# DESIGN AND TEST PROPERTIES OF SUPER WATER REDUCERS IN PORTLAND CEMENT CONCRETE

Final Report

by

Sheldon M. Law
Concrete Research Engineer

and

Masood Rasoulian
Research Engineer-In-Training

Research Report No. FHWA/LA-81/135
State Project No. 736-03-80
Research Project No. 77-1C

Conducted By
LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT
Research and Development Section
In Cooperation with
U. S. Department of Transportation
FEDERAL HIGHWAY ADMINISTRATION



DECEMBER 1980

# TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

METRIC CONVERSION CHART

To convert U.S. Units to Metric Units (S.I.), the following conversion factors should be noted:

| Multiply U.S. Units | By | To Obtain Metric Units |
|---|---|---|
| | LENGTH | |
| inches (in.) | 2.5400 | centimeters (cm.) |
| feet (ft.) | 0.3048 | meters (m.) |
| yards (yd.) | 0.9144 | meters (m.) |
| miles (mi.) | 1.6090 | kilometers (km.) |
| | AREA | |
| square inches ($in^2$) | 6.4516 | square centimeters ($cm^2$) |
| square feet ($ft^2$) | 0.0929 | square meters ($m^2$) |
| square yards ($yd^2$) | 0.8361 | square meters ($m^2$) |
| | VOLUME | |
| cubic inches ($in^3$) | 16.3872 | cubic centimeters ($cm^3$) |
| cubic feet ($ft^3$) | 0.0283 | cubic meters ($m^3$) |
| cubic feet ($ft^3$) | 28.3162 | liters (l.) |
| cubic yards ($yd^3$) | 0.7646 | cubic meters ($m^3$) |
| fluid ounces (fl. oz.) | 29.57 | milliliters (ml.) |
| gallons (gal.) | 3.7853 | liters (l.) |
| | MASS (WEIGHT) | |
| pounds (lb.) | 0.4536 | kilograms (kg.) |
| ounces (oz.) | 28.3500 | grams (g.) |
| | PRESSURE | |
| pounds per square inch (p.s.i.) | 0.07030 | kilograms per square centimeters ($kg/cm^2$) |
| pounds per square inch (p.s.i.) | 0.006894 | mega pascal (MPa) |
| | DENSITY | |
| pounds per cubic yard ($lb/yd^3$) | 0.5933 | kilograms per cubic meter ($kg/m^3$) |
| bags of cement per cubic yard (cement bags/$yd^3$) | 55.7600 | kilograms per cubic meter ($kg/m^3$) |
| | TEMPERATURE | |
| degrees fahrenheit (°F.) | 5/9 (°F.-32) | degrees celsius (°C.) or centigrade |

# ABSTRACT

Recently, new concrete admixtures (super water reducers) have been developed and marketed by private industry. These admixtures permit the mixing and placement of very low water-cement ratio (0.32 to 0.38) concretes at conventional consistencies (slumps of 2 1/2 to 3 1/2 inches) with conventional equipment and slightly modified procedures. Mixes at greater slumps (3 1/2 to 8 inches) are also possible.

It was the purpose of this research project to determine in the laboratory the properties of the portland cement concrete using super water reducers, with the materials from Louisiana, mixed and evaluated under Louisiana conditions. Information and procedures to be used with these admixtures were explored to permit the use of very low water-cement ratio, air-entrained concrete in highway applications, especially in bridge decks or structures. These aims, along with the literature review of available information and a field trip to Houston, Texas (to observe a concrete pour of a bridge deck replacement project), were a part of the laboratory evaluation of a number of mix designs.

Super water reducers are admixtures that are very useful in obtaining flowable (highly fluid) concrete needed for special cases such as in structures where close spacing in the forms would require fluid concrete and yet high strength needs to be retained. Super water reducers, when used with air-entraining agents, can help to give a good mix design and good concrete properties such as better freeze-thaw durability, high strength and good workability. In the laboratory study, there were generally no problems in obtaining high strengths, either with or without air-entrainment, gravel or limestone coarse aggregate. Variables which could affect the plastic properties of the mix were type of cement, chemical composition of the cement, type and brand of super water reducer, the dosage rate and the time of adding the admixture to the mix.

It was very difficult to get any consistent control of the slump when super water reducers were used in the mix. Air contents were hard to control in most of the mixes with air-entrainment. Observations (26) from the field trip to Houston emphasized that erratic results were obtained on the concrete pour when the concrete temperature was high, in addition to a high loss of slump with time. It was also noted from the literature review and verified in this study that there seems to be a high variability in the plastic properties of concrete and at present there is no method of reliably predicting that plastic behavior without previous testing with the same combination of materials.

Preliminary mixes should always be run before any project begins and the compatability of materials should be checked. There must be good control exercised in the concrete mix design and the batching of super water reduced concrete. Guidelines for the Use of Super Water Reducers in Concrete were prepared as a part of this research study and can be found after the appendix.

More research should be conducted on the use of these super water reducers in concrete, particularly in the compatability of super water reducers with other additives, cements or aggregates; the control of loss of slump with time; durability relationships and any possible chloride protection properties. Small experimental installations should be tried before any large bridge installations are attempted on an experimental basis. Field experience and familiarity with the material and both its plastic and hardened concrete properties should be strived for. The precast industry would be a good starting point in the use of these materials.

# IMPLEMENTATION

More research in certain areas of the use of super water reducers will be recommended. A recommendation will also be made to try some minor structural experimental projects, even maintenance projects, first, in order to gain field experience and, familiarity with the material and to obtain some positive field results. Then, it is recommended that small bridge deck experimental projects be tried. Large projects and any blanket acceptance should be avoided until some positive field results and experience are obtained. Use in the precast field would be a good starting point for these materials.

Since there are a large number of commercial brands of super water reducers on the market, each with somewhat different properties, it is recommended that any experimental use should be coordinated through the Department's New Products Evaluation Committee, tested individually in the laboratory, then field tried using the guidelines as described in this report. Field experience is essential prior to the routine use of these admixtures, especially in structural concrete.

# INTRODUCTION

As stated in the Federal Highway Administration Prospectus and Statement of Work (1), one of the major causes of deterioration of portland cement concrete in pavements and bridge decks is the ingress of moisture and deleterious ions into the concrete. If this ingress can be reduced substantially, a significant increase in life can be expected. One method of decreasing the ingress of water and water-borne ions is to reduce the water-cement ratio of the concrete to values only slightly greater than that required to hydrate cement.

Along with the reduction in permeability, other changes in concrete properties should result including: higher compressive and flexural strengths at all ages, increased abrasion resistance, and decreased shrinkage both upon set and over a long-term period. However, very low water-cement ratio concretes are normally very stiff (low slump) and difficult to mix, place and consolidate, even when the conventional water-reducing admixtures are used.

Recently, new concrete admixtures called super water reducers or super plasticizers have been developed and marketed by private industry. These admixtures have the potential to permit the mixing and placement of very low water-cement ratio concretes (water-cement ratios of 0.32 to 0.38 by weight) at conventional consistencies (i.e., slumps of 2 1/2 to 3 1/2 inches) with conventional equipment and slightly modified procedures. Mixes at greater slumps (3 1/2 to 8 inches) are also possible.

# PURPOSE AND SCOPE

It was the purpose of this research project to determine the properties of the portland cement concrete using these super water reducers, with materials from Louisiana, mixed and evaluated under Louisiana conditions. Along with learning the properties associated with these new types of mixes, information and procedures to be used with super water reducers were explored in order to permit the use of very low water-cement ratio, air-entrained concrete in highway applications, especially in bridge decks or structures.

These aims, along with the literature review of available information, were a part of the laboratory evaluation of a number of mix designs. A revised study outline included such variables as: air-entrainment, gravel or crushed limestone aggregate mixes, cement content, type super water reducer and admixture versus control mixes.

Guidelines were prepared for use with these admixtures, when in the future, there may be an application of the technology to the construction and evaluation of one or more experimental or demonstration projects, made with at least one of the super water reducers that were used in laboratory mixes on this research project.

# METHODOLOGY

## A. Literature Review

A literature review was made on super water reducers or superplasticizers, both before and as the research study progressed, as information was being brought up to date continually. Primary emphasis was put on data and information concerning the particular admixtures used on this research project. Other material that was reviewed consisted of information that was supplied by the various manufacturers, either test reports, material properties, studies or applications in construction. In addition, several other states have sponsored research in this area, and gleanings from these studies are included herein.

A section on Comments from the Literature Review is included on page 11 immediately before the Discussion of Results. A comprehensive discussion on information accumulated from this source is included there. Even though the product herein may be called either a super water reducer or a superplasticizer, these terms refer to the same product. In this report, we will generally refer to the admixture as a super water reducer.

## B. Laboratory Design and Procedures

After a review of all the available literature at the time, mix designs were prepared using the information that was available. Originally, it was intended to have forty (40) mix designs as shown in Table 1 on the following page. After some preliminary mixing and testing in the laboratory, an evaluation was made and a change in scope was initiated, as shown in Table 2, with subsequent emphasis made on two of the products and those same mixes with air-entrainment. This led to a revised study outline, in order to keep the total number of mixes at approximately the same level, and to avoid expanding the study too much. Product information is given in Table 21 in the appendix.

## TABLE 1

## ORIGINAL STUDY OUTLINE

<u>Variables</u>

| | |
|---|---|
| Aggregate: | (1) Gravel, (2) Limestone, |
| Cement, sacks per cubic yard: | (3) 5.0, (4) 6.0, (5) 6.5, (6) 7.0, |
| Type of Mix: | (7) Control, Reference, (8) Admixtures, |
| Materials, Super Water Reducers: | (9) Mighty 150, (10) Lomar D, (11) Melment and (12) FX-32 |

<u>Mix Design Key</u>

| | | | |
|---|---|---|---|
| (1) 1-3-7 | (11) 1-5-7 | (21) 2-3-7* | (31) 2-5-7 |
| (2) 1-3-8-9 | (12) 1-5-8-9 | (22) 2-3-8-9* | (32) 2-5-8-9 |
| (3) 1-3-8-10 | (13) 1-5-8-10 | (23) 2-3-8-10* | (33) 2-5-8-10* |
| (4) 1-3-8-11 | (14) 1-5-8-11 | (24) 2-3-8-11* | (34) 2-5-8-11 |
| (5) 1-3-8-12 | (15) 1-5-8-12 | (25) 2-3-8-12* | (35) 2-5-8-12* |
| (6) 1-4-7 | (16) 1-6-7 | (26) 2-4-7 | (36) 2-6-7* |
| (7) 1-4-8-9 | (17) 1-6-8-9 | (27) 2-4-8-9 | (37) 2-6-8-9* |
| (8) 1-4-8-10 | (18) 1-6-8-10 | (28) 2-4-8-10* | (38) 2-6-8-10* |
| (9) 1-4-8-11 | (19) 1-6-8-11 | (29) 2-4-8-11 | (39) 2-6-8-11* |
| (10) 1-4-8-12 | (20) 1-6-8-12 | (30) 2-4-8-12* | (40) 2-6-8-12* |

*-Later Deleted

TABLE 2

REVISED STUDY OUTLINE

Variables

| | |
|---|---|
| Aggregate: | (1) Gravel, (2) Limestone, |
| Cement, sacks per cubic yard: | (3) 5.0, (4) 6.0, (5) 6.5, (6) 7.0, |
| Type of Mix: | (7) Control, Reference, (8) Admixture, |
| Materials, Super Water Reducers: | (9) Mighty 150, (10) Lomar D, (11) Melment, (12) FX-32 and |
| Entrainment: | (13) Air. |

Mix Design Key

| | | | |
|---|---|---|---|
| (1) 1-3-7 | (11) 1-5-7 | (21) 2-4-7 | (31) 2-5-8-9-13+ |
| (2) 1-3-8-9 | (12) 1-5-8-9 | (22) 2-4-8-9 | (32) 2-5-8-11-13+ |
| (3) 1-3-8-10 | (13) 1-5-8-10 | (23) 2-4-8-11 | (33) 1-4-7-13+ |
| (4) 1-3-8-11 | (14) 1-5-8-11 | (24) 2-5-7 | (34) 1-4-8-9-13+ |
| (5) 1-3-8-12 | (15) 1-5-8-12 | (25) 2-5-8-9 | (35) 1-4-8-11-13+ |
| (6) 1-4-7 | (16) 1-6-7 | (26) 2-5-8-11 | (36) 1-5-7-13+ |
| (7) 1-4-8-9 | (17) 1-6-8-9 | (27) 2-4-7-13+ | (37) 1-5-8-9-13+ |
| (8) 1-4-8-10 | (18) 1-6-8-10 | (28) 2-4-8-9-13+ | (38) 1-5-8-9-13+ |
| (9) 1-4-8-11 | (19) 1-6-8-11 | (29) 2-4-8-11-13+ | |
| (10) 1-4-8-12 | (20) 1-6-8-12 | (30) 2-5-7-13+ | |

+-Added

Material properties of plastic and hardened concrete made with these four (4) admixtures were determined. During the mixing operations, the slump, air content, air temperature, concrete temperature and the unit weight were determined for each mix. Air-void contents and loss of slump with time were also studied on a limited basis. Different levels of admixture dosages were not checked on this study; however, at a later time this may be done in order to obtain more valuable information.

A guide range of 2 1/2 to 3 1/2" was used for the slump, while a range of 0.32 to 0.38 was used for the water-cement ratio.

The modified mixing procedure, which differed somewhat from the standard ASTM C-192 mixing procedure, for concrete made in the laboratory using super water reducers was as follows:

(1) begin by adding approximately 2/3 of the mixing water to the total coarse and fine aggregate (coarse aggregate placed in mixer first, then the fine aggregate and then the water) and mix for one (1) minute;

(2) stop the mixer for approximately three (3) minutes for the absorption to occur (all coarse aggregate under the saturated surface dry condition);

(3) start the mixer, add the cement, plus the remaining water with the super water reducer in the water, then mix for an additional three (3) minutes; and

(4) at the end of the mixing cycle, pour the concrete into a mixing pan and remix using shovels.

If an air-entraining admixture was used, then the admixture was poured onto the sand at the start of the mixing cycle. A 5 ± 1% air content was the target value for the study mixes. Figure 1 on the following page shows the concrete mixer (3.5 cu. ft.) which was used in the laboratory study.

This procedure was used for the laboratory mixes; however, any mixing in the field would necessitate some slight adjustment to the normal field mixing procedures. The super water reducer would have to be added to the concrete mix after it is delivered to the jobsite and not at the mixer (unless the mixer is at the jobsite), especially if there was any appreciable transport time.

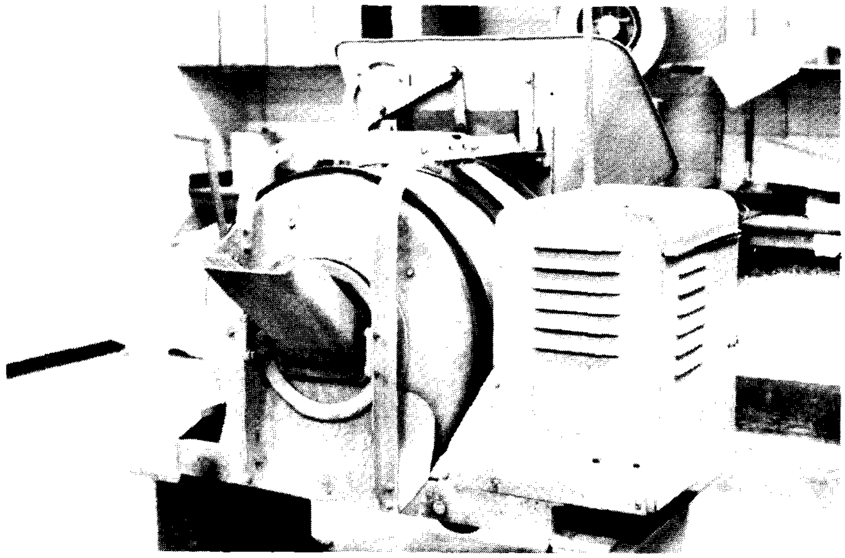

*FIGURE 1*

*Concrete Mixer*

Specimens prepared during the laboratory mixing operations were tested for the following:

(a) compressive strengths at 7, 28 and 200 days (6" x 12" cylinders) (ASTM C-39),

(b) flexural strengths at 7, 28 and 200 days (3" x 4" x 16" beams) (ASTM C-78),

(c) splitting tensile strengths at 7, 28 and 200 days (6" x 12" cylinders),

(d) indirect tension at 7, 28 and 200 days,

(e) abrasion resistance of concrete by sandblasting at 28 and 200 days (ASTM C-418),

(f) length change of hardened concrete at 28 days with initial reading at 24 hours (ASTM C-157), tests run until 64 weeks,

(g) test for time of setting of concrete mixtures by penetration resistance (ASTM C-403),

(h) test for resistance to rapid freezing and thawing to 300 cycles (ASTM C-660, Procedure B),

(i) test for scaling resistance of concrete surface exposed to deicing chemicals at 28 days (ASTM C-672) and

(j) air-void content determinations.

Figure 2 below shows the device used for measuring the time of setting of concrete by the penetration resistance method.

As stated before, the loss of slump with time, after the addition of a super water reducer, was determined for various mixes and tabulated for a reference. Mixing procedures were developed for standardization and to get better results for the concrete mixes.

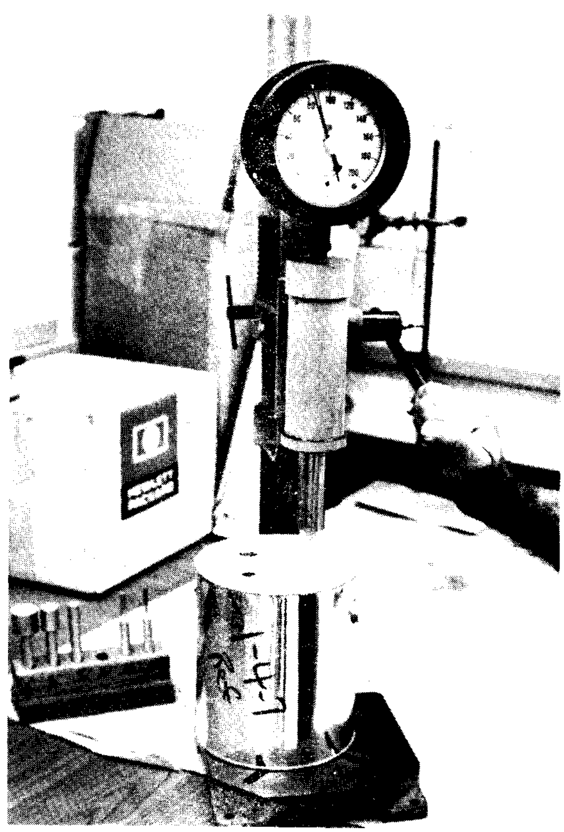

FIGURE 2

*Device for Measuring*
*Time of [illegible] of Concrete*

Although not specifically a part of the proposal or scope of this research study, a trip was made to Houston, Texas, to observe the pour on a bridge deck replacement project on I-45 using a superplasticizer. A brief discussion of the observations and findings from this field trip is included in this report, in addition to a copy of an FHWA report (26) on the field trip.

Guidelines were prepared for use of these admixtures in applying the technology to the construction program in the state. One of the key aims was to develop the technology for the routine use of thse admixtures without significant changes in the present mixing and placement procedures or equipment.

