LUMPS AND BALLS IN HIGH-SLUMP CONCRETE: REASONS AND REMEDY

Final Report

Submitted to:

Florida Department of Transportation (FDOT)

Submitted By:

Irtishad Ahmad, PhD. PE.
Principal Investigator and Associate Professor
Department of Civil and Environmental Engineering
Florida International University, Miami, Florida
Tel: (305) 348-3045
E-mail: ahmadi@fiu.edu

Salman Azhar, Ph.D. Candidate
Research Assistant
Department of Civil and Environmental Engineering
Florida International University, Miami, Florida
E-mail: salman.azhar@fiu.edu

John O. Sobanjo, PhD., P.E.
Co-Principal Investigator and Associate Professor
Department of Civil and Environmental Engineering
Florida State University, Tallahassee
E-mail: sobanjo@eng.fsu.edu

Under
Contract No. BC837

December 2002

DISCLAIMER

This research study was conduced with the aim to identify factors responsible for producing lumps and balls in high-slump concrete. Due to high cost of experimentation, limited experimental data was collected. As such, conclusions and recommendations made in this report should be considered based on this limitation.

ACKNOWLEDGMENTS

This report would never have seen the light of the day had it not received the help and support from the following individuals who directly or indirectly contributed to this research study. The authors would like to extend their gratitude and appreciation to:

Mr. Ken Blanchard, P.E.
Area Construction Engineer, Florida Department of Transportation, Tallahassee

Sastry Putcha, Ph.D, P.E.
State Construction Geotechnical Engineer, Florida Department of Transportation, Tallahassee

Mr. Leigh Markert
Districts 4 and 6 Concrete Engineer, Florida Department of Transportation, Broward

Mr. Michael Bergin, P.E.
State Structural/Materials Engineer, Florida Department of Transportation, Gainesville

Ms. Robbin Dano
Districts 4 and 6 Concrete Engineer, Florida Department of Transportation, Broward

Mr. Jerry Haught, P.E.
Director of Technical Services, CSR Rinker, West Palm Beach

The Authors would like to thank *Mr. Ivan Canino*, Graduate Student at the Department of Civil and Environmental Engineering, Florida International University, Miami for helping out during experiments.

Appreciation is also due to all personnel at CSR Rinker Concrete Plant for conducting the experiments and providing an insight on the concrete production plant processes.

EXECUTIVE SUMMARY

In high-slump truck-mixed concrete, mostly used in drilled shafts (deep foundation system for heavy loads), lumps and balls typically the size of a lemon to a baseball, are not uncommon. Such lumps and balls, usually composed of cement, sand and coarse aggregate, jeopardize structural integrity of concrete by forming weakened zones and by increasing the potential for soil intrusion. Florida Department of Transportation (FDOT) requires that the concrete should be free from lumps. Hence when lumps are found, concrete batches are to be rejected. Consequences are disruption of work, costly rework, and loss of valuable time.

This experimental study was conducted to find the root causes of lumps and balls formation in high-slump truck-mixed concrete and to develop procedures to avoid them. Experiments were conducted at the CSR Rinker Concrete Plant in Miami, Florida, based on a protocol developed by a team of Florida Department of Transportation (FDOT) concrete engineers, CSR Rinker concrete plant personnel, and the Florida International University research team. A total of seventeen truckloads were investigated in two phases, first in April 2001 and second in March 2002. The variables investigated were the materials discharge rate, size of truck-load, headwater percentage content and number of initial mixing revolutions.

It was found that using standard size of truck-load and discharge rate, namely 9 cu yd and 200 lbs/sec, a headwater percentage between 30%-40% of batch water, and between 90-100 initial number of revolutions at a speed of 12 revolutions per minute produce lumps-free concrete. It was further found that inadequate mixing and poor batching procedures caused concrete lumps. On the basis of experimental results, recommendations about specific size of truck-load, discharge rate, number of mixing revolutions, and headwater percentage are made. At the end, a set of guidelines is presented to produce lumps free concrete and a protocol to follow when lumps and balls are found in concrete batches.

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Chapter 1

INTRODUCTION

1.1 General

Ready-mix concrete can be produced in a number of ways; the most common methods are *central-mixing* and the *truck-mixing*. Central mixing plants usually provide good quality homogeneous concrete in large amounts. However, due to the large size, a great capital is required for their setup and operations. This is why large batching facilities are not abundant. Moreover, concrete delivery is limited to a specific diameter distance from the plant. Due to this limitation, concrete producers use other less expensive alternatives to produce and deliver ready-mixed concrete (NRMCA, 2002).

One alternative method of producing ready-mix concrete is to batch concrete in truck mixers. The components of concrete are mechanically introduced to the inclined drum of the truck and are then mixed in the truck. Truck mixing allows the concrete producer to batch concrete of particular requirements for a customer; and increases the range and reliability of the concrete delivery. In the United States, the overwhelming majority of ready mixed concrete producers use truck-mixed concrete due to its low capital cost and greater coverage area. Truck mixing allows more flexibility to a concrete producer to produce concrete according to customer specifications (NRMCA 2002). There are three production techniques for truck mixed concrete:

Concrete mixed at the job site: While traveling to the job site the drum is turned at agitating speed (slow speed). After arriving at the job site, the concrete is completely mixed. The drum is then turned for 70 to 100 revolutions, or about five minutes, at mixing speed to ensure uniform mixing.

Concrete mixed in the yard: The drum is turned at high speed (12-15 rpm) for 50 revolutions. This allows a quick mixing of the batch. The concrete is then agitated slowly while driving to the job site.

Concrete mixed in transit: The drum is turned at medium speed (about 8 rpm) for 70 revolutions while driving to the job site. The drum is then slowed to agitating speed till it reaches the job site.

Mixing concrete in a truck is different from mixing it in a central batch plant. Contrary to central stationary mixing plants, truck mixers do not have large mixing blades and high mixing capacities. Mixing blades in a plant lift and drop the concrete. Width limitations on truck mixers dictate the use of spiral blades that first move the concrete down towards the head end of the drum then back up the central axis towards the discharge end. Therefore, concrete mixed in a truck mixer is normally not as uniform as concrete from a central batching plant (Gaynor 1996).

In the State of Florida, the majority of ready-mix concrete producers produce truck mixed concrete. Therefore, investigation and research on truck mixing techniques are imperative in this region. Major clients, such as the Florida Department of Transportation (FDOT), have faced problems with the truck mixed high-slump concrete used in drilled shafts. It is found that the high-slump concrete is prone to forming cement balls when batched or mixed in a truck mixer (Figure 1.1). Cement balls are round lumps of cement, sand, and coarse aggregate, typically about the size of a lemon to a baseball (Gaynor, 1996). Mixing usually grinds them up in a low slump concrete mix (2-3 inch), however, in high-slump concrete (over 6 inch slump), such balls don’t breakup due to high fluidity of concrete.

Figure 1.1: Concrete in formwork with a cement ball (Gaynor, 1996)

1.2 Research Objectives

Florida Department of Transportation (FDOT) Standard Specifications for Road and Bridge Construction (2000) section 346-7.4.1 requires that concrete should be free from lumps and balls of cementations material. When lumps and balls are found, concrete batches are to be rejected, consequences of which may cause disruption of work, costly rework and loss of valuable time. This research was conducted with the objective of determining the reasons for the formation of lumps and balls in high-slump truck mixed concrete and to find ways to avoid them. The production of lumps-free concrete is in the best interest of all parties involved in the project, i.e. the concrete producer, the contractor and the FDOT. Major causes of lumps and balls formation, ways to avoid them, and a set of guidelines to follow when lumps and balls are found, are outlined in this report. A set of proposed specifications for high-slump truck mixed concrete is included for consideration by the FDOT to expand or amend the existing specifications.

1.3 Scope

All the experiments were carried out at the CSR concrete mixing plant in Miami. The concrete mix and its proportions were identical for all batches using the FDOT mix design (Class 4: #06-0281). Because of a large number of variables that can affect the quality of concrete and due to high cost of testing, variables were selected carefully by the research team to fulfill the objectives of this research study. The variables chosen for the study are: 1) discharge rate (speed at which the materials are charged into the mixing truck through chute), ii) size of concrete load (total volume of concrete), iii) number of initial revolutions (number of revolutions of truck mixer after addition of materials but before slump adjustment), and iv) headwater percentage (water added to the mixer before the addition of materials). The following variables were not studied and were kept at fixed level for all test batches: 1) the mixing rate and charging rate of the truck mixer drum, 2) the discharge sequence of the materials in to the tuck mixer, 3) the concrete mix design, and 4) the mixing equipment or truck. The same truck was used in all test batches, in order to eliminate variation caused by different truck.

It is important to note that the computer batching software at CSR Rinker concrete plant is set to produce 3 inch slump concrete. The 3 inch slump is selected because of its high demand and due to the fact that high-slump concrete can still be produced by adding additional water to the concrete. The reason is to minimize interruptions during batching at the plant. Since the software is set to produce 3 inch slump concrete, the FDOT mix design water (for 7-9 inch slump concrete) was trimmed. This trimmed water called as *jobsite allowable water* was later added to the mix to increase the slump to 7-9 inches. The amount of water needed as per the batching software for a regular 3 inch slump concrete was added in two parts, the first part was added before charging of materials called *headwater*, and the second part after charging of all the materials called *tailwater*. Thus the total mix design water for the high slump drilled shaft concrete was divided into three parts as follows:

Total mix design water = Headwater + Tailwater + Jobsite allowable water

The term batch water wherever used in this study means the mix design water for 3 inch slump concrete, i.e. total mix design water minus jobsite allowable water. The term *jobsite allowable water* is used to indicate the additional water needed to increase the slump of concrete from 3 inch to 7-9 inch. It should not be confused with so-called *tempered* water which means the water allowance available in some mix designs to increase the slump of concrete at the jobsite to compensate for slump loss.

Headwater percentage, as used in this report, means percentage of batch water (headwater + tailwater). However, if any plant is using a batching process without using any jobsite allowable water (with software configured to produce 7-9 inch slump concrete), headwater percentage would mean the percentage of total mix-design water, which is the batch water for such a case.

The investigation was conducted in two phases. In the first phase, discharge rate, size of concrete load and the headwater percentage were studied as variables. The results of the first phase indicated that the headwater percentage and the number of revolutions should be investigated further. Hence in the second phase, headwater percentage and the number of initial revolutions were selected as the variables. The following tests were carried out: *Slump test, Air content test, Density test* and the *compressive strength test (in first phase only)*. The standard ASTM testing procedures were followed. The concrete was passed through a grate having 2.5 inch openings to collect concrete lumps before discharging into another empty truck. The size and number of lumps were recorded for each batch and selected samples were sent to the laboratory for sieve analysis to determine their gradation.

1.4 Organization of the Report

This report is organized as follows: it begins with an introduction of concrete production techniques, a statement of the research objectives and the scope of the research (Chapter 1). In Chapter 2, a brief literature review on the problems associated with truck mixed concrete along with opinions of some professionals is presented. Next, in Chapter 3, the methodology and protocol used to carry out the investigations are described. Results and analysis of findings are discussed in Chapter 4. Further discussions, conclusions and recommendations made on the basis of the experimental findings are included in the last chapter (Chapter 5) The detailed experimental data is available in the appendices.

Chapter 2

PROBLEMS IN TRUCK MIXED CONCRETE

2.1 Mixing Concrete in a Truck Mixer

The National Ready Mix Concrete Association (NRMCA) has conducted extensive research on the batching and mixing sequence of truck mixed concrete (NRMCA, 1975). It is found that the batching and mixing procedures, if not properly followed, may produce a non-homogenous and non-uniform concrete. The factors that influence the homogeneity of the truck mixed concrete are summarized below (NRMCA, 1975).

2.1.1. Method of loading

This is the most influential variant and has the greatest effect on the batch uniformity. The water adding procedures also influence the homogeneity of concrete and should be investigated separately for a particular method of loading. Typical loading methods such as ribbon feeding, slurry mixing and cement-last mixing are explained in the following sections (NRMCA 1975).

<u>Blending fine and coarse aggregates</u>

When coarse aggregates are batched in two different sizes and the maximum size is greater than 1.5 inch, the fine and coarse aggregates should be blended during charging of materials. In all loadings, the feeding of coarse aggregates should start ahead of the fine aggregates in order to avoid head packs (dry sand streaks).

<u>Ribbon loading</u>

This method involves the blending of fine and coarse aggregates, and cement during the loading cycle of materials. Ribbon loading is more susceptible to the formation of head-packs and cement balls. In order to avoid these problems, the coarse aggregates and some water should be added in the mixer before the addition of fine aggregates and cement.

The charging of water is reasonably flexible in this loading method. The best uniformity is obtained when half of the water is batched before the solids and half after the solids.

Cement-last loading

This type of loading is very sensitive to the method of water addition and can result either excellent or poor uniformity in concrete. The advantage of this loading is that if the cement is loaded last without turning the drum and mixing is performed after arrival at the job site, then very little cement becomes wetted and delivery time can be extended an hour or more without compromising quality. It is useful when a plant needs to handle a variety of different cements and aggregates. The maximum batch size is however less than the rated mixer capacity. Coarse aggregate should lead the fine aggregates and cement to avoid head-packs and ¼ of the water should be added after the cement.

Sandwich loading

This loading involves charging the cement between equal increments of ribbon-fed aggregates and water.

Double batching

In double batching, concrete is batched in two, 4 cubic yards cement-last batches, which results in a better uniformity than a single eight cubic yards batch.

Slurry mixing

The time required for this procedure makes it impractical, but it produces the best uniformity and strength. Furthermore, it avoids the occurrence of head-packs, sand streaks and cement balls. This is a good loading method to try when nothing else works.

2.1.2. Mixing revolutions

When concrete is improperly mixed, additional revolutions will not necessarily to solve the problem. A change in loading procedure is likely to provide the best solution. In loadings where mixing is marginal to fair at 50 revolutions, the additional mixing of 100 or 150 revolutions will produce only modest improvement. Only rarely will an increase from the ASTM minimum of 70 to the maximum of 100 produce a marked improvement in uniformity. As a general rule the number of revolutions should be doubled to obtain significant improvement in uniformity.

2.1.3. Mixing speeds

The various tests demonstrated that in the range of 4 to 12 rpm, drum speed does not significantly affect the uniformity obtained in a fixed number of revolutions. However, mixing does improve in the range of 12 to 22 rpm's in some cases. Above 22 rpm mixing adversely affects concrete uniformity.

2.1.4. Charging speed and inclination of drum

This does not greatly influence mixing, head-packs, or cement balls.

2.1.5. Batch size

This is not one of the critical variables affecting uniformity. A one or two cubic yard reduction of the rated mixer capacity will produce a modest improvement in uniformity, but seldom will such a change solve serious uniformity problems.

2.1.6. Concrete proportions and materials.

Limited test are conducted with concrete of different slumps, air contents and cement contents using a variety of aggregates. These variations in the mix composition did not have large or constant effects on the ease or difficulty of producing well-mixed concrete.

2.2 Uniformity Problems in Truck Mixed Concrete

Mixing blades in a plant lift and drop the concrete. Width limitations on truck mixers dictate the use of spiral blades that first move the concrete down towards the head end of the drum then back up the central axis towards the discharge end. Therefore, concrete mixed in a truck mixer is normally not as uniform as concrete from a central batching plant (Gaynor 1996).

The non-uniformity of truck mixed concrete causes the development of *head packs* and *concrete balls*. Head packs refer to sand streaks that appear when discharging the final portions of the concrete. Head packs are produced when sand is loaded before coarse aggregates. The sand packs in the head of the drum and breaks loose after about half the load has been discharged. Usually the head pack goes unnoticed because the sand gets mixed into the concrete before it reaches the chute. Despite the absence of visual clues, head packs are undesirable because they cause variations in slump, air content, and strength. Head packs can be avoided by loading sand and cement together after 50-75% of the coarse aggregates and water has been charged in the truck (Gaynor 1996).

Concrete balls are round lumps of cement, sand and coarse aggregates, typically the size of a lemon to a baseball. Such lumps and balls jeopardize the structural integrity of hardened concrete by forming weakened zones and by increasing the potential for soil intrusion. Moreover, they reduce the freeze-thaw resistance of hardened concrete. Their occurrence usually indicates problems with batching and mixing, such as improper batching sequencing or not enough revolutions of the mixing drum (Suprenant 1992). Gaynor (1996) states that in a low-slump concrete (2-3 inch slump), concrete balls are usually grinded during mixing operation. However, in high-slump concrete (over 6 inch slump), such balls do not break up due to high fluidity of concrete. Hence a special loading and mixing sequence is desirable for high-slump concrete to produce lumps-free concrete.

2.3 Avoiding Uniformity Problems in Truck Mixed Concrete

There has not been much literature published on the uniformity problems of truck mixed concrete. However, a paper by Mr. Richard Gaynor, former Director of National Ready Mixed Concrete Association (NRMCA), outlines the various techniques to avoid problems arising from non-uniformity in truck mixed concrete (Gaynor, 1996).

Gaynor states "*You can eliminate cement balls by changing from ribbon feeding to slurry mixing. There isn't enough water to make a real slurry, but this procedure still works. Load all the water, then load the cement and mix for one minute at high drum speed. (Don't try to load cement before water. No known truck mixer will mix concrete properly if cement is the first ingredient). Next, ribbon in the fine and coarse aggregate. Although slurry mixing prevents cement balls, truck-loading can be slow and dusty*".

Gaynor (1996) recommended a more practical solution to the problem, by optimizing the loading procedure of coarse aggregates and water. He states "Put about 4,000 pounds of coarse aggregate into the drum first to avoid a head pack. Then add about ¾ of the water, ribbon in the rest of the aggregate (coarse and fine) and cement (Figure 2.1). And finally add the remaining ¼ of the water". To avoid head packs, Gaynor suggested batching about 2 tons of coarse aggregates into the drum before adding other ingredient.

Gaynor discourages the practice of batching a 2 or 3 inch slump concrete and then using the job site allowable water to increase the slump to 8 inches.

