TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. PRELIMINARY REVIEW COPY	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle THE EFFECTS OF WITHHOLDING MIXING WATER AND RETEMPERING ON PROPERTIES OF CONCRETE		5. Report Date February 1988 6. Performing Organization Code
7. Author(s) Scott M. Anderson and Ramon L. Carrasquillo		8. Performing Organization Report No. Research Report 1117-1
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin Austin, Texas 78712-1075		10. Work Unit No. 11. Contract or Grant No. Research Study 3-5-87-1117
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation; Transportation Planning Division P. O. Box 5051 Austin, Texas 78763-5051		13. Type of Report and Period Covered Interim 14. Sponsoring Agency Code

15. Supplementary Notes

Study conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration. Research Study Title: "Guidelines for Proper Use of Superplasticizers and the Effect of Retempering Practices on Performance and Durability of Concrete"

16. Abstract

The effects of withholding mixing water at initial batching followed by retempering of the mix at the jobsite on the properties of the concrete produced for highway applications was examined in an experimental program. Additionally, the effects of redosage with water above and beyond that called for in the specified mix design was examined. Tests were performed to determine the effects on slump, air content, unit weight, compressive strength, flexural strength, abrasion resistance, and freeze-thaw resistance.

The effects of varying the withholding amount, withholding time, and cement content on the fresh and hardened concrete properties mentioned above were examined. The concrete examined was produced at a ready-mixed concrete facility in order to duplicate as closely as possible job-site conditions arising in typical concrete construction.

The results of the study show that significant detrimental effects occur when mixing water is withheld and concrete is retempered at a later time. Slump, air content, abrasion resistance, and freeze-thaw resistance are all adversely affected. The effects were found to vary with variations in both withholding time and cement content. The strength was not affected when water was withheld and concrete was retempered, but a reduction in strength accompanied an increase in water-cement ratio above design values at redosage. The properties changed lead to concrete of reduced quality and questionable performance.

17. Key Words superplasticizers, retempering, withholding, concrete, redosage, slump, air content, abrasion resistance, freeze-thaw resistance, variation	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	128	

Form DOT F 1700.7 (8-69)

THE EFFECTS OF WITHHOLDING MIXING WATER AND RETEMPERING ON PROPERTIES OF CONCRETE

by

Scott M. Anderson
and
Ramon L. Carrasquillo

Research Report Number 1117-1

Research Project 3-5-87-1117

"Guidelines for Proper Use of Superplasticizers and the Effect of Retempering Practices on Performance and Durability of Concrete."

Conducted for

Texas
State Department of Highways and Public Transportation

In Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

by

CENTER FOR TRANSPORTATION RESEARCH
BUREAU OF ENGINEERING RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

February 1988

PREFACE

Retempering of concrete with water to restore lost workability is a common construction practice which has been questioned although practiced for many years. Similarly, the practice of batching on the dry side by withholding some mixing water at initial batching followed with later addition at the jobsite of the mixing water withheld has been a common practice in concrete construction during hot weather. This report evaluates the effects on concrete of both withholding mixing water at initial batching followed with later addition of the withheld mixing water and redosage of the concrete with water in excess of that called for in the mix design.

This work is part of Research Project 3-5-87-1117, entitled, "Guidelines for Proper Use of Superplasticizers and the Effect of Retempering Practices on Performance and Durability of Concrete." This study is being sponsored jointly by the Texas State Department of Highways and Public Transportation and the Federal Highway Administration and conducted by the Center for Transportation Research at the University of Texas at Austin.

The overall study was directed and supervised by Dr. Ramon L. Carrasquillo

SUMMARY

The effects of withholding mixing water at initial batching followed by retempering of the mix at the jobsite on the properties of the concrete produced for highway applications was examined in an experimental program. Additionally the effects of redosage with water above and beyond that called for in the specified mix design was examined. Tests were performed to determine the effects on slump, air content, unit weight, compressive strength, flexural strength, abrasion resistance, and freeze-thaw resistance.

The effects of varying the withholding amount, withholding time, and cement content on the fresh and hardened concrete properties mentioned above were examined. The concrete examined was produced at a ready-mixed concrete facility in order to duplicate as closely as possible job-site conditions arising in typical concrete construction.

The results of the study show that significant detrimental effects occur when mixing water is withheld and concrete is retempered at a later time. Slump, air content, abrasion resistance, and freeze-thaw resistance are all adversely affected. The effects were found to vary with variations in both withholding time and cement content. The strength was not affected when water was withheld and concrete was retempered, but a reduction in strength accompanied an increase in water-cement ratio above design values at redosage. The properties changed lead to concrete of reduced quality and questionable performance.

IMPLEMENTATION

This report summarizes the findings of an experimental investigation of the effects on concrete of withholding mixing water at initial batch followed with later addition of the withheld water and then redosage of the concrete with water above that called for in the mix design. Specific recommendations for the resident engineer are presented to ensure production of sound, durable concrete.

This study shows that significant detrimental effects occur when mixing water is withheld and concrete is retempered at a later time. Slump, air content, abrasion resistance, and freeze-thaw resistance could all be adversely affected. The strength was not affected, provided design water-cement ratios remained similar upon retempering. Further, no benefits in terms of workability of the concrete at time of placing was observed by withholding of mixing water. As a result, it is recommended that the practice of withholding of mixing water be discontinued for it only contributes to the increased potential of accepting and placing lower quality concrete in Texas highways. In addition, it is strongly recommended that field personnel be clearly informed of the TSDHPT policy regarding addition of water to concrete at the jobsite in order to ensure consistency in the implementation of any guidelines.

TABLE OF CONTENTS

Chapter

LIST OF TABLES

LIST OF FIGURES

Figure

CHAPTER 1

INTRODUCTION

1.1 General

An overview of the research program undertaken is presented in this chapter. A problem definition, the objective of the research, and the research plan are described to facilitate understanding of the work done. Finally the format of the report is outlined.

1.2 Definition of Terms

Clarification of the terms "withholding", "retempering" and redosage must be accomplished at the outset of this report. The "withholding of mixing water" indicates a reduction of the mixing water added at initial batching from that specified in the approved mix design. In the work done for this study, this amounted to five or ten percent less water than the theoretical design amount required at batching. This withheld mixing water was later added to the concrete mix to simulate addition at a jobsite to restore workability. "Retempering", as used in this report indicates addition of mixing water to concrete at a later time after initial batching of the mix. Specifically for tests undertaken in this study, the retempering water corresponded to the water that was withheld at initial batching. "Redosage" of the concrete refers to retempering with water beyond that used to reach the original design water-cement ratio of the mix. In other words, redosage refers to water added in excess of the withheld water.

1.3 Justification of Research

Retempering of concrete with water to restore workability lost is a common construction practice which has been questioned although practiced for many years. Similarly, the practice of batching on the dry side by withholding some of the mixing water at initial batching followed with later addition at the jobsite of the mixing water withheld is sometimes desirable and has been a common practice in concrete construction during hot weather. [4, 13] Both these practices have effects on the fresh properties, strength, and durability of the concrete produced.

The use of these practices is most prevalent in hot weather concreting. Many problems arise in hot weather concreting; increased concrete temperatures, loss of workability, and decreased setting times are just a few. All these problems lead to the desire to retemper the concrete to restore its workability at placing.

The integrity and quality of the retempered concrete produced has been questioned by engineers for many years. The workability, strength, permeability, and durability of the concrete are all affected. The research undertaken examines the extent to which these parameters are affected.

1.4 Research Objectives

The main objective of this study is to provide the resident engineer with guidelines for retempering practices for concrete used in highway applications. These recommendations are meant to supplement presently used guidelines and specifications for the placement of concrete. The research presented is intended to address the most commonly observed properties of concrete which determine its quality, including fresh and hardened states.

1.5 Overview of Testing Program

The research program undertaken in this study examined the effect of retempering on the quality of concrete produced during hot weather. Retempering as defined here is the withholding of some mixing water at initial batching of the concrete followed by the addition of this withheld mixing water at the jobsite. Three major variables were examined:

(1) amount of water withheld and later added;

(2) length of time water was withheld; and

(3) cement content of the mix.

In addition to the effect of retempering, the effect of redosage with water above and beyond the design water-cement ratio required was examined. This redosage attempts to simulate conditions on a jobsite where workability is reduced as a result of extended delays in placing of the concrete.

Properties of the concrete examined include slump, air content, compressive strength, flexural strength, abrasion resistance, and freeze-thaw resistance. These properties are used to measure the three main requirements expected of quality concrete: workability, strength, and durability. Additionally, the resistance of the retempered concrete to scaling and deicing chemicals will be the subject of a later report.

1.6 Format of Report

A review of the literature pertaining to hot weather and retempering concrete is given in Chapter 2. A description of the testing procedures and materials used in the experimental program is given in Chapter 3. Chapters 4 and 5 present and discuss the experimental test results in tabular and graphical form. Finally, a summary, conclusions, and recommendations are given in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A review of the literature concerning the effects on concrete of hot weather, withholding mixing water, and retempering is undertaken in this chapter. The review contained herein is restricted to literature relevant to the variables examined in this study. The results of this previous research will be incorporated wherever possible to support facts and conclusions obtained in the study undertaken.

2.2 Retempering Practices and Allowances

Retempering of concrete with water to restore workability lost is a common construction practice which has been questioned although practiced for many years. Similarly, the practice of batching on the dry side by withholding some of the mixing water with later addition of water at the jobsite is sometimes desirable and has been used in concrete construction during hot weather. [4, 13]

Currently, the American Concrete Institute (ACI) allows one addition of water at the jobsite to bring the plastic concrete to the specified slump so long as the maximum design water-cement ratio is not exceeded. The ACI recommends that later additions, and additions resulting in a water-cement ratio greater than the design amount, be prohibited. [3, 4]

The American Society for Testing and Materials "Standard Specification for Ready-Mixed Concrete" (ASTM C 94-86) also allows one retempering so long as the maximum design water-cement ratio is not exceeded. ASTM C 94-86 additionally sets limits on the minimum slump allowable at arrival of a ready-mixed concrete truck at a jobsite. Compensation for slump loss is limited to one to two inches. [8]

The Portland Cement Association recommends that small dosages of retempering water below the design water-cement ratio be allowed. They further stipulate however, that the additions should not exceed that necessary to compensate for one inch loss in slump. [23]

The Texas State Department of Highways and Public Transportation (Texas SDHPT) Standard Specification For Construction

<u>of Highways, Streets, and Bridges</u> limits the maximum water-cement ratio for concrete at the time of placing for a specified class of concrete. The Texas SDHPT also limits the number of revolutions at mixing speed for a ready-mixed concrete truck. Withholding of water and retempering are allowed so long as these criteria are not violated. Often, the design amount of mixing water in a mix may be lower than that required to reach the maximum permissible water-cement ratio allowed in the specification for a given class of concrete. Therefore, retempering this mix, while not exceeding the allowable water-cement ratio as per the specifications, may lead to the possible addition of water above and beyond that specified in the approved mix design proportions for the job. The concrete produced is required to be mixed 50 revolutions at initial batching and 25 revolutions at mixing speed for each further addition of water. Therefore, at most two additions of retempering water are allowed. [38]

2.3 <u>Slump</u>

The workability or measure of placeability of a portland cement concrete mix is usually determined by the slump. Many variables affect the slump of a concrete mix, including size and shape of coarse or fine aggregate, mix proportions, cement composition, duration and rate of mixing, length of haul, ambient conditions, concrete temperature, and use of admixtures. [5, 6, 9, 27, 29] Each of these variables can lead to an increased water demand and a corresponding slump loss of the fresh concrete with time after batching.

2.3.1 <u>Effect of Hot Weather</u>. In hot weather concreting, there is an increased water demand with time after batching for a concrete mix to maintain the same workability as that of a mix with a lower temperature. This is due to the combined effects of evaporation and accelerated hydration resulting in a lower water-cement ratio and reduced amount of free mixing water with time at elevated temperatures. Therefore, additional water must be added to higher temperature concrete mixes to maintain the same slump as mixes with a lower temperature, or a lower slump concrete will occur for the same water-cement ratio. [1, 5] Figure 2.1 and Figure 2.2 illustrate the effect of a rise in temperature from 40 degrees Fahrenheit to 120 degrees Fahrenheit. Figure 2.2 shows that a change in temperature from 70 degrees Fahrenheit to 100 degree Fahrenheit leads to an additional water demand of 18 pounds of water per cubic yard of concrete to maintain a slump of 3 inches or (Fig. 2.1) a decrease in slump of 1.25 inches will be experienced for the identical water content in concrete containing 1.5 inch maximum size coarse aggregate. The additional water demand amounts to over two gallons of water per

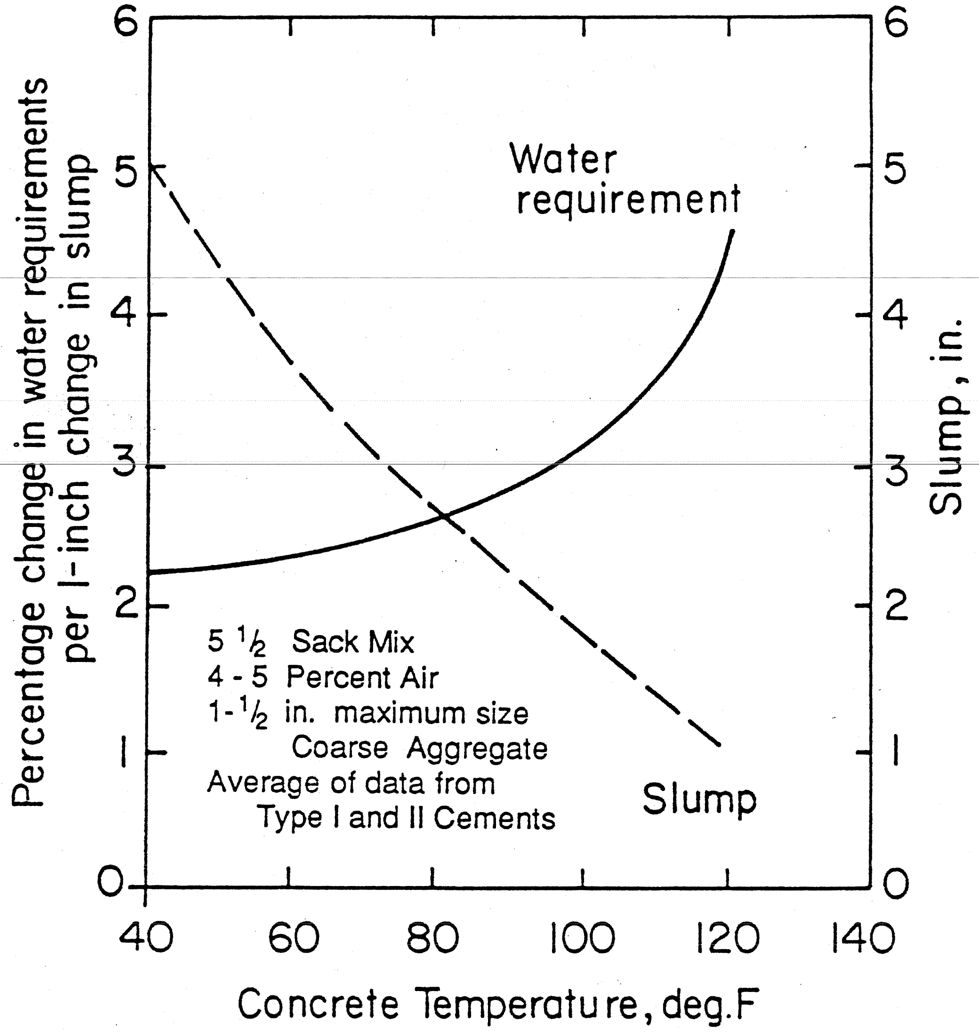

Figure 2.1 The effect of concrete temperature on the slump and water requirement to change the slump of concrete. [16]

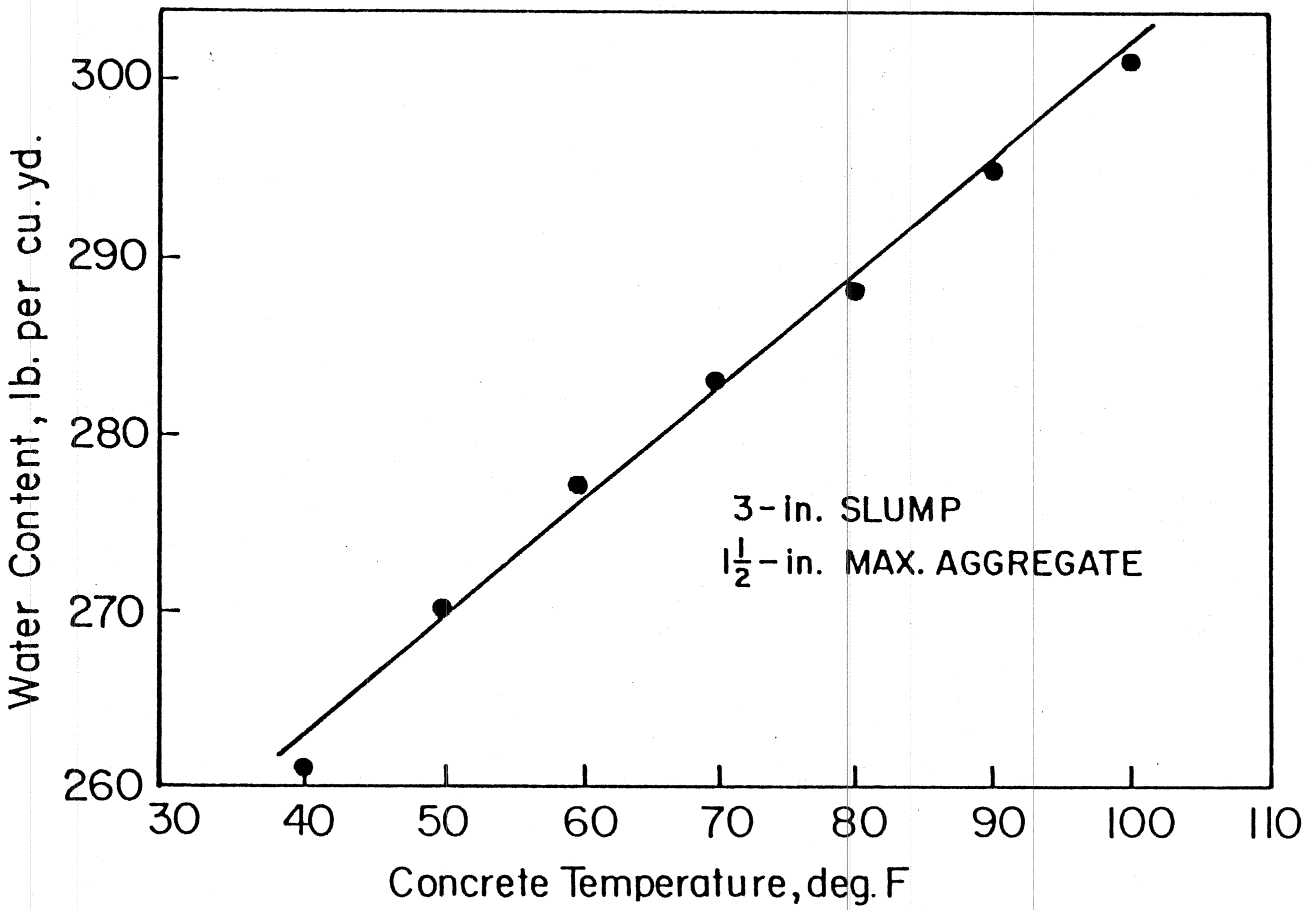

Figure 2.2 The water requirement of a concrete mix versus increasing temperature. [24]

cubic yard, which can have a significant effect on the strength of the concrete due to the increased water-cement ratio.

2.3.2 Slump Loss and Retempering. Slump loss of concrete is a normal process which is accelerated by a number of conditions. Increased temperatures of the concrete and air, along with lower relative humidities, all lead to greater rates of evaporation and greater slump losses. [4, 5, 27] Previous studies have shown that prolonged mixing and agitation tend to reduce slump even when the mixer is covered and evaporation is prevented. [9, 11, 18, 27] Additionally, Gonnerman and Woodworth showed that concrete kept standing (not agitated) for extended periods of time showed losses of slump as the standing time increased. [12]

Part of the mechanism of slump loss may be explained by the rate of setting in the concrete. As the temperature of a concrete mix increases, the time of setting decreases, as the hydration reaction proceeds more quickly. This is most noticeable when the concrete temperature approaches 95 degrees Fahrenheit, due to a decrease in the activation energy required in the hydration process from 8.45 kcal per mol to 5.70 kcal per mol. [31] This decrease makes the hydration reaction proceed more quickly and with greater ease.

Slump loss has been found to vary with the initial slump level. [27, 28, 29] The higher the initial slump the greater the rate of slump loss. Additionally, Ramakrishnan, Coyle, and Pande found that the rate of slump loss for retempered concrete was greater than that of concrete not retempered. [28] Ravindrarajah and Tam supported this conclusion and found additionally that the rate of slump loss increases as the number of retemperings increase. [30] Conventional water-reducing, set-retarding admixtures did not have a significant effect in reducing slump loss in the study done by Previte. [27] This is because these admixtures affect the concrete by extending the dormant period. Slump loss occurs during the period of rapid initial reactions which are not affected by conventional water-reducing, set-retarding admixtures. These admixtures do however result in a decrease in total mixing water upon retempering. [27, 29] The study by Ramakrishnan, Coyle, and Pande indicated that despite the higher rate of slump loss accompanying higher initial slumps, the total time span during which the concrete remains workable is greater for higher initial slumps. [28]

2.4 Air-Entrainment

Use of air-entrained concrete is recommended whenever the concrete will be exposed to freezing and thawing, deicing salts or potentially damaging environments. [2, 3, 6, 23] Many benefits arise from the use of entrained air in concrete; improved workability, improved cohesiveness and consistency, reduction in bleeding, decreased permeability, and improved durability being some. A detrimental effect is a decrease in strength associated with the use of entrained air. A compressive strength loss of approximately three to five percent occurs for every one percent entrained air. Figure 2.3 shows a typical relationship between strength and air content of concrete. The improved workability, and most important, needed durability, dictate the use of entrained air for most highway applications.

2.4.1 <u>Air-Void System</u>. Air-entrainment is accomplished through the use of air-entraining agents (AEA). These AEA consist of molecules with a hydrophobic end and a hydrophilic end as shown in Figure 2.4 (a). When mixed with water, these AEA molecules orient themselves to create perfect spheres with an air pocket inside as shown in Figure 2.4 (b). The spheres, which are locked into the cement paste when the concrete hardens, act as millions of tiny ball bearings to improve the workability while the concrete is plastic. Once the concrete has hardened, they provide an escape hatch to which free moisture may migrate and alleviate pressures built up during freezing. [25] These discrete cavities in the cement paste create barriers which help eliminate bleed channels in the plastic concrete and reduce the permeability of the concrete in the hardened state. [22]

Properly air-entrained concrete contains millions of tiny air bubbles ranging in size from 0.05 millimeters to 1.25 millimeters uniformly distributed throughout the cement paste. These discrete cavities create an air-void system. An adequate air-void system may be characterized by the following parameters;

1. a calculated bubble spacing factor of less than 0.008 inches;

2. a specific surface of 600 square inches per cubic inch of air void volume;

3. a number of air voids per linear inch of traverse equal to 1.5 to 2.0 times the air content in percent. [23]

Concrete which has these characteristics will generally show good resistance to freezing and thawing along with a good resistance to scaling and deicing chemicals.

2.4.2 <u>Factors Affecting Air-Entrainment</u>. Many factors affect the amount of air-entrainment accomplished by the addition of an air-entraining agent. Aggregate size and gradation, cement composition, temperature, mixing and agitation, and slump are just a

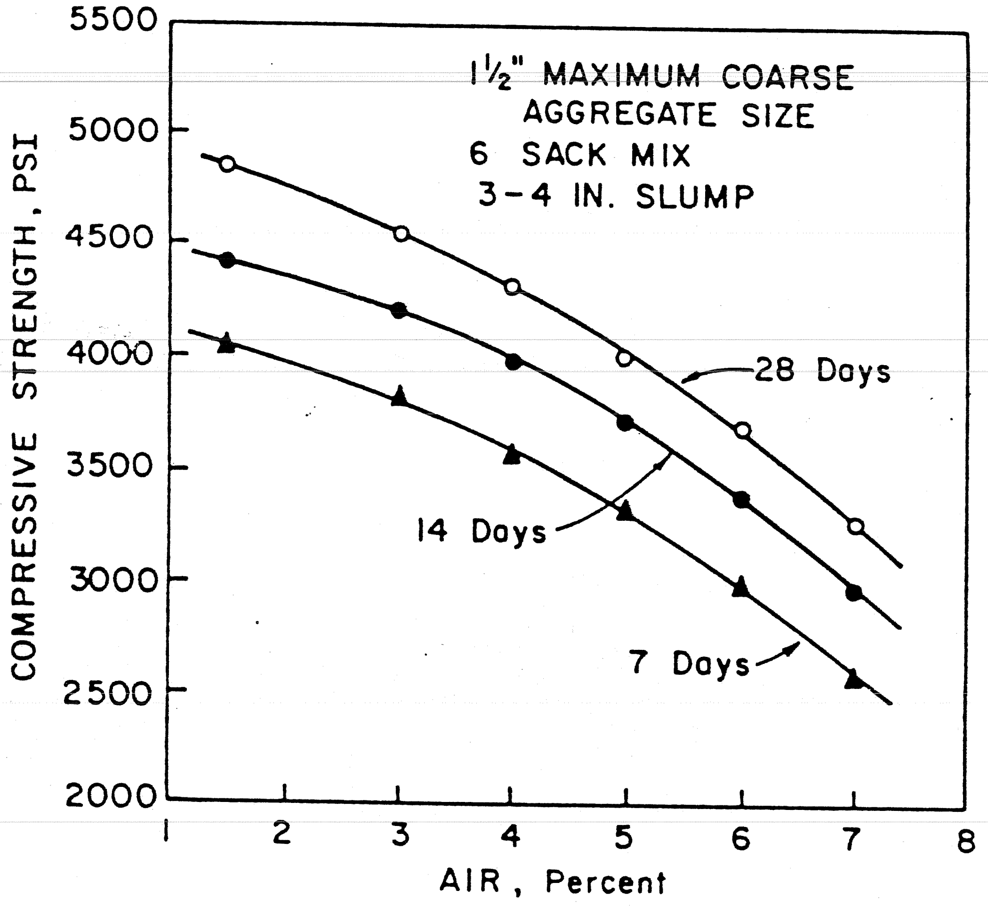

Figure 2.3 Typical relationship between strength and air content of concrete. [40]

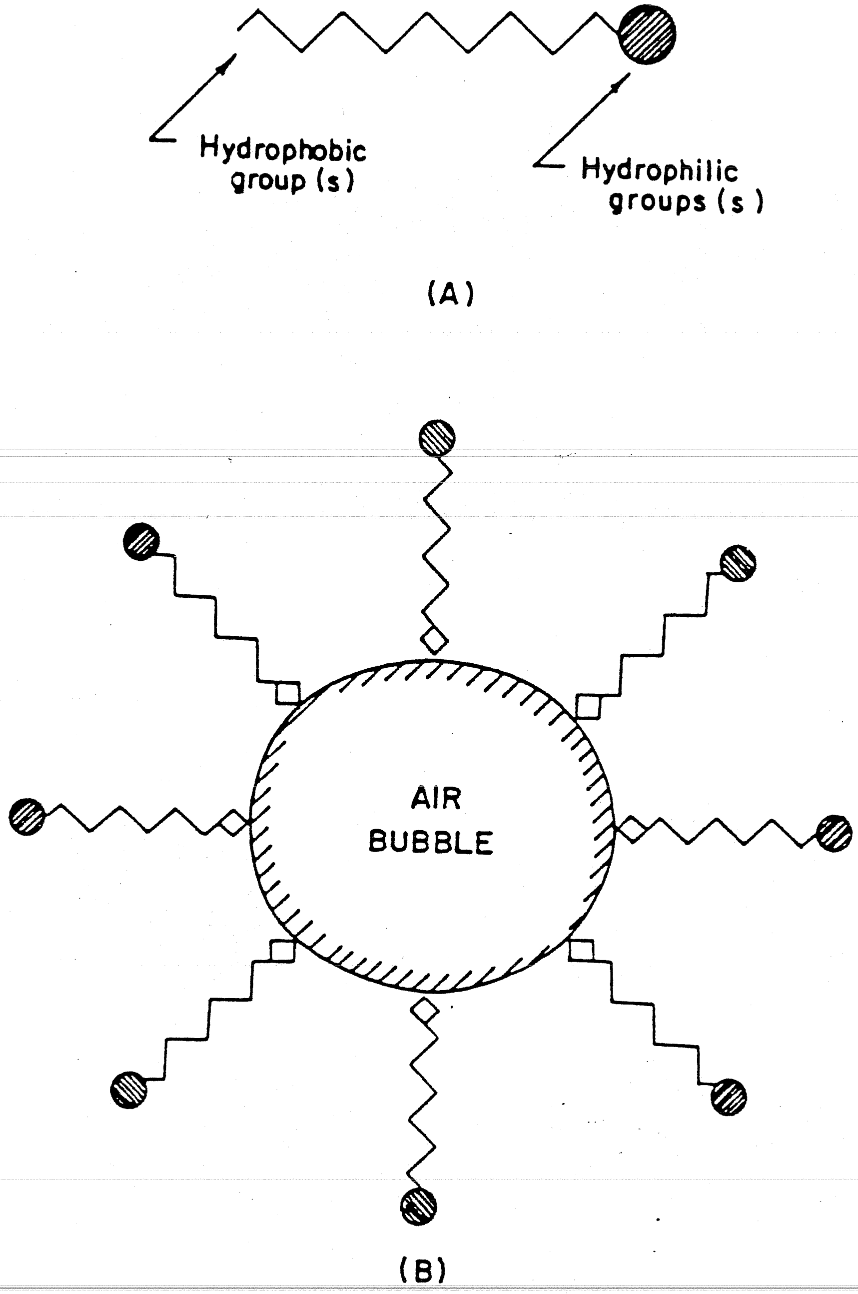

Figure 2.4 The mechanism of air-entraining agents. [21]

few of these factors. Literature concerning effects of parameters directly related to this research program will now be presented.

2.4.2.1 Effect of Temperature. Difficulties in controlling entrained air arise as concrete temperatures increase. [5] Part of this is due to the change in water demand in a mix as the temperature increases. The effective free mixing water decreases as the concrete temperature increases, resulting in a lower slump and reducing the ability of an AEA to effectively entrain air. Slump and air content are interdependent and a decrease in one will result in a decrease in the other for a given dosage rate of AEA. A second part of loss of entrained air is due to the decrease in the effectiveness of the AEA due to increased temperatures. [23] Figure 2.5 shows that for a given dosage of AEA, a reduction in air content occurs as the temperature of the concrete increases even when the initial slump is maintained constant.

2.4.2.2 Effect of Mixing Time. The efficiency of an AEA to create a proper air-void system is also affected by the mixing process. Too little mixing or prolonged mixing will reduce the effectiveness of the AEA. [23] Extended agitation similarly results in a loss of entrained air. [5, 18] Burg found that air content decreased approximately 1.7 percent for a period of agitation ranging from 20 to 45 minutes. [10] Langan and Ward had previously reported similar results with a loss of 2.0 percent in air content for a period of agitation of about 42 minutes. [18] This loss of air can be in part explained through the loss of slump accompanying prolonged agitation. Figure 2.6 shows that for an initial slump of four inches, agitation resulted in a reduction in the air content with time. Contrary to this, for high initial slump mixtures having a nine inch slump, agitation increased the air content with time. This can be attributed to an increase in the cohesiveness of the fresh concrete for the lower initial slump mixtures rendering agitation less effective in entraining air in concrete.

2.4.2.3 Effect of Retempering. Conflicting results have been reported as to the effect of retempering on air-entrainment in concrete. Langan and Ward reported an increase in total air content of about 0.35 percent upon retempering with nine percent of the total mixing water. [18] Burg reported an increase of about 0.6 percent total air content upon retempering with 5 to 15 pounds of water per cubic yard of concrete, equivalent to about 1.8 to 5.5 percent of the design mixing water. Microscopic analysis additionally indicated that the spacing factor decreased and the specific surface increased, both indications of a better air-void system upon retempering. [10]

More recently, Smutzer and Zander found a decrease in air content of 0.6 percent on average for an addition of five percent of

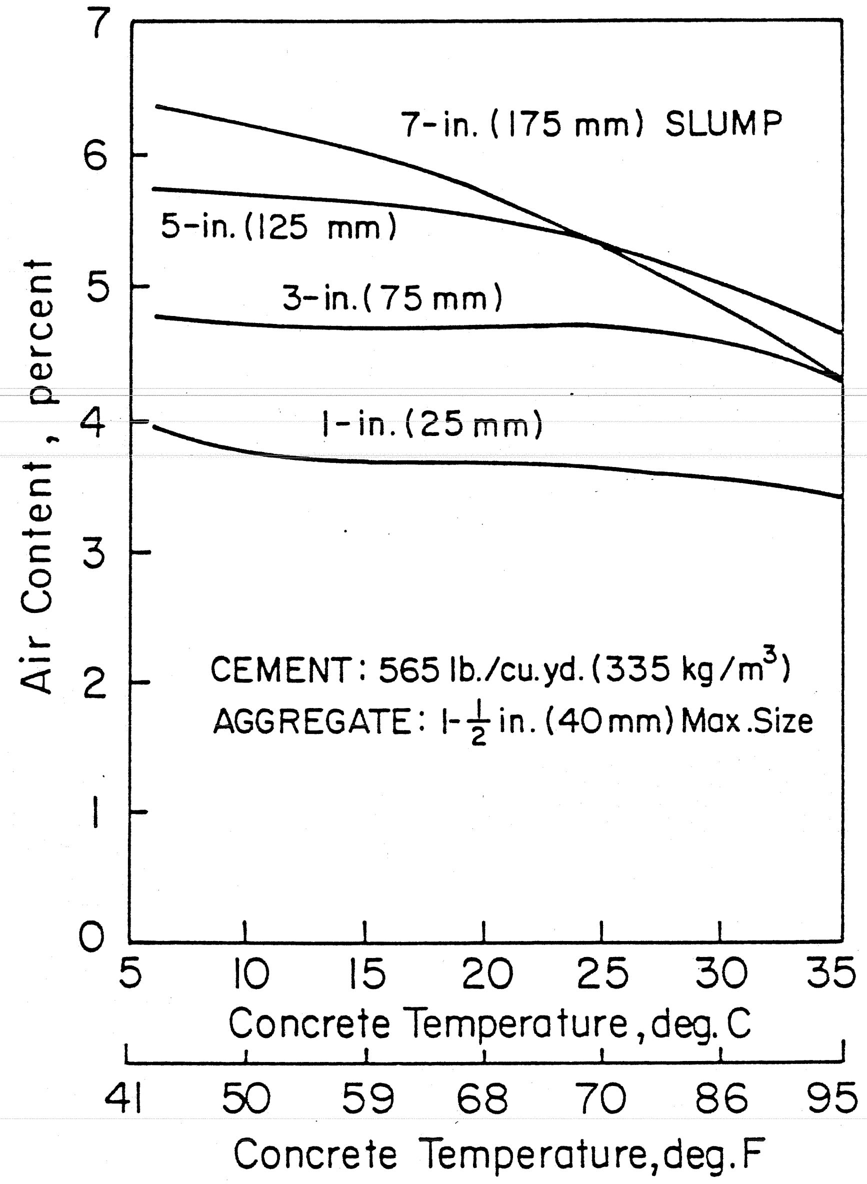

Figure 2.5 The relationship between temperature, slump, and air content of concrete. [23]

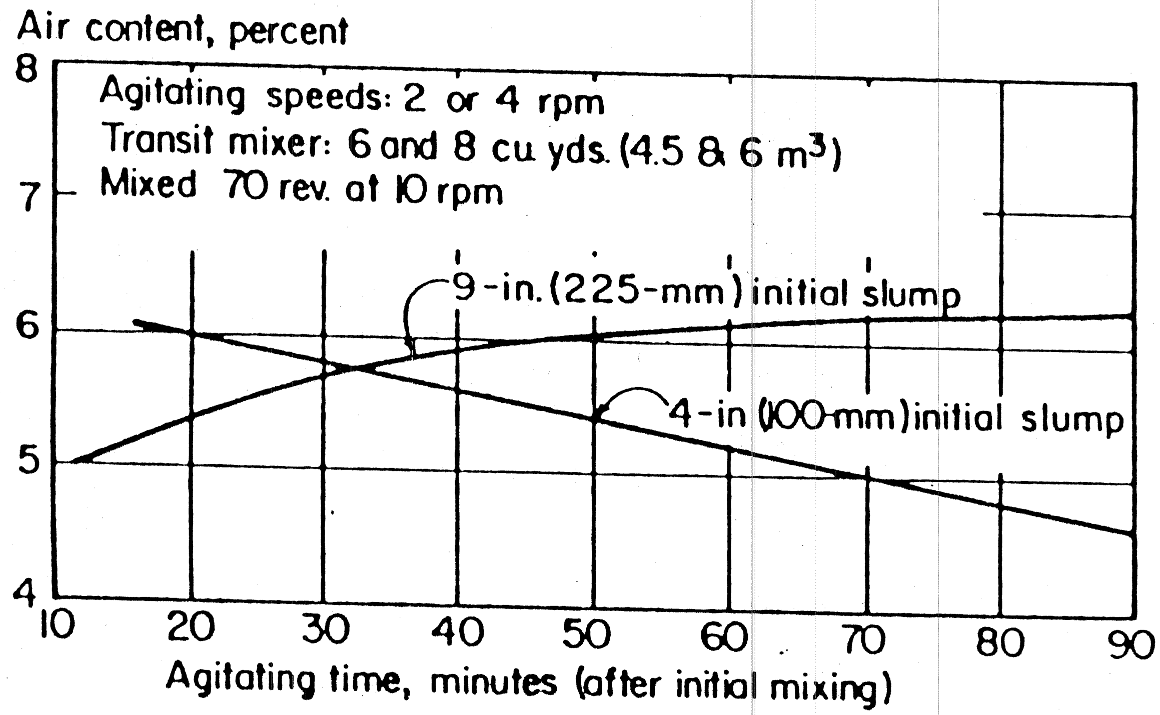

Figure 2.6 The relationship between agitating time, air content, and slump of concrete. [23]

the design water. Also, for three of the four batches examined, an increase in the spacing factor and a decrease in the specific surface accompanied retempering, giving an indication that the air-void system was not as good after retempering as before retempering. [34]

2.5 Concrete Strength

Compressive and flexural strength are the most commonly used parameters for determining the effects of hot weather and retempering upon the hardened properties of concrete. Most of the literature examined uses strength as the principal parameter for the evaluation of the quality of retempered concrete.

