THE RELATIONSHIP OF AGGREGATE DURABILITY TO TRACE ELEMENT CONTENT

Interim Report
HR-266

January 1984

Iowa Department
of Transportation
Highway Division

INTERIM REPORT

FOR

IOWA HIGHWAY RESEARCH BOARD

PROJECT HR-266

THE RELATIONSHIP OF AGGREGATE DURABILITY TO TRACE ELEMENT CONTENT

BY

WENDELL DUBBERKE
GEOLOGIST
515-239-1339

VERNON J. MARKS
RESEARCH ENGINEER
515-239-1447

OFFICE OF MATERIALS
HIGHWAY DIVISION
IOWA DEPARTMENT OF TRANSPORTATION
AMES, IOWA 50010

JANUARY 1984

TABLE OF CONTENTS

INTRODUCTION 1

PORE SIZE DISTRIBUTION AND THE IOWA PORE INDEX 2

AGGREGATE X-RAY ANALYSIS SYSTEMS 2

THE CHEMICAL EFFECTS ON CONCRETE DURABILITY 3

CURRENT IOWA DOT RESEARCH 3

Identification of Detrimental Chemical Elements 3

Salt Treatment Preparation Prior to Freeze and Thaw Testing 4

Concrete Mixture Ingredients Affecting Salt Treatment Durability 8

ACKNOWLEDGEMENT 12

REFERENCES 12

INTRODUCTION

This report is a brief overview of the recent Iowa Department of Transportation research in the area of durability of portland cement concrete under the direction of Wendell Dubberke. Present plans are to publish a more detailed report on Iowa portland cement concrete durability research in January, 1985.

D-cracking, a type of portland cement concrete pavement deterioration attributed to the coarse aggregate in the mixture, was first recognized on Iowa's primary road system in the late 1930s. D-cracking will be used in reference to a rapid deterioration characterized by fine parallel cracks along joints, random cracks, or free edges of the pavement slab. Generally, the first sign of D-cracking is a discoloration or staining at the intersection of transverse and longitudinal joints. All references to durability in this report will be in regard to the effect of the coarse aggregate. Iowa research has established that D-cracking in Iowa is a distress that results predominantly from freeze/thaw failure in the coarse aggregate particles.[1]

Iowa began using ASTM C666 Method B, "Freezing in Air -- Thawing in Water" to evaluate the durability of concrete in 1962. Continual testing of Iowa limestone coarse aggregates with a modified ASTM C666 Method B test yielded a good correlation with resulting service record in portland cement concrete pavements.

PORE SIZE DISTRIBUTION AND THE IOWA PORE INDEX

Since 1978 much research has been conducted in regard to the pore systems of limestones used as coarse aggregate in portland cement concrete and their relationship to freeze/thaw aggregate failure.[2,3]

This research has shown that with some exceptions, most nondurable aggregates analyzed exhibit a predominance of pore sizes in the 0.04 to 0.2 micron diameter range. The Iowa Pore Index was adapted as a standard test in 1978.[2] It is a very simple test utilizing a modified pressure meter as a test apparatus. A known volume of coarse aggregate is emersed in water in the base of the pressure meter. The amount of water injected into the aggregate under a constant 35 psi pressure is recorded. The volume of water injected in the period between one and 15 minutes after application of the pressure is the pore index. A pore index of 27 milliliters or more generally indicates a limestone susceptible to freeze/thaw D-cracking deterioration. Coarse aggregate pore sizes have been determined using a quantichrome scanning porosimeter using pressures from 0 to 60,000 psi.

AGGREGATE X-RAY ANALYSIS SYSTEMS

X-ray analysis systems available at Iowa State University have been utilized to further evaluate limestone coarse aggregates. The x-ray fluorescence system has been utilized to evaluate the elemental composition of various aggregates. X-ray diffraction techniques were used to determine the compound compositions of the aggregates. The scanning electron microscope has been used both to observe the pore sizes and crystal sizes of the aggregates in addition to elemental chemical identification and analysis.

