wastewater is to suppress dust in the concrete plant.

Table 4-3. Company Opinions on the Best Way to Handle Type II Wastewater

Response	Number of Responses
Concrete Batching Water	7
Reclamation Units/ Settling Ponds	5
Mixer Drum Wash	4
Aggregate Spray	3
Limit Amount Generated	2
Dust Suppressant on Plant Roads	1

Table 4-4 summarizes questions from the survey concerning the amount of concrete produced and the quantity of water used for different applications. Based on these responses the average concrete produced at ready-mix concrete plants in Florida was 340 cubic yards per day (CY/Day). Since responses were in a range format, the average was calculated by using 100 Cy/Day, 300 Cy/Day, and 500 Cy/Day for the ranges 0-200 Cy/Day, 200-400 Cy/Day, and 400+ Cy/Day, respectively. The average amount of water used per day was approximately 21,000 gallons with the greatest portion of this being used as mixing water.

Table 4-4. Average Daily Quantity of Water and Its Uses

Survey	Avg. Concrete Production CY/Day	Water Use					
		Concrete Production Gallons/Day	Aggregate Spray Gallons/Day	Mixer Drum Wash Gallons/Day	Other Gallons/Day	Total Gallons/Day	Total Gallons/ Cubic Yard
1	300	12,000				12,000	40
2	500	14,000				14,000	28
3	100	3,000	8,000	1,200		12,200	122
4	300	6,000	600	3,000		9,600	32
5	500	20,000	2,000	6,000	2,000	30,000	60
7	500	10,300	9,720	7,400	500	27,920	56
8	300	7,500	9,000	13,000	8,000	37,500	125
9	300	10,625		1,875		12,500	42
12	300	8,000	10,000	3,000	10,000	31,000	103
Average	**344**	**10,158**	**6,553**	**5,068**	**5,125**	**20,747**	**68**

* Some surveys excluded due to incompatible data

Figure 4-1 represents the different water uses at concrete plants and their respective contribution to the total amount of water used. Although the amount of Type II wastewater produced by the cleaning of the mixer drums is large, it can be seen that the amount needed to spray aggregate and batch concrete is large enough to consume this water if it were reused in these applications, thus alleviating the problem. Other water uses mentioned in the survey responses included: washing the production plant and equipment exterior, controlling dust, and to filling the truck water tank.

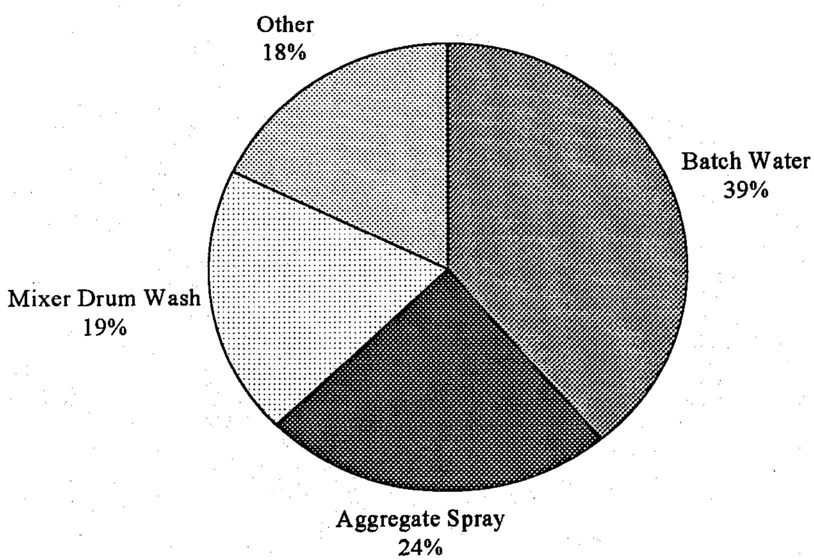


Figure 4-1. Water Applications

Table 4-5 represents survey responses pertaining to whether or not the FDOT allows the use of Type II wastewater in certain applications in the concrete production process. Less than half of the companies responded that they are allowed to use wastewater to saturate their aggregate piles. The number of responses claiming to be allowed to use wastewater in any manner is surprisingly low considering that 10 out of 13 companies claimed to recycle their wastewater.

Table 4-5. Florida Department of Transportation Wastewater Allowances

Response	Type II Wastewater Use		
	Concrete Batching Water	Aggregate Spray	Other
Allowed	1	5	1
Not Allowed	10	6	10
Don't Know	2	2	2

The final question of the survey asked the respondents to give any comments or suggestions that would help solve the problems faced by the ready-mix concrete industry regarding the handling of Type II wastewater. The following is a summary of their responses:

- "The Chappy Concept": concentrate all Type II wastewater in one location at the high point of the plant so storm water doesn't mix with it.
- "Both clarified Type II and slurry water need to be approved for FDOT applications. According to our results, the clarified water meets the ASTM C94 specifications, but not the FDOT specifications."
- "The FDOT should allow the use of Type II wastewater for aggregate spraying and concrete production. No qualified testing to date has shown any negative impact on the quality of ready-mix concrete when using Type II wastewater."
- "The Ready-Mix Industry, FDOT, and other regulatory agencies should form a task force to seek agreed uses for Type II wastewater."
- "The recycling of Type II wastewater through batching, stockpile irrigation, and truck washout is paramount. Continuing the open dialogue and cooperation that

exist between the concrete industry and federal, state, and local regulatory agencies will no doubt lead to a suitable solution."

- "Type II wastewater should be used for spraying aggregate piles and batching for FDOT projects with criteria set for water standards."

Analysis of Survey Responses

The environmental impact of wastewater discharge has been realized and regulations have been enacted. The industry has begun to meet the state's requirements for wastewater handling with multi-weir reclamation systems and now feel the need to be permitted to reuse it. The comments from the concrete production industry reiterate their desire and faith in the incorporation of wastewater into the production of concrete as an aggregate spray, as a batching water, or any other application deemed acceptable. The survey shows that recycling wastewater is a suitable solution to the problem as long as it can be shown that wastewater reuse has no detrimental effects on concrete properties. Results show that the quantity of water needed to batch concrete and to spray on aggregate piles is large enough to incorporate all the wastewater produced. The Florida Department of Environmental Protection has determined there is a need to handle Type II wastewater, the Ready-Mix Concrete Industry has shown its willingness to recycle it, now the task at hand is to prove its feasibility as a mix water complement or substitute having no detrimental effects on concrete properties.

CHAPTER 5

WATER SAMPLING & ANALYSES

Introduction

For the purpose of this study, a water sampling and analysis test plan was designed to determine the chemical properties of typical Type I and Type II wastewater being produced at ready-mix concrete plants in Florida. The Florida Concrete and Products Association (FC&PA) provided a list of concrete plants currently operating in Florida. It is believed that wastewater management systems will be the standard in the future and therefore the list was restricted to plants that are currently utilizing wastewater retention and management systems in accordance with the DEP's general permit for the handling of Type II wastewater. This list of ready-mix concrete plants was then analyzed and 10 plants were selected to be tested. At least one site was selected to represent each of the seven districts in Florida. Sites were also selected in order to represent several different companies. Table 5-1 gives a list of these 10 sites and is followed by a summary of several of the sites. The water samples were tested for properties that are limited by regulation and/or considered detrimental when used in the production of concrete including:

- total alkalinity
- sulfate content
- chloride content
- total solids
- total inorganic solids
- total alkalis
- total volatile solids

Testing of the water samples was performed by QST Environmental (see Appendix D).

Table 5-1. Water Sampling Sites

Company	Site	District
Ewell Industries	Davenport	1
Florida Rock Industries	Starke	2
CSR Rinker	St. Augustine	2
Florida Mining & Materials	Tallahassee	3
Continental Concrete	Riviera Beach	4
Florida Rock Industries	Clermont	5
Tarmac America	North Miami	6
Ewell Industries	Zephryhills	7
Florida Mining & Materials	Winter Park	7
Florida Rock Industries	Tampa	7

Description of Water Sampling Sites

The following is a description of several ready-mix concrete plants that were sampled. These sites are considered to be typical of those in accordance with the DEP's general permit for handling of Type II wastewater.

Starke

Florida Rock Industries
311 Edwards Road
Starke, FL. 32091

Plant description & layout: The Starke plant is a medium size plant with a capacity of approximately 8 trucks. The plant site is only partly paved with concrete. The inside of the trucks' mixer drums are cleaned with recycled Type II wastewater. A multi-weir system consisting of 2 settling ponds is used to recycle the Type II wastewater. Type II water samples were taken at the point where the pump is located (see figure 5-1). Type I wastewater from cleaning the outside of the trucks and plant equipment is retained in a separate pond. This water is then reused to clean the outside of the trucks and to fill the truck's water tank. Type I wastewater samples were collected at the point where the pump is located (see figure 5-2).

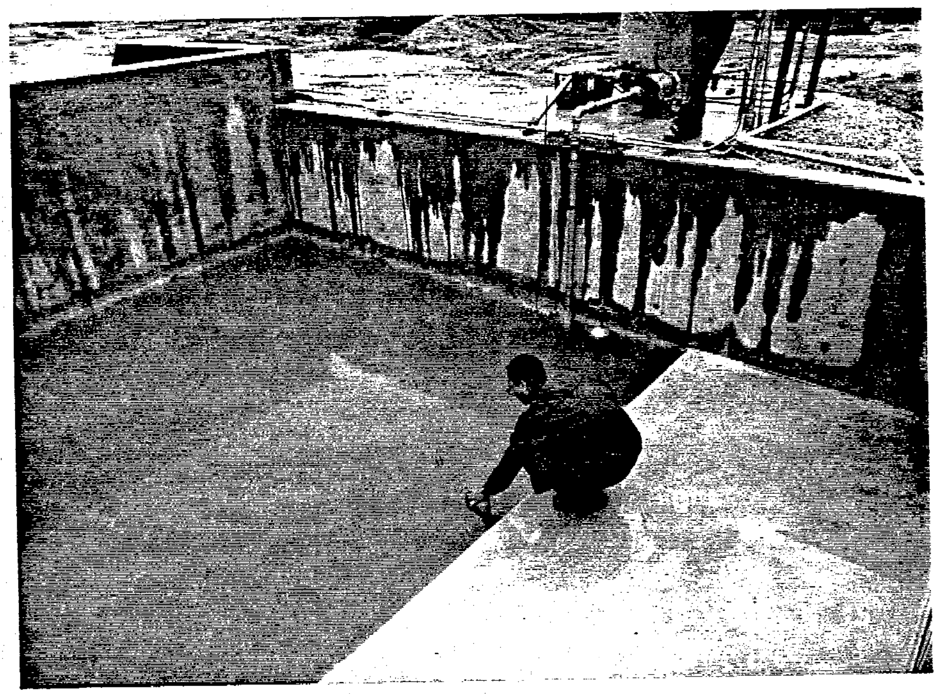


Figure 5-1. Sampling Type II wastewater at the Florida Rock ready mixed concrete plant in Starke, FL.

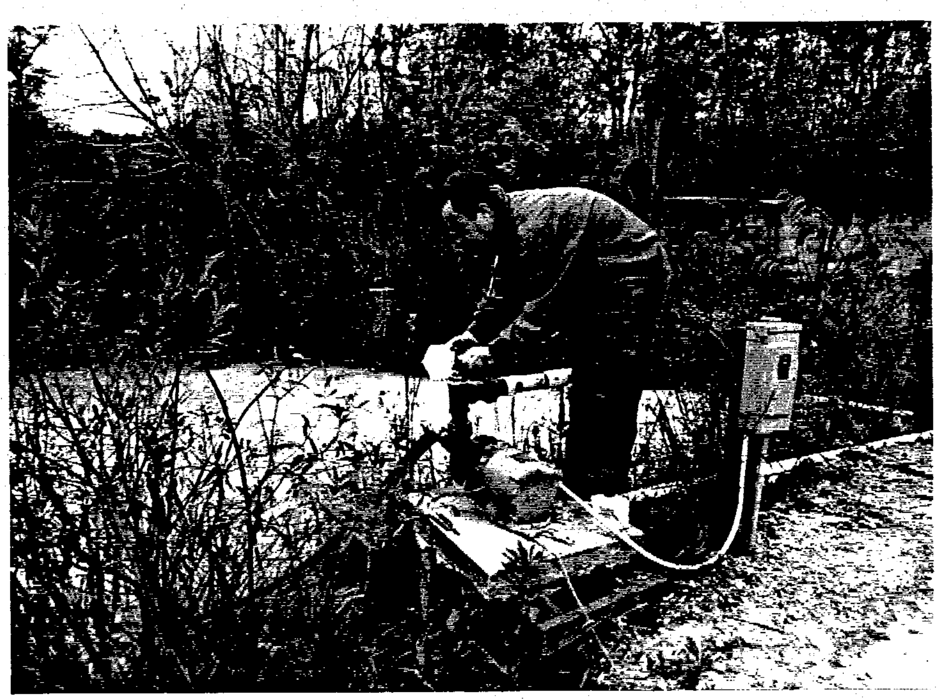


Figure 5-2. Sampling Type I wastewater at the Florida Rock ready-mixed concrete plant in Starke, FL.

Davenport

Ewell Industries
115 Lem Carnes Road
Davenport, FL. 33837

Plant description & layout: The Davenport plant is a medium size plant with a capacity of approximately 8 trucks. The plant site is paved with concrete. The inside of the trucks' mixer drums are cleaned at a separate location at the plant with recycled Type II wastewater, which is collected and recycling in a multi-weir system consisting of 3 settling ponds. Type II water samples were taken at the point where the pump is located (see figure 5-3). No Type I collection pit was present and therefore no Type I wastewater was sampled from this site.

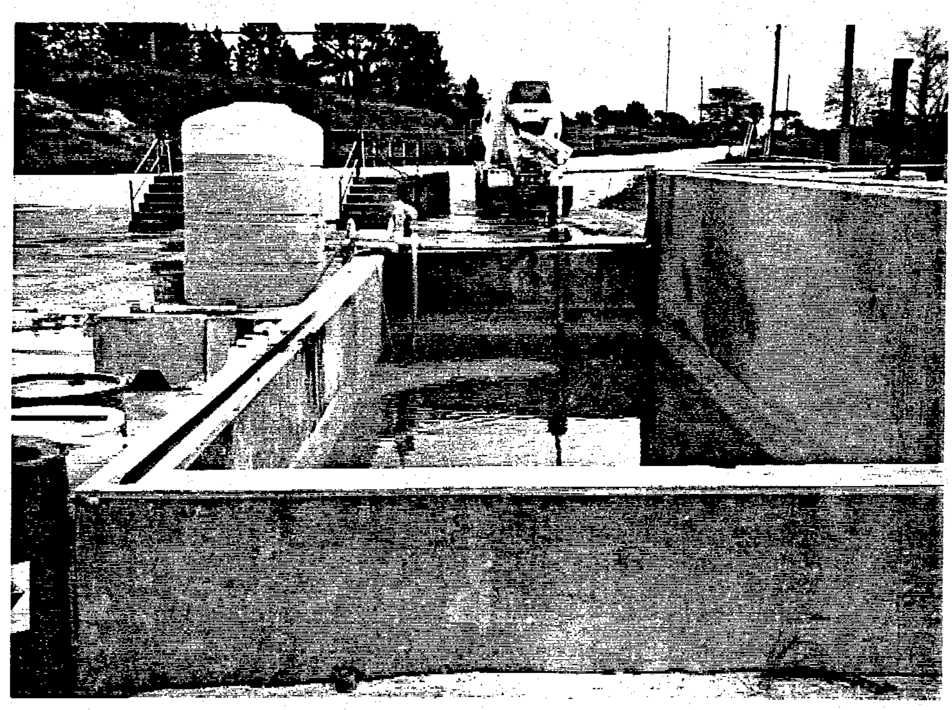


Figure 5-3. Sample location for Type II wastewater from Ewell plant in Davenport, FL.

Tampa

Florida Rock Industries
5609 N. 50th Street
Tampa, FL. 33610

Plant description & layout: The Tampa plant is a relatively large batch plant with a capacity of approximately 20 trucks. The plant site is partly paved with concrete. The inside of the trucks' mixer drums are cleaned at a separate location at the plant with recycled Type II wastewater. A multi-weir system consisting of 3 settling ponds is used to recycle the Type II wastewater. This water is used again to clean the inside of the trucks. Type I wastewater is more or less collected by a set of concrete irrigation channels, these channels finally end up in a larger channel that ends in an unlined pit located at the far end of the plant. The pump is located at the deepest side of the final and largest pond. Type II water samples where taken at the point where the pump is located and Type I wastewater samples were collected from an unlined pit at the end of the property.

Zephyrhills

Ewell Industries
9032 Wire Road
Zephyrhills, FL. 33599

Plant description & layout: The Zephyrhills plant has a capacity of approximately 10 trucks. The plant site is partly paved with concrete. Type II wastewater at this site is collected in a multi-weir system consisting of 4 settling ponds located at the lowest point of the site. Type I wastewater is also collected in this system. Water from this recycling

recycling system is used to clean the inside of the trucks' mixer drums and for aggregate irrigation. The pump is located at the deepest side of the final and largest tier. Type II water samples were taken from the deepest point of the tier prior to the final tier (see figure 5-4) and Type I wastewater samples were taken from the point where the pump is located (see figure 5-5).

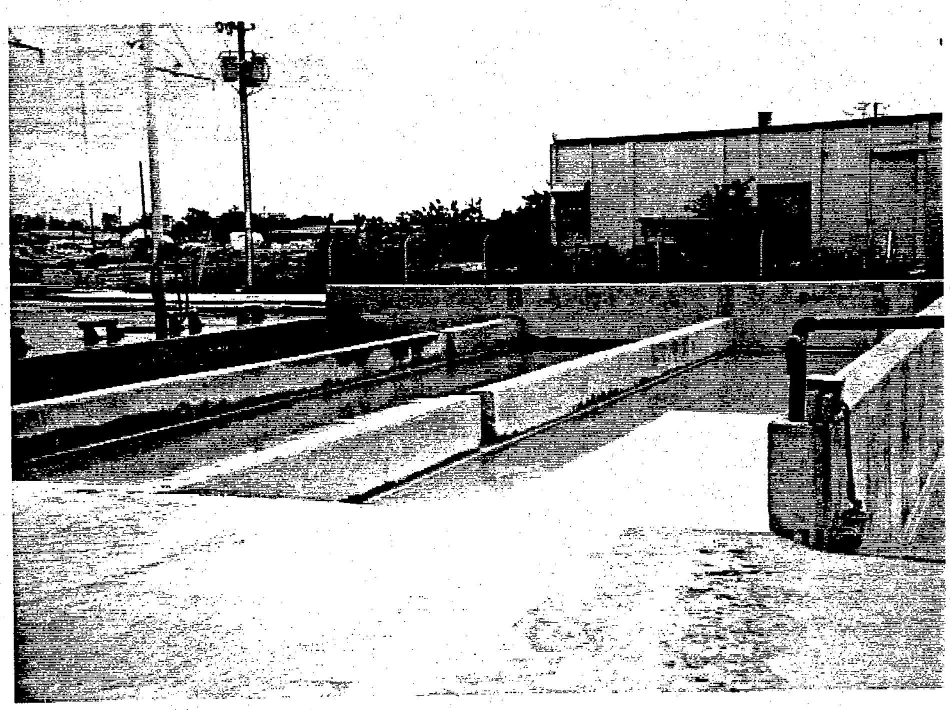


Figure 5-4. Location of Type II wastewater samples from Ewell Industries ready-mixed concrete plant in Zephyrhills, FL.

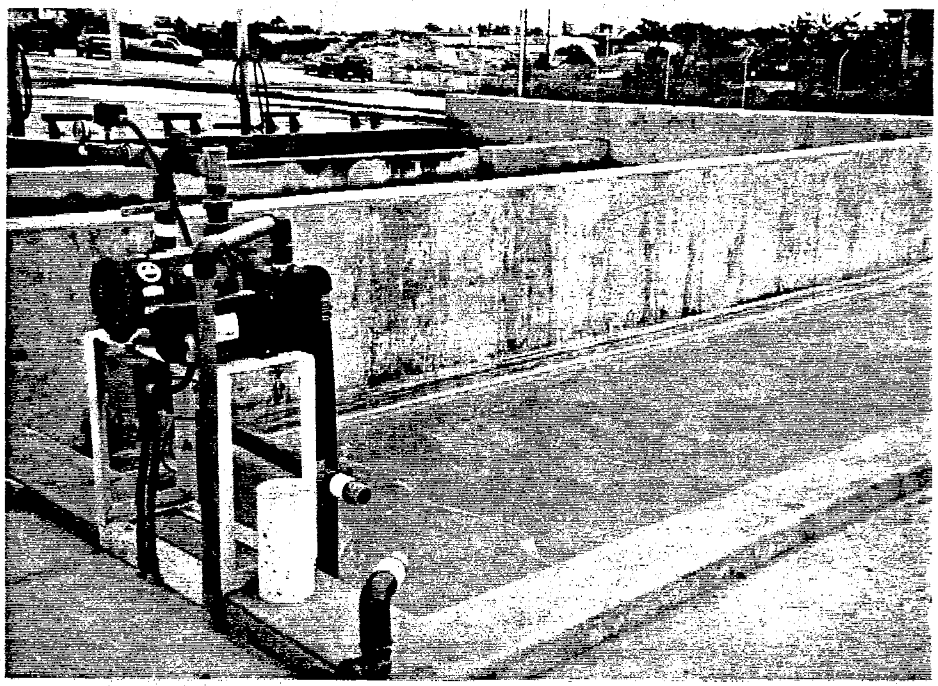


Figure 5-5. Type I wastewater sample location from Ewell plant in Zephyrhills, FL.

Clermont

Florida Rock Industries
15150 Pine Valley Blvd.
Clermont, FL. 32711

Plant description & layout: The Clermont plant is a relatively small and new batch plant with a capacity of approximately 2 trucks. The plant site is completely paved with concrete. Type II wastewater at this site is collected in a multi-weir system consisting of 3 settling ponds (see figure 5-6). The inside of the trucks' mixer drums are cleaned with tap water and collected in this system. From the final pond the water flows into a larger unlined pit and allowed to filter into the ground. Type I water from cleaning the outside of the trucks and cleaning of the plant is collected in two small concrete pits (see figure

5-7). From these two pits the water flows into the same pit as the Type II wastewater. The final unlined pit had an overflow that ended into a small lake located next to the batch plant.

