MICHIGAN
STATE HIGHWAY DEPARTMENT
G. Donald Kennedy
State Highway Commissioner

CONCRETE DURABILITY STUDY:

ACCELERATED SCALING STUDIES ON

CONCRETE PAVEMENT SURFACES

By

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Research Project 39 B-11

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CONTENTS

PREFACE

A survey of all concrete pavements on the Michigan State Trunk Line system revealed that approximately ten per cent of the surface is scaled in varying degrees. This condition has become more apparent as the use of chemical salts has increased for the removal of ice from pavements.

Consequently, a study of scaling, its causes and methods for prevention was incorporated into the research program of the Michigan State Highway Department as a definite project under the subject "Concrete Durability Study".

The Concrete Durability Study has been divided into three separate studies. First, a survey of existing concrete pavements, second, field studies on specially constructed pavements; and third, a laboratory study on concrete durability. The complete investigation as considered under these three studies will attempt to establish certain fundamental principles in concrete construction and to correlate certain laboratory studies with construction methods in order to develop more durable concrete pavements.

The purpose of this report is to present the results of accelerated scaling studies which were conducted on several concrete pavements during the winter seasons of 1940 - 1941 and 1941 - 1942. This report pertains to part two of the study on Concrete Durability.

The field scaling studies were under the general supervision of G. A. Mansfield assisted by Harley A. Bentley and Dale Parrish who were assigned to the scaling study on the Michigan Test Road and W. A. Keranen who was responsible for the scaling study program conducted on several projects throughout the Upper Peninsula.

INTRODUCTION

The performance of concrete under severity of service can not be predicated upon laboratory studies because of the numerous factors incidental to pavement construction which may effect surface conditions and their relationship to scaling. Such factors are, materials; construction operations including the concrete mixtures; finishing and curing; climate conditions during construction; etc.

In order to conduct observations under service conditions on controlled factors, specially constructed concrete pavements have been selected. The pavements selected for accelerated scaling studies are the Durability Project on the Michigan Test Road, Construction Project SN-FAP 3 (10) on US-41 North of L'Anse, Construction Project FA 175 Section J on US-41 eight miles North of Hancock, and Construction Project M-75 - 28, C2 on M-94 in the City of Manistique.

Embodied in these considerations are the newer concepts of concrete mi[redacted] regards proportioning and grading of aggregates with definite recognition of the materials passing 200 mesh; the comparative effect of various types of additives including physical and chemical varieties as well as cement blends and cements produced with grinding aids, the effect of variation in construction factors such as finishing and curing methods, types of aggregates including crushed limestone materials and stamp sand. In addition, consideration has been given to the study of the relative effect of calcium chloride for ice removal versus natural freezing and thawing of water on concrete pavements.

This report will discuss in detail the findings of the various studies in the order presented above.

PART ONE

DURABILITY PROJECT

MICHIGAN TEST ROAD

Part one presents the results obtained from the accelerated scaling studies conducted on the Durability Project of the Michigan Test Road during the winters of 1940 - 1941 and 1941 - 1942.

CONCRETE SCALING STUDIES ON MICHIGAN TEST ROAD

The durability project of the Michigan Test Road was constructed for the purpose of observing under service behavior certain factors in concrete pavement construction which might be effective in the prevention of scaling. The purpose of this pavement was not only to make observations under service conditions but to afford a field laboratory to obtain accelerated action of chloride salts or ice on concrete pavements and the study of resultant action. The durability study project entails a length of approximately 7.7 miles. The location is ideal from a standpoint of average weather conditions in Michigan and the length is sufficient to reduce the variables of construction to a minimum for each factor investigated. The supplemental specifications covered details for all variables unusual to Michigan State Highway Department specifications. They included cements, admixtures, mix designs, methods of construction which preliminary laboratory studies indicated to possess characteristics favorable to the prevention of scaling.

The cements used in the construction of the project included two brands of regular Portland cement as normally used in the construction of concrete pavements in Michigan. They have been designated as Brands 1 and 2. Admixtures included the use of certain proprietary materials known as Plastiment, Pozzolith, Orvus and Vinsol Resin. Natural cement was also included, which was ground with and without the use of beef tallow. Mix designs including the regular proportioning as determined by the material specifications and the mortar void design method of the Michigan State Highway Department, as well as the addition of fines supplementing the fine aggregates. These fines were added to increase the density and workability

of the mix and as a possible factor in the reduction of scaling. Several short test sections were included to study the relation of scaling to methods of curing.

The methods for finishing and curing of the concrete surface on the project included the standard methods specified in the specifications of the Michigan State Highway Department and other suggested methods.

The study of curing methods was incorporated into the project mainly for the purpose of determining the relative resistance to scaling of the same concrete under various curing treatments.

The final finishing operation as specified in the Michigan State Highway Department standard specification, requires the use of a burlap drag. In most cases, this method produces a satisfactory, non-skid surface, but it is observed, under certain conditions, that an excess amount of fine material still remains upon the surface. All studies of scaling seem to indicate that this thin layer of material is the first to be displaced. Brooming the concrete with stiff brooms as a final finishing operation has been used by some highway engineers to reduce the amount of fine superficial material. However, some engineers have contended that this method provided grooves for the concentration of salt solutions and a resultant unsatisfactory condition of aggravated scaling. Therefore, it was felt that a comparative study should be made of these two methods and obtain comparative data upon the two methods. Brooming was also included on certain sections of bituminous curing, since in the past, these methods of curing provided a rather slippery pavement for some time after construction, and it was hoped that a trial section of brooming would show how to overcome this difficulty if bituminous curing were allowed in the standard specifications.

On the Durability Project, all of the standard practices of construction were adhered to in the matter of design using 22 foot width, 9 inch edge and 7 inch center cross section, expansion joints spaced 120 feet, contraction joints spaced 60 feet and plane of weakness joints spaced at 30 feet. Between each section of concrete pavement where the mix was varied a 1200 foot section of standard concrete was placed to obtain comparative results between a standard and revised concrete mix under relative similar construction conditions. During the placing of the concrete numerous and complete observations were made on the character of the concrete for the various admixtures and standard mixes. These observations include placing of concrete, workability, finishing, bleeding, laitance, slump, curing and complete weather information.

The research information secured on the durability project divides itself into three groups, First, information obtained during construction; second, observations under service; and third, results of accelerated scaling studies.

Construction Observations and Data:

Observations and data obtained during construction are very important in the later interpretation of findings. Consequently, the observers were admonished to follow instructions closely and impressed with the importance of precise, unbiased and accurate analyses, observations and data. The information procured during this period consisted of the following items:

1. Soil surveys. Soil density and moisture content.
2. Meteorological observations including:
   a. Humidity
   b. Temperature
   c. Precipitation

d. Wind movement

e. Evaporation

3. Daily progress report including irregularities

4. Moisture content and temperature of concrete on special sections of curing.

5. Placing of concrete pavement.

6. Mechanical analysis of concrete to determine relative segregation.

7. Special observations relative to final finishing methods and curing.

Observations in Service:

The relative value of the various factors may be prophesied by laboratory tests and observations during construction, but the ultimate conclusions must be determined by observations made under actual service conditions. Therefore, it is planned to make periodic visual examinations together with measurement of physical conditions as outlined in the above mentioned instructions. These observations will include continuation of measurements of moisture content, temperature of slab, but for the most part will be concentrated upon the study of surface scaling due to action of traffic and climatic conditions.

Special Scaling Study:

During the actual service life of the pavement and for a period of 3 to 5 years, it was planned to study or observe certain sections of the project under the action of ice and salts in an accelerated manner.

The correlation of the observations made during construction and actual service together with the test information of the special scaling study should enable the Michigan State Highway Department to evaluate the many factors and determine their relative importance under the conditions imposed.

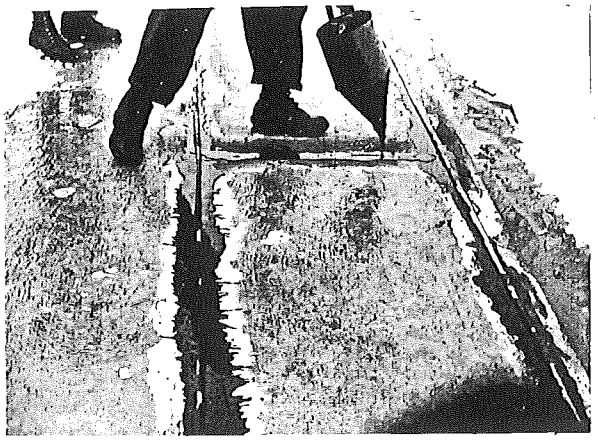
In conducting the scaling study definite pavement sections 120 feet in length were chosen with respect to the various concrete mixtures and surface treatments involved in the construction of the pavement. In each section two areas were dyked off, each area being 3 feet wide and 12 feet long. The dyked areas were established along the east edge of the pavement and parallel to it. Safety precautions were maintained day and night to warn traffic of the presence of the test areas and to prevent accidents. The methods used in construction of dykes are illustrated in Figure 1.

Two different types of accelerated test methods were employed. In Test area "A", a 10 percent solution of calcium chloride of 1/4 inch minimum depth was applied and allowed to remain in place 5 days. At the end of this period, the solution was removed, the panel flushed and water applied to a depth of 1/4 inch. After the water had frozen, the ice was melted by an application of 5 pounds of flake calcium chloride per area. When the ice was decomposed, it was removed from the test area, the surface was flushed and allowed to rest one day before completing the next cycle. Method "A" was discontinued after first winter season because it did not produce the desired results.

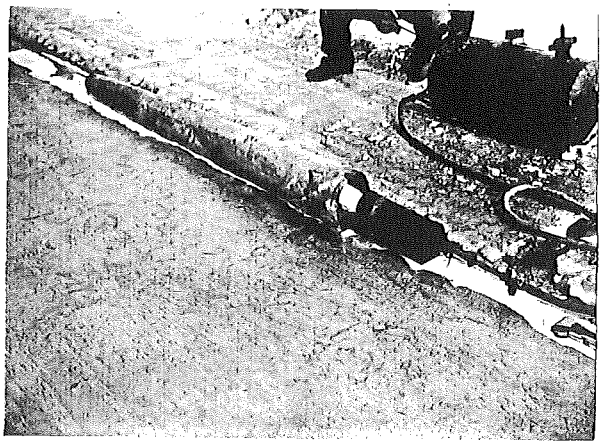
Test area "B" received a different treatment. Water was applied to the test area and allowed to freeze over night. The following morning the ice was melted by distributing calcium chloride over the area at the

A. IN 1940-1941- STEAM WAS USED TO REMOVE ICE FROM PAVEMENT PRIOR TO INSTALLING PANEL STRIPS

B. DRYING PAVEMENT SURFACE PRIOR TO INSTALLING DYKE STRIPS

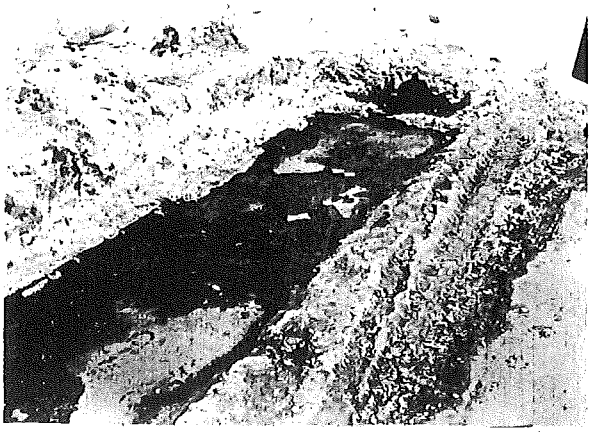


D. ONE METHOD OF CONSTRUCTING DYKES BY USE OF BITUMINOUS MATERIAL AND TWO NARROW STRIPS OF WOOD



C. DRYING EQUIPMENT CONSISTED OF KEROSENE TORCH AND SHIELD FOR FLAME

E. ANOTHER METHOD OF CONSTRUCTING DYKES WITH BITUMINOUS MATERIAL AND ONE STRIP OF WOOD



F. TYPICAL VIEW OF PANEL IN PROGRESS OF STUDY

FIGURE I

INSTALLATION OF SCALING PANELS

rate of 5 pounds per area. When the ice was decomposed it was removed from the test area and the surface was flushed. Fresh water was applied to the test area and the freezing and thawing cycle repeated. On the basis of the quantity of water resulting from the melted ice in each test area, it was calculated that 5 pounds of flake calcium chloride would be sufficient to produce a 10 per cent solution.