THE CHEMICAL EFFECTS ON CONCRETE DURABILITY

Much of our current research was generated by the fact that in Iowa we have some aggregates that do not exhibit consistent service records. A pavement containing a Pennsylvanian crushed limestone from the Exline quarry was incorporated into a pavement on primary highway U.S. 34 in southern Iowa in 1962. Today, it exhibits severe D-cracking. A secondary road containing the same Exline aggregate constructed in 1964 exhibits only staining and no D-cracking deterioration.

A D-crack susceptible gravel containing 70% carbonate was used in primary highway U.S. 30 in central Iowa in 1965. Today, it exhibits severe D-cracking. A secondary road containing the same gravel aggregate was constructed in 1966 and exhibits no indication of D-cracking today.

Major differences in the winter maintenance practices of secondary roads and primary roads may be the answer for the difference in performance of these two pairs of roadways. A substantial amount of sodium chloride deicing salt is used on primary roads, with limited use of deicing salt on the secondary roads. Research is needed to define and explain the mechanism that accelerates the D-cracking deterioration on the primary roadways.

CURRENT IOWA DOT RESEARCH

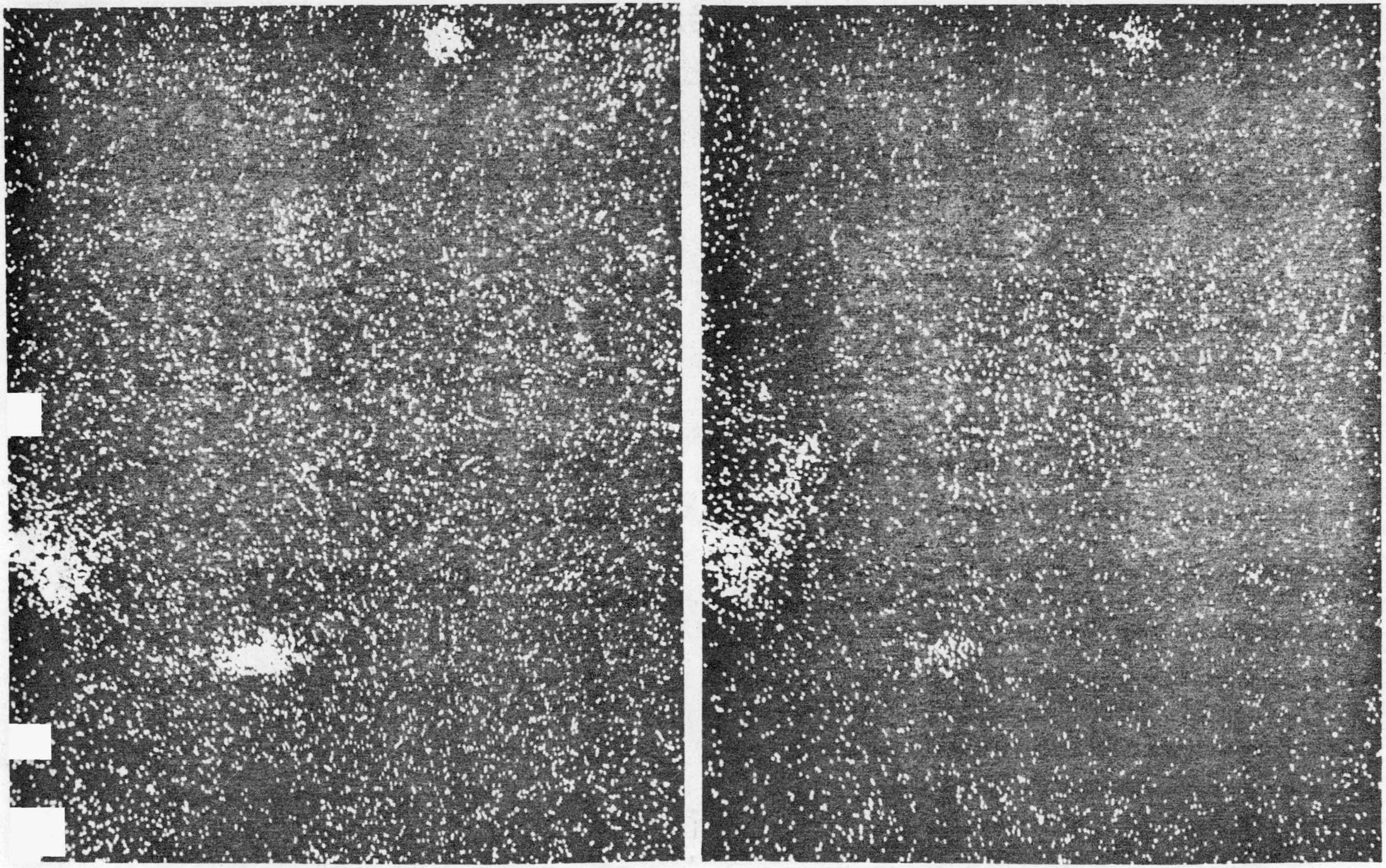
Identification of Detrimental Chemical Elements