A Type 1 cement was used on this research study from a common source used in this area. Table 22 in the appendix gives a list of the ASTM Test Procedures used on the study. Table 23 in the appendix gives the chemical composition of the cement used on the research study.

Natural sand from a local pit, with the following aggregate gradation, was used on this study:

CONCRETE SAND

| Sieve Size | Percent Passing (by Weight) |
|---|---|
| 3/8" | 100 |
| No. 4 | 97 |
| No. 16 | 74 |
| No. 50 | 17 |
| No. 100 | 1 |

The coarse aggregates used on this study were (1) chert gravel from a local pit and (2) a Kentucky limestone. A uniform aggregate gradation was used with the following proportions: 25% by weight of 100% passing the 1" screen and retained on the 3/4" screen, 45% by weight of 100% passing the 3/4" screen and retained on the 1/2" screen, and 30% by weight of 100% passing the 1/2" screen and retained on the No. 8 screen.

Of the four super water reducers used for this study, two (Mighty 150 and Lomar D) were of the naphthalene-sulfonate type and two (Melment and FX-32) were of the melamine-sulfonate type. All were in an aqueous solution. Actual dosage rates of the super water reducers used are shown at the end of Table 21 in the appendix (page 68).

The air-entraining admixture was a neutralized Vinsol resin, used in a 2% aqueous solution.

## COMMENTS FROM LITERATURE REVIEW

As determined through the literature review, two big advantages shown by these products were: a reduction in the water-cement ratio, giving higher strengths, and an increase in the workability brought about by the increase in the fluidity. These advantages are especially useful in the precast industry, where accelerated (steam) curing brings about higher strengths at earlier ages. The most obvious application would be in the case of bridge decks or structures where ease of placement would be beneficial.

Some useful information determined by the literature review was material gleaned from Highway Research Project No. 54 of the University of Arkansas (2) which included the following: "Super water reducers are the most important recent development in producing high strength concrete; super water reducers will be used in conjunction with a number of other admixtures, especially air-entraining agents and retarders; the rather fragile air-void structure of flowing concrete can be greatly affected by different techniques of compaction; the superior quality of super water reduced concrete will have implications for techniques of pavement construction and design; one of the two major difficulties in using the super water reducers is its possible effect on the air-void structure of the concrete and the resulting freeze-thaw resistance; the increased fluidity of the mortar fraction and the action of the super water reducer as a dispersant makes mix designs more complex; the effect of mixing intensity, time and sequence have been noted as affecting the plastic quality of super water reduced concrete; the wide range of strength and workability in super water reduced concrete gives some promise of applicability to slip-forming (would tend to doubt a rush to this, at least for the moment); the other most serious difficulty in the use of super water reducers is the phenomena of slump loss; the use of super water reduced concrete in the flowing mode has demonstrated the inadequacy of the slump test to measure both the static consistency and the dynamic workability of highly fluid concrete."

The following comments or excerpts were also made from the Arkansas Benchmark Report, Phase I - Literature Search (2) by Larry Pleimann: "One researcher with wide practical experience has indicated that the use of the super water reducers in initial conjunction with smaller dosages of typical hydroxylated-carboxylic acid type water reducers gives a retarding effect that minimizes the slump loss problem (9); there was disagreement as to which procedure in ASTM Standard C-666 was proper; those studies showing poor freeze-thaw resistance had typically been done according to Procedure A with water surrounding the sample during both the freezing and thawing cycles; most of the successful freeze-thaw results had used Procedure B allowing the sample to be surrounded by air during the freezing cycle; the discussion was further complicated by the challenge of several of the super water reducer manufacturers to the users to produce an example of freeze-thaw durability failure among the structures that have been built of super water reduced concrete in the last decade in severe climates; thus, they emphasized that the testing procedures of ASTM C-666 are measures of relative freeze-thaw resistance rather than an absolute test; it is important to note, however, that the makers of both Mighty 150 and Melment, the oldest and possibly the most popular of the super water reducers, announced the development of modified forms of their products that improve both the slump loss and the air-void problems; the third and final negative aspect to the use of the super water reducers seems to be the high variability in the properties of the plastic concrete and the lack of a present method of reliably predicting that plastic behavior without previous testing with the same combination of materials; hardened properties such as the compressive strength was shown time and again to consistently obey Abram's law; and among those factors suggested for this wide variability was the cement type and the actual chemical composition of the cement."

Simply stated, there is a wide variability in the plastic properties of super water reduced concrete. Among the variables which can affect this are: type of cement, chemical composition of the cement, type and/or brand of super water reducer, dosage rate and the time of adding the admixture to the concrete mix. Certain aggregates may affect the mix design and the plastic properties of the concrete.

Among the items generally examined in research projects using superplasticizers were: (1) the strength gain, along with the strength level; (2) dosage rate; (3) the time of adding the admixture to the mix; (4) the slump loss with time; (5) the effect of the aggregate type; (6) the air-void effect on the freeze-thaw durability; (7) the effect of air or non air-entrainment combined with the super water reducers on mixes; (8) the workability of the mixes; (9) the effect of the chemical composition of the cement on the mixes and (10) other properties of the hardened concrete.

Also of interest was a copy of a proposal for a research study by Dr. J. F. Young of the University of Illinois (4), along with the comments concerning the proposal from the Federal Highway Administration (5), both of which principally concerned an evaluation of slump loss and the retempering of superplasticized concrete. The objective of the Illinois research study was to develop procedures to maintain the workability of superplasticized concrete so that it can be handled and placed under normal operating conditions. The proposal was modified to include determination of the nature of the air-void system of this concrete and the effect on the freeze-thaw durability.

The following comments or excerpts were made from the proposal for the Illinois research project (4) and/or in the attached comments from the Federal Highway Administration (5): "Research is needed on the nature of the air-void system which results from using superplasticizers; the limited data indicate that a good air-void system can only be attained when the air content is above about 6.5 percent; little is known as to the effect of superplasticizers on sealing in freeze-thaw climates; experience has shown that superplasticizers must be handled differently than conventional water-reducing admixtures; because the improved workability gained from the use of superplasticizers is lost within about an hour, the beneficial effects on workability are greatest if the superplasticizer is added after the concrete is mixed and not added with the mix water as is customary; workability can be restored by a second dose of superplasticizer (retempering) without harm to the concrete; however, the use of additional admixture is expensive."

In May of 1978 an international symposium, Superplasticizers in Concrete, was held in Ottawa, Canada, (6) from which considerable information became available.

A review of the published literature makes it clear that the factors affecting slump loss were not fully understood. Among these factors were: amount of admixture, time of addition, initial slump, cement content, aggregates, type of admixture, other admixtures, cement composition, the temperature of the concrete and the time of setting.

At present, there is considerable discussion concerning the durability of superplasticized concrete under freeze-thaw conditions. It is generally agreed that concrete containing a superplasticizer should also be air-entrained in order to provide freeze-thaw resistance. However, there is some question as to it's affect on durability since the superplasticizer affects the nature of the air-void system. Superplasticizers can also alter the amount of air-entraining agents required for a given air content. Freeze-thaw durability needs to be researched more carefully.

# DISCUSSION OF RESULTS

The laboratory study on the evaluation of superplasticized concrete was an experience in that, as other research study efforts have found, the addition of this type of admixture to concrete yields a highly fluid, hard to control mix with unusual characteristics. High strength is obtained as a result of the lowered water-cement ratio with the increased water reduction. This type of concrete can also be used to advantage in a number of applications, which will be discussed herein later.

Guidelines for the Use of Super Water Reducers in Concrete will be included in this report after the appendix to better help field personnel to design and construct structural projects using this type of concrete. This should particularly benefit the field inspector. However, it will still require field experience in handling this type of concrete and judgment in mix designs, in order to use this type of admixture successfully.

Here, in the Discussion of Results, we will look at all of the laboratory test results and the observations of the individual mixes and groups of mixes, in addition to a discussion of the observations and findings (26) from a field trip to Houston, Texas, (for the purpose of observing a thin-bonded concrete overlay and a bridge deck replacement project using superplasticized concrete).

## Plastic Mix Data

Tables 3 and 4 in the appendix give summaries of all the individual plastic concrete mix data obtained on this research study. Table 3 gives the data on the gravel coarse aggregate mixes without air-entrainment. This includes a reference concrete mix, plus superplasticized concrete mixes of FX-32, Lomar D, Mighty 150 and Melment with 5.0, 6.0, 6.5 and 7.0 bag cement contents.

Table 4 includes data on concrete mixes for the reference concrete, along with superplasticized concrete mixes of Mighty 150 and Melment. These mixes are for 6.0 and 6.5 bag cement contents with air-entrainment and gravel coarse aggregate, 6.0 and 6.5 bag cement contents with no air-entrainment and limestone coarse aggregate, and 6.0 and 6.5 bag cement contents with air-entrainment and limestone coarse aggregate.

In looking at these two tables, one can see that generally the superplasticized concrete mixes have higher unit weights than the comparable reference concrete mixes (1.5 to 3.0% higher).

Figures 3 and 4 on the following page show the plastic state of the concrete. Figure 3 shows the concrete flowing down the chute into the concrete mixing pan, while Figure 4 shows the fluid concrete in the mixing pan before being remixed with the use of shovels.

*FIGURE 3*

*Plastic Superplasticized Concrete in Chute*

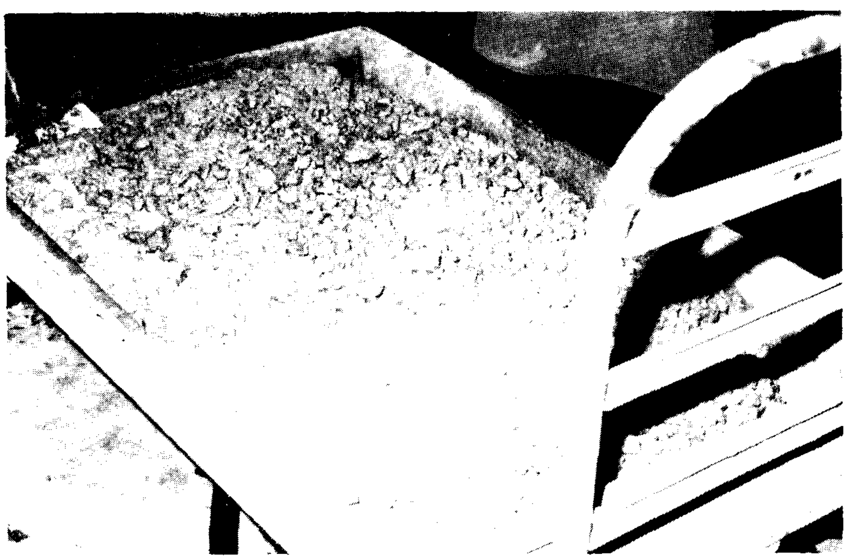

*FIGURE 4*

*Plastic Superplasticized Concrete in Mixing Pan*

The concrete mixes (both reference concrete and superplasticized concrete) using gravel coarse aggregate with no air-entrainment generally have the same unit weights as the concrete mixes (both reference concrete and superplasticized concrete) using limestone coarse aggregate and air-entrainment. Reference concrete mixes vary in unit weight generally from 147.0 to 150.8 pounds per cubic foot depending on whether there is gravel or limestone coarse aggregate and whether there is air-entrainment or not. In the same manner, the superplasticized concrete mixes vary in unit weight from 145.8 to 154.1 pounds per cubic foot. The change from gravel coarse aggregate to limestone coarse aggregate in the concrete mix will result in an increase in unit weight of approximately 3.1% (ranges from 2.5 to 3.8% increase). Use of air-entrainment in the concrete mix will result in a decrease in unit weight of approximately 2.8% (ranges from 2.4 to 3.7% decrease).

The slump range used as a guide in this study was from 2 1/2 to 3 1/2 inches; however, slump test results, as seen in Tables 3 and 4 in the appendix, fluctuated considerably, and it was very difficult to get any consistency or reasonable control of the slump with these types of mixes. The method of taking and reading slumps was considered inadequate, as others have found (2) (4), and a new method needs to be found which will better indicate the condition of the plastic concrete at that given time.

A water-cement (w/c) ratio of from 0.32 to 0.38 was used as a guide to keep the water cement (w/c) ratio design criteria fairly consistent in all the mixes. However, there was some variance from this intent, particularly on the upper end of the range of water-cement ratios. As seen in Tables 3 and 4, the water-cement ratios on the superplasticized concrete mixes did range up to 0.40, except for the 5.0 bag concrete mixes. The reference concrete mixes on the 6.0 and 6.5 bag mixes ranged in water-cement ratios from 0.40 to 0.50.

As can also be seen in Tables 3 and 4, the gravel coarse aggregate control mixes without air-entrainment resulted in a range of entrapped air from 1.1 to 1.4%. The mixes were designed for 1.5% air. The limestone coarse aggregate control mixes with no air-entrainment resulted in approximately 0.9% air, although they were designed for 1.0% air. Generally, the superplasticized concrete mixes having no air-entrainment were designed for 1.5 to 2.0% air. Test results showed these mixes had a range of 1.0 to 2.3% entrapped air. All mixes with air-entrainment (whether control mixes, superplasticized concrete mixes, or mixes containing gravel or limestone coarse aggregate) were designed for 5.0% air. Air contents in these mixes ranged from 3.0% to 6.2% air, which is a fairly wide range.

## Strength and Durability Test Data

Tables 5 through 11 in the appendix list the average strength (compressive, flexural and splitting tensile) test data for all the concrete mixes tested at 7, 28 and 200 days age; the freeze-thaw durability test data (with the durability factors and the number of cycles of freezing and thawing the specimens attained); along with the abrasion resistance test data at 28 days age and the scaling resistance test data. Percentages that the superplasticized concrete strength attained, as compared to the strength of the reference concrete, are also shown in these tables. Comparison strengths attained for gravel and limestone concrete using these admixtures, along with percentage comparisons, are shown in Figures 11 and 16 in the appendix. These are all for 6.5 bag mixes.

Strengthwise, it is evident that the superplasticized concrete was generally stronger than the reference concrete, comparing similar mixes. The use of suer water reducers resulted in lower water-cement ratios, thus bringing the strengths up. The strengths of these superplasticized mixes were more than adequate. Generally, it helped the durability properties. Some exceptions did occur, however, and will be mentioned herein. At lower cement contents (5.0 and 6.0 bags per cubic yard), FX-32 and Lomar D mixes showed comparative strengths lower than the reference concretes, roughly 80% for the 5.0 bag per cubic yard mix and 90% for the 6.0 bag per cubic yard mix. All of the other mixes had comparative strengths of 100% or more of the reference concrete mixes.

Seemingly the addition of air-entraining to any of the super-plasticized concrete mixes (particularly the mixes using gravel coarse aggregate) did not adversely affect the strengths (either compressive, flexural or splitting tensile) as much as did the addition of air-entraining to the reference mix with the same cement content and the same coarse aggregate.

For instance, in looking at 28 day compressive strengths, the reference concrete mix for 6.0 bag cement content, using gravel coarse aggregate with no air-entraining (Table 6 in the appendix), had a strength of 4,770 psi, but when air-entraining was added to the mix, only a strength of 3,831 psi was attained. This was a decrease in strength of 939 psi or 19.7%.

Figure 5 on the following page, a splitting tensile strength test specimen, shows good aggregate distribution, resulting in good splitting tensile strength properties. This specimen was from a 6.5 bag mix using Mighty 150 super water reducer and broken at 28 days.

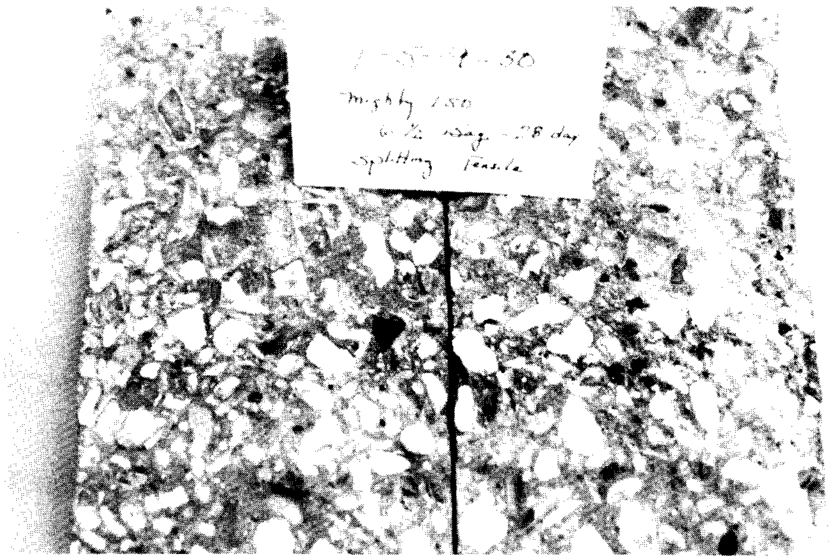

*FIGURE 5*
*Splitting Tensile Specimen*

The superplasticized concrete mix (using Mighty 150), for a 6.0 bag cement content using gravel coarse aggregate and no air-entraining, had a 28 day compressive strength of 6,407 psi (Table 6), but with air-entraining added, the strength of concrete decreased to 5,942 psi (Table 9 in the appendix), which was a decrease of 465 psi or 7.3%, much less of a decrease than the reference concrete mixes. The superplasticizer offset some of the decrease in strength due to the air-entraining.

Similar concrete mixes (6.0 bag cement content), using limestone coarse aggregate, gave somewhat different results. The 28 day compressive strength of the reference concrete dropped from 4,818 to 4,358 psi (Tables 10 and 11 in the appendix), a decrease of 460 psi or 9.5%, but when air entraining was added, the strength of the superplasticized concrete (Mighty 150) increased from 6,134 to 7,285 psi. This was an increase of 1,151 psi or 18.8%. This large increase, or any increase at all, cannot be explained except through the differences in air contents of the mixes, an occurrence which sometimes happens in concrete.

Normally, when an air-entraining agent is added to a concrete mix, the compressive strength is decreased; however, here an increase in strength was noted. The superplasticized concrete (Melment) mix, that was also used in comparison, gave predictable results, a decrease from 6,254 to 5,801 psi, a decrease of 453 psi or 7.2%. There are three variables affecting the strength here (one way or the other), type of coarse aggregate, superplasticizer and air content.

With the lower water-cement ratios, all of the superplasticized concrete mixes should generally give and did give more than adequate concrete strengths. Except for the FX-32 and Lomar D mixes for the lower cement contents, the 28 day compressive strengths exceeded 5,000 psi, both with and without air-entraining, and either with gravel or limestone coarse aggregate. Looking at the generally used 6.0 and 6.5 bag mixes, with only Mighty 150 and Melment mixes being used, those with gravel coarse aggregate with no air-entraining had a range of 28 day compressive strengths of from 6,143 to 6,690 psi, averaging 6,275 and 6,616 psi depending on whether it was a 6.0 or 6.5 bag mix. A good average strength would be approximately 6,500 psi. The gravel mixes with air entraining ranged from 5,306 to 6,022 psi, with averages being 5,624 and 5,968 psi for 6.0 and 6.5 bag mixes. A good average strength would be approximately 5,800 psi.