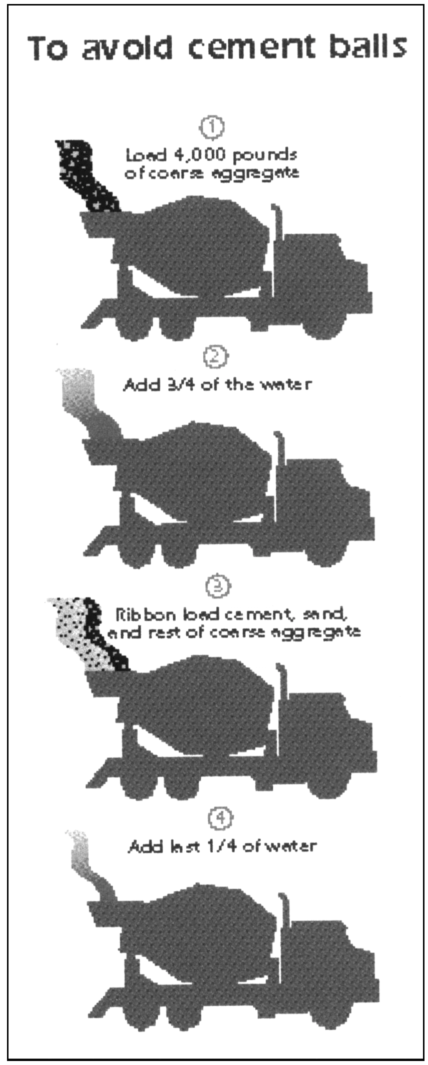

Figure 2.1: How to avoid cement balls?

> *"One quick way to produce high-slump concrete is to mix the concrete at a 2 inch slump, then add enough water to reach the desired slump. However, this is an ineffective solution because cement balls are a cause of improper loading or batching sequences. Moreover, this procedure creates other problems such as shrinkage and high creep; furthermore, this is an expensive and timely solution" (Gaynor, 1996).*

Nevertheless, to achieve the large amount of water needed in high-slump concrete, this method is most commonly practiced in Florida and is used by CSR Rinker concrete plant. However, this practice forms concrete lumps and balls in the high-slump concrete mix used by the FDOT for drilled shafts. Gaynor (1996) found out that concrete lumps are a cause of improper loading sequence and mixing procedures. Hence we conducted this research to find the critical loading sequence and mixing procedure to avoid non uniformity problems.

2.4 Professional Opinions

To deal with the fact that there are not much published literature on batching of high-slump truck mixed concrete, the authors contacted various government and private concrete engineers and inquired about their experiences in batching high-slump truck mixed concrete and in particular, if they had problems with formation of lumps in such concrete. Many commonalities were noticed in techniques for batching high-slump concrete and problems with such techniques. Following is a summary of these correspondences.

2.4.1 California Department of Transportation

Mr. Daniel Zuhlke from the California Department of Transportation states why cement balls are formed: "*increased water in a concrete mix tends to ball the cement since the dry cement coats rapidly with the water and leaves the interior dry*" (Zuhlke, 2001). In other words, the cement is mixed with the aggregates before the water can reach it. Mr. Zuhlke goes on to write on the remedy to the problem.

> "*To mitigate this condition, add mix water into the mixer over the full period of charging the mixer with the dry material. Ribbon feed the dry material at the same time. The mixer must be clean and in good condition, not overloaded, and operating at optimum speed; also make sure the mixer blades are not worn more than 10%*" (Zuhlke, 2001).

2.4.2 Georgia Department of Transportation

Mr. Robert Crown from the Georgia Department of Transportation writes:

> "*It is Georgia's experience that lumps are usually related more to the batching sequence of the materials at the plant site. Batching sequence will vary at different plants due to plant type, central mix, dry batch or shrink mix. We have had very few problems with lumping. Most plants charge a portion of the mix water first and then some aggregate before the cement is charged. We have had, in some instances, where the water and cement stick in the front of the drum (head pack) and comes loose during transit and we end up with 0" slump at the job and not enough water to bring it back to a usable slump. Changing the batch sequence solved the problem. Therefore, since there are varying batching situations, we depend on each producer to know his best batching sequence instead of specifying*" (Crown, 2001).

2.4.3 Online Concrete Database

Using an online concrete database called Dr. Concrete, Mr. Kenneth from Austin, TX. States:

> "*I don't know of any studies, but I can tell you from experience what can cause lumps or balls in the mix, whether it is high or low slump: There are several factors that contribute to those unsightly concrete balls coming*

> *out of your mixer and irritating the finishers. Worn down fins or fins with build up; charging speeds too slow or too fast; putting water in with cement; putting wet sand in with cement; not putting enough head water in the drum; not putting enough coarse aggregate in before adding sand and cement; not mixing long enough before leaving for the job; and the worst cause of all - clay balls in your aggregates. If you put as much water and coarse aggregate in the front of the load as you can, that will help overcome some of the other factors that create balls*" (Kenneth, 2001).

2.4.4 Interviews with Plant Personnel in Tallahassee, Florida

An interview was conducted with Mr. Dan Doerrfeld (Area Manager) and Mr. Don Patterson (Plant Superintendent) of SEMAX Plant on March 08, 2001 in Tallahassee, Florida. They expressed familiarities with the FDOT drilled shaft concrete specifications and production. The opinion of these personnel was that lumps and balls are formed in high-slump concrete because of the following reasons: (1) the high water requirement; (2) the loading (discharge) rate – you may need to load slower than normal rate; and (3) high cement requirement. Information derived at this meeting can be summarized as follows:

- Their plant uses a 100% truck mixing procedure, i.e. all materials batched at plant, and the mixing done in the truck, with a minimum of 75 revolutions of mixing being done on the plant site before leaving for delivery at the job site.
- Water is introduced first, with typical headwater at 80% of total water requirement. Aggregates (coarse and fine) are then loaded, before cement and fly ash. The cementitious materials (cement and fly ash) are introduced after about 15% of the total aggregates have been loaded. The timing of the loading is such that the cement and the fly ash should be loaded to finish simultaneously with the loading of the aggregates. The final water is introduced to the complete the loading and the mixing.
- It has been observed that fast loading of the materials may lead to inadequate blending of the concrete ingredients, and result in lumps and balls in the mix.

- If the cement and fly ash are introduced after all the aggregates have been loaded, the cementitious materials will not blend with the aggregate and may result in lumps and balls. The suggestion is to avoid finishing the aggregates loading before using up all the cementitious materials.
- Typical loading rate is 150 lb/sec to 180 lb/sec for the aggregates and 40 lb/sec for the cement.
- Lumps and balls may contain any or all of the ingredients of concrete (aggregates, cement, fly ask), not just only cement.

Another interview was conducted with a Quality Assurance Personnel (Meredith Brown) on March 07, 2001 at the Florida Rock Industries Plant, in Tallahassee, Florida. The opinion of Mr. Brown was that the high cement requirement of the FDOT drilled shaft concrete mix design necessitate fast loading rate of cement at the end of the overall material loading. This may cause inadequate blending, resulting in lumps and balls in the mix.

On June 06, 2001, a discussion was also done with the Plant Superintendent (Danny Collins) of Tallahassee RediMix Plant, in Tallahassee, Florida. Mr. Collin's opinions on the formation of lumps and balls in high-slump drilled shaft concrete include the following:

- The fast loading rate of materials into the truck may contribute to formation of lumps and balls.
- Aggregates should be blended adequately.
- Water and cement mixing together (alone) may result in formation of lumps and balls.
- There may be hard material build-ups inside the truck from previous jobs.

2.5 Testing for Mixing Uniformity

Standard Specifications for Ready Mixed Concrete, ASTM C94, contains uniformity testing procedures and requirements. Samples should be taken from two parts of the batch and be tested for slump, air content, strength, coarse aggregate content, and air free unit weight of concrete and of mortar. Usually changes in slump, air content, and strength correlate to changes in the other characteristics, and a complete test of all six characteristics is rarely necessary.

The specification also suggests that slump tests are a quick way of checking the probable degree of uniformity. Observation of concrete slump during unloading, supplemented by occasional testing, will be enough to confirm basic mixing uniformity.

Uniformity tests must be performed by skilled personnel because any variation in testing methods will be reflected in the uniformity test results. For instance, ASTMC C94 requires strength tests from two samples to agree within 7.5%. Based on ASTM precision statements for the strength test, about half of the strength difference between two concrete samples will be a result of testing variation rather than real variation in the concrete. The inherent variability in slump, air content, and unit weight tests is greater than that for strength tests, and deviations from standard testing methods increase variability. Thus, it is critical to perform these tests correctly (Gaynor, 1996).

2.6 Summary

Gaynor (1996) concluded that the method of materials loading and mixing sequence are the two major sources causing non-uniformity in the truck mixed concrete. Moreover, water addition procedure should be examined. Any incorrect timing or improper water loading affects the mix. Gaynor (1996) believes that ribbon loading is prone to form head-packs and concrete lumps. To avoid this, he suggested that the coarse aggregate and some water should be placed prior to the sand and cement. The tests performed in this research explored the effect of number of revolutions on formation of lumps and the findings are discussed later.

From the above discussions, one may think that concrete lumps are most likely caused by improper loading and poor sequencing procedures, especially in high-slump concrete. High-slump concrete requires an unusually high amount of water in order to meet workability requirements. Batching all materials including all the water at once, does not produce a good mix. This is because the excess water does not permit the individual materials to be thoroughly combined; instead it creates a sea of sporadic materials in the truck mixer. If the concrete does not mix properly, any addition of water will increase the problem and reduce the concrete strength. The purpose of this research is to improve the batching procedure by making it practical and efficient and by producing lumps-free high-slump concrete.

Chapter 3

METHODOLOGY

3.1 General

The research team has developed a protocol for conducting experiments in order to determine the causes of the problem and to find possible solutions that could eliminate lumps and balls in high-slump concrete. A total of seventeen test-loads were batched to study the effects of test variables, as mentioned earlier as well as in the following sections. Originally, just one phase of testing was planned, but the results of the first phase made additional testing necessary to further investigate the effect of some variables. The first phase of experiments was conducted in April 2001 and the second phase in March 2002. Quantitative analysis was performed on the results to determine the factors influencing the homogeneity of truck mixed high-slump concrete.

3.2 Test Variables

The uniformity of truck-mixed concrete depends on a number of variables such as the mixing sequence, mixing time, charging and mixing speed, discharge rate (speed at which the materials are charged into the mixing truck through chute), size of concrete load (total volume of concrete), number of initial revolutions (number of revolutions of truck mixer after addition of materials but before slump adjustment), and headwater percentage (water added to the mixer before the addition of materials, expressed as percentage of total water). The first three factors have been extensively studied by a number of researchers (Gaynor 1996; Suprenant 1992; Gaynor and Mullarky 1975) and FDOT has developed adequate specifications (FDOT specifications 346-8, 2002) to minimize their effect on concrete homogeneity. Hence the other four factors were selected as variables for this research.

The variables studied in phase I were: 1) discharge rate, 2) size of concrete load and 3) headwater percentage. In phase II, the testing variables were: 1) headwater percentage and 2) number of initial mixing revolutions.

3.3 Concrete Mix Design

FDOT standard mix design for drilled shafts (Class 4: #06-0281) was used for all the tests in both phases. A different admixture brand was used in phase II, however. The reason was that the admixture used in Phase I was not commercially available at the time phase II was carried out. However, this change in admixture should not have any effect on the variables under study and for all practical purposes it can be reasonably assumed that the concrete composition was same in both batches. The mix proportions are shown in Tables 1 and 2.

Due to the limitation of the computer batching software at the CSR Rinker concrete as described in section 1.3, the mix design water was trimmed to produce 3 inch slump concrete. This trimmed water or jobsite allowable water was added after the initial mixing revolutions to increase the slump to 7-9 inches. The truck drum was revolved for 30 additional mixing revolutions at 12 rpm to ensure homogeneity. It is important to note that the amount of jobsite allowable was not constant in all batches, but varied from 5 to 8 gallons/yard, as suggested by plant personal based on their experience to ensure more uniformity. This variation is within ±10% and is not expected to have an effect on the number of lumps and balls produced in different batches.

Table 3.1 FDOT Mix Design for Phase I

CONCRETE SUPPLIER: RINKER MATERIALS CORP.			
ADDRESS: 1501 BELVEDERE ROAD		WEST PALM BEACH, FL 33405	
PLANT LOCATION: LEJEUNE		TELEPHONE NO; 561/833-5555	
FDOT ASSIGNED PLANT NO. : 87-085		PROJECT NO: 87000-5601	
DATE: 10/22/98			
CLASS CONCRETE: IV DRILL SHAFT 4000PSI			
SOURCE OF MATERIAL			
COARSE AGGREGATE	: RINKER MATERIALS	GRADE : 57	S.G. (SSD): 2.460
FINE AGGREGATE	: E. R. JAHNA	F.M. : 2.40	S.G. (SSD): 2.630
PIT NO. (COARSE)	: 87-090	TYPE	: CRUSHED LIMESTONE
PIT NO. (FINE)	: 05-045	TYPS	: SILICA SAND
CEMENT	: RINKER PORTLAND MIAMI	SPEC	: AASHTO M-85 TYPE II
AIR ENTR ADMIX	: DAREX AEA W. R. GRACE	SPEC	: AASHTO M-154
1ST ADMIX	: **WRDA-60 W. R. GRACE**	SPEC	: AASHTO M-194 TYPE D
2ND ADMIX	: N/A	SPEC	: N/A
3RD ADMIX	: N/A	SPEC	: N/A
FLY ASH	: $ RPCC SLAG RINKER	SPEC	: ASTM C-989
HOT WEATHER DESIGN MIX			
$ BLAST FURNACE SLAG			
CEMENT (Kg) LBS	: 298	SLUMP RANGE	: 7.00 TO 9.00 (mm) IN
COARSE AGG (Kg) lbs	: 1667	AIR CONTENT	: 2.4 % TO 5.6 %
FINE AGG (Kg) LBS	: 1053	UNIT WEIGHT (wet)	: 139.7 (Kg./M3)PCF
AIR ENT ADMIX (ml) 02	: 7.5	W/C RAT 10 (plant)	: 0.41 (Kg/Kg) LBS/LB
1ST ADMIXTURE(ml)oz	: 23.8	W/C PATIO (field)	: 0.41 (Kg/Kg)LBS/LB
2ND ADMIX (ml) OZ	: 0	THEO YIELD	: 27.00 (M3)CU FT
3PD ADMIX (ml) OZ	: 0		
WATER (ml) GAL	: 37	PRODUCER TEST DATA	
WATER (Kg) LBS	: 308	CHLORIDE CONT	: 0.1 (Kg/M3) LB/CY
FLY ASH (Kg) LBS	: 447	SLUMP	: 7.5 (MM) IN
		AIR CONTEXT	: 3.6 %
		TEMPERATURE	: 97 DEG (C) F
		COMPRESSIVE STRENGHT (MPA) PSI	
		28- DAY : 7740 PSI	

Table 3.2 FDOT Mix Design for Phase II

CONCRETE SUPPLIER: RINKER MATERIALS CORP.	
ADDRESS: 1501 BELVEDERE ROAD	WEST PALM BEACH, FL 33405
PLANT LOCATION: LEJEUNE	TELEPHONE NO; 561/833-5555
FDOT ASSIGNED PLANT NO. : 87-085	PROJECT NO: 87000-5601
DATE: 10/22/98	

CLASS CONCRETE: IV DRILL SHAFT 4000PSI

SOURCE OF MATERIAL

COARSE AGGREGATE	: RINKER MATERIALS	GRADE : 57 S.G. (SSD): 2.460
FINE AGGREGATE	: E. R. JAHNA	F.M. : 2.40 S.G. (SSD): 2.630
PIT NO. (COARSE)	: 87-090	TYPE : CRUSHED LIMESTONE
PIT NO. (FINE)	: 05-045	TYPS : SILICA SAND
CEMENT	: RINKER PORTLAND MIAMI	SPEC : AASHTO M-85 TYPE II
AIR ENTR.ADMIX	: DAREX AEA W. R. GRACE	SPEC : AASHTO M-154
1ST ADMIX	: WRDA-64 W. R. GRACE	SPEC : AASHTO M-194 TYPE D
2ND ADMIX	: N/A	SPEC : N/A
3RD ADMIX	: N/A	SPEC : N/A
FLY ASH	: $ RPCC SLAG RINKER	SPEC : ASTM C-989

HOT WEATHER DESIGN MIX

$ BLAST FURNACE SLAG

CEMENT (Kg) LBS	: 298	SLUMP RANGE	: 7.00 TO 9.00 (mm) IN
COARSE AGG (Kg) lbs	: 1667	AIR CONTENT	: 2.4 % TO 5.6 %
FINE AGG (Kg) LBS	: 1053	UNIT WEIGHT (wet)	: 139.7 (Kg./M3)PCF
AIR ENT ADMIX(ml) 02	: 7.5	W/C RAT10 (plant)	: 0.41 (Kg/Kg) LBS/LB
1ST ADMIXTURE(ml)oz	: 23.8	W/C PATIO (field)	: 0.41 (Kg/Kg)LBS/LB
2ND ADMIX(ml) OZ	: 0	THEO YIELD	: 27.00 (M3)CU FT
3PD ADMIX (ml) OZ	: 0		
WATER (ml) GAL	: 37	PRODUCER TEST DATA	
WATER (Kg) LBS	: 308	CHLORIDE CONT	: 0.1 (Kg/M3) LB/CY
FLY ASH (Kg) LBS	: 447	SLUMP	: 7.5 (MM) IN
		AIR CONTEXT	: 3.6 %
		TEMPERATURE	: 97 DEG (C) F
		COMPRESSIVE STRENGHT (MPA) PSI	
		28- DAY : 7740 PSI	

3.4 Concrete Truck Mixer

The truck mixer used in this research is a ten cubic yard, rear loaded mixing truck, normally loaded with nine cubic yards of concrete (Figure 3.1). The truck has three internal blades (Figure 3.2), and both the blades and the truck were in perfect working condition at the time of testing. The truck had a drum volume of 473 ft^3, an agitating speed of 2-6 rpm, mixing speed of 12-16 rpm and water storage capacity of 80 gallons. The truck mixer was manufactured by McNeilus Inc. (Model KX6-414) and approved by National Ready Mix Concrete Association (NRMCA).