It is proposed to carry on these tests for several years to determine what effect age has on the ability of concrete to resist freezing, thawing and calcium chloride treatments. To this end, no calcium chloride has been applied to the durability section of the Test Road. During each winter it was planned to establish test areas in the same section and adjacent to the previous test areas.

The first and second of the series of scaling studies were completed during the winter of 1940-1941 and 1941-1942. The results obtained so far indicate that certain treatments of the concrete or its ingredients will tend to influence the ability of the concrete to resist scaling caused by the application of calcium chloride for ice removal.

RESULTS OF SCALING STUDIES

The results of the scaling studies on the Durability Project of the Michigan Test Road will be discussed in conjunction with the various features of construction as follows: finishing methods, curing methods, admixtures, grinding aids, natural cement blended with Portland cement, grading of aggregates, and limestone aggregates. The locations of the various scaling panels with respect to the construction features are given in Figure 2.

Finishing Studies: The brooming of concrete surfaces with stiff brooms as a final finishing operation has been used by some highway engineers to reduce the amount of fine superficial material. However, some engineers have contended that this method provided grooves for concentration of salt solutions and a resultant unsatisfactory condition of aggravated scaling. Therefore, it was felt that a comparative study should be made between burlap finish and brooming to obtain comparative data relative to the two methods.

Therefore in Series 1A and 2A of the durability project, a comparative study was made of burlap finish versus broom finishing, with and without wetted straw and bituminous membrane curing.

The bituminous membrane curing consisted of asphalt emulsion and cut back asphalt. The cut back asphalt was applied immediately after finishing operations whereas the asphalt emulsion was applied after initial curing with burlap. Standard construction procedure was exercised throughout the entire finishing studies.

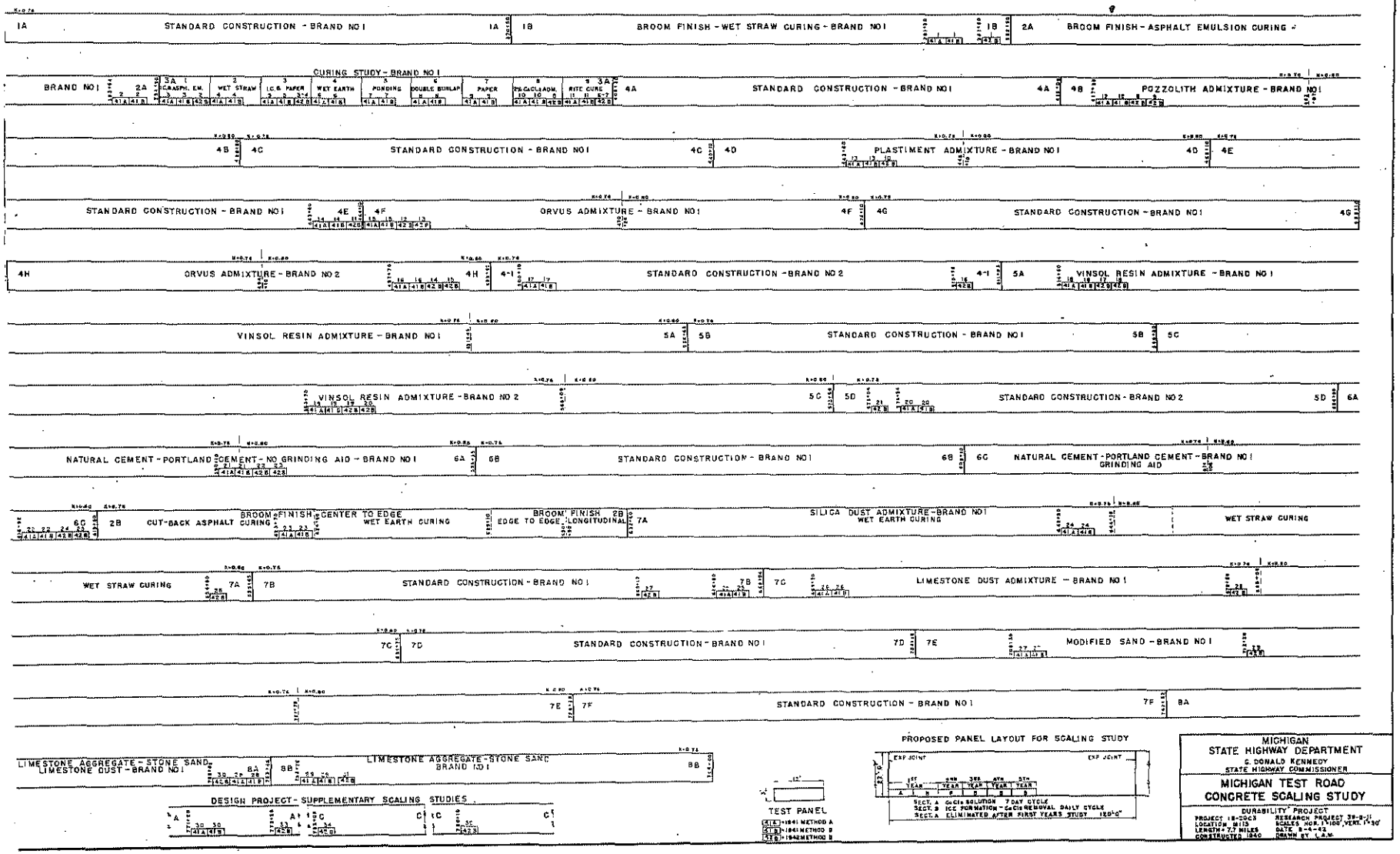

1A STANDARD CONSTRUCTION - BRAND NO 1
1A 1B BROOM FINISH - WET STRAW CURING - BRAND NO 1
1B 2A BROOM FINISH - ASPHALT EMULSION CURING
CURING STUDY - BRAND NO 1
BRAND NO 1
2A
3A CA.ASPH. EM.
WET STRAW
I.C.S. PAPER
WET EARTH
PONDING
DOUBLE BURLAP
PAPER
8% CaCl2 SOLN.
RITE CURE
3A 4A STANDARD CONSTRUCTION - BRAND NO 1
4A 4B POZZOLITH ADMIXTURE - BRAND NO 1
4B 4C STANDARD CONSTRUCTION - BRAND NO 1
4C 4D PLASTIMENT ADMIXTURE - BRAND NO 1
4D 4E
STANDARD CONSTRUCTION - BRAND NO 1 4E 4F ORVUS ADMIXTURE - BRAND NO 1
4F 4G STANDARD CONSTRUCTION - BRAND NO 1
4G
4H ORVUS ADMIXTURE - BRAND NO 2
4H 4-1 STANDARD CONSTRUCTION - BRAND NO 2
4-1 5A VINSOL RESIN ADMIXTURE - BRAND NO 1
VINSOL RESIN ADMIXTURE - BRAND NO 1
5A 5B STANDARD CONSTRUCTION - BRAND NO 1
5B 5C
VINSOL RESIN ADMIXTURE - BRAND NO 2
5C 5D STANDARD CONSTRUCTION - BRAND NO 2
5D 6A
NATURAL CEMENT - PORTLAND CEMENT - NO GRINDING AID - BRAND NO 1
6A 6B STANDARD CONSTRUCTION - BRAND NO 1
6B 6C NATURAL CEMENT - PORTLAND CEMENT - BRAND NO 1 GRINDING AID
6C 2B BROOM FINISH CUT-BACK ASPHALT CURING
2B FINISH CENTER TO EDGE WET EARTH CURING
BROOM FINISH EDGE TO EDGE LONGITUDINAL 2B 7A
7A SILICA DUST ADMIXTURE - BRAND NO 1 WET EARTH CURING
WET STRAW CURING
WET STRAW CURING 7A 7B STANDARD CONSTRUCTION - BRAND NO 1
7B 7C LIMESTONE DUST ADMIXTURE - BRAND NO 1
7C 7D STANDARD CONSTRUCTION - BRAND NO 1
7D 7E MODIFIED SAND - BRAND NO 1
7E 7F STANDARD CONSTRUCTION - BRAND NO 1
7F 8A
LIMESTONE AGGREGATE - STONE SAND LIMESTONE DUST - BRAND NO 1
8A 8B LIMESTONE AGGREGATE - STONE SAND BRAND NO 1
8B
DESIGN PROJECT - SUPPLEMENTARY SCALING STUDIES
TEST PANEL
4 1 A = 1941 METHOD A
4 1 B = 1941 METHOD B
4 2 B = 1942 METHOD B
PROPOSED PANEL LAYOUT FOR SCALING STUDY
EXP JOINT
EXP JOINT
1ST YEAR
2ND YEAR
3RD YEAR
4TH YEAR
5TH YEAR
SECT. A 4% CaCl2 SOLUTION 7 DAY CYCLE
SECT. B ICC FORMATION - 5% CaCl REMOVAL DAILY CYCLE
SECT. A ELIMINATED AFTER FIRST YEARS STUDY
MICHIGAN
STATE HIGHWAY DEPARTMENT
G. DONALD KENNEDY
STATE HIGHWAY COMMISSIONER
MICHIGAN TEST ROAD
CONCRETE SCALING STUDY
DURABILITY PROJECT
PROJECT 18-CO6S
LOCATION 8MI S
LENGTH = 7.7 MILES
CONSTRUCTED 1940
RESEARCH PROJECT 39-B-11
SCALES HOR. 1"=100', VERT. 1"=30'
DATE 8-4-43
DRAWN BY L.A.W.

FIGURE II

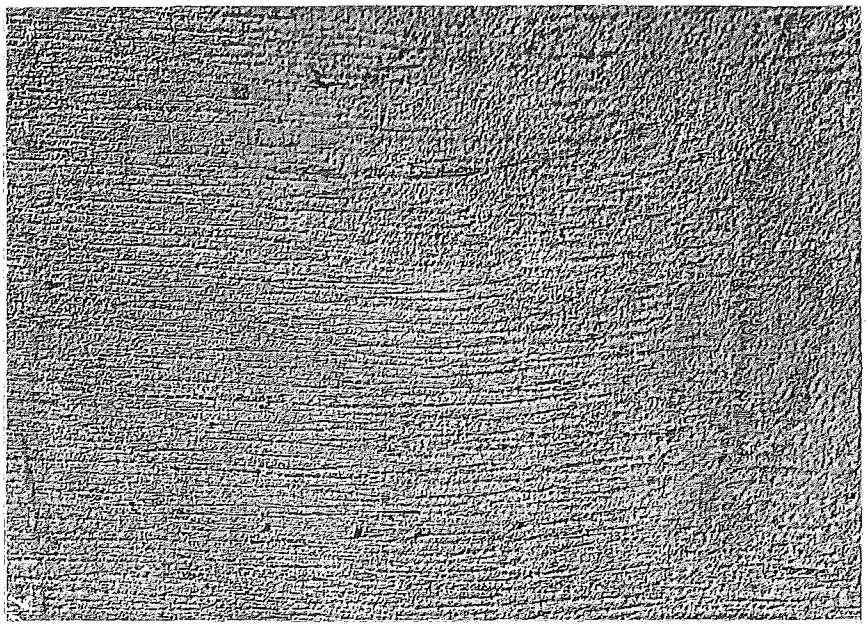
Burlap Finishing versus Brooming, Wetted Earth Curing: The burlap finish method consisted of dragging a strip of damp burlap longitudinally over the full width of the pavement at a time when the excess moisture has disappeared and while it is still possible to produce a uniform surface of gritty texture. See Figure 3.

Brooming operations were performed during a period after belting when the excess water and laitance had arisen to the surface, and before the concrete had become to such a condition that it would be unduly roughened or torn. The brooms were of an approved push broom type not less than 18 inches in width and constructed of bass or bassine fibre not more than 5 inches long. Each brush was equipped with a handle at least one foot longer than one-half the width of the pavement slab. It was required that the brooms be washed and dried at frequent intervals and that a sufficient number of brooms be provided to permit interchanging.