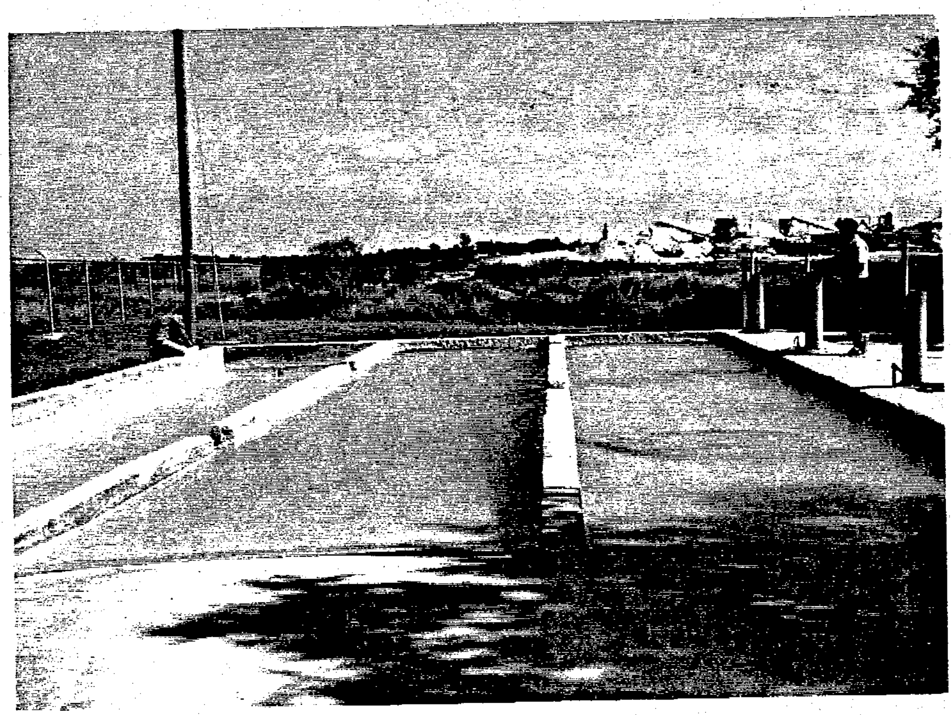


Figure 5-6. Taking a Type II wastewater sample from the Florida Rock ready-mixed concrete plant in Clermont, FL

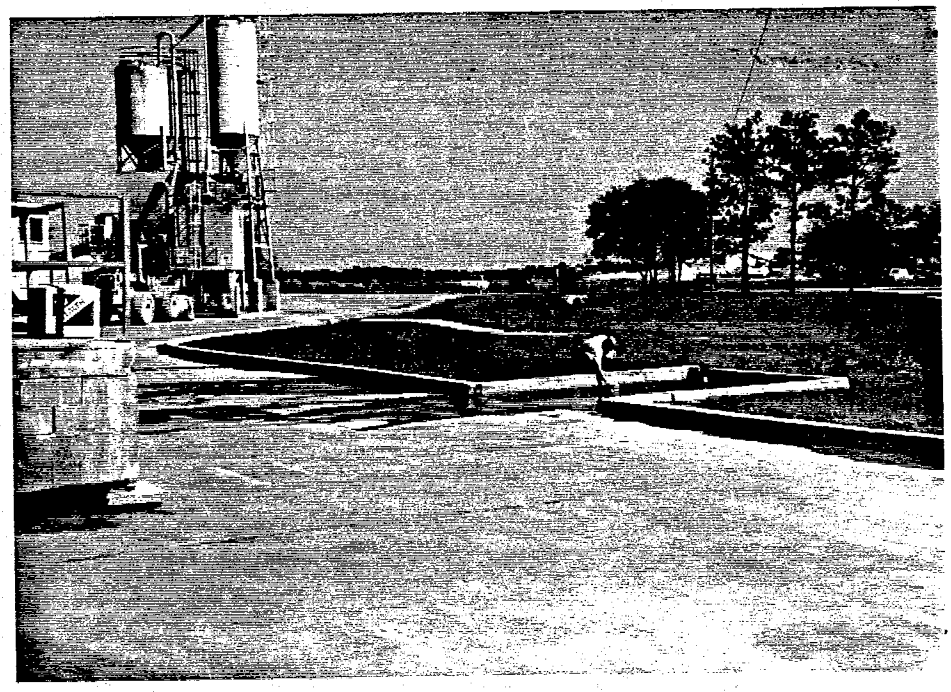


Figure 5-7. Taking a Type I wastewater sample from the Florida Rock ready-mixed concrete plant in Clermont, FL.

Tallahassee

Florida Mining & Materials
901 Mosley Street
Tallahassee, FL. 32304

Plant description & layout: The Tallahassee plant is medium size batch plant with a capacity of approximately 7 trucks. The plant site is completely paved with concrete. Type II wastewater at this plant is collected in a multi-weir system consisting of 3 settling ponds. This water is recycled and used to clean the inside of the trucks' mixer drum. From the final pond the water flows into a larger concrete pond located at the center of the plant where it is combined with Type I wastewater. A pump is installed at a niche of this larger pond. The water extracted by this pump is mixed with tap water and reused as batch water, aggregate irrigation, and to clean the inside and outside of the mixer trucks. Type II wastewater samples were taken at the location of the pump and Type I wastewater samples were taken using the tap water/wastewater mix.

Water Sampling Procedures

When possible, Type I and Type II wastewater samples were collected from each site. Eight Type I wastewater samples and ten Type II wastewater samples were tested. The Type II wastewater samples were collected as close as possible to the location of the water pump in the multi-weir system to most accurately represent the type of water to be recycled in the future. Three water samples of each type of wastewater were collected from each site in 1-liter polyethylene containers. One of the three samples was preserved with 5 milliliters of nitric acid. This sample was used in the determination of metal content in the wastewater. All samples were chilled to 4 degree centigrade to assure the preservation of the sample.

Water Quality Specifications

ASTM C 94, AASHTO M 157, and FDOT Specification Section 923, all outline specifications pertaining to the quality of water to be used in the production of concrete. These specifications give limitations on water quality characteristics such as total alkalinity, sulfate content, chloride content, alkalis, and total solids. Table 5-2 gives a summary of the limitations set forth by these specifications. These specifications are compared to the wastewater samples later in this chapter to determine what wastewater qualities do not meet current regulations. It can be seen from Table 5-2 that the ASTM C 94 and AASHTO M 157 specifications pertaining to water quality have relatively identical limitations, the only difference in the amount of chloride ion allowed. ASTM C94 allows 500 parts per million (ppm), while AASHTO M 157 allows 1000 ppm. The FDOT specification has a similar allowance for chloride (as NaCl), 500 ppm. The FDOT specification has no limitation for sulfate ion and divides solid limitations into inorganic, 800 ppm, and volatile solids, 500 ppm.

Table 5-2. Water Quality Specifications

	Specification		
Chemical Limit (ppm)	**ASTM C94**	**AASHTO M 157**	**FDOT**
Total Alkalinity, as Ca CO_3	-	-	500
Sulfate, as SO_4	3000	3000	-
Total Chloride, as NaCl	-	-	500
Total Chloride, as Cl-	500	1,000	-
Total Solids	50,000	50,000	-
Total Inorganic Solids	-	-	800
Total Volatile Solids	-	-	500
Alkalis, as Na_2O eqv.	600	600	-

Water Analysis Results for Initial 10 Plants

Total Alkalinitys as $CaCO_3$

According to FDOT specifications, the upper limit for total alkalinitys, as $CaCO_3$, is 500 ppm. Three of the eight Type I wastewater samples (38%) and seven of the ten Type II wastewater samples (70%) exceeded the FDOT upper limit for Calcium Carbonate. Values ranged from 47 ppm to 1,040 ppm for Type I wastewater and from 100 ppm to 1,660 ppm for Type II wastewater.

Sulfate as SO_4

Both AASHTO M 157 and ASTM C94 give an upper limit for sulfate content, as SO_4, of 3,000 ppm, FDOT has no limitation for sulfate content. All of the Type I and Type II wastewater samples were below the acceptable limit for sulfates. Values ranged from 8 ppm to 170 ppm for Type I wastewater and from 26 ppm to 521 ppm for Type II wastewater.

Total Chloride as NaCl

The FDOT's upper limit for NaCl content is 500 ppm. All of the Type I and Type II wastewater samples were below the acceptable limit for chloride as NaCl. Values ranged from 7 ppm to 99 ppm for Type I wastewater and from 15 ppm to 120 ppm for Type II wastewater.

Total Chloride as Cl^-

ASTM C94 and AASHTO M 157 give an upper limit for total chloride content, as Cl^-, is 500 and 1,000 ppm, respectively. All of the Type I and Type II wastewater samples were below the acceptable limit for chloride. Values ranged from 4 ppm to 60 ppm for Type I wastewater and from 9 ppm to 73 ppm for Type II wastewater.

Total Solids

ASTM C94 and AASHTO M 157 both give an upper limit of 50,000 ppm for total solids. All of the Type I and Type II wastewater samples fell well below the acceptable limit for total solids. Values ranged from 158 ppm to 1,090 ppm for Type I wastewater and from 264 ppm to 2,190 ppm for Type II wastewater.

Total Inorganic Solids

FDOT specifications give a maximum limit for total inorganic solids of 800 ppm. Two of the eight Type I wastewater samples (25%) and six of the nine Type II wastewater samples (67%) exceeded the limit for total inorganic solid content. Values ranged from 106 ppm to 1,080 ppm for Type I wastewater and from 156 ppm to 2,136 ppm for Type II wastewater.

Total Volatile Solids

FDOT specifications give a maximum limit for total volatile solids of 500 ppm. All of the Type I and Type II wastewater samples were below the acceptable limit for total volatile solids. Values ranged from 10 ppm to 88 ppm for Type I wastewater and from 10 ppm to 108 ppm for Type II wastewater.

Alkalis as Na_2O equivalent

Both ASTM C94 and AASHTO M 157 allow for an upper limit of 600 ppm for alkalis, as Na_2O equivalent. All of the Type I and Type II wastewater samples were below the acceptable limit for alkalis as Na_2O equivalent. Values ranged from 8 ppm to 165 ppm for Type I wastewater and from 30 ppm to 405 ppm for Type II wastewater.

Tables 5-3 gives a summary of the initial water analysis compared to FDOT specifications and 5-4 gives a summary of initial analysis results compared to AASHTO M 157, and ASTM C94 standards.

Table 5-3. Chemical Analysis vs. FDOT Specification

Sample	Total Alkalinity, as $CaCO_3$	Total Chloride, as NaCl	Total Inorganic Solids	Total Volatile Solids
FDOT	500	500	800	500
Starke I	86	28	316	27
Starke II	**1,250**	120	**1,882**	38
St. Augustine I	**1,040**	99	513	32
St. Augustine II	**610**	81	**914**	16
Riviera Beach II	78	35	311	11
North Miami II	100	71	326	11
Tampa I	47	48	222	<10
Tampa II	**1,180**	46	**2,136**	54
Zephyrhills I	**770**	18	**1,080**	<10
Zephyrhills II	**880**	20	**1,320**	<10
Clermont I	82	18	360	16
Clermont II	**890**	28	**1,597**	13
Tallahassee I	137	7	106	52
Tallahassee II	**650**	16	156	108
Davenport I	**950**	16	**982**	88
Davenport II	**1,660**	46	**1,873**	97
Winterpark II	202	15	312	55

Numbers in bold type do not meet FDOT specifications

Table 5-4. Chemical Analysis vs. AASHTO M 157 & ASTM C94

Sample	Sulfate, as SO_4	Total Chloride, as Cl-	Total Solids	Alkalis, as Na_2O eqv.
AASHTO M 157	3,000	1,000	50,000	600
ASTM C94	3,000	500	50,000	600
Starke I	135	17	343	48
Starke II	521	73	1,920	325
St. Augustine I	154	60	545	134
St. Augustine II	135	49	930	281
Riviera Beach II	56	21	322	80
North Miami II	64	43	337	132
Tampa I	69	29	232	82
Tampa II	170	28	2,190	356
Zephyrhills I	170	11	1,090	165
Zephyrhills II	188	12	1,330	183
Clermont I	41	11	376	21
Clermont II	414	17	1,610	288
Tallahassee I	8	4	158	8
Tallahassee II	71	10	264	30
Davenport I	45	10	1,070	157
Davenport II	167	28	1,970	405
Winterpark II	26	9	367	37

<u>Water Analysis Results for Tap Water and Starke & Davenport Type II Wastewater</u>

Of the ten sites sampled and analyzed, two were selected to be used in the study for aggregate irrigation (Phase I) and as batch water (Phase II). The sites selected were the Florida Rock Industries' Starke plant and the Ewell Industries' Davenport plant. These sites were selected based on their wastewater's high degree of total solids and therefore represent a worst case scenario for the plants sampled and are assumed to be representative of Type II wastewater produced at ready-mix concrete plants in Florida. Water samples from these two sites were taken several more times throughout the study to determine any variances. Table 5-5 gives a summary of the Starke Type II wastewater analysis and Table 5-6 gives a summary of the Davenport Type II wastewater analysis. Included in this phase of the water sampling and analysis is a tap water chemical analysis. Results can be found in Table 5-7. This tap water was used as the control water in the concrete testing phase of this study and is discussed further in chapter 6. The tap water samples met all criteria for acceptable water quality in the production of concrete and are thus not considered in the discussion below.

Total Alkalinity as $CaCO_3$

According to FDOT specifications, the upper limit for total alkalinity, as $CaCO_3$, is 500 ppm. All samples were above this limit with the exception of the Davenport sample used in Phase II of the study, which had an alkalinity of 340 ppm. Values ranged from 556 ppm to 1,250 ppm for Starke Type II wastewater and from 340 ppm to 1,660 ppm for Davenport Type II wastewater.

Sulfate as SO_4

Both AASHTO M 157 and ASTM C 94 give an upper limit for sulfate content as SO_4 of 3,000 ppm. The FDOT has no limitation for sulfate content. All samples met the criteria for acceptable sulfate content. Values ranged from 158 ppm to 554 ppm for Starke Type II wastewater and from 89 ppm to 167 ppm for Davenport Type II wastewater.

Total Chloride, as NaCl

The FDOT's upper limit for NaCl content is 500 ppm. All samples met the criteria for acceptable chloride content as NaCl. Values ranged from 58 ppm to 135 ppm for Starke Type II wastewater and from 44 ppm to 55 ppm for Davenport Type II wastewater.

Total Chloride as Cl^-

ASTM C94 and AASHTO M 157 give an upper limit for total chloride content, as Cl^-, is 500 and 1,000 ppm, respectively. All samples met the criteria for acceptable chloride content as Cl^-. Values ranged from 35 ppm to 82 ppm for Starke Type II wastewater and from 27 ppm to 33 ppm for Davenport Type II wastewater.

Total Solids

ASTM C94 and AASHTO M 157 both give an upper limit of 50,000 ppm for total solids. All samples met the criteria for acceptable total solids with a maximum content of 2,400 ppm for the Starke wastewater used in Phase II.

Total Inorganic Solids

FDOT specifications give a maximum limit for total inorganic solids of 800 ppm. The majority of the Starke and Davenport Type II wastewater samples exceeded the limit for total inorganic solid content. Values ranged from 707 ppm to 2,390 ppm for Starke Type II wastewater and from 286 ppm to 1,873 ppm for Davenport Type II wastewater.

Total Volatile Solids

FDOT specifications give a maximum limit for total volatile solids of 500 ppm. All of the Starke and Davenport Type II wastewater samples were below the acceptable limit for total volatile solids. Values ranged from 10 ppm to 363 ppm for Starke Type II wastewater and from 10 ppm to 97 ppm for Davenport Type II wastewater.

Alkalis as Na_2O equivalent

Both ASTM C 94 and AASHTO M 157 allow for an upper limit of 600 ppm for alkalis, as Na_2O equivalent. The Phase 2 Starke Type II wastewater was the only sample above the limit with 709 ppm. Values ranged from 138 ppm to 709 ppm for Starke Type II wastewater and from 270 ppm to 405 ppm for Davenport Type II wastewater.

Table 5-5. Starke Type II Wastewater Chemical Analysis

Chemical Tested	**Test Date**			
	1/5/98	Phase I **2/25/98**	Phase II **5/11/98**	**8/5/98**
Total Alkalinity as $CaCO_3$ (ppm)	**1,250**	**556**	**596**	**610**
Sulfate(ppm)	521	158	554	279
Total Chloride as NaCl (ppm)	120	58	135	75
Total Chloride as Cl- (ppm)	73	35	82	45
Total Solids(ppm)	1,920	1,070	2,400	1,200
Total Inorganic Solids(ppm)	**1,882**	707	**2,390**	**1,154**
Total Volatile Solids(ppm)	38	363	10	46
Total Alkali as Na_20 (ppm)	325	138	**709**	210

*numbers in bold face do not meet FDOT specifications

Table 5-6. Davenport Type II Wastewater Chemical Analysis

Chemical Tested	Test Date			
	1/30/98	Phase I 3/23/98	Phase II 5/12/98	7/29/98
Total Alkalinity as $CaCO_3$ (ppm)	**1,660**	**790**	340	**888**
Sulfate(ppm)	167	108	137	89
Total Chloride as NaCl (ppm)	46	52	44	55
Total Chloride as Cl-(ppm)	28	32	27	33
Total Solids(ppm)	1,970	1,340	1,110	380
Total Inorganic Solids(ppm)	**1,873**	**1,330**	**1,061**	286
Total Volatile Solids(ppm)	97	10	49	94
Total Alkali as Na_20 (ppm)	405	270	367	403

*numbers in bold face do not meet FDOT specifications

Table 5-7. Tap Water Chemical Analysis

Chemical Tested	(ppm)
Total Alkalinity($CaCO_3$)	36
Sulfate	85
Total Chloride (NaCl)	53
Total Chloride (Cl)	32
Total Solids	286
Total Inorganic Solids	214
Total Volatile Solids	72
Total Alkali as $Na_2 0$	27

Conclusions

It is assumed for this study that the Type II wastewater samples are representative of Type II wastewater produced by the ready mixed concrete batch plants. Therefore it may be concluded that the following characteristics of typical Type II wastewater meet specifications designated by the FDOT, ASTM C94, and AASHTO M 157 pertaining to the quality of water used in the production of concrete:

- Sulfate as SO_4
- Total chloride as NaCl
- Total chloride as Cl^-
- Total solids
- Total volatile solids

In general the samples were below the limit for alkalis as Na_2O equivalent of 600 ppm as designated by ASTM C 94 and AASHTO M 157 One sample was above this limit with an alkali content of 709 ppm. This was the highest measured value throughout the entire study.

The Type II wastewater samples did not meet current FDOT specifications limiting total inorganic solids and alkalinity in the form of calcium carbonate ($CaCO_3$). The FDOT limitation for $CaCO_3$ is 500ppm. The greatest $CaCO_3$ content found in the analysis was 1,660 ppm, more than triple the limit. The FDOT limitation for total inorganic solids is 800 ppm. The greatest for total inorganic solid content found in the analysis was 2,390 ppm, almost four times greater than the limit.

The Type II wastewater samples met all criteria specified by ASTM C 94 and AASHTO M 157 for acceptable water quality for the production of concrete.

CHAPTER 6

TEST MATERIALS AND METHODS

Introduction

The concrete testing portion of the study was split into two phases, Phase 1 and Phase 2. The objective of Phase 1 was to determine the effect on concrete properties when using Type II wastewater to irrigate coarse aggregate in the concrete production process. The concrete in this phase was batched using tap water. The designs in the first phase varied by the type of coarse aggregate used and type of water used to irrigate said coarse aggregate. Aggregate irrigation was accomplished by soaking the coarse aggregate in a 55 gallon drum filled with the pertinent water type.

Phase 2 was designed to determine the effects on concrete properties when using Type II wastewater to both irrigate the coarse aggregate and to batch the concrete. The designs varied by the type of coarse aggregate used and the type of water used to irrigate the coarse aggregate and to batch the concrete.

Each mix in both phases is designated by a two part code. The first part represents the water type and the second part represents the coarse aggregate type. The control water (tap water), Starke Type II wastewater, and Davenport Type II wastewater, are represented by STD, S, and D, respectively. The Brookesville, Oolitic, and Calera coarse aggregates are represented by 005, 090, and 351, respectively. For example, STD-005 designates a mix using Tap water and Brookesville coarse aggregate. Tables 6-1 and 6-2 give a summary of the different mixes performed in Phase 1 and Phase 2, respectively. The control samples produced in Phase 1 were used as a reference to compare to the variable samples in both Phases 1 and 2.

Table 6-1. Phase 1 Mixes

Mix Designation	Coarse Aggregate	Aggregate Irrigation Water Type	Mix Date
STD-005	Brookesville	Tap Water	March 17,1998
S-005	Brookesville	Starke Type II	March 19, 1998
D-005	Brookesville	Davenport Type II	April 2, 1998
STD-090	Oolitic	Tap Water	March 26, 1998
S-090	Oolitic	Starke Type II	March 31, 998
D-090	Oolitic	Davenport Type II	April 7, 1998
STD-351	Calera	Tap Water	April 9, 1998
S-351	Calera	Starke Type II	April 14, 1998
D-351	Calera	Davenport Type II	April 16, 1998

Table 6-2. Phase 2 Mixes

Mix Designation	Coarse Aggregate	Aggregate Irrigation & Batch Water Type	Mix Date
S-005II	Brookesville	Starke Type II	May 21,1998
D-005II	Brookesville	Davenport Type II	May 28, 1998
S-090II	Oolitic	Starke Type II	June 2, 1998
D-090II	Oolitic	Davenport Type II	June 4, 1998
S-351II	Calera	Starke Type II	June 9, 1998
D-351II	Calera	Davenport Type II	June 11, 1998

A typical FDOT project mix design was used in the study. The mixes were designed FDOT Class 1 Concrete having a 28 day compressive strength of 2,500 psi.

The mixes were designed to produce 6.0 cubic feet of concrete, a slump of 3 inches (+/- 3"), and a water-cement ratio 0.50. Tables 6-3 and 6-4 give summaries of the mix designs in Phase 1 and 2, respectively.

Table 6-3. Phase 1 Mix Designs

Material	**Mix Designation**								
	STD-005*	**S-005**	**D-005**	**STD-090**	**S-090**	**D-090**	**STD-351**	**S-351**	**D-351**
Cement (lb.)	76.7	83.5	83.5	83.5	83.5	83.5	83.5	83.5	83.5
Fly Ash (lb.)	19.2	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9
Water (lb.)	45.9	51.2	53.5	53.2	54.7	55.6	53.8	55.4	55.6
Fine Agg. (lb.)	268.0	291.5	291.5	291.5	291.5	291.5	291.5	291.5	291.5
Coarse Agg. (lb.)	352.8	382.8	380.5	377.7	376.2	375.3	425.7	427.9	427.9
Air Entr. (ml)	42.2	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0
Retardant (ml)	84.5	91.9	91.9	91.9	91.9	91.9	91.9	91.9	91.9

* STD-005 was designed for 5.5 cubic feet. All other mixes were designed for 6.0 cubic feet.

Table 6-4. Phase 2 Mix Designs

Material	Mix Designation					
	S-005II	D-005II	S-090II	D-090II	S-351II	D-351II
Cement (lb.)	83.5	83.5	83.5	83.5	83.5	83.5
Fly Ash (lb.)	20.9	20.9	20.9	20.9	20.9	20.9
Water (lb.)	54.1	51.4	57.9	57.7	56.2	53.2
Fine Agg. (lb.)	291.5	291.5	291.5	291.5	291.5	291.5
Coarse Agg. (lb.)	379.9	382.6	373.0	373.2	427.3	430.3
Air Entr. (ml)	46.0	46.0	46.0	46.0	46.0	46.0
Retardant (ml)	91.9	91.9	91.9	91.9	91.9	91.9

Materials

Coarse Aggregate

Three different no. 57 (max. nominal size 1") coarse aggregates were used to represent different regions of Florida. Brookesville Limestone aggregate was supplied by Vulcan Industries to represent Central Florida, Oolitic Limestone aggregate was supplied by Rinker CSR to represent South Florida, and Calera Limestone aggregate was supplied by Vulcan Industries to represent the Panhandle and North Florida. Table 6-5 summarizes the grading characteristics of these aggregates and gives a comparison to the ASTM C33, *Specification for Concrete Aggregates.*

Table 6-5. Grading Characteristics of Coarse Aggregate

Sieve Size	Percent Passing			ASTM C33 Specification
	Brookesville	Oolitic	Calera	
1- ½"	100%	100%	100%	100%
1"	99%	100%	99%	95% to 100%
½"	30%	31%	44%	25% to 60%
No. 4	4%	5%	3%	0% to 10%
No.8	3%	4%	2%	0% to 5%
No. 200	1.4%	-	0.5%	-

The specific gravity and absorption of the coarse aggregates were determined in accordance with ASTM C127, *Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate*. Table 6-6 gives a summary of the results.