Limestone mixes were generally higher in strength than the gravel mixes, however the limestone mixes with air entraining gave somewhat unpredictable results, but much better than expected. The non air-entraining mixes ranged from 6,134 to 6,254 psi (average 6,194 psi) for 6.0 bag cement content and 6,770 to 7,279 psi (average 6,924 psi) for 6.5 bag cement content mixes. There was a wide range of strengths for the air-entraining mixes, ranging from 5,801 to 7,285 psi (average of 6,542 psi) for 6.0 bag and from 6,148 to 8,298 psi (average of 7,223 psi) for 6.5 bag mixes.

Obviously the control was not here, as can be seen in the plastic mix data shown in Table 4 in the appendix, with the air contents varying too much for any comparative purposes, as was attempted here. However, it does emphasize the point that this type of concrete mix is hard to control closely and any variance in dosages, materials, slumps or air contents, among other things, will cause a considerable variation in concrete strength results.

Durability test data is shown in Tables 12 through 14 in the appendix. Two things become obvious when looking at the freeze-thaw results as shown in Table 12. One is that the higher the cement content, the higher the durability factor and the second is that of the superplasticizer mixes, FX-32 and Lomar D at 5.0 and 6.0 bag cement content are relatively poor performers as far as durability factors are concerned (strengths were low also), especially as compared to the other two superplasticizer mixes, Mighty 150 and Melment. However, at 6.5 7.0 bag cement contents, these mixes gave better results than the Mighty 150 and Melment mixes. All of the mixes shown in Table 12 are non-air mixes, with gravel as the coarse aggregate. Overall results concerning abrasion and scaling show very little difference between the reference concrete and any of the superplasticizer mixes.

Looking at Table 13 (which includes gravel mixes with air, limestone mixes with no air and limestone mixes with air), one can see that the limestone coarse aggregate will help the mixes a little, and the addition of a superplasticizer will also make a better mix; however, the difference in using limestone as the coarse aggregate is not that large. The biggest change comes about when air-entraining is used in any of the mixes.

Superplasticizers in a concrete mix will increase the durability of the hardened concrete by approximately an 8.0 durability factor (D.F.) with an increase of 38 cycles of freezing and thawing. The addition of entrained air to a concrete mix will increase the durability of hardened concrete by approximately a 20.0 durability factor with an increase of approximately 100 cycles of freezing and thawing in gravel mixes and an increase of approximately a 55 D.F. with an increase of from 150 to 275 cycles of freezing and thawing in limestone mixes. Limestone coarse aggregate in a concrete mix will increase the durability of the hardened concrete by approximately a 9.0 D.F. with an increase of approximately 45 cycles of freezing and thawing. These figures for the number of cycles of freezing and thawing or durability factors are only approximations to be used as guides, not hard line figures to be used as fact.

As seen in Tables 12 and 13 in the appendix, abrasion results are not very definitive. There are no notable differences shown that can be pulled out for any discussion or even mention, except possibly for the 5.0 bag gravel mixes with no air-entraining. These results generally were higher than those for the mixes with higher cement contents. However, even here as in all of the other type mixes, there was not much, if any, discernible difference between reference concrete mixes and any of the individual superplasticizer mixes, or even between air or non air mixes, gravel or limestone mixes.

However, scaling results show that with air in the mixes, both gravel and limestone mixes are considerably improved. Neither the superplasticizer or the coarse aggregate change seem to make much difference in the results; however, when air-entrainment is used, there are notable differences. Table 12 shows that generally after 50 cycles, ratings of 4 and 5 (these ratings are explained in the procedures as described in the appendix) are obtained for gravel mixes without any air-entraining. The same holds true for the limestone mixes without air, with ratings of 4 and 5 being obtained; however, looking at the gravel mixes and limestone mixes with air-entraining, as found in Table 13, one can see that ratings of generally 1 to 3 are obtained. These are good ratings; thus it seems that air-entraining is the prime material that can be used to improve the hardened concrete considerably. Figures 6 through 10 show some scaling samples, both before testing and after testing, with several type comparisons.

Figures 6 and 7 on page 26 show scaling samples prior to testing, Figure 6 is a 5.0 bag Lomar D specimen with no air, while Figure 7 is a 6.5 bag Lomar D specimen with no air. One can see the difference in surface texture. Figures 8 and 9 on page 27 show two scaling specimens after testing, both 6.5 bag mixes with no air, Figure 8 is a Melment sample and Figure 9 is a Mighty 150 sample. Figure 10 on page 28 is a 6.5 bag Melment sample with air-entrainment. Obviously, the air-entrained sample shows the better surface and a better rating.

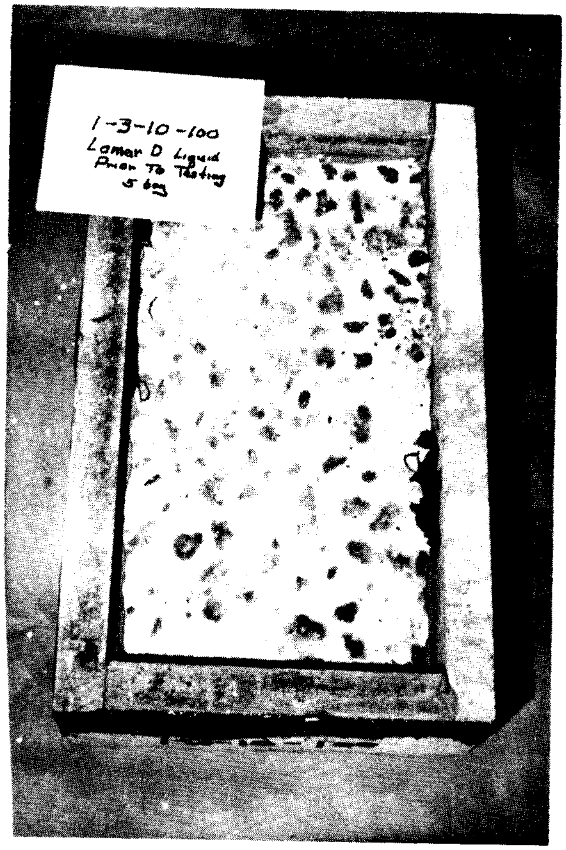


*FIGURE 6*

*Scaling Sample Prior to Testing*

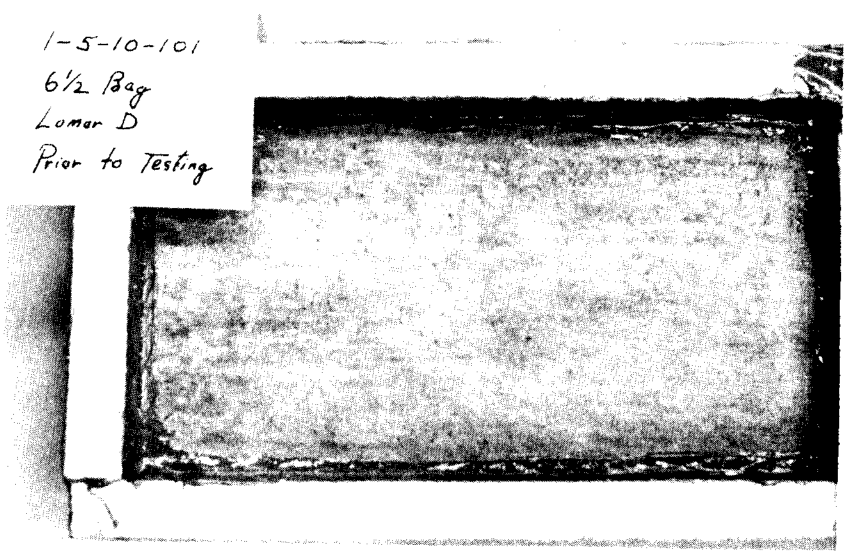


*FIGURE 7*

*Scaling Sample Prior to Testing*

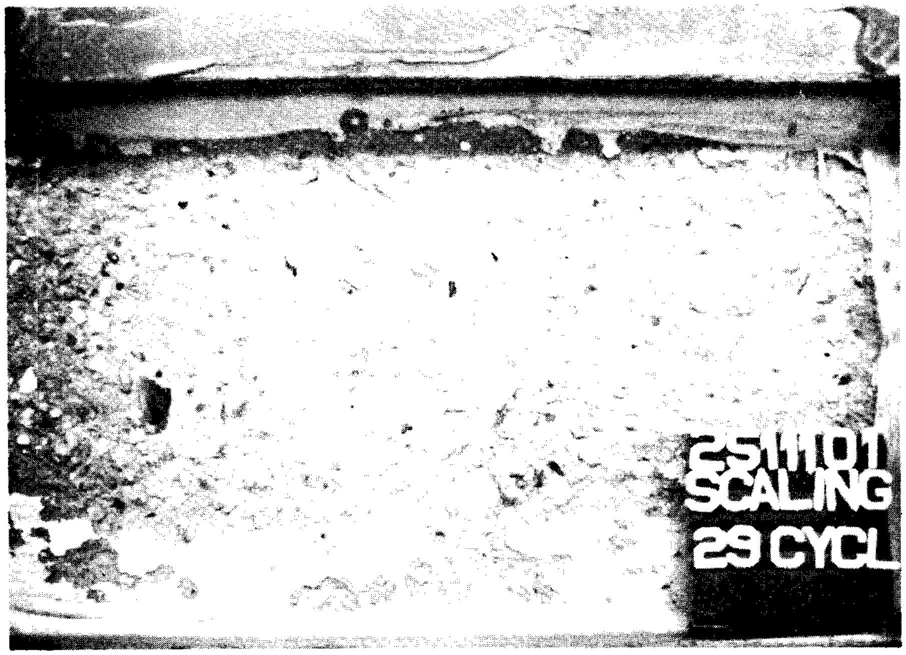


*FIGURE 8*

*Scaling Sample After Testing*

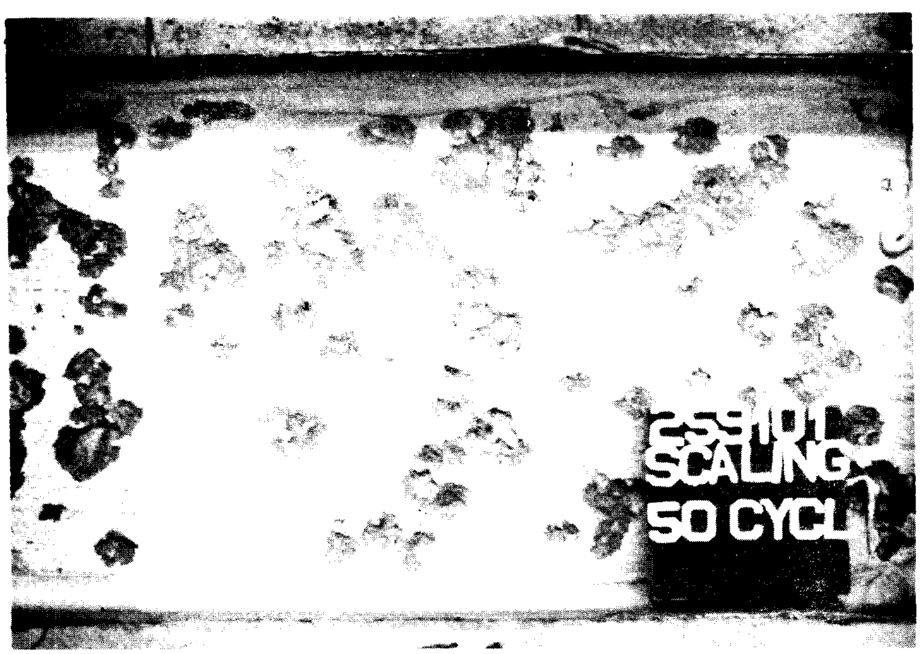


*FIGURE 9*

*Scaling Sample After Testing*

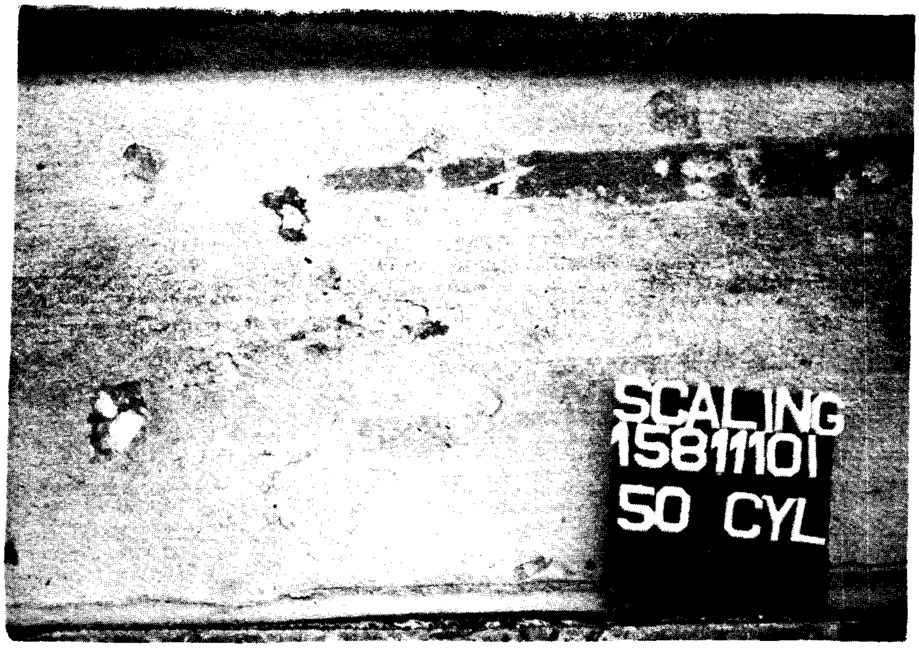


*FIGURE 10*

*Scaling Sample After Testing*

## Field Trip to Houston, Texas and Other Comments

A field trip was made to Houston, Texas, by the author and representatives of the Louisiana Department of Transportation and Development, along with FHWA representatives, to observe the use of super water reducers in bridge deck slabs and/or thin concrete overlays on pavements. This section of the report summarizes observations of the bridge deck placement portion on I-45 in Houston and gives useful information concerning the field use of this type of admixture to support the laboratory results.

Following the visit to the construction site, a meeting was held between representatives of FHWA, the Louisiana Department of Transportation and Development and Texas highway engineers to discuss the deck placement and prior experiences with super water reducers. R. J. Prochaska of FHWA (26) submitted a written report, a copy of which can be found after the appendix of this report.

Additional comments and more emphasis on some observations are included as follows:

(1) When using a super water reducer, the dosage should be added to the concrete mix at the construction site;

(2) As noted in the FHWA report by R. J. Prochaska (26), important items (inspection variables) were the concrete mix temperature, the initial slump at the jobsite before the dosage of super water reducer is added and also the absolute volume of water in the concrete mix;

(3) It should be emphasized that erratic results were obtained when the concrete temperatures were high, in addition to their being a high slump loss;

(4) Placement of the concrete should be continuous, and only one cement should be used on any project;

(5) In this regard, preliminary mixes should always be run before any project begins, using materials that are to be used on the project, checking on compatability of materials and obtaining mix information;

(6) Again emphasis should be on constant surveillance by experienced personnel;

(7) As learned from information gathered on this trip, if super water reducers are used in Louisiana, then they should first only be used on small maintenance or bridge deck construction or possibly at prestressed plants, until such time as experience with the material is obtained and personnel using it become familiar with the product; and

(8) In this regard, use of the product should be somewhat restricted to special cases where flowability is the prime consideration, not necessarily higher strengths, with emphasis being put on proper control of the concrete mix.

Time of Setting

It is concluded, from an overall evaluation of the data obtained on this portion of the study, that when a super water reducer is introduced in a portland cement concrete mix it will generally act as a set retarder. Melment, however, was the only one that accelerated the time of setting in half of the mixes run. This may be due to the difference in chemical composition of Melment, which is a melamine based product. Mighty 150 and Lomar D are naphathalene based products, while FX-32 also is a melamine based product. Dosage rates should be the variable which can affect the setting time.

Normally the initial and final times of setting of plain concrete decrease with an increase in cement content. This relationship, however, is changed somewhat with the presence of a super water reducer. On the average, the 6.5 bag and 7.0 bag gravel concrete mixes with no air-entrainment showed the largest amount of retardation (approximately 4 hours) when Mighty 150 and Lomar D were used as the super water reducer. This was followed by FX-32 with retardation time of approximately 1.5 to 2.5 hours (gravel mixes with no air). Melment showed the least amount of retardation (no more than 37 minutes) in all the mixes (when not accelerating the time of setting).

The amount of retardation in mixes using gravel with air entrainment and in limestone mixes with and without air entrainment were not as much as the gravel mixes with no air entrainment and did not exceed one hour at the most (only Melment and Mighty 150 used in limestone mixes with and without air entrainment and in gravel mixes with air). Refer to Tables 15 through 18 in the appendix for the data on time of setting.

Length Change of Hardened Concrete

Readings for this test were taken at 64 weeks. Generally, in gravel mixes with no air-entrainment, the 6.0 and 6.5 bag mixes showed the greatest shrinkage of the super water reduced specimens as compared to the reference concrete specimens.

In all of the gravel mixes with no air, the Mighty 150 mix specimens had as much or more shrinkage (from 0.024 to 0.028%) as any of the super water reduced mix specimens. The other three super water reduced mix specimens, FX-32, Lomar D and Melment, were more in line with each other (averaging approximately 0.020% with a range of from 0.012 to 0.028%).

The shrinkage in the limestone mix specimens (average approximately 0.031%) was generally higher than the gravel mix specimens. Although the addition of air-entrainment to the mixes decreased the shrinkage in reference concrete specimens, it did not make very significant difference with the super water reduced (Mighty 150) mix specimens. Generally, in the limestone mixes, the super water reduced mix specimens had less shrinkage than the reference concrete mix specimens.

Based on the results obtained and an overall evaluation of the 64-week old specimens, the following observations were made:

1. Mighty 150 mix specimens showed the greatest decrease in length in most of the mixes.
2. Generally, in gravel mixes with no air-entrainment, the 6.0 and 6.5 age mixes showed the greatest shrinkage of the super water reduced specimens as compared to the reference concrete specimens.
3. Generally, in the limestone mixes, the super water reduced mix specimens had less shrinkage than the reference concrete mix specimens and
4. Shrinkage in the limestone mix specimens were generally higher than the gravel concrete mix specimens.

Refer to Tables 19 and 20 in the appendix for data on shrinkage.

Loss of Slump with Time

In this portion of the research study, efforts were made to establish some kind of relationship between the loss of slump and time. Because of the lack of specific procedures which can be used for this test, a further literature review was called for, resulting in only a few mixes being run. This portion of the research was done as an extra effort, since it was not originally included in the proposal; therefore, the methods of procedure on some of these tests will be described in this section and not directly in the Methodology section.

The main efforts were concentrated on simulating the condition under which concrete in a plastic form is transported from the batch plant to the job site. Since the r.p.m. of the laboratory mixer used in this research study was at a fixed rate, the researchers were unable to directly produce the same r.p.m. of ready mixed trucks used in the transportation of plastic concrete to job sites. In these trucks, the drum is rotating very slowly while the truck is in motion to the job site, after the original mixing. Several methods were attempted to give at least some simulation of loss of slump with time; however, most effort was on retempering of the concrete.

The following are some of the methods used in this portion of the study:

(1) Using a 5.0 bag mix, the super water reducer (Melment) was added to the concrete mix as a part of the original mixing water. The water cement ratio was 0.46. The initial slump of 2 3/4" was reduced to 1/2" after 40 minutes. Since the super water reducer was originally in the mix, no conclusion on added workability time was obtained.