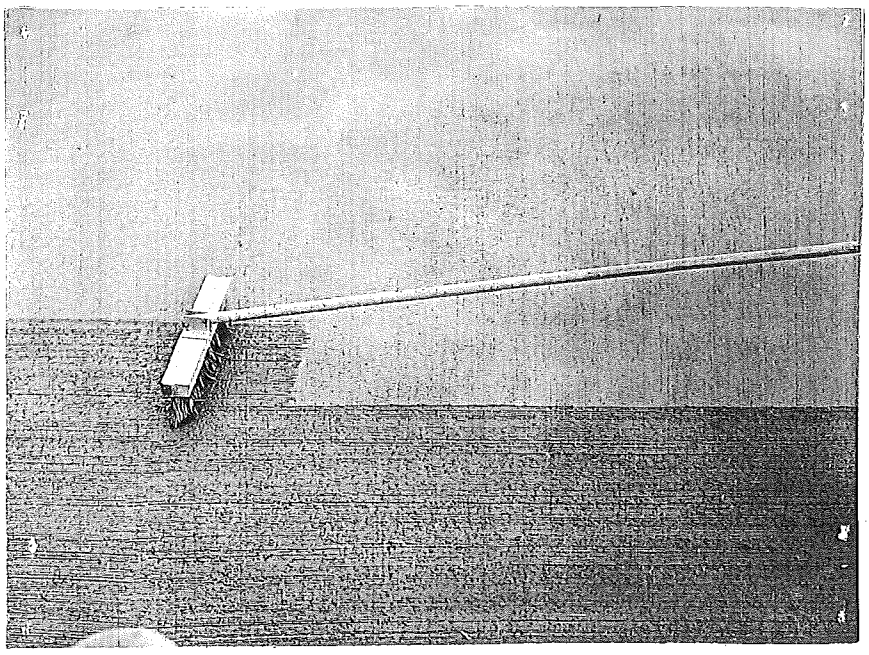
The brooms were drawn across the surface from the center line to each edge with not more than one stroke per width of broom. Each stroke slightly overlapped the adjacent stroke. The brooming operation should produce corrugation in the surface of the pavement, uniform in appearance and not more than 1/8 inch in depth.

The curing method consisted of 24 hour wet burlap followed by 6 days of wetted straw.

The results obtained from the accelerated scaling treatments are tabulated below in Table I. Figure 4 illustrates condition of concrete surface at termination of freezing and thawing treatment.

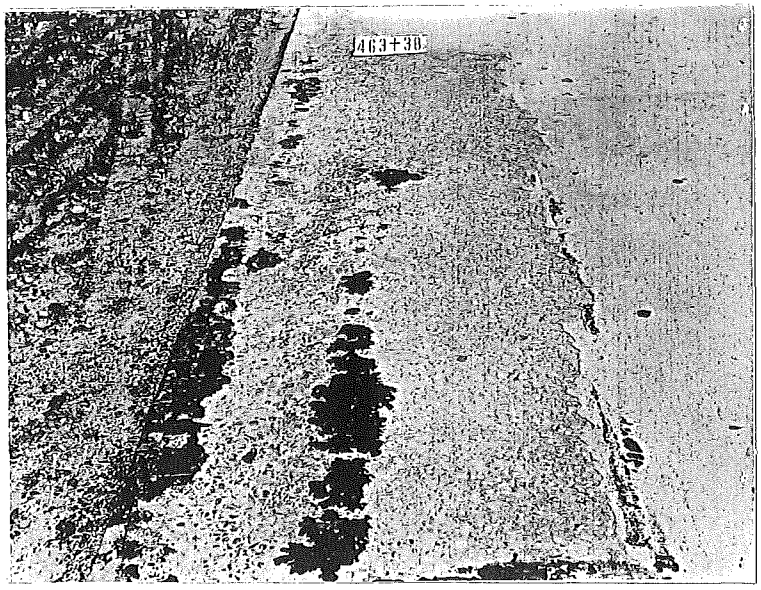


A. Typical Burlap Finish



B. Character of Surface After Brooming

Surface Finishing
Figure 3



A. Burlap Finish Wetted Straw Curing, 100% Scale, 41 Cycles, 1941-1942 Panel 11, Series 4E

B. Broom Finish Wetted Straw Curing, 100% Scale, 23 Cycles, 1941-1942 Panel 1, Series 1B

Figure 4

Results from Finishing Study

Table I

Burlap versus Brooming

Panel No.	Season	Finish	Curing	TEST METHOD A Cycle	A % Scaling	B Cycle	B % Scaling
4	1940-41	Burlap	Wetted Straw	6	6%	28	19%
1	1940-41	Broom	Wetted Straw	5	100%	33	94%
1	1941-42	Broom	Wetted Straw	-	---	23	100%
14	1940-41	Burlap	Wetted Straw	7	11%	33	61%
14	1940-42	Burlap	Wetted Straw	-	---	41	100%

It is apparent that brooming does not eliminate scaling. Throughout the text when the type of cement is not mentioned in the tables, it should be understood that Brand No. 1 (Petoskey) was used in the construction of the particular sections under discussion.

Burlap versus Brooming, Bituminous Curing: In series 2A, 2B, and 3A Bituminous Membranes consisting of Asphalt Emulsion and Cut Back Asphalt were applied to the concrete surface after burlap or brooming operations for the purpose previously explained. Scaling studies were conducted on these sections in conjunction with the curing studies.

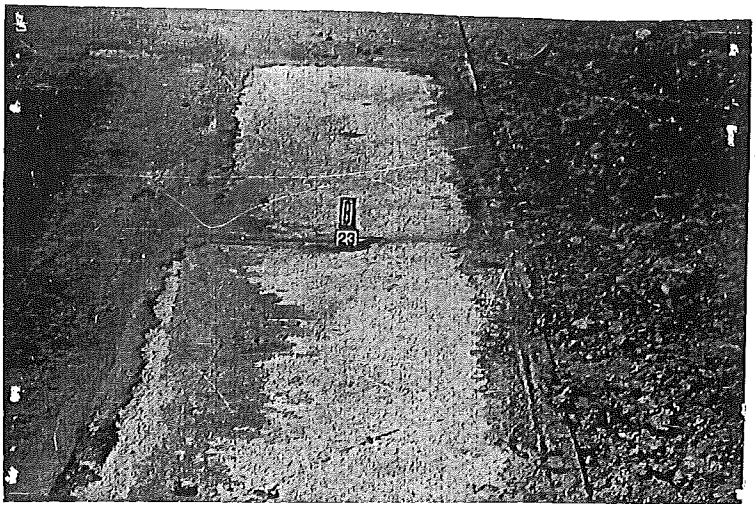
In series 2A, the Asphalt Emulsion, AE-1A furnished by the American Bituminous Company, was applied immediately after completion of finishing operations at the rate of not less than 1/20 gallon per square yard. In series 2B, the Cut Back Asphalt furnished by Johnson Marsh Corporation was applied immediately after completion of finishing operations at the rate of not less than 1/15 gallon per square yard. In series 3A, the Asphalt Emulsion was applied after an initial 24 hour curing period with wet burlap.

The results obtained from the acceleration scaling treatments on these various sections are tabulated below in Table II. Figure 5 illustrated the condition of the surface at termination of treatment.

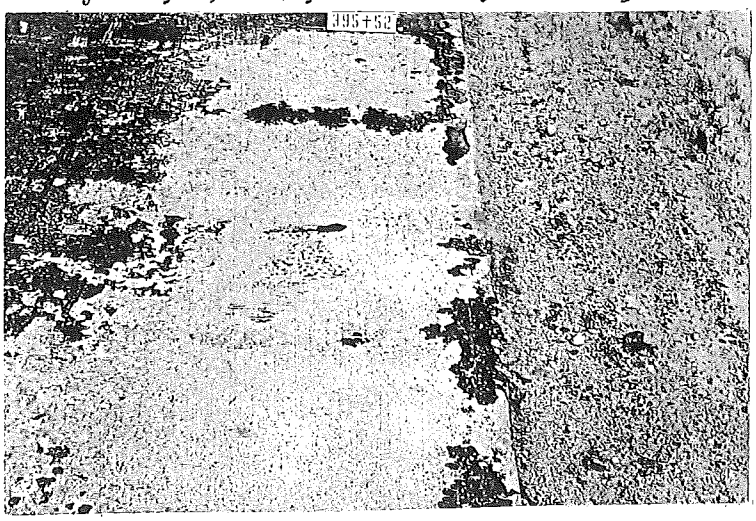
Discussion of Results:

From the results presented in Table II it is evident that brooming with bituminous curing is somewhat more effective than burlap curing with wetted straw curing in preventing scale. However, there is not enough difference in results to make the former method worth serious consideration.

A. Brooming, Asphalt Emulsion Curing, 92% Scale, 28 Cycles, 1940-41, Series 2A, Panel 2



B. Brooming - Cut Back Curing, 83% Scale, 33 Cycles, 1940-41, Series 2B, Panel 23



C. Burlap Finish Asphalt Emulsion After Initial Burlap Curing, 100% Scale, 47 Cycles, 1941-42 Series 3-A1, Panel 2

Figure 5

Bituminous Curing with Finishing Methods

Table II

Panel No.	Season	Finish	Curing	TEST METHOD A Cycle	A % Scaling	B Cycle	B % Scaling
4	1940-41	Burlap	Wetted Straw	6	6%	28	19%
1	1940-41	Broom	Wetted Straw	5	100%	33	94%
1	1941-42	Broom	Wetted Straw	-	-	23	100%
2	1940-41	Broom	Asphalt Emulsion	6	22%	28	92%
	1941-42	Broom	Asphalt Emulsion			NO TESTS	
23	1940-41	Broom	Cut Back Asphalt	7	42%	33	83%
	1941-42	Broom	Cut Back Asphalt			NO TESTS	
3	1940-41	Burlap	Initial Curing 24 hr. Asphalt Emulsion	6	42%	28	61%
2	1941-42	Burlap	Initial Curing 24 hr. Asphalt Emulsion	-	-	47	100%

Special Curing Study:

The relative merit of the various concrete curing methods have been based, in general, upon laboratory strength tests. Very little can be said as to the relative merit of the different curing mediums with respect to durability of concrete. Therefore, a study of curing methods under actual field conditions were included in Series 3 of the Durability Project. See Figure 6. Embodied in the curing study are such factors as moisture gradient, relative thermo insulation value of the different curing methods, membrane materials versus wetted coverings, and the relative durability of the slab surface.

To determine the relative durability of the various sections, each cured surface was subjected to the same acceleration freezing and thawing cycles as employed on the other concrete sections thoughout the Durability Project. The curing methods studied are asphalt emulsion, cut-back asphalt, wetted straw, paper curing without initial curing, wetted earth, ponding, double burlap, paper curing, calcium chloride integrally mixed and a membrane material called Rite-Cure. The different curing sections will be discussed briefly in the order mentioned above.

Initial Curing: Initial curing which is referred to frequently in the discussion of curing methods is described as follows. After finishing operations and when the surface has hardened sufficiently to prevent marring, strips of burlap are laid on the surface to overlap not less than 3 inches and shall be kept thoroughly wet until removed. The burlap must remain at least six hours after concrete is placed but not later than 10 a.m. on the

A. General View of Curing Section

B. Application of Rite Cure

Curing Studies
Figure 6

day following the placing of the concrete. Upon removal of the burlap, the surface is thoroughly wetted and the regular curing method applied.

Asphalt Emulsion Curing, Series 3A: 1. This test area consists of initial curing with wet burlap followed by an application of asphalt emulsion AE-1A. Immediately after finishing operation, wet burlap was applied to the surface and kept damp for a 24-hour period after which the burlap was removed and the surface coated and sealed with an uniform layer of asphalt emulsion. The emulsion was applied at the rate of not less than 1/20 gallon per square yard by means of a suitable pressure outfit.

Cut-Back Asphalt Curing, Series 2B: Relative to the study of brooming versus burlap finishing with and without bituminous curing, cut-back asphalt was applied immediately after finishing operations in the same manner as for the asphalt emulsion except that the rate of application was not less than 1/15 gallon per square yard. The application of cut-back asphalt on a concrete surface immediately after finishing is a patented method. The patentee is the Johnson March Corporation of New York City who also furnish the cut-back asphalt described below.