Magnesium, iron and sulfur may contribute a detrimental effect to durability and may be a factor in the accelerated deterioration on salted primary roads. Research has not yet been completed but initial data would indicate that pyrite or marcasite, both iron-sulfur compounds may contribute to the accelerated deterioration of salted primary roads. The scanning electron microscope has been used to evaluate coarse aggregates exhibiting an accelerated deterioration on salted primary roads. Energy plots from the scanning electron microscope (figure 1), of the salt affected aggregates, exhibit similar distributions of iron and sulfur. This would indicate that iron-sulfur particles in the 1-2 micron range are uniformly dispersed throughout the nondurable aggregate.

Salt Treatment Preparation Prior to Freeze and Thaw Testing

A salt treatment preparation was developed in an effort to duplicate the observed accelerated deterioration on primary roads as opposed to secondary roads. In Iowa, historically, the coarse aggregates have exhibited the most influence on the resulting durability of portland cement concrete. For that reason, it was theorized that the salt may be adversely affecting the coarse aggregate. A salt treatment of the coarse aggregate was developed to be used prior to addition of the coarse aggregate to the concrete mix. The salt treatment consists of five cycles of drying in an oven at 230°F for 24 hours, followed by immersion in a 70°F, 100% solution of sodium chloride for 24 hours. The 70°F salt brine is poured over the aggregate immediately after it is removed from the 230°F oven. After the five cycles of salt treatment, the coarse aggregate is rinsed with clean tap water just prior to being incorporated into a concrete mixture.

The ASTM C666 Method B, "Freezing in Air -- Thawing in Water" testing of concrete mixtures with and without sodium chloride coarse aggregate pretreatment prior to being incorporated into the concrete has correlated very well with field performance. The durability of high quality coarse aggregates such as those from the Alden or Mohs quarries (figures 2 and 3) have not been adversely affected by sodium chloride pretreatment. Even though the resulting durability may be