Figure 3.1: CSR Rinker concrete truck mixer

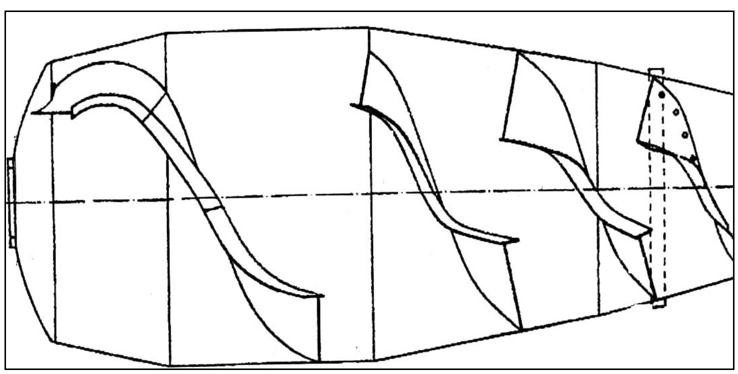

Figure 3.2: Concrete truck drum blades

3.5 Mixing Sequence

The standard batching sequence (discharge and mixing) adopted by CSR Rinker concrete plant was used in this study as illustrated in Figure 3.3.

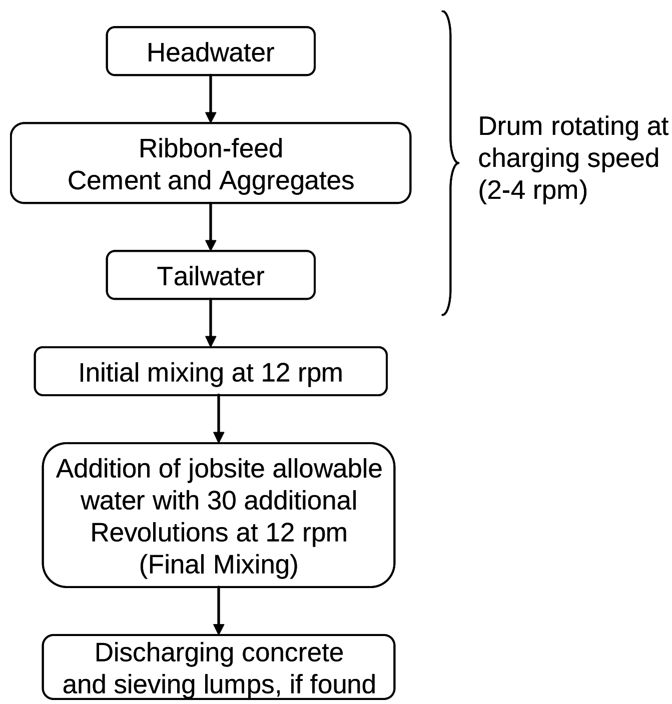

Figure 3.3: Batching sequence

The details of the mixing sequence are as follows:

1. With the drum rotating at charging mode (2-4 rpm), headwater and admixtures were introduced.
2. Next the coarse and fine aggregates were discharged into the truck. .
3. While this process continued, cementitious materials were ribbon fed into the aggregates stream. The aggregates were continuously being discharged in the truck during this entire process (even after the cementitious materials were all added).
4. Finally, the tail water was added.

The truck mixes the concrete using a specified number of initial revolutions (for example 40, 50, 70 etc) at a mixing speed of 12 rpm. This was followed by slump water adjustment (the concrete was initially batched for a slump of 3” as the computerized batching software is programmed for this slump) to increase the concrete slump up to 7-9 inch. This water termed as *jobsite allowable,* was originally deducted from the total mix design water (along with the moisture compensation). Additional 30 revolutions were given at mixing speed (12 rpm) after each addition of jobsite allowable water until the desired slump was achieved.

3.6 Experimental Details

The experimental details of both phases are described in the following sections.

3.6.1 Phase I

This part of the project consisted of 11 concrete batches tested during April and May of 2001.

Following variables were tested in Phase I.

a. Discharge rate: 150, 200 and 250 lbs/sec.
b. Size of truck-load: 3, 5, 7 and 9 cubic yards.
c. Headwater percentage: 80%, 70% and 60% of total water content

Slump, density, air content, and internal concrete temperature tests were performed on two different samples. The first sample was collected at the beginning of the concrete discharge and second was collected at around the middle. Three 6 x12 inch concrete cylinders were prepared from the second sample for compressive strength determination. The following standard ASTM testing procedures were followed throughout the experimentation.

a) Sampling Freshly Mixed Concrete: ASTM C172
b) Slump: ASTM C143
c) Density and Unit weight: ASTM C138

d) Temperature: ASTM C1064

e) Entrapped air: ASTM C 173, C231, C233

f) Compressive strength: ASTM C31 & C39

The concrete was passed through a grate with openings of 2.5 inch to collect lumps and then discharged into another empty truck as illustrated in Figures 3.4 through 3.6. The size and number of lumps and balls were recorded for each batch and selected samples were sent to the laboratory for sieve analysis to determine their gradation.

Figure 3.4: Discharging concrete into secondary truck

Figure 3.5: Collecting concrete lumps and balls

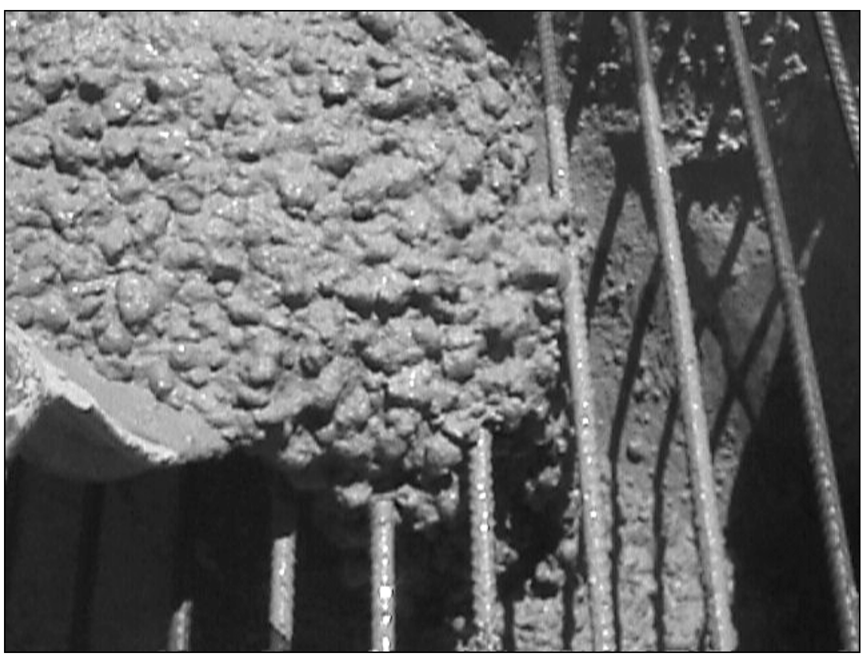

Figure 3.6 Sieving concrete through the grate

3.6.2 Phase II

Phase II was conducted in order to reaffirm Phase I conclusions and to test new untested variables. Except for the variables under study the methodology was very similar to Phase I. The following variables were studied in Phase II.

1. Headwater percentage : 55%, 30% and 20% of total water content
2. Number of initial revolutions: 55, 75 and 100

All tests performed in Phase I were also conducted in Phase II except the compressive strength test because the same concrete mix was used and the compressive strength variation has no effect on the formation of lumps and balls. However, the tests were performed on only one sample collected near the middle of the batch, since in Phase I, no variation was found between the results of the two samples.

Chapter 4

TEST RESULTS

4.1 General

The first phase of experiments consisted of 11 test batches and was conducted at the CSR Rinker concrete facility, at their Sweetwater plant in Miami, during three days in the months of April and May 2001. Almost a year later, during two days of March 2002, the second phase of testing was carried out. Phase II consisted of 5 nine cubic yard test batches, as described in chapter 3. All concrete test batches were consistent with the specified FDOT approved mix design number 06-0281 for high-slump concrete (Table 3.1 & 3.2). Personnel from CSR Rinker, Florida International University, Florida State University, and Florida Department of Transportation were present at the CSR Rinker concrete plant facility during both phases.

4.2 Test Results

The test results of Phase I and II are divided into 5 data sets based on different combination of variables and are summarized in Table 4.1.

Table 4.1: Summary of test results

Set	Load (yds^3)	Initial Rev.	Head Water (%)	Discharge Rate (lbs/sec)	Slump (inch)	Air Content (%)	Density (lbs/ft^2)	Number of Lumps and Balls							28 days Compressive Strength (psi)
								1″-2″	3″-4″	5″-6″	7″-8″	9″-10″	>10″	Total	
A (Phase I)	9	40	90	150	7.8	2.00	142.0	5	6	4	7	1	0	23	7185
	9	N.A.^	90	200	8.3	2.00	140.8	4	8	3	0	0	0	15	7775
	9	N.A.^	90	250	8.5	2.00	142.0	6	7	8	9	5	5	40	7275
B (Phase I)	3	48	90	200	8.0	2.25	139.6	0	0	0	0	0	0	0	7600
	5	N.A.^	90	200	7.5	2.00	141.2	0	2	0	0	0	0	2	6645
	7	38	90	200	7.5	2.00	140.4	7	5	12	11	0	0	35	6695
	9	31	90	200	7.5	2.00	140.8	8	9	15	8	2	3	45	6745
C (Phase I)	9	40	81*	200	7.8	2.25	140.4	0	2	3	3	0	1	9	6705
	9	35	78*	200	8.5	2.50	140.0	6	7	17	6	2	6	44	6765
	9	35	68*	200	8.0	2.00	141.2	1	2	1	1	0	0	5	7125
	9	49	64*	200	7.5	2.50	140.0	0	0	0	0	0	0	0	N.A.
D (Phase II)	9	55	50	200	8.3	3.20	140.6	9	13	11	2	3	2	40	N.A.
	9	55	30	200	8.8	2.80	141.6	1	4	0	1	0	0	6	N.A.
	9	55	20	200	9.0	2.80	141.0	3	3	3	0	0	1	10	N.A.
E (Phase II)	9	55	30	200	8.8	2.80	141.6	1	4	0	1	0	0	6	N.A.
	9	75	30	200	8.8	2.60	140.6	1	2	2	2	0	0	7	N.A.
	9	100	30	200	8.5	2.50	141.6	0	0	0	0	0	0	0	N.A.

** designed headwater percentages were 80%, 75%, 70% and 65%, respectively. Figures in Table show actually measured percentages.*

^ N.A.: not available or not recorded.

4.3 Discussion

4.3.1 Discharge Rate

The “discharge rate” (lbs/sec), refers to the speed at which the materials exit the loader through the chute into the mixing truck. Figure 4.1 shows the relation between the discharge rate and the number of concrete lumps (Data of set A as shown in Table 4.1).

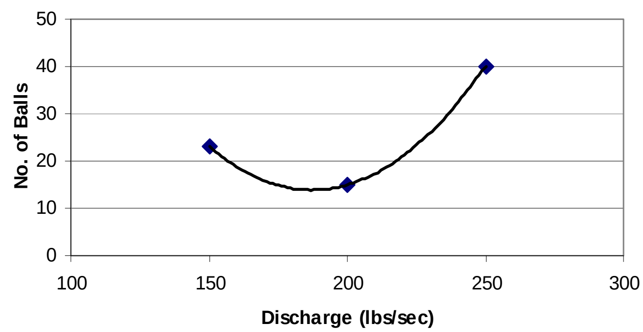

Figure 4.1: Effect of discharge rate on the number of concrete lumps and balls

It is evident from the figure that the optimum discharge rate to minimize concrete lumps is 200 lbs/sec. Fifteen small to medium size concrete lumps were present in this sample. Hence this discharge rate was selected for the rest of the experimentation. Moreover, since the discharge curve is nearly flat near 200 lbs/sec discharge rate, it is suggested to extend the limits of optimum discharge rate to 200±10 lbs/sec.

The concrete batch with discharge rate of 150 lbs/sec produced 23 balls while the one with 250 lbs/sec produced 40 balls. It was interesting to note that smaller size balls were found in the 200 lbs/sec discharge batch. The 150 lbs/sec discharge batch produced relatively smaller size balls as compared to 250 lbs/sec discharge batch. Please see photographs in Figures 4.2 and 4.3. The reason in the latter case could be the faster loading of the materials, not allowing the cementitious materials to mix adequately with the aggregates thus resulting in larger concrete lumps.

Information on the number of initial and total revolutions was not available, except for first batch (150 lb/sec), which was given 40 initial revolutions prior to slump water adjustment. This was because during the Phase I, number of initial revolutions was not considered a variable to investigate and was not recorded. Nevertheless, one may fairly assume that the number of initial mixing revolutions did not differ much in this set of test batches and is not likely to have an effect on the results.

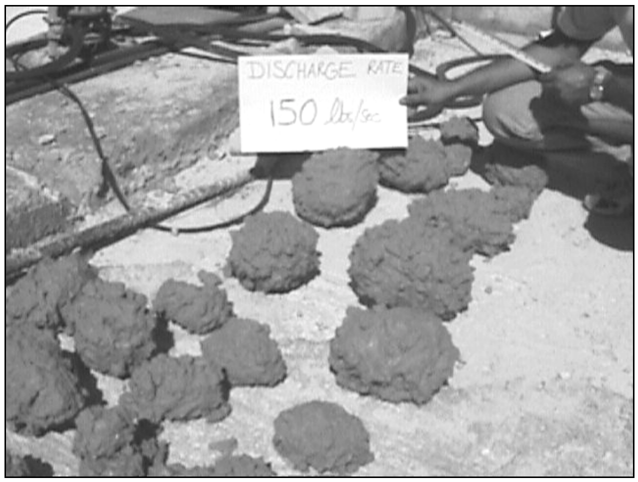

Figure 4.2: Concrete lumps in 150 lb/sec discharge rate batch

Figure 4.3: Concrete lumps in 250 lb/sec discharge rate batch

4.3.2 Size of Concrete Load

The relation between the size of concrete load (total volume of concrete) and the number of lumps is shown in Figures 4.4 and 4.5 (Data of set B as shown in Table 4.1).

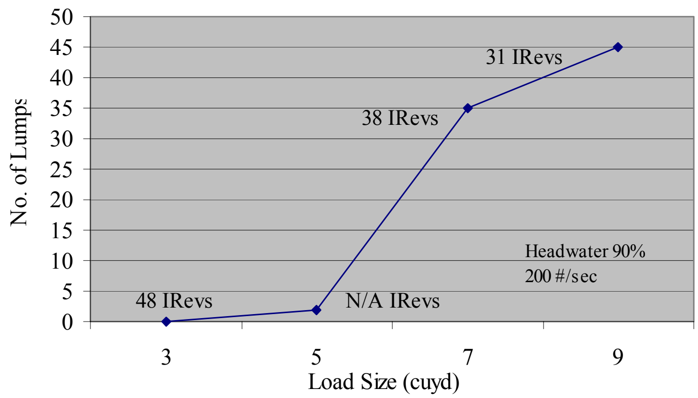

Figure 4.4: Effect of size of concrete load on the number of concrete lumps and balls

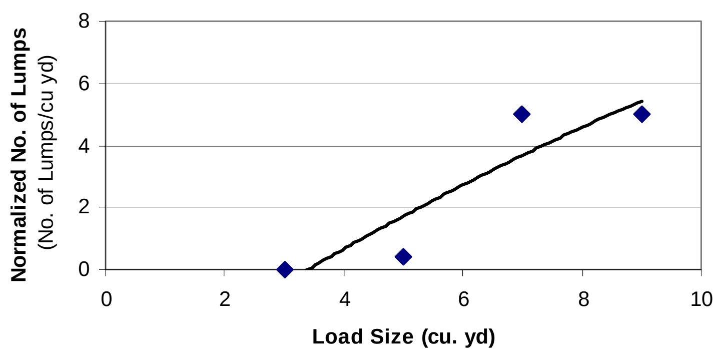

Figure 4.5: Effect of size of concrete load on the number of concrete lumps and balls

Figure 4.4 shows that 7 and 9 cu. yd. batches had many concrete lumps, while 3 and 5 cu. yd. batches had no, or very few, lumps. This is due to the fact that smaller load size can be mixed easily in a drum having a capacity of 2-3 times greater than the volume of loaded materials. An optimum load size between 3 to 5 cu. yd. would probably the best as indicated by Figure 4.4. However, this will not be practical from a productivity point of view as it will be very time consuming. This is not recommended by NRMCA either as explained in chapter 2 (section 2.1).

In Figure 4.5 number of concrete lumps normalized in terms of the load size (number of lumps/cu yd) is shown. The relationship is almost linear. This is to be expected as smaller concrete load would also have fewer lumps. The loads of 3 cu yd and 5 cu yd are not commercially feasible and hence are not considered any further. Since the normalized number of lumps between the loads of 7 cu yd and 9 cu yd are found to be the same, and also because the usual truck size is about 10 cu yd, it was decided that 9 cu yd is the load size to be recommended for use.

4.3.3 Headwater Percentage

Phase 1

In set C (phase I), four trial batches were made with varying headwater percentage (or ratio) (water added to the mixer before the addition of materials) of 81%, 78%, 68% and 64% (originally planned to be 80%, 75%, 70% and 65%). The test results are shown in Figure 4.6.

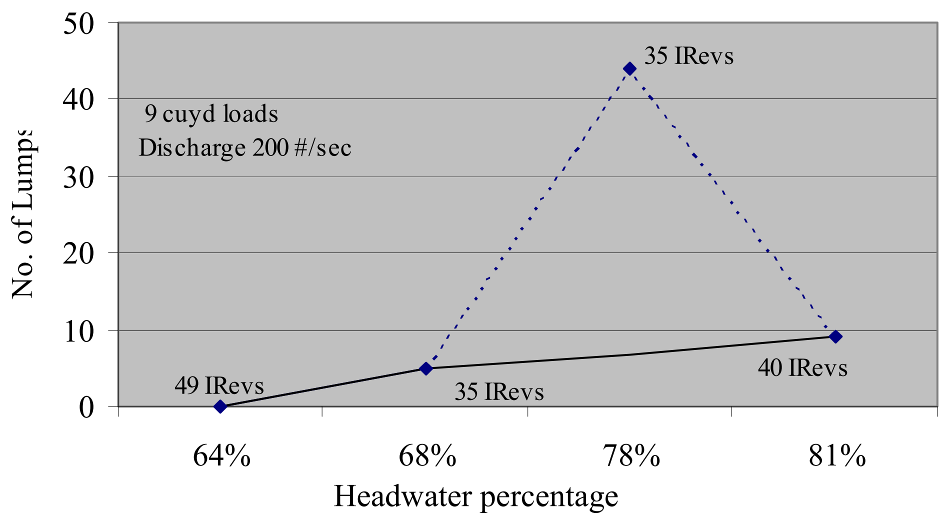

Figure 4.6: Effect of headwater percentage on number of lumps and balls (Phase I)

As illustrated in Figure 4.6 the 81% and the 78% batches of set C had almost the same headwater percentage but the 78% batch resulted in excessively large number of lumps. This data point is considered as outlier.