Wetted Straw: Series 3A-2: The wetted straw method consists of spreading hay or straw over the entire surface immediately upon removal of the burlap at the end of the initial 24 hour burlap curing period. The hay or straw is applied at the rate of not less than 4 pounds per square yard. The material is thoroughly wetted as soon as placed and kept saturated for 6 days.

Paper Curing with Initial Curing, Series 3A-3: In Series 3A-3, the first 24 hour period consisted of wet burlap curing after which the burlap was removed, the surface wetted and immediately covered with an impermeable paper covering. The paper blankets were composed of an approved moisture-proof paper of sufficient strength and thoroughness to permit handling without becoming unfit to

provide a sealed covering during the entire curing section. The paper blankets were of sufficient width to cover the top and edges of the slab to within 2 inches of the bottom with adequate provision for shrinkage.

Wetted Earth, Series 3A-4: After the initial curing period, the entire surface of the pavement was covered with earth to a minimum depth of 2 inches. The earth covering was thoroughly wetted after it was placed and kept saturated for a period of 6 days.

Ponding, Series 3A-5: After initial curing, the entire surface of the pavement was flooded with water which was held in place by a system of transverse and longitudinal dykes of earth. The surface was completely submerged for a period of 6 days.

Double Burlap, Series 3A-6: After initial curing, an additional layer of burlap was added to the surface and the double layer of burlap was kept saturated for a period of 6 days.

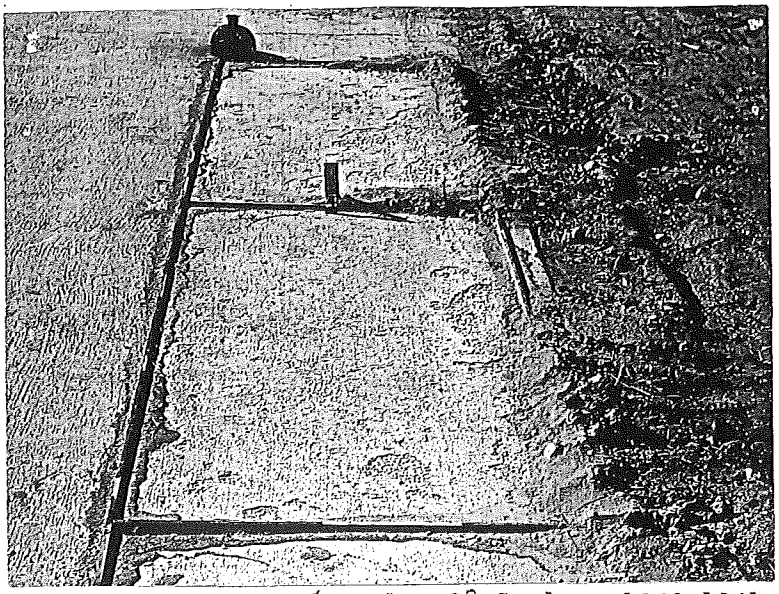
Paper Curing without Initial Curing, Series 3A-7: In Series 3A-7, the paper was applied to the surface immediately after finishing operations omitting the initial 24 hour curing period with wet burlap. The paper and method of application was the same as for Series 3A-3. The curing paper was furnished by the Sisal-Kraft Company.

Calcium Chloride Integral Mixed, Series 3A-8: Calcium chloride in flake form was added to the dry materials in the skip at the rate of 2 pounds of calcium chloride per sack of cement. Immediately after finishing, the concrete was covered with a single thickness of wet burlap. No subsequent curing treatment was applied to the surface after removal of burlap the following morning.

Transparent Membrane - Rite-Cure, Series 3A-9: After initial curing with burlap, a transparent membrane liquid, (Rite-Cure) was applied to the surface of the pavement by the method described for asphalt emulsion except that the rate of application was 1/20 gallon per square yard. Rite-Cure was furnished by the Johnson-March Corporation, 52 Vanderbilt Avenue, N.Y.

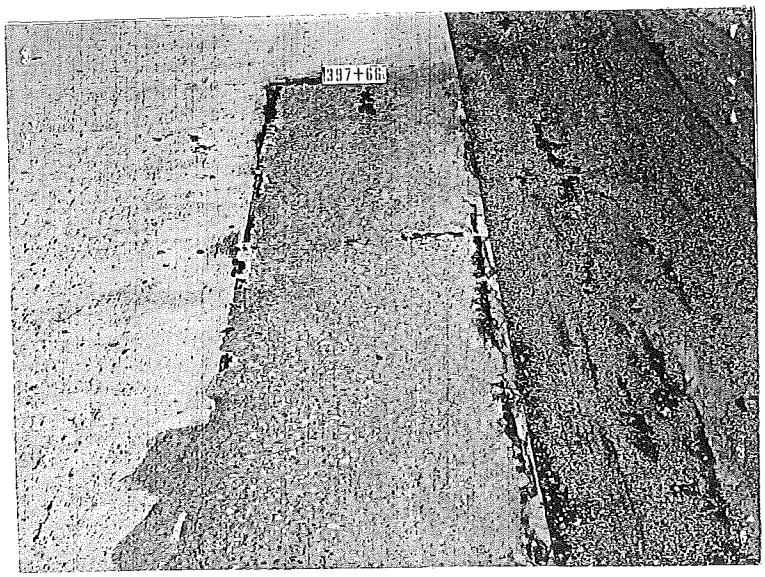
The results obtained from the accelerated scaling treatments on the curing section are tabulated in Table III. Figure 7 illustrated the condition of the pavement surface at the termination of the freezing and thawing treatment. All sections were finished by the burlap drag method.

From the data presented in Table III it is difficult to predict which curing method can be considered superior to the others because of many construction factors which may affect the final results. However, it is quite apparent that certain curing methods show in general a marked efficiency over others, for example, the particular methods which prevent excessive moisture loss during the first stages of construction such as paper curing without initial curing and transparent membrane curing (Rite-Cure) seem to produce a surface with a higher resistance to scaling than the other curing methods.



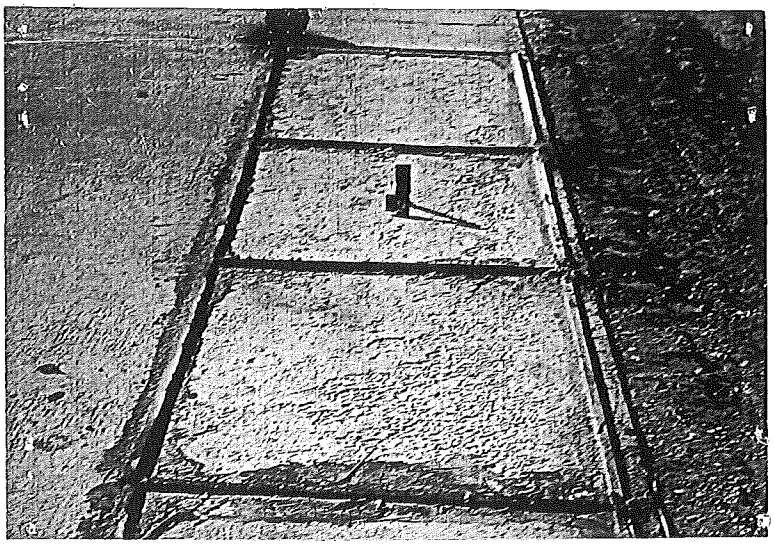
A. Wetted Straw 19% Scale, 28 Cycles, 1940-1941 Series 3A-2, Panel 4