2.5.1 Effect of Hot Weather. The effect of hot weather on the strength of concrete is manifested through the increased water demand accompanying higher temperatures for a given slump concrete. The increased water demand leads to a higher water-cement ratio and a lower compressive strength. [1, 5, 20] ACI Committee 304 suggests that at approximately 85 degrees Fahrenheit the rate of decrease in strength becomes significant. [5] Besides the increased water demand, no detrimental effects occur from hot weather on the plastic concrete provided it remains placeable.

Once the concrete is placed, continued high temperatures additionally affect the strength. Curing of the placed concrete at elevated temperatures will tend to result in a higher early strength, but lower strengths at later ages as compared with concrete cured at normal temperatures. [5] Abassi additionally indicates that the flexural strength of concrete is more adversely affected by elevated temperatures than compressive strength. [1]

2.5.2 Effect of Retempering. Of the literature examined which addresses retempering of concrete with water, most references indicate a loss of strength upon retempering. Gonnerman and Woodworth reported that the final water-cement ratio is the only factor affecting the strength of concrete that has been retempered. [12] They found that concrete exposed to air and retempered to its original workability after mixing for some time showed about the same strength as concrete stored in air-tight containers allowing no evaporation of the mixing water.

More recently, others have reported similar results indicating that the final water-cement ratio is the governing factor controlling the strength of retempered concrete. [9, 13, 30] Hawkins found that retempering reduced the compressive strength, but not as much as would be predicted by the final water-cement ratio. This was observed despite the fact that the concrete mixer was stopped and covered during periods between retempering. [13] Cook had shown similar results previously. He found that reductions in strength due to retempering were about one-half that which would have been predicted from the water-cement ratio. Cook attributed this to loss of water through evaporation. [11]

Ravina indicated the beneficial effect of using water reducing admixtures on the strength of retempered concretes. The use of a water reducing admixture decreases the amount of total mixing water after retempering leading to a lower final water- cement ratio and a higher strength as compared to concrete having the same slump but containing no water reducing admixtures. [29]

Ramakrishnan, Coyle, and Pande found that retempering with water had no adverse effects on the strength, and that the strength remained approximately the same as the concrete before retempering. [28] However, their study did not include a measurement of the air content after retempering, which could explain their consistent strength. If the concrete lost some entrained air upon retempering, a gain in strength approximately equal to the loss accompanying the higher water-cement ratio after retempering could account for the similar strengths.

2.5.3 Effect of Mixing Time. Extending the mixing time of concrete tends to increase the concrete strength. [9, 11, 12, 18, 28, 30] This mainly occurs due to the loss of water through evaporation and absorption by the aggregates, reducing the effective water-cement ratio. Additionally, loss of air is encountered in air-entrained concretes. In all the literature examined, including both air-entrained and non-air-entrained concretes, extending the mixing time resulted in an increase in concrete strength so long as the plastic concrete remained placeable. This extension of mixing time provided up to a 25 percent increase in strength for mixes in a study done by Ravindrarajah and Tam in which non-air-entrained concrete was used. [30] An increase due to prolonged mixing after retempering shows the same characteristics of gain in strength as concrete which has not been retempered.

2.6 Abrasion Resistance

The abrasion resistance of concrete is mainly governed by compressive strength and aggregate hardness. [21, 23] Other factors which tend to increase the abrasion resistance include proper curing, proper troweling of the surface, vacuum dewatering of the surface, and proper mix design.

Kettle and Sadegzadeh examined the influence of curing and finishing on the abrasion resistance of concrete. [15] They found that an increase in abrasion resistance resulted from efficient and proper curing as well as increased applications of troweling of the surface. Both techniques tended to increase the quality of the surface matrix. In addition, for the same curing and finishing techniques, a reduction in water-cement ratio increased the abrasion resistance of concrete. Figure 2.7 shows the influence of water-cement ratio on the abrasion resistance of concrete. Senbetta and Malchow concluded that proper curing increased the abrasion resistance. They reported an increase of up to 50 percent in abrasion resistance for moist cured specimens as opposed to air cured specimens. [32]

Kennedy reported on the influence of air content upon the abrasion resistance of concrete. He found that increases in air content led to a decrease in abrasion resistance. This decrease in resistance was slight for air contents up to six percent but became much more pronounced at air contents above six to ten percent. [14] In his paper however, he shows no correlation between concrete strengths and air content. The loss of abrasion resistance with increased air content could very well be attributed to the loss of compressive strength accompanying increased air content for a given mix.

Witte and Backstrom reported that strength is the most significant factor governing abrasion resistance of concrete. A lower water-cement ratio, lower slump, higher cement content, proper curing, and vacuum dewatering only increase abrasion resistance in so far as they increase the compressive strength of the concrete. [41] They showed that for a given water-cement ratio an increase in the air content resulted in a decrease in the abrasion resistance. Similarly for a given air content, an increase in the water-cement ratio leads to a decrease in the abrasion resistance. Based on these results they determined an air plus water to cement ratio (by volume), ie, voids to cement ratio, and related this to strength and abrasion resistance. Figure 2.8 and 2.9 show the relationship of the compressive strength and abrasion resistance to the voids-cement ratio for the specimens they tested. These plots clearly indicate that the compressive strength is the governing factor in the abrasion resistance of concrete.

2.7 Freeze-Thaw Resistance

The resistance of concrete to freezing and thawing is dependent upon the air-void system present and the properties of the aggregate. [17, 19, 21, 22, 25, 35, 36] Concrete made with culled, sound aggregates can be made resistant to freezing and thawing by the addition of entrained air for ordinary cement contents and water-

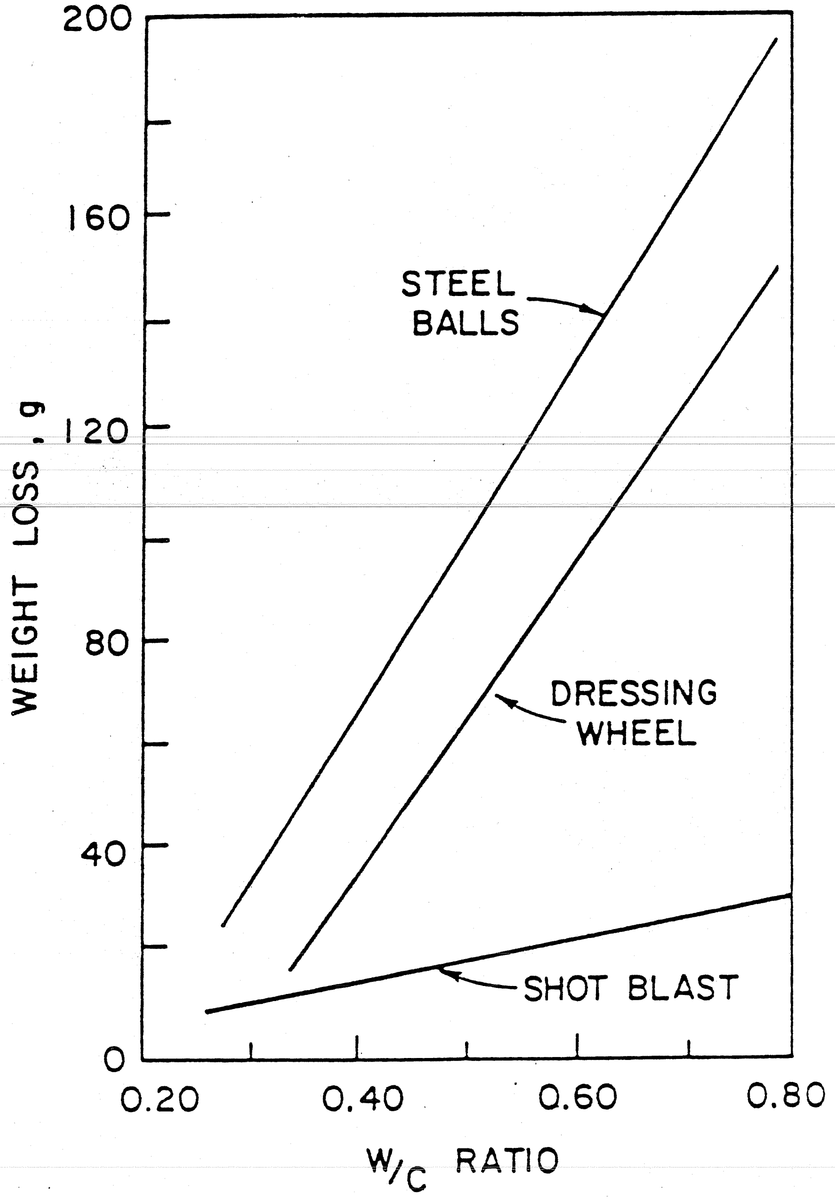

Figure 2.7 Influence of water-cement ratio on the abrasion resistance of concrete. [33]

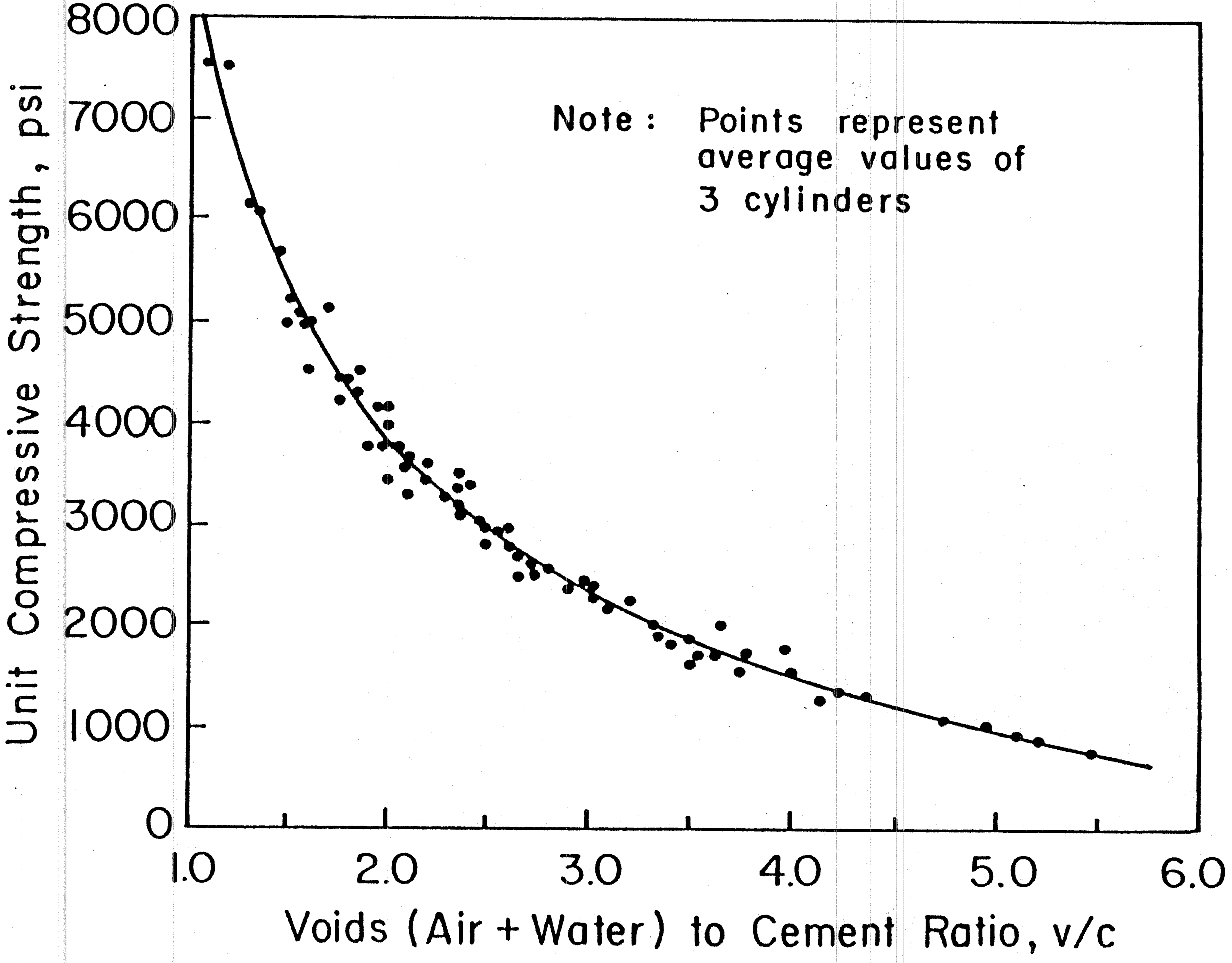

Figure 2.8 Influence of voids-cement ratio on the compressive strength of concrete. [41]

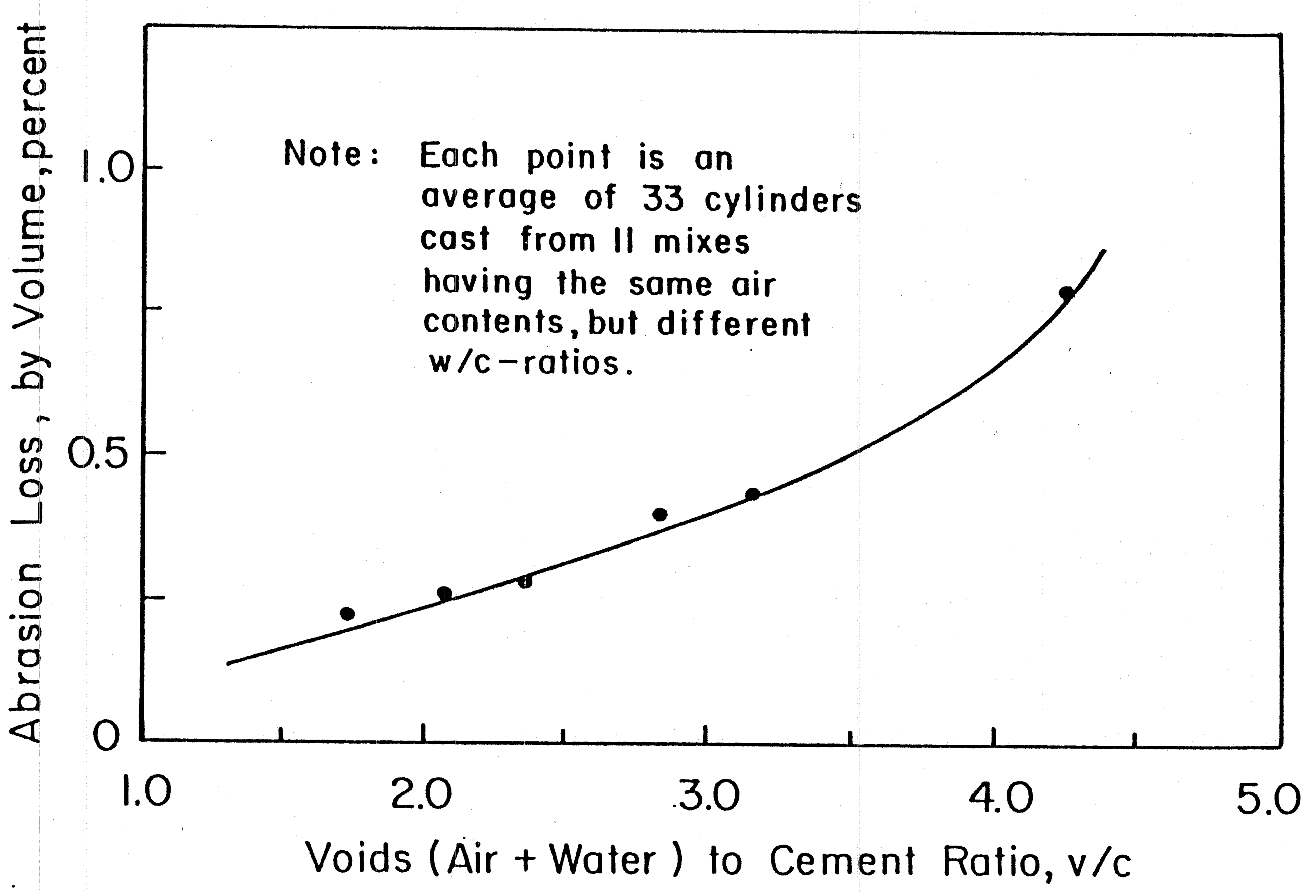

Figure 2.9 Influence of voids-cement ratio on the abrasion resistance of concrete. [41]

cement ratios. Figure 2.10 illustrates the effect of entrained air on concrete. Concrete made with entrained air can show freeze-thaw durabilities ten times that of non air-entrained concrete.

Powers showed that the mechanism of damage due to freezing and thawing in cement pastes is the movement of unfrozen water to freezing sites. [26] When a capillary cavity is full of solution and ice, osmotic pressure is generated. Entrained air bubbles in the cement paste prevent the development of osmotic pressure by competing for the movement of the free water to these capillary cavities. Elimination of almost all osmotic pressure can therefore be achieved if the air bubbles are maintained close enough and water is able to migrate to these cavities. [25] Figure 2.11 illustrates the concept of the migration of free water to air-voids during freezing.

Increasing the strength of a mix will also improve the freeze-thaw durability. This can be accomplished by increasing the cement content or lowering the water-cement ratio. Figure 2.12 shows that for a higher cement content, less entrained air is required to achieve the same durability when durability is measured by linear expansion of the specimen after 300 freeze- thaw cycles. Lowering the water-cement ratio gives similar results. Figure 2.13 shows that the number of cycles to cause 25 percent reduction in weight is increased when the water-cement ratio of air-entrained concrete is lowered. The increased durability in both cases can be accounted for by the increase in strength and lower permeability accompanying the increase in cement content or the lowering of the water-cement ratio.

Sound aggregate must also be used to produce freeze-thaw durable concrete. If unsound aggregate is used, increasing the cement content, air content, and decreasing the water-cement ratio will not prevent destruction of the concrete by frost action. [35, 36]

2.7.1 <u>Effect of Retempering</u>. The freeze-thaw durability of concrete that has been retempered has been shown to be about the same as concrete which has not been retempered so long as adequate entrained air remains. Hawkins showed that concrete retempered showed similar durability to that of the concrete before retempering for periods of up to four hours of mixing. [13] In this study, the air content of the mixes remained above 4.5 percent after retempering. Beyond four hours, loss of entrained air occurred and the durability was reduced.

Smutzer and Zander also found that the freeze-thaw durability of retempered concrete was about the same as concrete before retempering. [34] The air contents were 4.25 percent or greater after retempering.

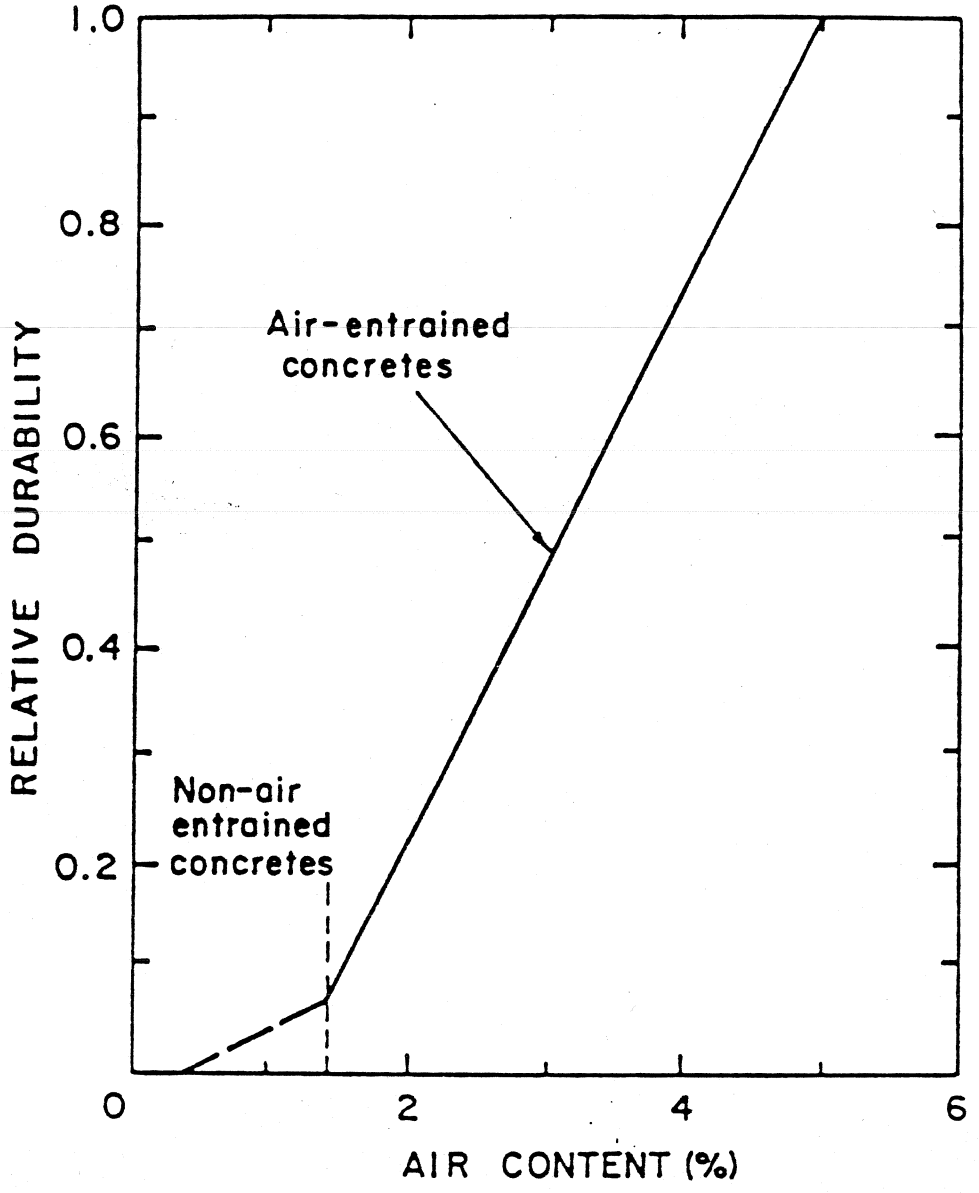

Figure 2.10 Durability of air-entrained concrete. [21]

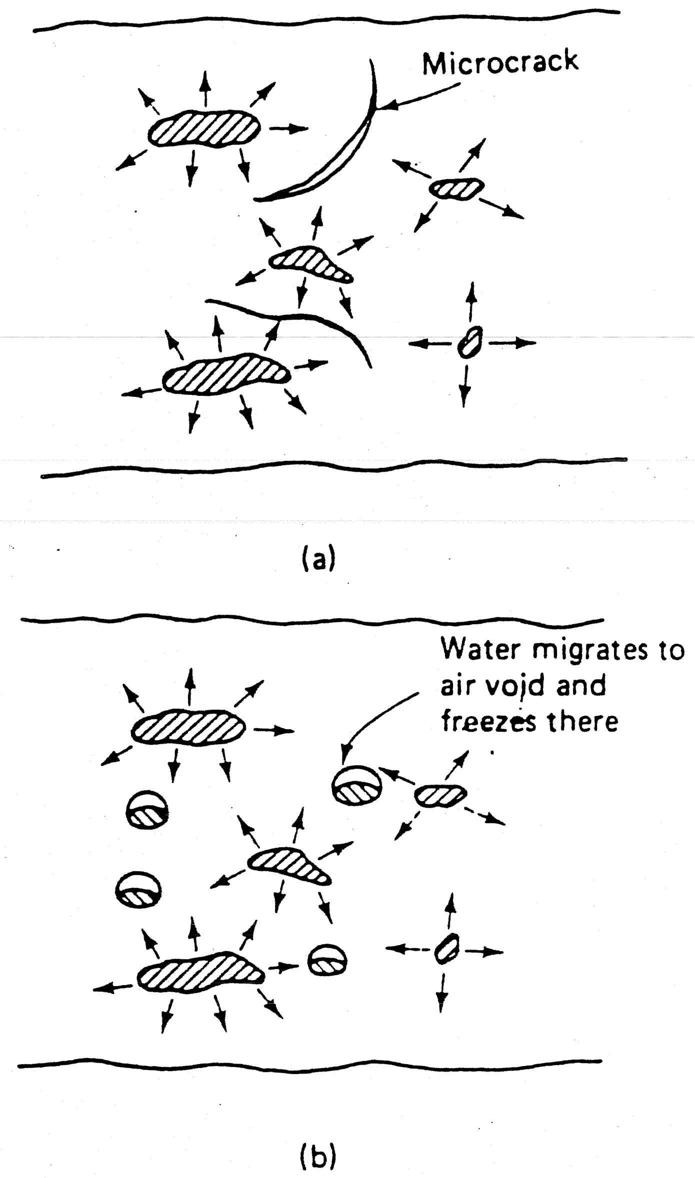

Figure 2.11 Creation of hydraulic pressure in cement paste: (a) non-air-entrained paste; (b) air-entrained paste. [21]

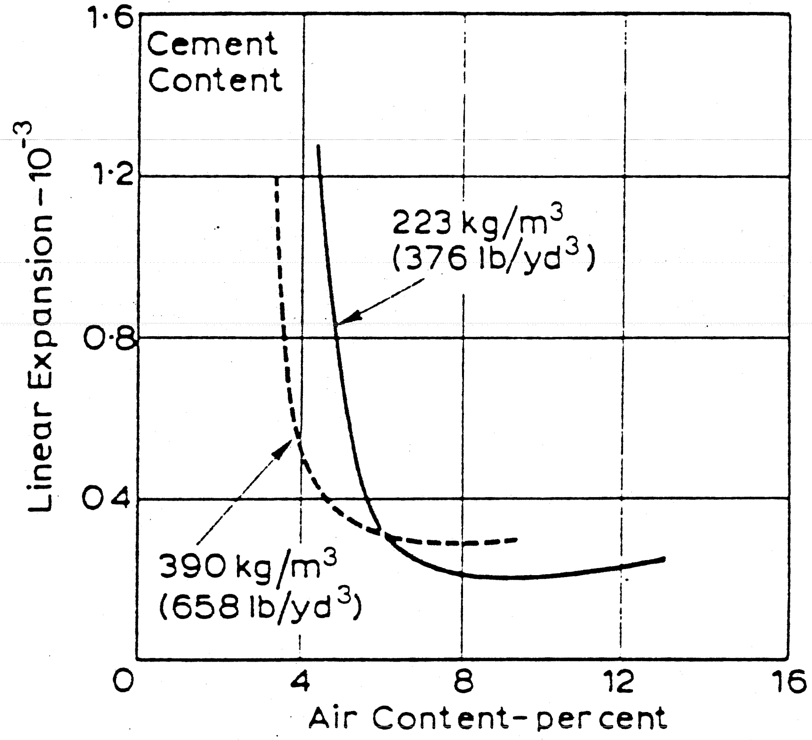

Figure 2.12 Influence of air content and cement content on expansion of concrete subjected to 300 cycles of freezing and thawing. [17]

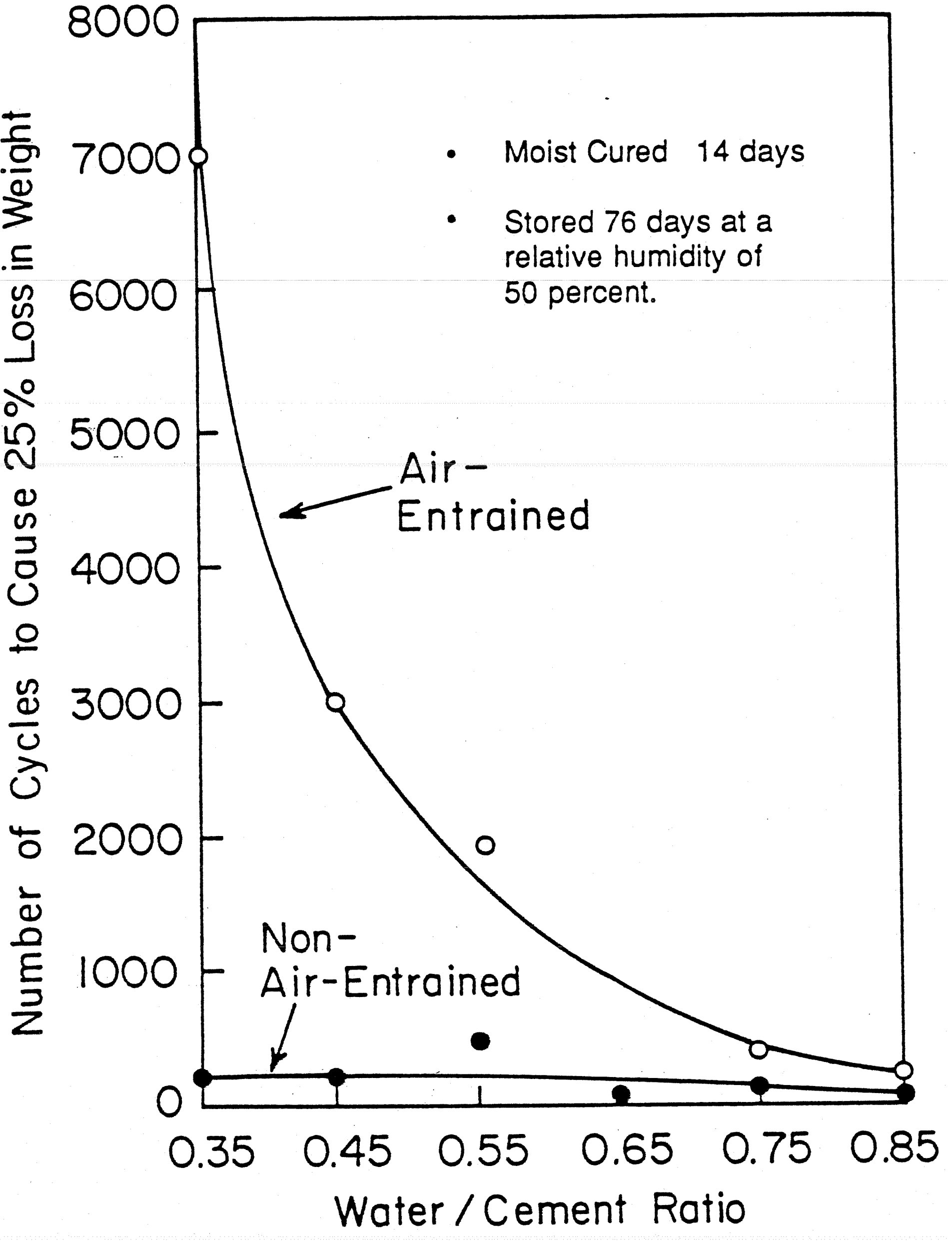

Figure 2.13 Influence of water-cement ratio on the freeze-thaw resistance of concrete. [39]

Burg observed the field performance of concrete retempered with approximately five percent of the total mixing water. The concrete had withstood three severe midwestern winters with little or no signs of distress at the time of his paper. Only a small area in which the air content determined from cores was 2.8 to 4.3 percent showed scaling or distress. The average air content for the remainder of the concrete observed was above the recommended amounts, being 6.3 percent after retempering to insure durability. [10]

CHAPTER 3

EXPERIMENTAL PROGRAM

3.1 Introduction

The experimental program undertaken in this study utilized twelve ready-mixed concrete trucks, each containing four cubic yards of concrete. From each truck, fresh concrete tests were performed and specimens were cast and tested to evaluate the effect of the following variables on the quality of the retempered concrete:

a) amount of mix water withheld;

b) time of withholding of mix water; and

c) cement content of the mix.

The following concrete properties were examined to help determine the effects of retempering:

a) slump of fresh concrete;

b) air content of fresh concrete;

c) unit weight of fresh concrete;

d) compressive strength of hardened concrete;

e) flexural strength of hardened concrete;

f) resistance of hardened concrete to abrasion; and

g) resistance of hardened concrete to freezing and thawing;

The testing procedures and materials used for this experimental program will be explained in this chapter. Results of these tests are presented in Chapter 4. The acquisition of data and testing used throughout this study conformed to ASTM and Texas SDHPT standards whenever a standard was available. [8, 37]

3.2 Testing Series

In order to evaluate the effects of withholding time, amount of water withheld, and cement content upon the physical properties of concrete, a testing program was devised which would incorporate all variables in a total of twelve ready-mixed truckloads. Four series of mixes were conducted. The term "series" refers to a set of three concrete loads having similar mix proportions, the same specified cement content and withholding time for addition of the withheld water. These three mixes in a series consist of a control mix with all water added at time of batching, a mix with 5 percent of the water withheld and a third mix having 10 percent of the mixing water withheld. The cement content, when referred to in "sacks" is defined hereafter as 94 pounds of cement per sack. Series 5-45 and 5-75 each contained a cement content of five sacks per cubic yard of concrete, with a 45 minute withholding time and a 75 minute withholding time respectively. Similarly, series 7-45 and 7-75 each contained a cement content of seven sacks per cubic yard of concrete, with a 45 minute withholding time and a 75 minute withholding time respectively.

For each of the four series cast, three percentages of mixing water were withheld at batching. The three percentages examined consisted of a control truck with no mixing water withheld, a truck with five percent of the mixing water withheld, and a truck with ten percent of the mixing water withheld. Three trucks were cast in one day to maintain consistent moisture conditions of the fine and coarse aggregate for a given mix design and withholding time (a given series).

The design amount of mixing water for each series with similar cement contents was slightly different, requiring more mixing water for the longer withholding period in order to maintain a minimum specified slump of three to six inches at 75 minutes mixing time. The mixing water withheld for the five percent and ten percent amounts was added to the concrete at the given time of withholding; 45 or 75 minutes, depending on the series. In addition, all three trucks were redosed with an additional five percent of the design mixing water one-half hour after the time of retempering. Mixture proportions for each of the mix series as batched are given in Tables 3.1 to 3.4.