The results indicate that a lower headwater percentage resulted in a reduced number of lumps and balls. The initial number of mixing revolutions was not considered as a variable in the early stages of the study. However, the results of this data set (C) raised the point that initial number of revolutions could have a vital effect on the number of lumps. The 68% headwater batch had 5 balls (35 initial revolutions) and 64% headwater batch had zero balls (49 initial revolutions) which indicated that for almost the same headwater percentage, the higher number of initial mixing revolutions could reduce the number of lumps in the concrete batch. So based on these results, it was decided to test some more batches with lower headwater percentage and higher initial number of mixing revolutions.

<u>Phase II</u>

The test results of set D (phase II) are shown in Figure 4.7.

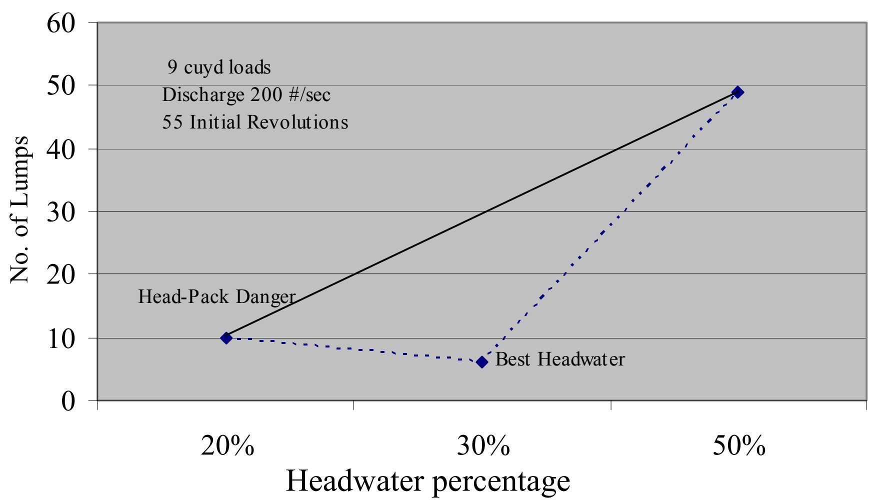

Figure 4.7: Effect of headwater percentage on number of lumps and balls (Phase II)

The set D was performed with 55 constant initial mixing revolutions, while the headwater percentage was decreased to 50%, 30%, and 20% of total water content. An optimum headwater percentage of 30% is indicated in Figure 4.7. The data point with 50% head water percentage showed an exceptionally high number of lumps (40) and is also inconsistent with the results of Phase I (set C), hence it is considered as an outlier. The test results seem to show almost a linear decrease in number of lumps with a decreasing headwater percentages. But, since the batch with 20% headwater percentage suffered from head-packs in the drum, it was considered unpractical and the 30% headwater percentage was accepted as the optimum value.

The results of set D support the conclusions made for set C, that a lower headwater percentage would result in a lower number of lumps and balls, provided the initial number of mixing revolutions are higher (the optimum number of initial mixing revolutions is explored in section 4.3.4). In addition, it was observed that the lump-sizes were reduced with a lower headwater percentage. An optimum headwater percentage of 30% was used for set E.

4.3.4 Initial Revolutions

Using a headwater percentage of 30% and a discharge rate of 200 lb/sec, 9cu yd concrete-loads were tested with initial mixing revolutions of 55, 75 and 100 (set E). In Figure 4.8 the influence of number of initial revolutions on the number of lumps are shown.

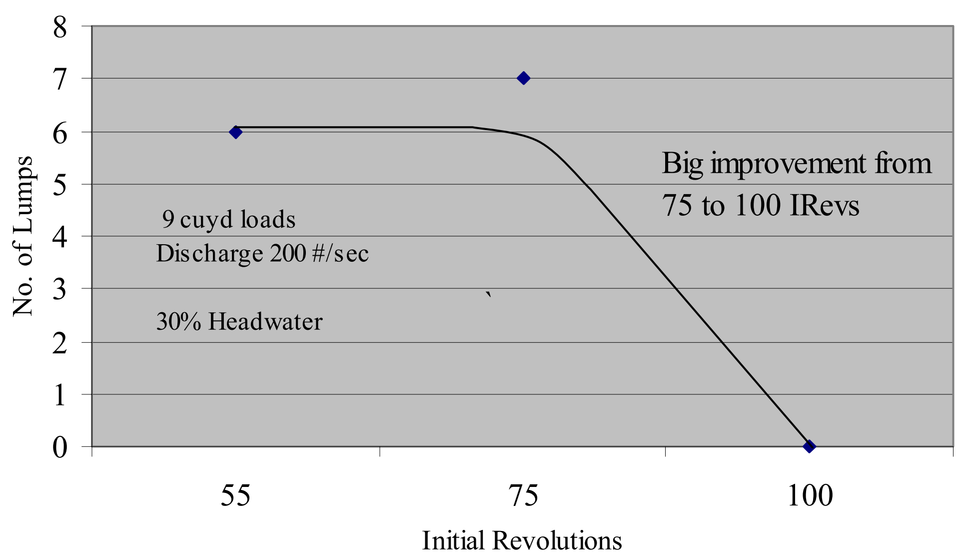

Figure 4.8: Effect of number of initial revolutions on the number of lumps

A considerable decrease in the number of lumps is observed in Figure 4.8 between 75 and 100 initial revolutions. Furthermore, it can also be seen in the figure that at 100 initial revolutions there is no lumps. The total number of revolutions (initial and final) was 130 at 12 rpm for this batch. FDOT specification (346-8) specifies a maximum of 100 total revolutions to mix concrete; therefore, according to this result , the specifications will have to be changed. The high number of mixing revolutions appears to provide preliminary confirmation of a correlationship between lower headwater percentage, higher number of initial revolutions, and fewer lumps and balls. This finding is further explored in the following section.

4.3.5 Combined Effect of Headwater Percentage and Initial Revolutions

The combined effect of headwater percentage and initial revolutions on the number of lumps is illustrated in Figure 4.9.

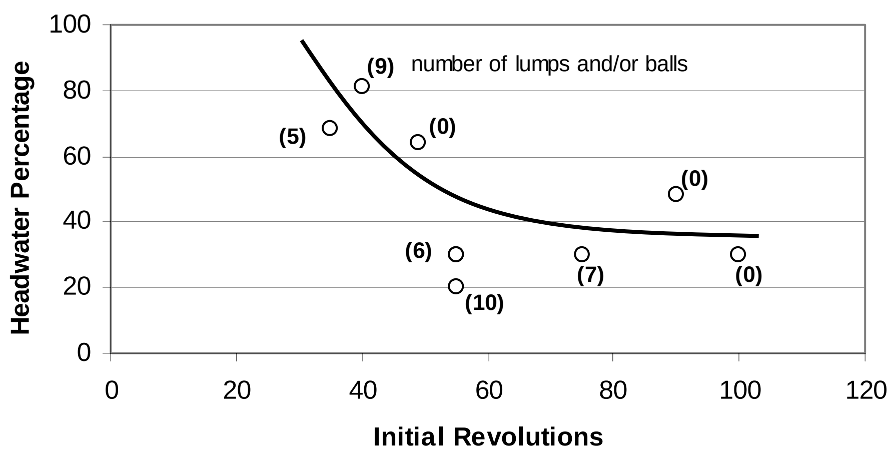

Figure 4.9: Effect of number of initial mixing revolutions and headwater percentage on number of lumps and balls

The data for concrete batches with lumps numbering 10 or less are plotted in Figure 4.9 using an average curve (approximated by eyeballing).

It is clear from Figure 4.9 that with increasing numbers of initial revolutions, the headwater percentage can be decreased in order to produce lumps-free concrete. However, the headwater percentage should not be less than 30%, as the headwater percentage lower than that resulted in head packs. It was further observed that the size of concrete lumps was smaller when lower headwater percentage was used with higher number of initial revolutions. The optimum headwater percentage was found to be between 30%-40% with initial revolutions ranging between 90 to 100.

4.4 Composition of Lumps and Balls based on Gradation

A visual inspection of lumps and balls indicated that they are made up of cement, coarse and fine aggregates. The composition of most of the lumps and balls seemed to be uniform with few exceptions where dry sand and coarse aggregates were found in the center of the lump. This might be due to too low headwater percentage followed by a low number of initial revolutions. In Figure 4.10, typical composition of a concrete lump is shown.

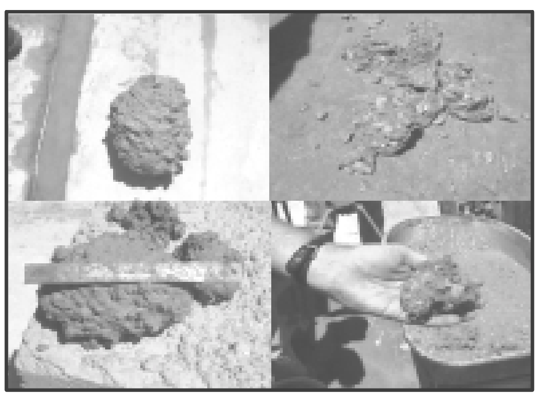

Figure 4.10: Composition of concrete lumps and balls

A representative number of samples of concrete lumps and balls were taken from different sets of batches and sent to the laboratory for sieve analysis to determine the gradation of materials. The results are shown in Table 4.1 and Figure 4.11.

Table 4.2: Grading of samples (percent passing)

PERCENT THAT PAST THE SIEVE BY WEIGHT (7 SAMPLES)

SIEVE	Percent Past Sample#1	Percent Past Sample#2	Percent Past Sample#3	Percent Past Sample#4	Percent Past Sample#5	Percent Past Sample#6	Percent Past Sample#7
1"	100	100	100	100	100	100	100
3/4"	92.1	91.6	92.8	92.6	97	99.2	95.6
1/2"	70.3	69.2	73.5	82.1	81.2	81.5	81.2
3/8"	57.2	58.6	61.2	72.2	71.2	72.9	69.1
#4	49.6	44	47.9	59.4	58.2	59.2	54.8
#8	48.9	41.4	45.2	56.7	55.7	56.4	52.1
#10	48.6	41.1	44.9	56.4	55.3	55.9	48.3
#16	46	38.4	42.1	52.9	51.7	52.3	22.8
#30	23.3	18.5	19.9	25.2	24.2	24.5	12.8
#40	12.7	10.4	10.9	14.2	13.6	13.5	7.7
#50	7.6	6.4	6.5	8.8	8.4	7.9	3
#80	2.1	2.7	2.5	3.9	3.6	2.9	1.7
#100	1.2	1.8	1.5	2.8	2.4	1.7	0.7
#200	0.3	0.8	0.5	1.7	1.4	0.6	0.2
M & C	0.1	0.4	0.1	1.1	0.9	0	0

M & C - Silts & Clays / Percent past of samples are in order (1-7) in Appendix E

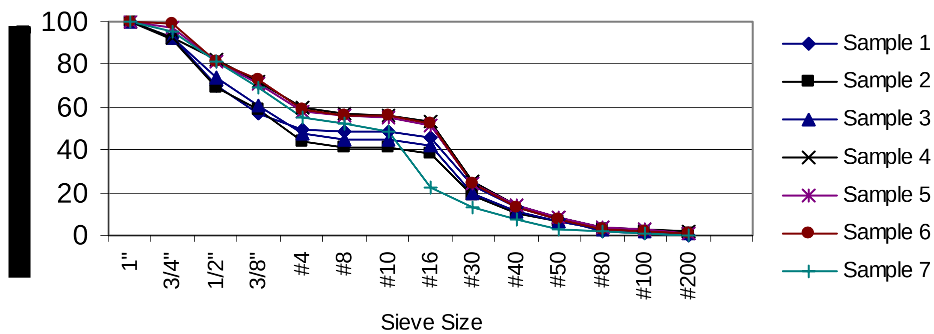

Figure 4.11: Sieve analysis results of concrete lumps and balls

The sieve analysis indicates a gap grading of materials with concentration of small size coarse aggregates (medium size coarse aggregates were negligible), fine sand and cement. This is very obvious as these materials are more prone to form lumps and balls in the presence of water. The percentage of cement content in the samples could not be determined due to the limited scope of experiments.

The size of concrete lumps varied between 1 inch to 14 inch and most batches showed a combination of various sizes. However, smaller lumps were found in batches with low headwater percentage and higher initial revolutions. This is due to the fact that less headwater reduces the chances of cement and sand to form clutches and if formed, high initial revolutions break them. Figure 4.13 shows the different sizes of concrete lumps and balls found in a particular batch.

Figure 4.13: Lumps and balls found in a typical concrete batch

4.5 Concrete Batches with Lumps and Balls

Based on the interviews conducted with concrete plant managers and supervisors, the following actions could be taken to break lumps and balls in concrete, based on the discretion of FDOT site engineer.

1. If the concrete lumps are large, rotate the concrete drum at high speed (12-15 rpm) for 2-3 minutes and then at slow speed (6-8 rpm) for 3-5 minutes. This action could break the large lumps and makes concrete more uniform.

2. If small size concrete balls are found, sieve the concrete using a grate of 2.5 inch openings before discharging it on the chute. This practice is recommended to avoid disruption of operations at the site to save time and cost.

Chapter 5

FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Findings and Conclusions

Based on the findings of this study, the following conclusions can be drawn.

1. Headwater percentage and initial revolutions have a combined effect on the number of lumps and balls produced. A low headwater percentage followed by higher number of initial revolutions can eliminate concrete lumps. The optimum combination was found to be 30% headwater percentage with 100 initial revolutions at a speed of 12 rpm. It can be concluded that a headwater percentage between 30-40% and number of initial revolutions between 90-100 can produce lumps free concrete. This implies that the total number of mixing revolutions should be between 120-130 as 30 additional revolutions are required after the addition of jobsite allowable water.

2. The optimum speed at which the materials exit the loader through the chute into the mixing truck (discharge rate) was found to be 200±10 lbs/sec.

3. Although the size of concrete load does have an effect on the number of lumps and balls formed, smaller than 9 cu yd load sizes are not commercially feasible. Since the number of lumps and balls formed with load sizes of 7 and 9 cu yd were found to be almost the same, it is recommended to use the 9 cubic yards load size, whenever concrete in large amounts is required.

4. The sieve analysis indicated that most of the concrete lumps and balls were similar in gradation and made up of small coarse aggregates, coarse sand and cement.

5.2 Recommendations

The results of this investigation, although limited by the number of data points, indicate that the main reason for lumps and balls formation in high-slump concrete used by FDOT is the result of inadequate mixing prior to addition of jobsite allowable water. To remedy this problem proper initial mixing must be performed, by using the following suggested step-by-step procedure.

1) A 9 cubic yard batch should be prepared by initially charging 30% to 40% (headwater) of the batch water with all the admixtures (please refer to section 1.3 for a clarification of the term batch water). However, if any plant is using a batching process without using jobsite allowable water (with software configured to produce 7-9 inch slump concrete) headwater percentage would be the percentage of total mix-design water.

2) The charging of headwater should be followed by the charging of aggregates at a discharge rate of 200 ± 10 lbs/sec.

3) After initiating the aggregate charge, cementitious materials should be “ribbon fed” into the aggregate stream at the same discharge rate (200±10 lbs/sec). Discharge of cementitious material should be completed prior to the completion of the aggregate charge. Finally the tailwater (remainder of the batch water) should be charged.

4) The drum should be rotated for 90-100 initial mixing revolutions at a speed of 12 rpm.

5) Once the initial mixing is completed, the jobsite allowable water should be added to increase the slump of concrete from 3 inch to 7-9 inch. The concrete is then mixed for an additional 30 revolutions at 12 rpm.

The suggestions made in this research are not radically different from previous batching procedures and can be easily implemented.

The authors recommend the following changes in the Draft FDOT Materials Manual (2002), as mentioned in the FDOT specification 6-8.1.1, *Quality Control Program for Material Producers* (FDOT 2002).

<u>Section 9.2.8.3. Transit Mixing</u>

"Initially mix each batch between 70 and 100 revolutions of the drum at mixing speed. When water is added at the job site, mix the concrete for 30 additional revolutions. When mixing for the purpose of adjusting consistency, do not allow the total number of revolutions at mixing speed to exceed 160. Discharge all concrete from truck mixers before total drum revolution exceed 300".

We suggest the following to replace the above section:

Initially mix each batch between 90 to 100 revolutions of the drum at mixing speed. When water is added at the job site, mix the concrete for 30 additional revolutions. When mixing for the purpose of adjusting consistency, do not allow the total number of revolutions at mixing speed to exceed 160. Discharge all concrete from truck mixers before total drum revolution exceeds 300.

<u>Section 9.2.8.4 Charging the Mixer</u>

"Charge each batch into the drum so that some water enters both in advance of and after the cementitious materials and aggregates. If using fly ash in the mix, charge it into the drum over approximately the same interval as cement. The concrete producer may use other time intervals for the introduction of materials into the mix when the concrete producer demonstrates, using test requirements specified in ASTM C94, that he can achieve uniformity of the concrete mix".

Our suggestion is:

Initially charge 30%-40% of the batch water with admixtures into the drum and then start charging the aggregates. After initiation of aggregate charge, ribbon-fed the cementitious materials into the aggregate stream. Discharge of cementitious materials should be completed prior to the completion of the aggregate charge. The concrete producer may use other time intervals for the introduction of materials into the mix when the concrete producer demonstrates, using test requirements specified in ASTM C94, that he can achieve uniformity of the concrete mix.