B. 24Hr. Initial Curing Plus Paper, 68% Scale, 89 Cycles Repeat Section, 1940-1941, 1941-1942, Series 3A-3, Panel 5

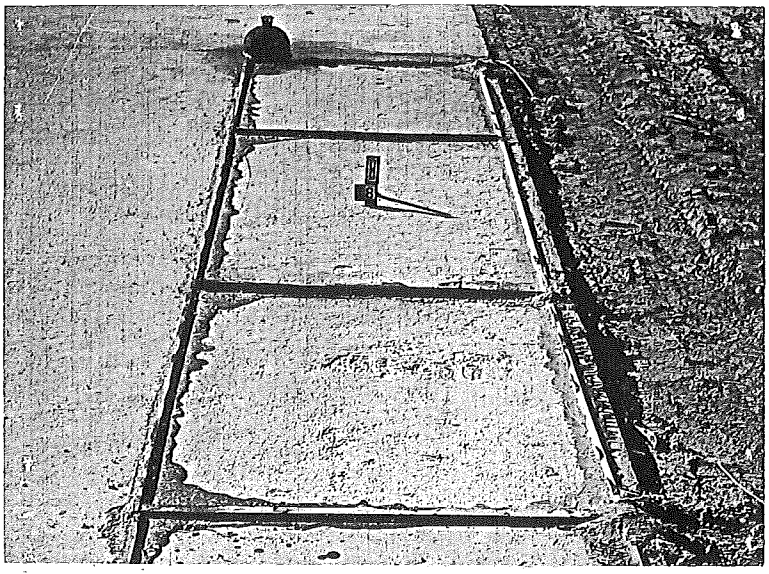


C. 24 Hr. Initial Curing Plus Paper, 100% Scale, 47 Cycles, 1941-1942, Series 3A-3, Panel 3

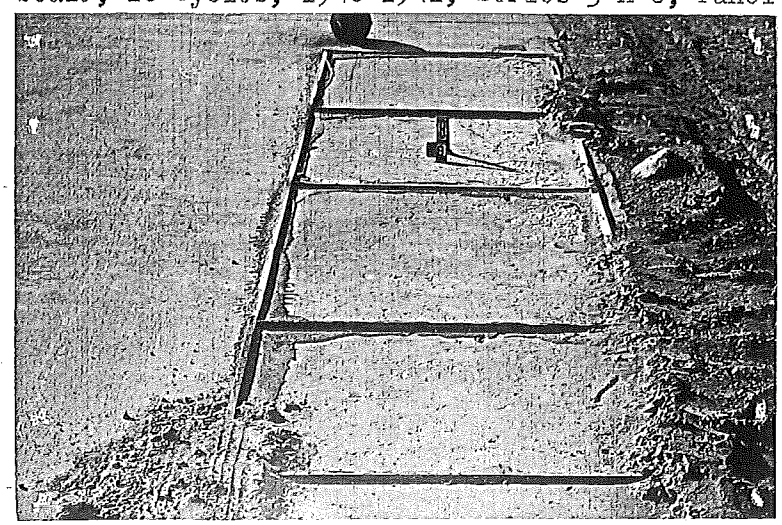
Figure 7



D. Ponding, 28% Scale, 28 Cycles 1940-1941, Series 3-A-5, Panel 7

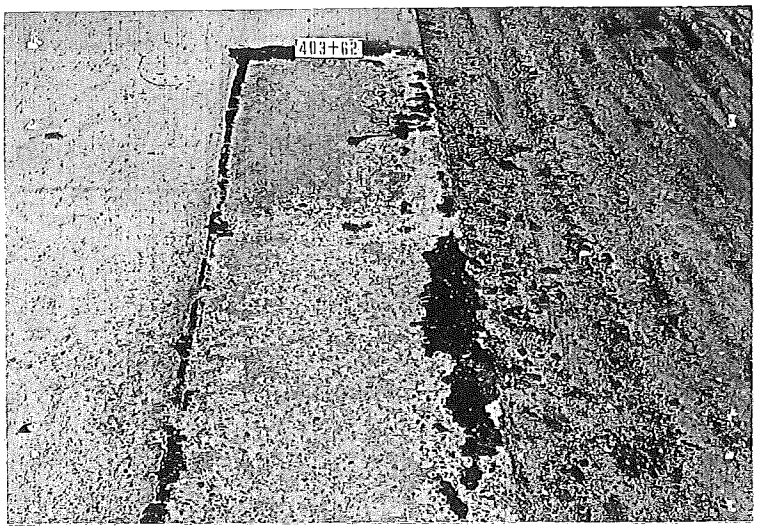


E. Double Burlap Curing
14% Scale, 28 Cycles, 1940-1941, Series 3-A-8, Panel 8

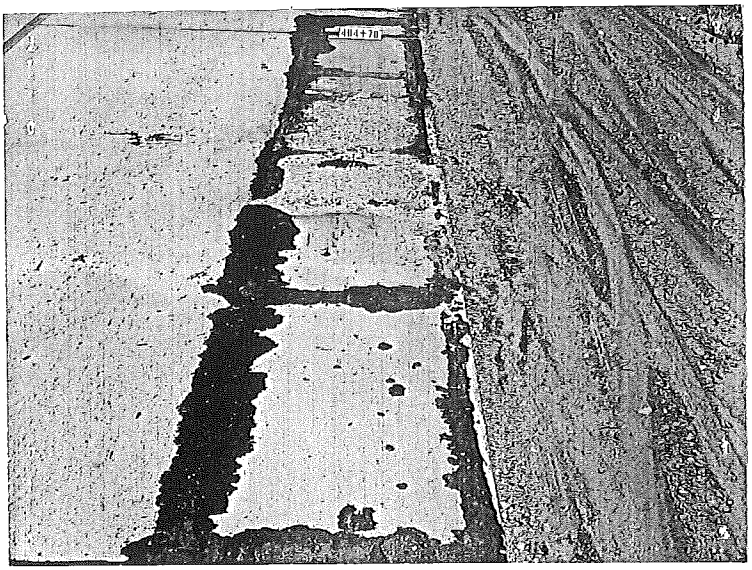


F. Paper Curing, No Initial Curing
3% Scale, 28 Cycles, 1940-1941, Series 3-A-7, Panel 9

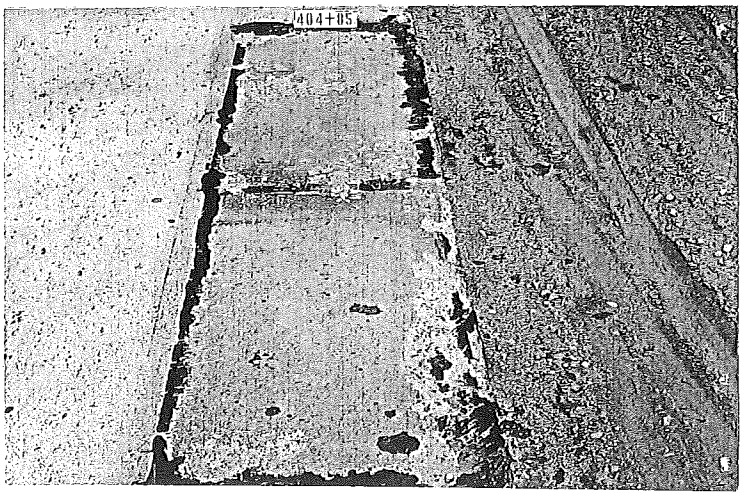
Figure 7



G. Burlap, 2% Calcium Chloride, Integral Mix
73% Scale, 61 Cycles, 1941-1942, Series 3-A-8



H. Burlap Rite-Cure, Repeat Panel
36% Scale, 89 Cycles, 1940-1941, 1941-1942
Series 3-A-9



I. Burlap Rite Cure
12% Scale, 61 Cycles, 1941-1942, Series 3-A-9

Figure 7

Table III

Effect of Curing Method on Scaling

Panel	Season	Curing	Section	TEST METHOD A Cycle	A % Scaling	B Cycle	B % Scaling
3	1940-41	Asphalt Emulsion	3-A-1	6	42	28	61%
2	1941-42	Asphalt Emulsion	3-A-1	-	-	47	100%
4	1940-41	Wetted Straw	3-A-2	6	6%	28	19%
	1941-42	Wetted Straw	3-A-2		NO TEST		
5	1940-41	Paper - Initial Curing	3-A-3	6	Trace	28	Trace
3	1941-42	Paper - Initial Curing	3-A-3			61	68%
4	1941-42	Paper - Initial Curing	3-A-3	-	-	47	100%
6	1940-41	Wetted Earth	3-A-4	6	14%	28	33%
	1941-42	Wetted Earth	3-A-4		NO TEST		
7	1940-41	Ponding	3-A-4	6	Trace	28	28%
	1941-42	Ponding	3-A-5		NO TEST		
8	1940-41	Double Burlap	3-A-6	6	Trace	28	14%
	1941-42	Double Burlap	3-A-6		NO TEST		
9	1940-41	Paper - No Initial Curing	3-A-7	6	0	28	5%
	1941-42	Paper - No Initial Curing	3-A-7		NO TEST		
10	1940-41	Calcium Chloride	3-A-8	6	Trace	28	17%
5	1941-42	Calcium Chloride	3-A-8	-	-	61	73%
11	1940-41	Rite-Cure	3-A-9	6	0	28	0%
6	1941-42	Rite-Cure	3-A-9	-	-	89	36%
7	1941-42	Rite-Cure	3-A-9	-	-	61	12%

Evaluation of Admixtures:

At the time of construction of the Michigan Test Road there were several proprietary brands of admixtures available for use in concrete mixtures. Their manufacturers made certain claims as to the benefits to be derived by their use in concrete for pavement purposes especially with regard to workability and durability. Consequently, it was decided to incorporate several of the most desirable types of admixtures in the durability project for comparative study and to determine what affect these various materials would have upon the design and physical characteristics of their respective concrete mixtures.

The proprietary admixtures selected for use in the test road were of the powder and liquid types. Using the mortar-void principle of concrete mix design, various quantities of sand, cement, water and additives were combined in varying amounts to determine the most desirable mortar from the standpoint of density and consequently the most desirable amount of admixture to use. In all cases the quantity of sand and cement were kept constant in accord with standard practice but the quantity of admixture varied. The liquid admixtures were added to the predesigned mortars in varying amounts to determine the most desirable quantities to use from the standpoint of physical characteristics of the mortar and concrete such as workability, density and durability.

Pozzolith, in Series 4B, is a patented plasticizing agent containing ferric alumina silicate and other ingredients, manufactured by the Master Builders Company, Cleveland, Ohio. Two pounds of Pozzolith per sack of cement were added to the dry batch at the mixer as recommended by the manufacturer.

Plastiment, in Series 4D, is another type of plasticizing agent manufactured by Sika Inc., 530 W. 42nd Street, New York, N.Y. Plastiment was added to the dry batch at the mixer in the amount of one pound per sack of cement as recommended by the manufacturer.

Orvus, W. S. Paste, in Series 4F-4H, is a "sulphated fatty alcohol", a patented wetting agent manufactured by Proctor and Gamble Company, Ivorydale, Ohio. Sufficient orvus was added to the mix to produce a drop in weight of 4 to 5 lbs. per cubic foot for concrete of specified consistency and cement content as compared with concrete of the same consistency and cement content without the addition of orvus. Since this requirement will vary in accordance with materials studied, the approximate quantity of orvus to use will be between 0.02 and 0.10 lbs. per barrel of cement. It was found that for the particular materials used on the durability project that 0.06 lbs. of orvus per barrel of cement gave a reduction in weight of approximately 5 lbs. per cubic foot.

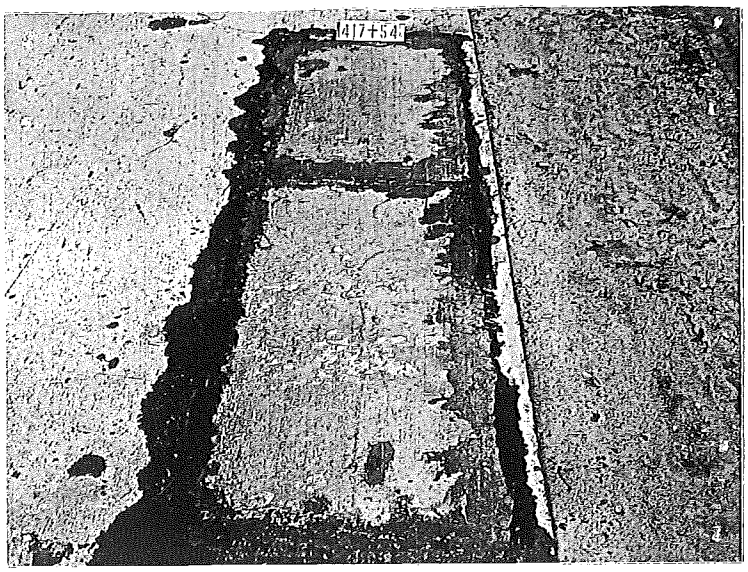
The orvus pastewas dissolved in water to form a solution of known concentration. The required amount of the solution per batch of concrete was added to the dry materials at the skip.

Vinsol Resin Portland Cement, Series 5A-5C. This cement consists of standard Portland Cement ground with Vinsol Resin to conform to the requirements of the current specifications for Portland Cement A.S.T.M. Designation C9 with following exceptions and additions: The cement shall be ground with 0.15 lb. (with a tolerance of $\pm$ 20% of pulverized Vinsol Resin per barrel), which shall be uniformly added to the clinker at time of grinding. The specific surface as determined in accordance with A.S.T.M. C115-38T shall not be less than 1750 nor more than 2100 sq. cm. per gram. Two brands of Portland cements were used on the durability project. The two brands of Vinsol Resin

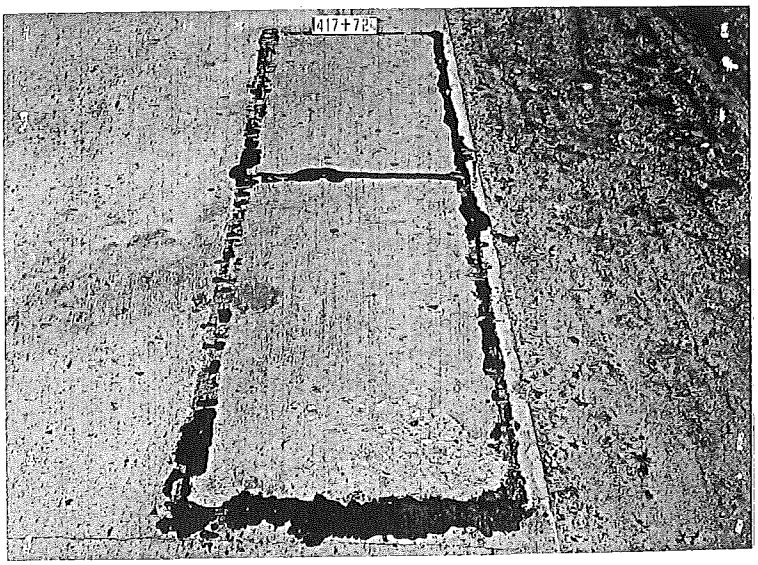
and Portland Cement were of the same brands and manufactured by the same mills as the standard Portland Cements.

Calcium Chloride Admixture: In Series 4A, 4F, and 5A, calcium chloride was added to the concrete mixtures for a distance of 120 feet in the amounts shown on the plan. The purpose of doing this work was to determine the effect of calcium chloride upon the physical characteristics of concrete containing such additions as Plastiment, Orvus and Vinsol Resin. The calcium chloride in flake form was added to the dry batch at the mixer skip. No scaling studies were conducted on the calcium chloride sections.

The results obtained from the accelerated scaling treatments are tabulated in Table 4. Figure 8 illustrates the condition of the surface at termination of treatment.