3.3 Concrete

The concrete used in this study was purchased from a local ready-mix concrete facility. The materials used were typical of those commercially available for ready-mixed concrete in Central Texas. Portland cement, ASTM Type I, natural siliceous Colorado River sand, and 3/4 in. maximum size Colorado River gravel were used for all mixes. In addition, an ASTM C 494-86 type D water reducing and retarding admixture and a vinsol resin air entraining admixture were used. The concrete was produced to meet Texas SDHPT standards. [38] Discharge of the ready-mixed truck and sampling of the concrete occurred within the maximum allowable time limit for all the concrete

Table 3.1 Mixture Proportions for Series 5-45 as Batched

	Theoretical Design	Control	5% held[1]	10% held[2]
Cement (lb.)	470	468	468	468
Fine Aggregate (lb.)	1385	1425	1362	1366
Coarse Aggregate (lb.)	1870	1860	1870	1850
Water (lb.)	240	250	226	218
Water Reducer/Retarder (fl.oz.)	18.0	18.0	18.25	18.0
Air Entraining Agent (fl.oz.)	2.5	2.5	2.5	2.5

(1) 12 pounds of water withheld at batching and added at initial addition after 45 minutes.

(2) 24 pounds of water withheld at batching and added at initial addition after 45 minutes.

Note: all measurements are per cubic yard of concrete, and aggregate proportions are at SSD.

Table 3.2 Mixture Proportions for Series 5-75 as Batched

	Theoretical Design	Control	5% held[1]	10% held[2]
Cement (lb.)	470	480	473	468
Fine Aggregate (lb.)	1385	1417	1368	1371
Coarse Aggregate (lb.)	1870	1860	1880	1860
Water (lb.)	245	247	231	220
Water Reducer/Retarder (fl.oz.)	18.0	18.0	18.0	18.0
Air Entraining Agent (fl.oz.)	2.6	2.6	2.6	2.6

(1) 12 pounds of water withheld at batching and added at initial addition after 75 minutes.

(2) 24 pounds of water withheld at batching and added at initial addition after 75 minutes.

Note: all measurements are per cubic yard of concrete, and aggregate proportions are at SSD.

Table 3.3 Mixture Proportions for Series 7-45 as Batched

	Theoretical Design	Control	5% held[1]	10% held[2]
Cement (lb.)	658	673	658	668
Fine Aggregate (lb.)	1280	1248	1285	1244
Coarse Aggregate (lb.)	1712	1720	1700	1720
Water (lb.)	290	293	276	257
Water Reducer/Retarder (fl.oz.)	26.0	26.0	26.25	26.0
Air Entraining Agent (fl.oz.)	4.6	4.6	4.6	4.6

(1) 15 pounds of water withheld at batching and added at initial addition after 45 minutes.

(2) 29 pounds of water withheld at batching and added at initial addition after 45 minutes.

Note: all measurements are per cubic yard of concrete, and aggregate proportions are at SSD.

Table 3.4 Mixture Proportions for Series 7-75 as Batched

	Theoretical Design	Control	5% held[1]	10% held[2]
Cement (lb.)	658	655	673	658
Fine Aggregate (lb.)	1280	1314	1231	1279
Coarse Aggregate (lb.)	1712	1740	1740	1710
Water (lb.)	290	297	280	270
Water Reducer/Retarder (fl.oz.)	26.0	26.0	26.0	26.0
Air Entraining Agent (fl.oz.)	5.9	5.9	5.9	5.9

(1) 15 pounds of water withheld at batching and added at initial addition after 75 minutes.
(2) 24 pounds of water withheld at batching and added at initial addition after 75 minutes.

Note: all measurements are per cubic yard of concrete, and aggregate proportions are at SSD.

tests at the time of initial addition and at the time of redosage for the 45-minute withholding time series. This time limit is 105 minutes for concrete containing a retarder with a temperature greater than 90 degrees Fahrenheit, with the exception of concrete used for bridge decks, top slabs of direct traffic culverts, and cased drilled shafts which must be placed within 75 minutes to meet specifications. Upon redosage, the time limit was exceeded for the 75 minute withholding time, but the information gained about the effect of redosage justifies the deviation from the specification time limit.

3.4 Batching Procedure

To eliminate discrepancies in the concrete mix proportions which could occur during batching, all operations at the batch plant were carefully monitored. The batching procedure for each truck consisted of the following:

(1) wash out drum with 600 to 800 pounds of water;

(2) inspect drum for cleanliness and emptiness;

(3) verify mix proportions with batchman;

(4) charge the ready-mix truck at mixing speed with four yards of material;

(5) mix the concrete for five minutes in addition to the time necessary to charge the mixer;

(6) verify the desired slump; and

(7) send the truck to the laboratory for further tests.

3.5 Casting Procedure

Three trucks in a series would arrive at the laboratory in a staggered time frame. At the time of initial addition, the withheld mixing water was added and the concrete was mixed for three minutes. For the control truck, no water was added at this time. To keep the concrete sample as representative as possible of the concrete in the truck, two wheelbarrows amounting to about 6 cubic feet of material were discarded before each concrete sampling. Subsequent wheelbarrows of material were then used for evaluation of the fresh properties of the plastic concrete, and for casting of specimens to be used for the determination of the hardened properties. Specimens cast from these mixes are referred to as control, 5% withheld, and 10% withheld.

One-half hour after the time of initial addition, the concrete was redosed with an additional five percent of the design mixing water and mixed for an additional three minutes. Once again two wheelbarrows of concrete were discharged and discarded. Subsequent wheelbarrows of material were used for evaluation of the fresh properties of the plastic concrete and for casting of specimens to be used for the determination of hardened properties of the retempered concrete. Specimens cast from these mixes are referred to as control redosed, 5% withheld redosed, and 10% withheld redosed. Figure 3.1 shows the casting setup used for each series, and Figure 3.2 shows a ready-mix truck preparing for discharge at the laboratory.

3.6 Fresh Concrete Testing

The fresh concrete was tested for slump, air content and unit weight both at the time of initial addition of withheld mixing water and at the time of redosage. The slump was measured according to ASTM C 143-78, "Standard Test Method for Slump of Portland Cement Concrete" and Texas SDHPT procedure TEX 415-A, "Slump of Portland Cement Concrete". Air content was determined using a volumetric air meter according to ASTM C 143-78, "Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method" and Texas SDHPT procedure TEX 416-A, "Air Content of Freshly Mixed Concrete, B: Volumetric Method". Unit weight was measured with a 0.5 cubic foot bucket in accord with ASTM C 138-81, "Standard Test Method for Unit Weight, Yield and Air Content of Concrete" and Texas SDHPT procedure TEX 417-A "Weight per Cubic Foot and Yield of Concrete". In addition, the temperature of the concrete was monitored throughout the duration of the time the concrete truck was at the laboratory.

3.7 Hardened Concrete Testing

Hardened properties of the concrete give an assessment of the quality of the concrete. The hardened properties of the concrete tested were the following:

a) compressive strength;

b) flexural strength;

c) resistance to abrasion; and

d) resistance to freezing and thawing;

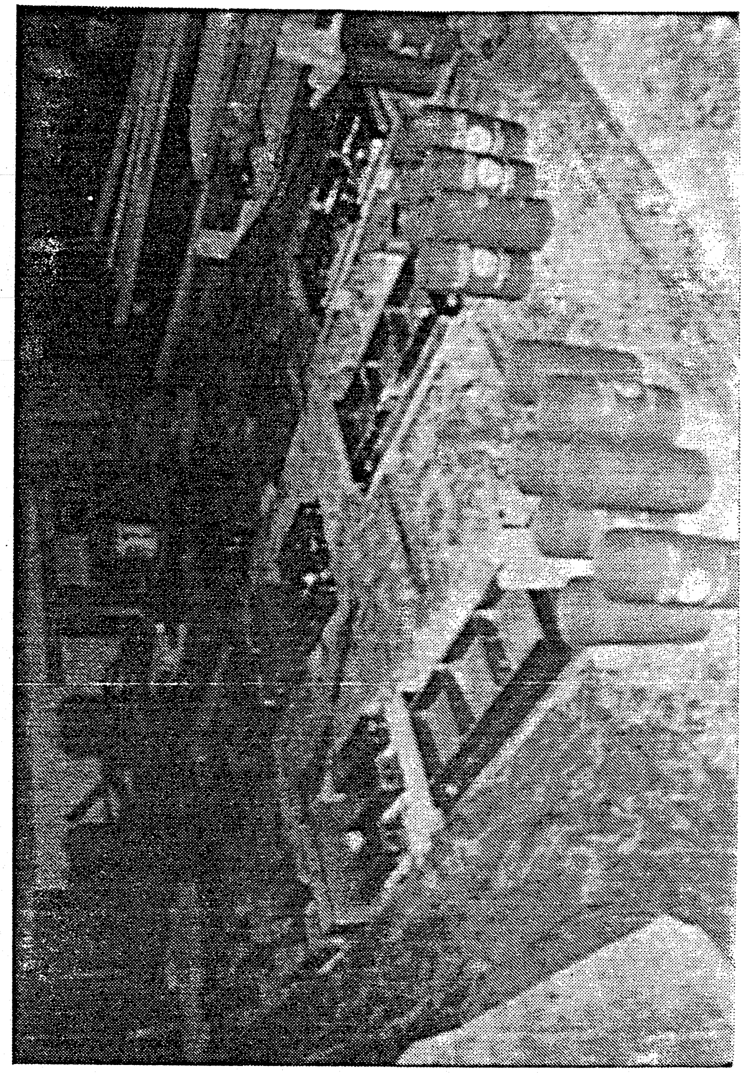

Figure 3.1 Casting setup.

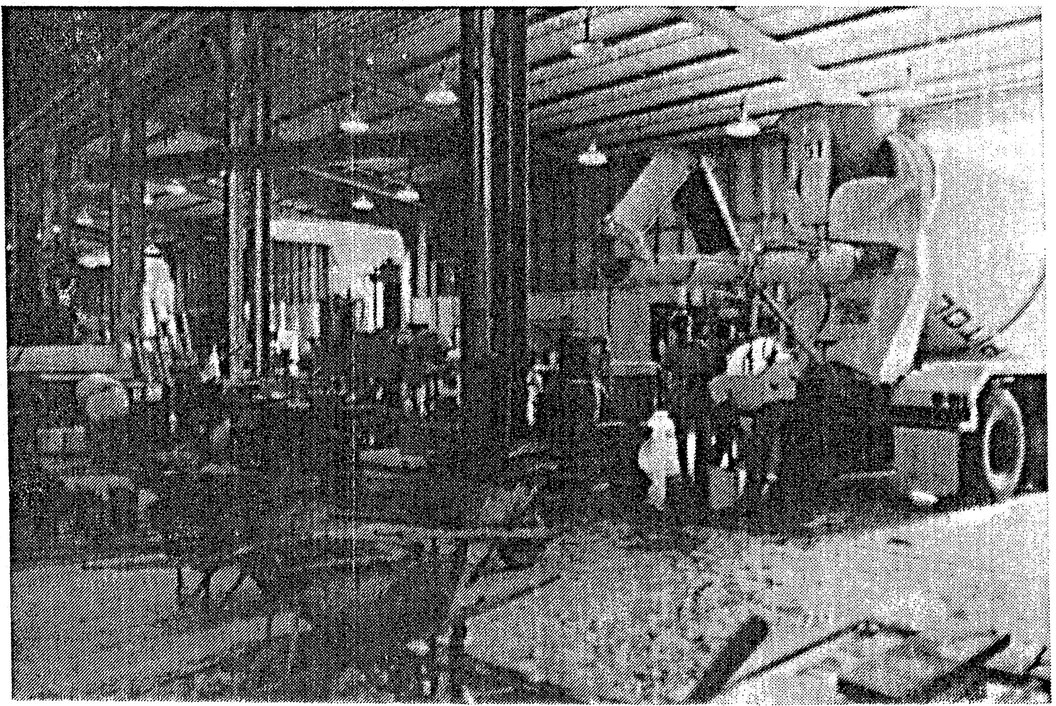

Figure 3.2 Ready-mixed truck preparing for discharge.

All specimens moist cured were cured in a saturated lime-water bath at 73°F +/- 3°F until the time of testing unless otherwise noted in accordance with ASTM C 192-81, "Standard Test Method for Making and Curing Concrete Test Specimens in the Laboratory". Data points for each mix examined represent the average of tests on three companion test specimens cast from the same concrete and cured and tested in the same manner. Additionally, for determination of depth of wear in the abrasion testing, three separate readings were taken with the micrometer for each set of demec points. Four sets of demec points were averaged for each specimen tested.

3.7.1 Compressive Strength. Compressive strength was determined using 6 in. by 12 in. cylinders tested using a 600 kip testing machine. Unbonded enoprene caps were used in lieu of the conventional sulfur mortar caps. Tests were conducted on three companion specimens at both 7 and 28 days. All cylinders were tested in accord with ASTM C 39-81, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens" and Texas SDHPT procedure TEX 418-A, "Compressive Strength of Molded Concrete Cylinders".

3.7.2 Flexural Strength. Flexural strength of the concrete was determined using 6 in. by 6 in. by 21 in. prismatic beams loaded at third-points. Testing was done according to ASTM C 78-84, "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)" and Texas SDHPT procedure TEX 420-A, "Flexural Strength of Concrete" with the exception of using third point loading. Testing was conducted on three companion specimens at both 7 and 28 days using a Rainhart Series 416 Beam Tester.

3.7.3 Abrasion Resistance. The abrasion resistance of concrete specimens was tested in accord with ASTM C 944-80, "Standard Test Method for Abrasion Resistance of Concrete or Mortar Surfaces by the Rotating-Cutter Method". All specimens tested for abrasion resistance were moist cured for seven days and air cured for one day. Specimens were tested on the eighth day after casting. All specimens were finished in the same manner to prevent the influence of finishing techniques upon the results. Three companion specimens were subjected to four-two minute abrasion periods with a ten kilogram force upon the dresser wheels. Depth of wear was measured using a micrometer mounted on an InVar reference frame.

3.7.4 Freeze-Thaw Resistance. The durability of concrete specimens subjected to freezing and thawing cycles was tested using 3 in. by 4 in. by 16 in. beams subjected to a cyclic temperature change of 0°F to 40°F. All specimens were tested in accord with ASTM C 666-84, "Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing", and Texas SDHPT procedure TEX 423-A, "Resistance of Concrete to Rapid Freezing and Thawing". The wet method described in these standards was used. Specimens were moist cured for 14 days. At 14 days the specimens were frozen at 0°F +/- 3°F until freeze-thaw cycling could begin. Decay of the dynamic modulus of elasticity was calculated from the fundamental transverse frequency of each specimen, and was used as an indication of the durability. Measurements of the fundamental transverse frequency for three companion specimens were taken at intervals of no greater than 32 freeze-thaw cycles, and were done in accord with ASTM C 215-85, "Standard Test Method for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens".

3.7.5 Scaling and Deicing Resistance. Resistance of the hardened concrete to scaling upon exposure to deicing chemicals and subjected to freezing and thawing cycles will be conducted in the spring of 1988 with the results being reported at a later time. Specimens were cast and moist cured for 14 days, and are currently being stored in a freezer at 0°F until testing can begin when new test facilities are operational. The results will be the subject of a later report.

CHAPTER 4

TEST RESULTS: THE EFFECT OF RETEMPERING ON CONCRETE

4.1 Introduction

The test results of the experimental program examining the effects of withholding and later addition of mixing water on concrete are presented in this chapter. Both tabular and graphical form are used to facilitate ease in presentation and understanding of the data. Discussion of these test results will be presented in the following chapter.

The nomenclature for each of the graphs corresponds to the variables examined in the study; cement content, withholding time, and withholding amount. Cement contents of five and seven sacks are indicated as well as withholding times of 45 and 75 minutes. Redosage of the concrete, when indicated, occurred 30 minutes beyond the specified withholding time. Specimens with no water withheld at batching were considered the control mix. All other withholding amounts are with respect to these control cases.

4.2 Mix Proportions

Mix proportions for the four series of mixes as batched at the ready mix plant were presented in the previous chapter. Use of a five and seven sack mix was established to examine cement contents used typically in highway construction. Tables 4.1 and 4.2 list the requirements for Texas SDHPT Specification Item 421, Class A and Class C concretes, which were the mixes used in this study.

4.3 Fresh Concrete Testing

Fresh concrete properties were tested on each truck at the time of initial addition of withheld mixing water and again at the time of redosage with five percent more water. Table 4.3 presents the unit weight of each mix cast. Figures 4.1 to 4.4 present the slump of each mix series tested. Figures 4.5 to 4.8 present the air content of each mix series tested. Note that the lines connecting points show the history of the plastic concrete if it is known throughout the entire testing time. Data points without lines connecting them indicate that the properties of the fresh concrete immediately prior to the addition of water were not evaluated due to time constraints.

Table 4.1 Texas SDHPT Specifications for Item 421 Class A Concrete

Minimum Cement Content	470 lb./cu. yd.
Minimum 28 Day Compressive Strength	3000 psi
Minimum 7 Day Beam Strength for Type I Cement	500 psi
Maximum Water/Cement Ratio by Weight	.58
Coarse Aggregate Number	1,2,3,4
Usage:	Drilled Shafts, Bridge Substructure, Culverts (Not Direct Traffic), Inlets, Manholes, Headwalls Concrete Approach Slab, Curb & Gutter, Concrete Barrier Railing, Concrete Retards, Sidewalks, Driveways

Table 4.2 Texas SDHPT Specifications for Item 421 Class C Concrete

Minimum Cement Content	564 lb./cu. yd.
Minimum 28 Day Compressive Strength	3600 psi
Minimum 7 Day Beam Strength for Type I Cement	600 psi
Maximum Water/Cement Ratio by Weight	.53
Coarse Aggregate Number	1,2,3,4,5,8*

Usage: Drilled Shafts, Bridge & Railing Substructure, Culverts, Wingwalls

Concrete Approach Slab, Concrete Barrier Railing, Machine Laid Curb

* Grade 8 aggregate for use in Machine laid curb.

Table 4.3 Unit Weight of Each Mix at the Time Specimens Were Cast (in pcf)

	5-45	5-75	7-45	7-75
Control	144.2	143.5	144.1	141.4
Control Redosed	144.5	142.2	143.8	138.4
5% Withheld	144.5	144.1	143.7	144.0
5% Withheld Redosed	143.8	145.4	139.8	139.4
10% Withheld	144.5	144.8	145.7	143.9
10% Withheld Redosed	144.3	143.4	143.8	142.4

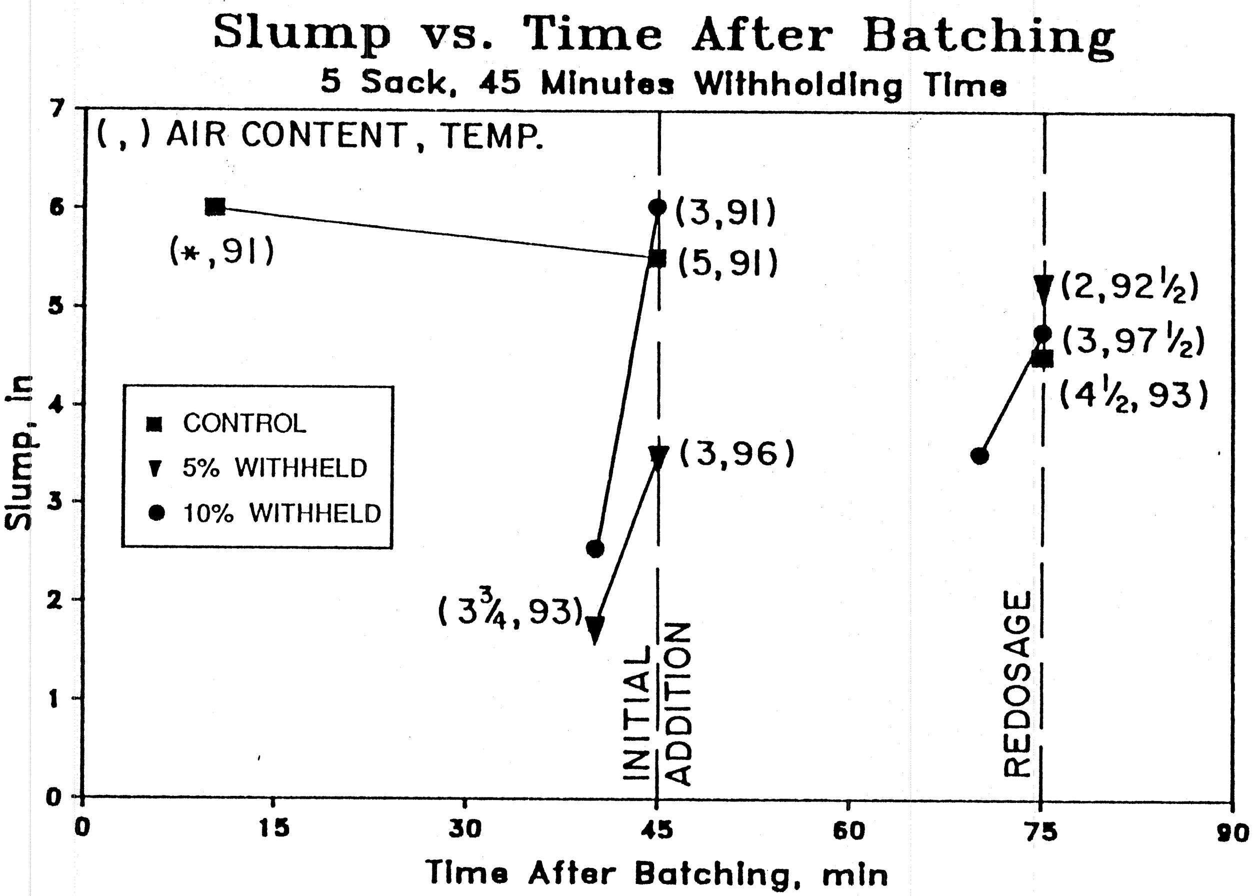

Figure 4.1 Slump of concrete in the 5-45 series.

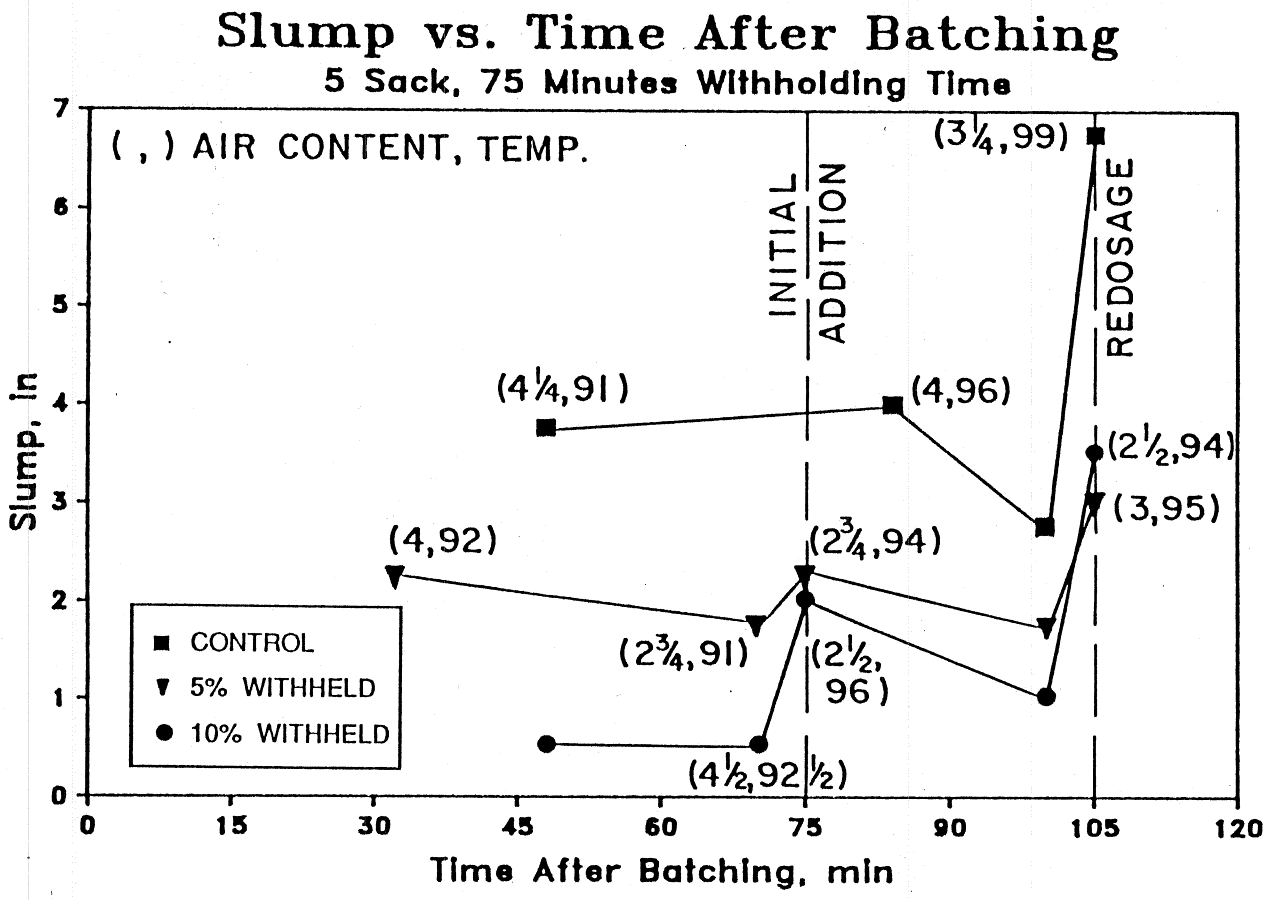

Figure 4.2 Slump of concrete in the 5-75 series.

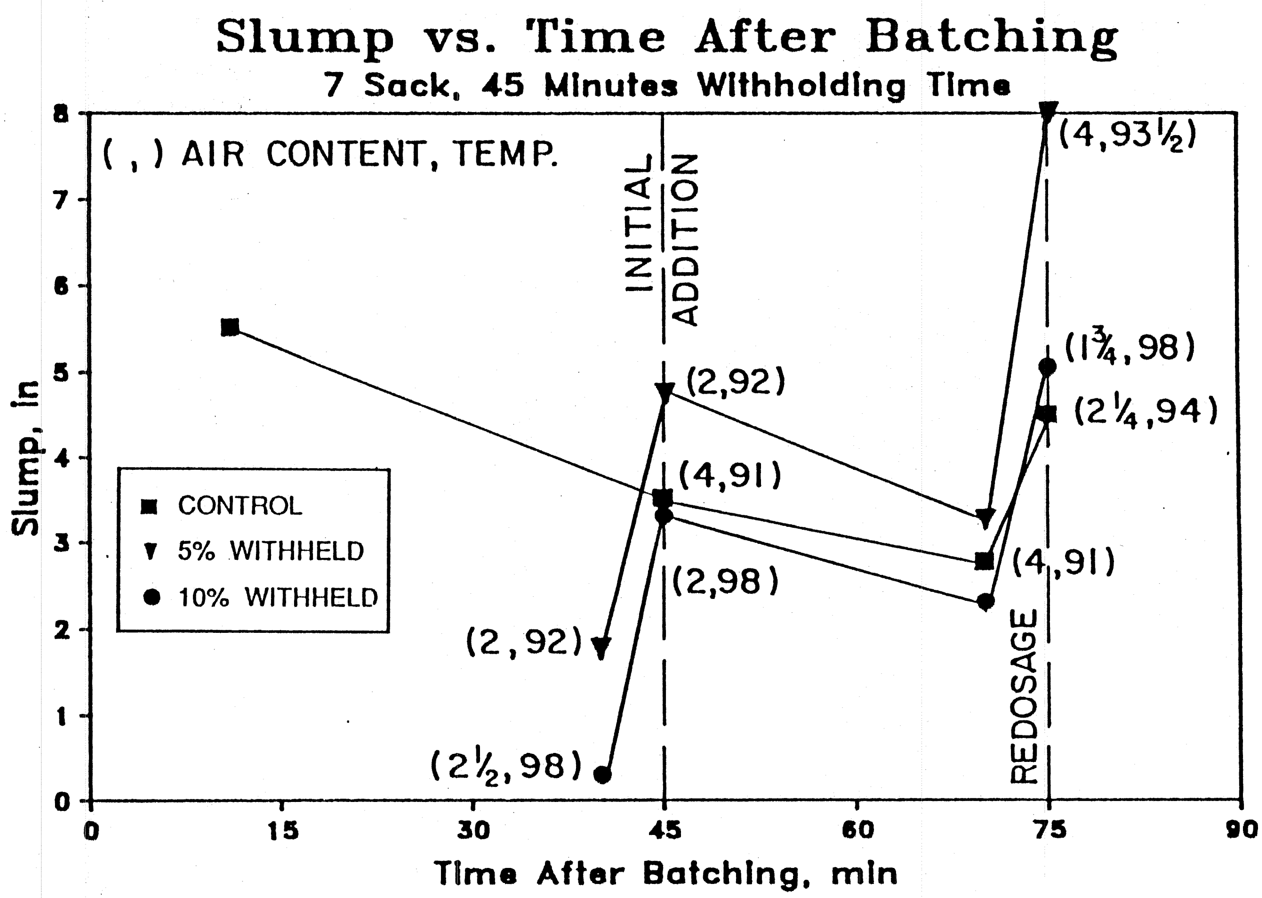

Figure 4.3 Slump of concrete in the 7-45 series.

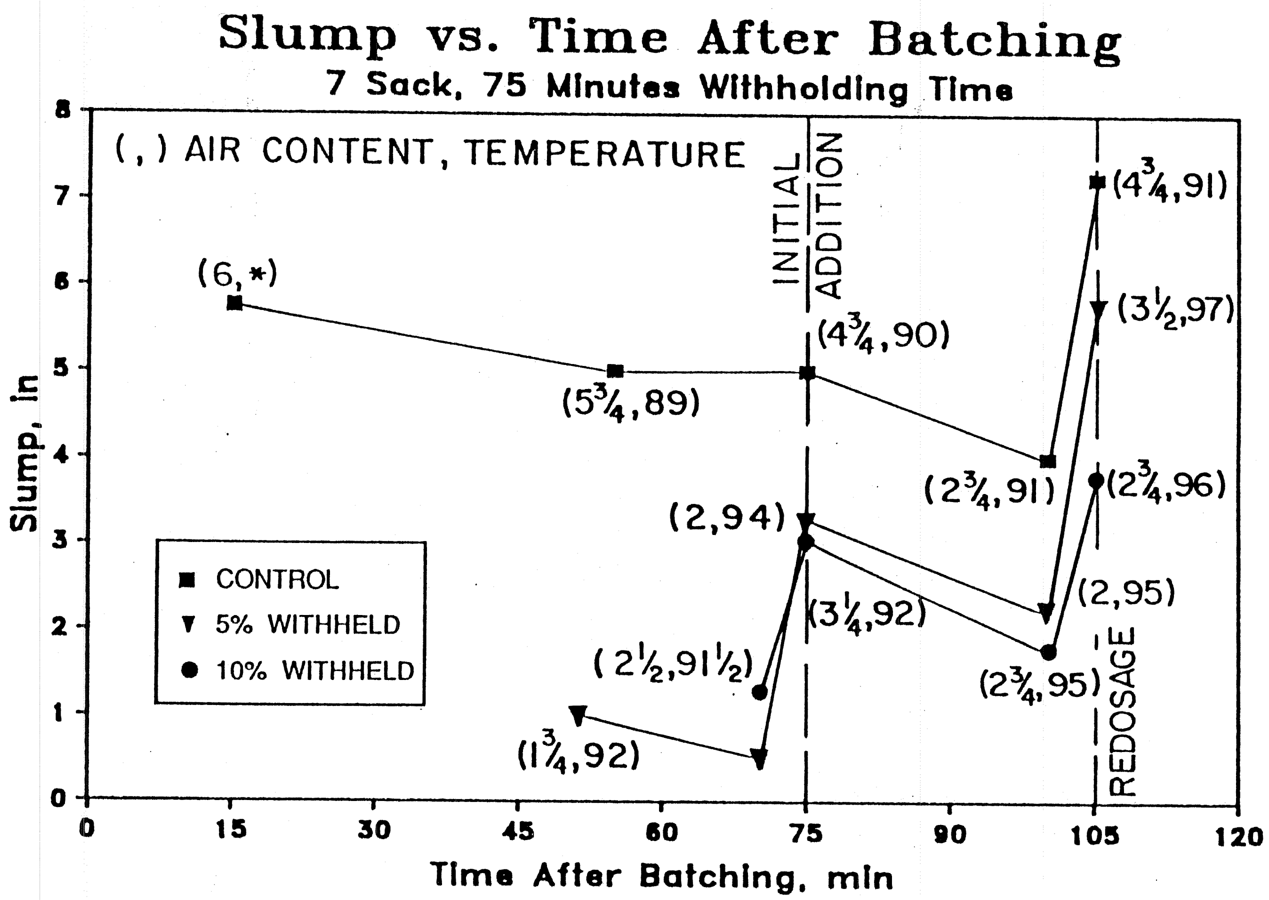

Figure 4.4 Slump of concrete in the 7-75 series.

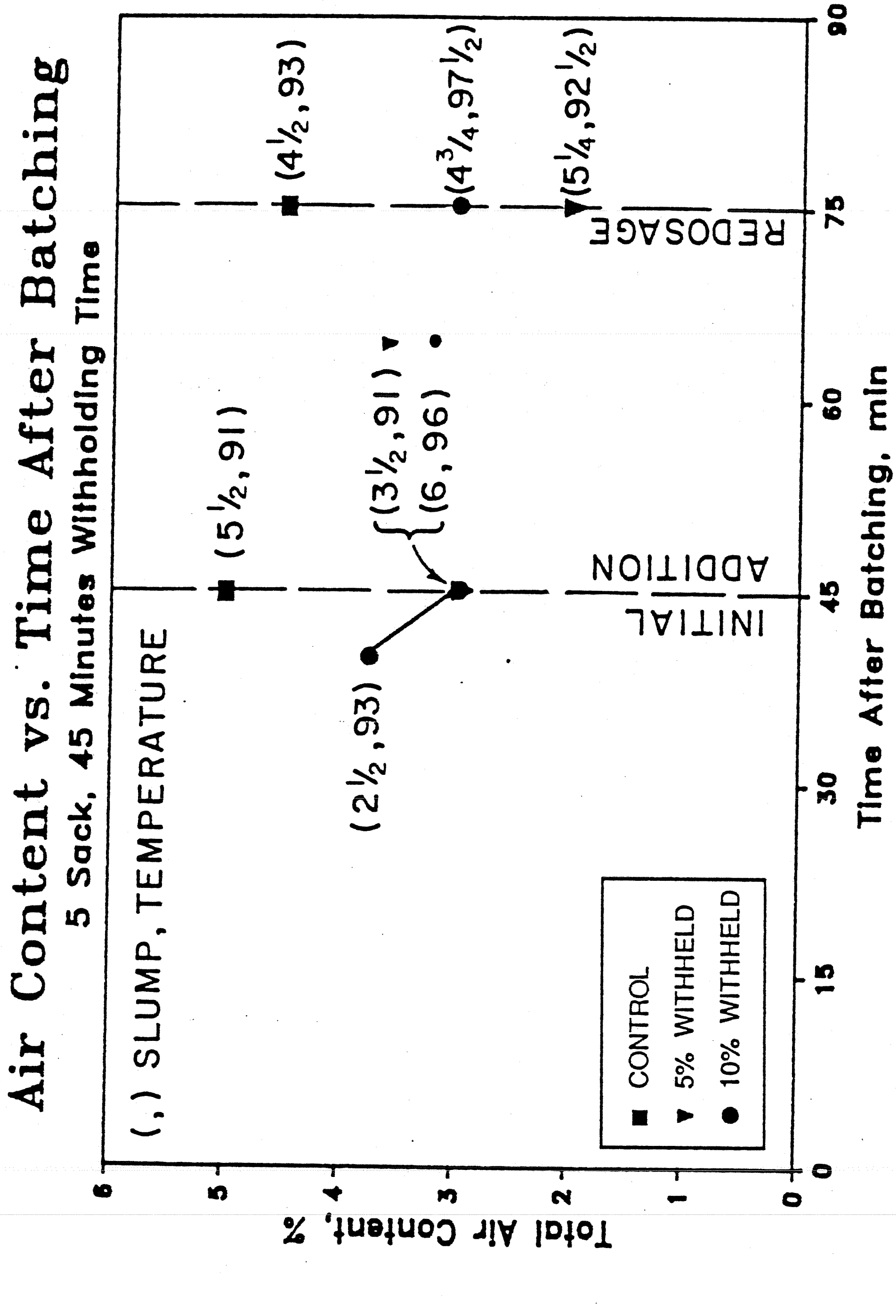

Figure 4.5 Air content of concrete in the 5-45 series.