SULFUR 10 Microns **IRON**

Figure 1 Scanning Electron Microscope Energy Plot Of Sulfur And Iron

Figure 2. **ALDEN DURABILITY FACTORS**

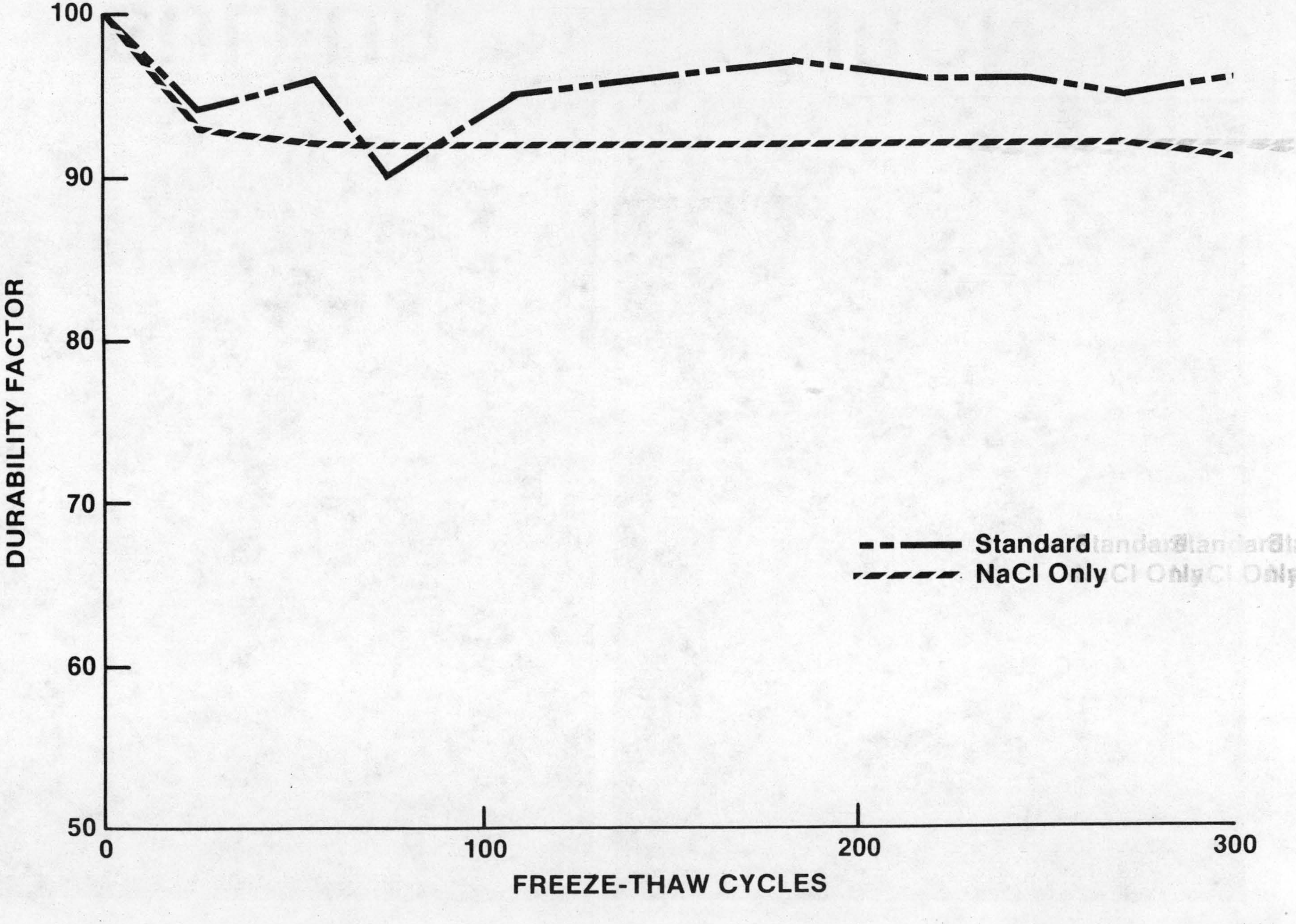
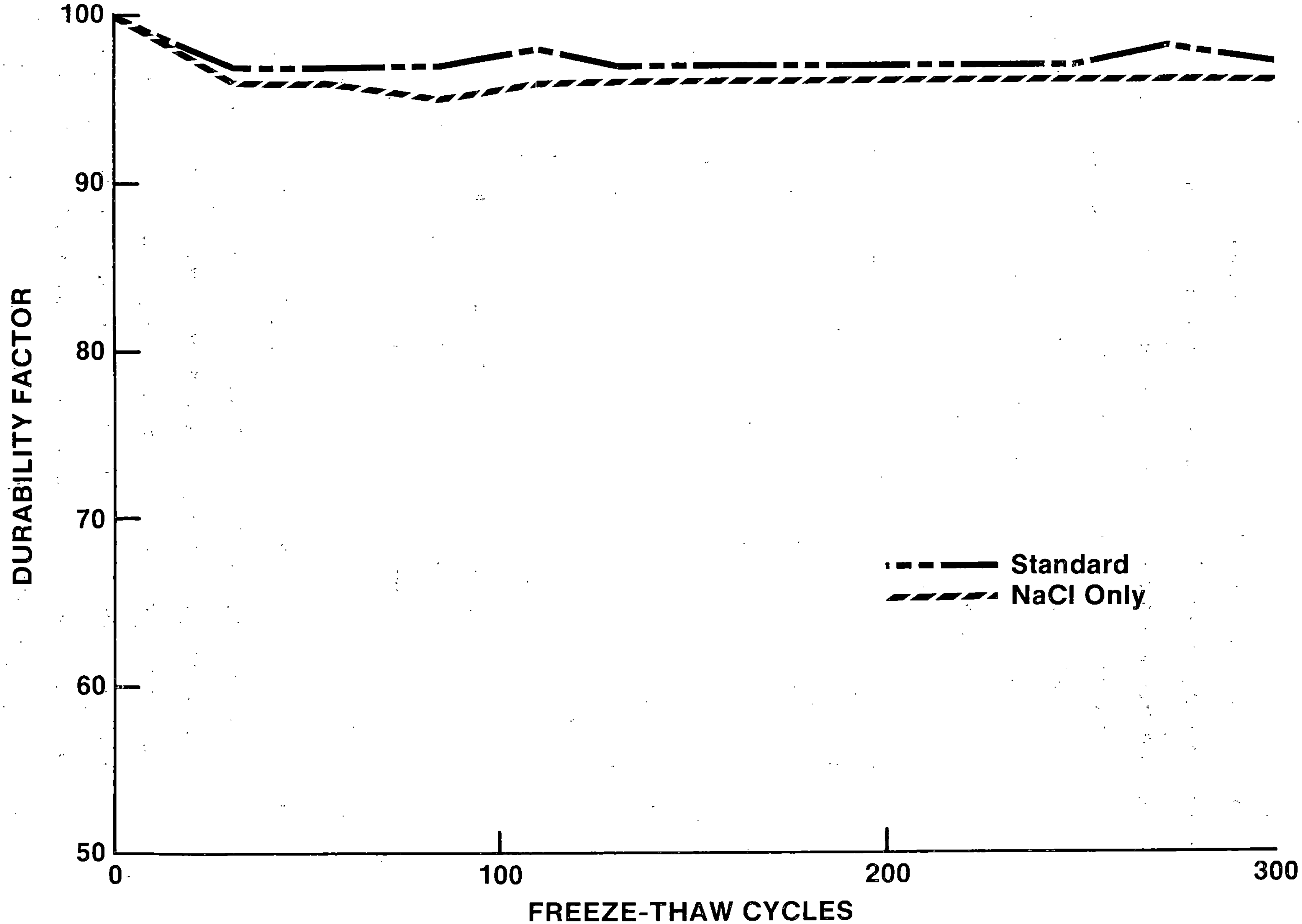