Table 6-6. Specific Gravity and Absorption of Coarse Aggregate

Coarse Aggregate	Specific Gravity	Absorption
Brookesville	2.42	2.6%
Oolitic	2.39	3.7%
Calera	2.73	0.4%

Fine Aggregate

The fine aggregate used in the study was Keuka Silica Sand provided by Florida Rock Industries. The fineness modulus was run in accordance with ASTM C 136, *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 6-7 summarizes the grading results for the fine aggregate and figure 6-1 presents this information in a grading curve.

Table 6-7. Grading Characteristics of Fine Aggregate

Sieve Size	Percent Passing	ASTM Specification	Cumulative % Retained, by Weight
3/8"		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)

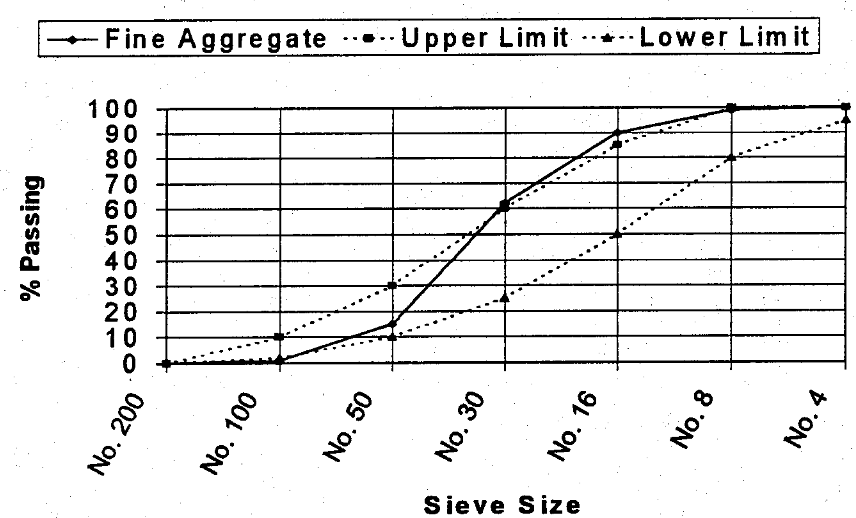


Figure 6-1. Fine Aggregate Grading Curve

Cement

A general purpose AASHTO Type I portland cement supplied by Broco Technologies was used in the production of all concrete test specimens. Table 6-8 gives a summary of the chemical analysis and Table 6-9 summarizes the physical analysis done on the cement.

Table 6-8. Cement Chemical Analysis

Analysis	**%**
Max. Loss on 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 6-9. Cement Physical Analysis

Analysis	
3 Day Strength	3350 psi
7 Day Strength	4720psi
Fineness	208 yd^2/lb
Initial Set Time	170 minutes
Final Set Time	245 minutes
Autoclave Soundness	-0.10

Admixtures

Mineral Admixtures

A Class F fly ash finely divided mineral admixture was used in the mix design to replace 20 percent 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 6-10 summarizes the test report for the fly ash used in this study.

Table 6-10. Fly Ash Test Report

Property	Result
Oxides of Silicon, Iron & Aluminum	85.14%
Sulfur Trioxide	0.3%
Moisture Content	0.7%
Loss on Ignition	3.7%
Specific Gravity	2.02
Autoclave Expansion	-0.03
% Passing 325 Sieve	30%
Strength Activity Index	80%
Percent Water	100%

Chemical Admixtures

The two commonly used, FDOT approved, chemical admixtures used in the study were Darex air-entrainment admixture (DAREX® AEA®) and WRDA®-64 set retarding admixture. The DAREX® AEA® 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. Typical addition rates for DAREX® AEA® range from ¾ to 3 fluid ounces per 100 pounds of cement. Air entraining admixtures increase the air content of concrete resulting in increased workability and durability. The WRDA®-64 is a polymer based aqueous solution of complex organic compounds, which produce a concrete with a lower water content (typically an 8% to 10% reduction), greater plasticity, and greater strength. Typical addition rates for WRDA®-64 range from 3 to 6 fluid ounces per 100 pounds of cement. DAREX® AEA® and WRDA®-64 are both products of Grace Construction Products (see Appendix E).

<u>Water</u>

After analysis of the Type II wastewater samples, it was decided that the wastewater samples with the highest degree of detrimental chemicals would be used in the study as a worst case scenario. For this reason, Type II wastewater from ready-mix concrete batch plants in Starke and Davenport were chosen to be used to soak the coarse aggregate in Phase 1 and as mix water and to soak the aggregate in Phase 2. Tap water from the FDOT State Materials Office in Gainesville, Florida was used as the control water for the study (See chapter 5 for details).

Test Program

A test program was designed to investigate the effects of Type II wastewater on concrete properties. Taking into account past experiments performed on wastewater and concerns stated by the FDOT, a test program was designed to determine the effects of wastewater on both fresh and hardened concrete properties. The following is a brief description of the tests performed. Table 6-11 summarizes the tests.

Compressive Strength

The compressive strength tests were performed according to ASTM C 39, *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"cylinder test specimens were produced for each mix. The compressive strength tests were performed on three test specimens at the ages of 7, 14, and 28 days.

Flexural Strength

The flexural strength tests were performed according to ASTM C 78, *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 36" prism test specimens were created for each mix. The flexural strength tests were performed at the age of 28 days.

Modulus of Elasticity

Modulus of elasticity test were performed by the University of Florida's Civil Engineering Department according to ASTM C 469, *Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression.* The modulus of elasticity is defined as the ratio of stress to strain in the elastic range of a stress-strain curve.

Rapid Chloride Permeability

The Rapid Chloride Permeability test was performed according to ASTM C 1202, *Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration,* to determine the electrical conductance of concrete and to provide an accelerated indication of its resistance to the penetration of chloride ions, which may corrode steel reinforcement or prestressed strands. Two 4" diameter x 8" cylinder test specimens were produced for each mix. The amount of electrical current passing through a 2" slice of the 4"x 8" cylinder test specimen was monitored over a six-hour period. Tests were performed at 28 day ages. It has been determined that the total charge passed is related to the resistance of the specimen to chloride ion penetration.

Drying Shrinkage

Drying shrinkage tests were performed according to ASTM C 157, *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. Three 3"x 3"x 11.25" prism test specimens were produced for each mix. After one day of curing, the specimens were removed from the molds and an initial reading was taken. The test specimens were then cured in lime-saturated water for 28 days. After a 28 day curing period, the specimens were removed from the lime-saturated water and a second length reading was taken. The specimens were then stored in air at a constant temperature and humidity for the remainder of the test period. The specimens' lengths were then measured 1, 2, 4, 8, 13, 20, and 32 weeks after initial air storage.

Sulfate Expansion

The sulfate expansion tests were performed in accordance with ASTM C 1012, *Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution.* This test was used to determine the length change of concrete submerged in a sulfate solution. The test specimens used to perform the tests were 3"x 3"x 11.25" prisms. After 24 hours of curing, the test specimens were removed from the molds and immediately placed in lime-saturated water where they were allowed to cure for 28 days. After 28 days, the test specimens were removed from the lime-saturated water and an initial length reading was taken. The test specimens were then stored in solution of 50.0 grams of sodium sulfate per 900 milliliters of water for the remainder of the testing period. Subsequent length readings were taken 1, 2, 3, 4, 8, 13, and 15 weeks after the initial length reading.

Flexural strength tests were done on two of the sulfate samples for each mix. The tests were run in accordance with ASTM 293, *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)*.

Impressed Current

The time to corrosion tests were performed in accordance with Florida Method 5-522, *An Accelerated Laboratory Method for Corrosion of Reinforced Concrete Using Impressed Current*. The test is an accelerated method of testing reinforced concrete for corrosion resistant properties. Three 4-inch diameter by 5.75-inch long cylinders were produced for each mix. Each test specimen was reinforced vertically with one No. 4 rebar. The top of the cylinder was finished with approximately a 108 taper from horizontal (see Figure 6-2). The impressed current specimens were allowed to cure for one day and then removed from their molds. The specimens were then moist cured for 28 days. The samples were then cured in a 5% NaCl solution for another 28 days. Each test specimen was subsequently attached to a closed circuit power supply of 6 Volts (see Figure 6-3). The current to each specimen was determined by measuring the voltage drop on a daily basis using Ohm's Law. Failure of the test specimens was determined by a visually detectable crack or a large increase in current.

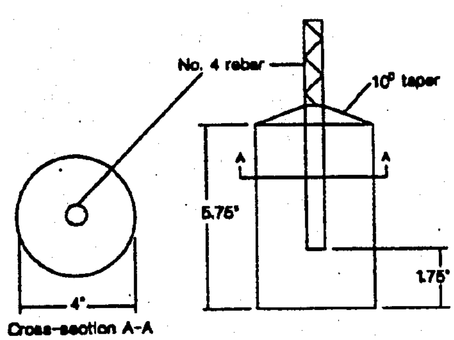


Figure 6-2. Impressed Current Test Schematic

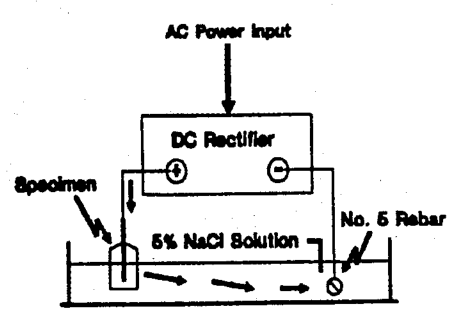


Figure 6-3. Impressed Current Specimen Dimension

Corrosion of Rebar in Concrete

The corrosion of rebar in concrete tests were performed in accordance with ASTM G 109, *Standard Test Method for Determining the Effects of Chemical Admixture on the Corrosion of Embedded Steel Reinforcement in Concrete Exposed to Chloride Environments*. Three 4.5"x 6"x 11" test specimens were produced for each mix (see Figure 6-4). Each specimen was reinforced with three 15" long No. 4 bars. After being removed from the forms, the specimens were moist cured for 28 days. After the curing period the test specimens were ponded using a 3% salt (NaCl) solution . The bottom two bars were then connected with a grounding wire and a 100-ohm resistor was connected to all three bars. The voltage across the resister was measured after 2 weeks and then every 4 weeks until visual corrosion could be seen or the average current in the control specimens was 10μA or greater. The specimens were then broken and the extent of corrosion on the rebar assessed.

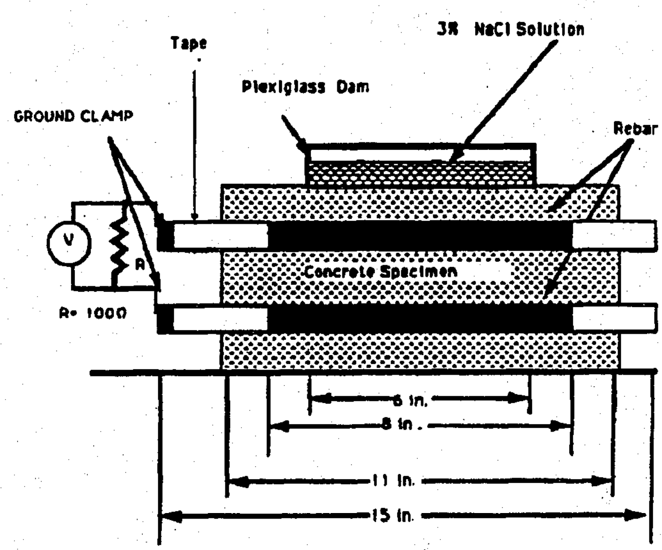


Figure 6-4.
G109 Concrete Beam (side view)

Table 6-11. Hardened Concrete Property Tests

Test	Designation	Sample Size	Number of Samples
Compressive Strength	ASTM C 39	6"x 12" cylinder	8 + 1*
Flexural Strength	ASTM C 78	6"x 6"x 36" prism	2
Modulus of Elasticity	ASTM C 469	6"x 12" cylinder	1
Rapid Chloride Permeability	ASTM C 1012	4"x 8" cylinder	2
Drying Shrinkage	ASTM C157	3"x 3"x 11.25" prism	3
Sulfate Expansion	ASTM C 1012	3"x 3"x 11.25" prism	5
Impressed current	FM 5-522	4'x 5.75" cylinder	3
Corrosion of Rebar in Concrete	ASTM G 109	11"x 6"x 4.5"	3

*1 sample also tested for modulus of elasticity

In addition to these hardened concrete tests, standard fresh concrete tests including slump, set time, unit weight, yield, and air content were also performed at the time the concrete mix was batched. Table 6-12 is a summary of these tests.

Table 6-12. Fresh Concrete Property Tests

Test	Designation	Sample Size
Slump	ASTM C 143	4"x 8"x 12" cone
Set Time	ASTM C 403	6"x 6" prism
Unit Weight	ASTM C 138	1/3 Cubic Foot
Air Content	ASTM C 173	0.075 Cubic Foot

CHAPTER 7

TEST RESULTS

For the purposes of this study, results have been divided into groups of coarse aggregate type. This allows us to compare the effects on mixes using different aggregate irrigation water types (Control, Starke, and Davenport) and all other variables remaining constant. The three coarse aggregate groups are Brookesville (005), Oolitic (090), and Calera (351). Phase 1 utilizes Type II wastewater for aggregate irrigation and Phase 2 for aggregate irrigation and batch water. Results for each phase are presented below.

Phase 1 Results

Slump

The slump tests were run in accordance with ASTM C 143. The objective was to maintain the slump around 2", which permits vibration of beam and prism samples rather than rodding. Water content was adjusted to achieve the desired slump. The majority of the mixes had a slump of 2 inches (see Table 7-4). All mixes were determined to have good workability with the exception of STD-005, which was stiff.

Set Time

The set time tests were run in accordance with ASTM C 403. ASTM C 94 outlines the acceptable criteria for questionable water supplies with regards to set time to be from 1 hour earlier to 1-1/2 hours later than that of the control. Both AASHTO M 157 and FDOT specifications give comparable qualifications for set time. All nine mixes in phase 1 fell within this range. Overall long times of set can be attributed to the set time tests being run in an air conditioned room with a constant temperature of about 72 degree Fahrenheit and the use of a Type D water reducer/retarder.

- *Brookesville*: The control mix (STD-005) in this group had an initial set time of 6 hours 45 minutes and a final set time of 8 hours 30 minutes. The mix using Starke wastewater with Brookesville aggregate (S-005) had little variation from the control mix with initial and final set times of 5 and 10 minutes less than the control mix, respectively. The mix using Davenport wastewater (D-005) had more variation in set time compared to the control mix with initial and final set times of 45 minutes and 60 minutes greater than the control mix, respectively. All mixes in this group were determined to be within the acceptable tolerance for concrete produced with an other than potable water supply.

- *Oolitic:* The control mix (STD-090) in this group had an initial set time of 6 hours 55 minutes and a final set time of 8 hours 45 minutes. The mix using Starke wastewater (S-090) had initial and final set times of 25 minutes and 45 minutes greater than that of the control mix, respectively. The mix using Davenport wastewater had initial and final set times of 20 minutes and 30 minutes greater than that of the control mix, respectively. All mixes in this group were determined to be within the acceptable tolerance for concrete produced with questionable water supplies according to the ASTM C 94.

- *Calera*: The control mix (STD-351) in this group had an initial set time of 8 hours 15 minutes and a final set time of 10 hours 50 minutes. The mix using Starke wastewater (S-351) had initial and final set times of 50 minutes less than that of the control mix. The mix using Davenport wastewater (D-351) had initial and final set times of 15 minutes greater than that of the control mix. All mixes in this group were determined to be within the acceptable tolerance for concrete produced with questionable water supplies according to the ASTM C 94.

In general, the mixes using the Calera coarse aggregate had set times greater than those of using Brookesville or Oolitic coarse aggregate although no absolute correlation can be made. Table 7-1 gives a summary of the set time results and Figures 7-1 and 7-2 give a graphical representation of the initial and final set time results, respectively.

Table 7-1. Set Time

Mix	Initial Set Time	Variance From Control	Final Set Time	Variance From Control	Air Temp.
STD-005	6 hrs. 45 min.	-	8 hrs. 30 min.	-	73° F
S-005	6 hrs. 35 min.	- 5 min.	8 hrs. 20 min.	- 10 min.	72° F
D-005	7 hrs. 30 min.	+ 45 min.	9 hrs. 30 min.	+ 60 min	74° F
STD-090	6 hrs. 55 min.	-	8 hrs. 45 min.	-	71° F
S-090	7 hrs. 20 min.	+ 25 min.	9 hrs. 30 min.	+ 45 min.	75° F
D-090	7 hrs. 15 min.	+ 20 min.	9 hrs. 15 min.	+ 30 min.	72° F
STD-351	8 hrs. 15 min.	-	10 hrs. 35 min.	-	76° F
S-351	7 hrs. 25 min.	- 50 min.	9 hrs. 45 min.	- 50 min.	70° F
D-351	8hrs. 30 min.	+ 15 min.	10 hrs. 50 min.	+ 15 min.	69° F

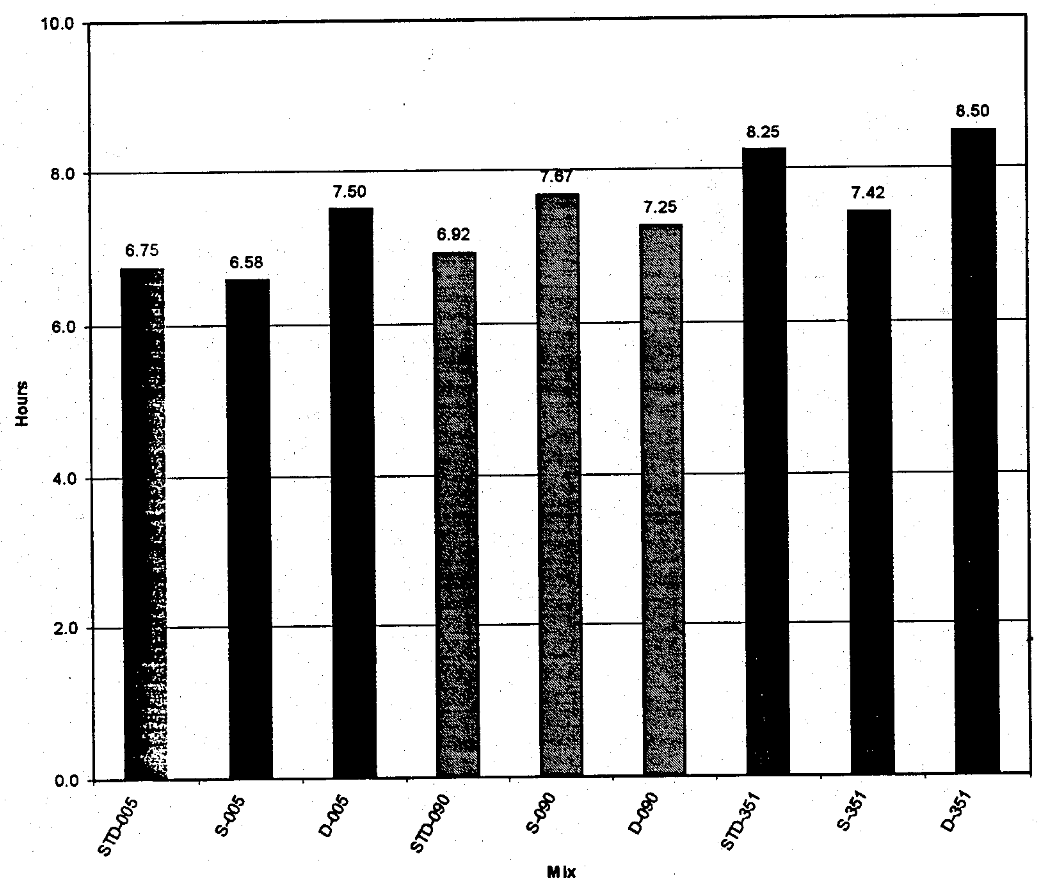


Figure 7-1. Initial Set Time Bar Graph

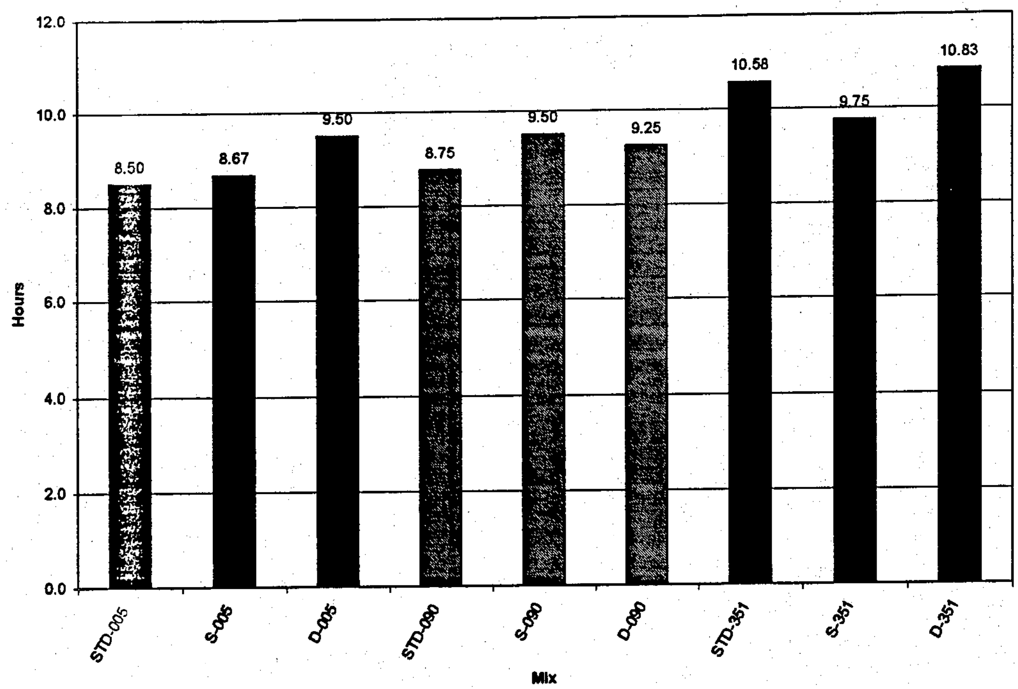


Figure 7-2. Final Set Time Bar Graph

Unit Weight

Unit weight tests were run in accordance with ASTM C 138, *Test Method for Unit Weight, Yield, and Air Content of Concrete*. The unit weights of the mixes ranged from 138.3 lb/cf to 146.2 lb/cf. Table 7-2 and Figure 7-3 summarize the results.

- *Brookesville*: The control mix (STD-005) in this group had a unit weight of 141.9 lb/cf. Unit weights for samples using Starke and Davenport wastewater were both determined to be less than that of the control mix with unit weights of 140.4 lb/cf and 140.0 lb/cf, respectively.
- *Oolitic:* The greatest variance when comparing the unit weights of mixes using the same aggregate and different water types was observed in the mixes containing

Oolitic coarse aggregate. The control mix (STD-090) in this group had a unit weight of 143.8 lb/cf. Both mixes using Starke and Davenport wastewater had much lower unit weights than that of the control mix, 139.4 lb/cf and 138.3 lb/cf, respectively. The variance in this group may be partially attributed to variance in water- cement ratio and air content. However, the high unit weight for STD-090 may be due to an error in reading or recording the weight.

- *Calera:* Mixes in this group were determined to have the highest unit weight. This is due to the higher density of the Calera coarse aggregate than that of the Brookesville and Oolitic aggregates. The control mix in this group had a unit weight of 145.3 lb/cf. Both mixes using Starke and Davenport wastewater had higher unit weights than the control mix, 146.1 lb/cf and 146.2 lb/cf, respectively.