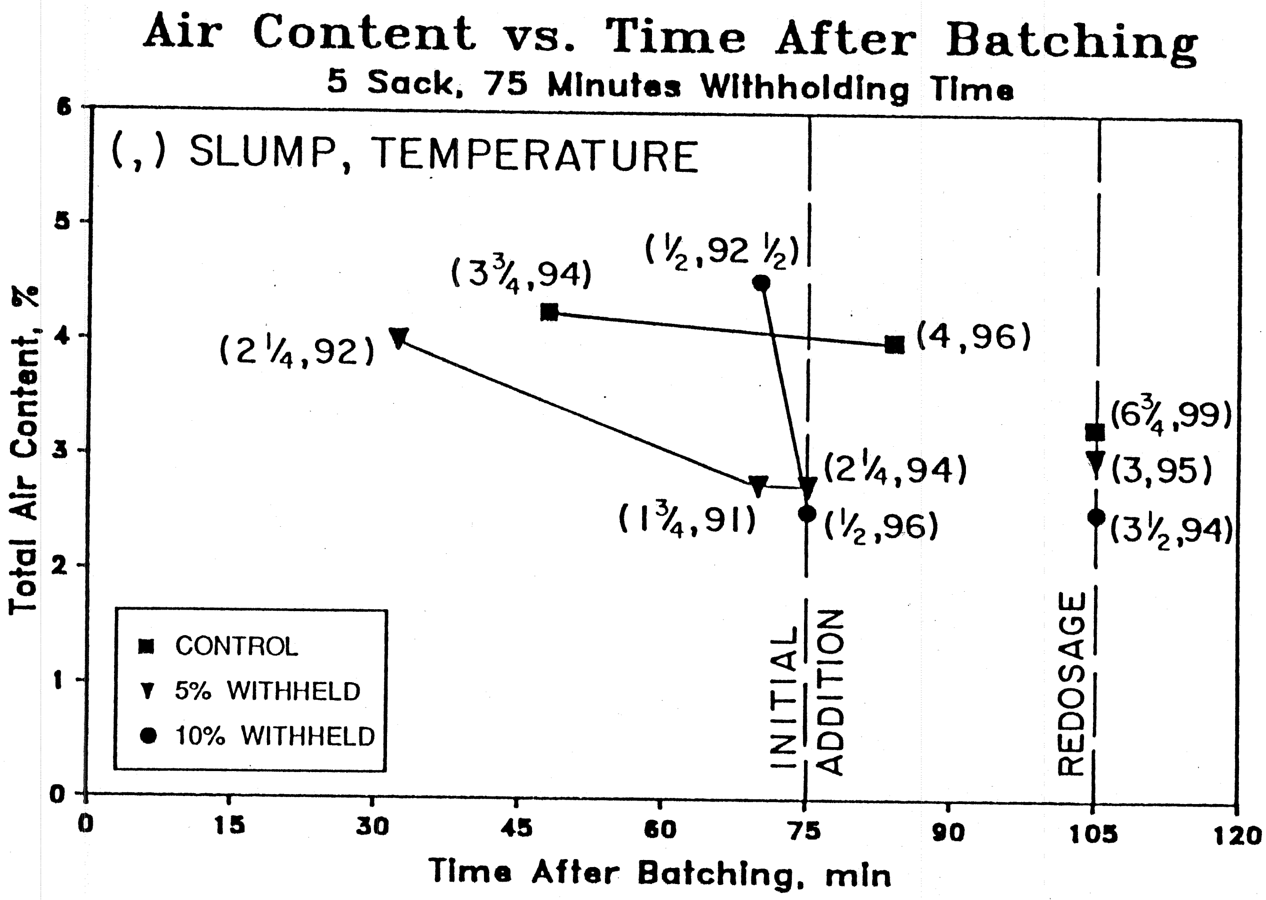

Figure 4.6 Air content of concrete in the 5-75 series.

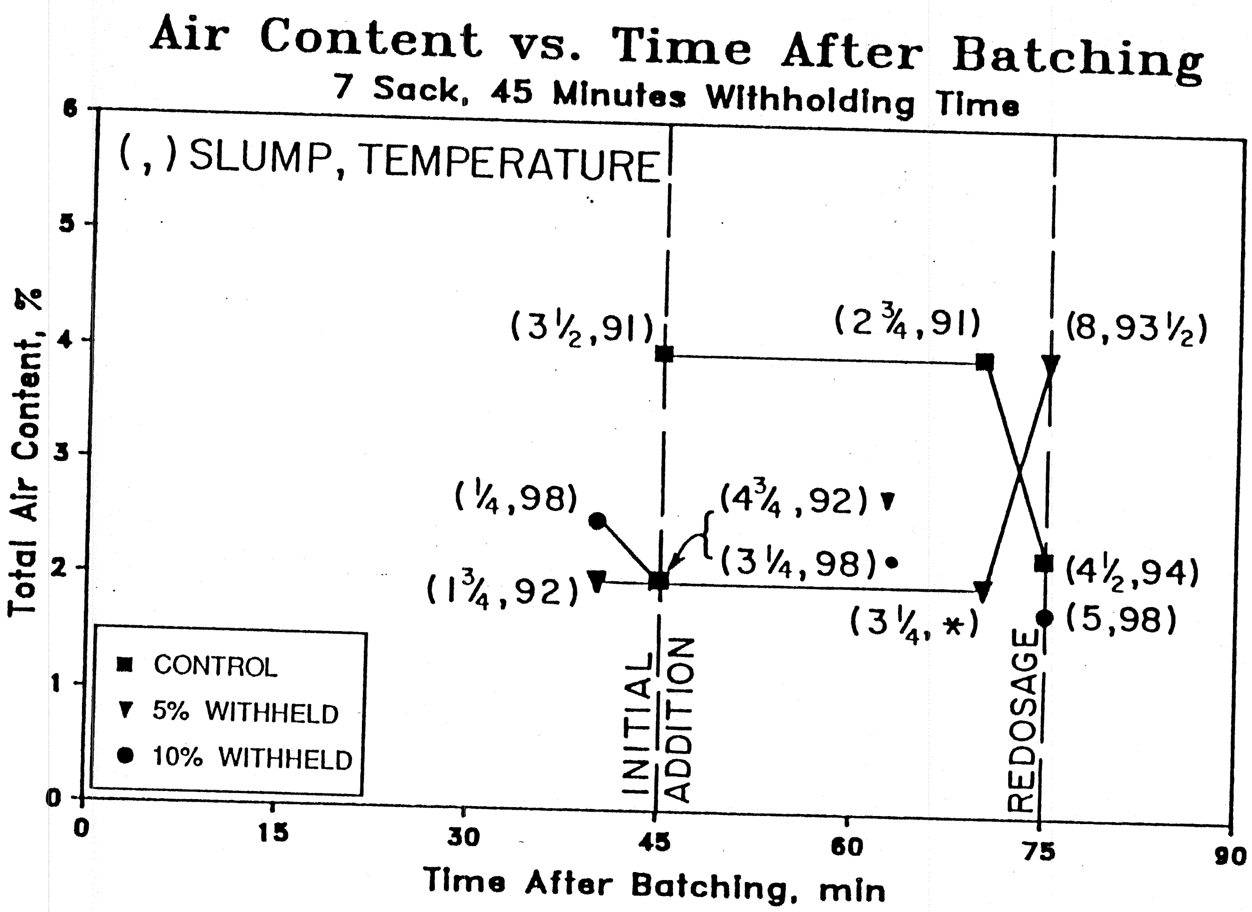

Figure 4.7 Air content of concrete in the 7-45 series.

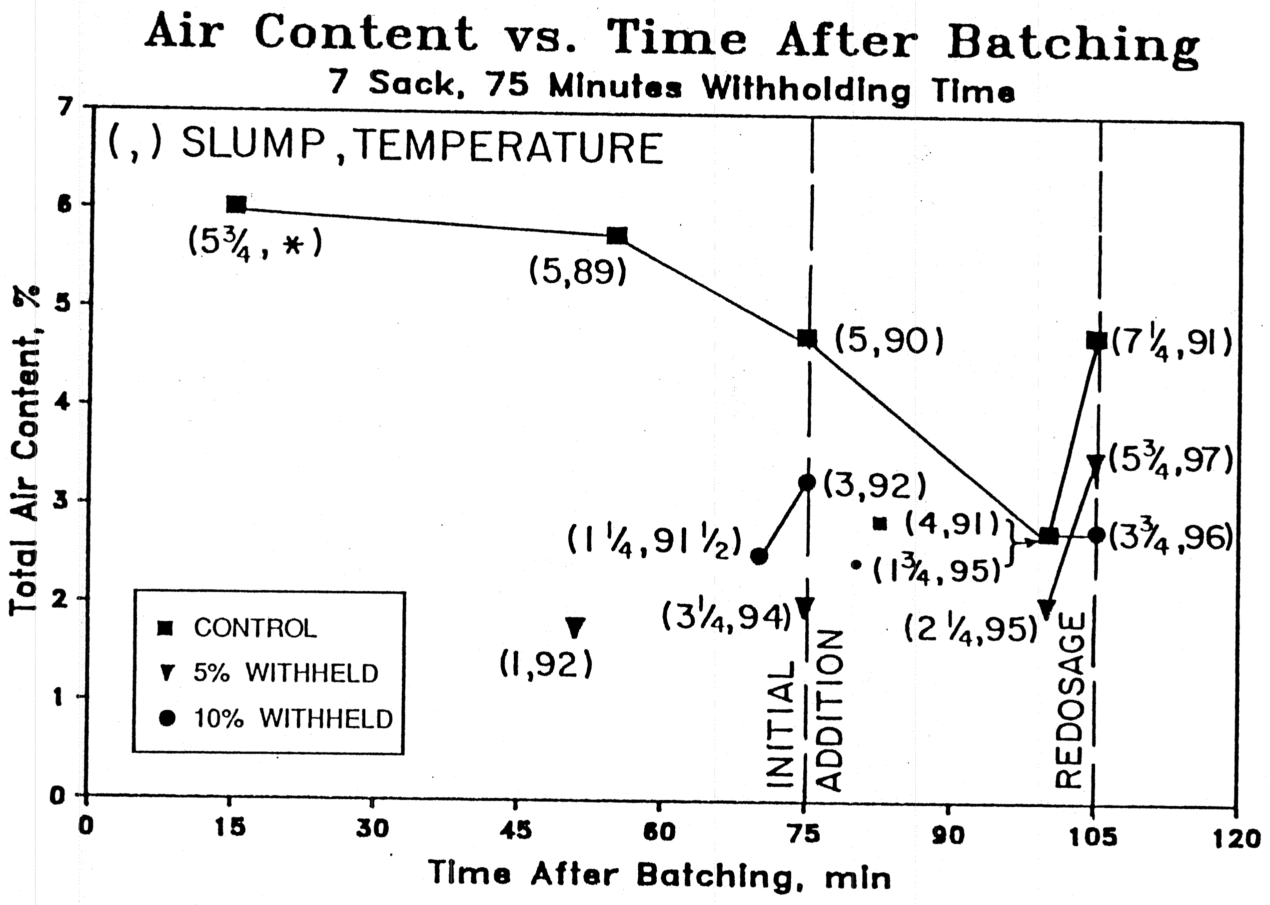

Figure 4.8 Air content of concrete in the 7-75 series.

4.4 Compressive Strength

The results of the compressive strength testing are plotted in Figures 4.9 to 4.12. Each figure corresponds to a given mix series. Both 7-day and 28-day strengths are plotted on the graphs. Data points connected indicate trucks with similar batch proportions; specimens cast after the initial addition of withheld mixing water (no addition for the control mix) or specimens cast after redosage with five percent more mixing water. The 28-day required compressive strength was 3000 psi for the five sack mixes and 3600 psi for the seven sack mixes. None of the concrete specimens tested fell below this level.

4.4.1 Effect of Extended Mixing Time. The effect of extending the mixing time of all three trucks in the seven sack, 45 minute withholding time series was examined. After redosage of each of the three trucks, each was agitated for an additional 30 minutes and samples taken. The results are presented in Table 4.4. A strength gain occurred in all three mixes.

4.5 Flexural Strength

The results of the flexural strength testing are plotted in Figures 4.13 to 4.16. Each figure corresponds to a given mix series. Both 7-day and 28-day strengths are plotted on the graphs. As with the compressive strength results, data points connected correspond to trucks with similar batch proportions. The required 7-day flexural strength was 500 psi for the five sack mixes and 600 psi for the seven sack mixes. Only one of the test results fell below the required level, being the control redosed test result in the seven sack, 75 minute series.

4.6 Abrasion Resistance

The effect of retempering on the abrasion resistance of concrete is plotted in Figures 4.17 to 4.20. Each figure corresponds to a given mix series. Depth of wear instead of weight loss was used to evaluate the abrasion resistance. In almost all cases, resistance to abrasion increased with the withholding and later addition of water. Upon redosage however, most specimens showed a decrease in abrasion resistance.

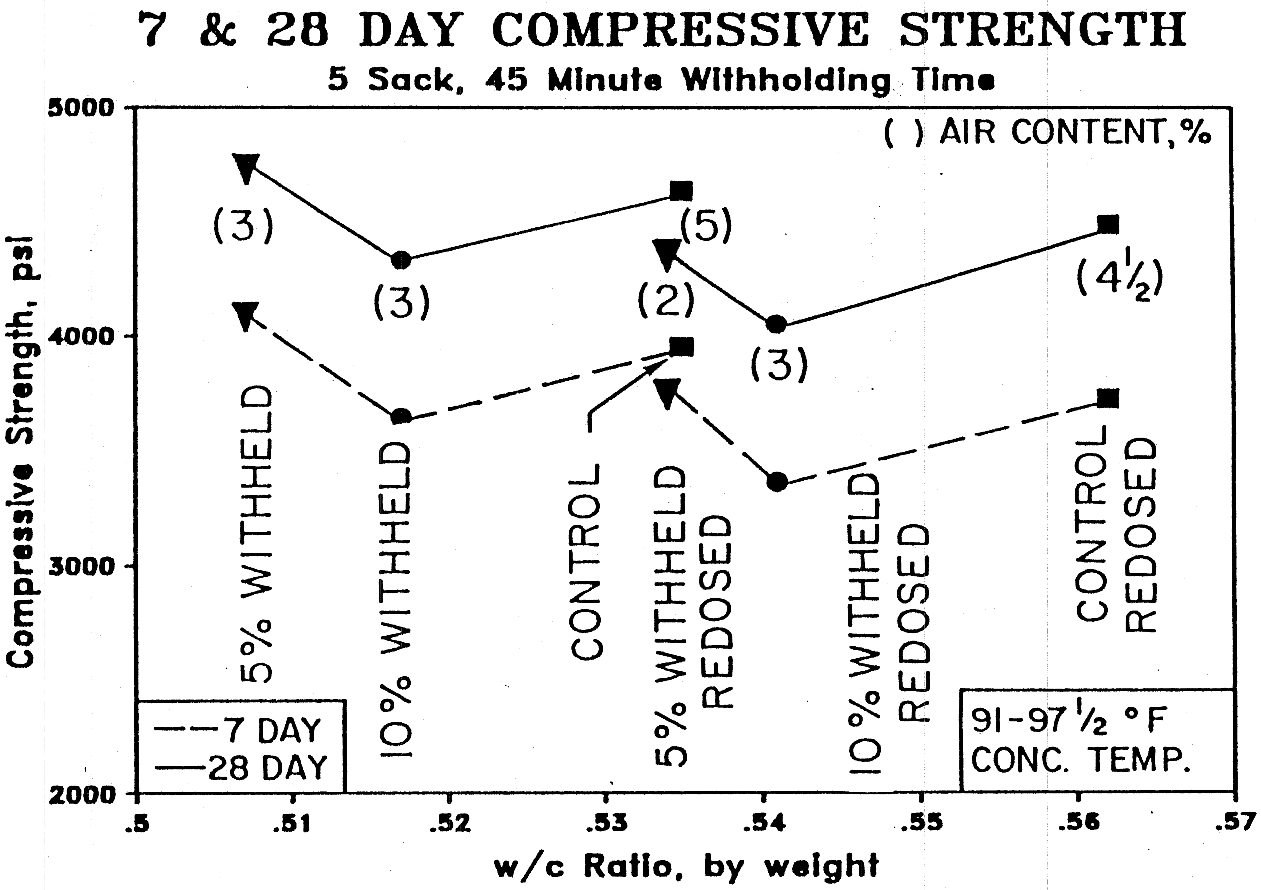

Figure 4.9 Compressive strength results of concrete in the 5-45 series.

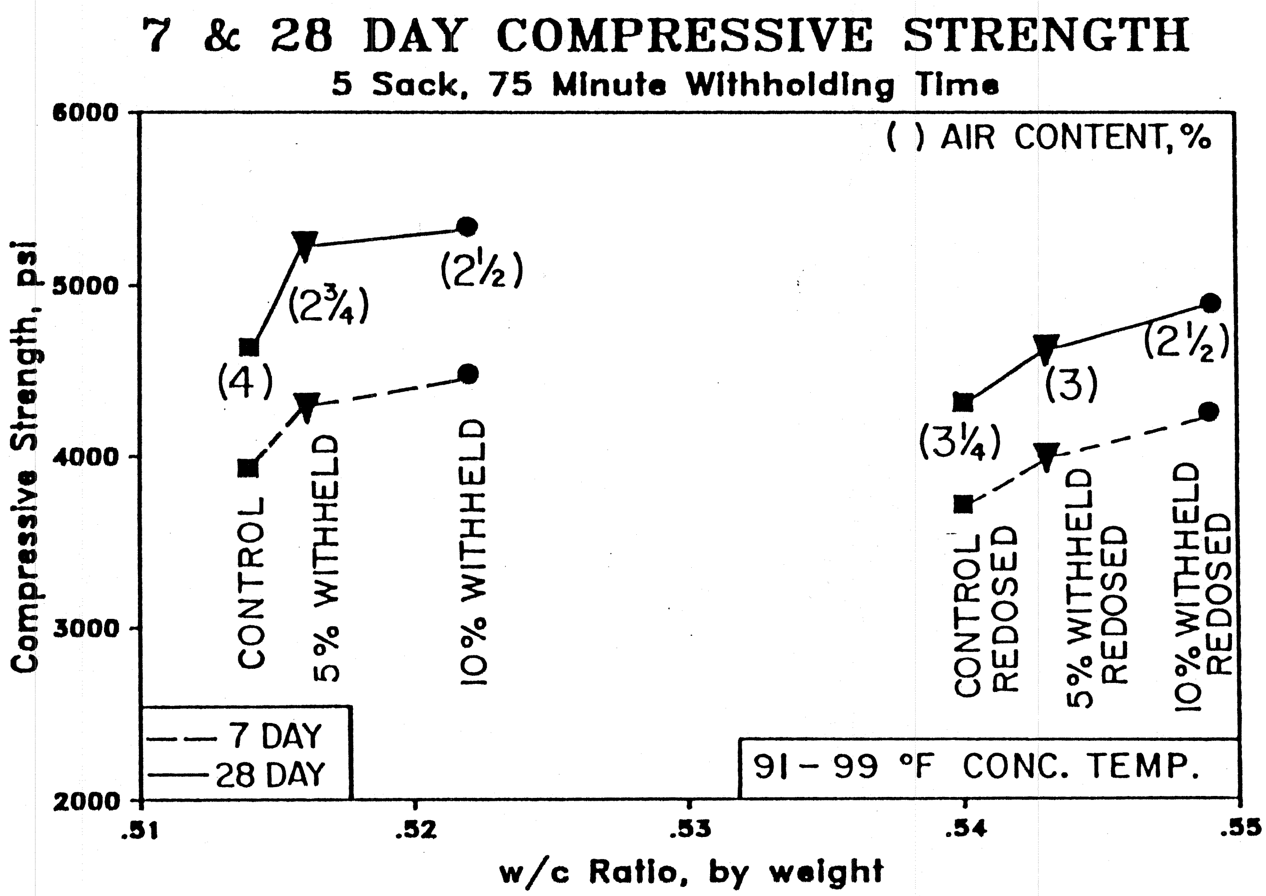

Figure 4.10 Compressive strength results of concrete in the 5-75 series.

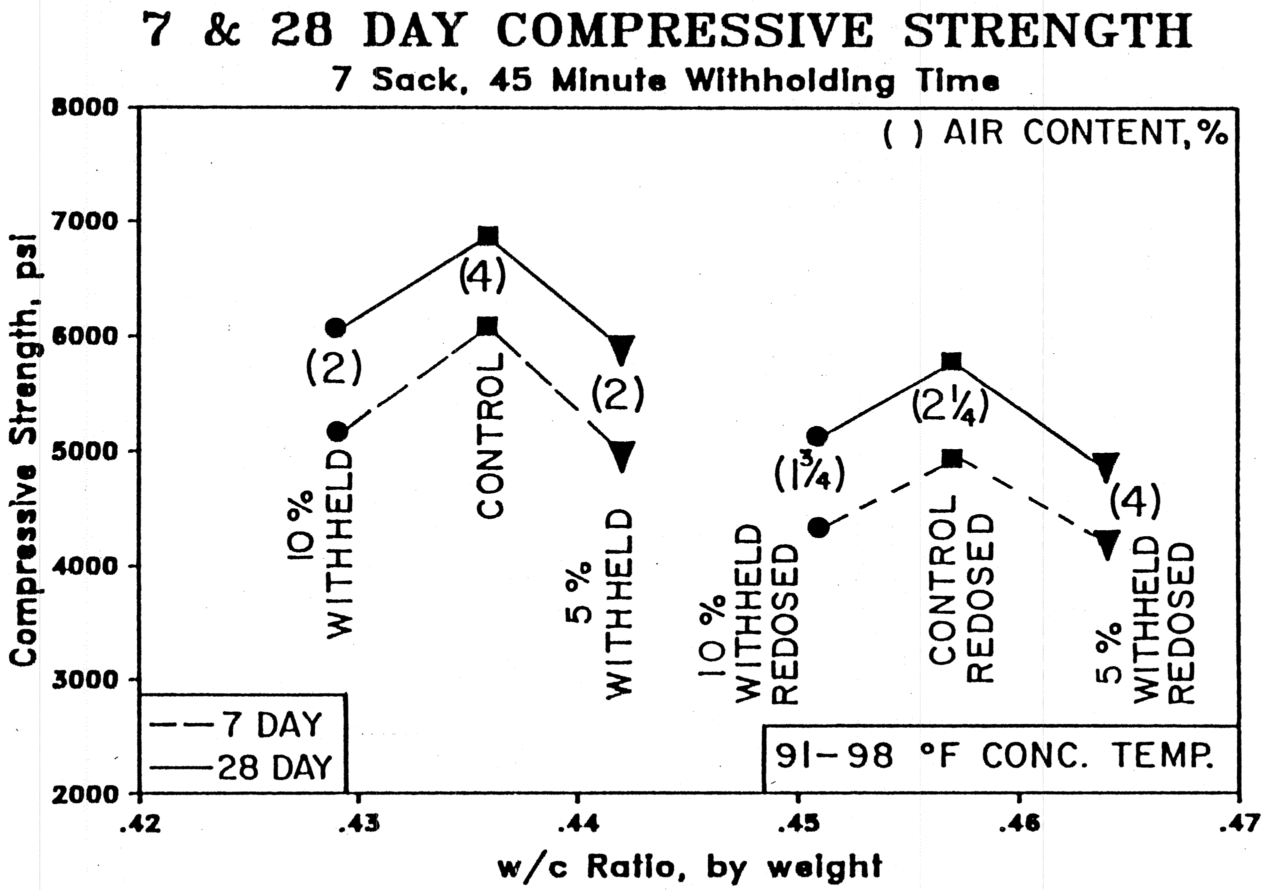

Figure 4.11 Compressive strength results of concrete in the 7-45 series.

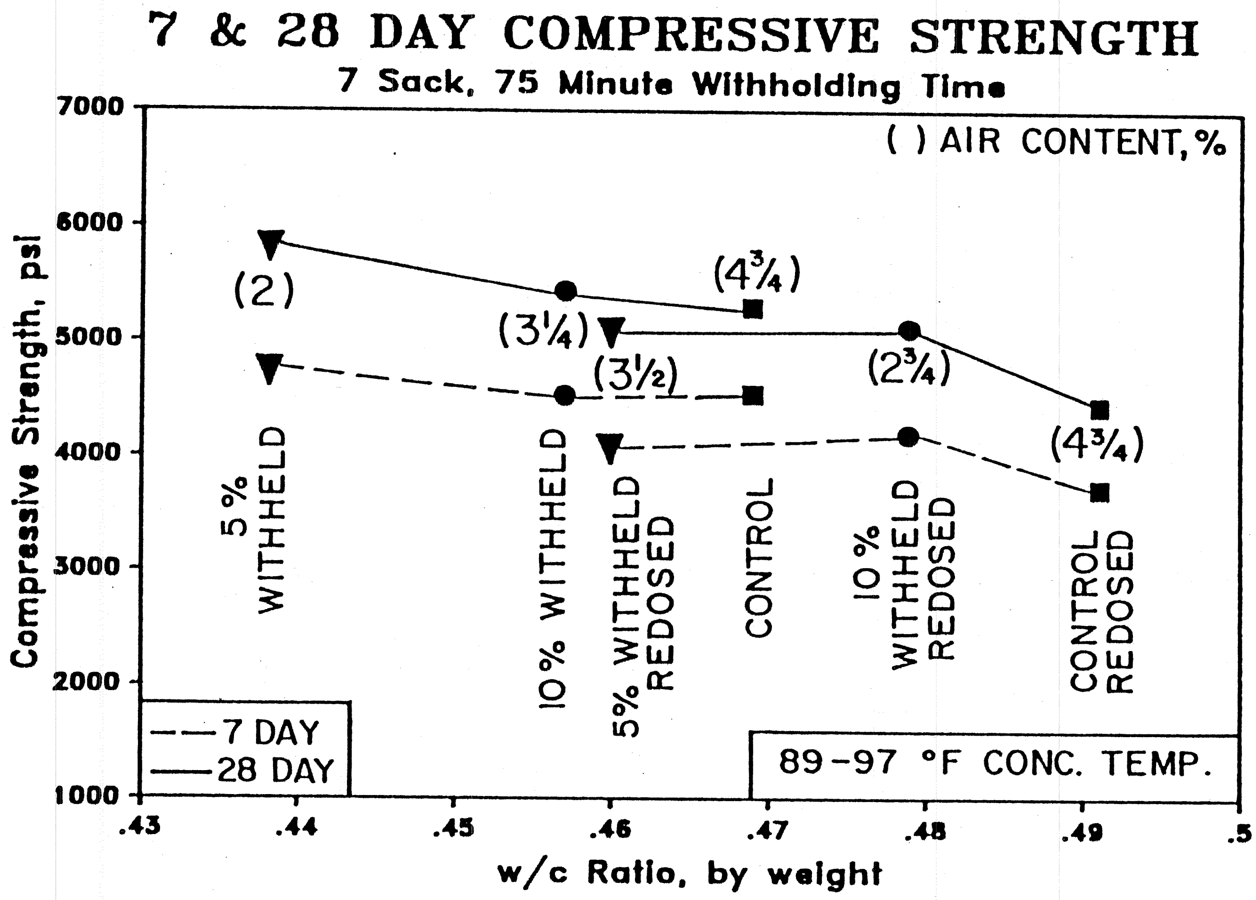

Figure 4.12 Compressive strength results of concrete in the 7-75 series.

Table 4.4 Effect of Extending the Mixing Time on the 28-Day Compressive Strength of the 7-45 Series.

(A) 28-Day Compressive Strength After Redosage:

Control Redosed	5790	psi
5% Withheld Redosed	4900	psi
10% Withheld Redosed	5160	psi

(B) 28-Day Compressive Strength After 30 Minutes Extended Mixing:

Control Redosed	6320	psi	(+9.2 %)
5% Withheld Redosed	5130	psi	(+4.7 %)
10% Withheld Redosed	5230	psi	(+1.3 %)

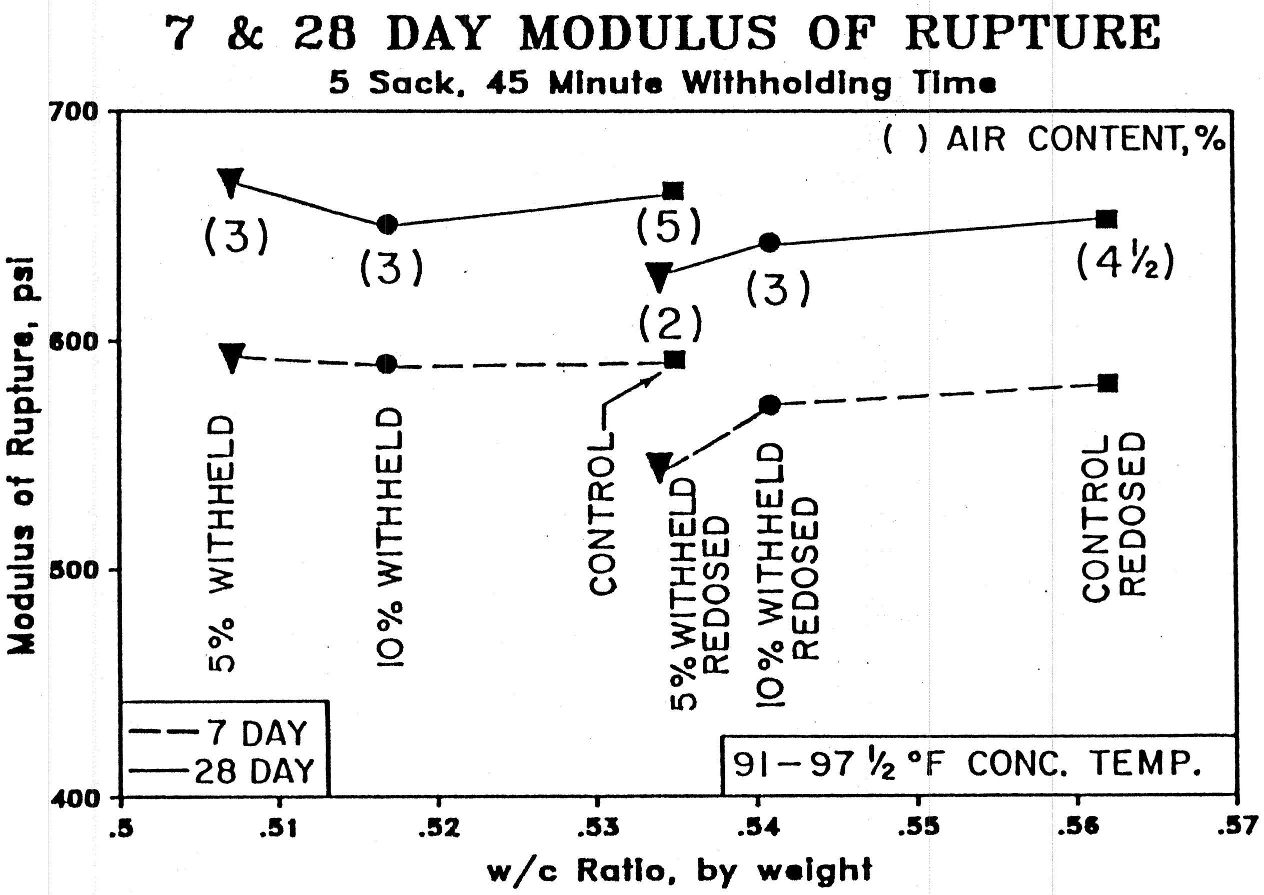

Figure 4.13 Flexural strength results of concrete in the 5-45 series.

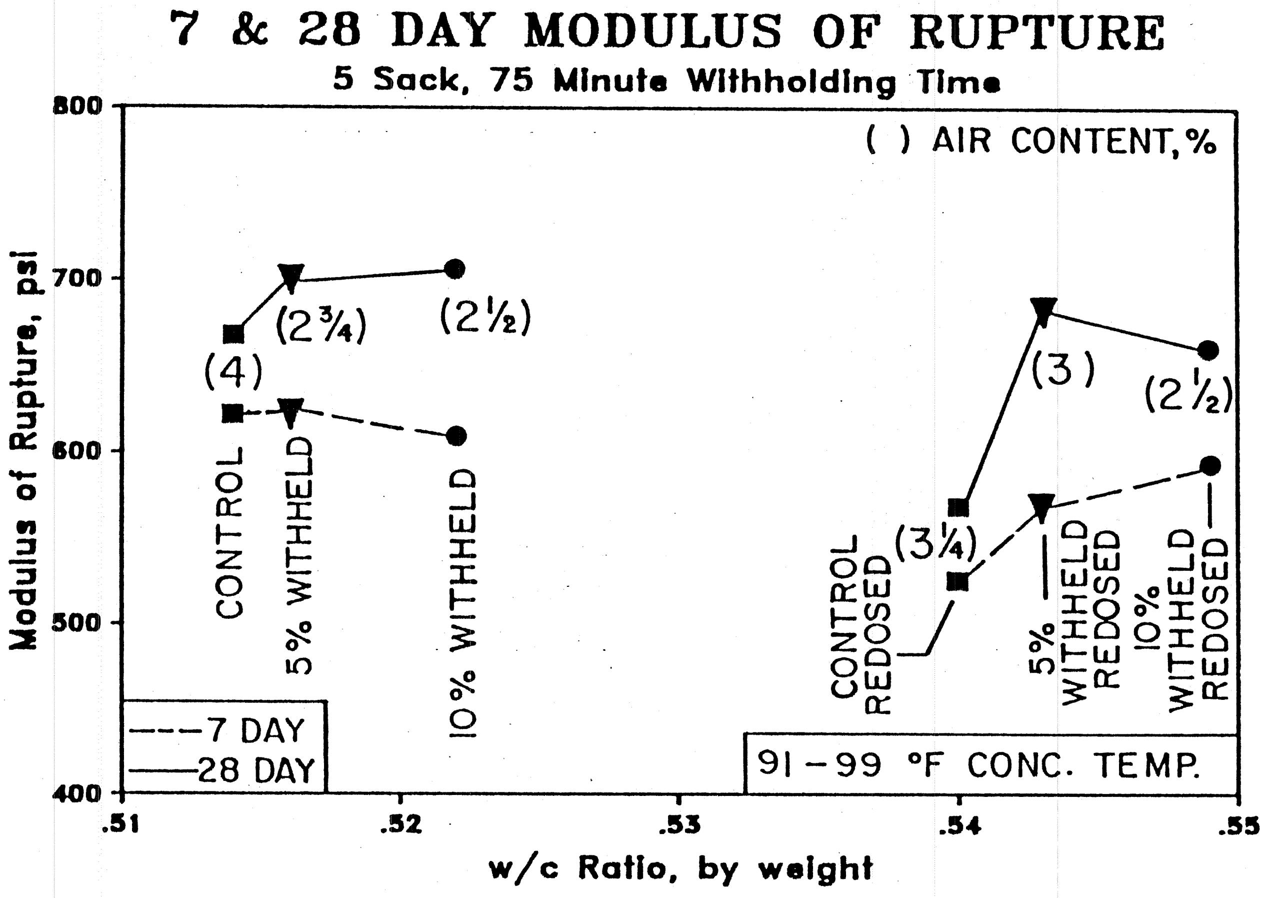

Figure 4.14 Flexural strength results of concrete in the 5-75 series.