Figure 3. **MOHS DURABILITY FACTORS**



somewhat below the concrete mix without sodium chloride pretreatment, it is not significant. Salt treatment of the limestone fraction of the Ames gravel (figure 4) results in an extremely rapid deterioration of the concrete under freezing and thawing testing. The Smith and Garrison quarries (figures 5 and 6) are others that exhibit extremely accelerated deterioration after salt treatment. This again correlates very well with field performance.

At this time Iowa DOT research has not progressed to a point to fully explain the mechanism causing the accelerated deterioration due to the salt treatment. One speculation is that the addition of the sodium chloride salt results in a greater affinity for water within the aggregate pores, thereby aggravating the deterioration under freeze/thaw. There is also, however, strong evidence that the accelerated mechanism may be of a chemical (SO_4) nature. With limited experience, Iowa DOT geologists have developed some confidence in predicting which aggregates will be adversely affected by salt treatment. A limited number of tests have supported their basis for prediction. Aggregates with a finely dispersed system of an iron-sulfur compound and sufficient porosity to allow the movement of brine are adversely affected. This has been the criteria for Iowa DOT geologist predictions.

Concrete Mixture Ingredients Affecting Salt Treatment Durability

After verifying that the salt treatment preparation did cause the ASTM C666 durabilities to correspond to field performance, it was decided to conduct research to determine if various ingredients would either adversely or beneficially affect the durability factor. Three different ingredients have been added to the concrete mixture (figure 6) to ascertain their effect on concrete durability. The first was the

Figure 4. **AMES PIT DURABILITY FACTORS**

(CARBONATE FRACTION ONLY)