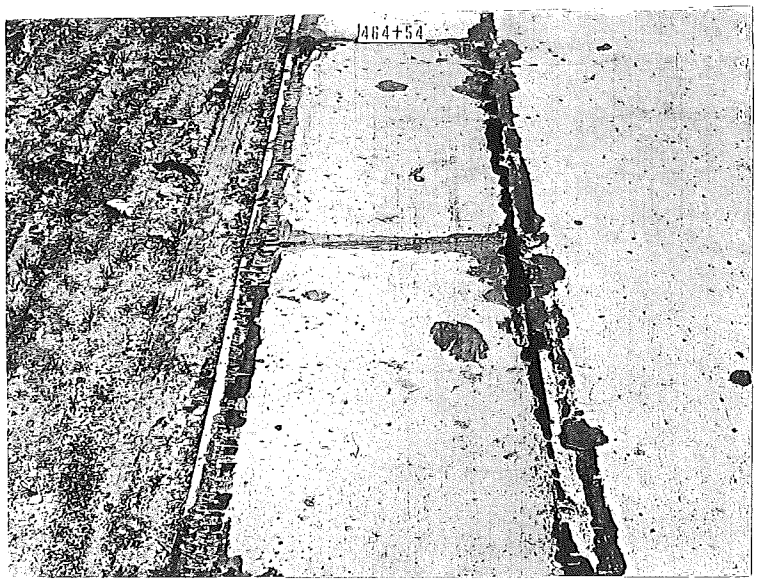
A. Pozzolith, Repeat Panel, 6% Scale, 93 Cycles, 1940-1941, Repeat in 1941-1942, Series 4B, Panel 8



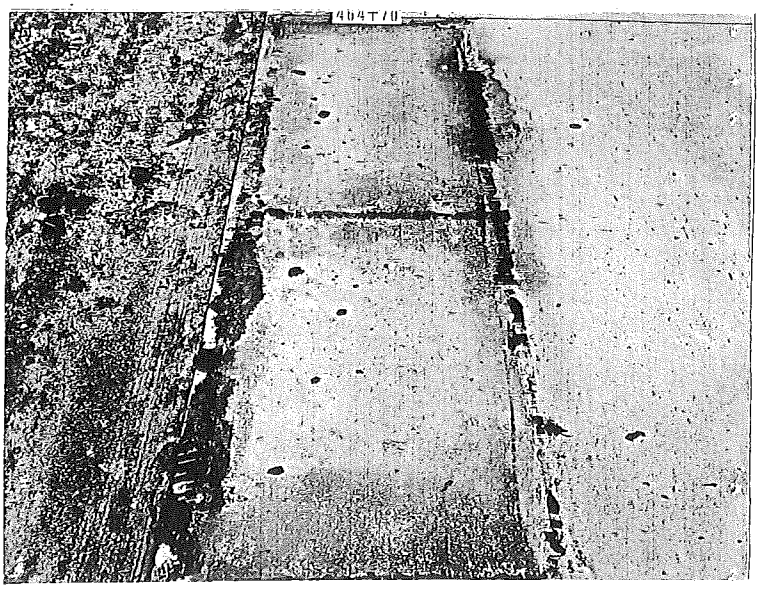
B. Pozzolith, 8% Scale, 61 Cycles, 1941-1942
Series 4B, Panel 9