(2) Using a 5.0 bag mix, the super water reducer (Mighty 150) was added to the concrete mix as a part of the mixing water. The water cement ratio was 0.43 with an initial slump of 1 1/4", that slump being reduced to 1/2" after 20 minutes. At this time, another dose of Mighty 150 was added to the mix and 20 minutes later a slump of 6 1/2" was obtained. The slump gradually decreased to 1 1/2" after another 20 minutes and was reduced to 3/4" after yet another 20 minutes. A total working time of approximately 60 minutes was obtained through this method.

(3) Using a 6.5 bag mix, the concrete mixing was started with 23% less water than the control mix. The water cement ratio was 0.34. After the regular mixing time, a slump test was conducted resulting in a no slump concrete. At this time, a dose of Mighty 150 (at the rate of 1.5% per weight of cement) was added to the cement and mixed for 1 minute with a 1 1/2" slump being obtained. Another dose at an increased amount (2.5% per weight of cement) was added and mixed for 2 minutes resulting in a 4" slump. The slump was 5" (concrete falling) after 15 more minutes (mixer running). At the same period of time again, the slump was reduced to 4", while again 15 minutes later, the slump was reduced to 1 1/2". The total working time for the test was 50 minutes with the additions of two dosages of super water reducer.

(4) Using a 6.0 bag mix with super water reducer being Mighty 150 and a water cement ratio of 0.48, the slump test was performed at 20 minute intervals. The original slump was 3 1/2", which was gradually reduced to 2 1/2" after 100 minutes. At this time, super water reducer was added (10 oz. per sack of cement) and after one minute of mixing the slump was as high as 8 3/4". After 60 minutes from this point, the slump was reduced to 2 1/2" and the test was then terminated. The added workability time on this test was approximately 60 minutes.

An overall evaluation of the above tests indicates that the super water reducers are helpful in increasing the slump of a dense concrete without addition of any more water, where there is a need for extra workability or working time. However, efforts should be made in the development of a method of using the super water reducer for this purpose. Basically, the initial slump of the concrete determines the dosage rate of the super water reducer. If the initial slump is indicative of satisfactory workability, the addition of a super water reducer is not necessary. If the concrete is too stiff when it gets to the job site, depending on the initial slump of the concrete, a dose of super water reducer is added to increase the slump and workability.

The dose should be carefully determined by an experienced technician at the job site. However, a minimum initial slump of 1" should be necessary for the super water reducer to be more effective, and the dosage determined by how much additional slump or workability is needed. Of course, the workability period that is produced with any repeated additions of super water reducer will decrease with time. The primary advantage of super water reducer usage for this purpose is the added workability. The strength of the concrete should be determined by the original mix design.

From the mixes that were run on this study, it was concluded that the rate of slump loss is slower when the super water reducer is originally in the mix. The rate of slump loss decreases after the extra addition of super water reducer. Much variation was seen in regard to the loss of slump with time. Before the addition of another dose of super water reducer, the rate of slump loss ranged from 1" per 20 minutes (initial slump ranged from 1 3/4" to 2 1/4" with Melment) to 1" of slump loss per 80 minutes (initial slump of 3 1/2" with Mighty 150). Of course, the initial slump and dosage rate affects these values very much. The loss of slump after the addition of another dose of super water reducer also varied, on the average about 1" per 6 minutes, with Mighty 150. The above conclusions were determined under laboratory conditions using various mix designs. These values should not be applied to the field since there are many other variables to consider, such as mix design using super water reducer, air temperature, transport time and other field conditions.

Some suggestions that might be useful in actual field conditions are given below:

(1) The time that is required to transport the plastic concrete to the job site should be considered in order to give some estimation of the initial slump required and any corrections needed in the mix design for slump adjustment.

(2) Normal procedures should be followed when mixing the concrete. The super water reducer could be added to the mix as part of the necessary mixing water (for strength purposes) if the batch plant is at the job site, or it could be added at the job site (for workability purposes) if the batch plant is some distance away. The amount of water reduction usually indicated by the manufacturer should be verified by a small trial batch to determine the correct dosage of super water reducer and the compatability of materials. Among other factors, the mixing intensity, time and sequence of mixing will affect the plastic properties of the concrete.

(3) The time to add the super water reducer and the dosage rate should be carefully determined at the job site depending on the initial slump of the concrete.

Added workability due to the additional dosages of super water reducer is one of the advantages of super water reducers, which do not have any obvious adverse effects on the strength.

Other Miscellaneous Points

Various miscellaneous pieces of information, restated here, have been accumulated on this research study, either directly from the laboratory test results, from the literature survey or from the field trip to Houston, Texas. No extensive discussion will be put forth on these points in this section; however, they have been discussed in other sections of the report.

Some of the factors that can affect the concrete mix designs or the plastic mixes, when using a super water reducer in a mix, are as follows:

(1) The type and brand of cement used and the chemical composition of the cement. One type and brand of cement should be used throughout any project.
(2) Type of coarse aggregate and the source. Again consistency on any project is essential, even with source approval.
(3) Cement content. Comparatively the same level of strengths can be obtained with less cement if a super water reducer is used in the concrete mix. One would have to be very careful in the control of this type of design.
(4) Amount of water and the water reduction. Less water can be used with higher strengths and more fluidity obtained.
(5) Water-cement (w/c) ratio. Items 3, 4 and 5 above are all interrelated, affecting the strength of the concrete. The lower the water-cement ratio, the higher the strength obtained.
(6) Type and dosage of air-entraining admixture. Compatability of the different admixtures should always be checked, as some brands are not compatable with some super water reducers.

Some significant facts found through the literature search and verified from laboratory test results were:

(1) There was great fluidity associated with these concrete mixes and a certain amount of densification or segregation of fines and coarse aggregate shown in the laboratory on some mixes before any further working of the mixes. This was not seen in the field pour on the bridge deck slab in Houston, Texas.
(2) Loss of slump with time was shown on all of the mixes, generally ranging from 39 minutes to 1 hour, at which time either a remixing or addition of more super water reducer was needed, if sufficient slump and workability were to be attained. Generally, most research studies of this type are conducting some investigation concerning the loss of slump with time.

(3) Inadequacy of the slump test to measure both the static consistency and the dynamic workability of these mixes was shown (2).

(4) There was a high variability shown in the properties of the plastic concrete and no reliable method of predicting the plastic behavior without any previous testing with the same combination of materials (2).

(5) All of these factors, including the increased fluidity and the action of the super water reducer, make the mix design very difficult and much more complex than would ordinarily be the case with a normal water reducer.

Super water reducers are a new "breed of animal" in the construction industry in the United States, although they have been used elsewhere in the world rather successfully. Laboratory mixing and test results from this study, along with observations from a field trip to Houston, Texas, have verified findings described by others in regard to the successful use of the high range water reducers, and the possibilities are still open for other uses. Continued effort is still necessary to understand and use these admixtures more effectively.

# CONCLUSIONS

Numerous conclusions, listed below, were determined from results of this research study. Some of these conclusions were determined directly from laboratory test results; others were evolved from observations from a field trip to Houston, Texas, some were verified conclusions from other studies and mentioned in the literature review for this study; and others were general conclusions made on this study.

Conclusions from laboratory test results were:

(1) It was very difficult to get any consistent or reasonable control of the slump when super water reducers were used in the concrete mixes. The actual slumps fluctuated considerably and the mixes were hard to control.

(2) Comparatively high strengths were obtained in most laboratory mixes, except for the 5.0 and 6.0 bag gravel mixes using Lomar D and FX-32 super water reducers with no air-entrainment.

(3) Air contents were hard to control in most of the mixes where air-entrainment was called for. The air contents varied considerably.

(4) More air is normally entrained because of the addition of a superplasticizer to a concrete mix and this would normally lower the strength of the concrete; however, increased strengths were obtained from the use of superplasticizers. The addition of an air-entrainment agent to the superplasticized mixes did not affect (decrease) the strengths as much as when an air-entrainment agent was added to a normal reference concrete mix.

(5) One may have to alter the normal design on mixes using air when superplasticizers are used; that is, alter the amount (dosage) of air-entraining agent added.

(6) In gravel mixes with no air-entrainment, the 6.0 and 6.5 bag mix specimens showed the greatest shrinkage of the super-plasticized concrete specimens as compared to the reference concrete specimens.

(7) Generally in limestone concrete mixes, the shrinkage was higher than in the gravel concrete mixes.

(8) Laboratory test results from this study did not necessarily corroborate some conclusions from other studies noted in the literature review, for instance, that superplasticizer concrete gives increased abrasion resistance and decreased shrinkage, both set and long term.

(9) Conversely, improved scaling resistance was noted in the concrete when superplasticizers were used. Use of air in the mixes also gave improved scaling resistance.

Other conclusions (26), evolved from the field trip to Houston, Texas, and noted and verified by the researchers were as follows:

(1) It was emphasized that erratic results were obtained on the concrete pour when the concrete temperatures were high, in addition to a high slump loss with time.

(2) Important items (inspection variables) in the field pour, aside from the concrete mix temperature, were the initial slump at the jobsite before the dosage of superplasticizer was added and the absolute volume of water in the mix.

(3) Among the other variables which also could affect the mix were the type and brand of super water reducer, the dosage rate and the time of adding the super water reducer to the mix. Different aggregates could also affect the mix and its properties.

(4) Placement of the concrete should be continuous and only one cement should be used on any project. Wide variability in plastic properties of concrete usggests that the cause may be cement type or chemical composition of the cement.

Conclusions from other studies, stated in the literature review, and verified on this study were as follows:

(1) As noted in (2), there seems to be a high variability in the plastic properties of concrete and no method of reliably predicting that plastic behavior without previous testing with the same combination of materials. Preliminary mixes should always be run before any project begins, using materials that are to be used on the project, checking also for compatability of materials and obtaining additional mix information.

(2) As noted in (2), the use of super water reduced concrete in the flowing mode demonstrated the inadequacy of the slump test to measure the static consistency and the dynamic workability of highly fluid concrete.

(3) The effect of mixing intensity, time and sequence affect the plastic quality of concrete.

(4) Also, as determined in this research study and in most other studies, when using super water reduced concrete, there is a slump loss with time. The concrete may be retempered to a certain extent, but there is a limit to this.

(5) As noted in (2), the increased fluidity of the mortar fraction and the action of the super water reducer as a dispersant makes the mix design more complex.

(6) There must be good control exercised in the concrete mix design and the batching of super water reduced concrete.

Some general conclusions reached on this research study were:

(1) Super water reducers are admixtures that are very useful in obtaining flowable (highly fluid) concrete for special cases (for instance, when space may be a problem in structures or the lack of vibration) and for obtaining good high strength properties in the concrete.

(2) Super water reducers, when used in conjunction with air-entraining agents, can give a good mix design, good concrete properties especially better freeze-thaw durability, particularly with limestone coarse aggregate, while still giving high strength and workable concrete.

(3) The reduction in the water-cement (w/c) ratio gives higher strengths in these super water-reduced concretes and also helps bring about the increased workability because of the increase in fluidity.

(4) These advantages are useful in the precast industry, with the ease of placement in structures or bridge decks being a positive advantage.

(5) Generally, there were no problems in obtaining high strengths using super water reducers in the concrete mixes, either with or without air-entrainment and either with gravel or limestone coarse aggregate in the mixes.

(6) Variables which can affect the plastic properties were: type of cement, chemical composition of the cement, type and brand of super water reducer, the dosage rate and the time of adding the super water reducer to the mix.

(7) Because of strength gains obtained with super water reduced concrete, possible savings in the use of cement (lower cement contents) are obtainable in order to achieve required relative strengths with the same plastic qualities of the mixes.

(8) A conclusion, which has a bearing on the concrete durability, is that the freeze-thaw test is a measure of relative resistance, not absolute.

(9) No definitive conclusions will be made regarding the pro's and con's (ratings) of the individual products (super-plasticizers), since this research study, in itself, was not a new product evaluation, but was conducted primarily to learn the properties of the plastic and hardened super-plasticized concrete.

# RECOMMENDATIONS

Super water reducers appear to be the coming thing in the construction industry in the use of admixtures, particulary to attain highly fluid concrete with high strength and other advantageous properties.

Since as much information as possible is needed on the use of super water reducers in concrete mixes and these type of admixtures can be of great value in the state construction program, recommendations are made as follows:

(1) More research should be conducted on the use of super water reducers in concrete, particularly in some needed areas such as the compatability of the super water reducers with other additives, cements and aggregates; the control of loss of slump with time; in addition to durability relationships and any possible chloride protection properties.

(2) Small experimental installations should be tried in the field using the super water reducers in concrete, first on small minor structures such as median barriers, retaining walls, box culverts or even sidewalks. Maintenance projects could provide field experience in the use of superplasticizers. A good starting point would be in the precast field.

(3) After gaining experience with this type of concrete and its use, other experimental installations should be made on small bridge decks. Large experimental installations and blanket acceptance of this type of concrete should be avoided until tangible positive field results are obtained.

(4) Whatever the use of super water reduced concrete, there should be very close control of operations to limit any variability in the properties of the concrete.

(5) "Guidelines for the Use of Super Water Reducers in Concrete", a copy of which is included after the appendix, should be followed closely on any construction projects; however, actual field experience is the one key requirement that is needed, and it is recommended that field personnel be given that experience through familiarity with the material, its uses, its properties and, finally, its behavior.

## BIBLIOGRAPHY


1. FHWA Prospectus and Statement of Work, "Use of Super Water Reducers in Concrete," December, 1976.

2. Pliemann, L., "Benchmark Report, Phase I - Literature Search," Highway Research Project No. 54, University of Arkansas, submitted June 1, 1978.

3. Sprinkel, M., "Effective Field Use of Superplasticized Concrete," Working Plan - VHTRC 77-WP2, Virginia Highway and Transportation Research Council, February, 1977.

4. Young, J. F., proposal, "Evaluation of Slump Loss and Retempering of Superplasticized Concrete," University of Illinois, 1979.

5. Pasko, Jr., T. J., and Kupac, P. A., comments, "Evaluation of Slump Loss and Retempering of Superplasticized Concrete," Illinois proposed Research Study IHR0412, May, 1979.

6. Malhotra, V. M., Berry, E. E., Wheat, T. A., Editors, "Superplasticizers in Concrete," Proceedings, International Symposium, Ottawa, Canada, May, 1978. (CANMET, Department of Energy, Mines and Resources, Ottawa, Canada).

7. Brooks, J. J., Wainwright, P. J., and Neville, A. M., "Time-Dependent Properties of Concrete Containing Mighty Admixture," Leeds University, England, presented at the Ottawa Symposium.

8. Collepardi, M., Corradi, M., "Influence of Naphthalene-Sulphonated Polymer Based Superplasticizers on the Strength of Ordinary and Lightweight Concretes," presented at the Ottawa Symposium.

9. Hattori, K., "Experiences with Mighty Superplasticizer in Japan," presented at the Ottawa Symposium.

10. Hester, W. T., "Field Applications of High-Range Water-Reducing Admixtures," University of California at Berkeley, presented at the Ottawa Symposium.

11. Hewlett, P. C., et. al., "Superplasticizing Admixtures in Concrete," Cement and Concrete Association, Wexham Springs, Slough, Berlshire, England, January, 1976.

12. Hewlett, P. C., "The Concept of Superplasticized Concrete," Cement and Concrete Association, presented at the Ottawa Symposium.

13. Hewlett, P. C., "Experiences in the Use of Superplasticizers in England," Cement and Concrete Association, presented at the Ottawa Symposium.

14. Hewlett, P. C. and Rixon, R., "Superplasticized Concrete," reprinted with permission from Concrete (London) Vol. 10, No. 9, pp. 39-42, September, 1976.

15. Holbek, K. and Skrastins, J. I., "Some Experiences with the Use of Superplasticizers in the Precast Concrete Industry in Canada," presented at the Ottawa Symposium.

16. Kasami, H., Ikeda, T. and Yamane, S., "On Workability of Superplasticized Concrete - Experience in Japan," presented at the Ottawa Symposium.

17. Lane, R. O. and Best, J. F., "Laboratory Studies on the Effects of Superplasticizers on the Engineering Properties of Plain and Fly Ash Concrete," presented at the Ottawa Symposium.

18. Mailvaganam, N. P., "Slump Loss in Flowing Concrete," Stemson Ltd., Brantford, Ontario, presented at the Ottawa Symposium.

19. Malhotra, V. M. and Malanka, D., "Performance of Superplasticizers in Concrete: Laboratory Investigation - Part 1," presented at the Ottawa Symposium.

20. Mather, B., "Tests of High-Range Water-Reducing Admixtures," presented at the Ottawa Symposium.

21. Meyer, A., "Experiences in the Use of Superplasticizers in Germany," Portland Zementwerke, Heidelberg, W. Germany, presented at the Ottawa Symposium.

22. Mielenz, R. C. and Sprouse, J. H., "High-Range Water-Reducing Admixtures; Effect on the Air-Void System in Air-Entrained and Non Air-Entrained Concrete," presented at the Ottawa Symposium.

23. Mukherjee, P. K. and Chojnacki, B., "Laboratory Evaluation of a Concrete Superplasticizing Admixture," presented at the Ottawa Symposium.

24. Murray, M. A. and Lynn, I. L., "Superplasticizers-Water Reducers or Flow Agents," presented at the Ottawa Symposium.

25. Perenchio, W. F., Whiting, D. A. and Kantro, D. L., "Water Reduction, Slump Loss and Entrained Air-Void Systems as Influenced by Superplasticizers," PCA, Skokie, Illinois, presented at the Ottawa Symposium.

26. Prochaska, R. J., "Use of Super Water Reducers in Bridge Deck Slabs in Houston," FHWA, October, 1979.

27. Ramakrishnan, V., "Workability and Strength of Superplasticized Concrete," South Dakota School of Mines and Technology, presented at the Ottawa Symposium.

28. Ryan, W. G. and Munn, R. L., "Some Recent Experiences in Australia with Superplasticizing Admixtures," presented at the Ottawa Symposium.

29. Seabrook, P. T. and Malhotra, V. M., "Accelerated Strength Testing of Superplasticized Concretes and the Effect of Repeated Doses of Superplasticizers on Properties of Concrete," presented at the Ottawa Symposium.

30. Tattersall, G. H., The Workability of Concrete, Cement and Concrete Association, London, 1976.

31. Valore, K. C., Kudrenski, W. and Gray, D. E., "Application of High-Range Water-Reducing Admixtures in Steam-Cured Cement-Fly Ash Concretes," presented at the Ottawa Symposium.

32. Whiting, D., "Effects of High-Range Water Reducers on Some Properties of Fresh and Hardened Concretes," Research and Development, Bulletin RD061.01T, Portland Cement Association, 1979.