In Addition, the authors suggest changes in the FDOT specification 346-7.4.1 as follows:

<u>346-7.4.1 General Requirements</u>
"Provide mixers of an approved type that are capable of combining the components of the concrete into a thoroughly mixed and uniform mass, free from balls or lumps of cementitious material, and that are capable of discharging the concrete with a satisfactory degree of uniformity".

The suggested specification is:

Provide mixers of an approved type that are capable of combining the components of the concrete into a thoroughly mixed and uniform mass, free from balls or lumps of cementitious material, and that are capable of discharging the concrete with a satisfactory degree of uniformity. If lumps and balls are found in a concrete batch, the FDOT engineer may allow the contractor to use a grate with 2.5 inch openings to sieve the concrete of first batch in order to avoid disruption of operation. However, the remaining batches will be rejected.

5.3 Future Studies

This research study has resulted in a possible solution to the problem of having lumps and balls in high-slump concrete. The solution involves mixing of the ingredients in a certain procedure with specified ranges of number of initial mixing revolutions and headwater percentages.

A continuation of this work is imperative in order to make conclusive recommendations. The following guidelines may serve as the basis for future studies.

1. More batches should be tested around the optimum values attained in this research. A minimum of fifteen test batches (requirement for mix designs are 15 to 30 for FDOT) of the procedure outlined in this report could indicate with certainty whether the conclusions of this research are statistically valid.

2. Charging and mixing sequence may have an effect on the formation of lumps and balls. A different charging and mixing sequence could produce different results even if other factors remain unchanged. This implies that a different combination of the headwater percentage and the initial mixing revolutions should be investigated for a different charging and mixing sequence, if large number of concrete lumps and balls appeared in the mix.

3. The effect of other variables such as cement content, retarder dose and amount of superplasticizer on the mix design need to be investigated. This research studied one mix design, which did not take into account the possible variations of admixtures and their affect on the mix homogeneity or the water content.

4. The influence of computer software should be investigated. Specifically, the discrepancy in the way FDOT mix design is implemented by the supplier (i.e. the concrete was initially mixed for 3 inch slump and then jobsite allowable water was added to raise the slump to 7-9 inches). The way software is configured or

programmed at the batching plant need to be addressed, to verify if a different configuration can batch a high-slump concrete directly from the batching machine, without the need for slump water adjustments.

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Appendix A

CONCRETE MIX DESIGN FOR EACH TEST MIX

(CSR RINKER MIX DESIGN)

E.1 Test Batch #1; Discharge Rate

E.1.1 Batch Data

Date	: 4/9/2001	Discharge Rate	**: 200 #/sec**
Drill Shaft Mix No.	: 06-0281	Truck Slump Gage	: 4.9 in
Truck Mixer No.	: 2969	Visual Slump	: 8.0 in
Headwater	: 90%	Load Size	: 9 cu yds
Wash water	: 10%	Mixing Speed	: 12 rpm

E1.2 Batch Record

Materials	Source and/or Type	Mix Design	Target Weight	Actual Weights	Tolerances	Auto or Manual	Moisture Percent
# 57	Rinker	1,667 lbs	15,288 lb	15,400 lb	IN	Auto	1.90%
Sand	Ortona	1,053 lbs	9,657 lbs	9,960 lbs	OUT	Auto	1.90%
Cement	Type II Rinker	298 lbs	2,682 lbs	2,680 lbs	IN	Auto	
Slag	Rinker	447 lbs	4,023 lbs	4,010 lbs	IN	Manual	
Air	Darex (Grace)	2 oz	54 oz	53 oz	IN	Auto	
Retarder	WRDA 60; Grace	8 oz	214 oz	215 oz	IN	Auto	
Water	Well	37 gal	249 gal	249 gal	IN	Auto	

Note 1: Water weight; mix design (333gal), minus moisture compensation (56gal), and jobsite allowable (28gal)

E 1.3 Batch Concrete Properties

	Slump	Air %	Temperature	Unit weight (#/cu ft)	Cylinder cast @ 7-days	Cylinder @ 28-days
Initial	8.25 in	3.00%	N/A	140	N/A	N/A
Final	8.50 in	2.00%	88 F	141.6	2	2

E1.4 Slump Stand Data

Allowed water	Visual slump	No initial revolutions	Water added	Additional revolutions	Total # revs discharge
28 gal	N/A	N/A	N/A	N/A	85

Note 2: No additional mixing revolution information. Due to inadequate slump board, slump was altered.

E1.5 Lumps Discharged

Size of Balls	3 to 4 (in)	5 to 6 (in)	7 to 8 (in)	9 to 10 (in)	11 to 12 (in)	> 12 (in)	Total # of Balls
# of Balls	12	3	0	0	0	0	**15**

E.2 Test Batch #2; Discharge Rate **(Rejected batch, due to inadequate slump.)**

E 2.1 Batch Data

Date	: 4/10/2001	Discharge Rate	<u>: 250 #/sec</u>
Drill Shaft Mix No.	: 06-0281	Truck Slump Gage	: N/A
Truck Mixer No.	: 2969	Visual Slump	: 6.0 in
Headwater	: 90%	Load Size	: 9 cu yds
Wash water	: 10%	Mixing Speed	: 12 rpm

Rejected Batch

E 2.2 Batch Record

Materials	Source/ Type	Mix Design	Target Weight	Actual Weights	Tolerances	Auto or Manual	Moisture Percent
# 57	Rinker	1,667 lbs	15,258 lb	15,320 lb	IN	Auto	1.70%
Sand	Ortona	1,053 lbs	9,714 lbs	9,760 lbs	IN	Auto	2.50%
Cement	Type II Rinker	298 lbs	2,682 lbs	2,700 lbs	IN	Auto	
Slag	Rinker	447 lbs	4,023 lbs	4,000 lbs	IN	Manual	
Air	Darex (Grace)	2 oz	54 oz	54 oz	IN	Auto	
Retarder	WRDA 64;Grace	8 oz	214 oz	215 oz	IN	Auto	
Water	Well	37 gal	247 gal	247 gal	IN	Auto	

<u>Note 1:</u> Water weight; mix design(333gal), minus moisture compensation(59gal), and jobsite allowable(28gal)

E 2.3 Batch Concrete Properties

	Slump	Air %	Temperature	Unit weight (#/cu ft)	Cylinder cast @ 7-days	Cylinder cast @ 28-days
Initial	5.50 in	N/A	N/A	N/A	N/A	N/A
8 gal water addition	N/A	N/A	N/A	N/A	N/A	N/A
6 gal water addition	N/A	N/A	N/A	N/A	N/A	N/A
Final	7.00 in	2.25%	82 F	142.3	2	2

<u>Note 2:</u>Inadequate slump, supplemental 6 gal and 8 gal water additions used to meet slump requirements

E 2.4 Slump Stand Data							
Allowed water	Visual slump	No. initial revolutions	Water added	Additional revolutions	Water added	Additional revolutions	Total # revs discharge
28 gal	N/A	50	8 gal	30	6 gal	30	120

Note 3: 12 gallons of water were added and the drum was given 30 additional revolutions.

Note 4: Slump inadequate, increments of water needed at slump stand.

Note 5: 175 total revolutions, prior to complete discharge of the mixer.

E 2.5 Lumps Discharged							
Size of Balls	3 to 4 (in)	5 to 6 (in)	7 to 8 (in)	9 to 10 (in)	11 to 12 (in)	> 12 in	Total # of Balls
Number of Balls	1	1	0	0	1	0	**3**

Note 6: One ball weight 32 lbs.

Note: Batch #2 rejected, due to inadequate slump.

E 3 Test Batch #3; Discharge Rate

E 3.1 Batch Data

Date	: 4/10/2001	Discharge Rate	**: 250 #/sec**
Drill Shaft Mix No.	: 06-0281	Truck Slump Gage	: N/A
Truck Mixer No.	: 2969	Visual Slump	: N/A
Headwater	: 90.00%	Load Size	: 9 cu yds
Wash water	: 10.00%	Mixing Speed	: 12 rpm

E 3.2 Batch Record

Materials	Source-Type	Mix Design	Target Weight	Actual Weight	Tolerances	Auto or Manual	Moisture Percent
# 57	Rinker	1,667 lbs	15,258 lb	15,280 lb	IN	Auto	1.70%
Sand	Ortona	1,053 lbs	9,714 lbs	9,760 lbs	IN	Auto	2.50%
Cement	Type II Rinker	298 lbs	2,682 lbs	2,680 lbs	IN	Auto	
Slag	Rinker	447 lbs	4,023 lbs	4,060 lbs	IN	Auto	
Air	Darex (Grace)	2 oz	54 oz	54 oz	IN	Auto	
Retarder	WRDA 64;Grace	8 oz	214 oz	215 oz	IN	Auto	
Water	Well	37 gal	247 gal	246 gal	IN	Auto	

Note 1: Water weight; mix design(333gal), minus moisture compensation(59gal), and jobsite allowable(28gal)

E 3.3 Batch Concrete Properties

	Slump	Air %	Temperature	Unit weight (#/cu ft)	Cylinder cast @ 7-days	Cylinder cast @ 28-days
Initial	8.25 in	2.50%	85 F	142	N/A	N/A
Final	7.50 in	2.00%	84 F	142	2	2

E 3.4 Slump Stand Data

Allowed water	Visual slump	No. initial revolutions	Water added	Additional revolutions	Total # revolutions @ discharge
28 gal	N/A	N/A	N/A	N/A	120

Note 2: No additional mixing revolution information available.

E 3.5 Lumps Discharged

Size of Balls	3 to 4 (in)	5 to 6 (in)	7 to 8 (in)	9 to 10 (in)	11 to 12 (in)	> 12 (in)	Total # of Balls
Number of Balls	13	8	9	5	5	0	**40**

E 4 Test Batch #4; Discharge Rate

E 4.1 Batch Data

Date	: 4/10/2001	Discharge Rate	**: 150 #/sec**
Drill Shaft Mix No.	: 06-0281	Truck Slump Gage	: N/A
Truck Mixer No.	: 2969	Visual Slump	: N/A
Headwater	: 90.00%	Load Size	: 9 cu yds
Wash water	: 10.00%	Mixing Speed	: 12 rpm

E 4.2 Batch Record

Materials	Source-Type	Mix Design	Target Weight	Actual Weight	Tolerances	Auto or Manual	Moisture Percent
#57	Rinker	1,667 lbs	15,258 lb	15,320 lb	IN	Auto	1.70%
Sand	Ortona	1,053 lbs	9,714 lbs	9,760 lbs	IN	Auto	2.50%
Cement	Type II Rinker	298 lbs	2,682 lbs	2,690 lbs	IN	Auto	
Slag	Rinker	447 lbs	4,023 lbs	4,030 lbs	IN	Auto	
Air	Darex (Grace)	2 oz	54 oz	54 oz	IN	Auto	
Retarder	WRDA 64;Grace	8 oz	214 oz	215 oz	IN	Auto	
Water	Well	37 gal	247 gal	246 gal	IN	Auto	

Note 1: Water weight; mix design(333gal), minus moisture compensation(59gal), and jobsite allowable(28gal)

E 4.3 Batch Concrete Properties

	Slump	Air %	Temperature	Unit weight (#/cu ft)	Cylinder cast @ 7-days	Cylinder cast @ 28-days
Initial	7.75 in	2.00%	82 F	142	N/A	N/A
Final	7.50 in	2.00%	84 F	142	2	2

E 4.4 Slump Stand Data

Allowed water	Visual slump	No. initial revolutions	Water added	Additional revolutions	Total #revolutions @ discharge
28 gal	N/A	40	9 gal	45	85

Note 2: No additional mixing revolution information available.

E 4.5 Lumps Discharged

Size of Balls	3 to 4 (in)	5 to 6 (in)	7 to 8 (in)	9 to 10 (in)	11 to 12 (in)	> 12 (in)	Total # of Balls
Number of Balls	11	4	7	1	0	0	**23**

E 5 Test Batch #5; Load Size

E 5.1 Batch Data

Date	: 4/16/2001	Discharge Rate	: 200 #/sec
Drill Shaft Mix No.	: 06-0281	Truck Slump Gage	: N/A
Truck Mixer No.	: 2969	Visual Slump	: N/A
Headwater	: 90.00%	Load Size	**: 7 cu yds**
Wash water	: 10.00%	Mixing Speed	: 12 rpm

E 5.2 Batch Record

Materials	Source-Type	Mix Design	Target Weight	Actual Weight	Tolerances	Auto or Manual	Moisture Percent
#57	Rinker	1,667 lbs	11,844 lb	11,840 lb	IN	Auto	1.50%
Sand	Ortona	1,053 lbs	7,563 lbs	7,600 lbs	IN	Auto	2.60%
Cement	Type II Rinker	298 lbs	2,086 lbs	2,100 lbs	IN	Auto	
Slag	Rinker	447 lbs	3,129 lbs	3,150 lbs	IN	Auto	
Air	Darex (Grace)	2 oz	42 oz	42 oz	IN	Auto	
Retarder	WRDA 64;Grace	8 oz	167 oz	167 oz	IN	Auto	
Water	Well	37 gal	194 gal	193 gal	IN	Auto	

Note 1: Water weight; mix design(259gal), minus moisture compensation(44gal), and jobsite allowable(22gal)

E 5.3 Batch Concrete Properties

	Slump	Air %	Temperature	Unit weight (#/cu ft)	Cylinder cast @ 7-days	Cylinder cast @ 28-days
Initial	7.50 in	2.00%	88 F	N/A	N/A	N/A
Final	7.50 in	2.00%	84 F	140.4	2	2

E 5.4 Slump Stand Data

Allowed water	Visual slump	No. initial revolutions	Water added	Additional revolutions	Total # revolutions @ discharge
22 gal	N/A	38	7 gal	42	80

Note 2: No additional mixing revolution information available.

E 5.5 Lumps Discharged

Size of Balls	3 to 4 (in)	5 to 6 (in)	7 to 8 (in)	9 to 10 (in)	11 to 12 (in)	> 12 (in)	Total # of Balls
Number of Balls	12	12	11	0	0	0	**35**

Note 3: 1 lump in the middle of load; 16 lbs.

E 6 Test Batch #6; Load Size

E 6.1 Batch Data

Date	: 4/16/2001	Discharge Rate	: 200 #/sec
Drill Shaft Mix No.	: 06-0281	Truck Slump Gage	: N/A
Truck Mixer No.	: 2969	Visual Slump	: N/A
Headwater	: 90.00%	Load Size	**: 5 cu yds**
Wash water	: 10.00%	Mixing Speed	: 12 rpm

E 6.2 Batch Record

Materials	Source-Type	Mix Design	Target Weight	Actual Weight	Tolerances	Auto or Manual	Moisture Percent
#57	Rinker	1,667 lbs	8,460 lb	8,440 lb	IN	Auto	1.50%
Sand	Ortona	1,053 lbs	5,402 lbs	5,360 lbs	IN	Auto	2.60%
Cement	Type II Rinker	298 lbs	1,490 lbs	1,510 lbs	IN	Auto	
Slag	Rinker	447 lbs	2,235 lbs	2,240 lbs	IN	Auto	
Air	Darex (Grace)	2 oz	30 oz	29 oz	IN	Auto	
Retarder	WRDA 64;Grace	8 oz	119 oz	120 oz	IN	Auto	
Water	Well	37 gal	139 gal	138 gal	IN	Auto	

Note 1: Water weight; mix design(185gal), minus moisture compensation(31gal), and jobsite allowable(16gal)

E 6.3 Batch Concrete Properties

	Slump	Air %	Temperature	Unit weight (#/cu ft)	Cylinder cast @ 7-days	Cylinder cast @ 28-days
Initial	7.50 in	N/A	83 F	N/A	N/A	N/A
Final	7.50 in	2.25%	86 F	141.2	2	2

E 6.4 Slump Stand Data

Allowed water	Visual slump	No. initial revolutions	Water added	Additional revolutions	Total # revolutions @ discharge
16 gal	N/A	N/A	N/A	N/A	82

Note 2: No additional mixing revolution information available.

E 6.5 Lumps Discharged

Size of Balls	3 to 4 (in)	5 to 6 (in)	7 to 8 (in)	9 to 10 (in)	11 to 12 (in)	> 12 (in)	Total # of Balls
Number of Balls	2	0	0	0	0	0	2

E 7 Test Batch #7; Load Size

E 7.1 Batch Data

Date	: 4/17/2001	Discharge Rate	: 200 #/sec
Drill Shaft Mix No.	: 06-0281	Truck Slump Gage	: N/A
Truck Mixer No.	: 2969	Visual Slump	: N/A
Headwater	: 90.00%	Load Size	**: 3 cu yds**
Wash water	: 10.00%	Mixing Speed	: 12 rpm

E 7.2 Batch Record

Materials	Source-Type	Mix Design	Target Weight	Actual Weight	Tolerances	Auto or Manual	Moisture Percent
#57	Rinker	1,667 lbs	5,076 lb	5,120 lb	IN	Auto	1.50%
Sand	Ortona	1,053 lbs	3,241 lbs	3,240 lbs	IN	Auto	2.60%
Cement	Type II Rinker	298 lbs	894 lbs	910 lbs	IN	Auto	
Slag	Rinker	447 lbs	1,341 lbs	1,330 lbs	IN	Auto	
Air	Darex (Grace)	2 oz	18 oz	17 oz	IN	Auto	
Retarder	WRDA 64;Grace	8 oz	71 oz	72 oz	IN	Auto	
Water	Well	37 gal	83 gal	82 gal	IN	Auto	

Note 1: Water weight; mix design(111gal), minus moisture compensation(19gal), and jobsite allowable(10gal)

E 7.3 Batch Concrete Properties

	Slump	Air %	Temperature	Unit weight (#/cu ft)	Cylinder cast @ 7-days	Cylinder cast @ 28-days
Initial	8.0 in	N/A	82 F	N/A	N/A	N/A
Final	8.0 in	2.25%	84 F	139.6	2	2

E 7.4 Slump Stand Data

Allowed water	Visual slump	No. initial revolutions	Water added	Additional revolutions	Total # revolutions @ discharge
10 gal	N/A	48	3 gal	32	80

Note 2: 107 total revolutions, prior to complete discharge of the mixer.