C. Plastiment, 56% Scale, 61 Cycles, 1941-1942
Series 4D, Panel 10

Figure 8

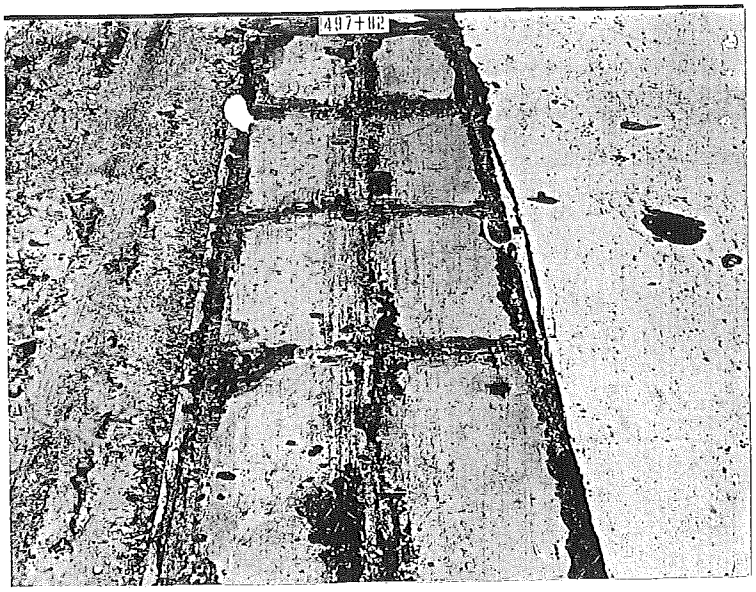


D. Orvus, Brand No. 1 Cement Repeat Panel, 1940-1941, 1941-1942, 0% Scale, 93 Cycles, Series 4F, Panel 12

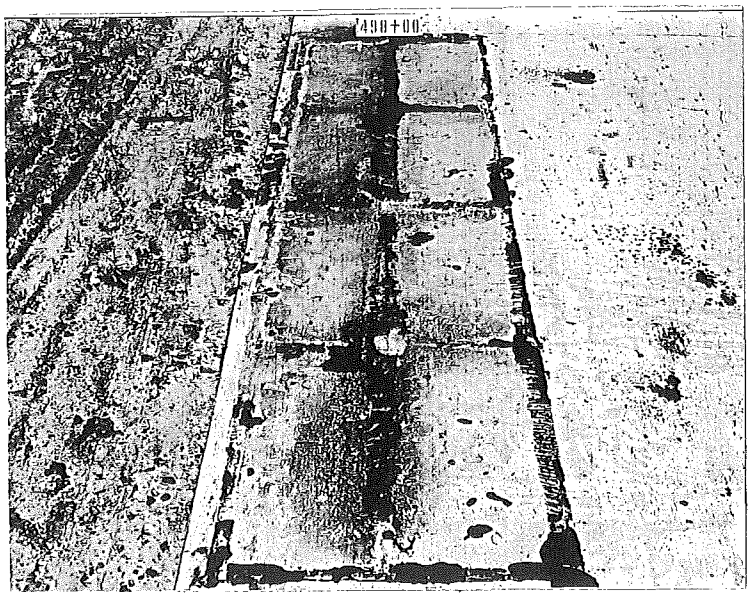


E. Orvus, Brand No. 1 Cement, 0% Scale, 61 Cycles, 1941-1942, Series F, Panel 13

Figure 8

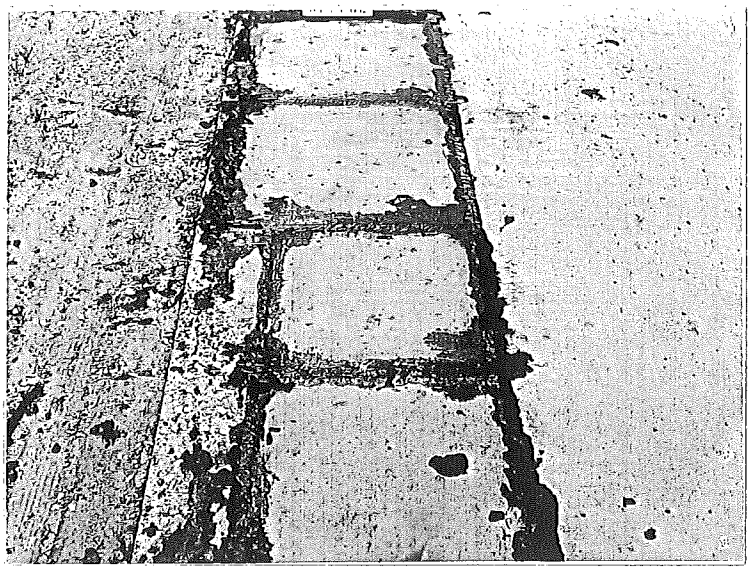


F. Orvus, Brand No. 2 Cement Repeat Panel, 1940-1941, 1941-1942, 0% Scale
94 Cycles, Series 4H, Panel 14

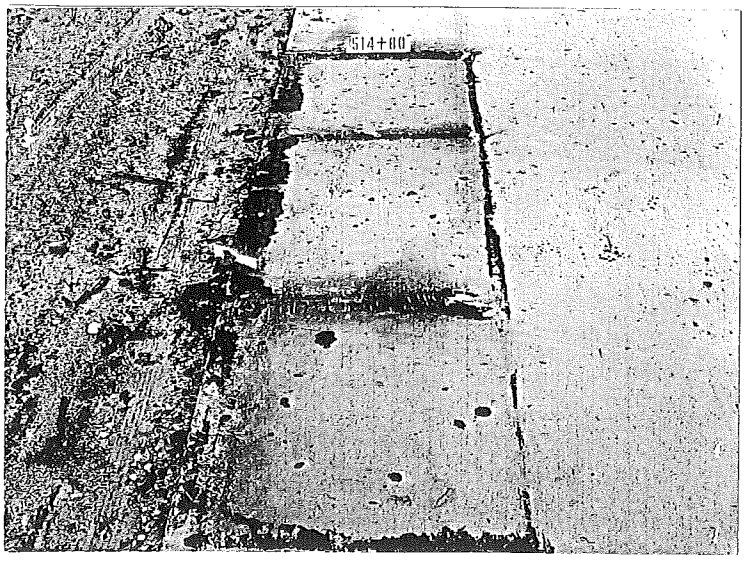


G. Orvus, Brand No. 2 Cement, 0% Scale, 61 Cycles, 1941-1942, Series 4H
Panel 15

Figure 8

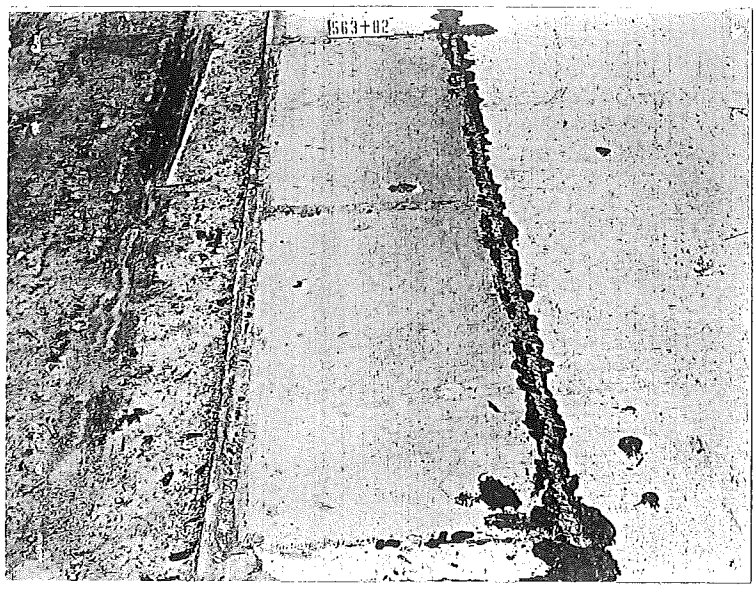


H. Vinsol Resin, Brand No. 1 Repeat Panel, 1940-1941, 1941-1942, Trace Scale, 93 Cycles Series 5A, Panel 17

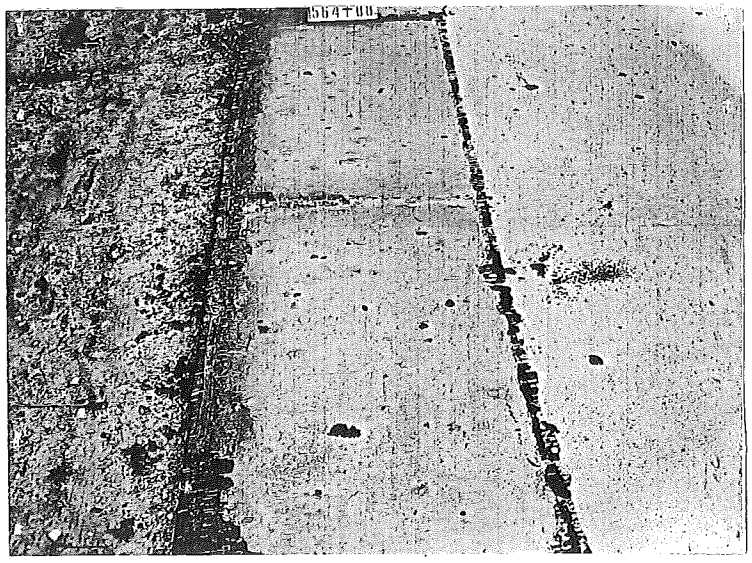


I. Vinsol Resin, Brand No. 1, Trace Scale, 61 Cycles, 1941-1942, Series 5A Panel 18

Figure 8

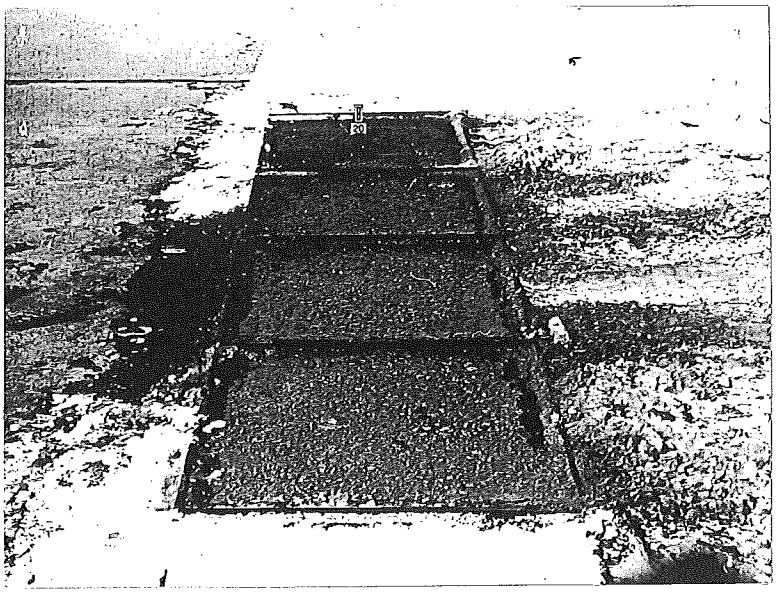


J. Vinsol Resin, Brand 2, Repeat Panel, Trace Scale 94 Cycles, 1940-1941, 1941-1942, Series 5C, Panel 19

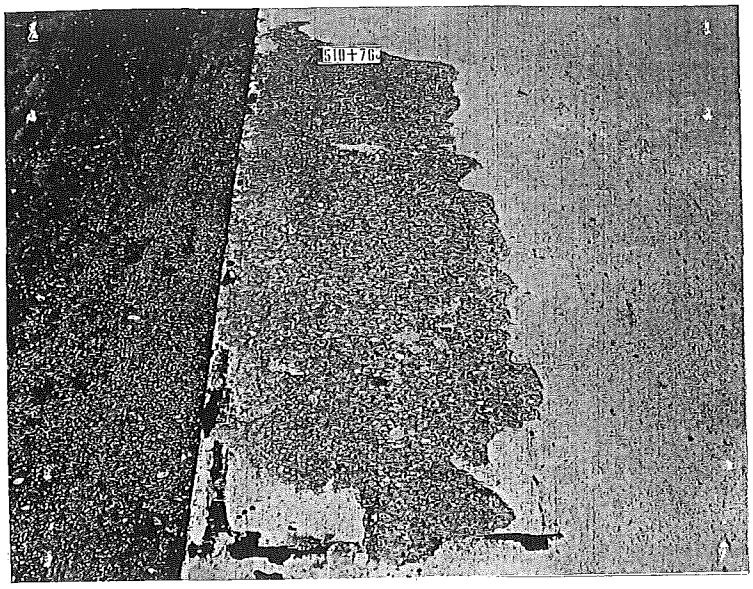


K. Vinsol Resin, Brand 2, Trace Scale, 61 Cycles, 1941-1942, Series 56 Panel 20

Figure 8



L. Standard Construction, Brand No. 2, Cement, 100% Scale, 21 Cycles 1940-1941, Series 5D, Panel 20



M. Standard Construction, Brand No. 2 Cement, 100% Scale, 32 Cycles, 1941-1942, Series 5D, Panel 21

Figure 8

TABLE IV

Concrete Containing Admixtures

Panel	Season	Admixture	TEST METHOD A Cycle	A % Scale	B Cycle	B % Scale
25	1940-1941	Standard Construction, Brand 1	3	100%	13	100%
27	1941-1942	Standard Construction, Brand 1	-	-	9	100%
14	1940-1941	Standard Construction, Brand 1	7	11%	33	61%
11	1941-1942	Standard Construction, Brand 1	-	-	41	100%
12	1940-1941	Pozzolith	7	0%	33	1.4%
8	1941-1942	Pozzolith, Repeat	-	-	93	6%
9	1940-1942	Pozzolith	-	-	61	8%
13	1940-1941	Plastiment	7	0%	33	22%
10	1941-1942	Plastiment	-	-	61	56%
15	1940-1941	Orvus - Brand 1	7	0%	33	0%
12	1941-1942	Orvus - Brand 1, Repeat	-	-	93	0%
13	1940-1942	Orvus - Brand 1	-	-	60	Trace
16	1940-1941	Orvus - Brand 2	7	Trace	33	Trace
14	1941-1942	Orvus - Brand 2, Repeat	-	-	94	0%
15	1941-1942	Orvus - Brand 2	-	-	61	0%
18	1940-1941	Vinsol Resin - Brand 1	7	0%	33	Trace
17	1941-1942	Vinsol Resin - Brand 1, Repeat	-	-	93	Trace
18	1940-1942	Vinsol Resin - Brand 1	-	-	60	Trace
19	1940-1941	Binsol Resin - Brand 2	7	0%	33	0%
19	1941-1942	Vinsol Resin - Brand 2, Repeat	-	-	94	Trace
20	1941-1942	Vinsol Resin - Brand 2	-	-	61	Trace
20	1940-1941	Standard - Brand 2	5	100%	21	100%
21	1941-1942	Standard - Brand 2	-	-	32	100%

Discussion of Results:

It is quite apparent from the results shown in Table 4 that certain admixtures are highly effective in increasing the resistance of concrete to scaling. Orvus and Vinsol Resin are the two outstanding admixtures in this respect. No apparent scaling was noted in those sections containing Orvus or Vinsol Resin at the end of 94 cycles of freezing and thawing. Pozzolith gave very good results with only 6% scale in 93 cycles while Plastiment was not as effective as the other admixtures.

Blending of Natural and Portland Cement:

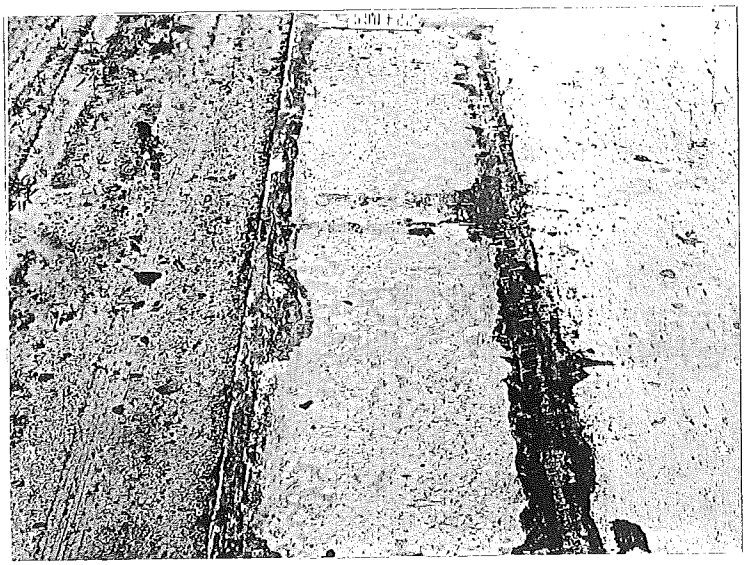
The blending of natural cement with Portland cement has been used in several states for the purpose of increasing the resistance of concrete to scaling. The results which they have obtained from such blends has varied considerably. Consequently, a section of blended cements was included in the Michigan Test Road for two purposes, first, to check the merit of natural cement blends as to their ability to reduce scaling, and second, to determine what effect the presence of a grinding aid in the natural cement might have upon the scale resistant properties of the concrete mixture.

The test sections are designated Series 6A and 6C of the durability project. Two types of natural cements were used on the durability project. One type was manufactured with and the other without the use of grinding aid. Both natural cements were of the same brand and manufactured by the Utica Cement Company, Utica, Illinois. The materials were furnished in sacks containing 75 lbs. each, net.

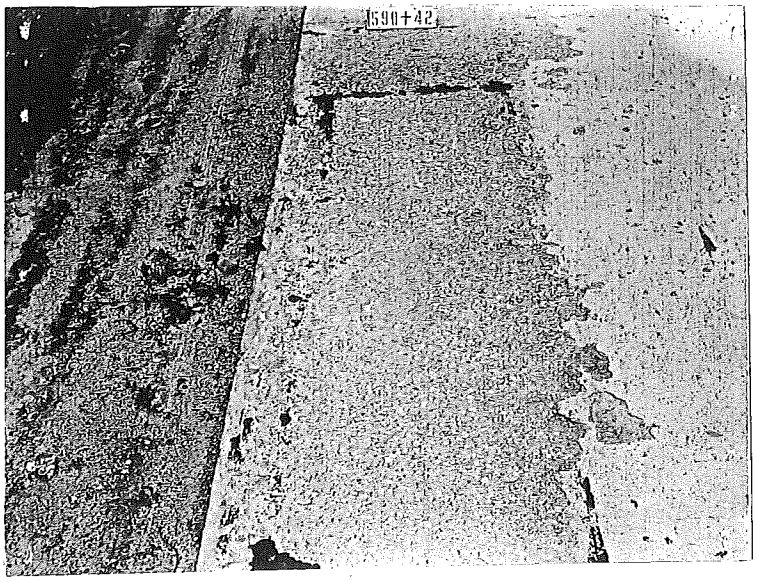
The natural cement without grinding aid was manufactured in accordance with Standard Specification for Natural Cement, A.S.T.M. Designation C10-37.

The natural cement with grinding aid was manufactured under the same requirements except beef tallow was used as a grinding aid. No requirements were placed upon the grinding aid itself because the natural cement with grinding aid has been a standard product with the Utica company for some time.

The Portland Natural Cement blend was made on the basis of a six sack batch comprising one sack (75 lbs.) of natural cement and 5 sacks of Portland Cement. The cement content, including both Portland and Natural Cement was 5.5 sacks (1,375 bbls.) per cubix yard of concrete as specified for the entire project.



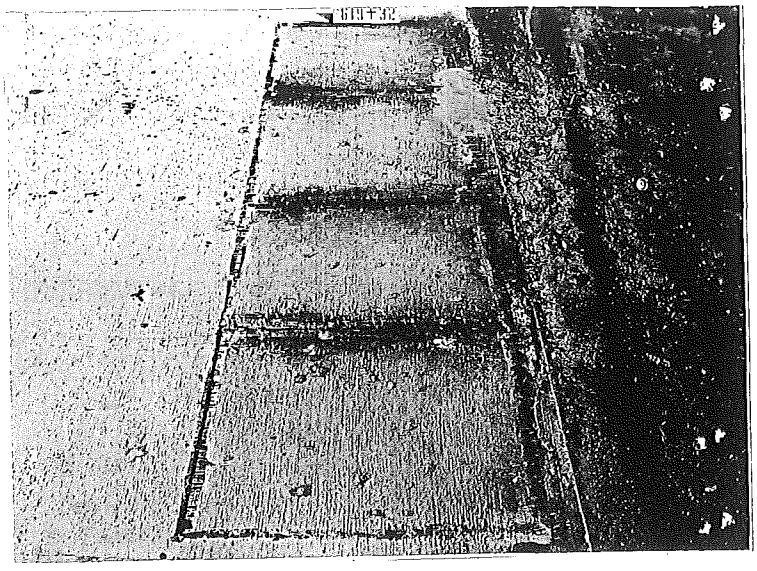
A. Natural Cement, No Grinding Aid, Repeat Panel, 44% Scale, 90 Cycles 1940-1941, 1941-1942, Series 6A, Panel 22



B. Natural Cement, No Grinding Aid, 100% Scale, 31 Cycles, 1941-1942, Series 6A, Panel 23

Figure 9

C. Natural Cement With Grinding Aid, Repeat Panel, 0% Scale, 94 Cycles, 1940-1941, 1941-1942, Series 6C, Panel 24



D. Natural Cement with Grinding Aid, 0% Scale, 61 Cycles, 1941-1942, Series 6C, Panel 25

Figure 9

The results obtained from the accelerated scaling treatments are tabulated below in Table V. Figure 9, illustrates the condition of the concrete surface at the termination of the freezing and thawing treatments.