Table 7-2. Unit Weight

Mix	Unit Weight (lb/cf)	Variance From Control
STD-005	141.9	-
S-005	140.4	-1.1 %
D-005	140.0	-1.3 %
STD-090	143.8	-
S-090	139.4	-3.1 %
D-090	138.3	-3.8%
STD-351	145.3	-
S-351	146.1	+0.5 %
D-351	146.2	+0.6 %

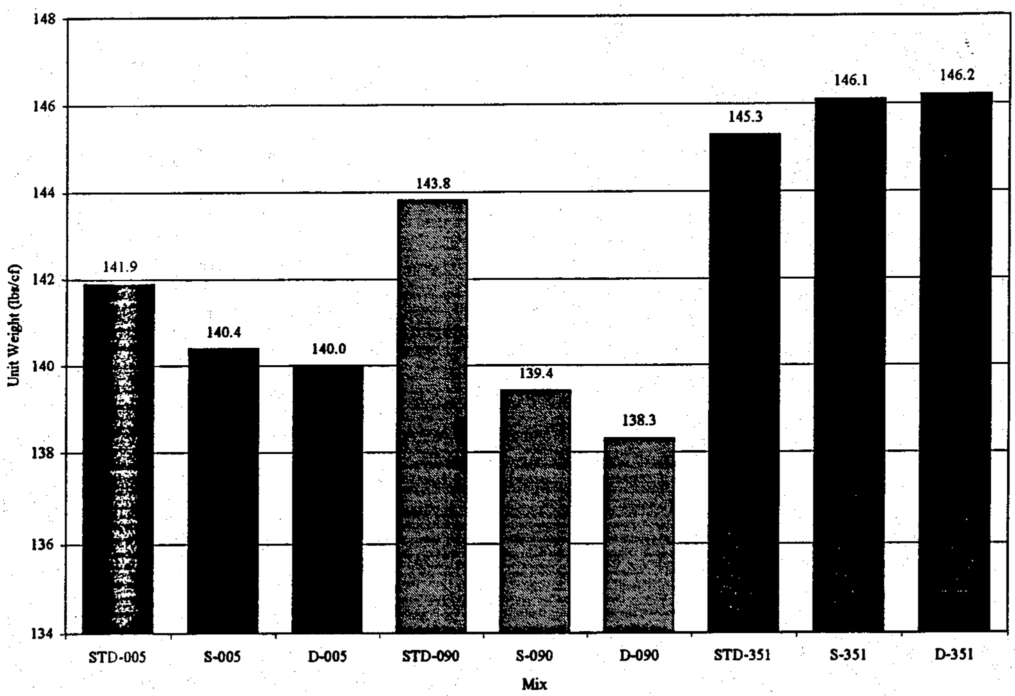


Figure 7-3. Unit Weight Bar Graph

Air Content

Air content tests were performed in accordance with ASTM C 173, *Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method.* The values for this test varied from 3 % air content for STD-005 to 4.6 % air content for STD-351. Table 7-3 and Figure 7-4 summarize the results for air content.

- Brookesville: The control mix (STD-005) for this group had an air content of 3 %. Both mixes using Starke and Davenport wastewater had slightly higher air contents, 3.7 % and 3.2 %, respectively.

- Oolitic: The control mix (STD-090) for this group had an air content of 3.7 %. Both mixes using Starke and Davenport wastewater again had slightly higher air contents, 4.1 % and 4.6 %, respectively.

- Calera: The control mix (STD-351) for this group had an air content of 3.7 %. The mix using Starke wastewater (S-351) had a lower air content, 3.4 %, than that of the control mix. The mix using Davenport wastewater had a higher air content than the control mix, 4.5 %.

Table 7-3. Air Content of Concrete Mixes

Mix	Air Content (%)
STD-005	3
S-005	3.7
D-005	3.2
STD-090	3.7
S-090	4.1
D-090	4.6
STD-351	4.6
S-351	3.4
D-351	4.5

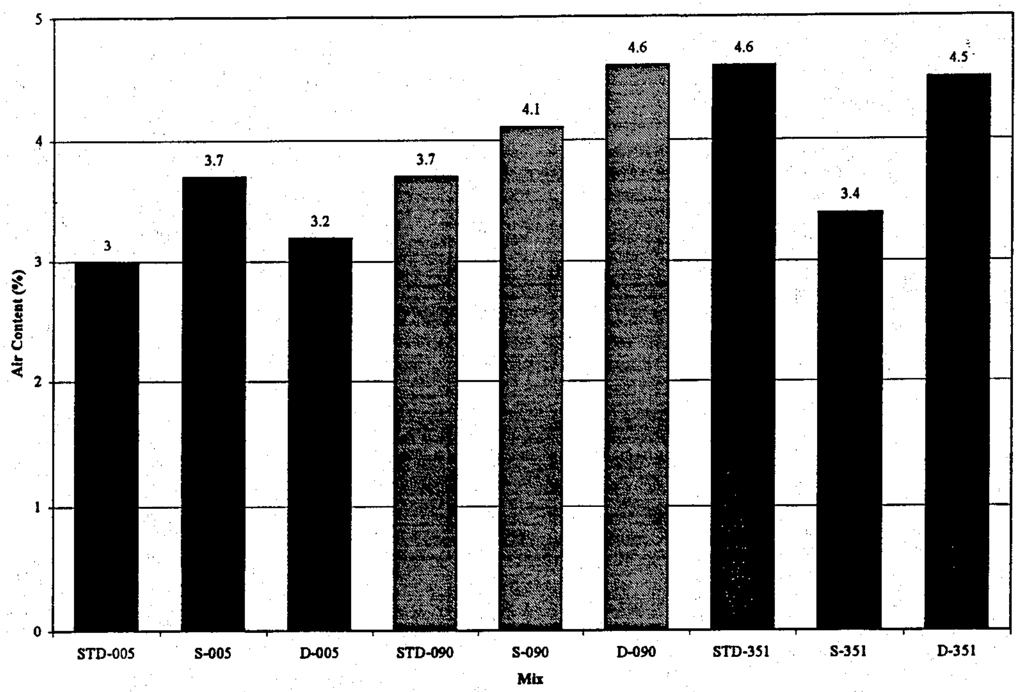


Figure 7-4. Air Content Bar Graph

Table 7-4. Fresh Concrete Test Result Summary

Mix	Test					
	Slump (in.)	Set Time		Unit Weight (PCF)	Mix Temp (°F).	Air Content (%)
		Initial	Final			
STD-005	2.0	6 hrs. 45 min.	8 hrs. 30 min.	141.9	76	3
S-005	2.0	6 hrs. 35 min.	8 hrs. 20 min.	140.4	78	3.7
D-005	2.0	7 hrs. 30 min.	9 hrs. 30 min.	140.0	78	3.2
STD-090	2.0	6 hrs. 55 min.	8 hrs. 45 min.	143.8	76	3.7
S-090	2.0	7 hrs. 20 min.	9 hrs. 30 min.	139.4	76	4.1
D-090	2.0	7 hrs. 15 min.	9 hrs. 15 min.	138.3	74	4.6
STD-351	2.75	8 hrs. 15 min.	10 hrs. 35 min.	145.3	80	4.6
S-351	2.0	7 hrs. 25 min.	9 hrs. 45 min.	146.1	72	3.4
D-351	1.75	8hrs. 30 min.	10 hrs. 50 min.	146.2	74	4.5

Compressive Strength

Results for the compressive strength test are an average of three specimens tested at each interval of 7, 14, and 28 days. The ASTM C 94 acceptance criteria 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 7-5 gives a summary of the water-cement ratio for each mix, which is inversely related to the compressive strength.

Table 7-5. Water-Cement Ratio

Mix	**Water-Cement Ratio**
STD-005	0.54
S-005II	0.55
D-005II	0.54
STD-090	0.51
S-090II	0.52
D-090II	0.52
STD-351	0.50
S-351II	0.49
D-351II	0.47

- Brookesville: The 7 day compressive strengths for the mixes using Starke (S-005) and Davenport (D-005) wastewater were determined to be 3,580 psi and 3,990 psi, respectively, greater than that of the control mix (STD-005), which had an average compressive strength of 3,170 psi. At 14 days the average compressive strength of the Starke wastewater mix (S-005) was lower, 4,080 psi, and the average compressive strength of the Davenport mix (D-005) was higher, 4,440 psi, than that of the control mix, which had an average 14 day compressive strength of 4,230 psi. The 28 day compressive strength test determined the control mix to have the highest compressive strength, 5,130 psi, of the three mixes in this group. The Starke and Davenport mixes had 28 day compressive strengths of 4,750 psi and 5,040 psi, respectively. All of the Starke and Davenport test specimens were within the 90 % strength range designated by ASTM C 94. Figure 7-5 gives a graphical representation of the results and Table 7-6 gives the complete results for the Brookesville group.

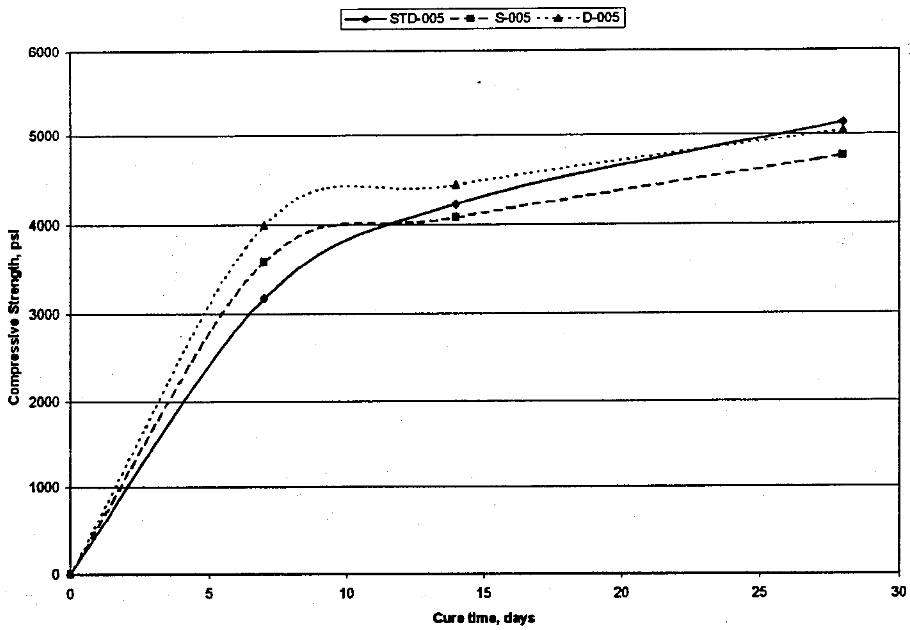


Figure 7-5. Compressive Strength vs. Time with Brookesville Coarse Aggregate

Table 7-6. Compressive Strength of Test Specimens with Brookesville Coarse Aggregate

MIX	STD-005	S-005	D-005
7 DAY COMPRESSIVE STRENGTH (psi)	3240	3660	3950
	2940	3480	3980
	3340	3610	4040
STD. Dev.	208	93	46
Average	**3173**	**3583**	**3990**
14 DAY COMPRESSIVE STRENGTH (psi)	4070	4030	4440
	4360	4100	4590
	4260	4100	4290
STD. Dev.	147	40	150
Average	**4230**	**4077**	**4440**
28 DAY COMPRESSIVE STRENGTH (psi)	5290	4750	4770
	4860	4630	5140
	5240	4880	5210
STD. Dev.	235	125	236
Average	**5130**	**4753**	**5040**

- *Oolitic:* The 7 day compressive strength of the control mix (STD-090) was 4,200 psi. The Starke mix (S-090) had a 7 day compressive strength lower than that of the control mix of 3,940 psi. The Davenport sample (D-090) had a 7 day compressive strength of 3,740, which was the lowest in the group. At 14 days the compressive strengths increased at relatively the same rate. The control mix remained the strongest with a 14 day compressive strength of 4,830 psi with the Starke and Davenport mixes having 14 day compressive strengths of 4,480 psi and 4,140 psi, respectively. The 28 day compressive strength tests determined the Davenport mix to be the weakest of the group with a 28 day compressive strength of 4,570 psi, which was lower than the 14 compressive strengths of the control and Starke mixes. The Starke mix had the greatest increase in compressive strength between the 14 and 28 day tests with a final 28 day compressive strength of 5,230 psi. The 28 day compressive strength of the control mix was 5,070 psi. All the specimens sampled in this group fell within the 90 % strength range designated by ASTM C94. Figure 7-6 gives a graphical representation of these results and Table 7-7 gives a complete listing of the results for the Oolitic group.

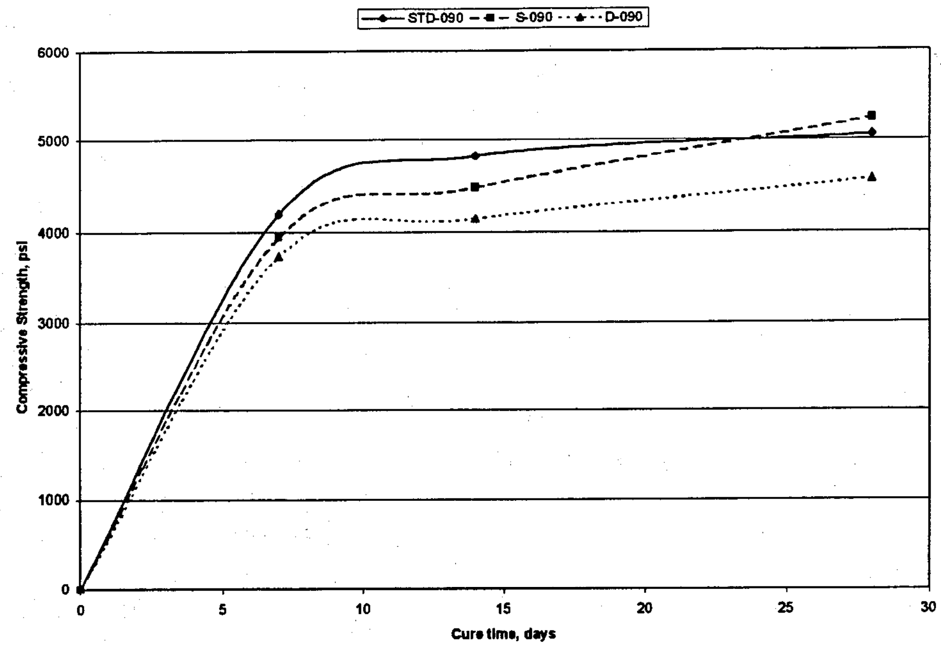


Figure 7-6. Compressive Strength vs. Time with Oolitic Coarse Aggregate

Table 7-7. Compressive Strength of Test Specimens with Oolitic Coarse Aggregate

MIX	TD-09	S-090	D-090
7 DAY COMPRESSIVE STRENGTH (psi)	4140	3900	3700
	4270	3960	3690
	4180	3980	3820
STD. Dev.	67	42	72
Average	**4197**	**3947**	**3737**
14 DAY COMPRESSIVE STRENGTH (psi)	4830	4440	4060
	4890	4610	4290
	4750	4410	4080
STD. Dev.	70	108	128
Average	**4823**	**4487**	**4143**
28 DAY COMPRESSIVE STRENGTH (psi)	5010	5030	4520
	5050	5250	4540
	5110	5400	4650
STD. Dev.	50	186	70
Average	**5056**	**5227**	**4570**

- *Calera:* The Calera group generally had the lowest compressive strengths of the three groups (Brookesville, Oolitic, and Calera). The highest 7 day compressive strength in the group was that of the Davenport mix, which had an average 7 day compressive strength of 3,650 psi. The Starke mix had an average 7 day compressive strength of 3,560 psi. The control mix in this group (STD-351) had the lowest 7 day compressive strength, 3,230 psi. The 14 day compressive strength tests determined the control mix and the Starke mix to have relatively similar average compressive strengths of 3,870 psi and 3,840 psi, respectively. The Davenport mix had the greatest average 14 day compressive strength in the group, 4,160 psi. The control mix had the highest average 28 day compressive strength of 4,810 psi with the Starke and Davenport mixes having average 28 day compressive strengths of 4,530 psi and 4,690 psi, respectively. All the samples in this group had average compressive strengths greater than the 90 % strength range designated by ASTM C 94. Figure 7-7 gives a graphical representation of these results and Table 7-8 gives a complete listing of the results for the Calera group.

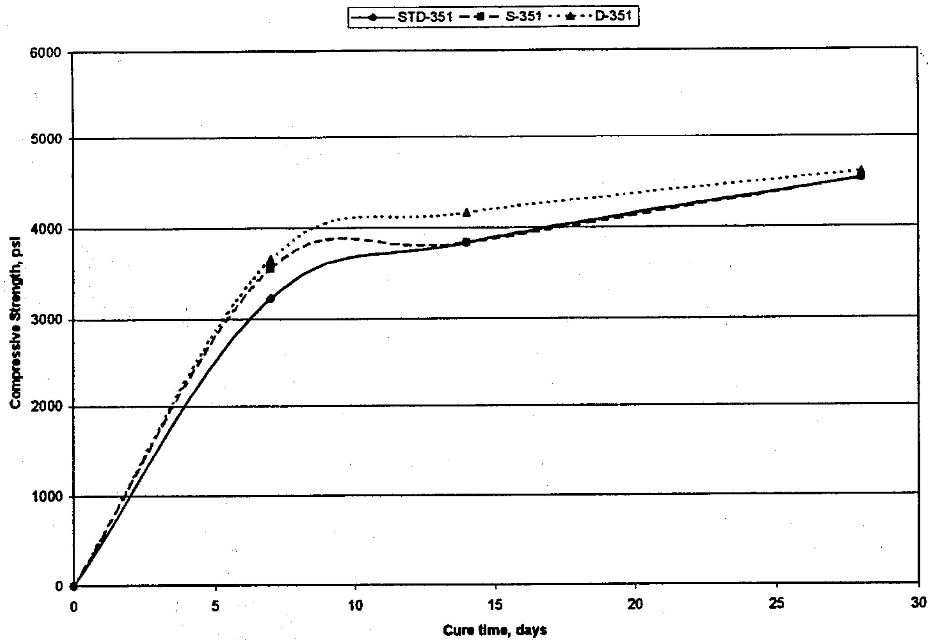


Figure 7-7. Compressive Strength vs. Time with Calera Coarse Aggregate

Table 7-8. Compressive Strength of Test Specimens with Calera Coarse Aggregate

MIX	TD-35	S-351	D-351
7 DAY COMPRESSIVE STRENGTH (psi)	3310	3590	3590
	2870	3510	3560
	3510	3580	3810
STD. Dev.	327	44	137
Average	**3230**	**3560**	**3653**
14 DAY COMPRESSIVE STRENGTH (psi)	3810	3910	4090
	4000	3500	4150
	3800	4110	4240
STD. Dev.	112	311	75
Average	**3870**	**3840**	**4160**
28 DAY COMPRESSIVE STRENGTH (psi)	4740	4230	4630
	4860	4790	4590
	4820	4560	4850
STD. Dev.	61	281	140
Average	**4807**	**4527**	**4690**

In general, the mixes containing the Type II wastewater seemed to gain their strength earlier in their curing period than the control mix; however, the control mix was determined to have the greatest ultimate compressive strength with the exception of the Oolitic aggregate group. It should be mentioned that the mixes were designed for a 28 day compressive strength of 2,500 psi and all were determined to have compressive strengths well above this number with an average overall compressive strength of 4,870 psi. All samples fell within the 90 % strength range designated by ASTM C 94.

<u>Modulus of Elasticity</u>

When Brookesville aggregate was used the control mix had a modulus of elasticity of 4.58 x 10^6 psi. Results were 32 %, and 16 % lower than the reference mix, respectively, when wastewater from Stark and Davenport was used. For the two other types of aggregate, modulus of elasticity results were both higher and lower than the reference mixes depending on the aggregate and water used. The differences however were relatively small. Table 7-9 presents the results obtained for the various mixes. Figure 7-8 gives a graphical representation.

Table 7-9. Modulus of Elasticity

Mix	Modulus of Elasticity (E + 06 psi)	Variance From Control
STD-005	4.58	-
S-005	3.10	-32 %
D-005	3.84	-16 %
STD-090	3.05	-
S-090	3.40	+11 %
D-090	2.88	-5 %
STD-351	4.60	-
S-351	4.15	-9 %
D-351	4.63	+0.7 %

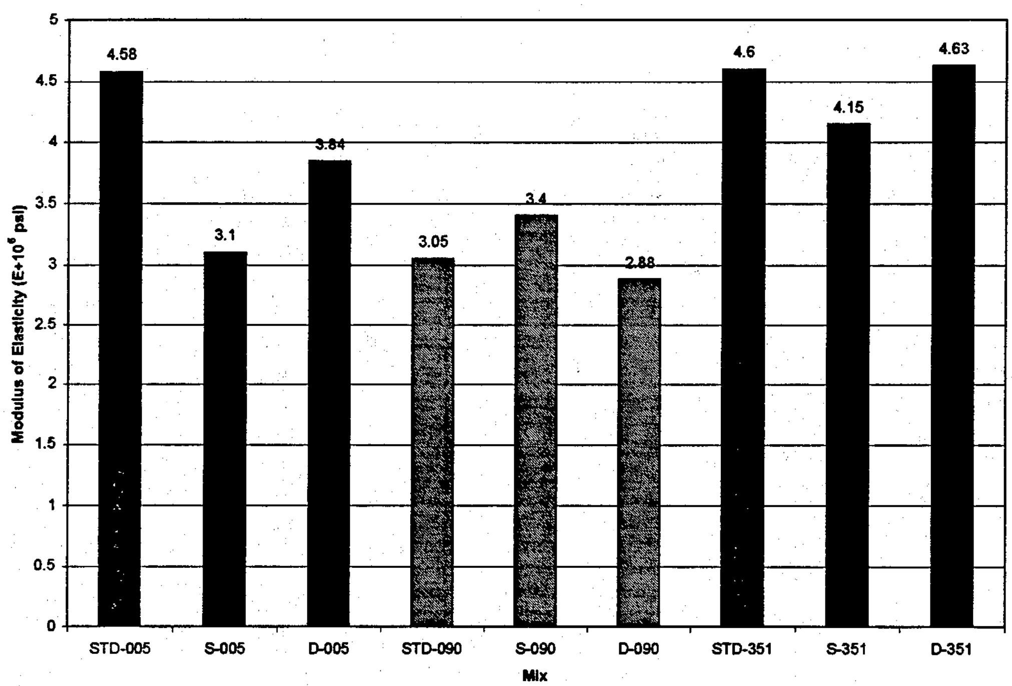


Figure 7-8. Modulus of Elasticity Bar Graph

Flexural Strength

Results for the flexural strength tests are an average of two test specimens tested per mix. Tests were run according to ASTM C 78. Test results are summarized in Table 7-10 and Figure 7-9.

- *Brookesville:* The control sample in this group (STD-005) had a flexural strength of 875 psi and the Starke mix (S-005) and Davenport mix (D-005) both had flexural strengths of 780 psi.

- *Oolitic:* The control mix in this group (STD-090) had a flexural strength of 885 psi. The Starke mix (S-090) had a flexural strength of 893 psi and the Davenport mix (D-090) had flexural strength of 834 psi.

- *Calera:* The control mix in this group (STD-351) had a flexural strength of 896 psi. The Starke mix (S-351) had a flexural strength of 903 psi and the Davenport mix (D-351) had flexural strength of 815 psi.