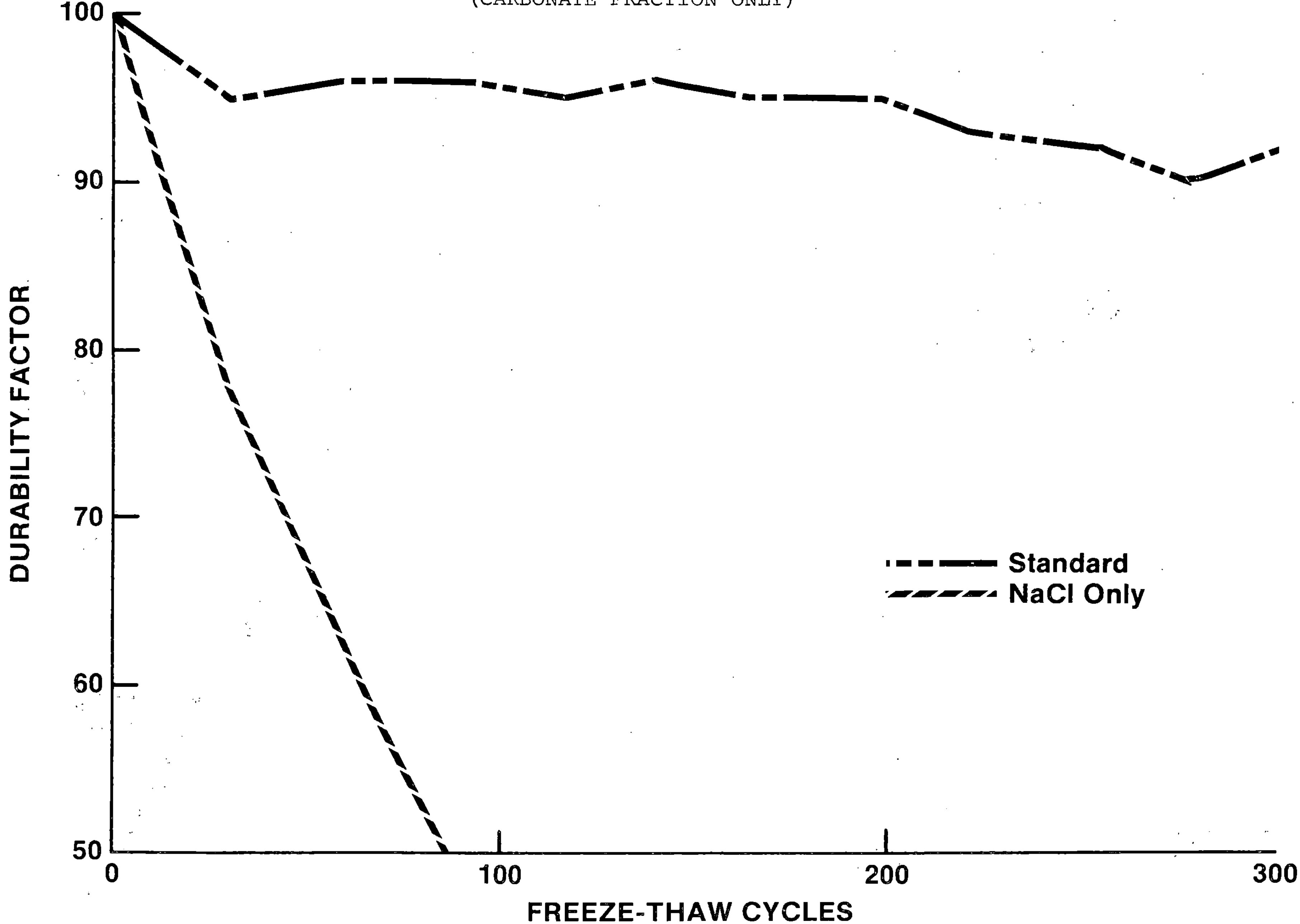


Figure 5. **SMITH DURABILITY FACTORS**