# APPENDIX

TABLE 3

PLASTIC MIX DATA

GRAVEL WITH NO AIR

| Mix Type | w/c ratio | % Air | Slump, in. | Unit Wt., $lb/ft^3$ | Air Temp., °F. | Concrete Temp., °F. |
|---|---|---|---|---|---|---|
| Reference, 5.0 Bag | 0.59 | 1.4 | 4-3/4 | 146.8 | 72 | 76 |
| FX-32 | 0.46 | 1.6 | 1-3/4 | 148.8 | 71 | 75 |
| Lomar D | 0.43 | 2.3 | 1-3/4 | 147.6 | 72 | 75 |
| Mighty 150 | 0.43 | 2.0 | 1-3/4 | 148.8 | 71 | 75 |
| Melment | 0.47 | 1.3 | 2 | 149.2 | 72 | 76 |
| Reference, 6.0 Bag | 0.48 | 1.2 | 3-1/4 | 147.2 | 75 | 78 |
| FX-32 | 0.38 | 1.0 | 6-1/2 | 150.8 | 71 | 75 |
| Lomar D | 0.36 | 1.8 | 2 | 148.8 | 69 | 75 |
| Mighty 150 | 0.36 | 1.6 | 1-3/4 | 150.0 | 76 | 78 |
| Melment | 0.38 | 1.3 | 1-1/4 | 149.6 | 70 | 75 |
| Reference, 6.5 Bag | 0.44 | 1.2 | 3-1/4 | 147.2 | 69 | 73 |
| FX-32 | 0.35 | 1.0 | 4-1/2 | 150.8 | 68 | 74 |
| Lomar D | 0.34 | 2.2 | 3-1/2 | 148.4 | 68 | 73 |
| Mighty 150 | 0.34 | 2.3 | 2-1/4 | 148.8 | 66 | 72 |
| Melment | 0.36 | 1.6 | 1-1/4 | 149.6 | 69 | 72 |
| Reference, 7.0 Bag | 0.42 | 1.3 | 3-1/4 | 147.2 | 71 | 75 |
| FX-32 | 0.32 | 1.1 | 6-1/2 | 150.0 | 72 | 76 |
| Lomar D | 0.33 | 2.0 | 4-1/2 | 148.8 | 66 | 72 |
| Mighty 150 | 0.33 | 1.9 | 3 | 149.6 | 68 | 73 |
| Melment | 0.35 | 1.3 | 2-1/2 | 150.0 | 70 | 74 |

TABLE 4

PLASTIC MIX DATA
VARIOUS MIX DESIGNS

| Mix Type | w/c ratio | % Air | Slump, in. | Unit Wt., lb/ft$^3$ | Air Temp., °F. | Concrete Temp., °F. |
|---|---|---|---|---|---|---|
| Reference, 6.0 Bag | | | | | | |
| Gravel with Air | 0.43 | 4.6 | 3 | 141.6 | 76 | 77 |
| Mighty 150 | 0.36 | 3.5 | 2 | 147.2 | 79 | 80 |
| Melment | 0.39 | 5.7 | 2-1/2 | 144.0 | 79 | 81 |
| Reference, 6.5 Bag | | | | | | |
| Gravel with Air | 0.40 | 6.1 | 3-1/2 | 141.6 | 79 | 81 |
| Mighty 150 | 0.34 | 5.0 | 4-1/2 | 146.4 | 80 | 81 |
| Melment | 0.36 | 5.0 | 2 | 145.6 | 76 | 81 |
| Reference, 6.0 Bag | | | | | | |
| Limestone, No Air | 0.50 | 0.9 | 4 | 151.2 | 73 | 75 |
| Mighty 150 | 0.38 | 1.7 | 1-3/4 | 152.8 | 78 | 80 |
| Melment | 0.40 | 1.2 | 1-3/4 | 153.6 | 72 | 74 |
| Reference, 6.5 Bag | | | | | | |
| Limestone, No Air | 0.46 | 0.9 | 3-3/4 | 150.4 | 70 | 73 |
| Mighty 150 | 0.36 | 1.5 | 2-1/2 | 156.8 | 73 | 76 |
| Melment | 0.37 | 1.5 | 1-1/2 | 153.2 | 73 | 74 |
| Reference, 6.0 Bag | | | | | | |
| Limestone with Air | 0.45 | 6.2 | 3-1/2 | 144.4 | 72 | 75 |
| Mighty 150 | 0.38 | 4.9 | 4-1/2 | 147.6 | 69 | 72 |
| Melment | 0.40 | 6.7 | 4-1/2 | 144.8 | 69 | 71 |
| Reference, 6.5 Bag | | | | | | |
| Limestone with Air | 0.42 | 2.5 | 2-3/4 | 149.6 | 70 | 72 |
| Mighty 150 | 0.33 | 3.7 | 3-1/2 | 152.4 | 70 | 73 |
| Melment | 0.37 | 5.7 | 4-1/4 | 147.2 | 70 | 72 |

TABLE 5

CONCRETE STRENGTH TEST DATA,

5.0 BAG CEMENT CONTENT, GRAVEL, NO AIR

| Type Mix | Age, days | Strength, psi Compressive | Splitting Tensile | Flexural |
|---|---|---|---|---|
| Reference | 7 | 2900 (-) | 335 (-) | 517 (-) |
| | 28 | 4081 (-) | 408 (-) | 741 (-) |
| | 200 | 5221 (-) | 476 (-) | 847 (-) |
| FX-32 | 7 | 2603 (90%) | 285 (85%) | 598 (116%) |
| | 28 | 3280 (90%) | 304 (75%) | 445 (60%) |
| | 200 | 3860 (74%) | 385 (81%) | 597 (70%) |
| Lomar D | 7 | 2847 (98%) | 292 (87%) | 404 (78%) |
| | 28 | 3216 (79%) | 326 (80%) | 511 (69%) |
| | 200 | 3996 (77%) | 386 (81%) | 645 (76%) |
| Mighty 150 | 7 | 3902 (135%) | 363 (108%) | 430 (83%) |
| | 28 | 4947 (121%) | 427 (105%) | 700 (94%) |
| | 200 | 5701 (109%) | 484 (102%) | 845 (100%) |
| Melment | 7 | 3875 (134%) | 391 (117%) | 599 (116%) |
| | 28 | 5033 (123%) | 488 (120%) | 730 (99%) |
| | 200 | 6137 (118%) | 568 (119%) | 870 (103%) |

TABLE 6

CONCRETE STRENGTH TEST DATA,
6.0 BAG CEMENT CONTENT, GRAVEL, NO AIR

| Type Mix | Age, days | Strength, psi | | |
|---|---|---|---|---|
| | | Compressive | Splitting Tensile | Flexural |
| Reference | 7 | 3646 (-) | 375 (-) | 624 (-) |
| | 28 | 4770 (-) | 501 (-) | 842 (-) |
| | 200 | 6515 (-) | 575 (-) | 966 (-) |
| FX-32 | 7 | 3893 (107%) | 318 (85%) | 652 (104%) |
| | 28 | 4835 (101%) | 444 (90%) | 712 (85%) |
| | 200 | 6163 (95%) | 512 (89%) | 814 (84%) |
| Lomar D | 7 | 3981 (109%) | 356 (95%) | 616 (99%) |
| | 28 | 4794 (101%) | 411 (82%) | 647 (77%) |
| | 200 | 6022 (92%) | 489 (85%) | 849 (88%) |
| Mighty 150 | 7 | 5103 (140%) | 464 (124%) | 738 (118%) |
| | 28 | 6407 (134%) | 500 (100%) | 824 (98%) |
| | 200 | 8298 (127%) | 573 (100%) | 1051 (109%) |
| Melment | 7 | 4679 (128%) | 451 (120%) | 725 (116%) |
| | 28 | 6143 (129%) | 489 (98%) | 828 (98%) |
| | 200 | 7762 (119%) | 619 (108%) | 1025 (106%) |

TABLE 7

CONCRETE STRENGTH TEST DATA,

6.5 BAG CEMENT CONTENT, GRAVEL, NO AIR

| Type Mix | Age, days | Strength, psi | | |
|---|---|---|---|---|
| | | Compressive | Splitting Tensile | Flexural |
| Reference | 7 | 3757 (-) | 406 (-) | 685 (-) |
| | 28 | 5171 (-) | 498 (-) | 835 (-) |
| | 200 | 6555 (-) | 594 (-) | 981 (-) |
| FX-32 | 7 | 5324 (141%) | 485 (119%) | 810 (118%) |
| | 28 | 6749 (131%) | 577 (116%) | 903 (108%) |
| | 200 | 7715 (118%) | 662 (111%) | 1093 (111%) |
| Lomar D | 7 | 5259 (140%) | 465 (115%) | 736 (107%) |
| | 28 | 6575 (127%) | 470 (94%) | 850 (102%) |
| | 200 | 7909 (121%) | 614 (103%) | 1060 (108%) |
| Mighty 150 | 7 | 5766 (153%) | 503 (124%) | 784 (114%) |
| | 28 | 6690 (129%) | 548 (110%) | 948 (114%) |
| | 200 | 8133 (124%) | 651 (110%) | 1071 (109%) |
| Melment | 7 | 5153 (137%) | 435 (107%) | 791 (115%) |
| | 28 | 6528 (126%) | 510 (102%) | 922 (110%) |
| | 200 | 7827 (119%) | 650 (109%) | 1097 (112%) |

TABLE 8

CONCRETE STRENGTH TEST DATA,

7.0 BAG CEMENT CONTENT, GRAVEL, NO AIR

| Type Mix | Age, days | Strength, psi | | |
|---|---|---|---|---|
| | | Compressive | Splitting Tensile | Flexural |
| Reference | 7 | 4235 (-) | 426 (-) | 738 (-) |
| | 28 | 5259 (-) | 446 (-) | 897 (-) |
| | 200 | 6979 (-) | 525 (-) | 930 (-) |
| FX-32 | 7 | 5810 (137%) | 489 (115%) | 881 (119%) |
| | 28 | 7421 (141%) | 554 (124%) | 1046 (117%) |
| | 200 | 8598 (123%) | 659 (126%) | 1174 (126%) |
| Lomar D | 7 | 6083 (144%) | 516 (121%) | 876 (119%) |
| | 28 | 6896 (131%) | 555 (124%) | 967 (108%) |
| | 200 | 7338 (105%) | 631 (120%) | 1086 (117%) |
| Mighty 150 | 7 | 5951 (141%) | 562 (132%) | 861 (117%) |
| | 28 | 7061 (134%) | 574 (129%) | 1029 (115%) |
| | 200 | 8263 (118%) | 666 (127%) | 1165 (125%) |
| Melment | 7 | 5035 (119%) | 443 (104%) | 896 (121%) |
| | 28 | 7444 (142%) | 594 (133%) | 1030 (115%) |
| | 200 | 7862 (113%) | 697 (133%) | 1123 (121%) |

TABLE 9

CONCRETE STRENGTH TEST DATA,

VARIOUS MIX DESIGNS WITH GRAVEL AND AIR

| Type Mix | Age, days | Strength, psi | | |
|---|---|---|---|---|
| | | Compressive | Splitting Tensile | Flexural |
| Reference, 6.0 Bag Cement Content | 7 | 2686 (-) | 300 (-) | 580 (-) |
| | 28 | 3831 (-) | 314 (-) | 705 (-) |
| | 200 | 4675 (-) | 432 (-) | 764 (-) |
| Mighty 150, 6.0 Bag Cement Content | 7 | 5236 (195%) | 448 (149%) | 728 (126%) |
| | 28 | 5942 (155%) | 537 (171%) | 884 (125%) |
| | 200 | 7786 (167%) | 646 (150%) | 932 (122%) |
| Melment, 6.0 Bag Cement Content | 7 | 5000 (186%) | 459 (153%) | 751 (129%) |
| | 28 | 5306 (139%) | 515 (164%) | 803 (114%) |
| | 200 | 7503 (160%) | 660 (153%) | 976 (128%) |
| Reference, 6.5 Bag Cement Content | 7 | 2965 (-) | 304 (-) | 520 (-) |
| | 28 | 3698 (-) | 379 (-) | 717 (-) |
| | 200 | 4523 (-) | 472 (-) | 773 (-) |
| Mighty 150, 6.5 Bag Cement Content | 7 | 5203 (175%) | 504 (166%) | 776 (149%) |
| | 28 | 5913 (160%) | 552 (146%) | 841 (117%) |
| | 200 | 7314 (162%) | 644 (136%) | 1063 (138%) |
| Melment, 6.5 Bag Cement Content | 7 | 5024 (169%) | 461 (152%) | 791 (152%) |
| | 28 | 6022 (163%) | 551 (145%) | 802 (112%) |
| | 200 | 7479 (165%) | 660 (140%) | 1090 (141%) |

TABLE 10

CONCRETE STRENGTH TEST DATA,

VARIOUS MIX DESIGNS WITH LIMESTONE AND NO AIR

| Type Mix | Age, days | Strength, psi Compressive | Splitting Tensile | Flexural |
|---|---|---|---|---|
| Reference, 6.0 Bag Cement Content | 7 | 3970 (-) | 435 (-) | 657 (-) |
| | 28 | 4818 (-) | 460 (-) | 722 (-) |
| | 200 | 5845 (-) | 550 (-) | 914 (-) |
| Mighty 150, 6.0 Bag Cement Content | 7 | 5032 (127%) | 430 (99%) | 747 (114%) |
| | 28 | 6134 (127%) | 569 (124%) | 892 (124%) |
| | 200 | 7609 (130%) | 633 (115%) | 966 (106%) |
| Melment, 6.0 Bag Cement Content | 7 | 5486 (138%) | 445 (102%) | 773 (118%) |
| | 28 | 6254 (130%) | 552 (120%) | 935 (130%) |
| | 200 | 7815 (134%) | 665 (121%) | 1020 (112%) |
| Reference, 6.5 Bag Cement Content | 7 | 4370 (-) | 433 (-) | 690 (-) |
| | 28 | 5156 (-) | 486 (-) | 809 (-) |
| | 200 | 7090 (-) | 597 (-) | 898 (-) |
| Mighty 150, 6.5 Bag Cement Content | 7 | 5536 (127%) | 524 (121%) | 902 (131%) |
| | 28 | 6770 (130%) | 580 (119%) | 903 (112%) |
| | 200 | 8922 (126%) | 599 (100%) | 1117 (124%) |
| Melment, 6.5 Bag Cement Content | 7 | 5680 (130%) | 457 (106%) | 903 (131%) |
| | 28 | 7079 (137%) | 521 (107%) | 915 (113%) |
| | 200 | 8404 (119%) | 644 (108%) | 1065 (119%) |

TABLE 11

CONCRETE STRENGTH TEST DATA,

VARIOUS MIX DESIGNS WITH LIMESTONE AND AIR

| Type Mix | Age, days | Strength, psi | | |
|---|---|---|---|---|
| | | Compressive | Splitting Tensile | Flexural |
| Reference, 6.0 Bag | | | | |
| Cement Content | 7 | 3928 (-) | 425 (-) | 572 (-) |
| | 28 | 4358 (-) | 440 (-) | 665 (-) |
| | 200 | 5936 (-) | 544 (-) | 899 (-) |
| Mighty 150, 6.0 Bag | | | | |
| Cement Content | 7 | 5945 (151%) | 525 (124%) | 760 (133%) |
| | 28 | 7285 (167%) | 560 (127%) | 874 (131%) |
| | 200 | 8198 (138%) | 670 (123%) | 962 (107%) |
| Melment, 6.0 Bag | | | | |
| Cement Content | 7 | 4906 (125%) | 445 (105%) | 688 (120%) |
| | 28 | 5801 (133%) | 527 (120%) | 784 (118%) |
| | 200 | 7197 (121%) | 608 (112%) | 1005(112%) |
| Reference, 6.5 Bag | | | | |
| Cement Content | 7 | 4514 (-) | 468 (-) | 670 (-) |
| | 28 | 5577 (-) | 555 (-) | 791 (-) |
| | 200 | 7450 (-) | 642 (-) | 1007 (-) |
| Mighty 150, 6.5 Bag | | | | |
| Cement Content | 7 | 6755 (150%) | 597 (128%) | 874 (130%) |
| | 28 | 8298 (149%) | 607 (109%) | 1010 (128%) |
| | 200 | 10200 (137%) | 698 (109%) | 1010 (100%) |
| Melment, 6.5 Bag | | | | |
| Cement Content | 7 | 5439 (120%) | 524 (112%) | 759 (113%) |
| | 28 | 6148 (110%) | 585 (105%) | 819 (104%) |
| | 200 | 7597 (102%) | 616 (96%) | 909 (90%) |

TABLE 12

DURABILITY TEST DATA,

GRAVEL MIX WITH NO AIR

| Type Mix | Freeze and Thaw No. Cycles | Freeze and Thaw D.F. | Abrasion, $cm^3/cm^2$ @ 28 days | Abrasion, $cm^3/cm^2$ @ 200 days | Scaling No. Cycles | Scaling Rating |
|---|---|---|---|---|---|---|
| Reference, 5.0 Bag* | 50 | 10 | 0.05 | 0.02 | 47 | 5 |
| FX-32, 5.0 Bag* | 8 | 1.6 | 0.04 | 0.04 | 48 | 5 |
| Lomar D, 5.0 Bag* | 8 | 1.6 | 0.04 | 0.04 | 62 | 4 |
| Mighty 150, 5.0 Bag* | 57 | 11.5 | 0.05 | 0.02 | 33 | 5 |
| Melment, 5.0 Bag* | 61 | 11.5 | 0.05 | 0.05 | 25 | 5 |
| Reference, 6.0 Bag* | 36 | 7.2 | 0.03 | 0.06 | 42 | 5 |
| FX-32, 6.0 Bag* | 38 | 7.6 | 0.04 | 0.02 | 53 | 3 |
| Lomar D, 6.0 Bag* | 37 | 7.3 | 0.02 | 0.02 | 50 | 4 |
| Mighty 150, 6.0 Bag* | 113 | 22.6 | 0.02 | 0.02 | 49 | 3 |
| Melment, 6.0 Bag* | 79 | 15.8 | 0.03 | 0.02 | 50 | 4 |
| Reference, 6.5 Bag* | 47 | 9.4 | 0.02 | 0.02 | 14 | 5 |
| FX-32, 6.5 Bag* | 108 | 21.6 | 0.02 | 0.03 | 54 | 4 & 5 |
| Lomar D, 6.5 Bag* | 89 | 17.8 | 0.02 | 0.07 | 53 | 4 |
| Mighty 150, 6.5 Bag* | 85 | 17 | 0.02 | 0.05 | 50 | 4 |
| Melment, 6.5 Bag* | 75 | 15 | 0.02 | 0.02 | 50 | 4 |
| Reference, 7.0 Bag* | 53 | 10.6 | 0.03 | 0.03 | 34 | 5 |
| FX-32, 7.0 Bag* | 108 | 21.6 | 0.02 | 0.02 | 52 | 2 |
| Lomar D, 7.0 Bag* | 94 | 18.8 | 0.02 | 0.01 | 49 | 3 |
| Mighty 150, 7.0 Bag* | 70 | 14.0 | 0.04 | 0.02 | 49 | 4 & 3 |
| Melment, 7.0 Bag* | 74 | 14.8 | 0.02 | 0.01 | 52 | 3 |

*Note: Cement Content of Concrete Mix.