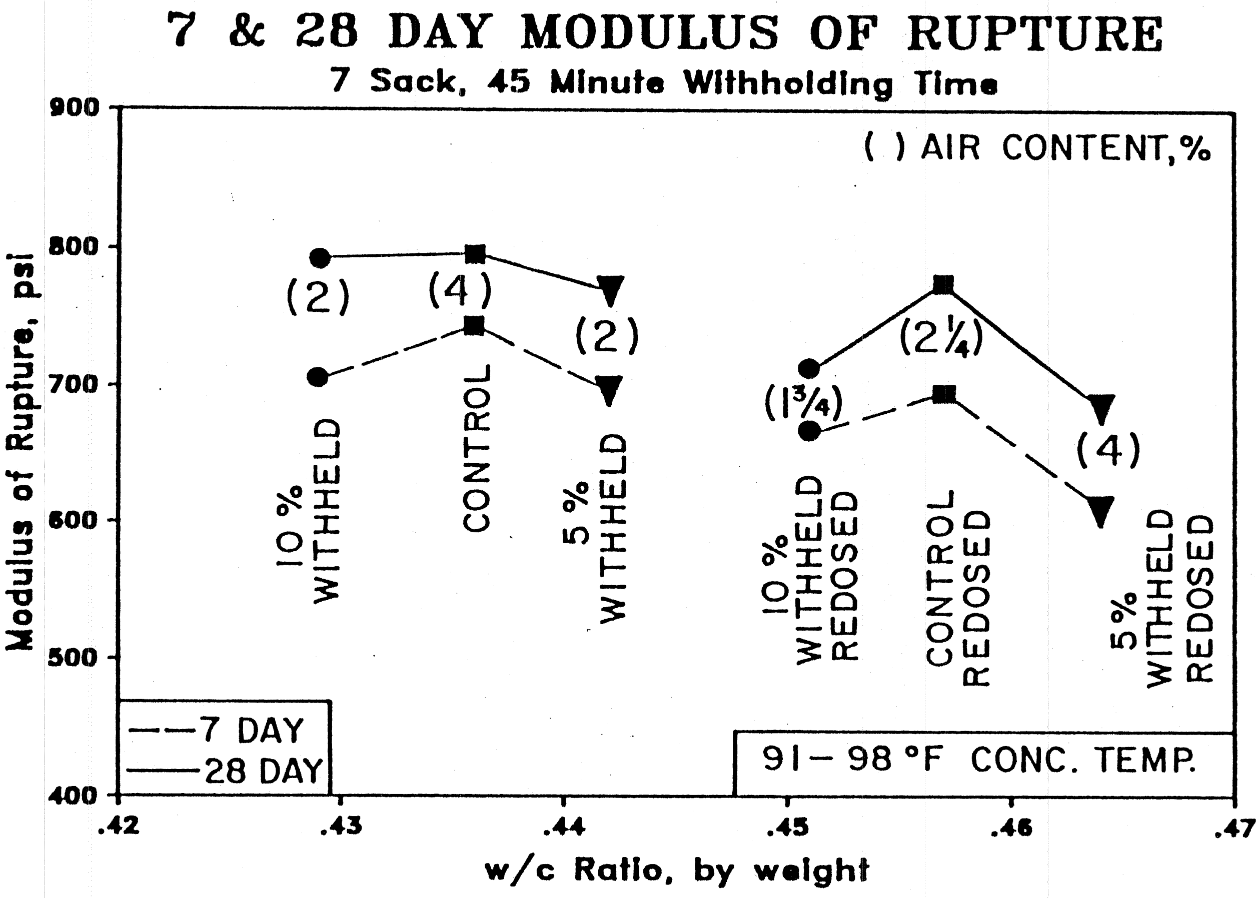

Figure 4.15 Flexural strength results of concrete in the 7-45 series.

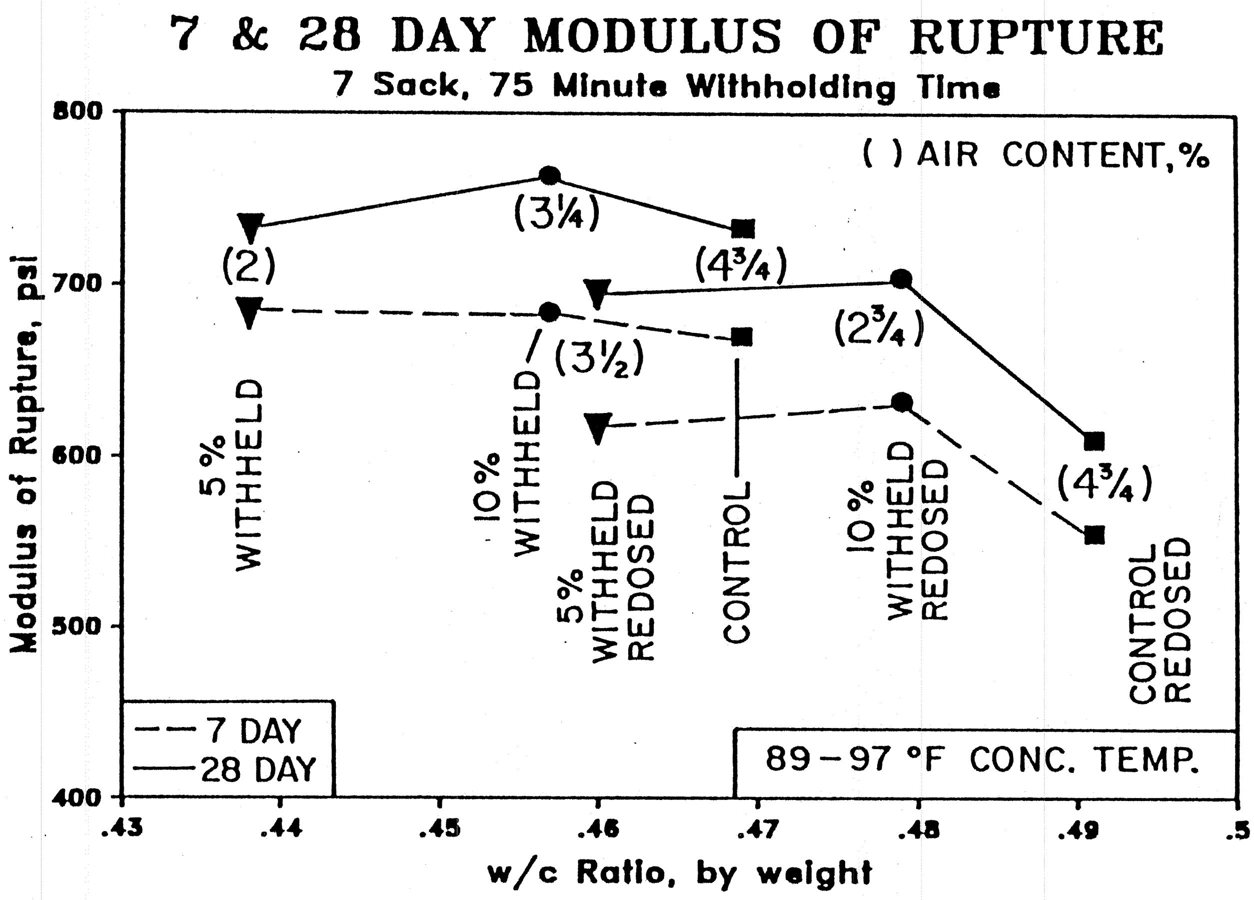

Figure 4.16 Flexural strength results of concrete in the 7-75 series.

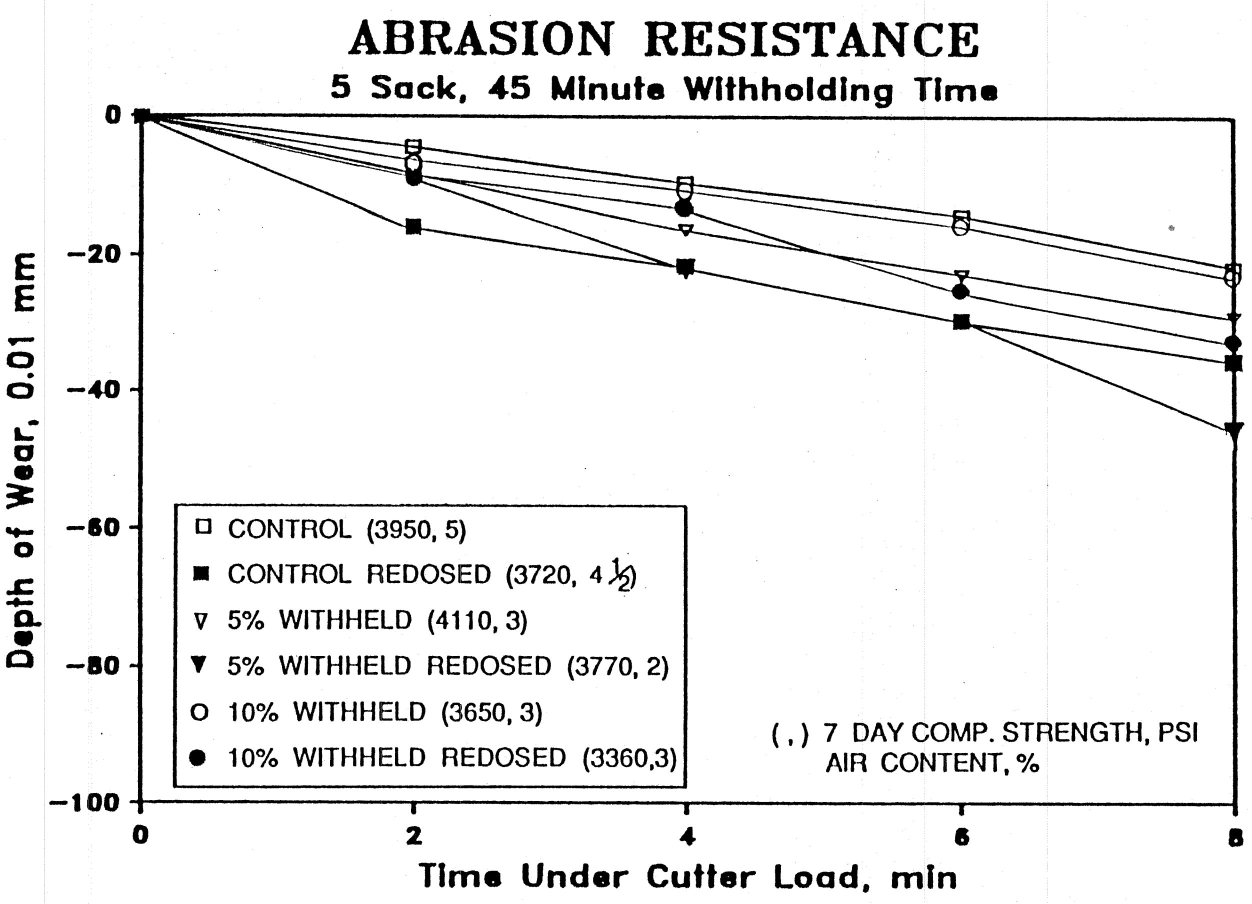

Figure 4.17 Abrasion resistance of concrete in the 5-45 series.

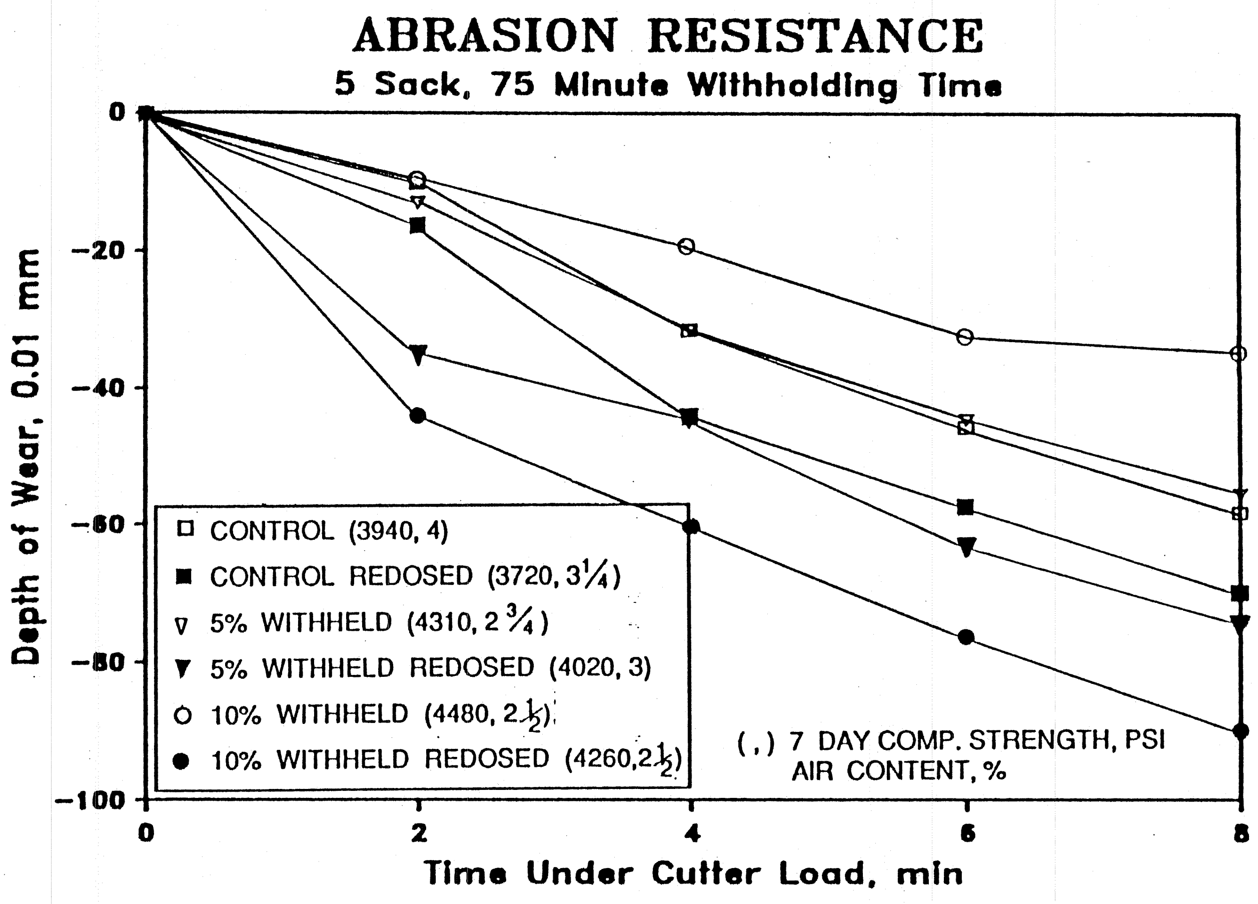

Figure 4.18 Abrasion resistance of concrete in the 5-75 series.

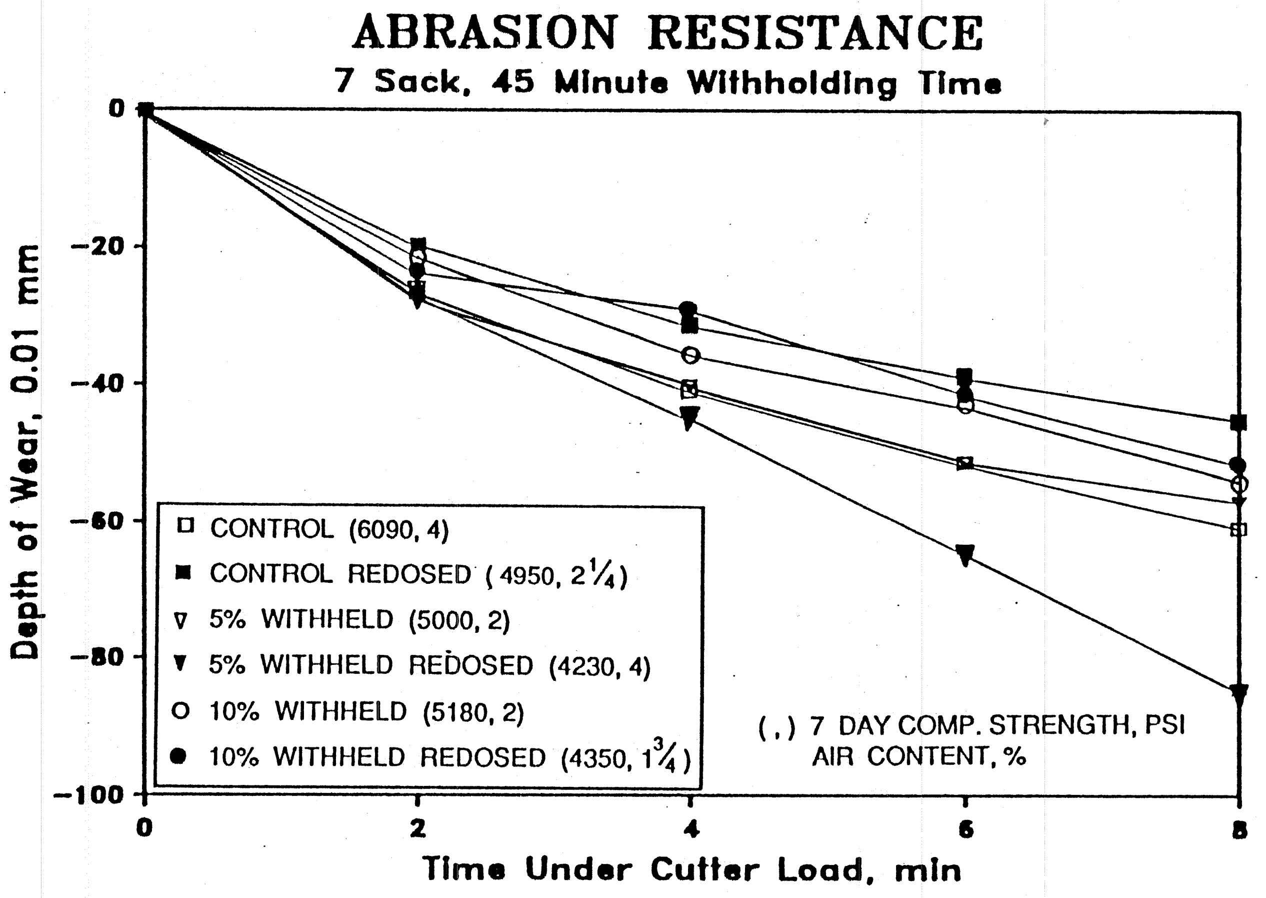

Figure 4.19 Abrasion resistance of concrete in the 7-45 series.

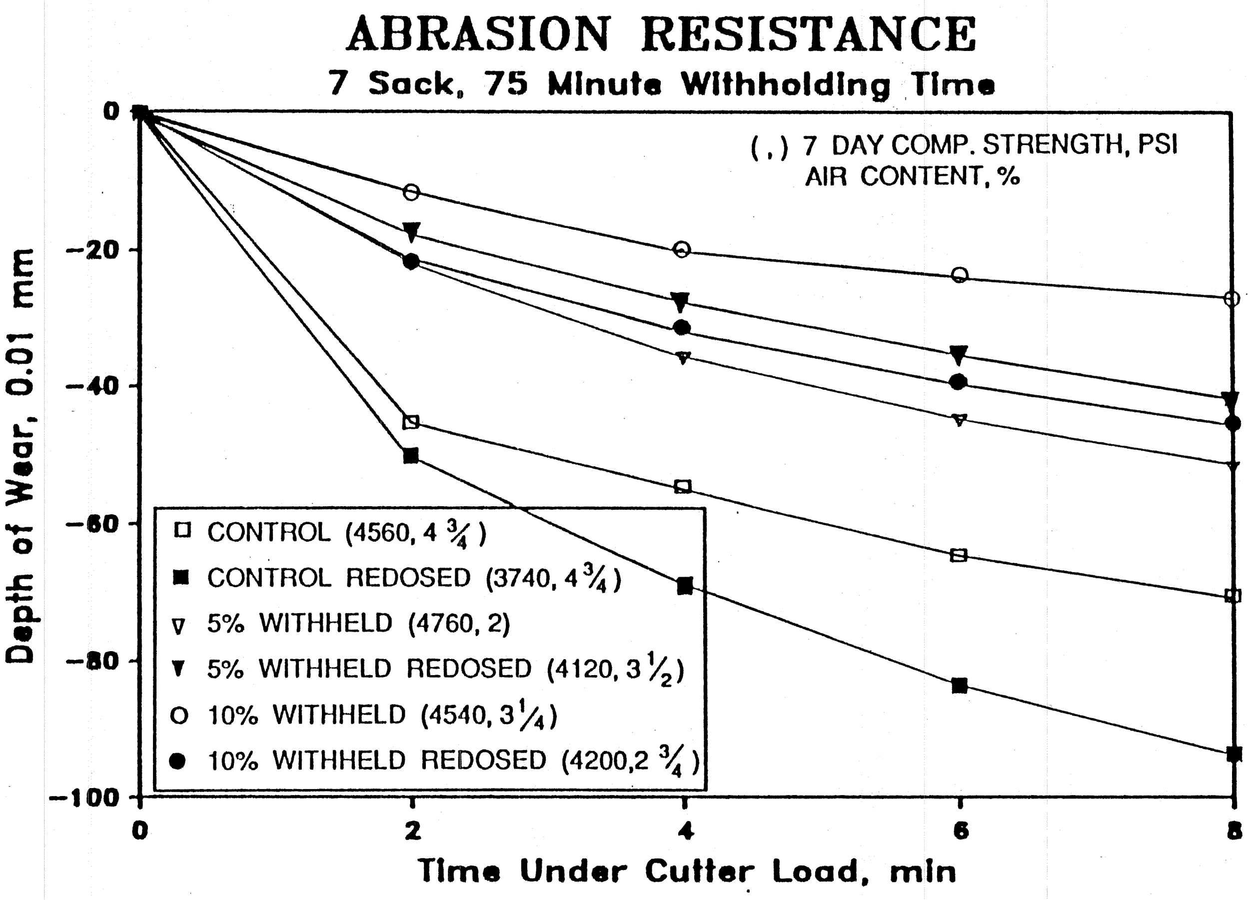

Figure 4.20 Abrasion resistance of concrete in the 7-75 series.

4.7 Freeze-Thaw Resistance

The freeze-thaw resistance of each specimen was determined according to ASTM C 666-84. Decay of the fundamental transverse frequency (FTF) with increase in the number of freeze-thaw cycles was used as a measure of the effects of freezing and thawing on the concrete. Two different calculations and plots were prepared for each mix series; the Durability Factor (DF) versus the number of freeze-thaw cycles and the decay of the Dynamic Modulus of Elasticity (DM) versus the number of freeze-thaw cycles. The dynamic modulus of elasticity was calculated according to the formula below:

$$DM = C\ W\ n^2 \qquad \text{Eq. 4.1}$$

where,

DM = dynamic modulus of elasticity, psi

C = a geometric constant calculated from beam dimensions

W = weight of the specimen in pounds

n = fundamental transverse frequency of the specimen in cycles per second.

The durability factor was calculated as the ratio of the square of the FTF after the specified amount of freeze-thaw cycles to the original FTF before the first cycle, expressed as a percentage.

All specimens for a given mix series were tested at one time, and termination of the testing for each specimen was specified at 300 cycles or when the relative dynamic modulus of elasticity reached 60 percent of the initial modulus.

Figures 4.21 to 4.24 present the durability factor versus the number of freeze-thaw cycles test results. Figures 4.25 to 4.28 present the dynamic modulus of elasticity versus the number of freeze-thaw cycles test results. Each figure for both the durability factor and the dynamic modulus corresponds to the specified mix series.

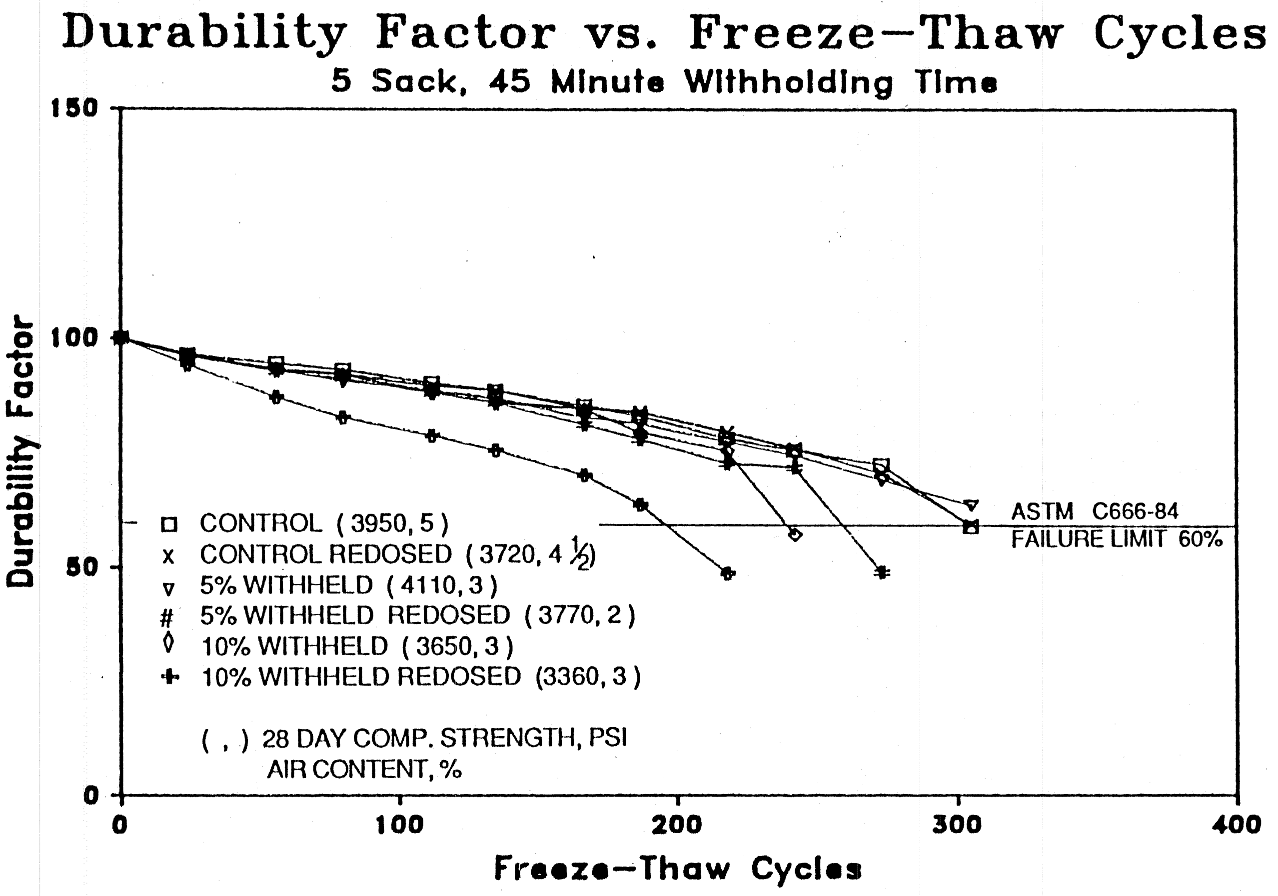

Figure 4.21 Durability Factor of concrete in the 5-45 series.

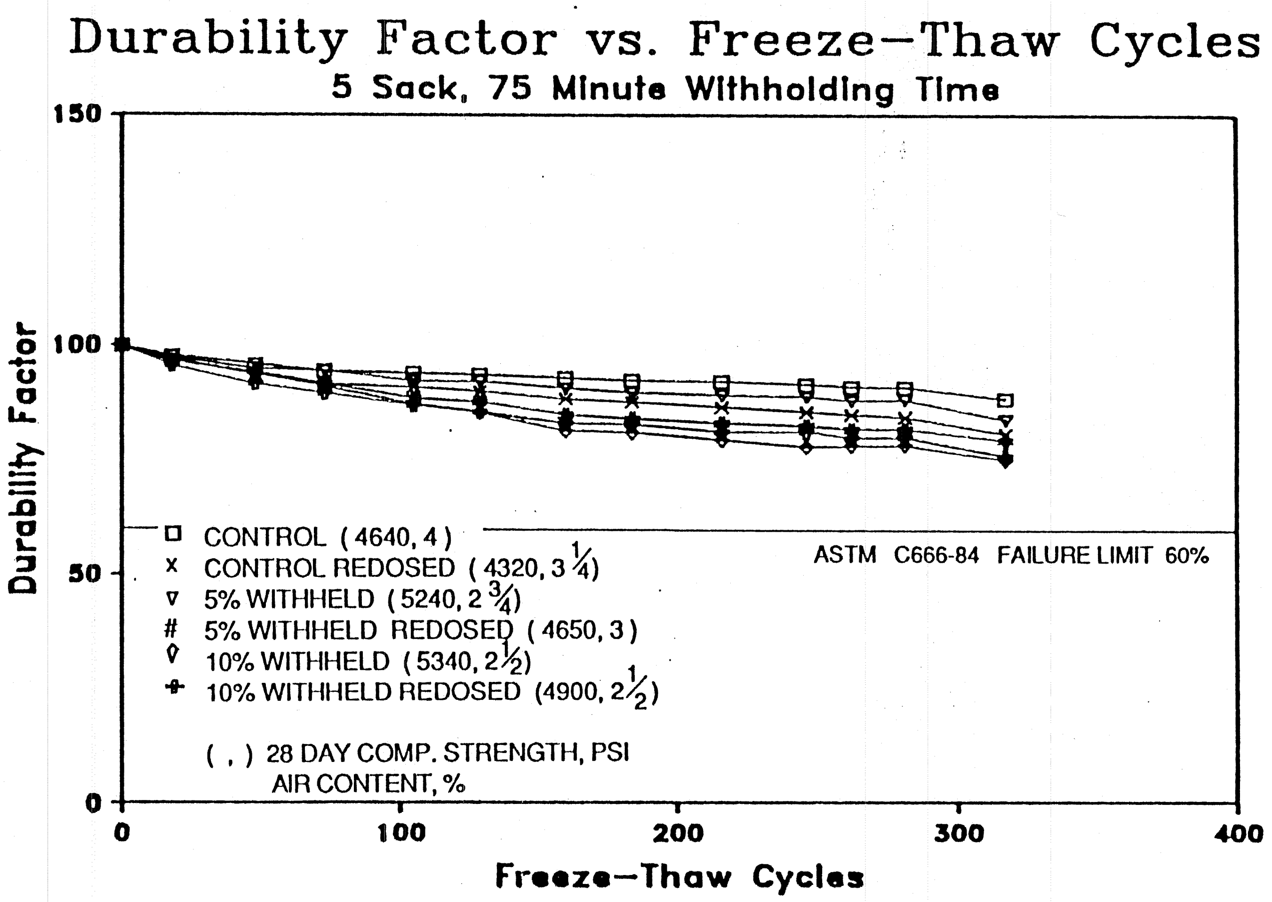

Figure 4.22 Durability Factor of concrete in the 5-75 series.

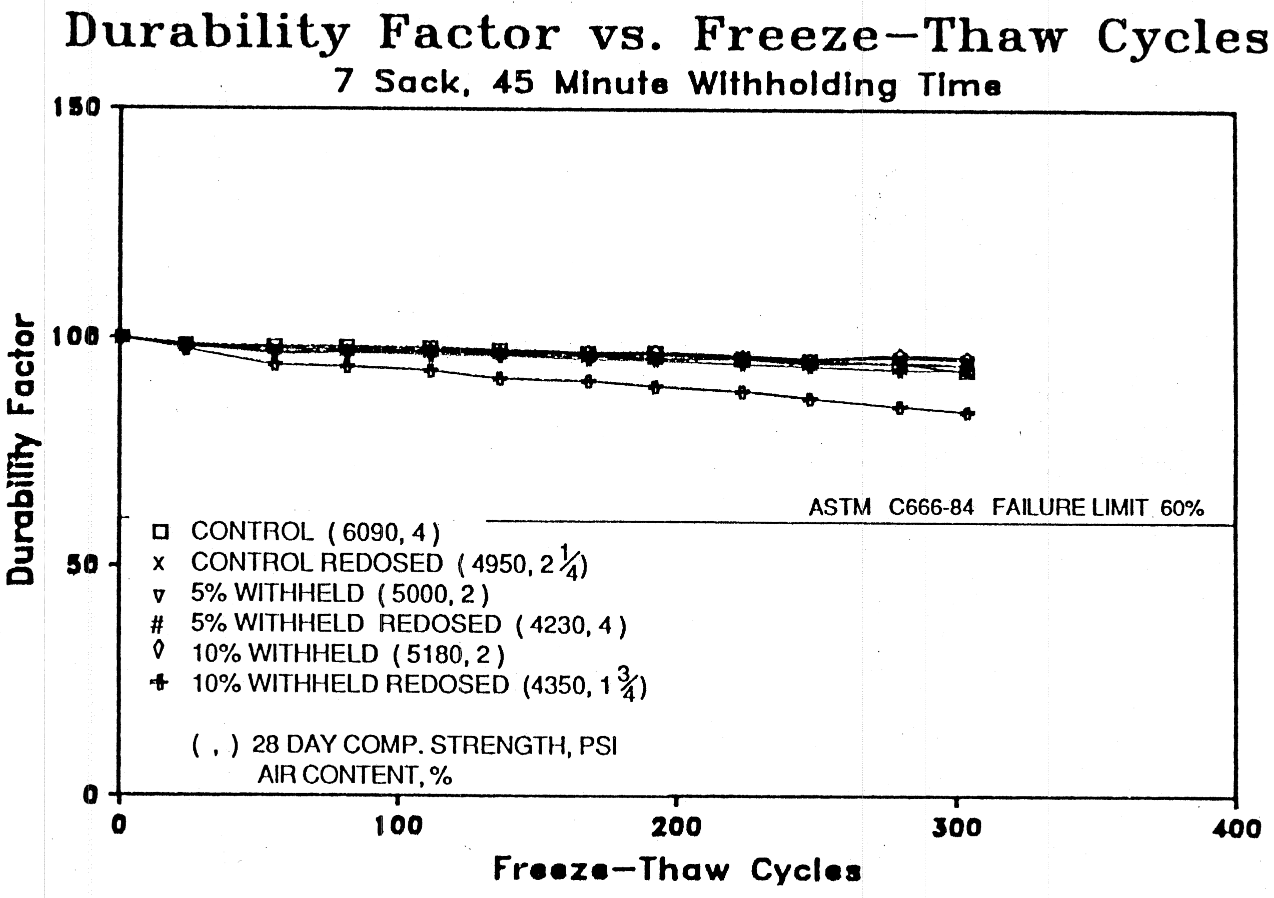

Figure 4.23 Durability Factor of concrete in the 7-45 series.