E 7.5 Lumps Discharged

Size of Balls	3 to 4 (in)	5 to 6 (in)	7 to 8 (in)	9 to 10 (in)	11 to 12 (in)	> 12 (in)	Total # of Balls
Number of Balls	0	0	0	0	0	0	**0**

E 8 Test Batch #8; Load Size

E 8.1 Batch Data

Date	: 4/17/2001	Discharge Rate	: 200 #/sec
Drill Shaft Mix No.	: 06-0281	Truck Slump Gage	: N/A
Truck Mixer No.	: 2969	Visual Slump	: N/A
Headwater	: 90.00%	Load Size	**: 9 cu yds**
Wash water	: 10.00%	Mixing Speed	: 12 rpm

E 8.2 Batch Record

Materials	Source-Type	Mix Design	Target Weight	Actual Weight	Tolerances	Auto or Manual	Moisture Percent
#57	Rinker	1,667 lbs	15,228 lb	15,240 lb	IN	Auto	1.50%
Sand	Ortona	1,053 lbs	9,722 lbs	9,720 lbs	IN	Auto	2.60%
Cement	Type II Rinker	298 lbs	2,682 lbs	2,690 lbs	IN	Auto	
Slag	Rinker	447 lbs	4,022 lbs	4,030 lbs	IN	Auto	
Air	Darex (Grace)	2 oz	54 oz	54 oz	IN	Auto	
Retarder	WRDA 64;Grace	8 oz	214 oz	215 oz	IN	Auto	
Water	Well	37 gal	252 gal	251 gal	IN	Auto	

Note 1: Water weight; mix design(333gal), minus moisture compensation(56gal), and jobsite allowable(26gal)

E 8.3 Batch Concrete Properties

	Slump	Air %	Temperature	Unit weight (#/cu ft)	Cylinder cast @ 7-days	Cylinder cast @ 28-days
Initial	7.50 in	N/A	84 F	142	N/A	N/A
Final	7.50 in	2.00%	83 F	140.8	2	2

E 8.4 Slump Stand Data

Allowed water	Visual slump	No. initial revolutions	Water added	Additional revolutions	Total #revolutions @ discharge
26 gal	N/A	31	10 gal	49	80

Note 2: 120 total revolutions, prior to complete discharge of the mixer.

E 8.5 Lumps Discharged

Size of Balls	3 to 4 (in)	5 to 6 (in)	7 to 8 (in)	9 to 10 (in)	11 to 12 (in)	> 12 (in)	Total # of Balls
Number of Balls	13	18	6	2	6	0	**45**

E 9 Test Batch #9; Head Water

E 9.1 Batch Data

Date	: 5/7/2001	Discharge Rate	: 200 #/sec
Drill Shaft Mix No.	: 06-0281	Truck Slump Gage	: N/A
Truck Mixer No.	: 2969	Visual Slump	: N/A
Headwater	: 81.00%	Load Size	: 9 cu yds
Wash water	: 19.00%	Mixing Speed	: 12 rpm

E 9.2 Batch Record

Materials	Source-Type	Mix Design	Target Weight	Actual Weight	Tolerances	Auto or Manual	Moisture Percent
# 57	Rinker	1,667 lbs	15,228 lb	15,280 lb	IN	Auto	1.50%
Sand	Ortona	1,053 lbs	9,704 lbs	9,680 lbs	IN	Auto	2.40%
Cement	Type II Rinker	298 lbs	2,682 lbs	2,710 lbs	OUT	Auto	
Slag	Rinker	447 lbs	4,022 lbs	4,040 lbs	IN	Auto	
Air	Darex (Grace)	2 oz	54 oz	54 oz	IN	Auto	
Retarder	WRDA 64;Grace	8 oz	214 oz	215 oz	IN	Auto	
Water	Well	37 gal	226 gal	225 gal	IN	Auto	

Note 1: Water weight; mix design(333gal), minus moisture compensation(54gal), and jobsite allowable(54gal).

E 9.3 Batch Concrete Properties

	Slump	Air %	Temperature	Unit weight (#/cu ft)	Cylinder cast @7days	Cylinder cast @ 28-days
Initial	6.75 in	N/A	82 F	N/A	N/A	N/A
4 gal water addition	7.25 in	N/A	82 F	N/A	N/A	N/A
Final	7.75 in	2.25%	82 F	140.4	2	2

Note 2: Supplemental 4 gal water addition, meets slump requirements.

E 9.4 Slump Stand Data

Allowed water	Visual slump	No. initial revolutions	Water addition	Supplemental water addition	Additional revolutions	Total # revolutions @ discharge
54 gal	N/A	40	7 gal	4 gal	43	83

Note 3: 181 total revolutions, prior to complete discharge of the mixer.

E 9.5 Lumps Discharged

Size of Balls	3 to 4 (in)	5 to 6 (in)	7 to 8 (in)	9 to 10 (in)	11 to 12 (in)	> 12 (in)	Total # of Balls
# of Balls	2	3	3	0	0	1	**9**

E10 Test Batch #10; Head Water

E 10.1 Batch Data

Date	: 5/7/2001	Discharge Rate	: 200 #/sec
Drill Shaft Mix No.	: 06-0281	Truck Slump Gage	: N/A
Truck Mixer No.	: 2969	Visual Slump	: N/A
Headwater	: 78.00%	Load Size	: 9 cu yds
Wash water	: 22.00%	Mixing Speed	: 12 rpm

E 10.2 Batch Record

Materials	Source-Type	Mix Design	Target Weight	Actual Weight	Tolerances	Auto or Manual	Moisture Percent
# 57	Rinker	1,667 lbs	15,288 lb	15,240 lb	IN	Auto	1.50%
Sand	Ortona	1,053 lbs	9,704 lbs	9,680 lbs	IN	Auto	2.40%
Cement	Type II Rinker	298 lbs	2,682 lbs	2,700 lbs	IN	Auto	
Slag	Rinker	447 lbs	4,022 lbs	4,030 lbs	IN	Auto	
Air	Darex (Grace)	2 oz	54 oz	53 oz	IN	Auto	
Retarder	WRDA 64;Grace	8 oz	214 oz	214 oz	IN	Auto	
Water	Well	37 gal	218 gal	217 gal	IN	Auto	

Note 1: Water weight; mix design(333gal), minus moisture compensation(54gal), and jobsite allowable(62gal)

E 10.3 Batch Concrete Properties

	Slump	Air %	Temperature	Unit weight (#/cu ft)	Cylinder cast @ 7-days	Cylinder cast @ 28-days
Initial	8.25 in	N/A	82 F	N/A	N/A	N/A
Final	8.75 in	2.50%	N/A	140	2	2

E 10.4 Slump Stand Data

	Allowed water	Visual slump	No. initial revolutions	Water added	Additional revolutions	Total # revolutions @ discharge
	62 gal	N/A	35	9 gal	50	85

Note : 181 total revolutions, prior to complete discharge of the mixer.

E 10.5 Lumps Discharged

Size of Balls	3 to 4 (in)	5 to 6 (in)	7 to 8 (in)	9 to 10 (in)	11 to 12 (in)	> 12 (in)	Total # of Balls
Number of Balls	13	17	6	2	2	4	**44**

E 11 Test Batch #11; Head Water

6.11.1 Batch Data			
Date	: 5/7/2001	Discharge Rate	: 200 #/sec
Drill Shaft Mix No.	: 06-0281	Truck Slump Gage	: N/A
Truck Mixer No.	: 2969	Visual Slump	: N/A
Headwater	: 68.00%	Load Size	: 9 cu yds
Wash water	: 32.00%	Mixing Speed	: 12 rpm

E 11.2 Batch Record

Materials	Source-Type	Mix Design	Target Weight	Actual Weight	Tolerances	Auto or Manual	Moisture Percent
#57	Rinker	1,667 lbs	15,228 lb	15,240 lb	IN	Auto	1.50%
Sand	Ortona	1,053 lbs	9,704 lbs	9,720 lbs	IN	Auto	2.40%
Cement	Type II Rinker	298 lbs	2,682 lbs	2,700 lbs	IN	Auto	
Slag	Rinker	447 lbs	4,022 lbs	4,010 lbs	IN	Auto	
Air	Darex (Grace)	2 oz	54 oz	53 oz	IN	Auto	
Retarder	WRDA 64;Grace	8 oz	214 oz	214 oz	IN	Auto	
Water	Well	37 gal	190 gal	189 gal	IN	Auto	

Note 1: Water weight; mix design(333gal), minus moisture compensation(54gal), and jobsite allowable(90gal)

E 11.3 Batch Concrete Properties

	Slump	Air %	Temperature	Unit weight (#/cu ft)	Cylinder cast @ 7-days	Cylinder cast @ 28-days
Initial	8.0 in	N/A	82 F	N/A	N/A	N/A
Final	7.75 in	2.00%	N/A	141.2	2	2

E 11.4 Slump Stand Data

Allowed water	Visual slump	No. initial revolutions	Water added	Additional revolutions	Total # revolutions @ discharge
62 gal	N/A	35	40 gal	57	92

Note 2: 181 total revolutions, prior to complete discharge of the mixer.

E 11.5 Lumps Discharged

Size of Balls	3 to 4 (in)	5 to 6 (in)	7 to 8 (in)	9 to 10 (in)	11 to 12 (in)	> 12 (in)	Total # of Balls
Number of Balls	3	1	1	0	0	0	**5**

E 12 Test Batch #12; Head Water

E 12.1 Batch Data

Date	: 5/8/2001	Discharge Rate	: 200 #/sec
Drill Shaft Mix No.	: 06-0281	Truck Slump Gage	: N/A
Truck Mixer No.	: 2969	Visual Slump	: N/A
Headwater	: **64.00%**	Load Size	: 9 cu yds
Wash water	: 36.00%	Mixing Speed	: 12 rpm

E 12.2 Batch Record

Materials	Source-Type	Mix Design	Target Weight	Actual Weight	Tolerances	Auto or Manual	Moisture Percent
# 57	Rinker	1,667 lbs	15,258 lb	15,240 lb	IN	Auto	1.70%
Sand	Ortona	1,053 lbs	9,670 lbs	9,720 lbs	IN	Auto	3.00%
Cement	Type II Rinker	298 lbs	2,682 lbs	2,670 lbs	IN	Auto	
Slag	Rinker	447 lbs	4,022 lbs	4,010 lbs	IN	Auto	
Air	Darex (Grace)	2 oz	54 oz	53 oz	IN	Auto	
Retarder	WRDA 64;Grace	8 oz	214 oz	215 oz	IN	Auto	
Water	Well	37 gal	180 gal	179 gal	IN	Auto	

Note 1: Water weight; mix design(333gal), minus moisture compensation(64gal), and jobsite allowable(90gal).

E 12.3 Batch Concrete Properties

	Slump	Air %	Temperature	Unit weight (#/cu ft)	Cylinder cast @ 7-days	Cylinder cast @ 28-days
Initial	6 in	3.00%	88 F	N/A	N/A	N/A
5 gal addition	7.50 in	2.50%	N/A	140	N/A	N/A
Final	7.50 in	2.00%	81 F	140	2	2

Note 2: Supplemental 5 gal water addition, meets slump requirements.

E 12.4 Slump Stand Data

Allowed water	Visual slump	No. initial revolutions	Water addition	Supplemental water addition	Additional revolutions	Total # revolutions @ discharge
90 gal	N/A	49	45 gal	5 gal	49	98

Note 3: 175 total revolutions, prior to complete discharge of the mixer.

E 12.5 Lumps Discharged

Size of Balls	3 to 4 (in)	5 to 6 (in)	7 to 8 (in)	9 to 10 (in)	11 to 12 (in)	> 12 (in)	Total # of Balls
# of Balls	0	0	0	0	0	0	**0**

E 13 Test Batch #1; Head Water

E 13.1 Batch Data

Date	: 3/11/2002	Discharge Rate	: 200 #/sec
Drill Shaft Mix No.	: 06-0281	Truck Slump Gage	: N/A
Truck Mixer No.	: 2969	Visual Slump	: 8.25 in
Headwater	: **50.00%**	Load Size	: 9 cu yds
Tailwater	: 50.00%	Mixing Speed	: 12 rpm

E 13.2 Batch Record

Materials	Source and/or Type	Mix Design	Target Weight	Actual Weights	Tolerances	Auto or Manual	Moisture %
#57	Rinker	1,667 lbs	15,183 lb	15,200 lb	IN	Auto	1.20%
Sand	Ortona	1,053 lbs	9,723 lbs	9,720 lbs	IN	Auto	2.60%
Cement	Type II Rinker	298 lbs	2,682 lbs	2,680 lbs	IN	Auto	
Slag	Rinker	447 lbs	4,023 lbs	4,030 lbs	IN	Manual	
Air	Darex (DOT)	2 oz	54 oz	53 oz	IN	Auto	
Retarder	WRDA 60; Grace	8 oz	215 oz	215 oz	IN	Manual	
Water	Well	37 gal	237 gal	236 gal	IN	Auto	

Note 1: Water weight; mix design(333gal), minus moisture compensation(51gal), and jobsite allowable(46gal).

E 13.3 Slump Stand Data

Initial revs	Water added	Additional revs	Total revs	Note: Middle of load
55	???	30	85	

E 13.4 Concrete Properties

Slump	Air %	Unit weight (#/cuft)
8.25 in	2.00%	141.6

Note 2: After initial 55 revs (12 rpm), the tailwater was added while the truck drum was at agitating speed (2 to 4 rpm), then mixed at mixing speed (12 rpm) for additional 30 revs.

E 13.5 Lumps Discharged

Size of Balls	1 to 2 (in)	3 to 4 (in)	5 to 6 (in)	7 to 8 (in)	9 to 10 (in)	> 10 (in)	Total # of Balls
Number of Balls	9	13	11	1	3	2	**49**

Note 2: Six samples were taken to a laboratory for grading and analysis.

E 14 Test Batch #2; Head Water OF PHASE I

E 14.1 Batch Data

Date	: 3/11/2002	Dicharge Rate	: 200 #/sec
Drill Shaft Mix No.	: 06-0281	Truck Slump Gage	: N/A
Truck Mixer No.	: 2969	Visual Slump	: 8.75 in
Headwater	: 30.00%	Load Size	: 9 cu yds
Tailwater	: 70.00%	Mixing Speed	: 12 rpm

E 14.2 Batch Record

Materials	Source and/or Type	Mix Design	Target Weight	Actual Weights	Tolerances	Auto or Manual	Moisture %
#57	Rinker	1,667 lbs	15,183 lb	15,200 lb	IN	Auto	1.20%
Sand	Ortona	1,053 lbs	9,723 lbs	9,760 lbs	IN	Auto	2.60%
Cement	Type II Rinker	298 lbs	2,682 lbs	2,690 lbs	IN	Auto	
Slag	Rinker	447 lbs	4,023 lbs	4,040 lbs	IN	Manual	
Air	Darex (DOT)	2 oz	54 oz	53 oz	IN	Auto	
Retarder	WRDA 60; Grace	8 oz	215 oz	215 oz	IN	Manual	
Water	Well	37 gal	210 gal	209 gal	IN	Auto	

Note 1: Water weight; mix design(333gal), minus moisture compensation(51gal), and jobsite allowable(73gal).

E 14.3 Slump Stand Data

Initial revs	Water added	Additional revs	Total revs
55	**35 to 62 gal**	30	85 to 160

E 14.4 Concrete Properties

Note : Middle of load	Slump	Air %	Unit weight (#/cuft)
	8.75 in	2.80%	??

Note 2: After initial 55 revs (12 rpm), the tailwater was added twice for slump requirements at the trucks drum charging speed (2 to 4 rpm). Additional revolutions were provided after each addition at 12 rpm .

E 14.5 Lumps Discharged

Size of Balls	1 to 2 (in)	3 to 4 (in)	5 to 6 (in)	7 to 8 (in)	9 to 10 (in)	> 10 (in)	Total # of Balls
Number of Balls	1	4	0	1	0	0	**6**

Note 2: Lumps & balls appeared homogenous with slightly dryer core.
Note 3: **Test is unusable, the multiple water additions created inconclusive results.**

E 15 Test Batch #3; Head Water of Phase II

E 15.1 Batch Data

Date	: 3/12/2002	Dicharge Rate	: 200 #/sec
Drill Shaft Mix No.	: 06-0281	Truck Slump Gage	: N/A
Truck Mixer No.	: 2969	Visual Slump	: 9 in
Headwater	: 20.00%	Load Size	: 9 cu yds
Tailwater	: 80.00%	Mixing Speed	: 12 rpm

E 15.2 Batch Record

Materials	Source and/or Type	Mix Design	Target Weight	Actual Weights	Tolerances	Auto or Manual	Moisture %
#57	Rinker	1,667 lbs	15,288 lb	15,280 lb	IN	Auto	1.90%
Sand	Ortona	1,053 lbs	9,723 lbs	9,720 lbs	IN	Auto	2.60%
Cement	Type II Rinker	298 lbs	2,682 lbs	2,690 lbs	IN	Manual	
Slag	Rinker	447 lbs	4,023 lbs	4,090 lbs	IN	Manual	
Air	Darex (DOT)	2 oz	54 oz	54 oz	IN	Auto	
Retarder	WRDA 60; Grace	8 oz	214 oz	215 oz	IN	Manual	
Water	Well	37 gal	197gal	196 gal	IN	Auto	

Note 1: Water weight; mix design(333gal), minus moisture compensation(64gal), and jobsite allowable (73gal)

E 15.3 Slump Stand Data / **E 15.4 Concrete Properties**

Initial revs	Water added	Additional revs	Total revolution	Note: Middle of load	Slump	Air %	Unit weight (#/cuft)
55	**56 gal**	30	85		9 in	2.80%	141

Note 2 : After initial 55 revs (12 rpm), the tailwater was added while the truck drum was at agitating speed (2 to 4 rpm), then mixed at mixing speed (12 rpm) for additional 30 revs.