TABLE 13
DURABILITY TEST DATA,
VARIOUS MIX DESIGNS

| Type Mix | Freeze and Thaw No. Cycles | Freeze and Thaw D.F. | Abrasion, $cm^3/cm^2$ @ 28 days | Abrasion, $cm^3/cm^2$ @ 200 days | Scaling No. Cycles | Scaling Rating |
|---|---|---|---|---|---|---|
| | | | Gravel Mixes with Air | | | |
| Reference, 6.0 Bag* | 146 | 29.2 | 0.09 | 0.03 | 52 | 3 |
| Mighty 150, 6.0 Bag* | 192 | 37.6 | 0.02 | 0.02 | 50 | 4 |
| Melment, 6.0 Bag* | 185 | 38.7 | 0.02 | 0.02 | 50 | 2 & 3 |
| Reference, 6.5 Bag* | 170 | 34.0 | 0.03 | 0.06 | 51 | 1 |
| Mighty 150, 6.5 Bag* | 248 | 49.6 | 0.01 | 0.03 | 50 | 3 |
| Melment, 6.5 Bag* | 293 | 58.6 | 0.02 | 0.04 | 50 | 2 & 3 |
| | | | Limestone Mixes with No Air | | | |
| Reference, 6.0 Bag* | 91 | 18.9 | 0.02 | 0.01 | 33 & 40 | 5 & 5 |
| Mighty 150, 6.0 Bag* | 100 | 21.6 | 0.03 | 0.02 | 50 | 4 |
| Melment, 6.0 Bag* | 95 | 19.1 | 0.03 | 0.02 | 44 | 5 |
| Reference, 6.5 Bag* | 98 | 19.5 | 0.04 | 0.02 | 34 | 5 |
| Mighty 150, 6.5 Bag* | 101 | 20.1 | 0.02 | 0.03 | 50 | 5 & 4 |
| Melment, 6.5 Bag* | 83 | 16.7 | 0.01 | 0.01 | 29 | 5 |
| | | | Limestone Mixes with Air | | | |
| Reference, 6.0 Bag* | 300 | 86.0 | 0.03 | 0.04 | 51 | 0 & 1 |
| Mighty 150, 6.0 Bag* | 300 | 83.0 | 0.02 | 0.03 | 50 | 4 & 3 |
| Melment, 6.0 Bag* | 300 | 99.0 | 0.02 | 0.03 | 50 | 3 |
| Reference, 6.5 Bag* | 300 | 81.0 | 0.02 | 0.02 | 51 | 3 |
| Mighty 150, 6.5 Bag* | 300 | 80.0 | 0.02 | 0.02 | 50 | 3 |
| Melment, 6.5 Bag* | 300 | 82.0 | 0.02 | 0.02 | 49 | 1 |

*Note: Cement Content of Concrete Mix.

TABLE 14

COMPARISON OF

FREEZE-THAW DURABILITY TEST RESULTS

| Type Mix | Control, Reference | | Mighty 150 | | Melment | | FX-32 | | Lomar D | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Cycles | DF | Cycles | DF | Cycles | DF | Cycles | DF | Cycles | DF |
| 5.0 Bag Cement, Content, Gravel, No Air | 50 | 10.0 | 57 | 11.5 | 61 | 11.5 | 8 | 1.6 | 8 | 1.6 |
| 6.0 Bag Cement Content, Gravel, No Air | 36 | 7.2 | 113 | 22.6 | 79 | 15.8 | 38 | 7.6 | 37 | 7.3 |
| 6.5 Bag Cement Content, Gravel, No Air | 47 | 4.4 | 85 | 19.0 | 75 | 15.0 | 108 | 21.6 | 89 | 17.8 |
| 7.0 Bag Cement Content, Gravel, No Air | 53 | 10.6 | 70 | 14.0 | 74 | 14.8 | 94 | 18.8 | 108 | 21.6 |
| 6.0 Bag Cement Content, Gravel, Air | 146 | 29.2 | 192 | 37.6 | 185 | 38.7 | - | - | - | - |
| 6.5 Bag Cement Content, Gravel, Air | 170 | 34.0 | 248 | 49.6 | 293 | 58.6 | - | - | - | - |
| 6.0 Bag Cement Content, Lime-stone, No Air | 91 | 18.9 | 100 | 21.6 | 95 | 19.1 | - | - | - | - |
| 6.5 Bag Cement Content, Lime-stone, No Air | 98 | 19.5 | 101 | 20.0 | 83 | 16.7 | - | - | - | - |
| 6.0 Bag Cement Content, Lime-stone, Air | 300 | 86.0 | 300 | 83.0 | 300 | 99.0 | - | - | - | - |
| 6.5 Bag Cement Content, Lime-stone, Air | 300 | 81.0 | 300 | 80.0 | 300 | 82.0 | - | - | - | - |

TABLE 15

SETTING TIME OF SWR CONCRETE

GRAVEL MIXES WITH NO AIR

| C. F. | Admixture | Time of Set Hr. - Min. Initial | Final | Retardation Hr. - Min. Initial | Final |
|---|---|---|---|---|---|
| | Reference | 3:47 | 5:21 | - | - |
| | FX-32* | 6:54 | 8:24 | 2:27 | 2:21 |
| 7 | Mighty 150 | 7:54 | 9:24 | 4:07 | 4:03 |
| | Lomar D* | 6:21 | 7:57 | 1:54 | 1:54 |
| | Melment | 4:24 | 5:57 | 0:37 | 0:36 |
| | Reference | 4:27 | 5:57 | | |
| | FX-32 | 6:24 | 8:27 | 1:57 | 2:30 |
| 6.5 | Mighty 150 | 6:00 | 7:54 | 1:33 | 1:57 |
| | Lomar D | 8:03 | 9:42 | 3:36 | 3:45 |
| | Melment | 3:57 | 5:54 | 0:30 | 0:30(-) |
| | Reference | 4:19 | 6:00 | | |
| | FX-32 | 5:55 | 7:27 | 1:36 | 1:27 |
| 6.0 | Mighty 150 | 4:53 | 6:25 | 0:34 | 0:25 |
| | Lomar D | 6:13 | 7:40 | 1:54 | 1:40 |
| | Melment | 4:05 | 5:28 | 0:14 | 0:32(-) |
| | Reference | 4:24 | 6:20 | | |
| | FX-32 | 6:37 | 8:20 | 2:13 | 2:00 |
| 5.0 | Mighty 150 | 6:50 | 8:22 | 2:26 | 2:02 |
| | Lomar D | 6:45 | 8:23 | 2:21 | 2:03 |
| | Melment | 4:48 | 6:30 | 0:24 | 0:10 |

*Reference for these mixes - Initial 4:27
Final 6:03

(-) accelerated set

TABLE 16

SETTING TIME OF SWR CONCRETE
GRAVEL MIXES WITH AIR ENTRAINED

| C. F. | Admixture | Time of Set Hr. - Min. Initial | Final | Retardation Hr. - Min. Initial | Final |
|---|---|---|---|---|---|
| | Reference | 4:21 | 6:06 | | |
| 6.5 | Mighty 150 | 4:39 | 6:09 | 0:18 | 0:03 |
| | Melment | 4:12 | 5:54 | 0:09 | 0:12(-) |
| | Reference | 4:21 | 6:12 | | |
| 6.0 | Mighty 150 | 5:06 | 6:51 | 0:45 | 0:39 |
| | Melment | 4:15 | 5:45 | 0:06 | 0:27(-) |

(-) accelerated set

TABLE 17

SETTING TIME OF SWR CONCRETE
LIMESTONE MIXES WITH NO AIR

| C. F. | Admixture | Time of Set Hr. - Min. Initial | Time of Set Hr. - Min. Final | Retardation Hr. - Min. Initial | Retardation Hr. - Min. Final |
|---|---|---|---|---|---|
| | Reference | 4:12 | 5:40 | | |
| 6.5 | Mighty 150 | 4:30 | 5:48 | 0:18 | 0:08 |
| | Melment | 4:12 | 5:30 | 0:00 | 0:10(-) |
| | Reference | 5:42 | 7:30 | | |
| 6.0 | Mighty 150 | 5:36 | 7:15 | 0:06 | 0:15(-) |
| | Melment | 4:48 | 6:27 | 0:54 | 1:03(-) |

TABLE 18

SETTING TIME OF SWR CONCRETE
LIMESTONE MIXES WITH AIR

| C. F. | Admixture | Time of Set Hr. - Min. Initial | Time of Set Hr. - Min. Final | Retardation Hr. - Min. Initial | Retardation Hr. - Min. Final |
|---|---|---|---|---|---|
| | Reference | 3:54 | 5:27 | | |
| 6.5 | Mighty 150 | 4:24 | 5:42 | 0:30 | 0:15 |
| | Melment | 4:12 | 5:27 | 0:18 | 0:00 |
| | Reference | 4:24 | 6:18 | | |
| 6.0 | Mighty 150 | 4:48 | 6:24 | 0:24 | 0:06 |
| | Melment | 4:32 | 5:57 | 0:08 | 0:21(-) |

(-) accelerated set

TABLE 19

DRY SHRINKAGE DATA (64 WEEKS)

GRAVEL MIXES

| Cement Factor | Admixture | No Air % Shrinkage | Air % Shrinkage |
|---|---|---|---|
| 7 | Reference | 0.021 | |
| | Mighty 150 | 0.024 | |
| | Melment | 0.017 | |
| | FX-32 | 0.015 | |
| | Lomar D | 0.018 | |
| 6.5 | Reference | 0.019 | 0.038 |
| | Mighty 150 | 0.029 | 0.027 |
| | Melment | 0.026 | 0.028 |
| | FX-32 | 0.022 | |
| | Lomar D | 0.016 | |
| 6.0 | Reference | 0.019 | 0.040 |
| | Mighty 150 | 0.027 | 0.027 |
| | Melment | 0.028 | 0.033 |
| | FX-32 | 0.020 | |
| | Lomar D | 0.019 | |
| 5.0 | Reference | 0.024 | |
| | Mighty 150 | 0.026 | |
| | Melment | 0.022 | |
| | FX-32 | 0.026 | |
| | Lomar D | 0.012 | |

TABLE 20

DRY SHRINKAGE DATA (64 WEEKS)

LIMESTONE MIXES

| Cement Factor | Admixture | No Air % Shrinkage | Air % Shrinkage |
|---|---|---|---|
| 6.0 | Reference | 0.041 | 0.035 |
| | Mighty 150 | 0.039 | 0.031 |
| | Melment | 0.033 | 0.033 |
| 6.5 | Reference | 0.038 | 0.027 |
| | Mighty 150 | 0.030 | 0.031 |
| | Melment | 0.035 | 0.029 |

TABLE 21

PRODUCT INFORMATION

Product A

Mighty 150 - ICI Americas, Inc.
Kao Soap Company, Ltd.

Class B Sulfonated naphthalene-formaldehyde condensate
Type A Water Reducer, ASTM C-494, AASHTO M-194
- Water Reduction - 15-25%
- Dosage - 1.5% (or 19 fluid oz.) per 100 lbs. cement
- 42% aqueous solution of sulfoaryl alkylen (% solids - 42.7)
- pH (2% aqueous solution) - 9.0 + 1.0
- Specific Gravity - 1.2
- Density - 10 lbs./gal.

Cost - \$1.75 - \$2.25/yd$^3$ (\$0.36 - \$0.44/lb. liquid)

Product B

Melment - American Admixtures Corp.

Class A Sulfonated melamine-formaldehyde condensate
Type A Water Reducer, ASTM C-494, AASHTO M-194
- Water Reduction - 22-30%
- Dosage - 42 fluid oz. per 100 lbs. cement
- 20% solids in aqueous solution (% solids - 20.9)
- pH - 7.9
- Density - 1.1 g./cm.$^3$
- Chloride Content - less than 0.005%

Cost - \$2.24/gallon

Product C

FX-32 - Fox Industries

Class A Sulfonated melamine-formaldehyde condensate
Type A Water Reducer, ASTM C-494, AASHTO M-194
- Water Reduction - 20%
- Dosage - 1 lb. powder or 2 quarts per sack cement (1% by wt.)
- % solids - 19.3

Cost - \$3.60/gallon

TABLE 21 (CONTINUED)

PRODUCT INFORMATION

Product D

Lomar D - Diamond Shamrock

Class B Sulfonated naphthalene-formaldehyde condensate
Type A Water Reducer, ASTM C-494, AASHTO M-194
Water Reduction - 20-35%
Dosage - 2.1 lbs. liquid per sack cement
High molecular weight condensed naphthalene sulfonate
34% active aqueous solution (% solids - 35.8)
Cost - $0.18 - $0.25/lb. liquid

ACTUAL DOSAGE RATES OF SUPER WATER REDUCERS USED

| | |
|---|---|
| Mighty 150 | - 535 ml. or 18.1 fl. oz. per sack cement |
| Melment | - 1113 ml. or 37.6 fl. oz. per sack cement |
| FX-32 | - 1892 ml. or 64.0 fl. oz. per sack cement |
| Lomar D | - 953 ml. or 32.2 fl. oz. per sack cement |

TABLE 22

LIST OF ASTM TEST PROCEDURES

| | | |
|---|---|---|
| 1. | ASTM C-39 | Standard Method of Test for Compressive Strength of Cylindrical Concrete Specimens |
| 2. | ASTM C-78 | Standard Method of Test for Flexural Strength of Beams |
| 3. | ASTM C-138 | Standard Method of Test for Unit Weight, Yield and Air Content (Gravimetric) of Concrete |
| 4. | ASTM C-143 | Standard Method of Test for Slump of Portland Cement Concrete |
| 5. | ASTM C-157 | Standard Method of Test for Length Change of Cement Mortar and Concrete |
| 6. | ASTM C-192 | Standard Method of Making and Curing Concrete Test Specimens in the Laboratory |
| 7. | ASTM C-231 | Standard Method of Test for Air Content of Freshly Mixed Concrete by the Pressure Method |
| 8. | ASTM C-403 | Standard Method of Test for Time of Setting of Concrete Mixture by Penetration Resistance |
| 9. | ASTM C-418 | Standard Method of Test for Abrasion Resistance of Concrete |
| 10. | ASTM C-660, Procedure B | Standard Method of Test for Resistance of Concrete to Rapid Freezing and Thawing |
| 11. | ASTM C-672 | Standard Method of Test for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals |

TABLE 23

CHEMICAL COMPOSITION CEMENT

Source: Lone Star Industries
Type: 1B
Loss on Ignition, %: 1.7
Sulfur Trioxide, %: 2.8
Iron and Aluminum Oxide, %: 7.7
Magnesium Oxide, %: 1.3

Insoluble Residue, %: 0.10
Tricalcium Aluminate, %: 7.0
Ferric Oxide, %: 3.1
Aluminum Oxide, %: 4.6
Ratio of $AlO_3$ to $FeO_3$: 1.5
Alkalies, T: 0.30