Table 7-10. Flexural Strength

Mix	ASTM C 78 Flexural Strength (psi)	Variance From Control
STD-005	875	-
S-005	780	- 10 %
D-005	780	- 10 %
STD-090	885	-
S-090	893	+ 1 %
D-090	834	-5 %
STD-351	896	-
S-351	903	+ 1 %
D-351	815	- 1 %

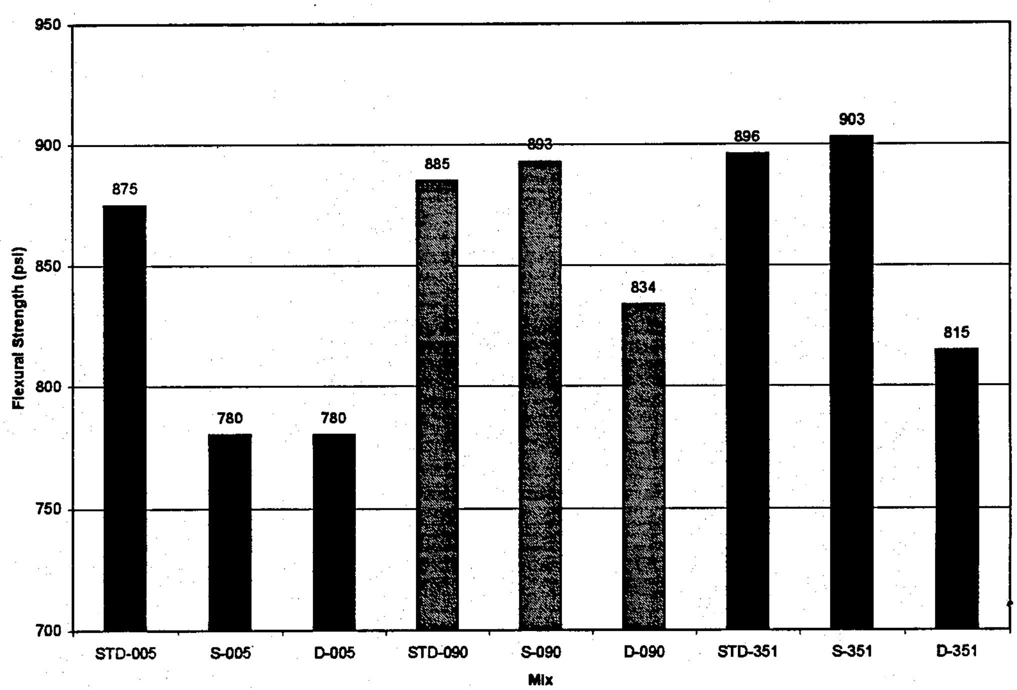


Figure 7-9. Flexural Strength Bar Graph

Rapid Chloride Permeability

High, moderate, and low readings were obtained. It is clear from the results that the age of the sample has the most effect on the outcome of the results. Samples ages of 28 days gave high readings with average values ranging from 2,747 Coulombs (Moderate) to 5,107 Coulombs (High). At the 56 day age, samples showed less propensity towards chloride permeability with values ranging from 1,523 Coulombs (Low) for the S-351 sample to 3105 Coulombs (Moderate) for the S-090 sample. Table 7-11 gives a summary of the results and Table 6-12 gives a summary of the rating system used for the rapid chloride permeability tests. A graphical representation of the 28 and 56 day results is given in Figures 7-10 and 7-11, respectively.

Table 7-11. Rapid Chloride Permeability

	28 day age		**56 day age**	
Mix	**Coulombs**	**Rating**	**Coulombs**	**Rating**
STD-005	4658	High	2825	Moderate
S-005	5107	High	2641	Moderate
D-005	4873	High	2770	Moderate
STD-090	4898	High	2792	Moderate
S-090	5016	High	3105	Moderate
D-090	4257	High	2573	Moderate
STD-351	3376	Moderate	1809	Low
S-351	2747	Moderate	1523	Low
D-351	3397	Moderate	1748	Low

Table 7-12. Value table for Coulomb rating

Value	Rating
0 - 100	Negligible
101 - 1000	Very Low
1001 - 2000	Low
2001 - 4000	Moderate
4001 - up	High

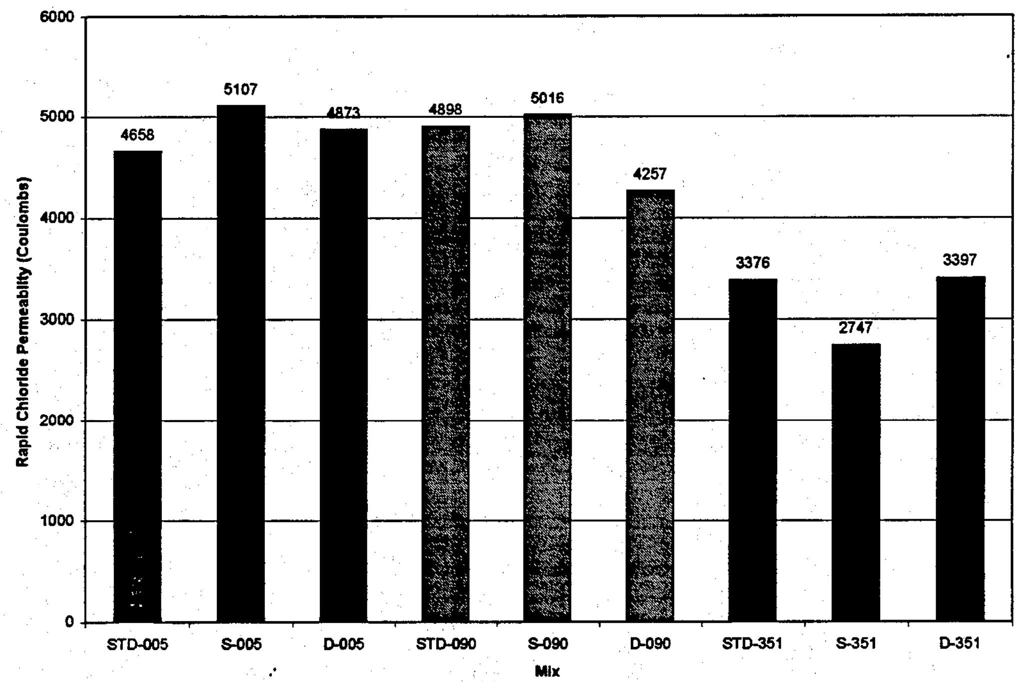


Figure 7-10. Rapid Chloride Permeability 28 Day Results Bar Graph

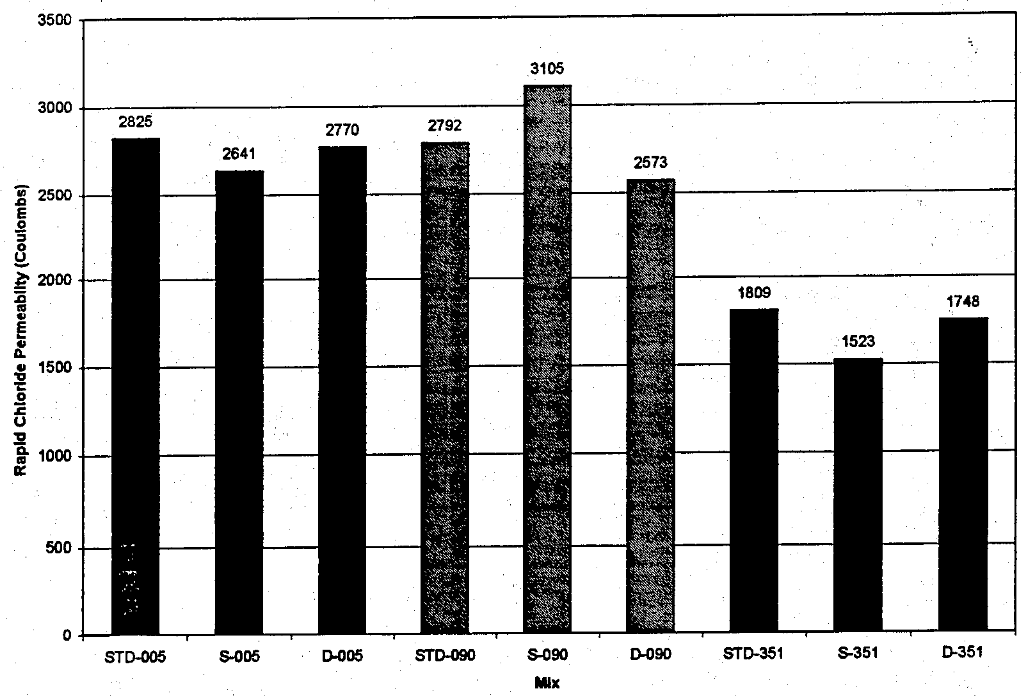


Figure 7-11. Rapid Chloride Permeability 56 Day Results Bar Graph

Drying Shrinkage

ASTM C157 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:

$$\Delta L = \frac{L_x - L_i}{L_g} \times 100$$

ΔL = change in length at x age, %
L_x = comparator reading of specimen at x age
L_i = initial comparator reading of specimen
L_g = nominal gage length (10.0 in.)

Results presented in this study 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 test specimens were considered. The overall greatest change in length was that of the mix incorporating Davenport Type II wastewater and Calera coarse aggregate (D-351) with a decrease in length compared to the gage length of 0.032 %. All of the nine mixes resulted in an average decrease in length. Results as of the 13th week are summarized in Table 7-13 and Figure 7-12

- *Brookesville:* The greatest percent change, when Brookesville Aggregate was used, was produced by the Starke mix with a decrease in length of 0.028 % of the gage length. The Davenport mix was found to have the highest standard deviation in this group.

- *Oolitic:* The greatest average percent length change, when Oolitic aggregate was used, was the control mix, which had a 0.029 % reduction in length compared to the gage length. The greatest standard deviation was among the Starke samples.

- *Calera:* The greatest average percent length change, when Calera aggregate was used, was the Davenport samples which had an decrease in length of 0.032 % compared to the gage length. The Davenport samples had the highest standard deviation in this group as well.

Table 7-13. Drying Shrinkage Length Change Results (13 Week Age)

Mix	Mean % Change	Std. Deviation
STD-005	-0.019 %	N/A*
S-005	-0.011 %	0.0014 %
D-005	-0.028 %	0.0045 %
STD-090	-0.029 %	0.0040 %
S-090	-0.024 %	0.0101 %
D-090	-0.027 %	0.0064 %
STD-351	-0.022 %	0.0035 %
S-351	-0.029 %	0.0042 %
D-351	-0.032 %	0.0078 %

* Only one suitable test specimen available

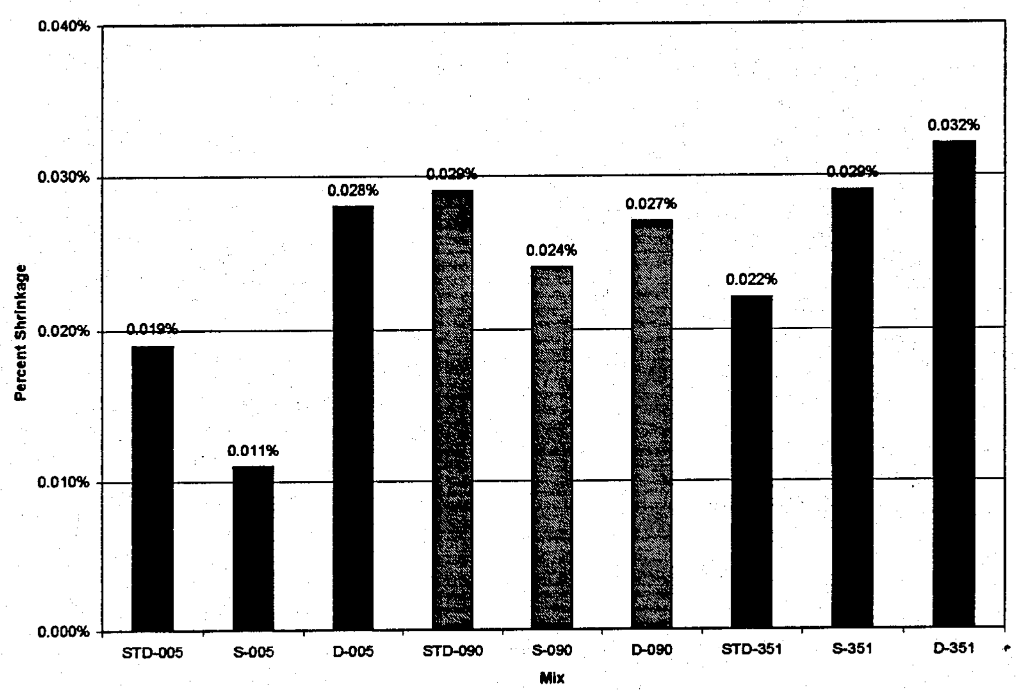


Figure 7-12. Drying Shrinkage Bar Graph

Sulfate Expansion

Initially five test specimens were produced for each mix. After 13 weeks 2 test specimens were picked from each mix to be tested for modulus of rupture (discussed below). The results presented for this test utilized all five test specimens. In some instances, as was the case in the drying shrinkage tests, less than five test specimens were measurable. In these cases the remaining suitable specimens have been used to represent the mix. Only one of the nine mixes showed an increase in length when exposed to sulfate with eight of the mixes producing specimens, which on average had a decrease in length when, exposed to sulfate. The values ranged from an average increase of 0.002 % (D-090) compared to the gage length to an average decrease of 0.017 % (STD-351). Results from these tests are somewhat surprising since the majority of the mixes showed a propensity to decrease in length when exposed to the sulfate solution. Table 7-14 and Figure 7-13 give a summary of the sulfate expansion test results. In addition to the length change tests done on these specimens, flexural strength tests were also done on two of the prism specimens according to ASTM C 293. It should be noted that this test method produces values of flexural strength significantly higher than that of ASTM C 78. Results of these tests are summarized in Table 7-15 and Figure 7-14.

- *Brookesville:* All three samples in the Brookesville group showed a decrease in length when exposed to sulfate. The largest decrease in length was that of the Starke

- *Oolitic:* Two of the three samples in the Oolitic group produced samples with an average decrease in length. The largest change in length in this group was the control samples with an average decrease of 0.003 %. The Davenport samples had a slight increased in length of 0.002 %.

- *Calera:* All of the three mixes in the Calera group showed a decrease in length when exposed to sulfate. The largest increase in this group was the control mix with an increase in length of 0.017 %.

Table 7-14. Sulfate Expansion Test Results

Mix	Mean % Change	Std. Deviation
STD-005	-0.004 %	0.0120 %
S-005	-0.008 %	0.0075 %
D-005	-0.006 %	N/A*
STD-090	-0.003 %	0.0041 %
S-090	-0.002 %	0.0115 %
D-090	0.002 %	0.0045 %
STD-351	-0.017 %	0.0070 %
S-351	-0.013 %	0.0028%
D-351	-0.008 %	0.0068%

* Only one suitable test specimen available

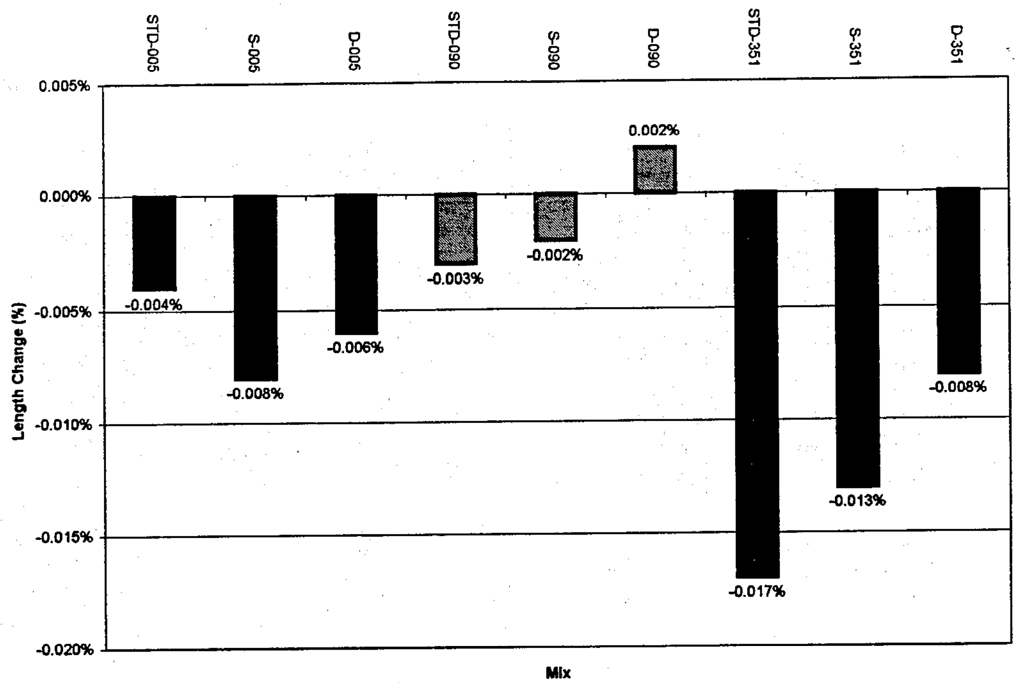


Figure 7-13. Sulfate Expansion Bar Graph

Table 7-15. Sulfate Flexural Strength Test Results

Mix	ASTM C 78 Flexural Strength (psi)	Variance From Control
STD-005	1057	-
S-005	1456	+ 38 %
D-005	1301	+ 23 %
STD-090	1564	-
S-090	1494	- 4 %
D-090	1205	- 23 %
STD-351	1360	-
S-351	1289	- 5 %
D-351	1271	- 7 %

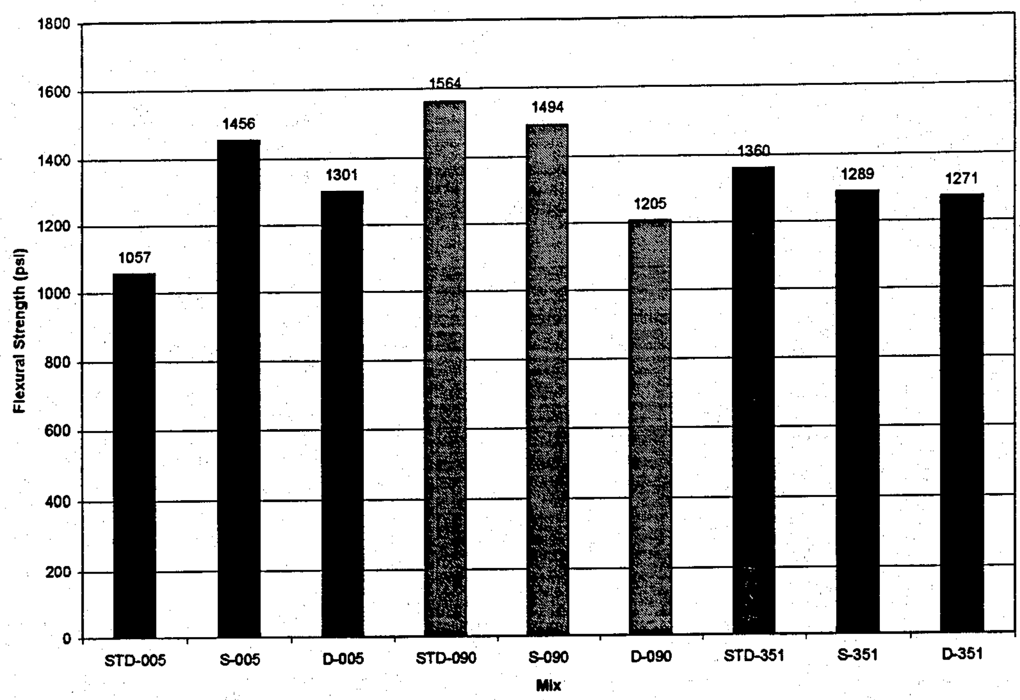


Figure 7-14. Sulfate Flexural Strength Bar Graph

Impressed current

Impressed current results ranged from 24 days to 51 days for time-to-failure. The Calera group appeared to have the longest time-to-failure of all the groups on average. Table 7-16 gives a summary of the impressed current test and Figure 7-15 gives a graphical representation of these results.

Table 7-16. Impressed Current

Mix	Time-to-Failure (days)	Resistance (ohms)
STD-005	31	1372
S-005	35	1317
D-005	28	1205
STD-090	34	1195
S-090	24	1120
D-090	37	1450
STD-351	46	1607
S-351	51	1725
D-351	44	1540

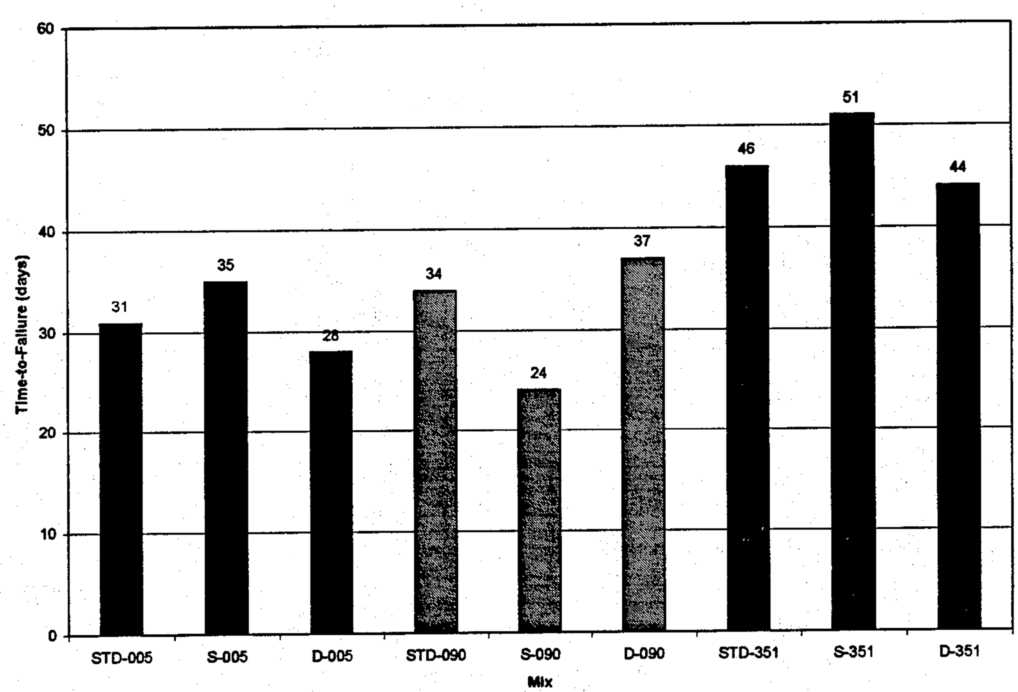


Figure 7-15. Time-to-Failure Bar Graph

Corrosion of Rebar in Concrete

Due to the long test period associated with this test, no results were available at the time of this report.

Phase 2 Results

Slump

The slump tests were run in accordance with ASTM C 143. As in Phase 1, water content was adjusted to achieve slumps of about 2 inches. Resulting slumps ranged from a low of 1.75" to a high of 2.25".

Set Time

The set time tests were run in accordance with ASTM C 403. As discussed in Phase 1, ASTM C 94 outlines the acceptable criteria for questionable water supplies with regards to set time to be from 1 hour earlier to 1-1/2 hours later than that of the control set time. Only one of the nine mixes fell outside this range (S-005II) with an initial set time of 1 hour 5 minutes greater than that of the control mix. Table 7-17 summarizes the results and Figures 7-16 and 7-17 give a graphical representation of the initial and final set times, respectively.

- *Brookesville*: The control mix (STD-005) in this group had an initial set time of 6 hours 45 minutes and a final set time of 8 hours 30 minutes. The mix using Starke wastewater in this group (S-005II) had the greatest variance from the control sample of all the mixes with initial and final set times of 1 hour 5 minutes greater and 10 minutes less than that of the control mix, respectively. The mix using Davenport wastewater (D-005II) had initial and final set times of 20 and 45 minutes greater than that of the control mix, respectively.

- *Oolitic:* The control mix (STD-090) in this group had an initial set time of 6 hours 55 minutes and a final set time of 8 hours 45 minutes. The mix using Starke wastewater in this group (S-090II) had initial and final set times of 20 minutes and 40 minutes greater than that of the control mix, respectively. The mix using Davenport wastewater in this group (D-090II) had initial and final set times of 30 minutes and 1 hour greater than that of the control mix, respectively. All mixes in this group were determined to be within the acceptable tolerance for concrete produced with questionable water supplies according to the ASTM C 94.