E 15.5 Lumps Discharged

Size of Balls	1 to 2 (in)	3 to 4 (in)	5 to 6 (in)	7 to 8 (in)	9 to 10 (in)	> 10 (in)	Total # of Balls
Number of Balls	3	3	3	0	0	1	**10**

Note 3: Lumps extremly moist & soft, homogeneous in composition with slightly dryer core. **A head-pack possibility was close to dangerous, with 20% head-water**.

E 16 Test Batch #4; Initial Revolutions (30% Head Water) of Phase II

E 16.1 Batch Data

Date	: 3/12/2002	Dicharge Rate	: 200 #/sec
Drill Shaft Mix No.	: 06-0281	Truck Slump Gage	: N/A
Truck Mixer No.	: 2969	Visual Slump	: 8.75 in
Headwater	: 30.00%	Load Size	: 9 cu yds
Tail water	: 70.00%	Mixing Speed	: 12 rpm

E 16.2 Batch Record

Materials	Source and/or Type	Mix Design	Target Weight	Actual Weights	Tolerances	Auto or Manual	Moisture %
#57	Rinker	1,667 lbs	15,288 lb	15,320 lb	IN	Auto	1.90%
Sand	Ortona	1,053 lbs	9,723 lbs	9,800 lbs	IN	Auto	2.60%
Cement	Type II Rinker	298 lbs	2,682 lbs	2,680 lbs	IN	Auto	
Slag	Rinker	447 lbs	4,023 lbs	4,000 lbs	IN	Manual	
Air	Darex (DOT)	2 oz	54 oz	53 oz	OUT	Manual	
Retarder	WRDA 60; Grace	8 oz	214 oz	215 oz	IN	Manual	
Water	Well	37 gal	197 gal	196 gal	IN	Auto	

Note 1: Water weight; mix design(333gal), minus moisture compensation(64gal), and jobsite allowable (73gal)

E 16.3 Slump Stand Data / **E 16.4 Concrete Properties**

Initial revs	Water added	Additional revs	Total revs	Note: Middle of load.	Slump	Air %	Unit weight (#/cuft)
75	55 gal	30	**105**		8.75 in	2.60%	140.6

Note 2 : After initial 75 revs (12 rpm), the tailwater was added while the truck drum was at agitating speed (2 to 4 rpm), then mixed at mixing speed (12 rpm) for additional 30 revs.

E 16.5 Lumps Discharged

Size of Balls	1 to 2 (in)	3 to 4 (in)	5 to 6 (in)	7 to 8 (in)	9 to 10 (in)	> 10 (in)	Total # of Balls
Number of Balls	0	1	2	2	2	0	**7**

Note 3: Lumps homogeneous in composition with slightly dryer core & the mix very fluid.

E 17 Test Batch #5;Initial Revolutions (30% Head Water) of Phase II

E 17.1 Batch Data			
Date	: 3/12/2002	Discharge Rate	: 200 #/sec
Drill Shaft Mix No.	: 06-0281	Truck Slump Gage	: N/A
Truck Mixer No.	: 2969	Visual Slump	: 8.50 in
Headwater	: 30.00%	Load Size	: 9 cuyds
Tailwater	: 70.00%	Mixing Speed	: 12 rpm

E 17.2 Batch Record

Materials	Source and/or Type	Mix Design	Target Weight	Actual Weights	Tolerances	Auto or Manual	Moisture %
#57	Rinker	1,667 lbs	15,288 lb	15,280 lb	IN	Auto	1.90%
Sand	Ortona	1,053 lbs	9,723 lbs	9,720 lbs	IN	Auto	2.60%
Cement	Type II Rinker	298 lbs	2,682 lbs	2,670 lbs	IN	Auto	
Slag	Rinker	447 lbs	4,023 lbs	3,990 lbs	IN	Manual	
Air	Darex (DOT)	2 oz	54 oz	53 oz	IN	Auto	
Retarder	WRDA 60;Grace	8 oz	214 oz	215 oz	IN	Manual	
Water	Well	37 gal	197 gal	197 gal	IN	Auto	

Note 1: Water weight; mix design(333gal), minus moisture compensation(64gal), and jobsite allowable (72gal)

E 17.3 Slump Stand Data / E 17.4 Concrete Properties

Initial revs	Water added	Additional revs	Total revs	Note:	Slump	Air %	Unit weight (#/cuft)
100	58 gal	30	**130**	Middle of load.	8.50 in	2.50%	141.4

Note 2 : After initial 100 revs (12 rpm), the tailwater was added while the truck drum was at agitating speed (2 to 4 rpm), then mixed at mixing speed (12 rpm) for additional 30 revs.

E 17.5 Lumps Discharged

Size of Balls	1 to 2 (in)	3 to 4 (in)	5 to 6 (in)	7 to 8 (in)	9 to 10 (in)	> 10 (in)	Total # of Balls
Number of Balls	0	0	0	0	0	0	**0**

Note 3: Concrete was extremely fluid (very good workability).

Appendix B

SIEVE ANALYSIS RESULTS

CONCRETE BALL GRADATONS

Tech.	BB
Date	4/18/2001

INIT. WT. 4512.9

SIEVE	WT.	%ret.	% cum.	%pass
1 1/2"	0.0	0.0	0.0	100.0
1"	0.0	0.0	0.0	100.0
3/4"	357.0	7.9	7.9	92.1
1/2"	985.0	21.8	29.7	70.3
3/8"	589.0	13.1	42.8	57.2
#4	342.0	7.6	50.4	49.6
#8	35.0	0.8	51.1	48.9
#10	9.6	0.2	51.4	48.6
#16	118.6	2.6	54.0	46.0
#30	1026.0	22.7	76.7	23.3
#40	479.1	10.6	87.3	12.7
#50	226.4	5.0	92.4	7.6
#80	251.4	5.6	97.9	2.1
#100	41.2	0.9	98.8	1.2
#200	40.0	0.9	99.7	0.3
pan	10.0	0.2	99.9	0.1
Total	4510.3	99.9		

3/4 max in High slump

Pan and sample wet	6494.3
Pan & sample after wash wt.dry	5761.4
Pan wt.	1232.3
%diff.	16.2

Init Wt. g 1079.5

Ball Wt. g. before wash 2975.0
Dry Wt after wash 1079.5

Gilson pan wt. g 442.5

init wt. g= 442.5

sieve	WT.	ind %ret	cum%ret	cum % pass	wt	factor
1"	0.0	0.0	0.0	100.0		
3/4"	90.5	8.4	8.4	91.6		
1/2"	242.0	22.4	30.8	69.2		
3/8"	114.0	10.6	41.4	58.6		
#4	158.5	14.7	56.0	44.0		
#8	28.0	2.6	58.6	41.4		
#10	3.3	0.3	58.9	41.1	3.30	0.01
#16	28.6	2.6	61.6	38.4	28.60	0.06
#30	215.4	20.0	81.5	18.5	215.40	0.49
#40	86.9	8.1	89.6	10.4	86.90	0.20
#50	43.7	4.0	93.6	6.4	43.70	0.10
#80	39.8	3.7	97.3	2.7	39.80	0.09
#100	9.4	0.9	98.2	1.8	9.40	0.02
#200	10.4	1.0	99.2	0.8	10.40	0.02
pan	4.6	0.4	99.6	0.4	4.60	0.01
Total	1075.1	99.6	99.6		442.10	1.00

Init Wt. g 1981.5

Ball Wt. g before wash 2975
Dry Wt. after wash 1981.5

Gilson pan wt. g 895.50

init wt g.= 326.10

sieve	WT.	ind %ret	cum%ret	cum % pass	wt	factor
1"	0.0	0.0	0.0	100.0		
3/4"	142.5	7.2	7.2	92.8		
1/2"	383.0	19.3	26.5	73.5		
3/8"	244.0	12.3	38.8	61.2		
#4	263.5	13.3	52.1	47.9		
#8	52.0	2.6	54.8	45.2		
#10	6.6	0.3	55.1	44.9	2.4	0.01
#16	56.3	2.8	57.9	42.1	20.5	0.06
#30	439.6	22.2	80.1	19.9	160.1	0.49
#40	177.1	8.9	89.1	10.9	64.5	0.20
#50	88.4	4.5	93.5	6.5	32.2	0.10
#80	79.4	4.0	97.5	2.5	28.9	0.09
#100	19.2	1.0	98.5	1.5	7.0	0.02
#200	20.0	1.0	99.5	0.5	7.3	0.02
pan	8.2	0.4	99.9	0.1	3.0	0.01
Total	1980.0	99.9	99.9		325.90	1.00

Init Wt. g 5596.0

Ball Wt. g before wash 8307.0
Dry Wt. after wash 5596.0

sieve	WT.	ind %ret	cum%ret	cum % pass	wt	factor
1"	42.0	0.8	0.0	100.0		
3/4"	192.0	3.4	3.4	96.6		
1/2"	811.0	14.5	17.9	82.1	Gilson pan wt. g	3114.0
3/8"	552.5	9.9	27.8	72.2		
#4	718.0	12.8	40.6	59.4	init wt g.=	318.10
#8	151.5	2.7	43.3	56.7	wt	factor
#10	15.7	0.3	43.6	56.4	1.6	0.01
#16	196.8	3.5	47.1	52.9	20.1	0.06
#30	1546.7	27.6	74.8	25.2	158.0	0.50
#40	617.7	11.0	85.8	14.2	63.1	0.20
#50	302.5	5.4	91.2	8.8	30.9	0.10
#80	273.1	4.9	96.1	3.9	27.9	0.09
#100	64.6	1.2	97.2	2.8	6.6	0.02
#200	56.8	1.0	98.3	1.7	5.8	0.02
pan	34.3	0.6	98.9	1.1	3.5	0.01
Total	5575.1	99.6	98.9		317.5	1.00

Init Wt. g 4363.0

Ball Wt. g before wash 6297.0
Dry Wt. after wash 4363.0

sieve	WT.	ind %ret	cum%ret	cum % pass	wt	factor
1"	19.5	0.4	0.4	100.0		
3/4"	129.0	3.0	3.4	97.0		
1/2"	689.5	15.8	19.2	81.2	Gilson pan wt. g	2395.0
3/8"	438.0	10.0	29.2	71.2		
#4	566.5	13.0	42.2	58.2	init wt g.=	345.70
#8	111.5	2.6	44.8	55.7	wt	factor
#10	16.6	0.4	45.2	55.3	2.4	0.01
#16	155.9	3.6	48.7	51.7	22.5	0.07
#30	1202.0	27.5	76.3	24.2	173.5	0.50
#40	460.7	10.6	86.8	13.6	66.5	0.19
#50	227.9	5.2	92.1	8.4	32.9	0.10
#80	209.2	4.8	96.9	3.6	30.2	0.09
#100	49.9	1.1	98.0	2.4	7.2	0.02
#200	43.6	1.0	99.0	1.4	6.3	0.02
pan	24.9	0.6	99.6	0.9	3.6	0.01
Total	4344.8	99.6	99.6		345.1	1.00

Init Wt. g 3080.5

Ball Wt. g before wash 4656.0
Dry Wt after wash 3080.5

Gilson pan wt. g 1736.0

init wt g.= 456.90

sieve	WT.	ind %ret	cum%ret	cum % pass	wt	factor
1"	0.0	0.0	0.0	100.0		
3/4"	24.5	0.8	0.8	99.2		
1/2"	546.0	17.7	18.5	81.5		
3/8"	265.0	8.6	27.1	72.9		
#4	421.0	13.7	40.8	59.2		
#8	88.0	2.9	43.6	56.4		
#10	13.7	0.4	44.1	55.9	3.6	0.01
#16	109.8	3.6	47.7	52.3	28.9	0.06
#30	859.1	27.9	75.5	24.5	226.1	0.49
#40	337.8	11.0	86.5	13.5	88.9	0.19
#50	172.1	5.6	92.1	7.9	45.3	0.10
#80	155.4	5.0	97.1	2.9	40.9	0.09
#100	36.5	1.2	98.3	1.7	9.6	0.02
#200	32.3	1.0	99.4	0.6	8.5	0.02
pan	18.6	0.6	100.0	0.0	4.9	0.01
Total	3079.7	100.0	100.0		456.7	1.00

Init Wt. g 2419.5

Ball Wt. g before wash 3665.0
Dry Wt. after wash 2419.5

Gilson pan wt. g 1259.0

init wt g.= 319.10

sieve	WT.	ind %ret	cum%ret	cum % pass	wt	factor
1	0.0	0.0	0.0	100.0		
3/4	105.5	4.4	4.4	95.6		
1/2	349.5	14.4	18.8	81.2		
3/8	293.0	12.1	30.9	69.1		
4	346.0	14.3	45.2	54.8		
8	64.0	2.6	47.9	52.1		
10	11.0	0.5	48.3	51.7	2.8	0.01
16	81.3	3.4	51.7	48.3	20.6	0.06
30	616.7	25.5	77.2	22.8	156.3	0.49
40	243.8	10.1	87.2	12.8	61.8	0.19
50	123.1	5.1	92.3	7.7	31.2	0.10
80	113.2	4.7	97.0	3.0	28.7	0.09
100	29.2	1.2	98.2	1.8	7.4	0.02
200	26.4	1.1	99.3	0.7	6.7	0.02
pan	11.8	0.5	99.8	0.2	3.0	0.01
Total	2414.6	99.8	99.8		318.5	1.00

Appendix C

COMPRESSIVE STRENGHT TEST RESULTS

CSR
Rinker

Cylinder Compressive Strength **6" x 12"** **CMEC ACCREDITATION NO: EN1591**

Customer:
Project:
Contractor:

Date: June 29, 2001
Plant: 1053 Sweetwater

Mix Code: 1213131
Specified Strength: 4,000 PSI
06-0281 CLIV DS (4000)

Slump: 8.0 + / - 1.50 in.
Air Content: 3 +/- 1.5

Delivery Ticket No:	154094	Load Size:	9.0 Cyd.	Slump:	7.75 in.
Date Sampled:	05/07/2001	Water Added:		Air Content:	2.3 %
Time Sampled:	12:32	Before Test:	9.00 Gal.	Unit Wt.:	140.4 PCF
Time Batched:	12:15	After Test:	Gal.	Conc. Temp:	82 F
Truck No.:	2969	Weather Cond.:	Fine	Air Temp:	79 F
Sampled By:	js				

Specimens Received in LCentral LAB
Location of Specimen:

Time Received in Lab: 07:00

Spec.No	Date Tested	Age	Density PCF	Diameter in.	Area Sq In	Max Load Lb	Compressive Strength Psi	FT	Remarks
154094A	05/14/2001	7	139.8	6.00	28.27	167,050	5,910	a	Cone
154094B	05/14/2001	7	140.1	6.00	28.27	165,280	5,850	a	Cone
154094C	06/04/2001	28	138.8	6.00	28.27	201,020	7,110	a	Cone
154094D	06/04/2001	28	139.8	6.00	28.27	205,160	7,260	b	Cone And Split

Notes:

1. Sampling, Specimen Molding , Curing, and Testing have been performed in Accordance with Applicable ASTM Standards and Methods, unless otherwise noted.
2. Specimen Consolidation is by rodding unless otherwise noted.
3. Specimen Capping is with Sulfur mortar, unless otherwise noted.
4. Mass per volume hardened concrete was determined in standard moisture condition, uncapped, unless otherwise noted.
5. Fracture type noted is that shown in ASTM C39 - 9.16 Figure 2.

General Remarks:

Distribution:

RG 7/3/01
Alberto J. Romanach, P.E.
Florida License No. 56002

CSR Rinker Materials Corporation, W.P.B. Laboratory, 1501 Belvedere Rd., West Palm Beach, FL 33406, PO Box 24635, West Palm Beach, FL 33416
Telephone (561) 820-8519 Facsimile (561) 820-8518

CSR Rinker

Cylinder Compressive Strength **6" x 12"**

CMEC ACCREDITATION
NO: EN1591

Customer:
Project:
Contractor:

Date: June 22, 2001
Plant: 1053 Sweetwater

Mix Code: 1213131
Specified Strength: 4,000 PSI
06-0281 CLIV DS (4000)

Slump: 8.0 + / - 1.50 in.
Air Content: 3 +/- 1.5

Delivery Ticket No:	154078	Load Size:	9.0 Cyd.	Slump:	8.50 in.
Date Sampled:	04/09/2001	Water Added:		Air Content:	%
Time Sampled:	14:15	Before Test:	Gal.	Unit Wt.:	141.6 PCF
Time Batched:	13:46	After Test:	Gal.	Conc. Temp:	88 F
Truck No.:	2969	Weather Cond.:	Fine	Air Temp:	F
Sampled By:	js				

Specimens Received in LCentral LAB
Location of Specimen:

Time Received in Lab: 07:00

Spec.No	Date Tested	Age	Density PCF	Diameter in.	Area Sq In	Max Load Lb	Compressive Strength Psi	FT	Remarks
154078A	04/16/2001	7	140.3	6.00	28.27	164,100	5,800	a	Cone
154078B	04/16/2001	7	139.8	6.00	28.27	162,030	5,730	a	Cone
154078C	05/07/2001	28	141.1	6.00	28.27	223,330	7,900	a	Cone
154078D	05/07/2001	28	140.3	6.00	28.27	216,190	7,650	a	Cone

Notes:
1. Sampling, Specimen Molding , Curing, and Testing have been performed in Accordance with Applicable ASTM Standards and Methods, unless otherwise noted.
2. Specimen Consolidation is by rodding unless otherwise noted.
3. Specimen Capping is with Sulfur mortar, unless otherwise noted.
4. Mass per volume hardened concrete was determined in standard moisture condition, uncapped, unless otherwise noted.
5. Fracture type noted is that shown in ASTM C39 - 9.16 Figure 2.