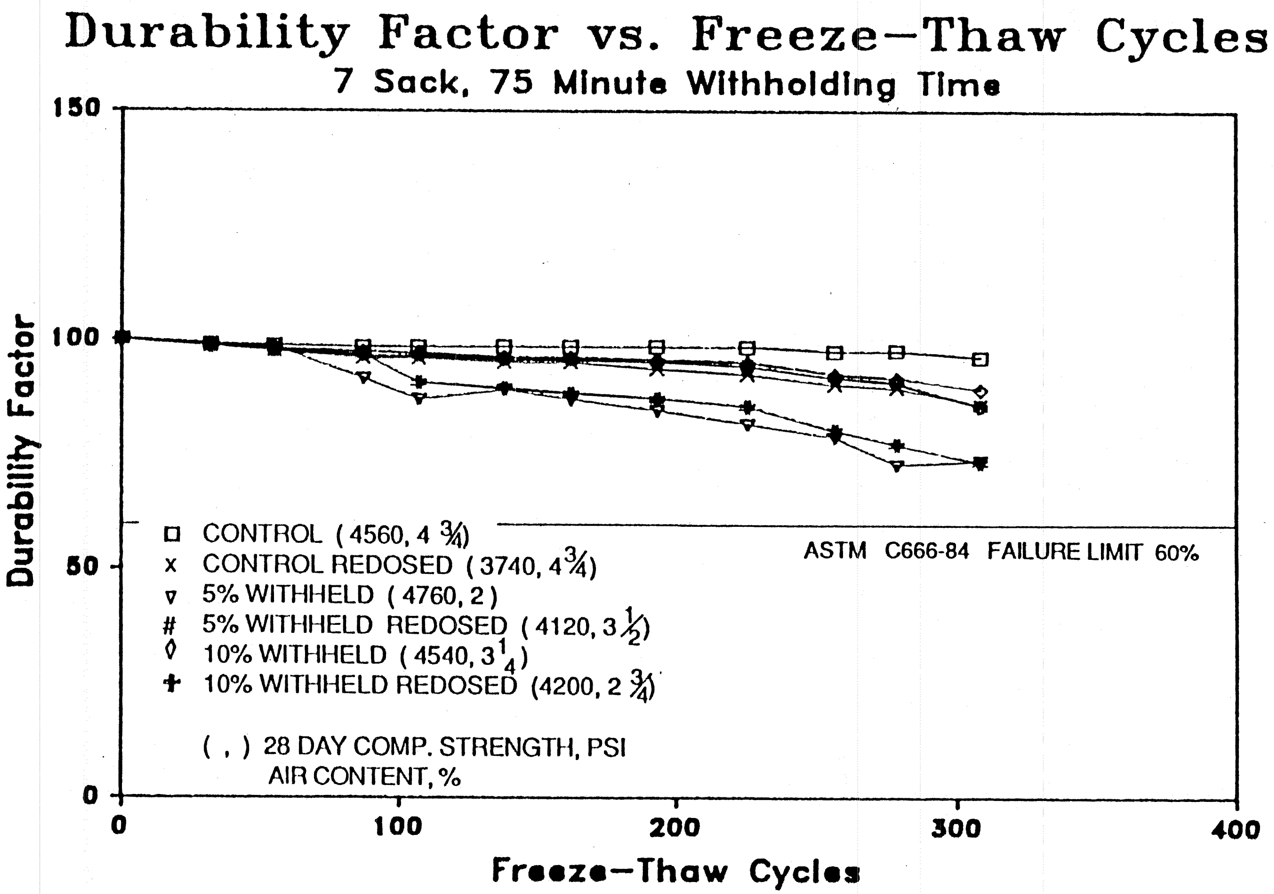

Figure 4.24 Durability Factor of concrete in the 7-75 series.

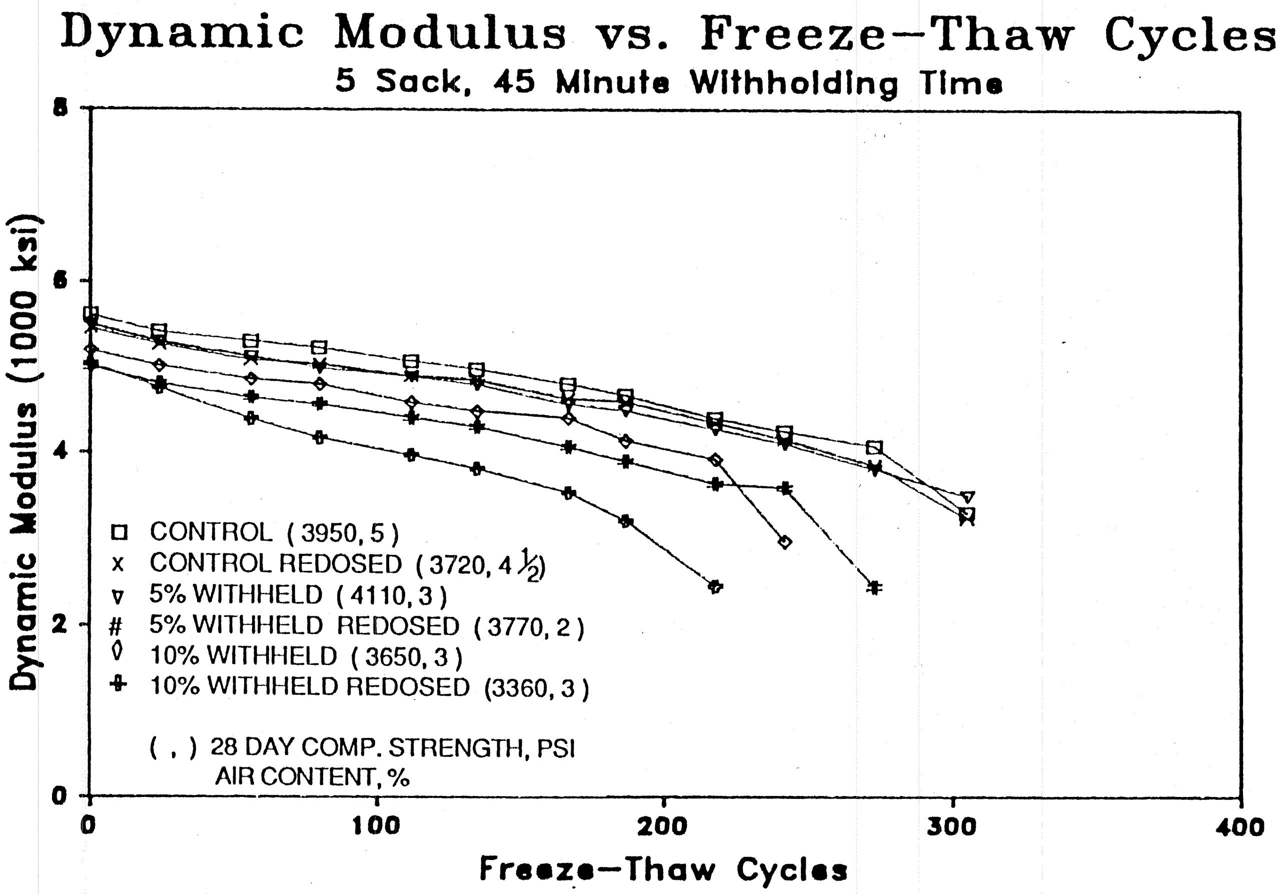

Figure 4.25 Dynamic Modulus of concrete in the 5-45 series.

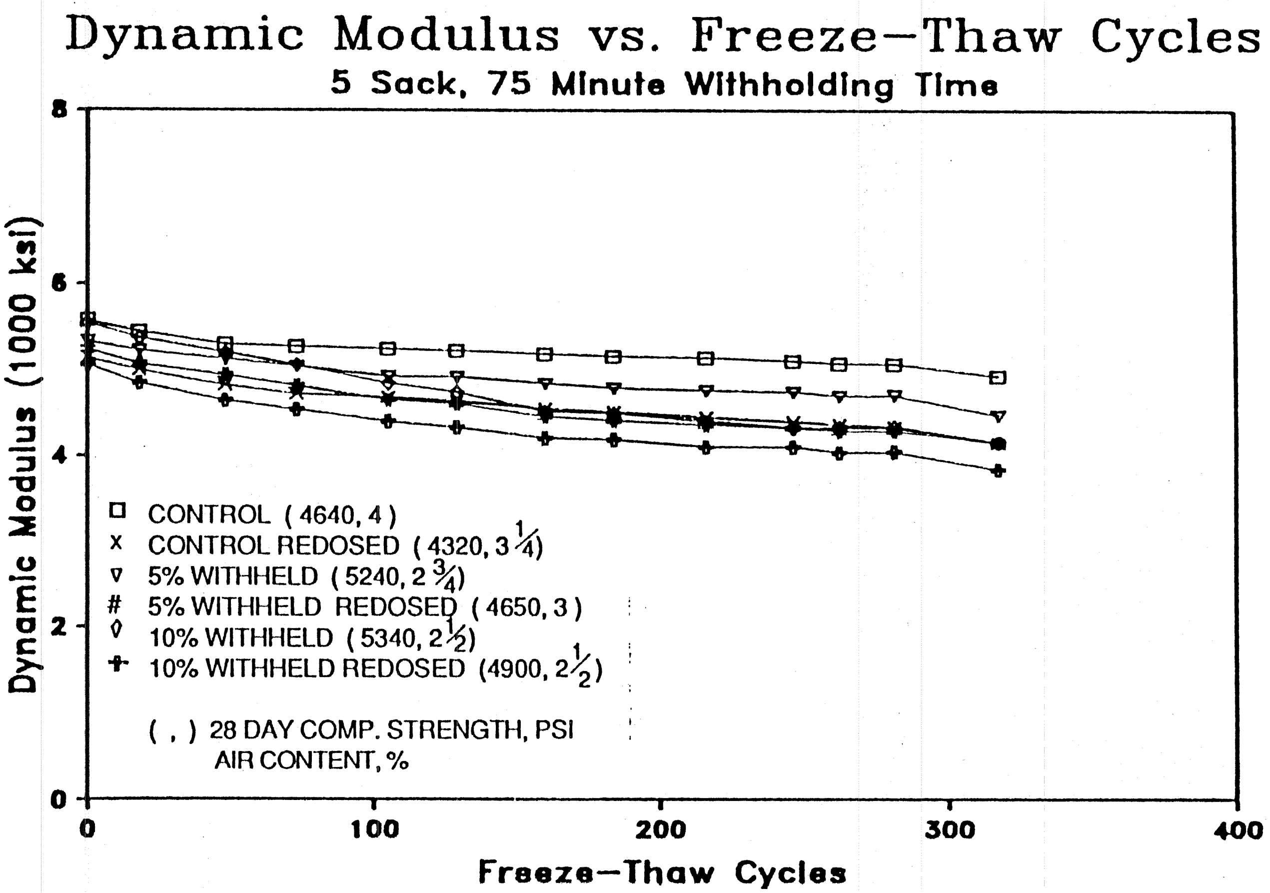

Figure 4.26 Dynamic Modulus of concrete in the 5-75 series.

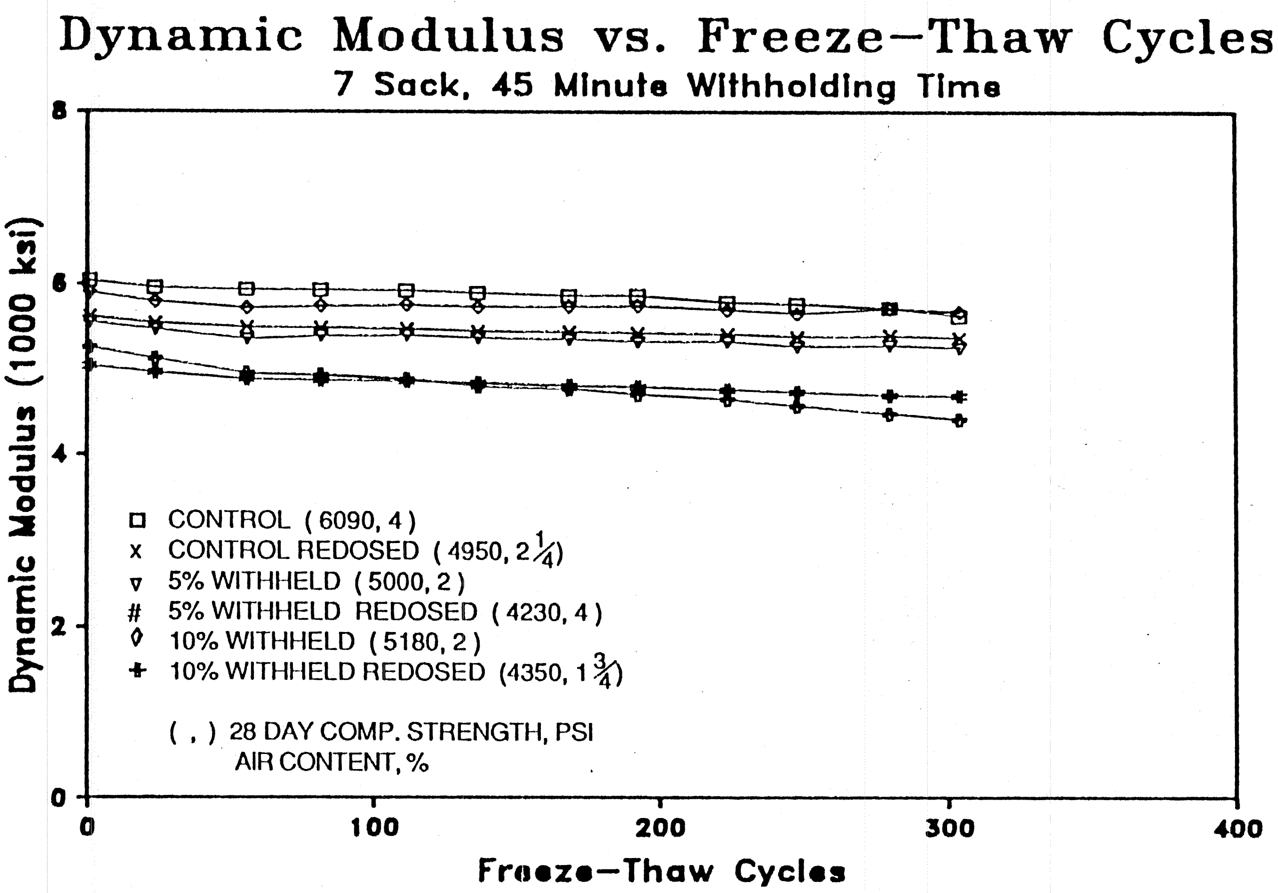

Figure 4.27 Dynamic Modulus of concrete in the 7-45 series.

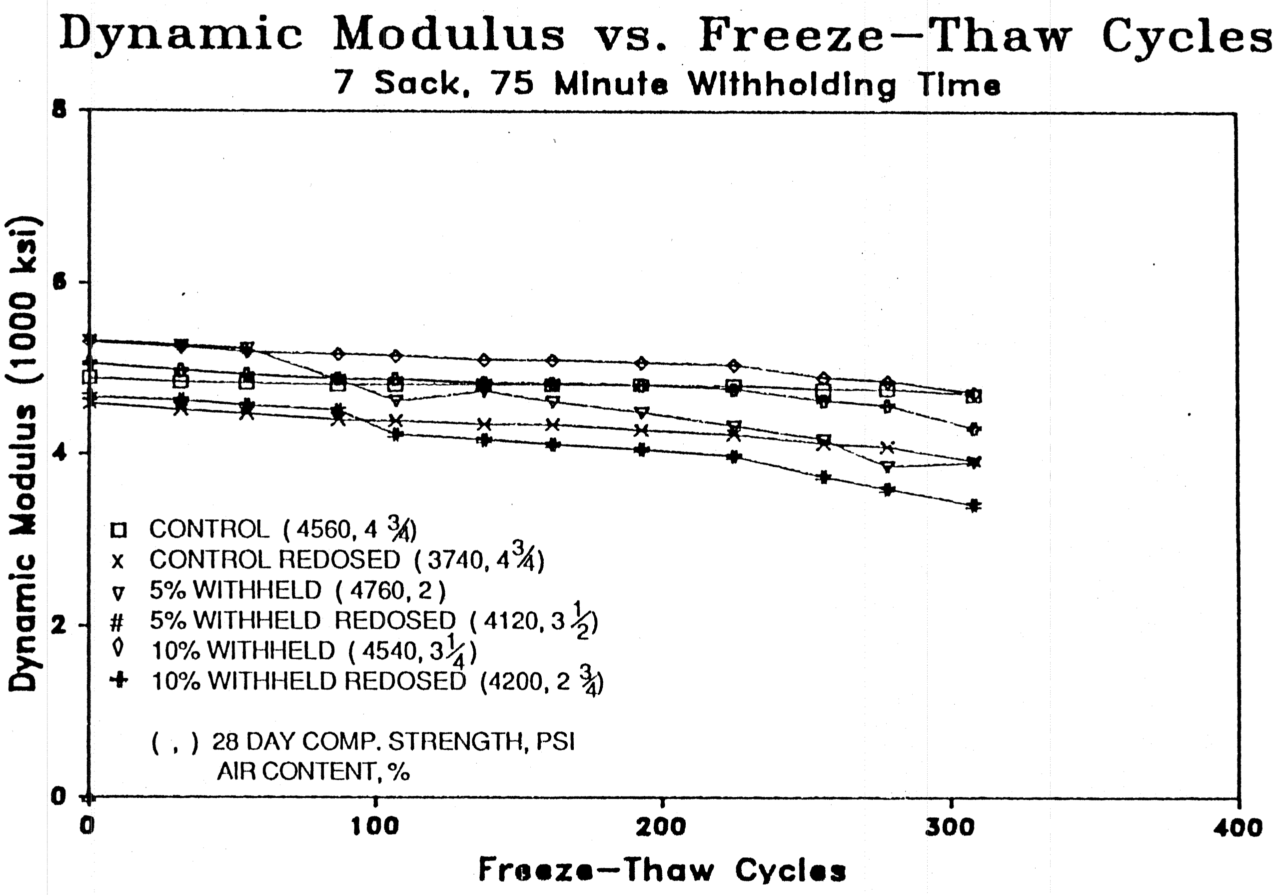

Figure 4.28 Dynamic Modulus of concrete in the 7-75 series.

CHAPTER 5

DISCUSSION OF RESULTS

5.1 General

A discussion of the test results presented in the previous chapter is given in this chapter. Trends in the data and comparison of these test results to those of previous research are presented. A summary and conclusions obtained from this investigation are presented in Chapter 6.

Whenever "initial addition" is specified, it is hereafter referring to properties of the concrete after the initial addition of the withheld mixing water at the given time of withholding. Similarly, reference to "retempering" indicates the concrete after initial addition unless specified otherwise. For control mixes, since no water is added at initial addition, properties refer to the concrete without any addition but sampled at the given time of withholding. Whenever "redosage" is specified, it indicates properties after redosage of the concrete with five percent additional mixing water 30 minutes after the time of initial addition.

5.2 Effect of Retempering on Slump

The target slump for all control mixes was specified as three to six inches at the time of initial addition. All the control trucks for the four different series examined remained within this specified range.

Increasing the withholding time from 45 minutes to 75 minutes has a pronounced effect on the slump of the retempered mixes. Figures 5.1 and 5.2 show a summary of the slumps for all the mixes. Examination of Figures 5.1 and 5.2 shows that the slump of retempered mixes for a 45 minute withholding time were about equal to or slightly greater than that of the corresponding control mix for three of the four mixes examined. This is despite an accompanying loss of air, which would tend to reduce workability. In contrast to this, the slump for the mixes examined with a 75 minute withholding time are up to 2.0 inches less than that of the corresponding control truck at the time of initial addition. This was the case for all four of the mixes examined. The loss in air for these mixes was similar to that of the 45 minute withholding time mixes. This reduced slump for the 75 minute mixes indicates a loss of workability

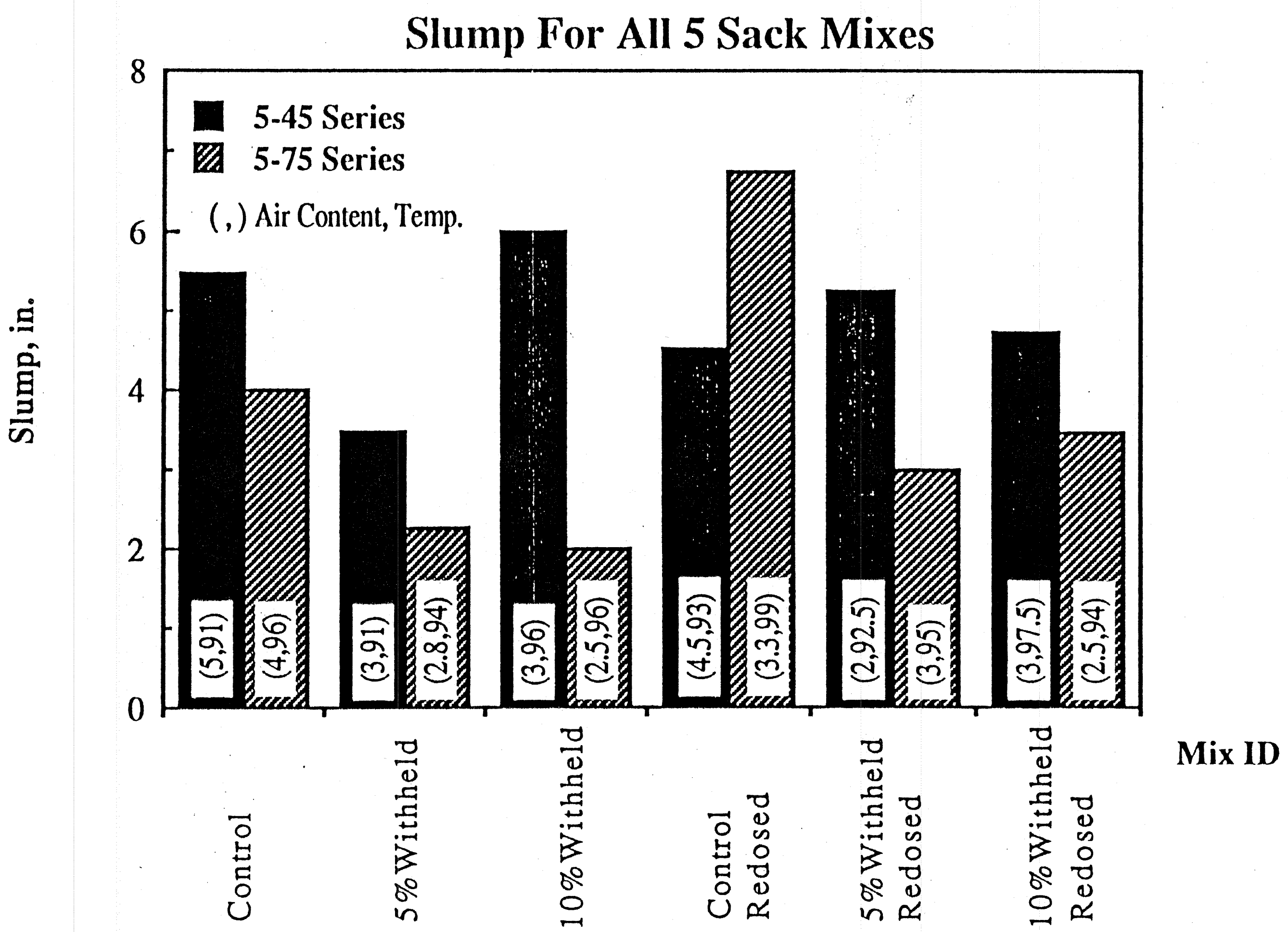

Figure 5.1 Summary of the slump of concrete for the 5 sack mixes.

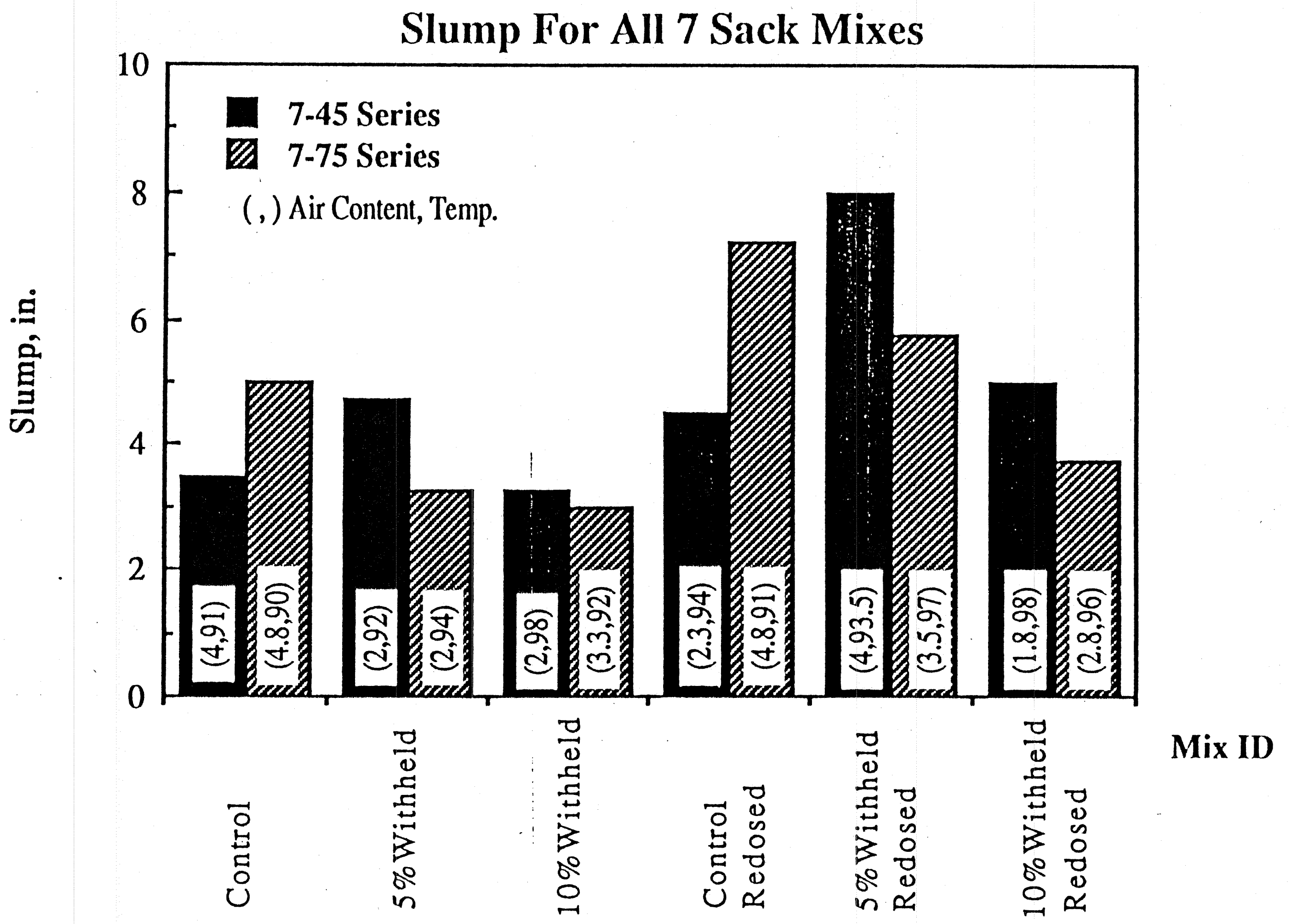

Figure 5.2 Summary of the slump of concrete for the 7 sack mixes.

accompanying withholding and later addition of mixing water as compared to that of the control mixes having similar mixture proportions in which there was no retempering. Therefore, if the same slump is to be obtained at placement of the retempered concrete mixes, more water is required than if all the water were added at initial batching, as was the case for the control mixes. This will result in a lower quality concrete due to the increased water-cement ratio. The temperature of the five and ten percent withheld trucks tended to be greater than that of the corresponding control trucks for the seven sack mixes. The temperature of the five and ten percent withheld trucks for the five sack mixes was about equal to that of the corresponding control trucks. This included temperatures measured at both initial addition and redosage. Since all trucks in a given series were batched on the same day within two hours of each other, temperatures were expected to be approximately the same at initial batching. For a higher cement content of seven sacks as compared to five sacks, withholding water resulted in a higher temperature for the mix. This greater temperature accounts for some of the lost workability for the five and ten percent trucks with a 75 minute withholding time. The greatest temperature differential was seven degrees Fahrenheit, which could account for some slump decrease.

In general, redosage of the concrete resulted in increased slump, independent of cement content, withholding time, and withholding amount. The amount of increase however was not the same for all the mixes examined. Upon redosing, the slump increase was smaller for the five and ten percent withheld mixes as compared to the control mix for the two 75 minute withholding time series. The slumps after redosage for the 45 minute withholding time are about equal, except for the five percent withheld truck in the 7-45 series. This truck showed a significant increase in workability upon redosage. An increase in air content accompanied redosage for this truck, which helps account for the increased workability. There was no increase in air for the ten percent truck for this series, therefore giving no benefit in increased workability. For a 75 minute withholding time, redosing with more than five percent mixing water will be required to restore the slump of the concrete to that of the control mix redosed with five percent mixing water.

Slump loss after initial addition appeared to be about the same for all the trucks in a given series. This can be seen by the similar slope of the lines connecting data points after the addition of water in Figure 5.3 which shows the 7-75 series as a typical example. Since all slumps were approximately in the same range, similar slump loss is expected, since slump loss is believed to be dependent upon initial slump. These results are in agreement with those reported by both Previte and Ravina, who indicated that slump loss is dependent on initial slump level. [27,29]

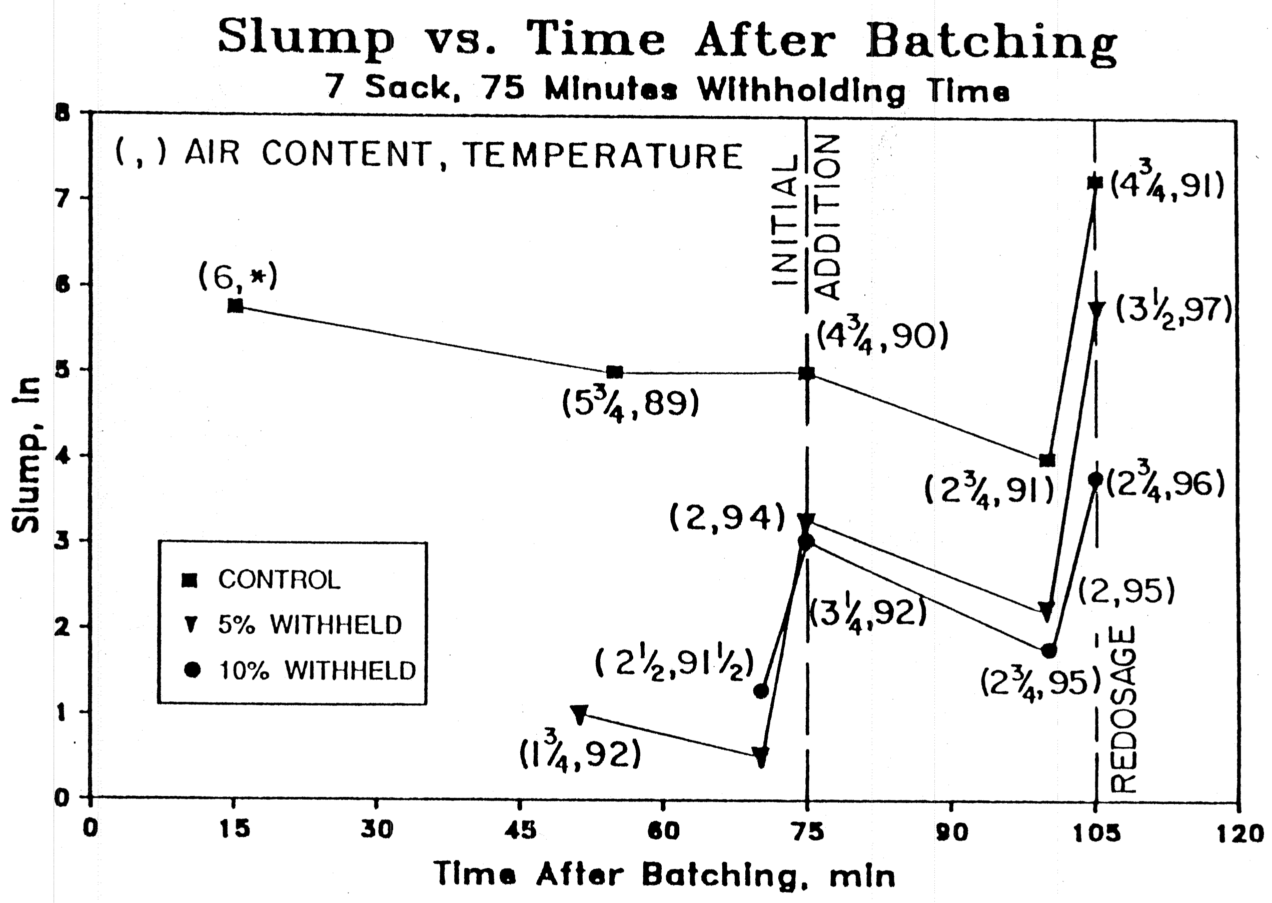

Figure 5.3 Slump of concrete in the 7-75 series.

In summary, withholding of mixing water at initial batching and retempering not to exceed the design mixing water does not have any advantages in terms of improving slump. In general, redosage of the concrete resulted in increased slump, but did not offset any disadvantages occurring with withholding and retempering. For a withholding time of 45 minutes, slumps of the retempered trucks were approximately equal to that of the trucks in which all mixing water was added at initial batching, whereas for a 75 minute withholding time the slump for the retempered trucks was lower.

5.3 Effect of Retempering on Air-Entrainment

The target air content for the control mixes of each series was specified as four to six percent of the concrete by volume. All the control mixes for the four series examined remained within this specified range.

The withholding and later addition of mixing water affects the air content. Figures 5.4 and 5.5 summarize all the air contents for the five sack and seven sack mixes. Examination of these figures shows that the five and ten percent withheld mixes had air contents which were less than their corresponding control mix after initial addition for all eight of the experimental mixes examined. This loss in air is partly due to the decreased slump accompanying withholding of water at initial batching.

The increased temperatures of the five and ten percent withheld trucks could help account for some of the air lost when water is withheld at initial batching. Increased temperatures have been shown to decrease the effectiveness of an AEA. [23] This, combined with the lower slump created by the reduction in mixing water, would explain the lower air contents determined upon retempering with the withheld mixing water. This is in agreement with results previously reported and discussed in Section 2.4.2.1. An increase in air-entraining agent dosage at batching was necessary when withholding time was increased in order to achieve a given air content, due to a loss of air with the longer agitation period accompanying increased withholding time. Once similar air contents were achieved for the control mix at the specified time of withholding, the effects of retempering do not appear to differ with an increase in the withholding time. For 3/4 inch maximum size aggregate, entrapped air is usually present in the amount of 3 percent for concrete with a cement content of 5 sacks per cubic yard and 2-1/2 percent for concrete with a cement content of 7 sacks per cubic yard. [23] The control trucks showed the presence of entrained air with air contents ranging from 4 to 5 percent at the time of initial addition in all series. Figures 5.4 and 5.5 show that

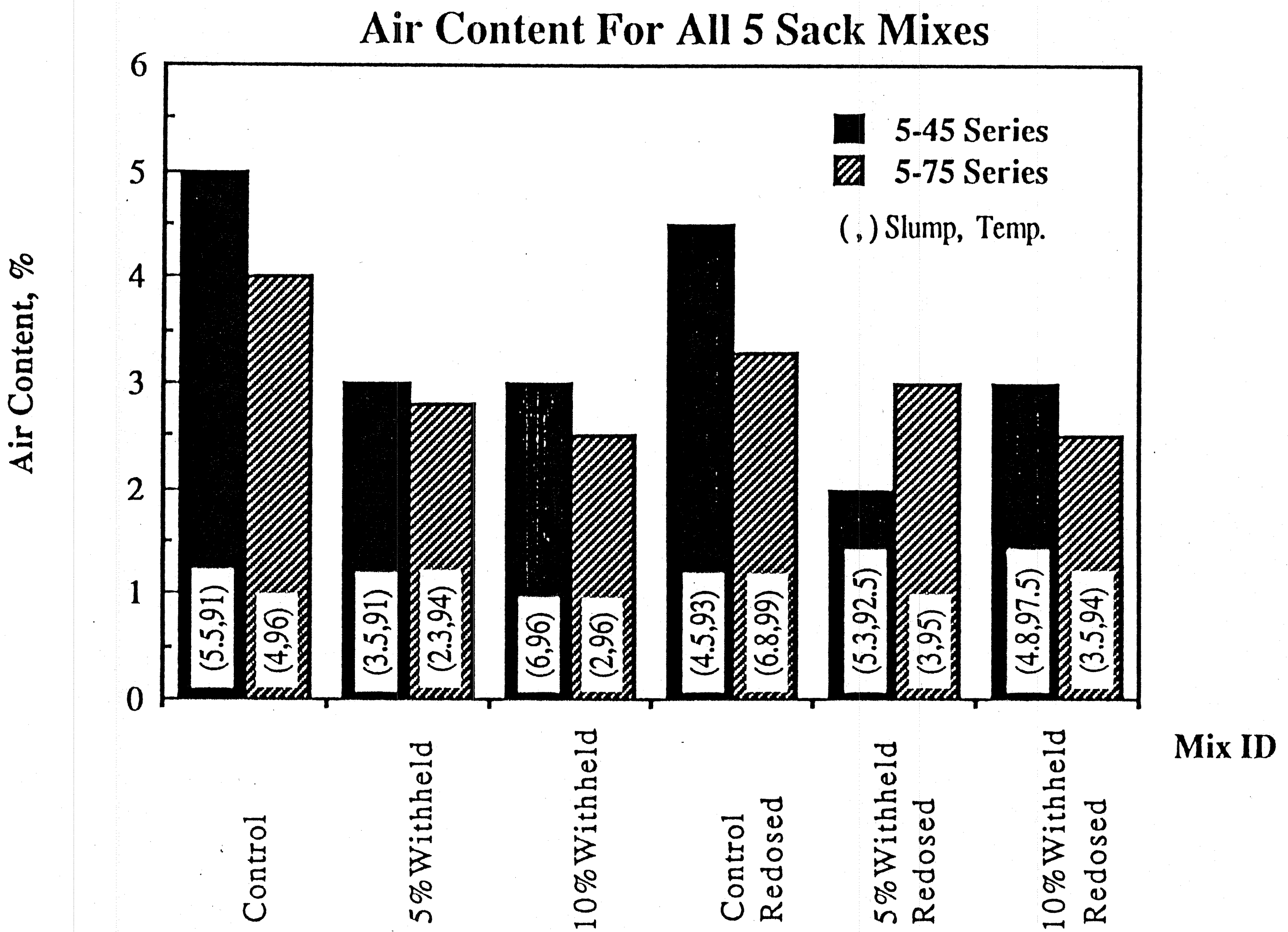

Figure 5.4 Summary of the air content of concrete for the 5 sack mixes.