- *Calera*: The control mix (STD-351) in this group had an initial set time of 8 hours 15 minutes and a final set time of 10 hours 50 minutes. The mix using Starke wastewater in this group (S-351II) had initial and final set times of 35 minutes greater and 10 minutes less than that of the control mix, respectively. The mix using Davenport wastewater (D-351II) had initial and final set times of 45 minute less than that of the control mix. All samples in this group were determined to be within the acceptable tolerance for concrete produced with questionable water supplies according to the ASTM C 94.

Table 7-17. Set Time

Mix	Initial Set Time	Variance From Control	Final Set Time	Variance From Control
STD-005	6 hrs. 45 min.	-	8 hrs. 30 min.	-
S-005II	7 hrs. 50 min.	1 hr. 5 min.	8 hrs. 20 min.	- 10 min.
D-005II	7 hrs. 5 min.	+ 20 min.	9 hrs. 15 min.	+ 45 min.
STD-090	6 hrs. 55 min.	-	8 hrs. 45 min.	-
S-090II	7 hrs. 15 min.	+ 20 min.	9 hrs. 25 min.	+ 40 min.
D-090II	7 hrs. 25 min.	+ 30 min.	9 hrs. 45 min.	+ 60 min.
STD-351	8 hrs. 15 min.	-	10 hrs. 35 min.	-
S-351II	8 hrs. 50 min.	+ 35 min.	10 hrs. 25 min.	- 10 min.
D-351II	7 hrs. 30 min.	- 45 min.	9 hrs. 50 min.	- 45 min.

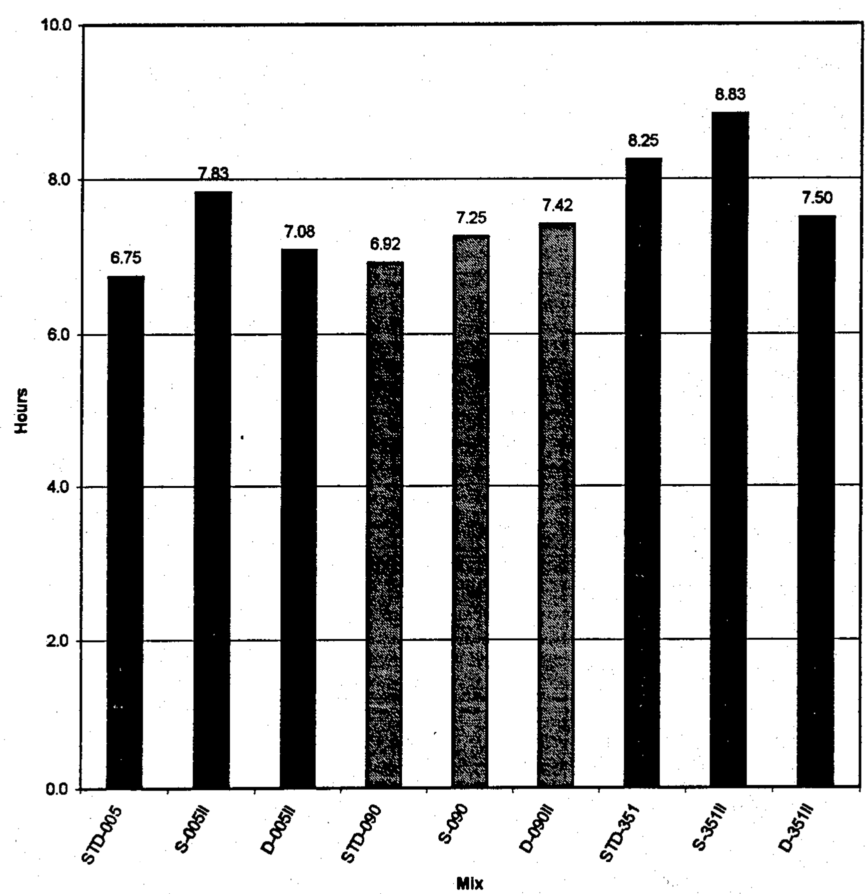


Figure 7-16. Initial Set Time Bar Graph

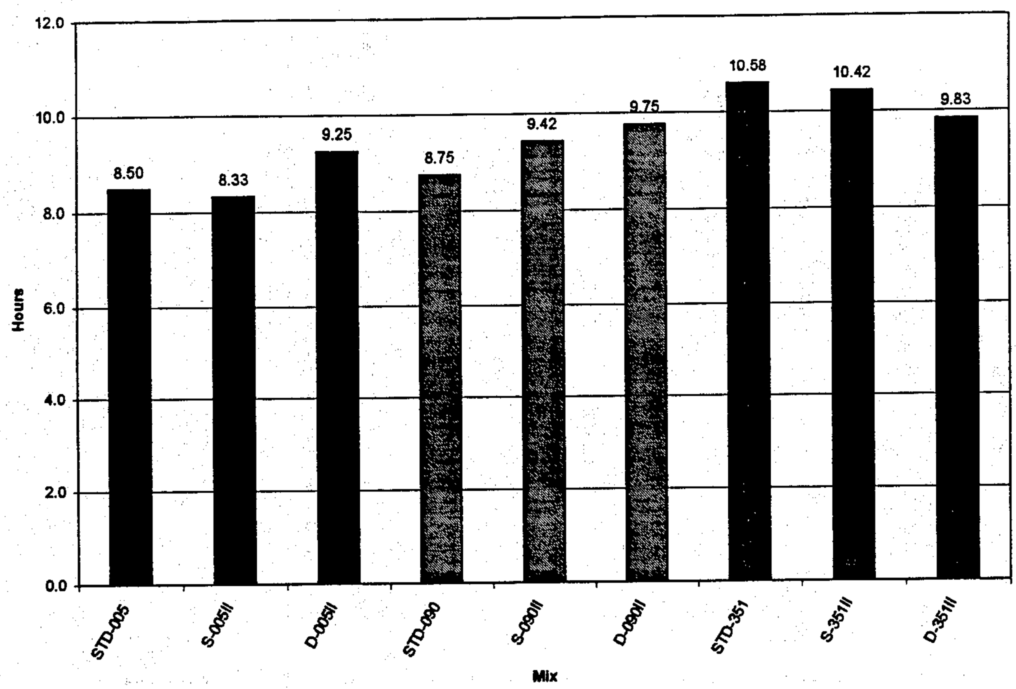


Figure 7-17. Final Set Time Bar Graph

Unit Weight

Unit weight tests were run in accordance with ASTM C 138. The unit weights of the mixes fell within the range of 138.2 lb/cf to 145.7 lb/cf. Table 7-18 and Figure 7-18 summarize the results.

- *Brookesville*: The control mix (STD-005) in this group had a unit weight of 141.9 lb/cf. The mixes using Starke (S-005II) and Davenport (D-005II) wastewater in this group had unit weights of 139.5 lb/cf and 141.0 lb/cf, respectively.

- *Oolitic:* The control mix (STD-090) in this group had a unit weight of 143.8 lb/cf. The mixes in this group using Starke (S-090II) and Davenport (D-090II) wastewater had unit weights of 138.4 lb/cf and 138.2 lb/cf, respectively. The variance in this group may be attributed to variance in water/ cement ratio and air content.

- *Calera:* The control mix in this group had a unit weight of 145.33 lb/cf. The mix in this group using Starke wastewater had a unit weight of 144.6 lb/cf and the Davenport mix had unit weight of 145.7 lb/cf.

Table 7-18. Unit Weight of Concrete Mixes

Mix	**Unit Weight (lb/cf)**	**Variance From Control**
STD-005	141.9	-
S-005II	139.5	-1.73 %
D-005II	141.0	-0.68 %
STD-090	143.8	-
S-090II	138.4	-3.78 %
D-090II	138.2	-3.92 %
STD-351	145.3	-
S-351II	144.6	-0.50 %
D-351II	145.7	0.25 %

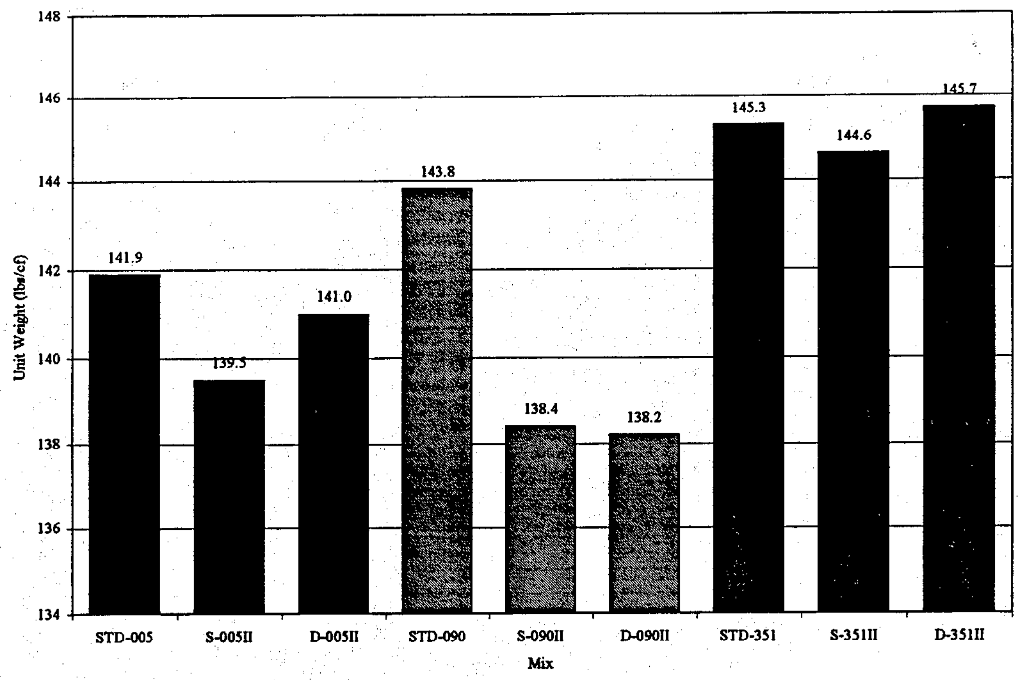


Figure 7-18. Unit Weight Bar Graph

Air Content

Air content tests were performed in accordance with ASTM C 173. Air contents ranged from 3.0 % to 4.6 %. Table 7-19 and Figure 7-19 summarize the results for air content.

- Brookesville: The control mix (STD-005) for this group had an air content of 3.0 %. The Mixes using Starke and Davenport wastewater had air contents of 4.0 % and 4.6 %, respectively.

- Oolitic: The control mix (STD-090) for this group had an air content of 3.7 %. The Mixes using Starke and Davenport wastewater had air contents of 4.5 % and 3.8 %, respectively.

- Calera: The control mix (STD-351) for this group had an air content of 4.6. The Mixes using Starke and Davenport wastewater had air contents of 4.4 % and 4.0 %, respectively.

Table 7-19. Air Content of Concrete Mixes

Mix	Air Content (%)
STD-005	3.0
S-005II	4.0
D-005II	4.6
STD-090	3.7
S-090II	4.5
D-090II	3.8
STD-351	4.6
S-351II	4.4
D-351II	4.0

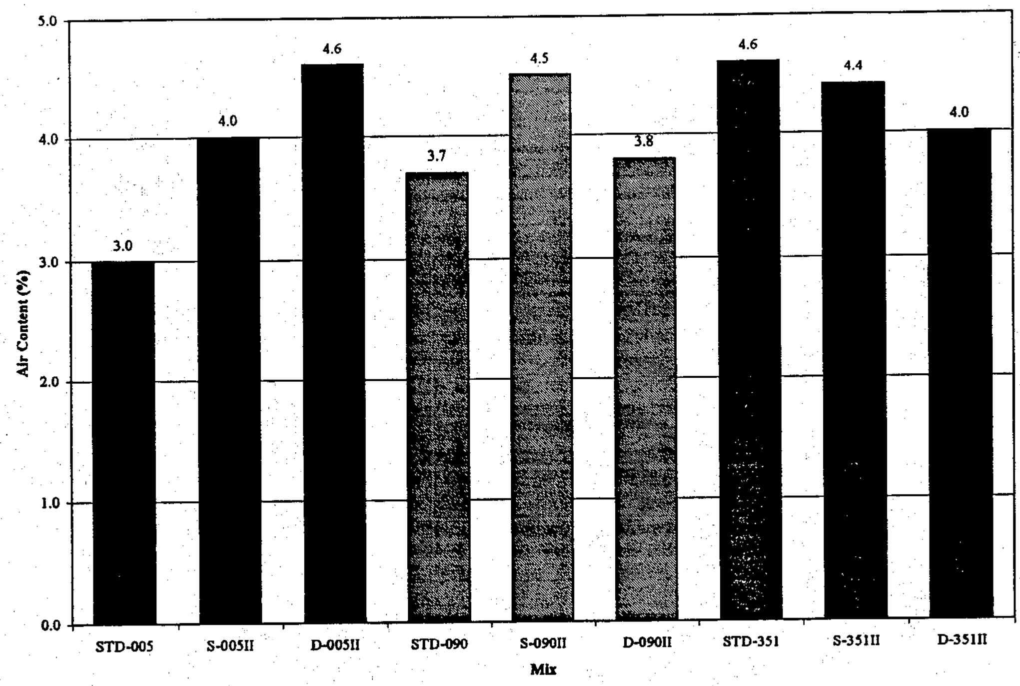


Figure 7-19. Air Content Bar Graph

Table 7-20. Fresh Concrete Test Result Summary

Mix	Test					
	Slump (in.)	Set Time		Unit Weight (PCF)	Mix Temp (°F)	Air Content (%)
		Initial	Final			
STD-005	2.0	6 hrs. 45 min.	8 hrs. 30 min.	141.9	76	3.0
S-005II	1.75	7 hrs. 50 min.	8 hrs. 20 min.	139.5	76	4.0
D-005II	2.0	7 hrs. 5 min.	9 hrs. 15 min.	141.0	75	4.6
STD-090	2.0	6 hrs. 55 min.	8 hrs. 45 min.	143.8	76	3.7
S-090II	2.0	7 hrs. 15 min.	9 hrs. 25 min.	138.4	80	4.5
D-090II	2.25	7 hrs. 25 min.	9 hrs. 45 min.	138.2	80	3.8
STD-351	2.75	8 hrs. 15 min.	10 hrs. 35 min.	145.3	80	4.6
S-351II	1.75	8 hrs. 50 min.	10 hrs. 25 min.	144.6	75	4.4
D-351II	2.0	7 hrs. 30 min.	9 hrs. 50 min.	145.7	78	4.0

Compressive Strength

Results for the compressive strength test are an average of three specimens tested at each interval of 7, 14, and 28 days. As in Phase 1, ASTM C 94 requires the compressive strength produced with a questionable water supply to be at least 90 % of the compressive strength of a sample incorporating potable water. Table 7-21 gives a summary of the water-cement ratio for each mix, which is inversely related to the compressive strength.

Table 7-21. Water-Cement Ratio

Mix	Water-Cement Ratio
STD-005	0.54
S-005II	0.53
D-005II	0.52
STD-090	0.51
S-090II	0.49
D-090II	0.49
STD-351	0.50
S-351II	0.49
D-351II	0.47

- Brookesville: The 7 day compressive strengths for mixes using Starke (S-005) and Davenport (D-005) wastewater were determined to be much greater than that of the control mix (STD-005) which had an average compressive strength of 3,170 psi. At 14 days the compressive strengths of the Starke (S-005II) and Davenport (D-005II) mixes were again both greater than that of the control mix, which had a 14 day compressive strength of 4,230 psi. The 28 day compressive strengths of the three mixes in this group were relatively close. The control mix (STD-005) had a 28 day compressive strength of 5,130 psi and the Starke (S-005II) and Davenport (D-005II) mixes had 28 day compressive strengths of 5,230 psi and 5,280 psi, respectively. All of the Starke and Davenport test specimens were within the 90 % strength range designated by ASTM C 94. Figure 7-20 gives a graphical representation of the results and Table 7-22 gives the complete results for the Brookesville group.

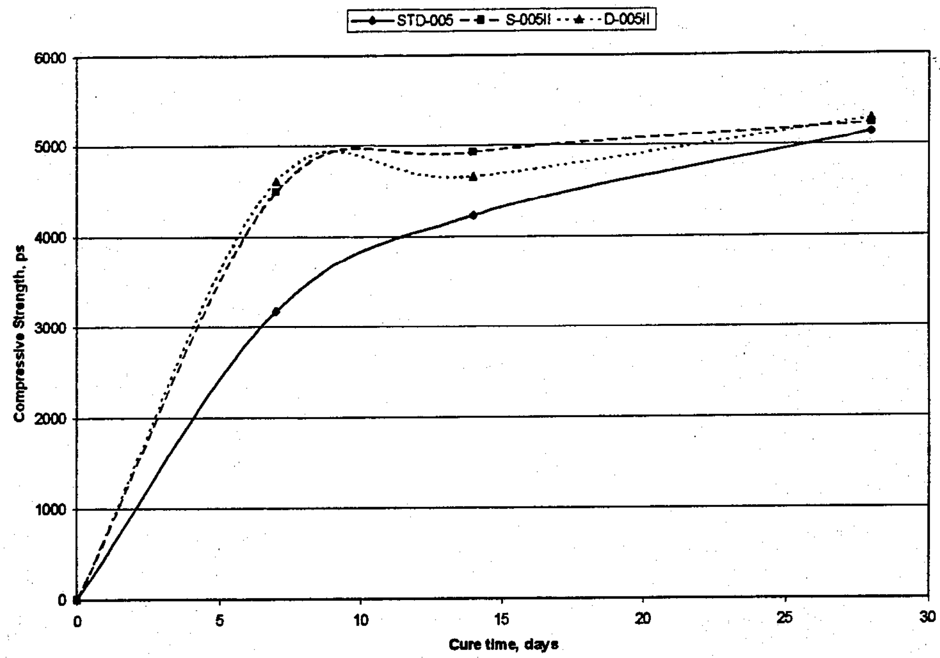


Figure 7-20. Compressive Strength vs. Time with Brookesville Coarse Aggregate

Table 7-22. Compressive Strength of Test Specimens with Brookesville Coarse Aggregate

MIX	STD-005	S-005II	D-005II
7 DAY COMPRESSIVE STRENGTH (psi)	3240	4630	4590
	2940	4460	4500
	3340	4390	4730
STD. Dev.	208	123	116
Average	**3173**	**4493**	**4607**
14 DAY COMPRESSIVE STRENGTH (psi)	4070	5040	4640
	4360	4720	4610
	4260	5000	4700
STD. Dev.	147	174	46
Average	**4230**	**4920**	**4650**
28 DAY COMPRESSIVE STRENGTH (psi)	5290	5230	4760
	4860	5150	5440
	5240	5310	5650
STD. Dev.	235	80	465
Average	**5130**	**5230**	**5283**

- *Oolitic:* The 7 day compressive strength of the control mix (STD-090) was 4,200 psi. The Starke mix (S-090II) had an average 7 day compressive strength of 3,880 psi, lower than that of the control mix. The Davenport sample (D-090II) had a 7 day compressive strength of 4,270 psi. The control mix had a 14 day compressive strength of 4,820 psi and the Starke and Davenport mixes had 14 day compressive strengths of 4,400 psi and 4,920 psi, respectively. The 28 day compressive strength tests determined the control mix to be the weakest of the group with a 28 day compressive strength of 5,060 psi. The Starke and Davenport mixes had final 28 day compressive strengths of 5,120 psi and 5,380 psi, respectively. All the specimens sampled in this group fell within the 90 % strength range designated by ASTM C94. Figure 7-21 gives a graphical representation of the results and Table 7-23 gives a complete listing of the results for the Oolitic group.

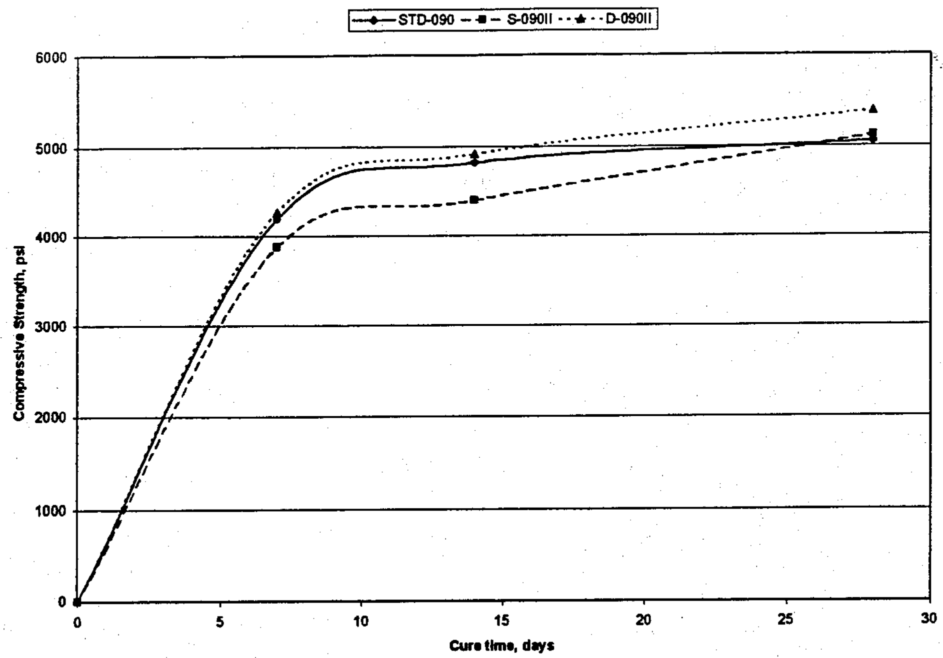


Figure 7-21. Compressive Strength vs. Time with Oolitic Coarse Aggregate

Table 7-23. Compressive Strength of Test Specimens with Oolitic Coarse Aggregate

MIX	STD-090	S-090II	D-090II
7 DAY COMPRESSIVE STRENGTH (psi)	4140	3840	4360
	4270	3850	4150
	4180	3940	4300
STD. Dev.	67	55	108
Average	**4197**	**3877**	**4270**
14 DAY COMPRESSIVE STRENGTH (psi)	4830	4490	5000
	4890	4240	4990
	4750	4470	4770
STD. Dev.	70	139	130
Average	**4823**	**4400**	**4920**
28 DAY COMPRESSIVE STRENGTH (psi)	5010	5100	5270
	5050	5100	5390
	5110	5150	5480
STD. Dev.	50	29	105
Average	**5056**	**5117**	**5380**

- *Calera:* The highest 7 day compressive strength in the group was that of the Davenport mix (D-351II), which had an average 7 day compressive strength of 4,110 psi. The Starke mix (S-351II) had an average 7 day compressive strength of 3,760 psi. The control sample in this group (STD-351) had the lowest 7 day compressive strength, 3,230 psi. Strength tests determined the control mix to have the lowest 14 day compressive strength, 3,870 psi. The Starke and Davenport mixes had 14 day compressive strength of 4,270 psi and 4,800 psi, respectively. The control mix and the Davenport mix had identical 28 day compressive strengths of 4,810 psi. The Starke mix had the greatest 28 day compressive strength, 5,150 psi. All the samples in this group had compressive strengths greater than the 90 % strength range designated by ASTM C 94. Figure 7-22 gives a graphical representation of these results and Table 7-24 gives a complete listing of the results for the Calera group.