General Remarks:

Distribution:

PE 6/27/01
ALBERTO J. ROMANACH, P.E.
FLORIDA LICENSE NO. 56002

CSR Rinker Materials Corporation, W.P.B. Laboratory, 1501 Belvedere Rd., West Palm Beach, FL 33406, PO Box 24635, West Palm Beach, FL 33416
Telephone (561) 820-8519 Facsimile (561) 820-8518

CSR
Rinker

Cylinder Compressive Strength **6" x 12"** **CMEC ACCREDITATION NO: EN1591**

Customer:
Project:
Contractor:

Date: June 29, 2001
Plant: 1053 Sweetwater

Mix Code: 1213131
Specified Strength: 4,000 PSI
06-0281 CLIV DS (4000)

Slump: 8.0 + / - 1.50 in.
Air Content: 3 +/- 1.5

Delivery Ticket No:	154079	Load Size:	9.0 Cyd.	Slump:	7.50 in.
Date Sampled:	04/10/2001	Water Added:		Air Content:	2.0 %
Time Sampled:	14:24	Before Test:	Gal.	Unit Wt.:	142.0 PCF
Time Batched:	14:24	After Test:	Gal.	Conc. Temp:	85 F
Truck No.:	2969	Weather Cond.:	Fine	Air Temp:	F
Sampled By: js					

Specimens Received in LCentral LAB
Location of Specimen:

Time Received in Lab: 07:00

Spec.No	Date Tested	Age	Density PCF	Diameter in.	Area Sq In	Max Load Lb	Compressive Strength Psi	FT	Remarks
154079A	04/17/2001	7	140.6	6.00	28.27	168,670	5,970	a	Cone
154079B	04/17/2001	7	141.6	6.00	28.27	166,460	5,890	a	Cone
154079C	05/08/2001	28	140.6	6.00	28.27	206,630	7,310	a	Cone
154079D	05/08/2001	28	140.8	6.00	28.27	204,710	7,240	a	Cone

Notes:

1. Sampling, Specimen Molding , Curing, and Testing have been performed in Accordance with Applicable ASTM Standards and Methods, unless otherwise noted.
2. Specimen Consolidation is by rodding unless otherwise noted.
3. Specimen Capping is with Sulfur mortar, unless otherwise noted.
4. Mass per volume hardened concrete was determined in standard moisture condition, uncapped, unless otherwise noted.
5. Fracture type noted is that shown in ASTM C39 - 9.16 Figure 2.

General Remarks:

Distribution:

7/3/01
Alberto J. Romanach, P.E.
Florida License No. 56002

CSR Rinker Materials Corporation, W.P.B. Laboratory, 1501 Belvedere Rd., West Palm Beach, FL 33406, PO Box 24635, West Palm Beach, FL 33416
Telephone (561) 820-8519 Facsimile (561) 820-8518

CSR
Rinker

Cylinder Compressive Strength 6" x 12"

CMEC ACCREDITATION
NO: EN1591

Customer:
Project:
Contractor:

Date: June 29, 2001
Plant: 1053 Sweetwater

Mix Code: 1213131
Specified Strength: 4,000 PSI
06-0281 CLIV DS (4000)

Slump: 8.0 + / - 1.50 in.
Air Content: 3 +/- 1.5

Delivery Ticket No:	154080	Load Size:	9.0 Cyd.	Slump:	7.75 in.
Date Sampled:	04/10/2001	Water Added:		Air Content:	2.0 %
Time Sampled:	15:25	Before Test:	Gal.	Unit Wt.:	142.0 PCF
Time Batched:	15:25	After Test:	Gal.	Conc. Temp:	82 F
Truck No.:	2969	Weather Cond.:	Fine	Air Temp:	F
Sampled By:					

Specimens Received in LCentral LAB
Location of Specimens:

Time Received in Lab: 07:00

Spec.No	Date Tested	Age	Density PCF	Diameter in.	Area Sq In	Max Load Lb	Compressive Strength Psi	FT	Remarks
154080A	04/17/2001	7	143.9	6.00	28.27	170,590	6,030	a	Cone
154080B	04/17/2001	7	143.9	6.00	28.27	168,380	5,960	a	Cone
154080C	05/08/2001	28	140.6	6.00	28.27	219,480	7,760	a	Cone
154080D	05/08/2001	28	140.6	6.00	28.27	210,330	7,440	c	Cone And Shear

Notes:
1. Sampling, Specimen Molding, Curing, and Testing have been performed in Accordance with Applicable ASTM Standards and Methods, unless otherwise noted.
2. Specimen Consolidation is by rodding unless otherwise noted.
3. Specimen Capping is with Sulfur mortar, unless otherwise noted.
4. Mass per volume hardened concrete was determined in standard moisture condition, uncapped, unless otherwise noted.
5. Fracture type noted is that shown in ASTM C39 - 9.16 Figure 2.

General Remarks:

Distribution:

Alberto J. Romanach, P.E.
Florida License No. 56002

CSR Rinker Materials Corporation, W.P.B. Laboratory, 1501 Belvedere Rd., West Palm Beach, FL 33406, PO Box 24635, West Palm Beach, FL 33416
Telephone (561) 820-8519 Facsimile (561) 820-8518

CSR Rinker

Cylinder Compressive Strength **6" x 12"**

CMEC ACCREDITATION
NO: EN1591

Customer:
Project:
Contractor:

Date: June 22, 2001
Plant: 1053 Sweetwater

Mix Code: 1213131
Specified Strength: 4,000 PSI
06-0281 CLIV DS (4000)

Slump: 8.0 + / - 1.50 in.
Air Content: 3 +/- 1.5

Delivery Ticket No:	144073	Load Size:	7.0 Cyd.	Slump:	7.50 in.
Date Sampled:	04/16/2001	Water Added:		Air Content:	2.0 %
Time Sampled:	14:39	Before Test:	Gal.	Unit Wt.:	140.4 PCF
Time Batched:	14:25	After Test:	Gal.	Conc. Temp:	86 F
Truck No.:	2969	Weather Cond.:	Fine	Air Temp:	84 F
Sampled By:	js				

Specimens Received in LCentral LAB
Location of Specimen:

Time Received in Lab: __:__

Spec.No	Date Tested	Age	Density PCF	Diameter in.	Area Sq In	Max Load Lb	Compressive Strength Psi	FT	Remarks
144073A	04/23/2001	7	139.5	6.00	28.27	156,710	5,540	a	Cone
144073B	05/14/2001	28	139.8	6.00	28.27	183,150	6,480	a	Cone
144073C	05/14/2001	28	140.3	6.00	28.27	192,600	6,810	a	Cone

Notes:
1. Sampling, Specimen Molding , Curing, and Testing have been performed in Accordance with Applicable ASTM Standards and Methods, unless otherwise noted.
2. Specimen Consolidation is by rodding unless otherwise noted.
3. Specimen Capping is with Sulfur mortar, unless otherwise noted.
4. Mass per volume hardened concrete was determined in standard moisture condition, uncapped, unless otherwise noted.
5. Fracture type noted is that shown in ASTM C39 - 9.16 Figure 2.

General Remarks:

Distribution:

P.E. 6/25/01
ALBERTO J. ROMANACH, PE.
FLORIDA LICENSE No. 56002

CSR Rinker Materials Corporation, W.P.B. Laboratory, 1501 Belvedere Rd., West Palm Beach, FL 33406, PO Box 24635, West Palm Beach, FL 33416
Telephone (561) 820-8519 Facsimile (561) 820-8518

CSR Rinker

Cylinder Compressive Strength 6" x 12"

CMEC ACCREDITATION NO: EN1591

Customer:
Project:
Contractor:

Date: June 29, 2001
Plant: 1053 Sweetwater

Mix Code: 1213131
Specified Strength: 4,000 PSI
06-0281 CLIV DS (4000)

Slump: 8.0 + / - 1.50 in.
Air Content: 3 +/- 1.5

Delivery Ticket No: 144075
Date Sampled: 04/17/2001
Time Sampled: 14:05
Time Batched: 13:55
Truck No.:
Sampled By: js

Load Size: 3.0 Cyd.
Water Added:
Before Test: Gal.
After Test: Gal.
Weather Cond.: Fine

Slump: 8.00 in.
Air Content: 2.3 %
Unit Wt.: 139.6 PCF
Conc. Temp: 84 F
Air Temp: F

Specimens Received in LCentral LAB
Location of Specimen:

Time Received in Lab: 07:00

Spec.No	Date Tested	Age	Density PCF	Diameter in.	Area Sq In	Max Load Lb	Compressive Strength Psi	FT	Remarks
144075A	04/24/2001	7	139.0	6.00	28.27	151,840	5,370	a	Cone
144075B	05/15/2001	28	138.3	6.00	28.27	185,810	6,570	a	Cone
144075C	05/15/2001	28	138.3	6.00	28.27	192,900	6,820	a	Cone

Notes:

1. Sampling, Specimen Molding , Curing, and Testing have been performed in Accordance with Applicable ASTM Standards and Methods, unless otherwise noted.
2. Specimen Consolidation is by rodding unless otherwise noted.
3. Specimen Capping is with Sulfur mortar, unless otherwise noted.
4. Mass per volume hardened concrete was determined in standard moisture condition, uncapped, unless otherwise noted.
5. Fracture type noted is that shown in ASTM C39 - 9.16 Figure 2.

General Remarks:

Distribution:

7/3/01
Alberto J. Romanach, P.E.
Florida License No. 56002

CSR Rinker Materials Corporation, W.P.B. Laboratory, 1501 Belvedere Rd., West Palm Beach, FL 33406, PO Box 24635, West Palm Beach, FL 33416
Telephone (561) 820-8519 Facsimile (561) 820-8518

CSR
Rinker

Cylinder Compressive Strength 6" x 12"

CMEC ACCREDITATION NO: EN1591

Customer:
Project:
Contractor:

Date: June 29, 2001
Plant: 1053 Sweetwater

Mix Code: 1213131
Specified Strength: 4,000 PSI
06-0281 CLIV DS (4000)

Slump: 8.0 + / - 1.50 in.
Air Content: 3 +/- 1.5

Delivery Ticket No:	144076	Load Size:	9.0 Cyd.	Slump:	7.50 in.
Date Sampled:	04/17/2001	Water Added:		Air Content:	2.0 %
Time Sampled:	15:00	Before Test:	Gal.	Unit Wt.:	140.8 PCF
Time Batched:	14:47	After Test:	Gal.	Conc. Temp:	83 F
Truck No.:	2969	Weather Cond.:	Fine	Air Temp:	F
Sampled By:	js				

Specimens Received in LCentral LAB
Location of Specimen:

Time Received in Lab: 07:00

Spec.No	Date Tested	Age	Density PCF	Diameter in.	Area Sq In	Max Load Lb	Compressive Strength Psi	FT	Remarks
144076A	04/24/2001	7	141.1	6.00	28.27	154,940	5,480	a	Cone
144076B	05/15/2001	28	140.8	6.00	28.27	192,010	6,790	a	Cone
144076C	05/15/2001	28	139.5	6.00	28.27	189,350	6,700	a	Cone

Notes:

1. Sampling, Specimen Molding , Curing, and Testing have been performed in Accordance with Applicable ASTM Standards and Methods, unless otherwise noted.
2. Specimen Consolidation is by rodding unless otherwise noted.
3. Specimen Capping is with Sulfur mortar, unless otherwise noted.
4. Mass per volume hardened concrete was determined in standard moisture condition, uncapped, unless otherwise noted.
5. Fracture type noted is that shown in ASTM C39 - 9.16 Figure 2.

General Remarks:

Distribution:

7/3/01
Alberto J. Romanach, P.E.
Florida License No. 56002

CSR Rinker Materials Corporation, W.P.B. Laboratory, 1501 Belvedere Rd., West Palm Beach, FL 33406, PO Box 24635, West Palm Beach, FL 33416
Telephone (561) 820-8519 Facsimile (561) 820-8518

CSR
Rinker

Cylinder Compressive Strength 6" x 12" CMEC ACCREDITATION NO: EN1591

Customer:
Project:
Contractor:

Date: June 22, 2001
Plant: 1053 Sweetwater

Mix Code: 1213131
Specified Strength: 4,000 PSI
06-0281 CLIV DS (4000)

Slump: 8.0 + / - 1.50 in.
Air Content: 3 +/- 1.5

Delivery Ticket No:	144074	Load Size:	5.0 Cyd.	Slump:	7.50 in.
Date Sampled:	04/16/2001	Water Added:		Air Content:	2.5 %
Time Sampled:	15:42	Before Test:	Gal.	Unit Wt.:	141.2 PCF
Time Batched:	15:24	After Test:	Gal.	Conc. Temp:	88 F
Truck No.:	2969	Weather Cond.:	Fine	Air Temp:	84 F
Sampled By:	js				

Specimens Received in LCentral LAB
Location of Specimen:

Time Received in Lab: 07:00

Spec.No	Date Tested	Age	Density PCF	Diameter in.	Area Sq In	Max Load Lb	Compressive Strength Psi	FT	Remarks
144074A	04/30/2001	14	138.3	6.00	28.27	184,180	6,510	a	Cone
144074B	05/14/2001	28	139.0	6.00	28.27	193,640	6,850	a	Cone
144074C	05/14/2001	28	139.3	6.00	28.27	185,360	6,560	a	Cone

Notes:
1. Sampling, Specimen Molding , Curing, and Testing have been performed in Accordance with Applicable ASTM Standards and Methods, unless otherwise noted.
2. Specimen Consolidation is by rodding unless otherwise noted.
3. Specimen Capping is with Sulfur mortar, unless otherwise noted.
4. Mass per volume hardened concrete was determined in standard moisture condition, uncapped, unless otherwise noted.
5. Fracture type noted is that shown in ASTM C39 - 9.16 Figure 2.

General Remarks:

Distribution:

PE. 6/25/01
ALBERTO J. ROMANACH, PE.
FLORIDA LICENSE NO. 56002.

CSR Rinker Materials Corporation, W.P.B. Laboratory, 1501 Belvedere Rd., West Palm Beach, FL 33406, PO Box 24635, West Palm Beach, FL 33416
Telephone (561) 820-8519 Facsimile (561) 820-8518

CSR Rinker

Cylinder Compressive Strength 6" x 12"

CMEC ACCREDITATION
NO: EN1591

Customer:
Project:
Contractor:

Date: June 22, 2001
Plant: 1053 Sweetwater

Mix Code: 1213131
Specified Strength: 4,000 PSI
06-0281 CLIV DS (4000)

Slump: 8.0 + / - 1.50 in.
Air Content: 3 +/- 1.5

Delivery Ticket No:	154095	Load Size:	9.0 Cyd.	Slump:	8.75 in.
Date Sampled:	05/07/2001	Water Added:		Air Content:	2.5 %
Time Sampled:	13:47	Before Test:	10.00 Gal.	Unit Wt.:	140.0 PCF
Time Batched:	13:30	After Test:	Gal.	Conc. Temp:	84 F
Truck No.:	2969	Weather Cond.:	Fine	Air Temp:	78 F
Sampled By:	js				

Specimens Received in LCentral LAB
Location of Specimen:

Time Received in Lab: 07:00

Spec.No	Date Tested	Age	Density PCF	Diameter in.	Area Sq In	Max Load Lb	Compressive Strength Psi	FT	Remarks
154095A	05/14/2001	7	139.3	6.00	28.27	153,310	5,420	a	Cone
154095B	05/14/2001	7	138.3	6.00	28.27	150,360	5,320	a	Cone
154095C	06/04/2001	28	138.8	6.00	28.27	188,470	6,670	a	Cone
154095D	06/04/2001	28	138.5	6.00	28.27	193,930	6,860	a	Cone

Notes:
1. Sampling, Specimen Molding , Curing, and Testing have been performed in Accordance with Applicable ASTM Standards and Methods, unless otherwise noted.
2. Specimen Consolidation is by rodding unless otherwise noted.
3. Specimen Capping is with Sulfur mortar, unless otherwise noted.
4. Mass per volume hardened concrete was determined in standard moisture condition, uncapped, unless otherwise noted.
5. Fracture type noted is that shown in ASTM C39 - 9.16 Figure 2.

General Remarks:

Distribution:

PE 6/25/01
ALBERTO J. ROMANACH, PE.
FLORIDA LICENSE NO. 56002

CSR Rinker Materials Corporation, W.P.B. Laboratory, 1501 Belvedere Rd., West Palm Beach, FL 33406, PO Box 24635, West Palm Beach, FL 33416
Telephone (561) 820-8519 Facsimile (561) 820-8518

CSR Rinker

Cylinder Compressive Strength **6" x 12"**

CMEC ACCREDITATION
NO: EN1591

Customer:
Project:
Contractor:

Date: June 22, 2001
Plant: 1053 Sweetwater

Mix Code: 1213131
Specified Strength: 4,000 PSI
06-0281 CLIV DS (4000)

Slump: 8.0 + / - 1.50 in.
Air Content: 3 +/- 1.5

Delivery Ticket No:	154096	Load Size:	9.0 Cyd.	Slump:	8.00 in.
Date Sampled:	05/07/2001	Water Added:		Air Content:	2.0 %
Time Sampled:	14:47	Before Test:	40.02 Gal.	Unit Wt.:	141.2 PCF
Time Batched:	14:20	After Test:	Gal.	Conc. Temp:	82 F
Truck No.:	2969	Weather Cond.:	Fine	Air Temp:	79 F
Sampled By:	js				

Specimens Received in LCentral LAB
Location of Specimen:

Time Received in Lab: 07:00

Spec.No	Date Tested	Age	Density PCF	Diameter in.	Area Sq In	Max Load Lb	Compressive Strength Psi	FT	Remarks
154096A	05/14/2001	7	139.8	6.00	28.27	164,390	5,810	a	Cone
154096B	05/14/2001	7	139.0	6.00	28.27	152,870	5,410	c	Cone And Shear
154096C	06/04/2001	28	138.5	6.00	28.27	198,950	7,040	a	Cone
154096D	06/04/2001	28	140.1	6.00	28.27	203,980	7,210	a	Cone

Notes:

1. Sampling, Specimen Molding , Curing, and Testing have been performed in Accordance with Applicable ASTM Standards and Methods, unless otherwise noted.
2. Specimen Consolidation is by rodding unless otherwise noted.
3. Specimen Capping is with Sulfur mortar, unless otherwise noted.
4. Mass per volume hardened concrete was determined in standard moisture condition, uncapped, unless otherwise noted.
5. Fracture type noted is that shown in ASTM C39 - 9.16 Figure 2.

General Remarks:

Distribution:

PE 6/25/01
ALBERTO J. ROMANACH, P.E.
FLORIDA LICENSE NO. 56002

CSR Rinker Materials Corporation, W.P.B. Laboratory, 1501 Belvedere Rd., West Palm Beach, FL 33406, PO Box 24635, West Palm Beach, FL 33416
Telephone (561) 820-8519 Facsimile (561) 820-8518