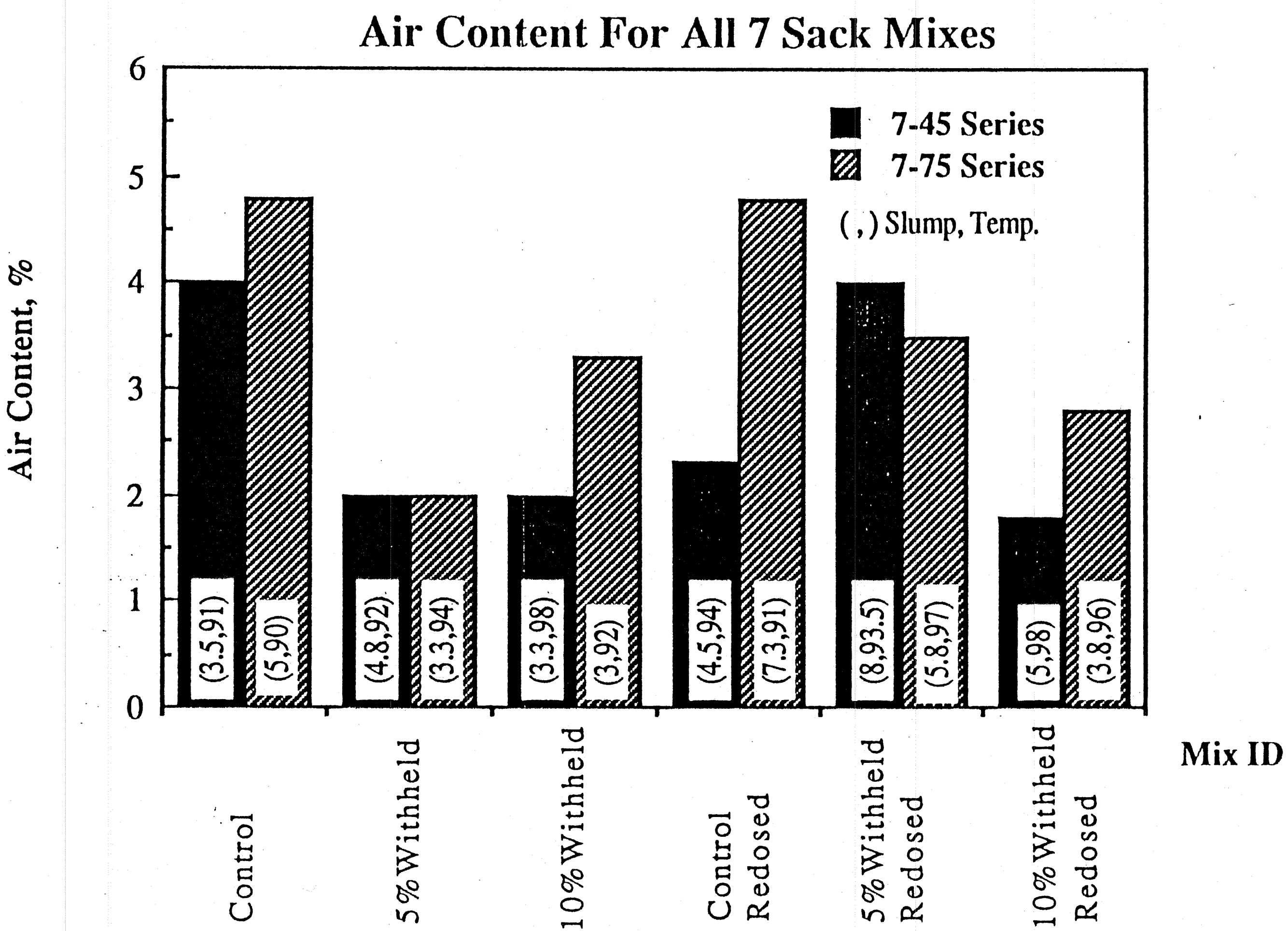

Figure 5.5 Summary of the air content of concrete for the 7 sack mixes.

for each given cement content, withholding mixing water with later addition results in a loss of almost all entrained air. This occurred for all mixes in both the 45 minute withholding time and the 75 minute withholding time.

Figure 5.6 shows the air content versus time for the 7-45 series as a typical example. The figure shows that the air contents were variable upon redosage with the addition of more mixing water. Air contents increased or decreased with retempering and redosage for all the series examined, and this is exemplified in Figure 5.6. The literature presented in Section 2.4.2.3 of this report indicated that conflicting results arose from previous studies, with some reporting increased air contents upon redosage and others reporting decreased air contents upon redosage. Therefore the variations in how the air content behaves upon redosage for this study support the conflicting results reported previously. Prediction of how the air content will behave upon redosage is therefore not possible, leading to questions for an engineer regarding the durability of concrete which has been redosed.

In summary, withholding of mixing water at initial batching and retempering does not have any advantages in terms of entrainment of air. Loss of almost all entrained air occurs with withholding and retempering for all the mixes examined. Increased dosages of AEA are required to accomplish satisfactory air contents for the concrete when the time to placement or sampling increases. Prediction of the behavior of the air content upon redosage was not possible, leading to questions regarding production of quality, durable concrete.

5.4 Effect of Retempering on Compressive Strength

The compressive strength results for the mixes examined showed very little effect caused by the withholding and later addition of mixing water. The 28-day compressive strength of any one test differed by no more than 9.4 percent from the average of three trucks with a similar water-cement ratio in a given series. The average standard deviation for 28-day compressive strength between groups of three mixes in a series was 276 psi for the five sack mixes and 409 psi for the seven sack mixes, including both initial addition and redosage of the concrete. A standard deviation of 500 to 600 psi is considered good quality control. Excellent quality control is indicated by the standard deviation being 300 to 400 psi. [7] The maximum standard deviation occurring for this study was 516 psi indicating that the worst result was still within a range where quality is considered good. The results for the differences among the strengths between control trucks, five percent withheld, and ten percent withheld trucks may be considered as normal variations which

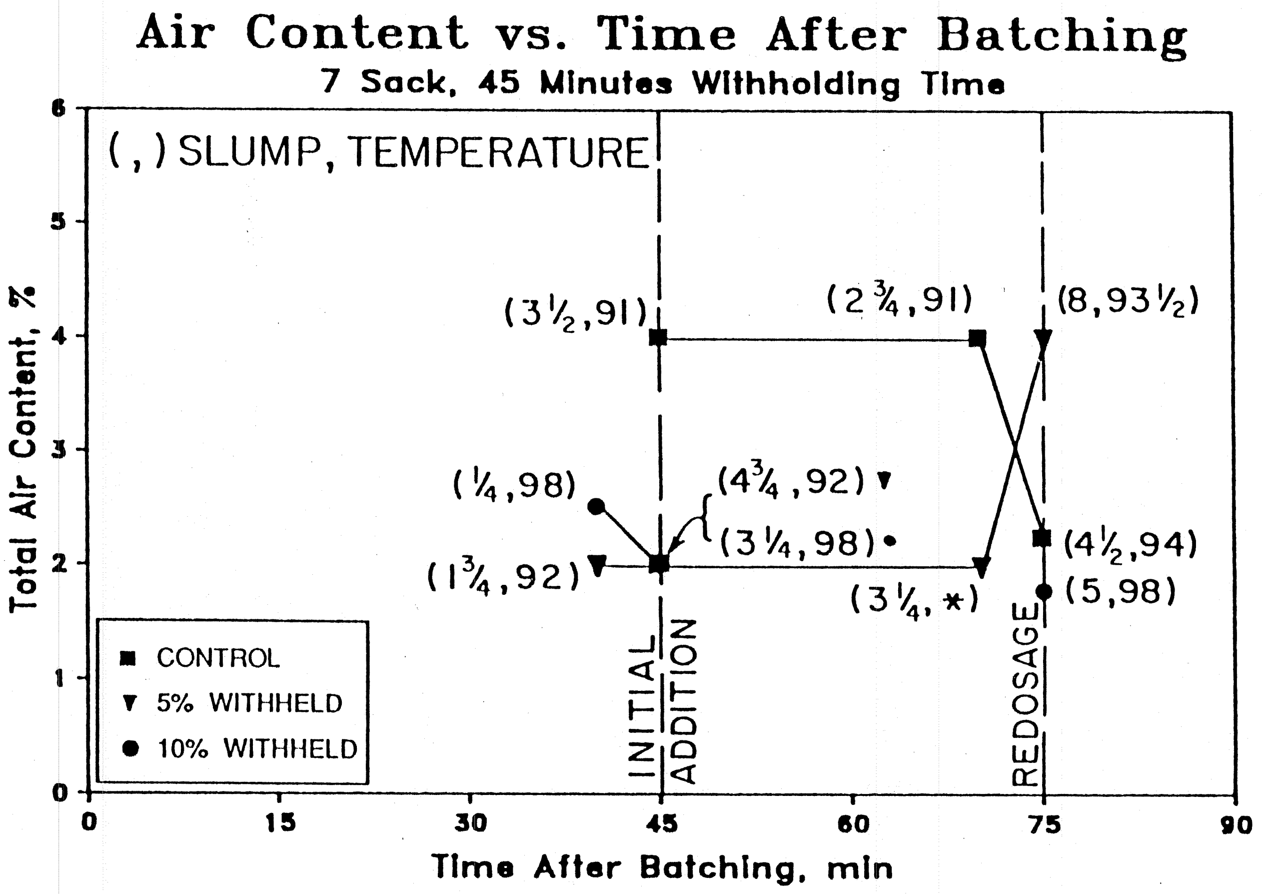

Figure 5.6 Air content of concrete in the 7-45 series.

occur in ready-mixed concrete production. Therefore, withholding and later addition of the withheld mixing water up to 75 minutes does not have any significant effects on the compressive strength of the concrete produced.

Figure 5.7 shows good correlation between the 7-day and 28-day compressive strengths with water-cement ratio. This, coupled with the good to excellent standard deviations encountered tends to strengthen the hypothesis that the final water-cement ratio is the governing factor controlling the strength of retempered concrete. Previous literature cited in Section 2.5.1 is in agreement with this result.

The compressive strength gain characteristics from 7 to 28 days are similar for all the mix series examined. Figure 5.8 shows that the ratio of 7-day to 28-day compressive strengths remains fairly constant at 0.85 with a standard deviation of 0.020 for all the mixes examined. Retempering therefore appears to have no effect on the compressive strength gain of concrete from 7 to 28 days.

Redosage of the concrete with an additional five percent mixing water did consistently reduce the compressive strength of all the mixes examined. Figure 5.9 shows that a reduction in both 7-day and 28-day compressive strength occurred for all mixes upon redosage. Reduction of the 28-day compressive strength was greater for the seven sack mixes than the five sack mixes, with the average reductions being 13.8 percent and 7.3 percent respectively. The reduction in strength accompanying an increase in water-cement ratio is usually greater at lower water-cement ratios for concrete. Since the seven sack mixes had a lower water-cement ratio than the five sack mixes, a larger reduction in compressive strength accompanying redosage of the seven sack mixes is expected. The air contents of the mixes after redosage did not seem to have much effect on the compressive strengths produced. The air content was variable depending on the particular case, with no significant effects on compressive strength.

5.4.1 <u>Effect of Extended Mixing Time</u>.

Extending the agitation period after redosage of the 7-45 series increased the compressive strength for all three trucks. The most significant gain in compressive strength occurred for the control truck, with the effect becoming less as greater water percentage was withheld at batching. The control truck showed an increase in strength of 9.2 percent, the five percent withheld truck an increase of 4.7 percent, and the ten percent withheld truck an increase of 1.3 percent. The control truck showed a substantial increase; 9.2 percent is approximately a 530 psi increase due to extending the period of agitation. The other two trucks exhibit less of a strength gain, but

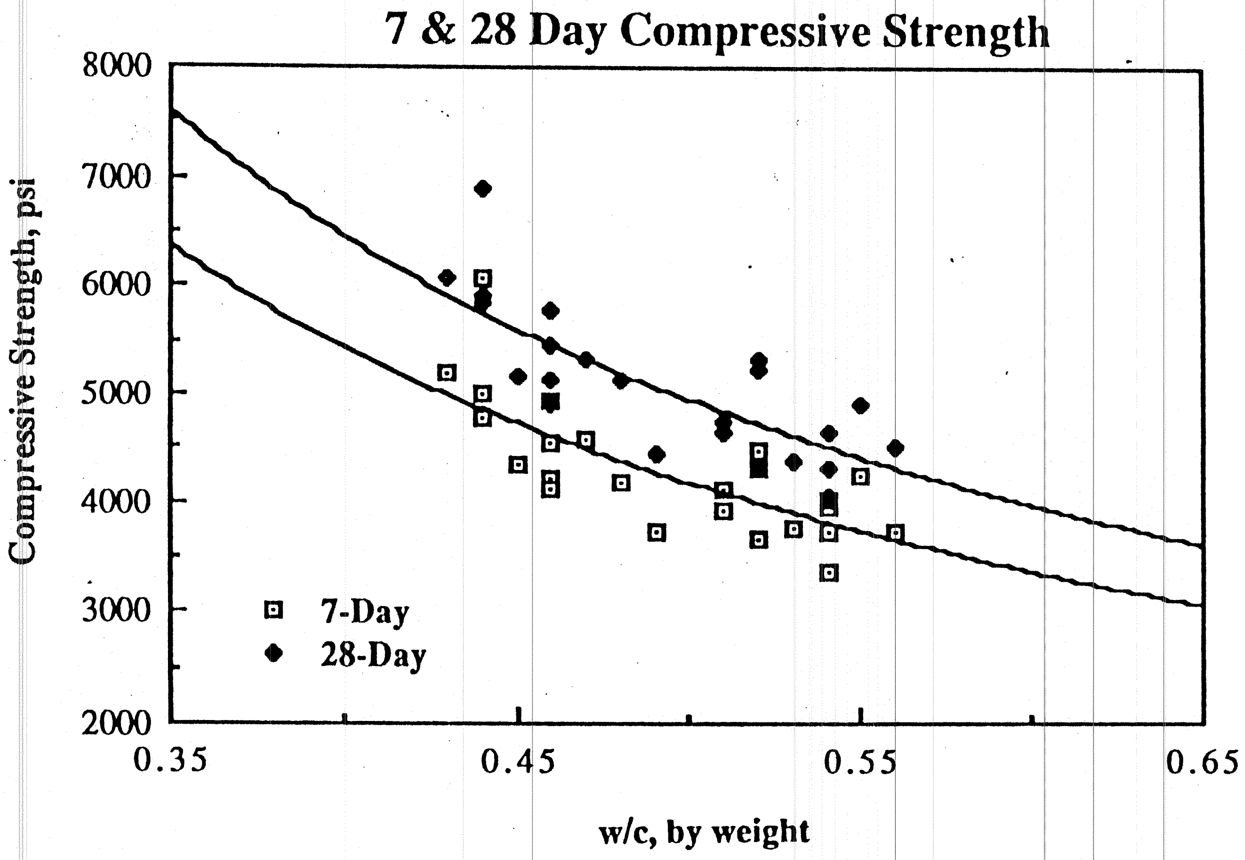

Figure 5.7 Relationship between compressive strength and water-cement ratio for all mixes examined.

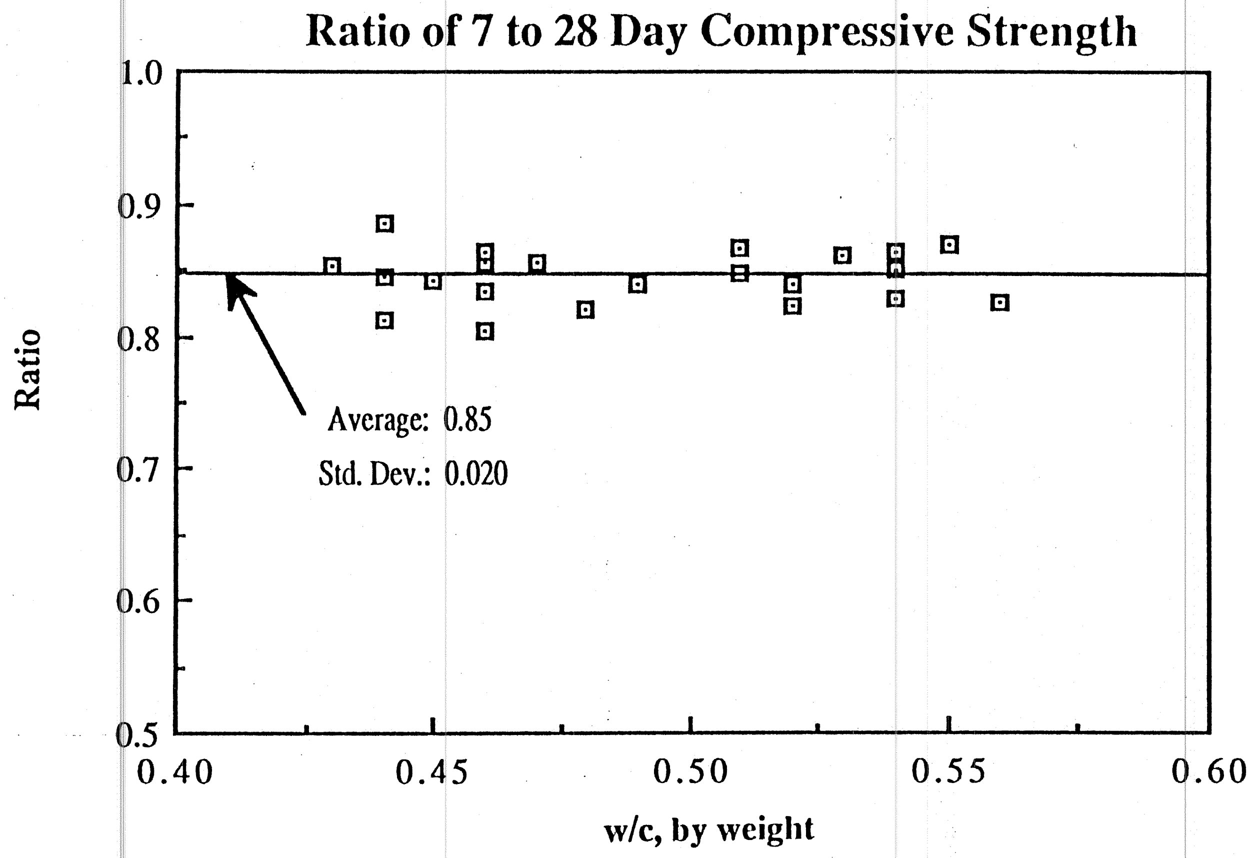

Figure 5.8 Ratio of 7 to 28-day compressive strength versus water-cement ratio for all the mixes examined.

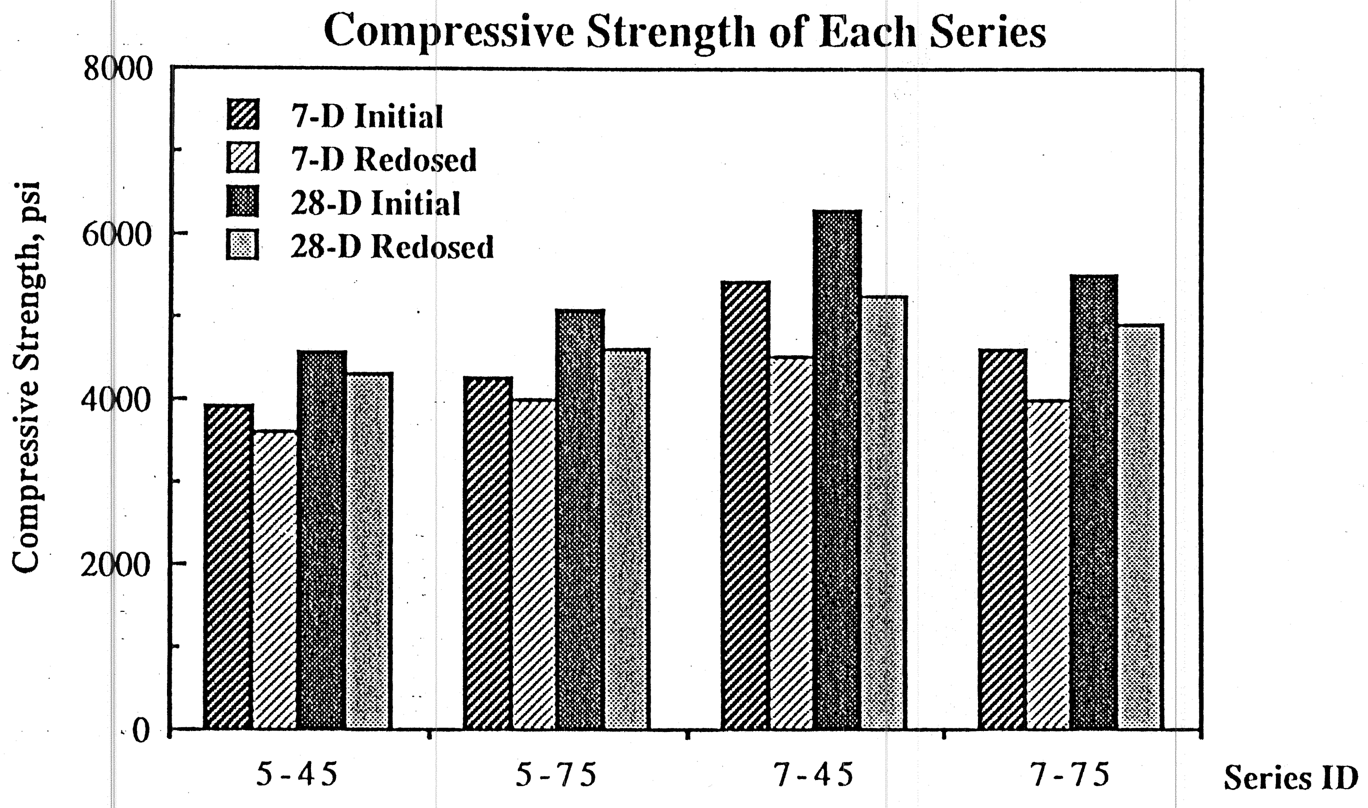

Figure 5.9 Summary of compressive strength results for all the mixes examined.

based on the limited testing done here, it can be stated that extending the mixing time increases the compressive strength.

The air contents of the control redosed and five percent withheld redosed specimens indicated the presence of only entrapped air after redosage. Therefore no reduction in air content could occur with an accompanying gain in strength with extending the agitation period. The ten percent withheld redosed specimens contained minimal entrained air, and gained the least strength with extended agitation. Therefore, loss of air accompanying extended agitation is not contributing to the strength gain accomplished. Researchers have attributed this increased strength to factors such as the loss of water to evaporation, absorption by the aggregates, and revibration. The results are in agreement with the results of other experimental studies previously presented in Section 2.5.2.

In summary, withholding mixing water at initial batching and retempering not to exceed the design mixing water had no significant effects on the compressive strength of the concrete. Redosage of the concrete reduced the compressive strength with increased water-cement ratio. Extending the mixing time can help offset this reduction through the strength gain accomplished. Finally, compressive strength gain characteristics from 7 to 28 days were not affected by withholding and retempering or redosage of the concrete.

5.5 Effect of Retempering on Flexural Strength

The flexural strength results were very similar to the compressive strength results in that very little effect resulted from withholding and later addition of mixing water. The average coefficient of variation for the 7-day flexural strength between groups of three mixes in a given series was 3.6 percent, with no coefficient of variation being greater than 6.6 percent. This included both the mixes after initial addition and after redosage. The 28-day flexural strength test results showed a slightly higher variability, with an average coefficient of variation of 4.3 percent and a particular mix with a coefficient of variation of 9.5 percent. However, these results tend to show no difference between the results of control, five percent withheld, and ten percent withheld trucks in terms of flexural strength.

Examination of Figure 5.10 gives an indication of the flexural strength gain from 7 to 28 days. Figure 5.10 shows the ratio of the 7 to 28 day flexural strengths for all the mixes examined. The average is slightly higher for the ratio of 7-day to 28-day flexural strength than that of the 7-day to 28-day compressive strength, being 0.90 as compared to 0.85. This indicates that there is less gain in

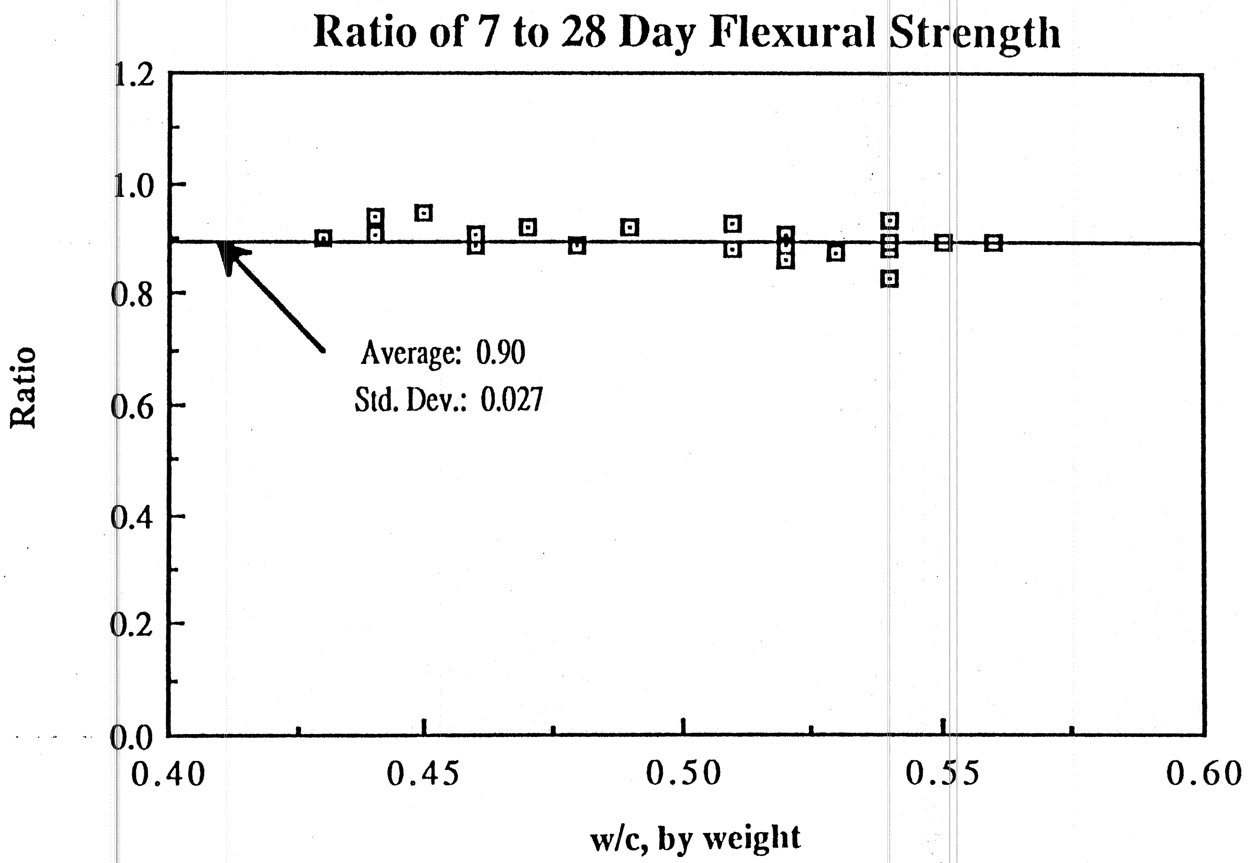

Figure 5.10 Ratio of 7 to 28-day flexural strength versus water-cement ratio for all the mixes examined.

flexural strength from 7 to 28 days than there is gain in compressive strength, and that most of the flexural strength is gained in the first 7 days for the materials used. Also, the increases in flexural strength are not as consistent as with the compressive strength as indicated by the increased standard deviation of 0.027 compared to 0.020. However, the standard deviation is still quite good and the flexural strength gain characteristics are similar for all the mixes examined. Retempering, therefore, appears to have no significant effect on the flexural strength gain characteristics of the concrete.

Redosage of the concrete with an additional five percent of mixing water did consistently reduce the flexural strength of all mixes examined. Figure 5.11 shows that a reduction occurred for all the mixes examined in both the 7-day and the 28-day flexural strengths. As with the compressive strength results, the seven sack mixes were affected more than the five sack mixes. Average reductions in 7-day flexural strength were 6.7 percent for the five sack mixes and 9.8 percent for the seven sack mixes. This can once again be explained due to the lower water-cement ratios of the seven sack mixes as compared to the values for the five sack mixes. The variations in air contents were not great enough to significantly affect the flexural strengths produced upon redosage.

In summary, withholding mixing water at initial batching and retempering not to exceed the design mixing water had no significant effects on the flexural strength of the concrete. Redosage of the concrete reduced the flexural strength with increased water-cement ratio. Flexural strength gain characteristics were not affected by withholding and retempering or redosage of the concrete.

5.6 Effect of Retempering on Abrasion Resistance

All the specimens for abrasion resistance were cured and finished in the same manner to eliminate discrepancies caused by changing these parameters.

Withholding water at initial batching and then later addition of this water tended to increase the abrasion resistance of the hardened concrete. The depth of wear decreased as the amount of withheld mixing water increased for a given cement content, despite the concrete having similar strengths. Figure 5.12 shows this observation for the 5-75 series as a typical example. This could possibly be explained by the loss of air that accompanied the withholding and then later addition of mixing water. The surface matrix tends to be more dense when air content is reduced resulting in an increase in the abrasion resistance.

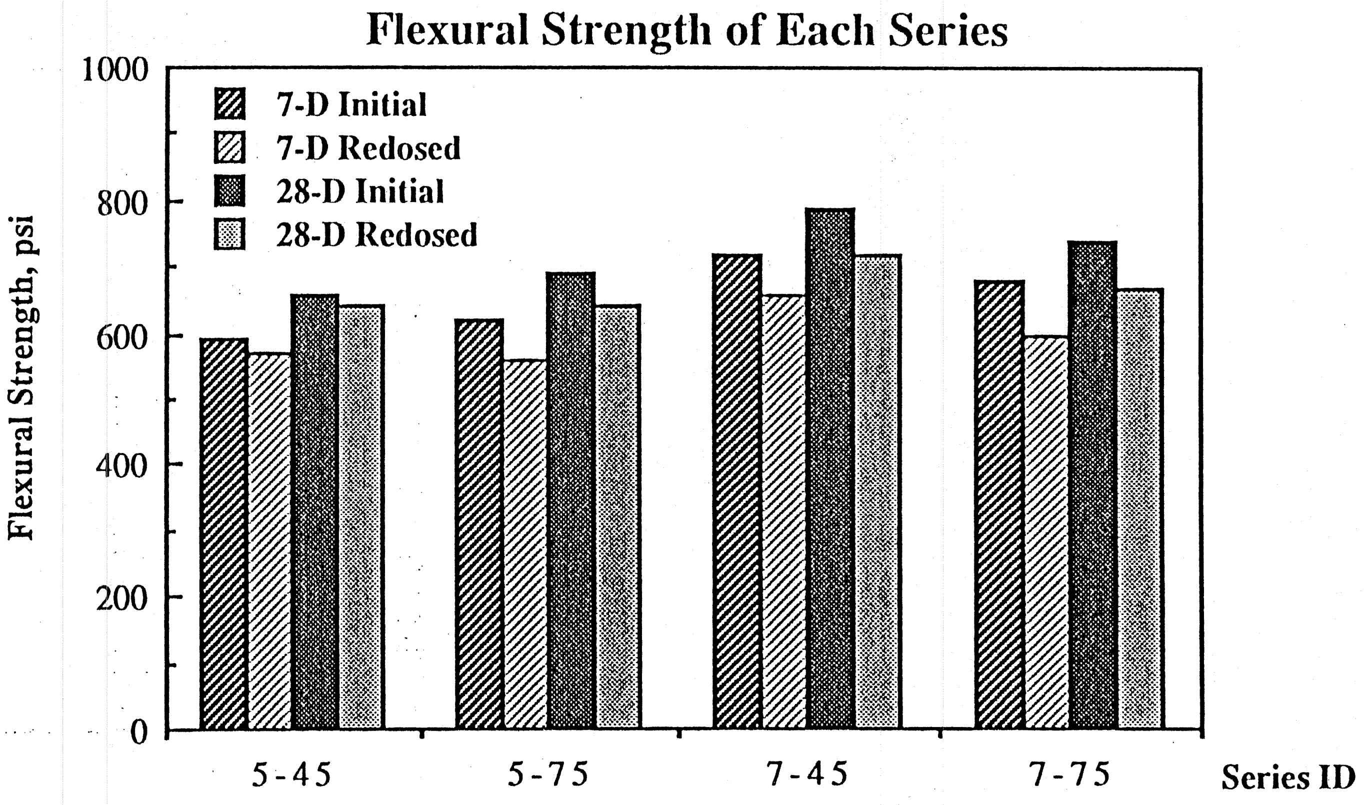

Figure 5.11 Summary of flexural strength results for all the mixes examined.

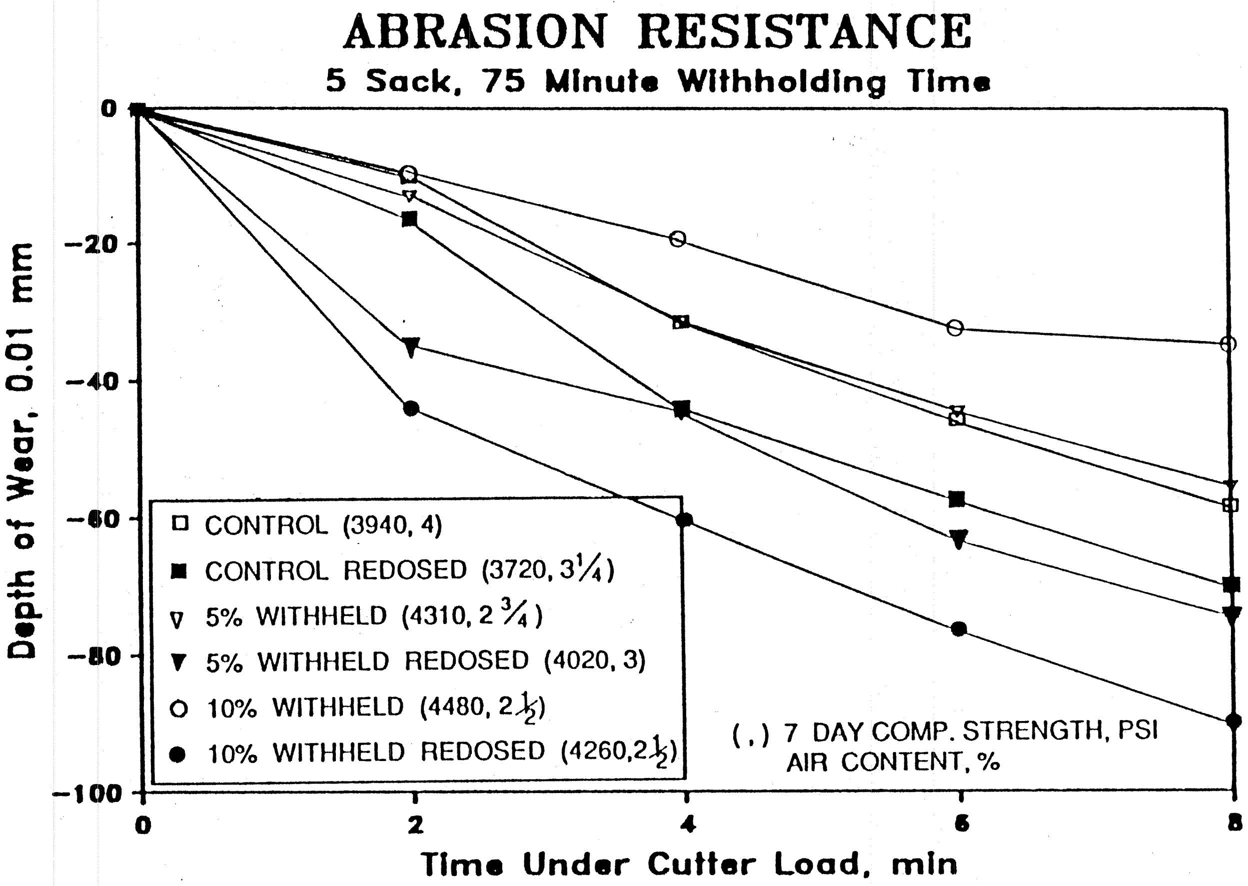

Figure 5.12 Abrasion resistance of concrete in the 5-75 series.