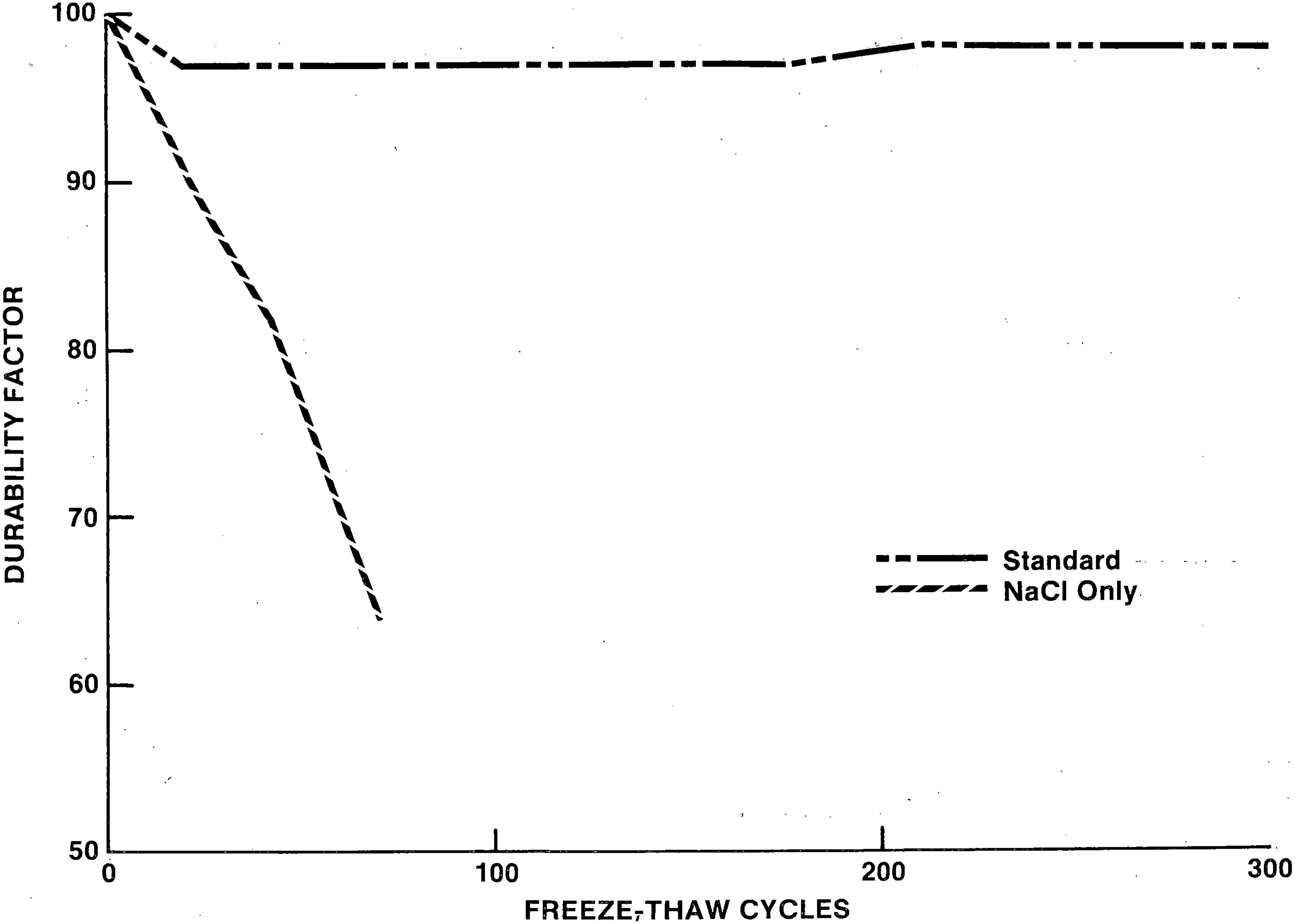
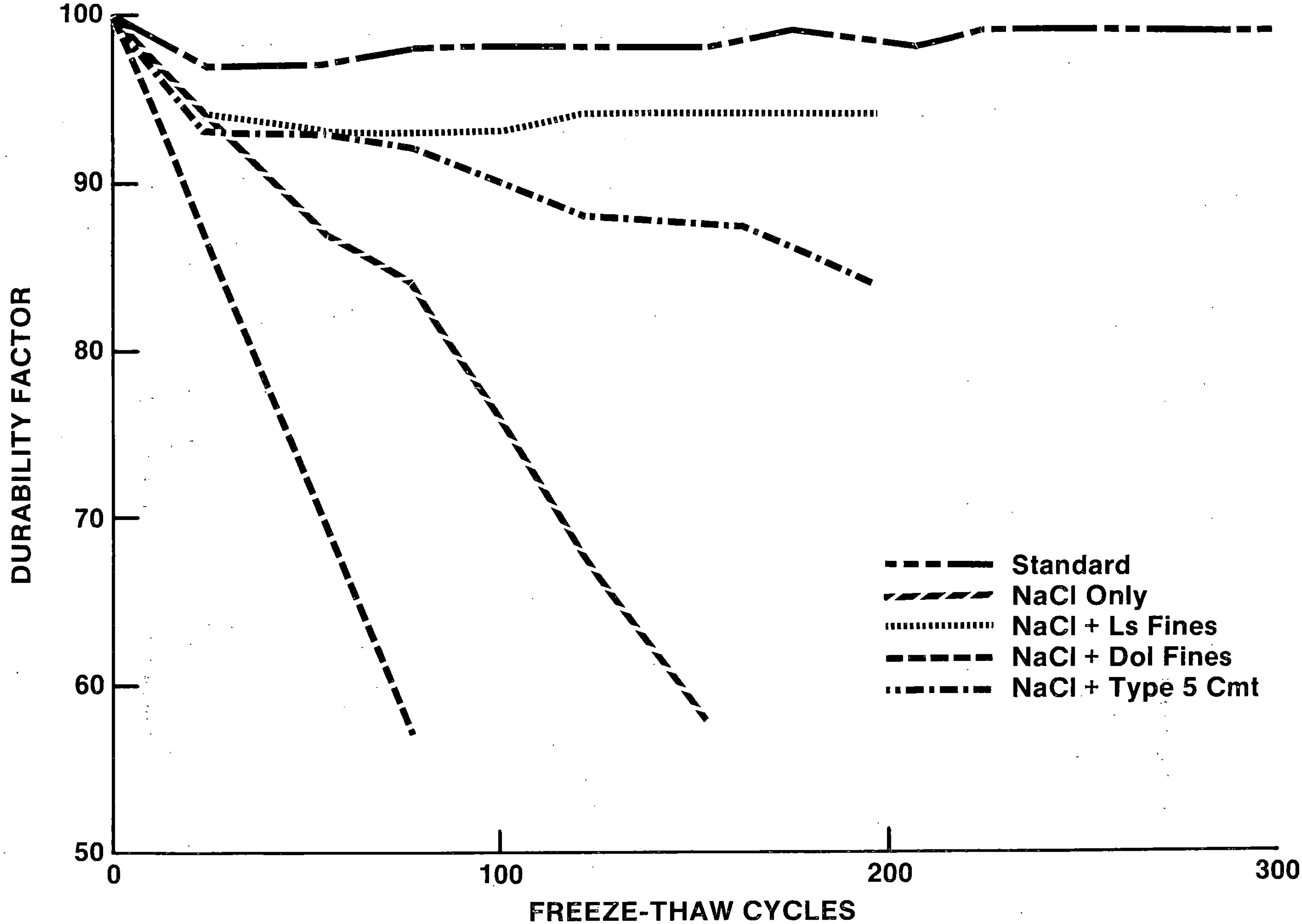