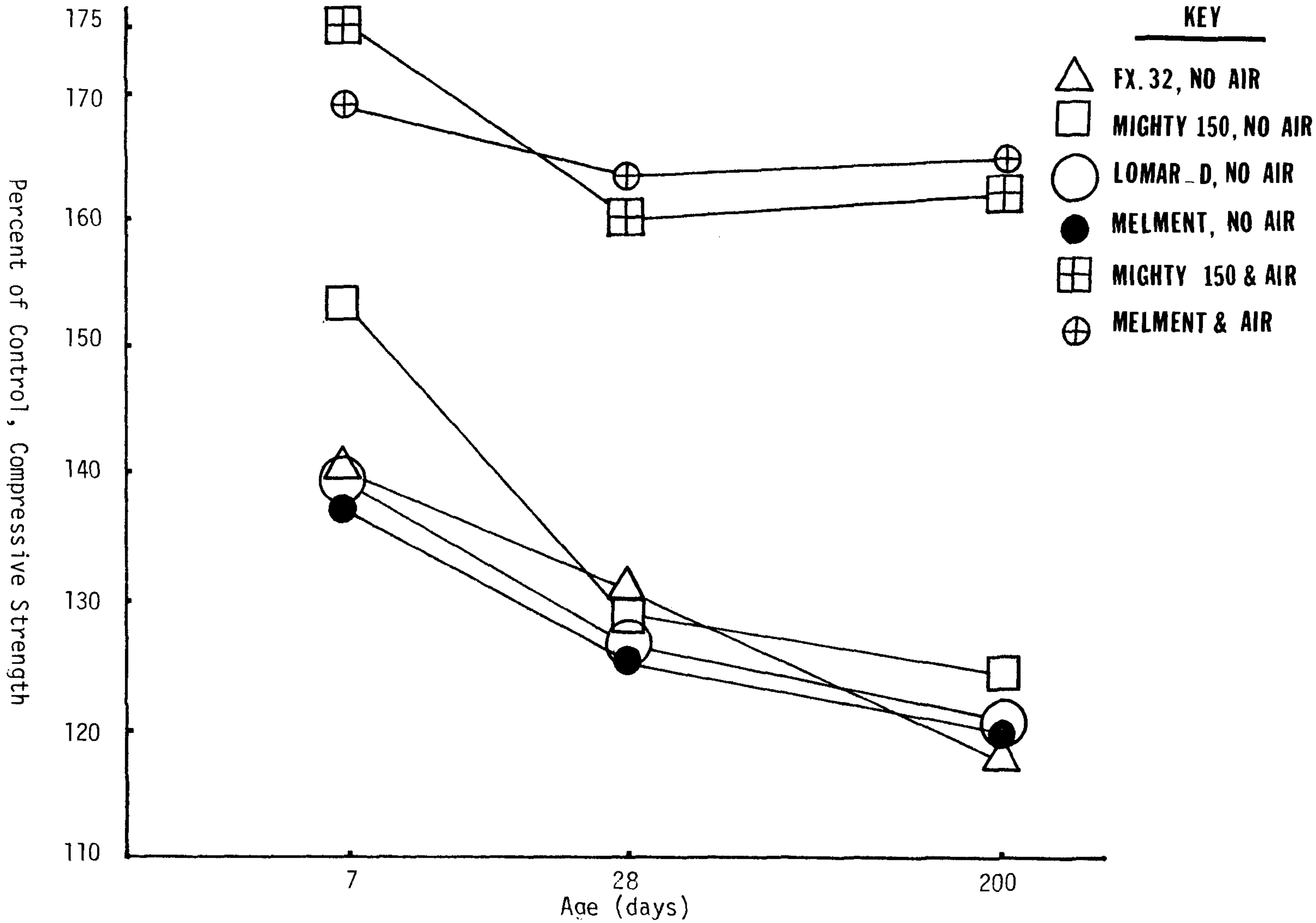


*FIGURE 11*

*Percentage Compressive Strength, 6.5 Bag Gravel Mixes*

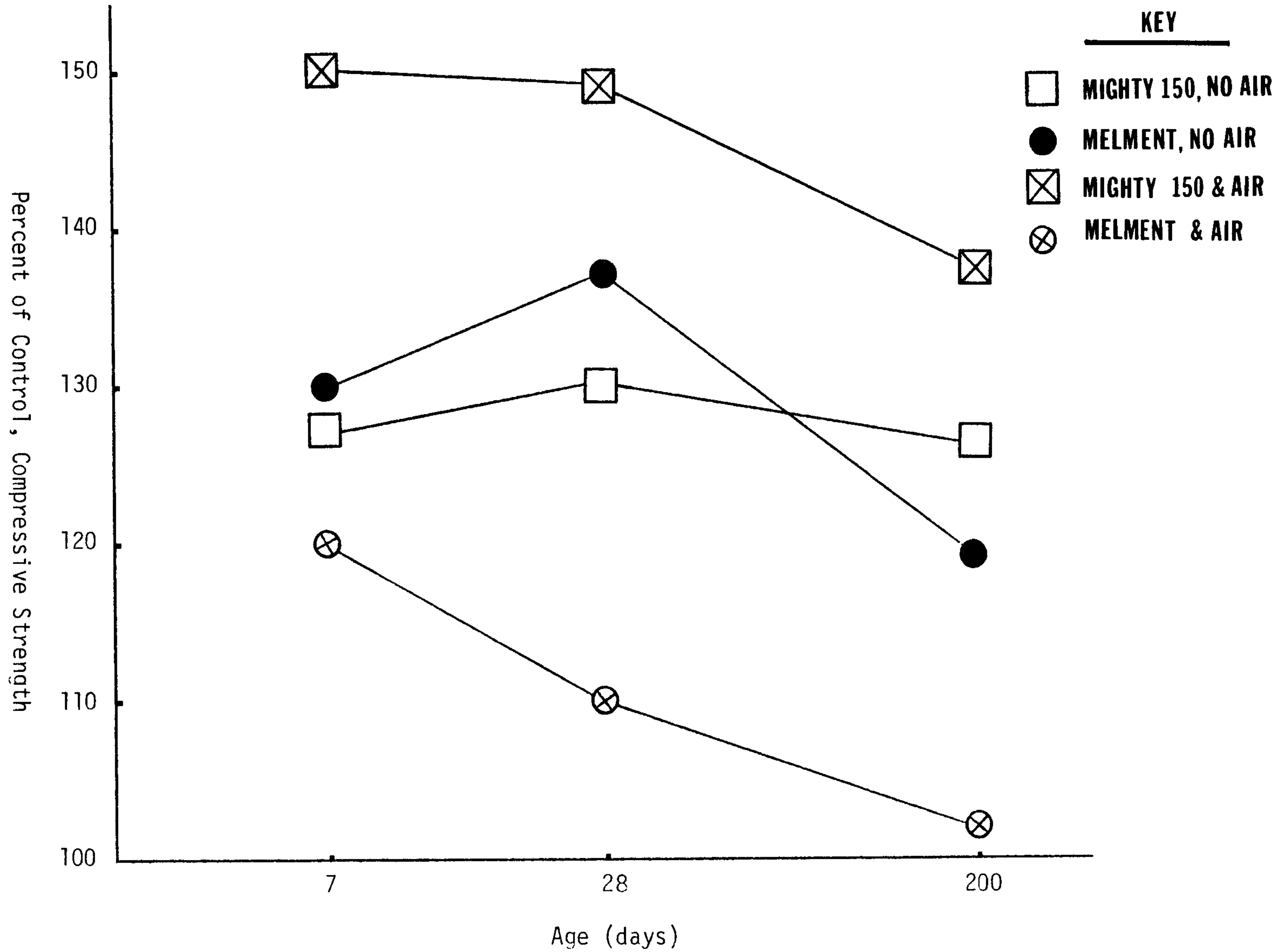


*FIGURE 12*

*Percentage Compressive Strength,
6.5 Bag, Limestone Mixes*

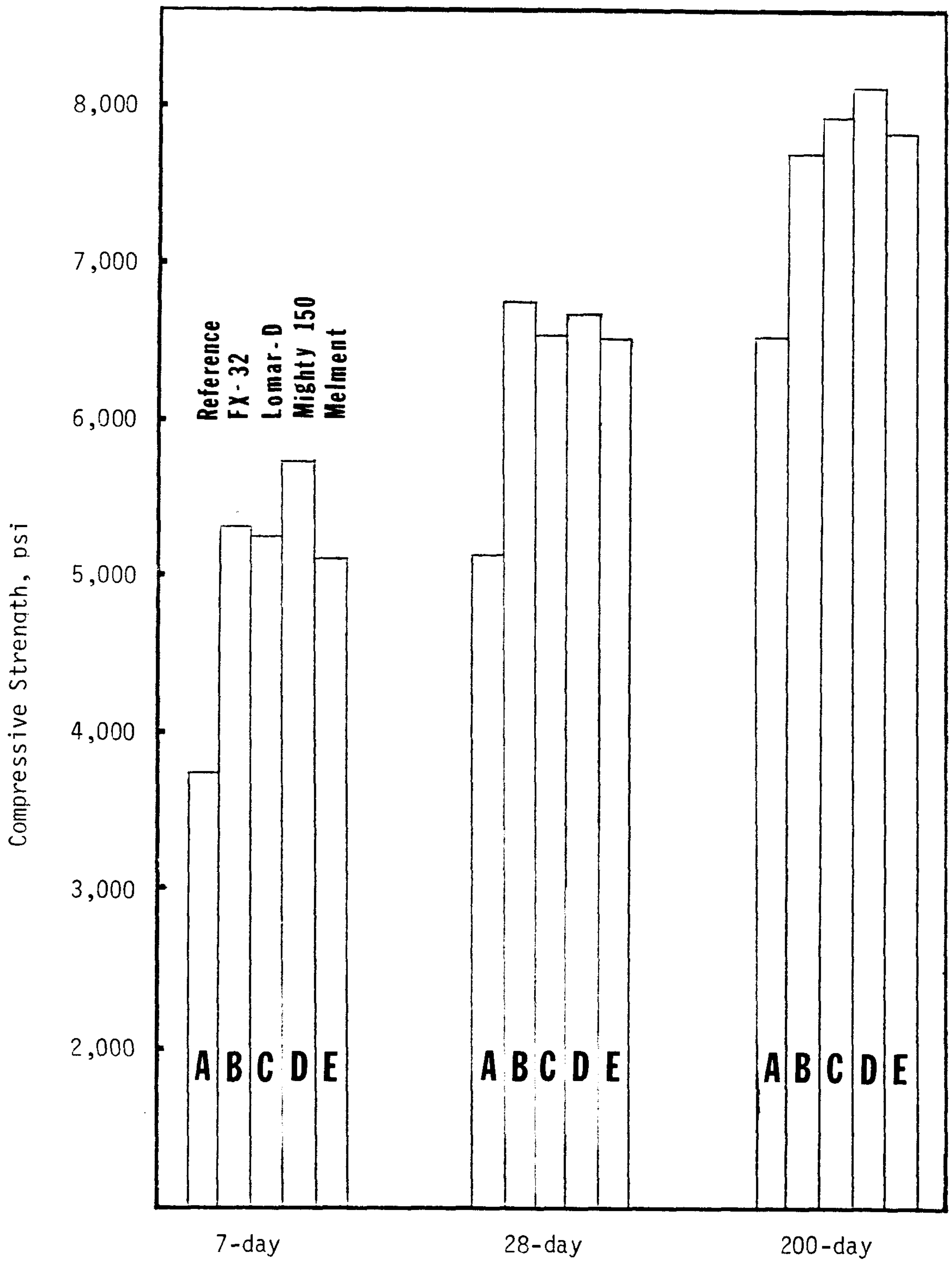


*FIGURE 13*

*6.5 Bag Comparative Compressive Strengths, Gravel Mixes, No Air*

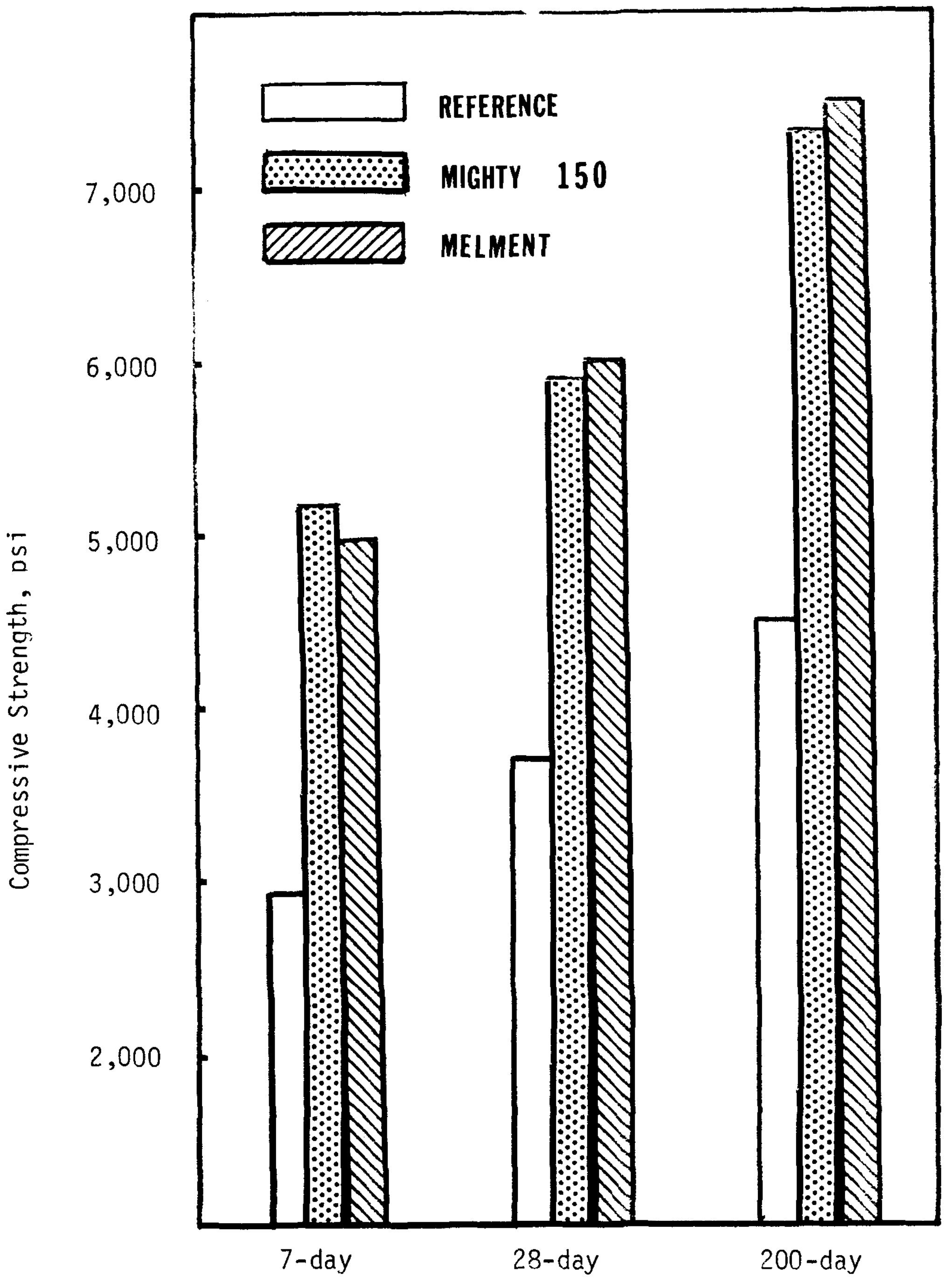


*FIGURE 14*

*6.5 Bag Comparative Compressive Strength, Gravel Mixes, with Air*

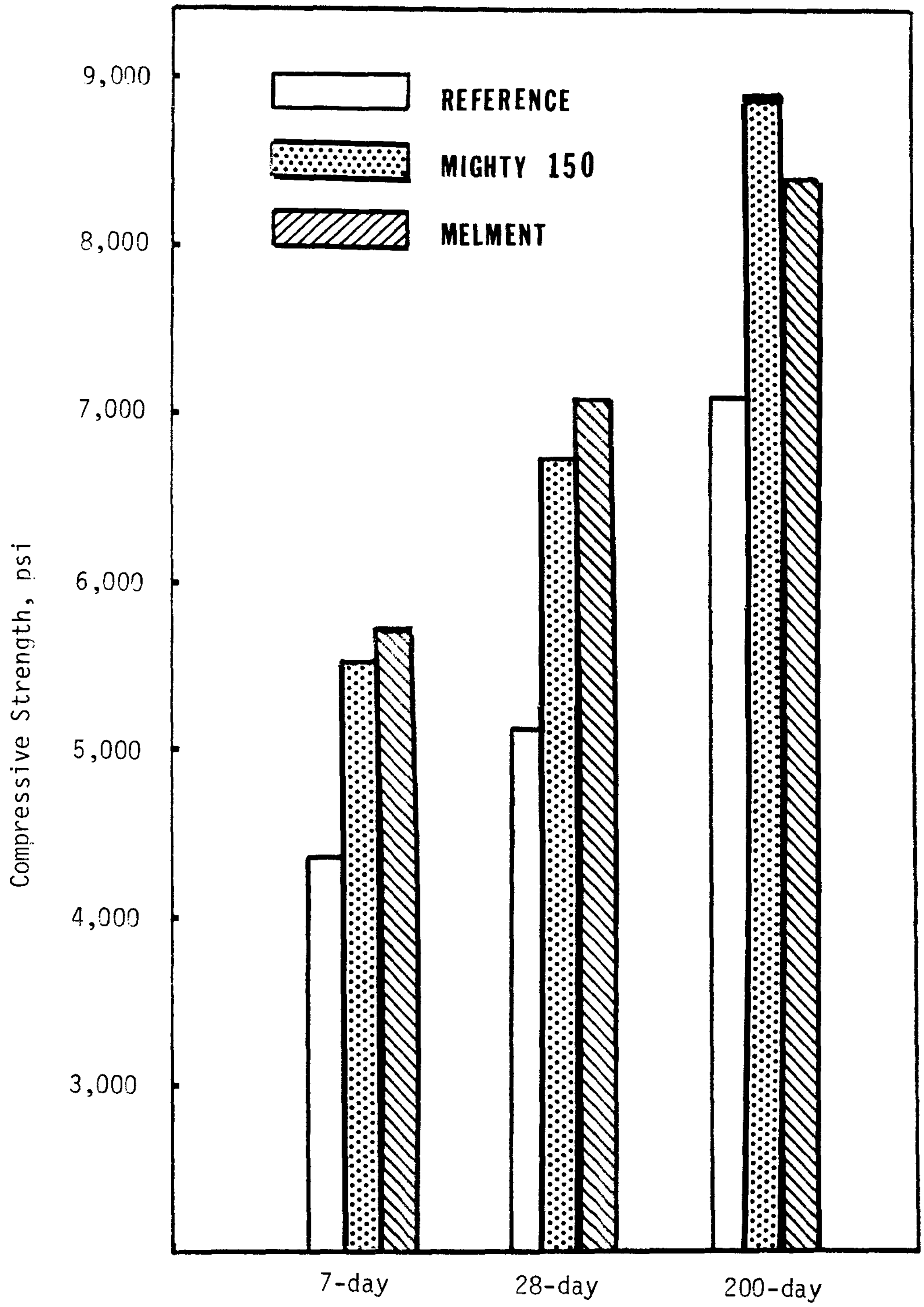


*FIGURE 15*

*Comparative Compressive Strength,*
*6.5 Bag Limestone Mixes, No Air*

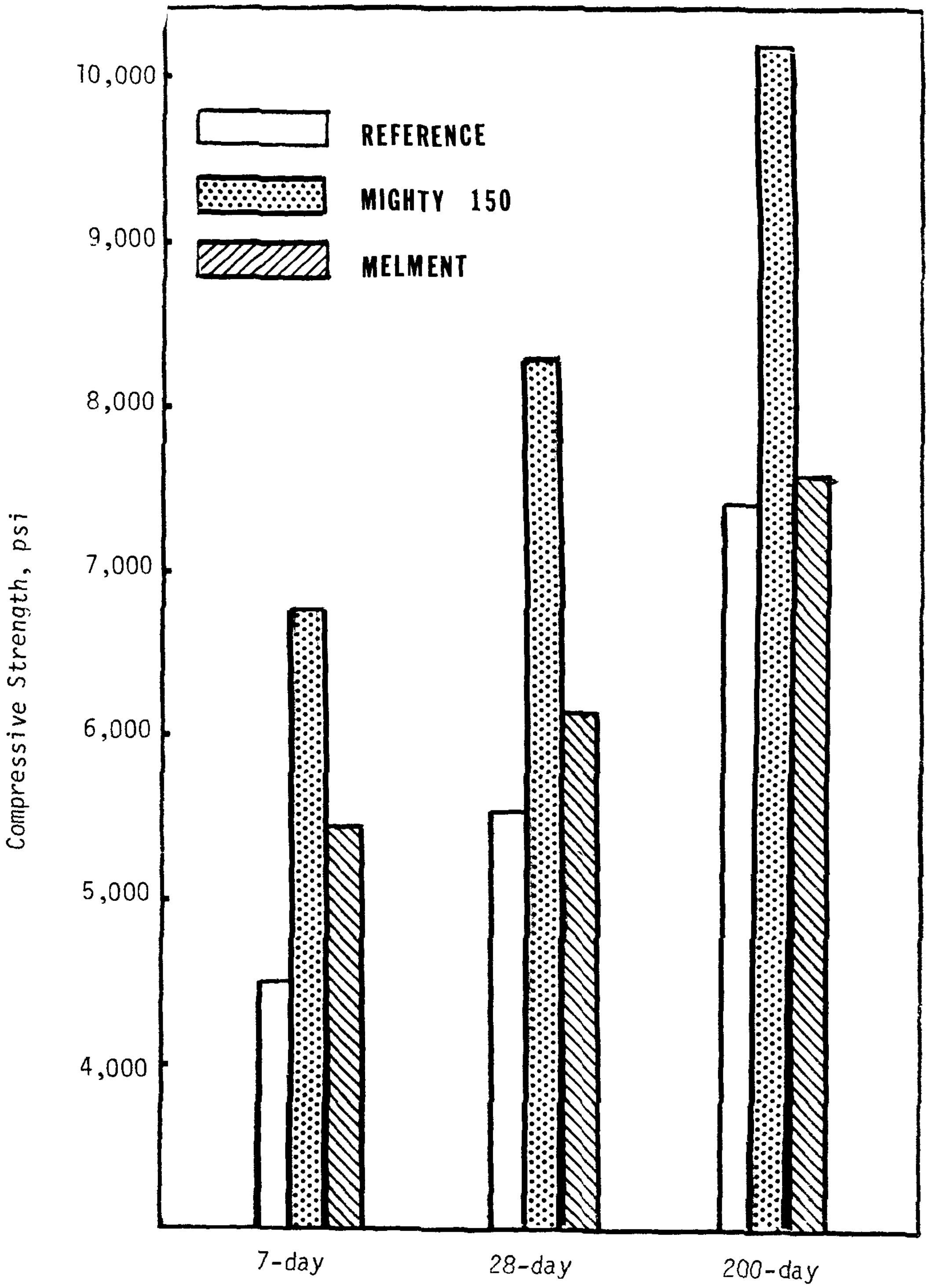


*FIGURE 16*

*Comparative Compressive Strength, 6.5 Bag Limestone Mixes with Air*

USE OF SUPER WATER REDUCERS IN

BRIDGE DECK SLABS IN HOUSTON

Use of Super Water Reducers in
Bridge Deck Slabs in Houston
R. J. Prochaska - October 24, 1979

This report summarizes observations of a deck placement on IH-45 in Houston which included a super plasticizer in the concrete and also notes advantages and disadvantages that the State has experienced on this job resulting from the use of super plasticizers. Representatives of FHWA and the Louisiana Department of Transportation also observed this deck placement and participated in a meeting with the Texas Department of Highways and Public Transportation to discuss their experiences with super water reducers on this project.

This project involves the reconstruction of bridge decks on an elevated freeway of IH-45 in Houston. The ADT on the 8-lane facility is in excess of 150,000 VPD. The project involved rebuilding the decks one-half of a 4-lane section at a time and maintaining 3 lanes of traffic on the old or completed half section of the bridge. The original decks consisted of both lightweight and hardrock concrete. The lightweight concrete decks were removed and replaced with an 8" full depth concrete slab and the hardrock slabs were scarified and a 2" overlay was placed on these decks.