Redosage of the concrete with an additional five percent of mixing water increased the depth of wear in almost all cases. Once again, Figure 5.12 shows this for a typical mix. The control trucks showed a better abrasion resistance than the five or ten percent withheld trucks upon redosage. This is contrary to the initial addition results. The observed loss of abrasion resistance upon redosage is in agreement with the loss of strength due to an increase in the water-cement ratio upon redosage of all concrete mixes.

The effect of withholding time is exhibited in the variability of the results for specimens. The 75 minute withholding time shows a greater range of abrasion resistances than the 45 minute withholding time. In both the five sack and the seven sack series, the range of abrasion resistance increased with increased withholding time. The variability is due to the increased variability in the air contents, strengths, and difficulty in finishing with increase in the withholding time. The quality of the concrete becomes more suspect as the withholding time increases.

Correlation of the final depth of wear with the voids-cement (water plus air by volume) ratio as done by Witte and Backstrom was attempted. [41] Figure 5.13 shows that the 7-day compressive strength correlates very well with the voids-cement ratio. This is in agreement with the results of Witte and Backstrom. Figure 5.14 however, shows no correlation between the final depth of wear and the voids-cement ratio. This is contrary to what was found by Witte and Backstrom. The scatter is much too great to draw any conclusions about a relationship for the mixes examined here.

Correlation between the final depth of wear and 7-day compressive strength is shown in Figure 5.15. Once again the scatter proves too great to draw any conclusions about a possible relationship. This is contrary to conclusions reported from the literature examined for this study, which indicate that compressive strength is a governing factor in the abrasion resistance of concrete. These conclusions indicate that some parameter other than the voids- cement ratio and compressive strength is governing the abrasion resistance of the retempered concrete for the mixes examined.

Part of the lack of correlation between abrasion resistance and voids-cement may be accounted for by the hardness of the coarse aggregate used in this study. Since abrasion resistance was minimal for all specimens examined due to the hard river gravel used as coarse aggregate, the effect of the voids-cement ratio and or strength of the paste on the abrasion resistance may be reduced.

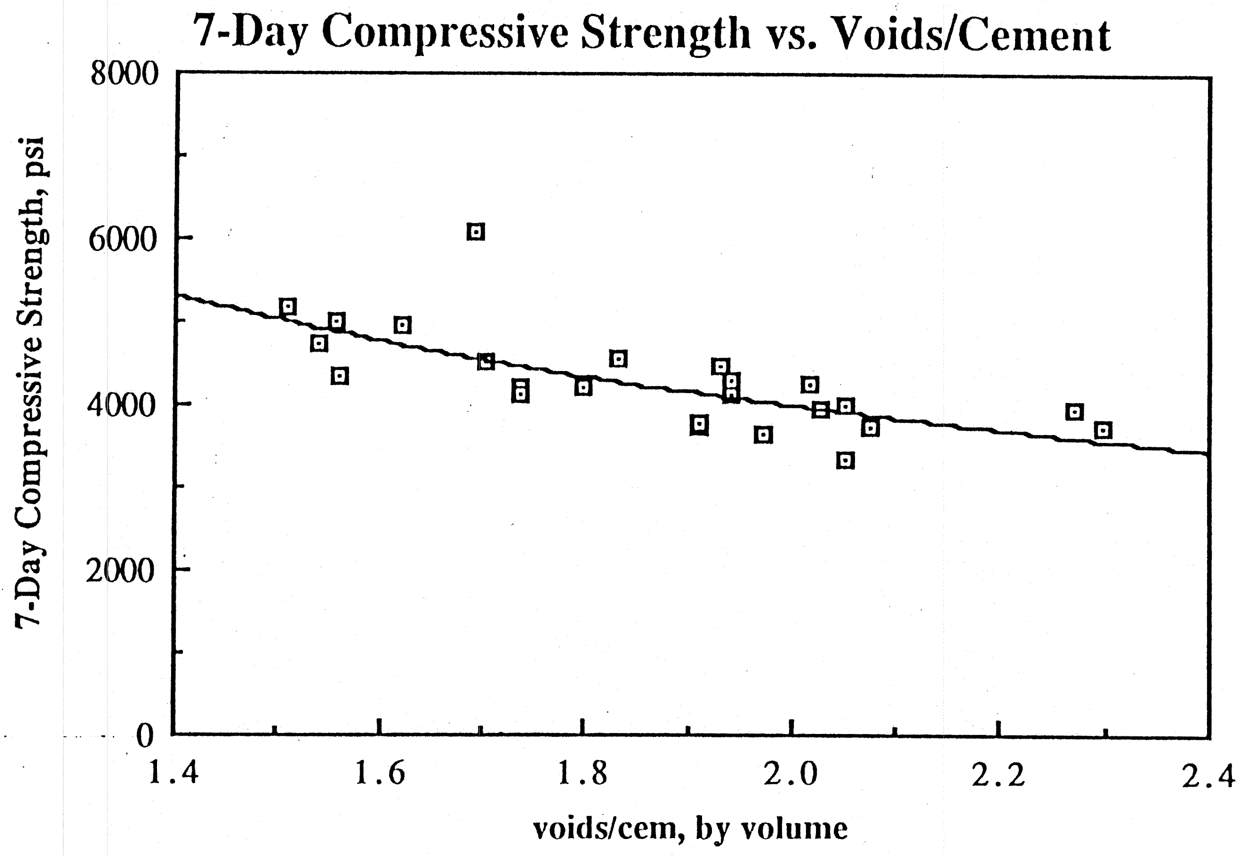

Figure 5.13 Relationship between 7-day compressive strength and voids-cement ratio for all the mixes examined.

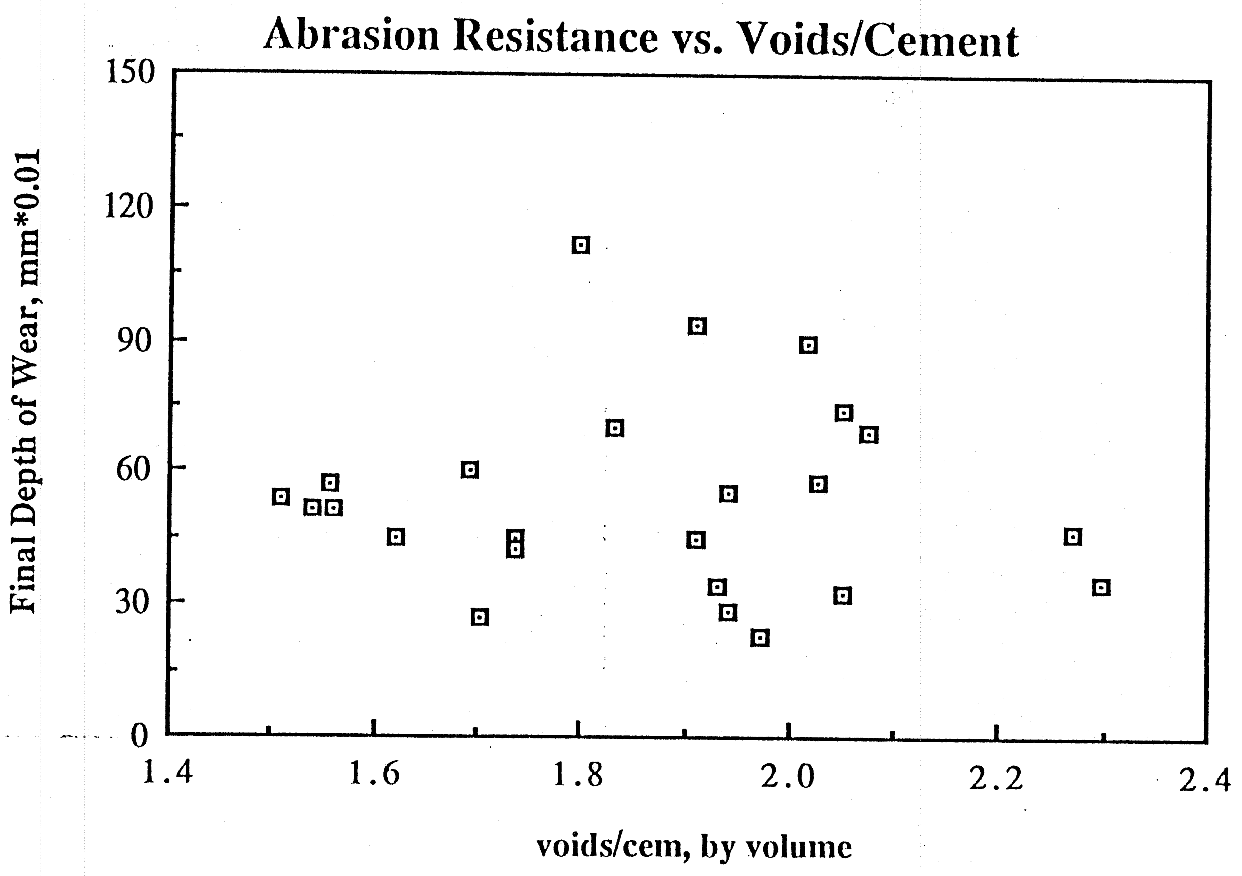

Figure 5.14 Plot of abrasion resistance versus voids-cement ratio for all the mixes examined.

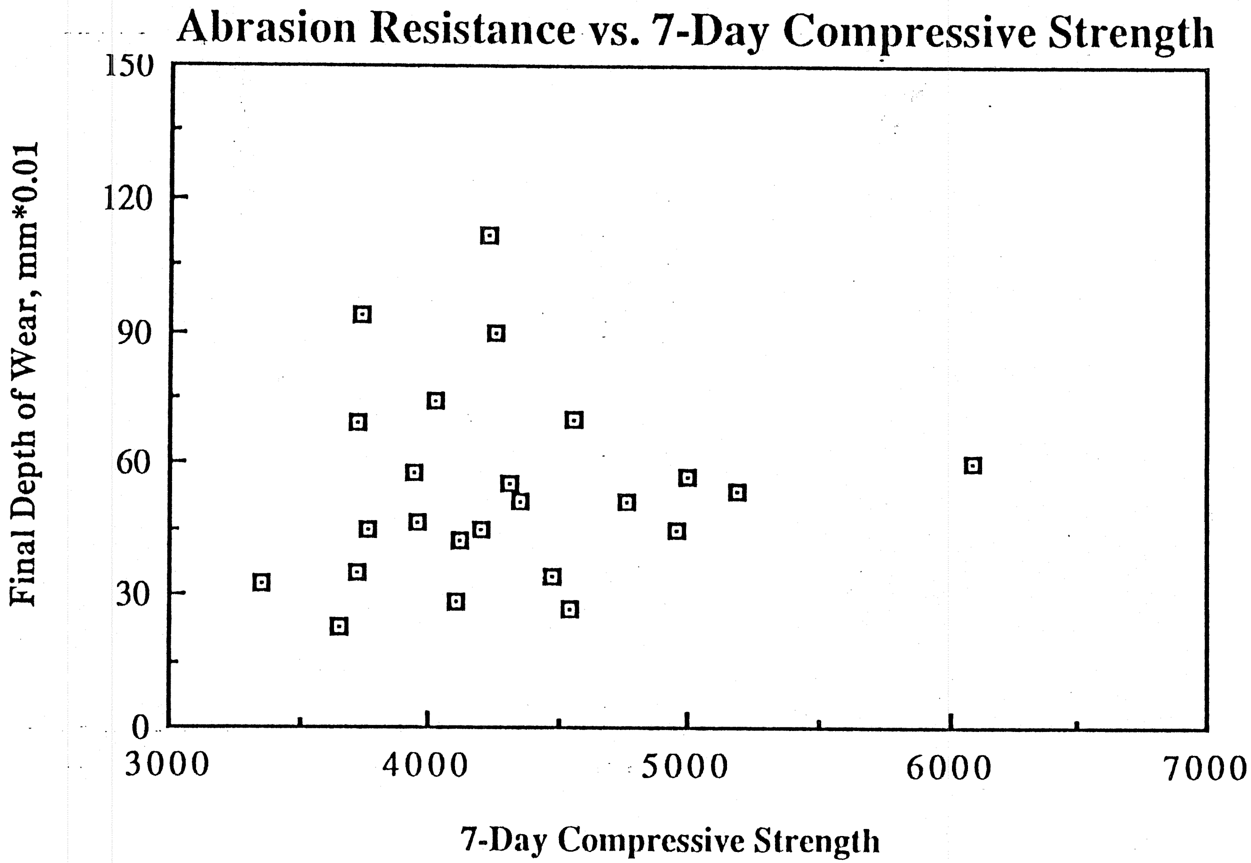

Figure 5.15 Plot of abrasion resistance versus 7-day compressive strength for all the mixes examined.

In summary, withholding mixing water at initial batching and retempering increased the abrasion resistance. Redosage of the concrete however, reduced the abrasion resistance, with the specimens in which water was withheld generally showing worse abrasion resistance than the control specimens. Increasing the withholding time from 45 minutes to 75 minutes resulted in increased variability for the abrasion resistances due to the lower slumps and increased finishing difficulties. Finally, no correlation between abrasion resistance and strength could be accomplished.

5.7 Effect of Retempering on Freeze-Thaw Resistance

Figures 5.16 and 5.17 summarize the durability factor after 300 cycles of freezing and thawing for both the five sack and seven sack mixes. Durability factors ranged from excellent to very poor for the mixes examined, with some specimens failing before reaching 300 freeze-thaw cycles.

Examination of Figures 5.16 and 5.17 shows the effect of cement content on the resistance of the concrete to freezing and thawing. The seven sack mixes generally outperformed the five sack mixes with similar air contents, except for the five percent withheld truck in the 5-75 series. The 7-45 series performed the best of the mixes examined. Durability factors for this series were 84.2 or better with five of the six specimens at 93.2 or better indicating excellent resistance to freezing and thawing for all the specimens in the series. The increased strength accompanying the increase in cement content from five to seven sacks seems to reduce the need for entrained air to achieve similar durabilities. This result is in agreement with the literature examined in Section 2.7 of this report.

Examination of the mixes in a given series shows the effect of withholding water and retempering. The control mixes generally show better durability than the trucks in which mixing water was withheld and later added. This was the case for all but the 7-45 series. This series showed excellent durability for all the specimens, mainly due to the higher strengths achieved by the seven sack per cubic yard cement content and low water-cement ratios. Reduction in durability was due to the loss of air accompanying withholding and retempering.

In general, redosage of the concrete led to a reduction in freeze-thaw durability. Once again, the 7-45 series was an exception due to the higher strengths achieved. For the majority of the mixes however, the lower strengths accompanying redosage of the concrete lead to a reduction in the freeze - thaw durability. In the cases

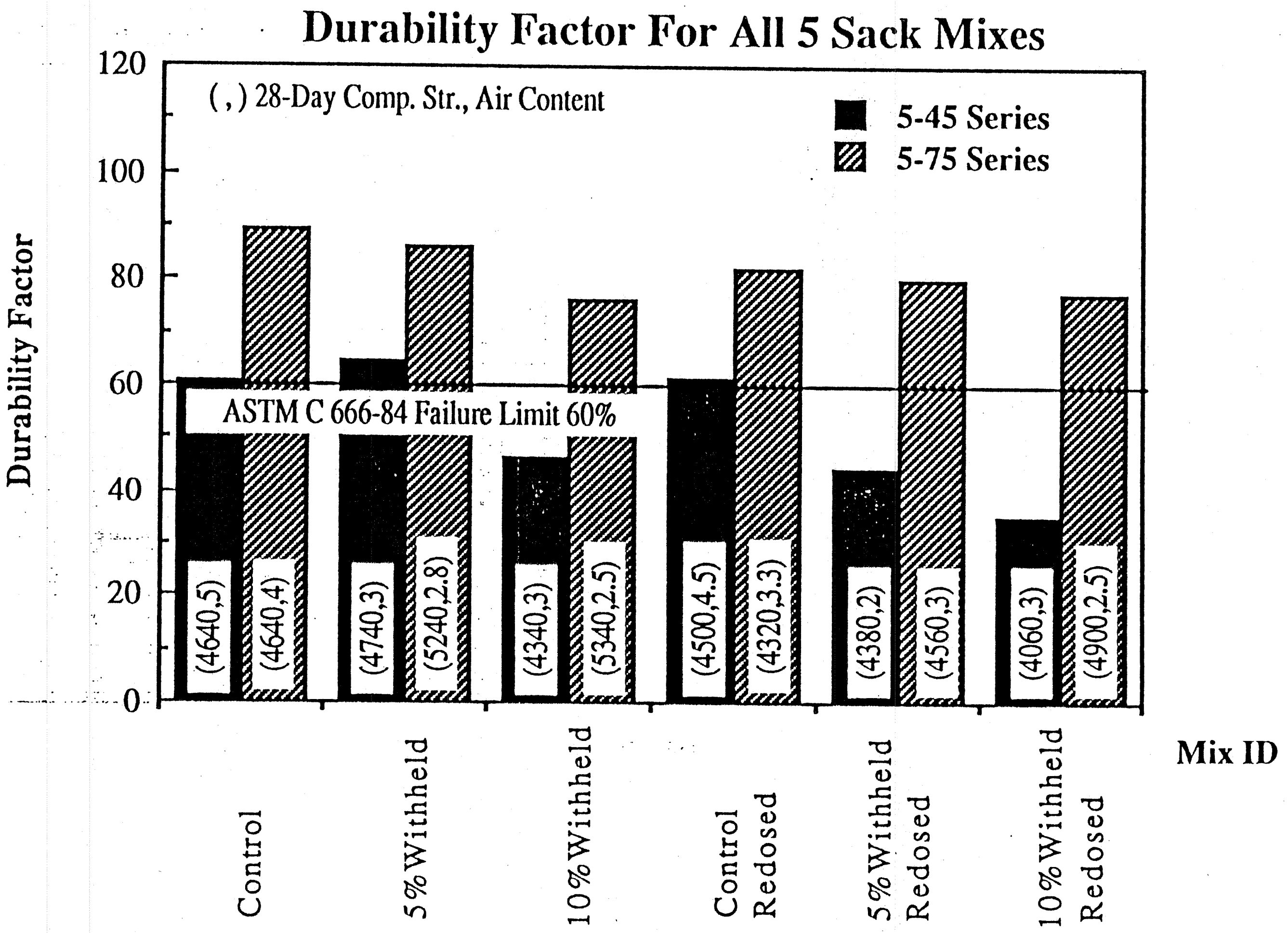

Figure 5.16 Durability Factor at 300 freeze-thaw cycles for the 5 sack mixes.

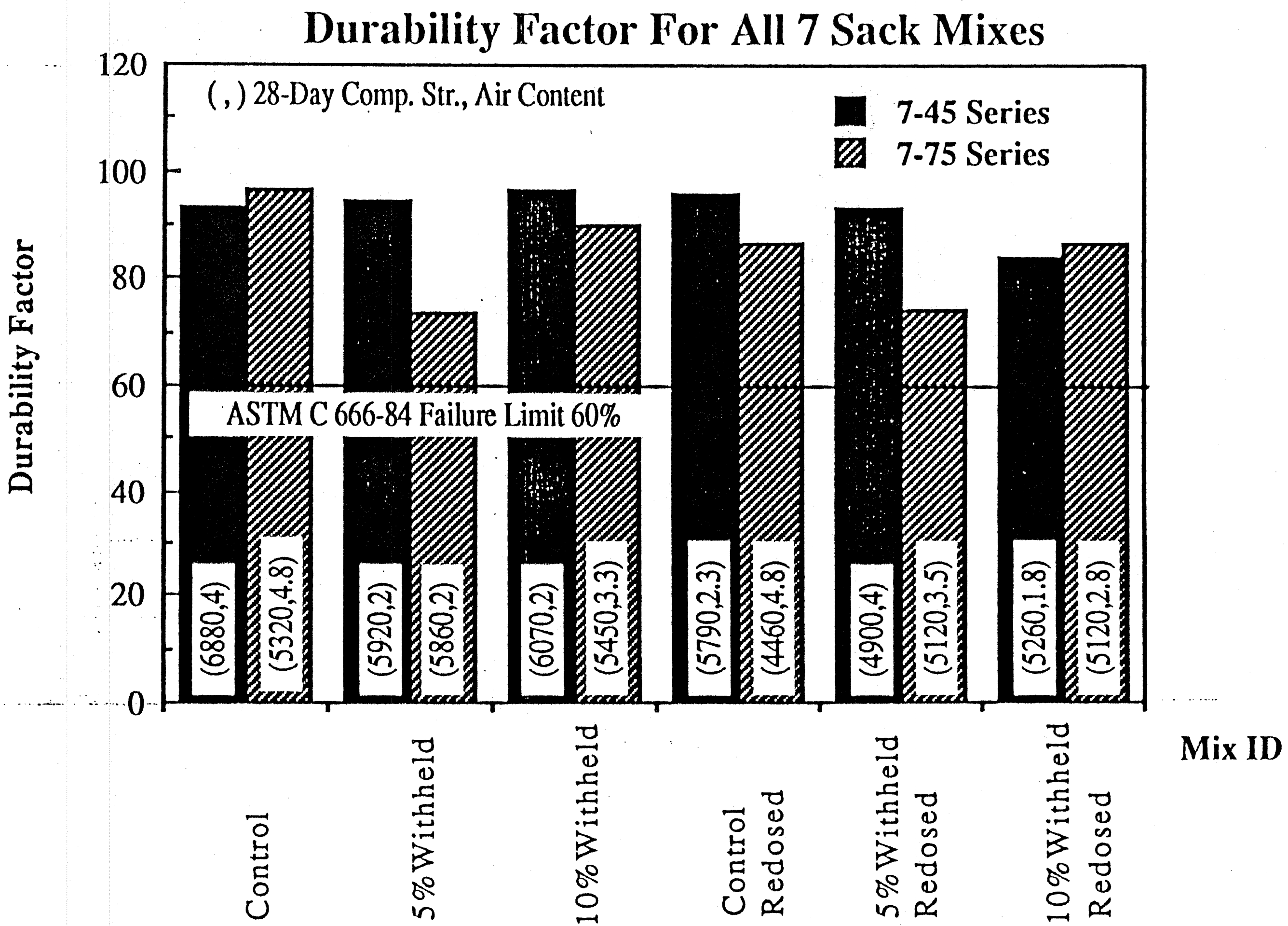

Figure 5.17 Durability Factor at 300 freeze-thaw cycles for the 7 sack mixes.

where the durability factor increased or remained the same, the amount of air present after redosage was generally the same or greater than before redosage, which would explain the adequate resistance to freeze-thaw deterioration.

The 5-45 series control truck results show poor durability despite adequate air. The progression of deteriorating concrete quality due to withholding and later addition and also redosage is clear with this series. Durability factors below the failure limit defined in ASTM C 666-84 are encountered. The strengths of these mixes are the lowest of all the mixes tested, indicating the importance of both strength and adequate entrained air for good resistance of concrete to frost action.

In summary, withholding mixing water at initial batching and retempering reduced the durability of concrete to freeze-thaw action. The loss of air accompanying retempering was mainly responsible for the lower durabilities. Redosage additionally resulted in a reduction in freeze-thaw durability due to a reduction in strength accompanying the increased water-cement ratio. Finally, the detrimental effects of retempering on freeze-thaw durability were more pronounced for the lower cement content of five sacks as compared to seven sacks.

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 Summary

The withholding of mix water at batching and retempering of concrete produced for highway applications in hot weather has been examined in this study. In addition, the effect of redosing the concrete with water above and beyond that required in the mix design was examined. Both fresh properties and hardened properties of the concrete were used as an indication of the effects.

The results of this investigation of retempered concrete indicate that many of the properties of the concrete are significantly affected. This study showed that, in general, the retempered concrete does not perform as well as concrete which has not been retempered.

6.2 Conclusions

The purpose of this study, was to provide the resident engineer with guidelines about the effects of retempering with water upon the quality of the concrete produced. The properties of the concrete produced were changed in most aspects considered by the study. Some of the important changes that engineers should be aware of include:

(1) There was no benefit in workability attained by withholding mixing water followed by retempering when compared to a mix with a similar water-cement ratio in which all the water was added at initial batching. For the same amount of design mixing water, and a 45 minute withholding time, the slump of the retempered concrete was equal to that of concrete produced with the addition of all the mixing water at batching. For a 75 minute withholding time, the slump of the retempered concrete was less than that of the control. Therefore, if the same slump were to be obtained at placement of the retempered concrete mixes as that of the control mix, water in excess of that called for in the design would be required. This will result in a lower quality concrete due to the increase in water-cement ratio.

(2) Slump loss of retempered concrete versus time was approximately the same as that of the corresponding control mix. Slump loss was found to be dependent upon initial slump level.

(3) The effectiveness of air-entraining agents and the resulting entrainment of air was reduced when water was withheld and concrete was retempered. Air contents for all eight retempered mixes were lower than their corresponding control mix at the time of initial addition. Loss of air was greater for the seven sack mixes than the five sack mixes.

(4) Increasing the withholding time requires an increase in air-entraining agent dosage to achieve similar air contents independently if water is being withheld or not.

(5) Prediction of the behavior of air content upon redosage was not possible because of the variable results encountered.

(6) The temperature of retempered mixes was about equal to the corresponding control mixes for a five sack cement content and greater than their corresponding control mixes for a seven sack cement content. The increased cement content of the seven sack mixes results in greater hydration activity and a corresponding increase in the temperature rise of concrete. These increased temperatures helped account for the reduced slump and air contents of the retempered mixes when compared to their corresponding control mix.

(7) Withholding of mixing water and retempering of concrete appears to have no effects on either the compressive or flexural strength characteristics of the concrete. The final water-cement ratio remains the governing factor for strength.

(8) Strength gain characteristics from 7 to 28 days were the same for all the mixes examined. Strength gain characteristics remained independent of cement content, amount of water withheld, time of withholding, and redosage.

(9) Redosage of the concrete led to a significant reduction in both the compressive and flexural strengths of the concrete. The seven sack mixes were more greatly

affected by redosage than the five sack mixes due to their lower initial water-cement ratio.

(10) Extending the time of placement and thus mixing and agitation time increases the compressive strength of the concrete.

(11) Withholding of mixing water followed by retempering resulted in an increase in the abrasion resistance of the concrete produced. Reduction in air content accompanying the withholding and retempering was probably the cause of this since compressive strengths were similar for all the mixes in a typical series.

(12) In general, redosage of the concrete decreased the abrasion resistance. Upon redosage, the five and ten percent withheld redosed specimens generally showed worse abrasion resistance than the control redosed specimens.

(13) Increasing the withholding time from 45 minutes to 75 minutes results in more variability of abrasion resistances between mixes in a given series. The longer withholding time and lower slump made finishing more critical, which helps explain the variable abrasion resistances encountered.

(14) Determination of a relationship between abrasion resistance and voids-cements ratio or compressive strength was not possible. Some factor other than compressive strength or voids-cement ratio seems to be the governing factor controlling the abrasion resistance of the concrete.

(15) Withholding of mixing water and retempering reduced the durability of concrete to freeze-thaw action. This occurred mainly due to the loss of air accompanying withholding of mixing water and retempering.

(16) Redosage of the concrete also resulted in reduction of the freeze-thaw durability due to the reduction in strength accompanying the increase in water-cement ratio.

(17) The detrimental effects of retempering on freeze-thaw durability of concrete are more pronounced for lower cement contents as shown in this study for the five sack mixes as compared to the seven sack mixes.

6.3 Recommendations

Based upon the conclusions obtained in this investigation, engineers should not allow retempering of air-entrained concrete. The effects of withholding and later addition of water to concrete at the jobsite are detrimental to the quality of the concrete produced. Workability, air-entrainment, abrasion resistance, and freeze-thaw resistance are all affected. Additionally, redosage beyond the design water-cement ratio should not be allowed. Significant strength reductions can occur, with resulting loss of durability. If withholding and retempering are necessary, short withholding times and higher cement contents should be used, as these help reduce the detrimental effects which occur with this practice.

REFERENCES

1. Abbasi, A.F. and Al-Tayyib, A.J.; "Effect of Hot Weather on Modulus of Rupture and Splitting Tensile Strength of Concrete," Cement and Concrete Research, Vol. 15, 1985, pp.233-244.

2. American Concrete Institute Committee 201; "Guide to Durable Concrete," ACI Publication 201.2R-77, 1977.

3. American Concrete Institute Committee 211; "Standard Practice for Proportioning Normal, Heavyweight, and Mass Concrete," ACI Publication 211.1-81.

4. American Concrete Institute Committee 304; "Recommended Practice For Measuring, Mixing, Transporting, and Placing Concrete," ACI Journal, July 1972, pp. 374-414.

5. American Concrete Institute Committee 305; "Hot Weather Concreting," ACI Publication 305R-77, August 1977.

6. American Concrete Institute; Proportioning Concrete Mixes, Special Publication SP-46.

7. American Concrete Institute Standard; "Recommended Practice for Evaluation of Strength Test Results of Concrete", ACI Publication 214-77, 1977.

8. American Society of Testing and Materials; 1986 Annual Book of ASTM Standards, ASTM, Philadelphia, 1986.

9. Beaufait, Fred W. and Hoadley, Peter G.; "Mix Time and Retempering Studies on Ready-Mixed Concrete," ACI Journal, December 1973, pp. 810-813.

10. Burg, G.R.U.; "Slump Loss, Air Loss, and Field Performance of Concrete," ACI Journal, July-August 1983, pp. 332-339.

11. Cook, G.; "Effect of Time of Haul on Strength and Consistency of Ready-Mixed Concrete," ACI Journal, Proceedings, Vol. 39, No. 5, April 1943, pp. 413-426.

12. Gonnerman, H.F. and Woodworth, P.M.; "Tests of Retempered Concrete," ACI Journal, Proceedings, Vol. 25, 1929, pp. 344-387.

13. Hawkins, M.J.; "Concrete Retempering Studies," ACI Journal, Jan. 1962, pp. 63-71.

14. Kennedy, H.L.; "Homogeneity of Air-Entraining Concrete," ACI Journal, Vol. 17, No. 6, June 1946.

15. Kettle, R. and Sadegzadeh, M.; "The Influence of Construction Procedures on Abrasion Resistance," Concrete Durability, ACI Special Publication SP 100-71, Vol. 2, 1987, pp. 1385-1410.

16. Klieger, P.; "Effect of Mixing and Curing Temperature on Concrete Strength", ACI Journal, Proceedings, Vol. 54, No. 12, Jun. 1958, pp. 1063-1081.

17. Klieger, P.; "Further Studies on the Effect of Entrained Air on Strength and Durability of Concrete With Various Sizes of Aggregates", Highway Research Board Bulletin No. 128, pp. 1-19, Washington D.C., 1956.

18. Langan, B.W. and Ward, M.A.; "A Laboratory Investigation for Potential Durability of Ready-Mixed Concrete Retempered for Air Content and Workability," Canadian Journal of Civil Engineering, Vol. 3, 1976, pp. 570-577.

19. Legg, F.E., Jr.; "Freeze-Thaw Durability of Michigan Concrete Coarse Aggregates", Highway Research Board Bulletin No. 143, Washington D.C., 1956, pp. 1-13.

20. Mehta, Kumar P.; Concrete Structure, Properties, and Materials, Prentice-Hall Inc., Englewood Cliffs, 1986.

21. Mindess, Sidney and Young, J. Francis; Concrete, Prentice- Hall, Inc., Englewood Cliffs, 1981.

22. Neville, A.M.; Properties of Concrete, Third Edition, Pitman Publishing, 1981.

23. Portland Cement Association; Design and Control of Concrete Mixtures, Twelfth Edition, PCA Publication, Skokie, 1979.

24. Portland Cement Association; "Hot Weather Concreting", Concrete Information Sheets, IS 14.02T, Chicago, 1966.

25. Powers, T.C.; "Freezing Effects in Concrete," Durability of Concrete, ACI Special Publication SP 47-1, 1975, pp. 1-11.

26. Powers, T.C.; "Resistance of Concrete to Frost at Early Ages", Research Bulletin, No. 71, Portland Cement Association.

27. Previte, R.W.; "Concrete Slump Loss," ACI Journal, August 1977, pp. 361-367.

28. Ramakrishnan, V., Coyle, W.V., and Pande, S.S.; "Workability and Strength of Retempered Superplasticized Concretes," Transportation Research Record, No. 720, 1979, pp. 13-19.

29. Ravina, D.; "Retempering of Prolonged Mixed Concrete with Admixtures in Hot Weather," ACI Journal, June 1975, pp. 291-295.

30. Ravindrarajah, R. S. and Tam, C.T.; "Retempering of Plain and Superplasticized Concretes," The International Journal of Cement Composites and Lightweight Concrete, Vol. 7, No. 3, August 1985.

31. Samarai, M., Popovics, S., and Malhotra, V.M.; "Effects of High Temperature on the Properties of Fresh Concrete," Transportation Research Record, No. 924, 1983, pp. 42-50.

32. Senbetta, E. and Malchow, G.; "Studies on Control of Durability of Concrete Through Proper Curing," Concrete Durability, ACI Special Publication SP 100-7, Vol. 1, ACI, 1987, pp. 73-87.

33. Smith, F.L.; "Papers on Cement and Concrete," ASTM STP 205, 1958, pp. 91-105.

34. Smutzer, R.K. and Zander, A.R.; "A Laboratory Evaluation of the Effects of Retempering Portland Cement Concrete With Water and a High-Range Water-Reducing Admixture," Transportation Research Record, No. 1040, pp. 34-39.

35. Tatu, D. and Teodoru, G.; "Influence of Aggregate Quality on the Frost Resistance of Concrete", Studii di Cercetari Hidroenergetice, No. 3, 1971, pp. 248-259.

36. Teodoru, G.; "Aggregate - The Decisive Element in the Frost Resistance of Concrete", Concrete Durability, ACI Special Publication SP 100-66, Vol. 2, ACI, 1987, pp. 1297-1311.

37. Texas Department of Highways and Public Transportation; Manual of Testing Procedures, Texas SDHPT, Rev. January, 1986.

38. Texas State Department of Highways and Public Transportation; 1982 Standard Specifications for Construction of Highways, Streets, and Bridges, Texas SDHPT, 1982.

39. U.S. Bureau of Reclamation; "Investigation Into the Effect of Water/Cement Ratio on the Freezing-Thawing Resistance of Non-Air and Air-Entrained Concrete", Concrete Laboratory Report No. C-810, Denver, 1955.

40. Washa, G.W. and Withey, N.H.; "Strength and Durability of Concrete Containing Fly Ash", Proceedings, American Concrete Institute, Vol. 49, 1953.

41. Witte and Backstrom; "Some Properties Affecting the Abrasion Resistance of Air Entrained Concrete," Proceedings, ASTM, Vol. 51, pp. 1141-1155.