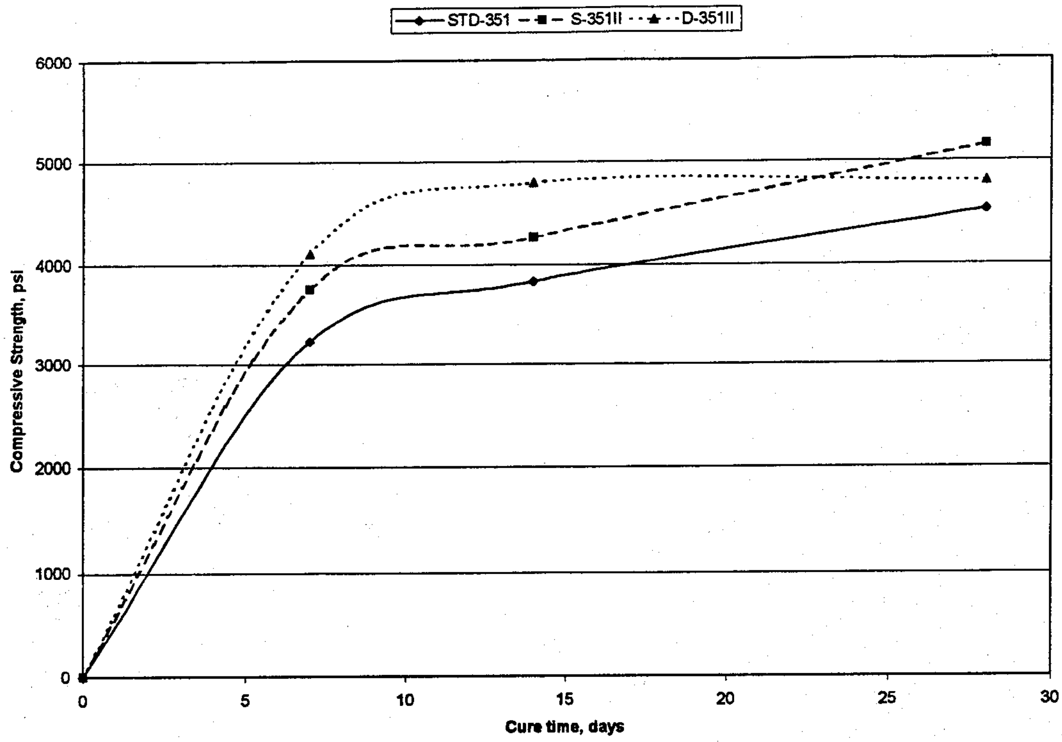


Figure 7-22. Compressive Strength vs. Time with Calera Coarse Aggregate

Table 7-24. Compressive Strength of Test Specimens with Calera Coarse Aggregate

MIX	STD-351	S-351II	D-351II
7 DAY COMPRESSIVE STRENGTH (psi)	3310	3970	4020
	2870	3720	4100
	3510	3590	4210
STD. Dev.	327	193	95
Average	**3230**	**3760**	**4110**
14 DAY COMPRESSIVE STRENGTH (psi)	3810	3960	4670
	4000	4230	4690
	3800	4610	5030
STD. Dev.	112	327	202
Average	**3870**	**4267**	**4797**
28 DAY COMPRESSIVE STRENGTH (psi)	4740	5110	4810
	4860	5150	4780
	4820	5200	4830
STD. Dev.	61	45	25
Average	**4807**	**5153**	**4807**

In general, the samples containing the Type II wastewater seemed to gain their strength earlier in their curing period than the control samples, as was the case in Phase 1. Again, all the mixes were well above their designed compressive strength of 2,500 psi, with an overall average 28 day compressive strength of 4,920 psi. All samples fell within the 90 % strength range designated by ASTM C 94.

Modulus of Elasticity

The control mix had a modulus of 4.58 x 10^6 psi when Brookesville aggregate was used. Results were 33 %, and 32 % lower than the reference mix, respectively, when wastewater from Stark and Davenport was used. The Oolitic group had relatively identical moduli of elasticity, in the range of 3.05 x 10^6 psi to 3.08 x 10^6 psi. In the Calera group the control mix had a modulus of elasticity of 4.60 x 10^6 psi and the Starke and Davenport mix results were about 20% lower. Only one specimen per mix was tested for modulus of elasticity, which may account for the high variance. Table 7-25 and Figure 7-23 summarize the results.

Table 7-25. Modulus of Elasticity

Mix	Modulus of Elasticity (E + 06 psi)	Variance From Control
STD-005	4.58	-
S-005II	3.08	-33 %
D-005II	3.11	-32%
STD-090	3.05	-
S-090II	3.02	-1 %
D-090II	3.08	+1 %
STD-351	4.60	-
S-351II	3.59	-22 %
D-351II	3.66	-21 %

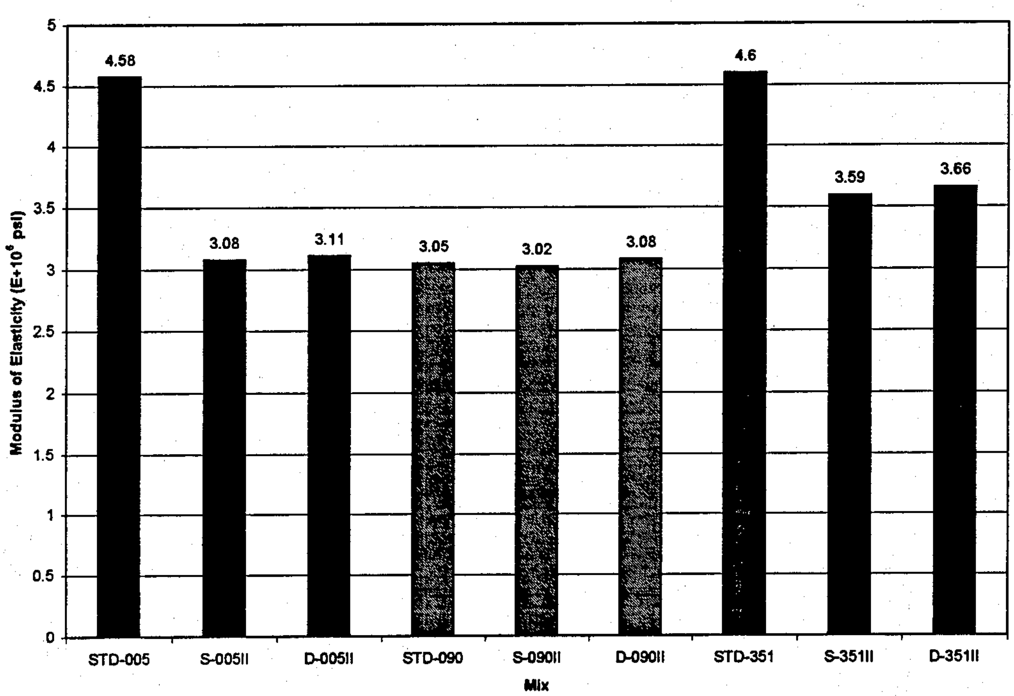


Figure7-23. Modulus of Elasticity Bar Graph

Flexural Strength

Results for the flexural strength tests are an average of two test specimens per mix and are summarized in Table 7-26 and Figure 7-24. Values ranged from 759 psi to 952 psi. Flexural strength tests in Phase 2 were run in accordance with ASTM C78.

- *Brookesville:* The control mix in this group (STD-005) had a flexural strength of 875 psi. The Starke mix (S-005II) had a flexural strength of 784 psi and the Davenport mix (D-005II) had flexural strength of 810 psi.

- *Oolitic:* The control mix in this group (STD-090) had a flexural strength of 885 psi. The Starke mix (S-090II) had a flexural strength of 759 psi and the Davenport mix (D-090II) had flexural strength of 826 psi.
- *Calera:* The control mix in this group (STD-351) had a flexural strength of 896 psi. The Starke mix (S-351II) had a flexural strength of 927 psi and the Davenport mix (D-090II) had flexural strength of 952 psi.

Table 7-26. Flexural Strength

Mix	Flexural Strength (psi)	Variance From Control
STD-005	875	-
S-005	784	- 10 %
D-005	810	- 7 %
STD-090	885	-
S-090	759	- 14 %
D-090	826	-7 %
STD-351	896	-
S-351	927	+ 3 %
D-351	952	+ 6 %

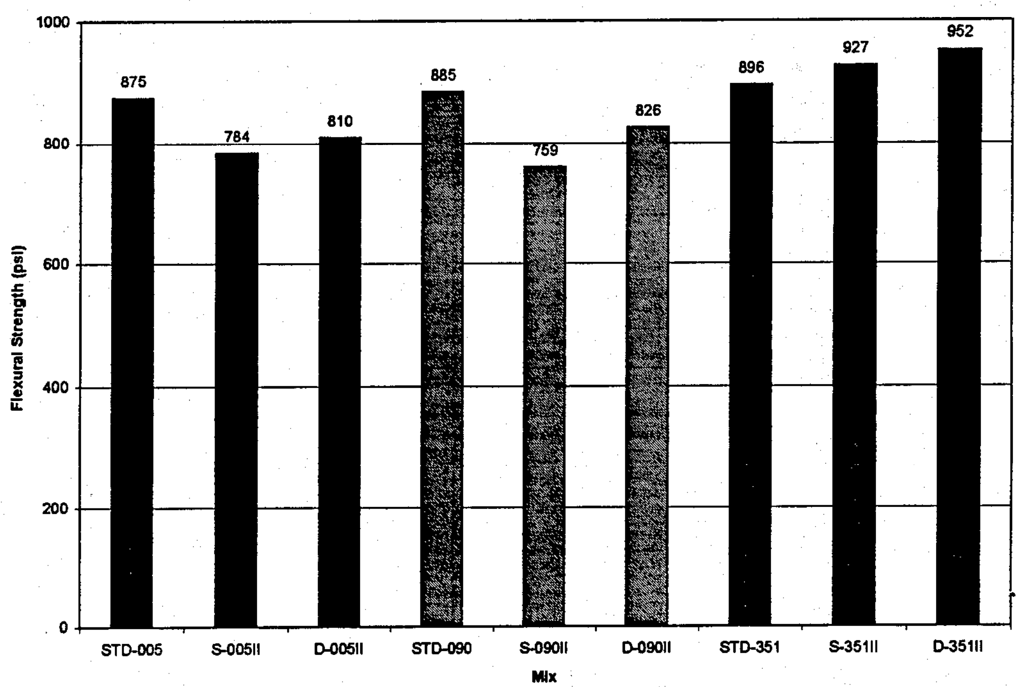


Figure 7-24. Flexural Strength Bar Graph

Rapid Chloride Permeability

High, moderate, and low readings were obtained. Sample ages of 28 days gave average values ranging from 2,549 Coulombs (Moderate) to 5,667 Coulombs (High). At the 56 day age, samples showed less propensity toward chloride permeability with values ranging from 1,259 Coulombs (Low) to 2,906 Coulombs (Moderate). Table 7-27 gives a summary of the results. Figures 7-25 and 7-26 give a graphical representation of the 28 day and 56 day results, respectively.

Table 7-27. Rapid Chloride Permeability

	28 day age		**56 day age**	
Mix	**Coulombs**	**Rating**	**Coulombs**	**Rating**
STD-005	4658	High	2825	Moderate
S-005II	5667	High	2906	Moderate
D-005II	5662	High	2589	Moderate
STD-090	4898	High	2792	Moderate
S-090II	4232	High	2165	Moderate
D-090II	5503	High	2439	Moderate
STD-351	3376	Moderate	1809	Low
S-351II	2634	Moderate	1259	Low
D-351II	2549	Moderate	1259	Low

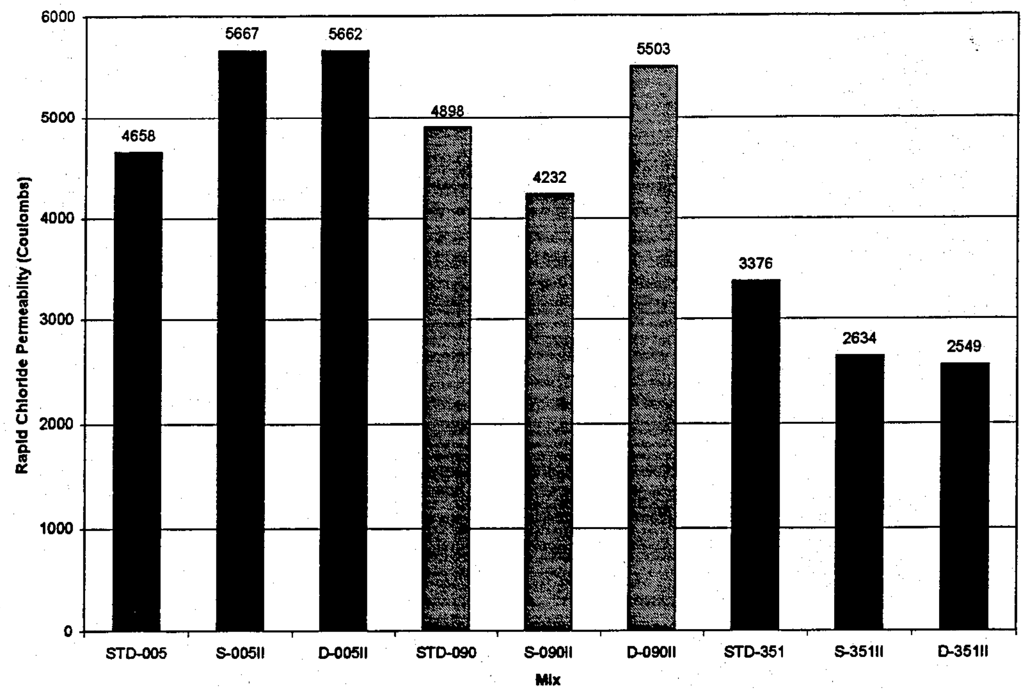


Figure 7-25. Rapid Chloride Permeability 28 Day Results Bar Graph

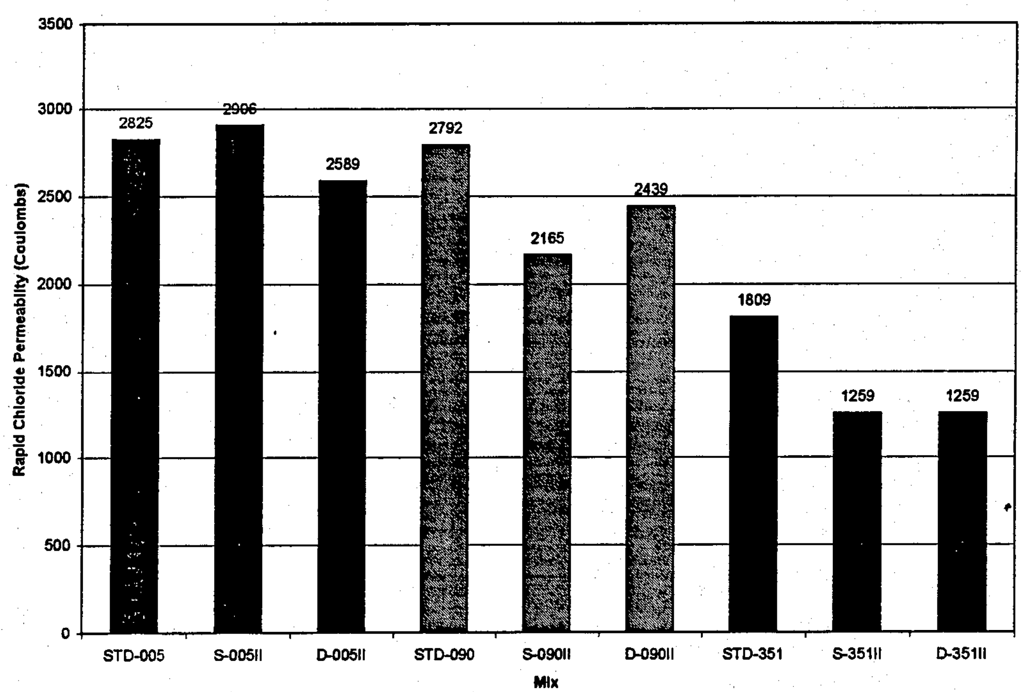


Figure 7-26. Rapid Chloride Permeability 56 Day Results Bar Graph

Drying Shrinkage

Results presented in this study are an average of three test specimens when available. The overall greatest change in length was that of the mix incorporating Davenport Type II wastewater and Brookesville coarse aggregate (D-005II) with a decrease in length compared to the gage length of 0.045 %. All of the nine mixes resulted in an average decrease in length. Mixes using Type II wastewater tended to decrease in length more than the control mixes. Results as of the 13th week are given in Table 7-28 and Figure 7-27 gives a graphical representation.

- *Brookesville:* The greatest percent change, when Brookesville Aggregate was used, was produced by the Davenport mix with a decrease in length of 0.045 % of the gage length. The Starke mix (S-005II) decreased 0.031 % compared to the gage length.

- *Oolitic:* The greatest average percent length change, when Oolitic aggregate was used, was the Starke sample (S-090II), which had a 0.043 % reduction in length compared to the gage length. The Davenport mix (D-090II) displayed similar characteristics with a decrease in length of 0.042 %.

- *Calera:* The greatest average percent length change, when Calera aggregate was used, was the Starke mix (S-351II), which had a decrease in length of 0.040 % compared to the gage length.

Table 7-28. Drying Shrinkage Length Change Results (13 Week Age)

Mix	Mean % Change	Std. Deviation
STD-005	-0.019%	N/A*
S-005II	-0.031%	0.007%
D-005II	-0.045%	0.006%
STD-090	-0.029%	0.004%
S-090II	-0.043%	0.003%
D-090II	-0.042%	0.005%
STD-351	-0.022%	0.004%
S-351II	-0.040%	0.023%
D-351II	-0.034%	0.009%

* Only one suitable test specimen available

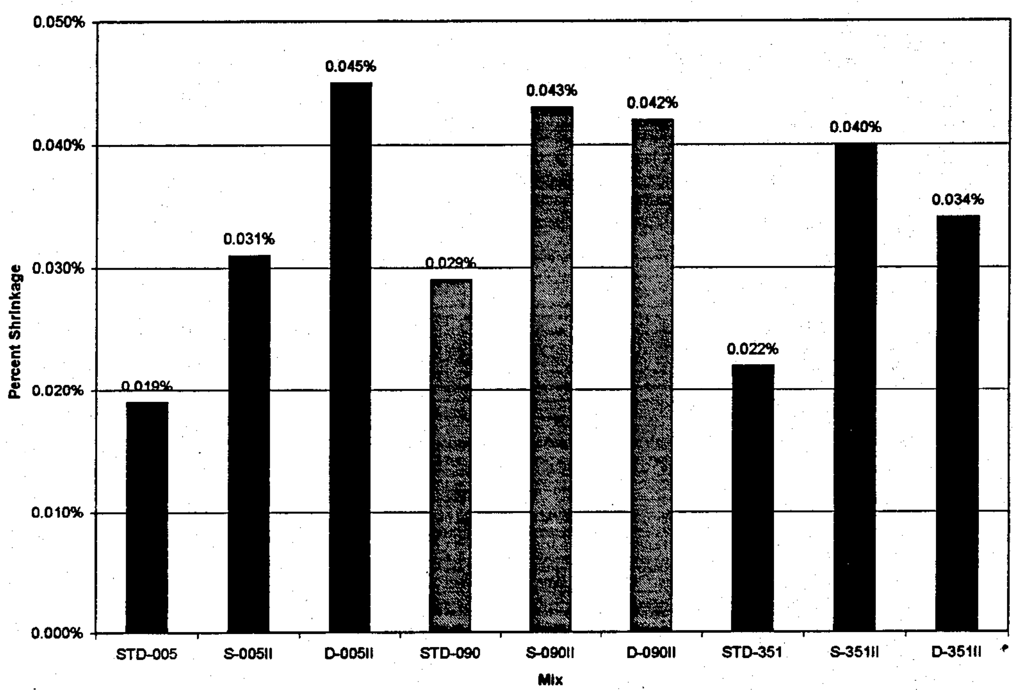


Figure 7-27. Drying Shrinkage Bar Graph

Sulfate Expansion

The values for the sulfate expansion tests ranged from an average decrease of 0.004 % to 0.032% compared to the gage. Table 7-29 and Figure 7-28 give a summary of the sulfate expansion test results.

- *Brookesville:* All three samples in the Brookesville group showed a tendency to decrease in length when exposed to sulfate. The largest decrease in length was that of the Davenport mix, which shrank 0.024 % compared to the gage length.

- *Oolitic:* All three samples in the Oolitic group showed a tendency to decrease in length when exposed to sulfate. The largest change in length in this group was the Starke mix with an average decrease of 0.027 %.

- *Calera:* All of the three mixes in the Calera group showed a decrease in length when exposed to sulfate. The largest decrease in this group was the Davenport mix with a decrease in length of 0.032 %.

Table 7-29. Sulfate Expansion Test Results

Mix	Mean % Change	Std. Deviation
STD-005	-0.004%	0.0120%
S-005II	-0.021%	0.0071%
D-005II	-0.024%	0.0151%
STD-090	-0.003%	0.0041%
S-090II	-0.027%	0.0202%
D-090	-0.020%	0.0089%
STD-351	-0.017%	0.0070%
S-351II	-0.030%	0.0145%
D-351II	-0.032%	0.0110%

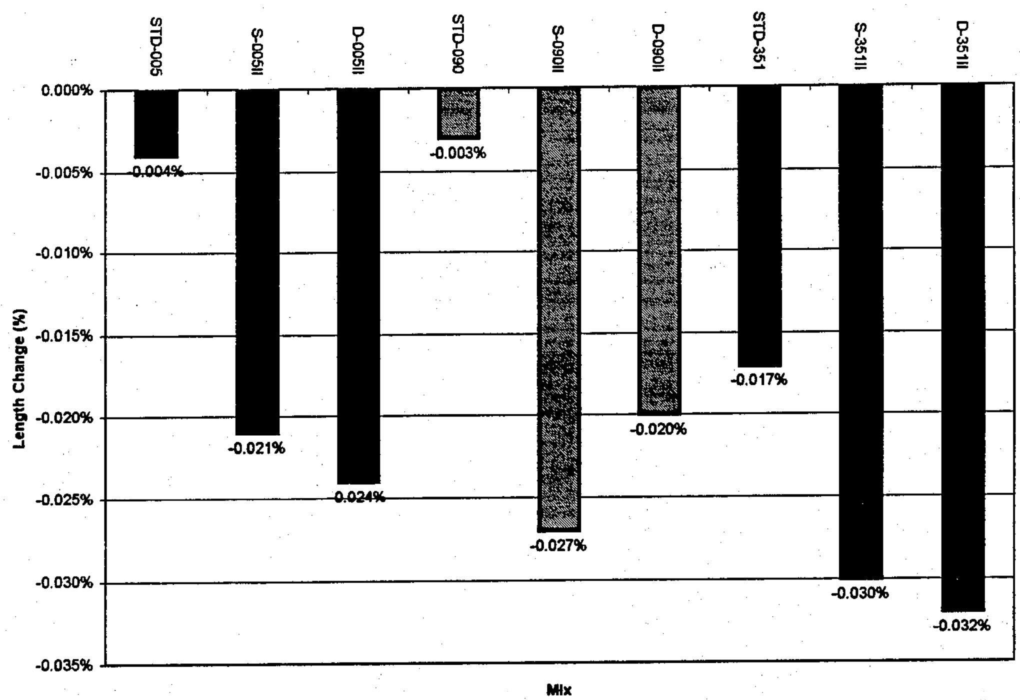


Figure 7-28. Sulfate Expansion Bar Graph

Impressed current

Impressed current results ranged from 16 days to 47 days. As was the case in Phase 1, the Calera group appeared to have the longest time-to-failure of all the groups. In the Brookesville and Oolitic groups, the time-to-failure noticeably lower than the control mix when Type II wastewater was used. Table 7-30 and Figure 7-79 give a summary of the impressed current test results.