The placement that we observed was a full 8" concrete slab which required approximately 112 cubic yards of concrete. The construction of this bridge deck appeared routine and similar to any major bridge deck construction expected on highway work. The construction operations involving placement, vibration,screeding, finishing, and tining of the concrete presented no unusual problems on the day of this review. Of particular significance was the fact that the 105' long deck was longitudinally screeded and the concrete remained quite plastic and workable throughout the placement operation. The tining was accomplished without difficulty.

The State told us that they had many days where the placement operations were routine as those that we had observed. However, they also had numerous problems with the super plasticized concrete decks over the last year. The State cautioned us that the effect of the addition of a super-plasticizer to a concrete mix requires constant surveillance since several variables are always at work. Such factors as mix temperature, initial slump and absolute volume of water in mix can affect the behavior of super plasticizers.

There were also some circumstances on this project which contributed to the variability of this bridge deck concrete. The contractor could not set up his own batch plant because of the lack of available material and aggregate storage near the project site. The concrete

-more-

for this project comes from a commercial batch plant in Houston which was the only practical source of concrete for this contractor. There are only a limited number of major concrete suppliers in Houston and the demand for this concrete due to the building boon in the city requires very special coordination and planning with the concrete suppliers to assure dependable delivery to the job site. Even with careful coordination with the redi-mix supplier, the delivery time of the concrete was not consistent and the consistency of the redi-mix concrete was variable although it did meet with the State's specifications.

The State did an extensive amount of testing and lab work with super water reducers prior to the development of this project. They had used the plasticizers on maintenance construction and some small bridge decks with excellent results. Prior to the placement of deck slabs on this project, the State used the plasticizers on construction of concrete median barriers to gain further experience in handling concrete using this product.

The State specification for concrete for this job is attached. The concrete specified is c-cy with a minimum 6 sack concrete required and the maximum water-cement ratio is .40. The minimum 28-day compressive strength is 5500 psi and all concrete for the bridge slabs would contain a super plasticizer.

The State used several super plasticizers in both liquid and powder form on this project and found that FX 32 powder by Fox Industries gave them the most consistent results. The procedure that they used on this project was to slump the concrete from the redi-mix truck at the job site. A trained inspector would add the FX 32 powder to increase the slump from 1-1/2± to about 7" to 8". An eight yard truck usually took around 8 lbs. of FX 32 and at the time of this pour, the inspector was getting fairly uniform results. The test records for the last several months indicated that the amount of plasticizer varied from 2 lbs. to 38 lbs. for some trucks. There is a minimum of 70 revolutions of the mixer (minimum 3 minutes) to gain uniformity after the FX 32 was added.

In the early stages of this project, the State did not have acceptable success with the six bag concrete and through trial and error raised the design to 6.7 sack concrete which gave them adequate water to deliver concrete with an acceptable consistency with about 1-1/2" slump. The State believed that they needed to maintain an absolute volume of water sufficient to cause the super plasticizer to react with the mix.The contractor further modified the design to a 7 sack mix to assure even more uniform and consistent concrete and this is the concrete presently used on this project.

-more-

With the above introduction and background of experience, the following items summarize the advantages and disadvantages of super plasticizers as experienced on this project. These items should be considered by designers and contractors prior to the use of super plasticizers on other projects.

- The addition of the super plasticizer produced a more workable and fluid mix. The State's objectives in using this super plasticizer were to get high strength and a workable concrete that would bond easily on an overlay. They also wanted a durable concrete with a low water cement ratio.

- The deck concrete produced on this project was consistently above the design strength for 7-day strength and the 28-day strength varied between 6000 and 8000 psi.

- The concrete was pumped from the ground to these decks (20 to 40 feet) without any difficulty. This mix had 1" maximum aggregate. The State and contractor indicated that pumping the concrete presented no problem as long as the pumping equipment used was adequate for the job conditions.

- The State engineers on this project would have reservations about using the super plasticized concrete on another bridge reconstruction project of this magnitude. As the present design is a 7 sack mix, it would have achieved the desired strength and workability characteristics even without the super plasticizer. There are certain applications such as retaining walls and other constricted areas for which a high slump concrete is needed. This concrete with super water reducers does not segregate like a normal high slump concrete.

- The super plasticized concrete exhibited consistent cohesive quality and did not exhibit any segregation of aggregates unless the slump exceeded 10 inches.

- Houston does not normally require air entrained concrete since they do not use salt on their freeways and the decks are not subject to freeze-thaw cycles. The State, however, did attempt to use an air entraining agent on this job and their target air content was 3%. This was not consistently attained and the average air content was about 3:5%. The State indicated they could not maintain a uniform air content although they attempted this on a daily basis.

- The temperature of the concrete was considered to be the most significant factor contributing to the variability of the results from adding a super water reducer. When the concrete temperature

-more-

was maintained below 75°F, the results were generally predictable. When the concrete was about 75°F, the results were more erratic. The slump loss is very rapid and maintains at that high level for up to approximately 30 minutes.

- Some of the concrete on these decks was very difficult to screed and finish. A retarder was also used in all concrete although this did not consistently assure the plasticity needed at the time of screeding and finishing.

- There is a definite difference in water demand for different cements when using super plasticizers. The State strongly endorsed the need to maintain only one cement for all concrete on a project and that all lab testing and designing for the super plasticizer be done using that cement.

- The State does not have adequate research and lab experience to determine the compatibility of the super plasticizer with other concrete additives. They noted that there is a need for more research in this area prior to widespread use of super plasticizers.

- Placement operations should be continuous to avoid problems with screeding and tining. Any delays with delivery and/or delay time at job site can have a definite impact on workability of concrete.

The above statements are indicative of the findings and experiences of the State with their work on this project in Houston. It should be noted that super plasticizers are currently used routinely in some prestressed concrete product plants in the State and are serving very satisfactorily. This supports the need to have very close control of all the construction operations that can affect concrete variability.

The attached technical article on Super Plasticized Concrete is from a British publication dated September 1976 and contains a good basic discussion of plasticized concrete.

# GUIDELINES FOR THE USE OF SUPER WATER REDUCERS IN CONCRETE

GUIDELINES FOR THE USE OF
SUPER WATER REDUCERS IN CONCRETE

## INTRODUCTION

Use of water reducing admixtures in portland cement concrete is common these days, with primarily two types being used, either normal set or set retarding water reducers. Air-entraining agents may be combined with a conventional water reducer to give added benefits to the plastic or hardened concrete. Generally, 5 to 10 percent water reduction is possible with the use of conventional water reducers in a concrete mix. This reduction in the water content of a mix will lower the water-cement (w/c) ratio, thus increasing the strength of the concrete, along with reducing the permeability of the concrete. There is a drawback to the use of this type of admixture, when a greater amount of water reduction is desired, in that high dosages will cause excessive set retardation.

However, new products have been developed and come on the market to alleviate this problem. These new products have been termed either high-range water reducers, super water reducers or superplasticizers. Use in Europe and Japan has been primarily in the area of fluid or plasticized (flowing) concrete, not in obtaining high strengths which are an important additional benefit of this type of product.

The use of superplasticizers is relatively new in the United States. Water reductions from 10 to 30 percent are possible with the use of super water reducers, thus low water-cement ratios (0.32 to 0.42) are possible, resulting both in fluid concrete and high strength concrete. The advantages of the superplasticizers are that they can improve the workability of concrete, resulting in more rapid and uniform placement, as well as increasing the strength and durability of the concrete at normal workability by reducing the water-cement ratio.

There are several commercial brands of high-range water reducers available on the market today. Each of these products has somewhat different properties and dosage rates, proper use of which should be *determined in pre-trial mixes. The manufacturer's recommendations* become a very important starting point in the usage of these products; however, experience will be the principal factor in their successful use.

The general guidelines provided herein are not established specifications, but are only general guides (acquired from limited laboratory and field experience, along with extensive literature survey sources) to help field personnel in the use or inspection of portland cement concrete, using super water reducers in the mixes. These guidelines should help the field personnel avoid some of the problems associated with the use of these products. Problems will still occur; however, these guidelines should help to minimize them and give the personnel some insight into what to expect in certain situations. The use of these guidelines would be recommended for use in any future projects where super water reducers are used in the portland cement concrete.

PURPOSE

The purpose of these guidelines is to provide the field personnel some written guidelines on the use of super water reducing admixtures in portland cement concrete and some information on possible problems that may be associated with their use. As emphasized before, these guidelines are not a substitution for a set of specifications, for field experience or for direct information on specific areas of batching, mixing, transportation and finishing which a set of specifications may offer.

## SCOPE

These guidelines offer broad and general information or guides on the use of super water reducers in field applications of portland cement concrete. Possible uses, material information, mix design and proportioning, mix procedures, dispensing information, handling information, plastic properties and possible problems are provided herein for the field personnel's use.

## POSSIBLE USES

Super water reduced concrete can be provided in the following forms:

(1) fluid concrete, which is produced at normal water-cement ratios, but possessing such extreme workability (without excessive bleeding or segregation) that the concrete can be placed with little or no vibration or compaction; and

(2) water-reduced, high-strength concrete, which is produced at much lower water-cement ratios than normally experienced and having a workability in the range used by the concrete industry.

The main reasons for using superplasticizers in precast concrete are to improve the physical properties of either the fresh or hardened concrete, to facilitate the placement and compaction of concrete in structural molds, to obtain better finishes or possibly to reduce the costs of these operations.

Some of the possible uses of fluid concrete are:

(1) placing of concrete with reduced vibration in areas of closely spaced reinforcement and in areas of poor access,

(2) the capability of placing, very rapidly, easily and without vibration, concrete for floor slabs, roof decks and similar structures, and

(3) the very rapid pumping of concrete.

As well as those areas that may benefit from concrete having high fluidity, it is necessary to mention those areas which would not benefit such as:

(1) where slow placing methods are normally used,

(2) if the slope on which the concrete is to be placed exceeds 3° to the horizontal, and

(3) situations where high workability can be obtained by water addition without subsequent adverse effects (e.g., pipe spinning).

Fluid concrete can be used to advantage to construct new bridge decks or repair existing areas. Alternatively, the use of a lower water-cement ratio concrete with normal workability could provide better durability of bridge decks.

Possible applications of superplasticized concrete for high strength are as follows:

(1) steam-cured prestressed units - the use of superplasticizers in heat cured, high strength concrete has gained considerable acceptance in Japan;

(2) concrete having high-early strength to allow quick mold stripping for precast items;

(3) manufacture of precast units, reinforced and prestressed concrete piles; and

(4) production of high-slump concrete at a lower water-cement ratio.

MATERIALS

Cements - The cement used on any project should be an approved cement passing Standard Specifications, but at any one time, should be the same brand and type as when the project begins. Different cements can influence how super water reducers affect workability. On the chemical composition, $C_3A$ content seems to be important, along with the $SO_3$ content. An important factor to take into account is the compatability of the cement with the other materials that are used, particularly the admixtures. This should be checked in pre-trial concrete mixes.

Aggregates - Fine and coarse aggregates should be approved materials passing Standard Specifications, and as in the case of cement, should be compatable with the admixtures, cement and other materials. Pre-trial mixes should be run to check the compatability of materials.

Admixtures - There are four types of super water reducers on the market today, of which there are two principal types, one a naphthalene-sulfonate type and the other a melamine-sulfonate type. Most of these admixtures are supplied in aqueous solution; however, some may be supplied in a powder form. At all times, it is advisable to use the manufacturer's recommended dosage rates or rates as determined in pre-trial mixes. The amount of liquid admixture should be calculated as a part of the total water content of the mix.

Other types of admixtures may be used in conjunction with the super water reducers, such as air-entraining agents or even other conventional water reducers in small dosages to offset the loss of slump with time and give a retarding effect. If an air-entraining agent is used in the mix, this agent should be checked for compatability with the super water reducer and other materials, as determined in a pre-trial mix.

MIX DESIGN AND PROPORTIONING

Experience has shown that superplasticizers must be handled differently than conventional water reducers. Improved workability gained from its use is usually lost within about an hour, therefore the beneficial effects on workability are greatest if the superplasticizer is added after the concrete is mixed and not added with the mix water, as is customary. The ideal place to add the material is at the jobsite. The minimum water content should be approximately 3.8 gal/cwt. cement. Also workability can be restored by a second dose of admixture without harm to the concrete; however the use of addtional admixture is expensive and should be avoided, if possible.

High workability of fluid concrete can be readily achieved by the addition of a superplasticizer, but for such concretes to remain cohesive special attention has to be paid to the overall mix proportioning. Conventional mix proportioning procedures are used to determine the water-cement ratio and mix proportions needed to give a specified strength with a slump of 1 to 3 inches. The proportion of cement, sand and aggregate must then be checked and altered so as to avoid segregation. Increasing the sand content will help this situation when superplasticizers are used.

In structural concrete, particularly bridge decks, if a super water reducer is used in the mix, usually a minimum cement content of 6.5 bags per cubic yard of concrete would be recommended for durability protection, however for minimum strength requirements with the use of super water reducers, the possibility occurs to lower the cement content to 6.0 bags per cubic yard of concrete and still retain the needed strength.

The concrete producer must always have accurate knowledge of aggregate moisture contents when air-entraining agents are used in the mix along with the super water reducer. Due to the wide variability of air contents which may be obtained when these combinations are used in the mixes, the proper dosage rate of the air-entraining agent should also be determined in the pre-trial mixes. Slight adjustments may be necessary over normal air dosage rates.

MIX PROCEDURES

Careful control of porportioning at the batch plant is most essential. On any construction project where the concrete has to be transported over a great distance to the jobsite, the super water reducer should be added at the jobsite, unless the batch plant is at the jobsite, such as in a precast or prestressed plant. There are disadvantages to adding the admixture at the jobsite, in that it is often difficult to ensure complete, uniform mixing of the admixture, and there is more room for error in providing the correct addition. Proper supervision of the concrete at this stage is very important.

When using a high-range water reducer, there will be anywhere from 10 to 30 percent water reduction in the concrete mix, resulting in a low water-cement ratio. Different kinds of high-range water reducers affect the concrete differently. Admixtures of the sulfonated melamine type generally require higher dosages than those of the sulfonated naphthalene type.

Slumps should be measured at the jobsite. Depending on the initial slump, the dosage rate of super water reducer to be added to the mix will vary and this amount should be determined by a trained inspector, and always by the same man during the entire day's run of concrete. The minimum initial slump should be at least 1", preferably 1 to 2 inches at the jobsite before addition of the super water reducer, in order to obtain the best action from the admixture. The slump measured after the addition of the admixture should never exceed 10", preferably not over 8", to avoid segregation of the aggregate and to obtain good plastic qualities of the concrete. If the initial slump is indicative of a satisfactory workability (above 5"), the addition of a super water reducer may not be required, particularly if sufficient strength would be anticipated.

A minimum of 70 revolutions of the mixer (approximately 2 to 3 minutes) is required to gain uniformity of the mix, after the super water reducer is added to the mix. Placement operations should be continuous to avoid problems with screeding and tining. The time from initial batching to placement and screeding should not exceed 30 to 45 minutes. Strike off and screeding should take place not more than 10 to 15 minutes after depositing the concrete on the bridge deck or pavement. Any delay with delivery and/or delay time at the jobsite can have definite impact on the workability of the concrete. Delivery time should be consistent, along with the concrete itself. Oscillating type screeds with vibratory capabilities appear to be necessary for proper placement and consolidation of superplasticized concrete on bridge decks or pavements. Internal vibration is probably not necessary if vibratory screeds are used.

DISPENSING

Usually the high-range water reducing admixture is in a solution. Whenever the admixture is in solution, the amount of solution needs to be calculated as part of the toal mixing water. If the admixture is in powder form, then it could be directly added to the mix and no further calculations need to be made.

The concrete arriving at the jobsite should have a slump variation within the range of 1 to 3 inches, preferably 1 to 2 inches. While it might be possible to obtain flowing concrete by either adding water to increase initial slump, or reducing the admixture dosage to offset high initial slump, it is best to be cautious with concrete made to receive a superplasticizer that arrives with a slump outside of the above limits, unless the high slump is in the range of workability (slump) the project calls for.

Addition of the superplasticizer should occur just before use of the concrete. Having added the admixture the total mix is spun at a maximum speed (minimum of 70 revolutions) for approximately 2 to 3 minutes. Having obtained fluidity, the concrete should be used without delay, since the maximum workability is usually retained for only 30 to 60 minutes after the addition.

As a general rule, if delay should occur after the concrete is fluid, leave the superplasticized concrete undisturbed until it is ready for placing, when a short period of remixing will be needed. It is possible to reinstate lost high workability by adding further amounts of the admixture. However, this is not generally recommended and can induce segregation. One should not wait too long before retempering is attempted.

Superplasticized concrete releases large quantities of air since the fluid state is conducive to rapid air release. However, residual air content figures are normally in the range of 1 to 3 percent.

## HANDLING

As far as can be ascertained, all types of superplasticizers are based on chemicals classed as nonhazardous in terms of flammability, toxicity and corrosion. However, advice on handling these materials and action to be taken in the event of spillage should be sought from the individual manufacturer. Printed labels on the materials should always be read and instructions followed.

## PLASTIC PROPERTIES

Results of research studies with superplasticizers have indicated it takes approximately 1 hour for the concrete to lose its flowability. Each redose of the admixture will produce a reduction in entrained air content of approximately 1 1/2%. Each successive retempering of the concrete will produce less workability and less air content.

Measuring the high workability properties of flowing concrete requires different methods than those normally used. The slump and compacting factor tests are not readily suitable, since they are all at their practical limit. The flow table test or an adaption of it is now quite widely used. Simply stated, the flow table test consists of the radial spread of a truncated cone of concrete being measured after the concrete has been vibrated under standard conditions.

It is relevant that superplasticizers, contrary to normal plasticizers, do not markedly change the surface tension of water and consequently may be used at high dosage levels without adverse air entrainment.

There is limited information available on the setting or stiffening characteristics, but thus far no adverse properties are reported.

## POSSIBLE PROBLEMS

Specific field applications have revealed that concrete properties are particularly sensitive to mix proportioning, cement type and plastic concrete temperature together with the superplasticizer type and dosage rate.

The temperature of the plastic concrete is considered to be the most significant factor contributing to the variability of the results of the use of superplasticizers in portland cement concrete. In Texas, engineers have determined that to get better quality mixes and plastic properties, the plastic concrete temperature should be 75° F. or less. Use of chilled water may be necessary to lower the plastic concrete temperature.

Use of air-entraining agents have caused problems in air-void structure of the concrete affecting durability. Some manufacturers have developed forms of their products that supposedly improve the slump loss with time and the air-void problems that have been determined in research studies and field applications of this type of concrete.

The use of super water reducers in conjunction with smaller dosages of conventional water reducers gives a retarding effect that minimizes the slump loss problems. However, if one uses this approach to this problem, this usage should be checked in a pre-trial mix.

Four areas of difficulties associated with the use of these admixtures in concrete have been:

(1) the loss of workability (slump) with time,
(2) the effect of super water reducer admixtures on the air-void structure of the concrete and the resulting effect on the freeze-thaw durability of the concrete,
(3) the need for high fines content in the concrete mix to reduce bleeding and segregation, and
(4) the wide variability in the plastic properties of the super water reduced concrete.

Superplasticizers are not recommended for long or delayed hauls in ready-mixed trucks.