Figure 6. GARRISON DURABILITY FACTORS



use of a Type V portland cement rather than the regular Type I. Type V cement (4.8 tricalcium aluminate) did exhibit a significant beneficial affect on the concrete durability after salt treatment preparation.

Fine limestone with very low magnesium content was added to a concrete mixture in the amount of 5%. This addition of 5% limestone fines yielded a greater beneficial effect than did the Type V cement.

An addition of 5% of dolomitic fines yieled an adverse effect on the salt treated durability beams. From this research it would appear that magnesium is a chemical element that aggrevated the adverse affect in the freeze/thaw durability of concrete mixes containing porous, pyritic carbonate coarse aggregate.

ACKNOWLEDGEMENT

The authors wish to express their appreciation to Turgut Demirel and Jerry Amenson of Iowa State University for their assistance in x-ray analysis of various aggregates.

REFERENCES

1. V. Marks and W. Dubberke, Durability of Concrete and the Iowa Pore Index Test, Transportation Research Board, Transportation Research Record 853, 1982, pp. 25 through 30.

2. J. Myers and W. Dubberke, Iowa Pore Index Test, Interim Report, Iowa Department of Transportation, January, 1980.

3. W. Dubberke, Factors Relating to Aggregate Durability in Portland Cement Concrete, Interim Report for Project HR-2022, Iowa Department of Transportation, January, 1983.