Table 7-30. Impressed Current

Mix	Time-to-Failure (days)	Resistance (ohms)
STD-005	31	1372
S-005II	23	1040
D-005II	24	1182
STD-090	34	1195
S-090II	16	974
D-090II	19	1077
STD-351	46	1607
S-351II	38	1281
D-351II	47	1598

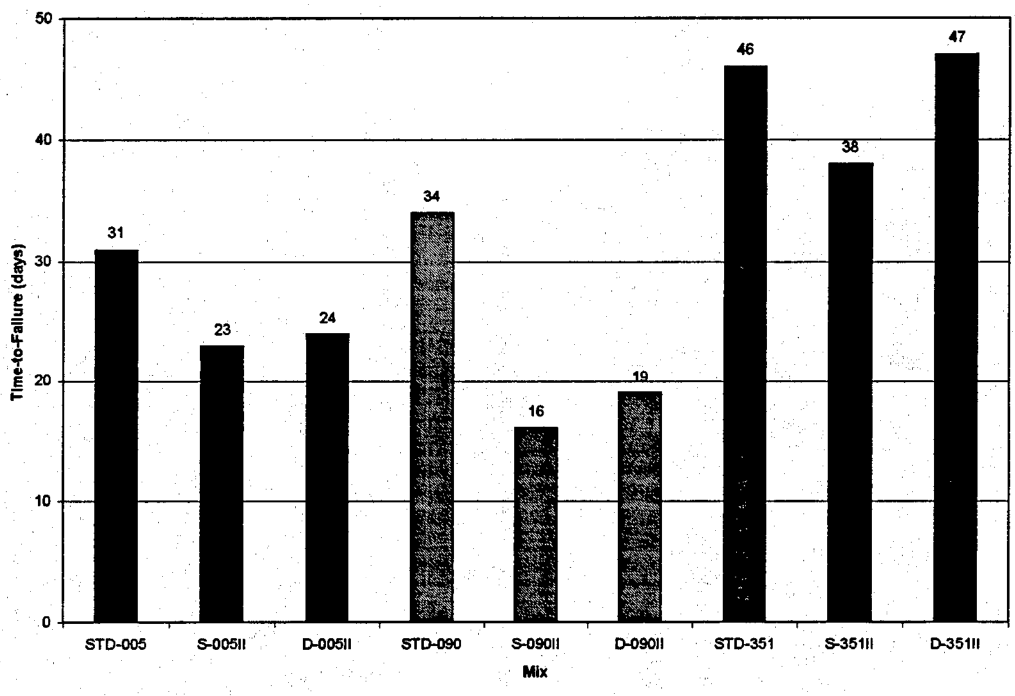


Figure 7-29. Time-to-Failure Bar Graph

Corrosion of Rebar in Concrete

Due to the long test period associated with this test, no results were available at the time of this report.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be made from the information reported in this document:

1. It appears from the survey of State Highway Agencies that the majority do not currently allow the reuse of Type II wastewater in the production of concrete, but several states are investigating this option.
2. The survey of ready-mix concrete plants in Florida clearly indicates that the ready-mix industry is very interested in recycling Type II wastewater into concrete production.
3. The Type II wastewaters used in this study were chosen on the basis of their high total solids content, which although they met the water quality standards of AASHTO M 157, "*Standard Specification for Ready-Mixed Concrete*," they did not meet the FDOT water quality specification, Section 923 entitled, "Water for Concrete."
4. Phase 1 test results indicate that Type II wastewater has no significant effect on fresh concrete properties, mechanical properties of hardened concrete, length change, sulfate resistance and corrosion resistance of hardened concrete, when used to saturate the limestone coarse aggregates used to produce Class I concrete.

5. Phase 2 test results also indicate that Type II wastewater has no significant effect on fresh concrete properties, mechanical properties of hardened concrete, length change, sulfate resistance and corrosion resistance of hardened concrete, when used to both saturate the coarse aggregates, and be used as the mix water to produce Class I concrete.
6. The results of both Phase 1 and 2 indicates that both Type II wastewaters used in this study, which did not meet the FDOT water quality specification, Section 923 entitled, "Water for Concrete," but did comply with the water quality standards of AASHTO M 157, "*Standard Specification for Ready-Mixed Concrete*," had no detrimental effects on concrete properties.

Based on the data produced during this project, we recommend the following:

1. The FDOT water quality specification, Section 923 entitled, "Water for Concrete" be supplemented to address the use of Type II wastewater as aggregate irrigation and/or batch mixing water in the production of fresh concrete.
2. Type II wastewater shall be tested for compliance with the requirements established by AASHTO M 157 specification entitled, "*Standard Specification for Ready-Mixed Concrete*." The M 157 specification sets limits on the amount of sulfate, chloride ion, total solids, and total alkalies, as Na_2O equivalent, for water used in concrete. The frequency of testing shall be once per week for 4 weeks and once per month for 4 months prior to using the Type II wastewater for concrete production, provided no single sample fails to comply with AASHTO M 157 limits. After which, testing frequency will occur at bimonthly (once every other month) intervals. If a sample

fails to meet the AASHTO M 157 requirements, the sampling and testing procedure will be repeated at the previous testing frequency of once per week for 4 weeks, and once a month for 4 months prior to reusing the wastewater in concrete production.

3. Type II wastewater that complies with the required limits established by AASHTO M 157 and the frequency of testing established by Recommendation Number 2, should be primarily reused for irrigation of limestone coarse aggregate stockpiles in the concrete production process. This application would limit any effects of Type II wastewater on the fresh and hardened properties of the produced concrete. At the same time the limestone aggregate would buffer or lower the pH of the Type II wastewater, such that the effluent from the irrigation procedure (Type I wastewater) would no longer be considered hazardous and need to be stored in a lined settling pond.
4. If Type II wastewater were to be used as either partial or total mixing water for concrete production, it would have to meet:
    - the water quality limits of AASHTO M 157,
    - comply with these requirements at the frequency of testing provided in Recommendation Number 2, and
    - be used ONLY for Class I non-structural concrete applications.
5. Develop a test kit to quickly, accurately and economically sample and analyze Type II wastewater at ready-mix concrete production facilities to insure quality control and adherence to AASHTO M 157 limits on the amount of sulfate, chloride ion, total solids, and total alkalies, as Na_2O equivalent.

APPENDIX A

STATE HIGHWAY AGENCY SURVEY QUESTIONNAIRE

Name____Date_______________
Position____
Agency____
Phone Number____
E-mail Address ____
Agency's WWW Address http://____

The following survey contains six items and should take approximately ten minutes to complete. Once again, thank you for your participation.

Please check this box if you would like the results of the survey sent to you.□

1a. Is the reuse of wash water as mixing water in the production of new concrete allowed by your agency? Yes__________ No__________

1b. If Yes, what are the acceptance criteria (physical test limits and/or chemical limits)?

1c. If you do not allow the reuse of wash waters, why?

2a. Does your agency currently have any <u>standards</u> for the reuse of wash water as mixing water in new concrete? Yes__________ No__________

2b. If yes, please include a copy of the specifications your agency references to govern the reuse of wash water (if you are unable to include a copy, please list the title and section number of the specification referenced).

3. Please give any comments or suggestions you may have regarding handling of wash water from ready-mixed concrete operations.

APPENDIX B

FLORIDA READY MIXED CONCRETE PRODUCERS SURVEY QUESTIONNAIRE

QUESTIONNAIRE RELATED TO HANDLING OF WASTEWATER FROM READY-MIXED CONCRETE OPERATIONS

Contact Person:____
Title:____
Company Name:_______________________________________
Address:____
____
____

Tel. #____
Fax #____
E-mail:____

---

1. Does your company recycle wastewater? Yes ☐ No ☐ (If the answer is No skip questions 2 & 3)

2. How do you recycle wastewater? (please supply any sketches of your recycling system and also give a brief description of the operations)____________________

3. In what application do you use recycled wastewater?____________________

4. Have you performed any physical or chemical tests on wastewater to check if it complies with the requirements of DOT specifications or ASTM C94?
   Yes ☐ No ☐
   If yes, please indicate the type of wastewater* you tested and provide a copy of the test results. ____________________

5. With the cooperation of the ready-mixed concrete industry we will be performing tests to determine the physical and chemical properties of wastewater and the possibilities of recycling it. Would you be willing to have your wastewater sampled and tested? Yes ☐ No ☐

6. Based on your experience, what is the best way to handle wastewater?__________

7. What is your plant's average daily concrete production?
☐ 0-200 cyds/day ☐ 200-400 cyds/day ☐ 400+ cyds/day

8. What is the average daily quantity of water used for?
a) concrete production__________
b) spraying aggregate piles__________
c) washing out the inside of the concrete mixer drum__________
d) other operations associated with concrete production (please list)__________

9. What is your average amount of type I* wastewater generated in a normal working day?__________

10. Does the DOT allow you to use wastewater:
a) as concrete batching water? Yes ☐ No ☐
b) for spraying aggregate piles? Yes ☐ No ☐
c) for other purposes? Yes ☐ No ☐

11. Please give any comments or suggestions that will help solve the problems faced by the ready-mixed concrete industry regarding handling of wastewater.__________

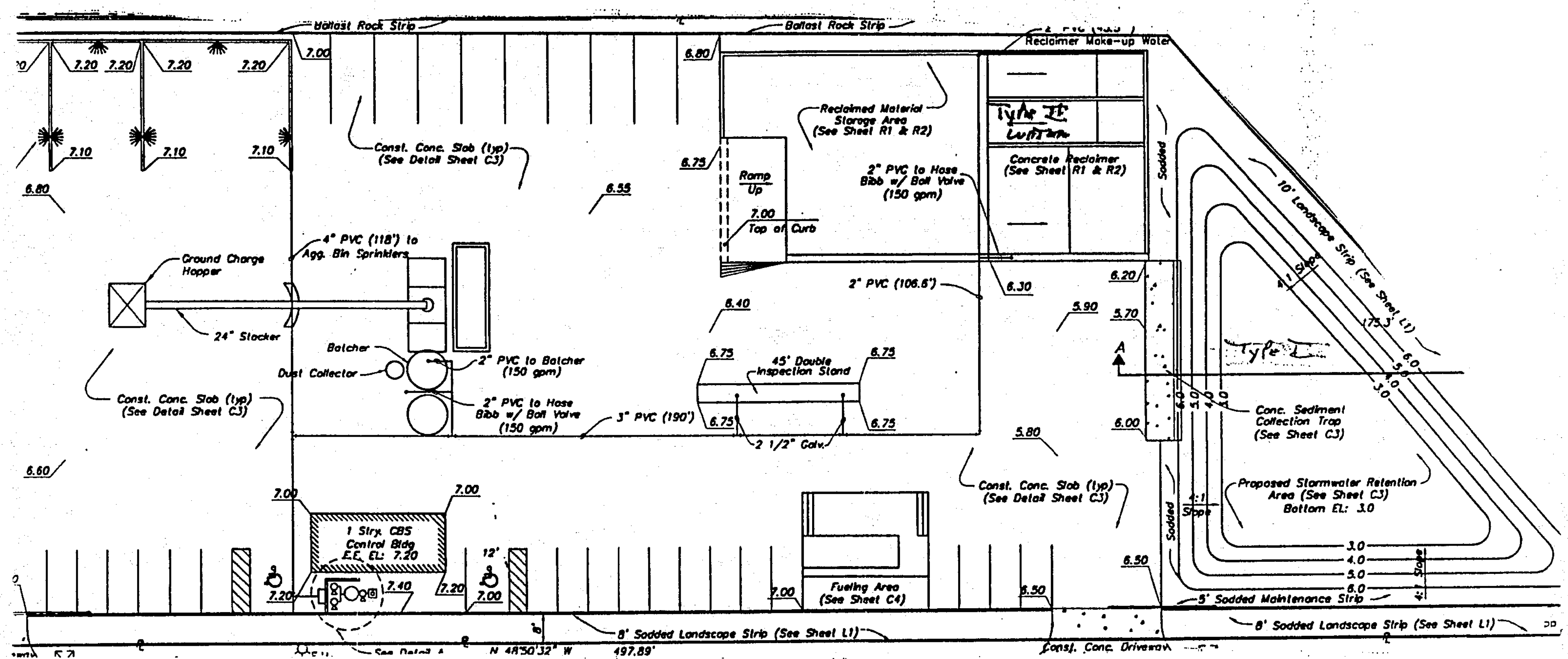
*Type I wastewater – waste water generated during general industrial activities at a concrete batch plant including conveyor washdown; spraying of water on aggregate piles; cleaning of the mixing plant and slump racks; and other similar sources of industrial activities: truck exterior washing: and contact stormwater runoff.

Type II wastewater – wastewater generated during internal concrete truck washout activities associated with a concrete batch plant and any other water commingled with this wastewater, including rainfall that falls or drains directly into Type II wastewater containment system.

RETURN TO: S. Abdol Chini, Ph.D., P.E., Associate Professor, M.E. Rinker School of Building Construction. University of Florida, P.O. Box 115703, Gainesville, FL 32611

APPENDIX C

TYPICAL READY-MIXED CONCRETE PRODUCTION PLANT WASTEWATER MANAGEMENT SYSTEM DESIGN



Ballast Rock Strip
Ballast Rock Strip
Reclaimer Make-up Water
Reclaimed Material Storage Area (See Sheet R1 & R2)
Concrete Reclaimer (See Sheet R1 & R2)
Const. Conc. Slab (typ) (See Detail Sheet C3)
Ramp Up
Top of Curb
2" PVC to Hose Bibb w/ Ball Valve (150 gpm)
2" PVC (106.6')
4" PVC (118') to Agg. Bin Sprinklers
Ground Charge Hopper
24" Stacker
Batcher
Dust Collector
2" PVC to Batcher (150 gpm)
3" PVC (190')
45' Double Inspection Stand
2 1/2" Galv.
1 Stry. CBS Control Bldg F.F. EL: 7.20
Fueling Area (See Sheet C4)
Conc. Sediment Collection Trap (See Sheet C3)
Proposed Stormwater Retention Area (See Sheet C3) Bottom EL: 3.0
10' Landscape Strip (See Sheet L1)
Sodded
5' Sodded Maintenance Strip
8' Sodded Landscape Strip (See Sheet L1)
Const. Conc. Driveway
N 48°50'32" W
497.89'
See Detail A
4:1 Slope
Type II
Type I

APPENDIX D

SAMPLE WATER ANALYSIS FROM QST ENVIRONMENTAL

PROJECT NUMBER 1297303V L228 PROJECT NAME UF BUILDING SCHOOL OF CONSTRUCTION
FIELD GROUP UFBCW LAB COORDINATOR RICHARD ROBINSON

CLIENT SAMPLE ID'S:			STARK2A
QST FIELD GROUP:			UFBCW
QST SEQUENCE #:			18
DATE COLLECTED:			02/25/98
TIME COLLECTED:			15:20
PARAMETERS	UNITS	METHOD	
SODIUM,TOTAL	MG/L	EPA 6010	16.6
POTASSIUM,TOTAL	MG/L	EPA 6010	58.8
ALKALINITY,TOTAL	MG/L-CACO3	EPA 310.1	556
ALKALINITY,BICARBONATE	MG/L-CACO3	EPA 310.1	<5.0
ALKALINITY,CARBONATE	MG/L-CAC03	EPA 310.1	32.0
SULFATE	MG/L	EPA 9056	157.6
CHLORIDE	MG/L	EPA 9056	35.46
RESIDUE,TOT.(TS)	MG/L	EPA 160.3	1070
RESIDUE,SUSPENDED.(TSS)	MG/L	EPA 160.2	48
RESIDUE,TOT. VOLATILE	MG/L	EPA 160.4	363
RESIDUE,DISS (TDS)	MG/L	EPA 160.1	977

APPENDIX E

ADMIXTURE INFORMATION SHEETS

GRACE · concrete admixtures

DAREX® AEA® admixture is an aqueous solution of a complex mixture of organic acid salts. It contains a catalyst for more rapid and complete hydration of portland cement. DAREX AEA is specially formulated for use as an air entraining admixture for concrete and is manufactured under rigid control which provides uniform, predictable performance. It is supplied ready-to-use and does not require premixing with water. One gallon weighs approximately 8.5 lbs.

USES:

DAREX AEA is used in ready-mix, block, and concrete products plants. It is also used on the job with job-site mixers, highway pavers. . .wherever concrete is mixed and there is a need for purposeful air entrainment.

Because DAREX AEA plasticizes or "fattens" the mix, it is particularly effective with slag, lightweight, or manufactured aggregates which tend to produce harsh concrete. It also makes possible the use of natural sand deficient in fines.

AIR ENTRAINING ACTION:

Air is entrained by the development of a semi-microscopic bubble system—introduced into the mix by agitation and stabilized by DAREX AEA—in the mortar phase of the concrete.

Air Content is Controlled. Because excessive entrained air may be detrimental to strengths, DAREX AEA is designed to limit the maximum amount of air entrained despite an inadvertent overdose. DAREX AEA is not supersensitive. Small variations in addition rate are not critical and do not materially affect the amount of air entrained.

Workability is Improved. Millions of tiny air bubbles entrained with DAREX AEA act as flexible ball bearings, lubricating and plasticizing the concrete mix. This permits a substantial reduction in mixing water with no loss in slump. Placeability is improved. . . bleeding, green shrinkage and segregation are minimized.

Durability is Increased. DAREX AEA concrete is extremely durable, particularly when subjected to freezing and thawing. It has a remarkable resistance to frost and deicing salts, as well as to sulfate, sea and alkaline waters.

COMPATIBILITY WITH OTHER ADMIXTURES:

DAREX AEA is compatible in concrete with all known water reducing admixtures and water reducing retarders, such as WRDA® with HYCOL™, WRDA® and DARATARD®. By combining the separate effects of air entrainment with the dispersion of a water reducing admixture, the water requirement of concrete may be reduced up to 20%—with proportional increases in strength and outstanding improvement in durability. DAREX AEA is also compatible with concrete mixes containing calcium chloride. EACH ADMIXTURE SHOULD BE ADDED SEPARATELY TO THE MIX.

ADDITION RATES:

There is no standard addition rate for DAREX AEA. The amount to be used will depend upon the amount of air required under job conditions, usually in the range of 4 to 8%. Typical factors which might influence the amount of air entrained are: temperature, cement, sand gradation, and use of extra fine materials such as fly ash. Typical DAREX AEA addition rates range from ¾ to 3 fluid ounces per 100 lbs. of cement.

The air entraining efficiency of DAREX AEA becomes even greater when used with water reducing and set retarding agents. This may allow a reduction of up to two-thirds in the amount of DAREX AEA required for the specified air content.

MIX ADJUSTMENT:

Entrained air results in increased yields with a consequent decrease in the cement content of the placed concrete. This condition calls for a mix adjustment, usually accomplished by reducing the fine aggregate content. This is in addition to the reduction in water content brought about by the increase in plasticity.

DISPENSING EQUIPMENT:

A complete line of automatic DAREX AEA dispensers is available. Accurate and simple, these dispensers are easily adapted to existing facilities on paving mixers and in batching plants.

PACKAGING:

DAREX AEA is available in bulk, delivered in metered tank trunks, and 55-gallon drums. DAREX AEA contains no flammable ingredients. IT FREEZES AT ABOUT 30°F, BUT ITS AIR ENTRAINING PROPERTIES ARE COMPLETELY RESTORED BY THAWING AND THOROUGH AGITATION.

ARCHITECTS' SPECIFICATION FOR CONCRETE AIR ENTRAINING ADMIXTURE:

Concrete shall be air entrained concrete, containing 4 to 8% entrained air. The air contents in the concrete shall be determined by the pressure method (ASTM Designation C 231) or gravimetric method (ASTM Designation C 138). The air entraining admixture shall be a purified hydrocarbon type with a cement catalyst, such as DAREX AEA, as manufactured by the Construction Products Division of W.R. Grace & Co.–Conn., or equal. The air entraining admixture shall be added at the concrete mixer or batching plant at approximately ¾ to 3 fluid ounces per 100 lbs. of cement, or in such quantities as to give the specified air contents.

GRACE
Construction Products

AIR-5

Printed in U.S.A. 3/89 FA/GPS/2500

WRDA®-64

WATER-REDUCING ADMIXTURE ASTM C 494 TYPES A & D

Description:

WRDA®-64 is a polymer based aqueous solution of complex organic compounds. WRDA-64 is a ready-to-use low viscosity liquid which is factory pre-mixed in exact proportions to minimize handling, eliminate mistakes and guesswork.

WRDA-64 contains no calcium chloride and weighs approximately 10.1 lbs./gallon (1.21 kg/L).

Uses:

WRDA-64 produces a concrete with lower water content (typically 8 to 10% reduction), greater plasticity and higher strength. It is used in ready-mix plants, block and concrete product plants, in lightweight and prestressed work . . . wherever concrete is produced.

Advantages:

WRDA-64 offers significant advantages over single component water reducers. Water reduction and setting times are more consistent due to the polymer components. WRDA-64 also performs especially well in concrete containing fly ash and other pozzolans.

The use of WRDA-64 produces a plastic concrete that is more workable, easier to place and more finishable than plain or other admixtured concrete. In the hardened state, WRDA-64 concrete has higher compressive and flexural strengths at all ages than untreated or conventional admixtured concrete.

The greater degree of plasticity achieved, compared with conventional water-reducing admixtures, allows improved finishability.

Finishability:

Finishers have stated that the cement paste, or mortar, in WRDA-64 admixtured concrete has improved trowelability. The influence of WRDA-64 on the finishability of lean mixes has been particularly noticeable. Floating and troweling, by machine or hand, imparts a smooth, close tolerance surface.

Addition Rate:

The addition rate range of WRDA-64 is 3 to 6 fluid ounces per 100 pounds (195-390 mL/100 kg) of cement. Pretesting is required to determine the appropriate addition rate for Type A and Type D performance. Optimum addition depends on the other concrete mixture components, job conditions, and desired performance characteristics.

Dispensing Equipment:

A complete line of accurate, automatic dispensing equipment is available. WRDA-64 may be introduced to the mix on the sand or in the water.

Compatibility with other Admixtures:

WRDA-64 is compatible in concrete with all air-entraining admixtures such as Darex® II AEA and Daravair®. Due to the slight air entraining properties of WRDA-64, itself, the addition rate of air-entraining admixture may be reduced by about 25%. By combining the separate effects of air-entraining and dispersion, the water requirement of concrete may be reduced up to 15%. Each admixture should be added separately. While WRDA 64 contains no calcium chloride, it is compatible with calcium chloride in concrete mixes. Again, each should be added separately.

Packaging:

WRDA-64 is available in bulk, delivered by metered tank trucks, and in 55 gallon (210 L) drums. WRDA-64 contains no flammable ingredients. It will freeze at about 28°F (-2°C), but will return to full strength after thawing and thorough agitation.

Architects' Specification for Concrete Water-Reducing Admixture:

Concrete shall be designed in accordance with ACI Standard Recommended Practice for Selecting Proportions for Concrete, ACI 211.

The water-reducing (or water-reducing and retarding) admixture shall be WRDA-64, as manufactured by Grace Construction Products, or equal. The admixture shall not contain calcium chloride. It shall be used in strict accordance with the manufacturer's recommendations. The admixture shall comply with ASTM Designation C 494, Type A water-reducing (or Type D water-reducing and retarding) admixtures. Certification of compliance shall be made available on request.

The admixture shall be considered part of the total water. The admixture shall be delivered as a ready-to-use liquid product and shall require no mixing at the batching plant or job site.

W.R. Grace & Co.-Conn. 62 Whittemore Avenue, Cambridge, MA 02140-1692 Tel.: (617) 876-1400

CMD-366B Printed in U.S.A. 2/95 FA/GPS/5M

GRACE
Construction Products

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