TABLE V

Results of Natural Cement Blends

Panel	Season	Blend	Test Method A		Test Method B	
			Cycle	% Scale	Cycle	% Scale
25	1940-1941	Standard Construction Brand 1	3	100%	13	100%
27	1941-1942	Standard Construction Brand 1	-	-	9	100%
21	1940-1941	Natural Cement, No Grinding Aid	7	6%	29	Trace
22	1941-1942	Natural Cement, No Grinding Aid, Repeat	-	-	90	44%
23	1941-1942	Natural Cement, No Grinding Aid	-	-	31	100%
22	1940-1941	Natural Cement with Grinding Aid	7	0%	33	Trace
24	1941-1942	Natural Cement with Grinding Aid, Repeat	-	-	94	0%
25	1941-1942	Natural Cement with Grinding Aid	-	-	61	0%

Discussion of Results:

The data in Table V shows quite conclusively that the blending of natural cement with Standard Portland Cement will materially improve the resistance of the concrete to scaling over that of concrete with standard cement alone.

However, in the section containing natural cement with a grinding aid no scaling was observed under the maximum of treatment. We may conclude then that the grinding aid is perhaps the most important element contributing to the scale resistant properties of the concrete.

Grading of Aggregates:

Poorly graded aggregates are inducive to poor workability, segregation, difficult finishing, bleeding and laitance. These factors are contributory to a certain degree to inferior concrete and subsequent scaling, a disintegration of the surface of pavements. One phase of the durability study was to design a practical and economical dense concrete mix that would show improvement to resistance to scaling. In the grading of the sand and coarse aggregate it was attempted to approach an ideal gradation as near as possible and still be conservative as to cost and application. A study of the general characteristics of available concrete aggregates meeting Michigan State Highway Department 1940 specifications, showed that it was desirable to improve the gradation of the fine aggregate 2NS, particularly the material passing the #50 - 100 and 200 sieves.

In order to improve the gradation of the fine aggregate two methods were employed. One method consisted of adding commercial mineral fillers to the fine aggregate in pre-determined amounts, the other method consisted of employing natural fines obtained locally to improve the gradation of the sand,

Mineral Fillers: In Series 7A-7C and 8A, two types of mineral fillers were added to the concrete to provide additional fines. These materials were silica dust and limestone dust meeting Michigan State Highway Department gradation requirements for Mineral Filler 3 M F. as follows:

Passing No. 40 sieve	100%
Passing No. 200 sieve, not less than	75%

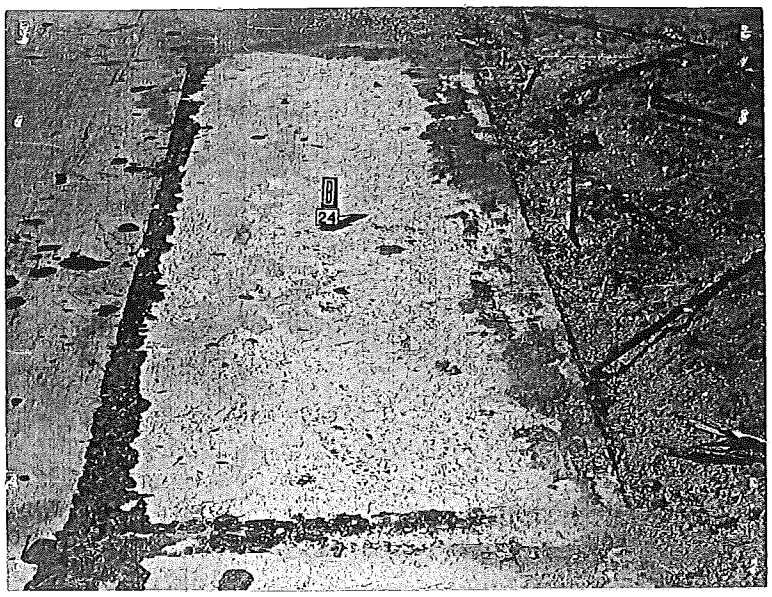
The mineral filler was added to each batch in the amount of 85 pounds per cubic yard of concrete. The quantity of mineral filler to add was determined from laboratory analysis taking into consideration the amount of fines

in the fine aggregate, the fineness of the Portland cement and the gradation of the mineral filler.

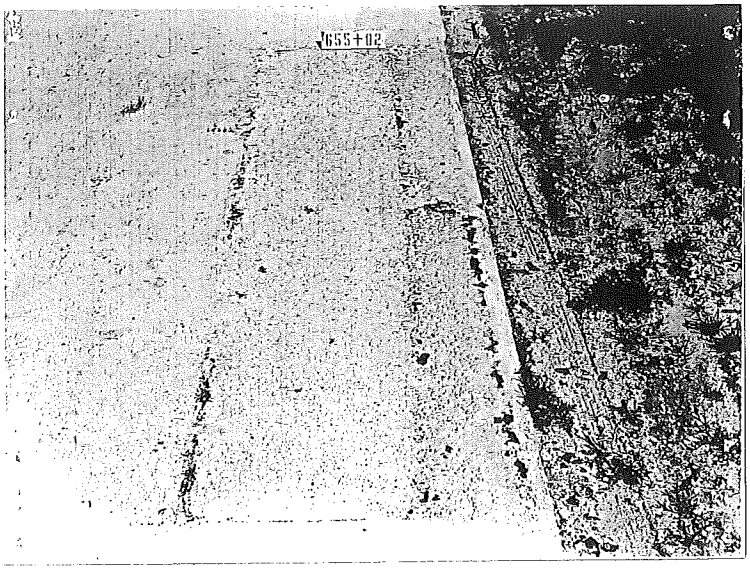
Natural Fines: In Series 7E of the durability section 175 lbs. of special fine sand, obtained from a local natural deposit, was blended with one cubic yard of 2 NS material. The grading of the respective materials is as follows. The combined mixture of fine aggregates is designated as Modified Sand.

Passing	Nat. Sand 2NS 100%	Blend Sand
3/8 inch		
" No. 4	95 - 100%	
" 10	60 - 90%	
" 20	25 - 65%	
" 40		100%
" 50	8 - 25%	
" 100	0 - 5%	55 - 85%
" 200		25 - 50%
Loss by washing not more than 2 1/2%		5%

The results obtained from the acceleration scaling treatments are tabulated below Table VI. Figure 10 illustrates the condition of the concrete surface at the termination of the freezing and thawing treatments.

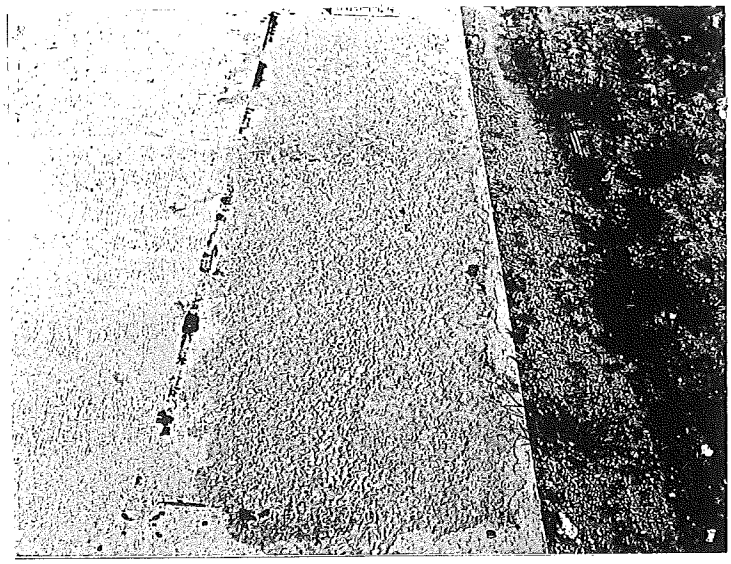


A. Silica Dust, Brand No. 1 Cement, 70% Scale, 33 Cycles, 1940-1941, Series 7A, Panel 24



B. Silica Dust, Brand No. 1 Cement, 100% Scale, 33 Cycles, 1941-1942, Series 7A, Panel 26

Figure 10



C. Standard Construction Brand No. 1 Cement, 100% Scale, 9 Cycles, 1941-1942, Series 7B, Panel 27

D. Limestone Dust, Brand No. 1 Cement, 100% Scale, 8 Cycles, 1941-1942, Series 7C, Panel 28

E. Modified Sand, Brand No. 1 Cement, 100% Scale, 12 Cycles, 1941-1942, Series 7E, Panel 29

Figure 10

TABLE VI

Results of Gradation Study

Panel	Season	Fillers	TEST METHOD A Cycle	A % Scale	B Cycle	B % Scale
25	1940-1941	Standard Construction	3	100%	13	100%
27	1941-1942	Standard Construction	-	-	9	100%
24	1940-1941	Silica Dust	7	17%	33	70%
26	1941-1942	Silica Dust	-	-	33	100%
26	1940-1941	Limestone Dust	7	59%	33	95%
28	1941-1942	Limestone Dust	-	-	8	100%
27	1940-1941	Modified Sand	3	100%	21	100%
29	1941-1942	Modified Sand	-	-	12	100%

Discussion of Results:

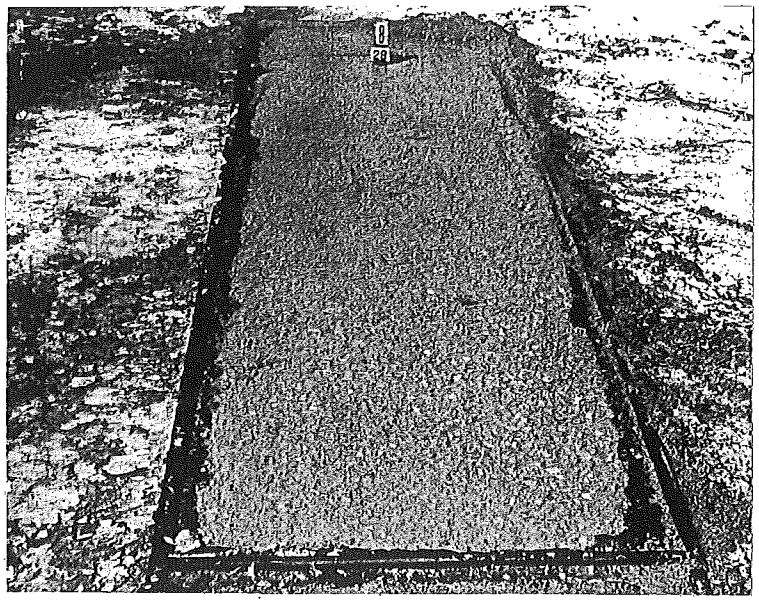
It is apparent from the results in Table VI that the addition of fines to improve the gradation characteristics of the aggregates is not a [illegible]ory method for improving the scale resistant properties of concrete.

Limestone Aggregates:

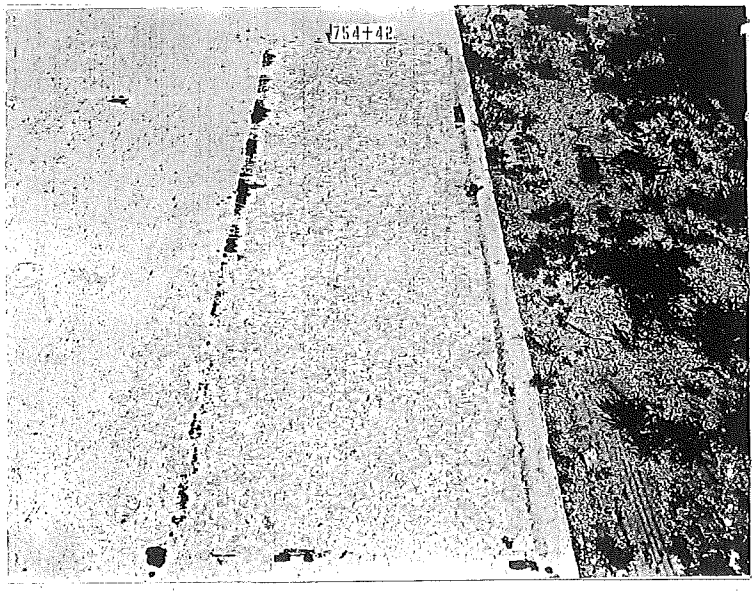
The use of limestone sand as a fine aggregate in concrete construction has been in disfavor not only in Michigan, but also in other States where this material is available. The main objection to its use in concrete are reduced workability, excessive bleeding, difficult finishing and a tendency to produce scaling of pavement surfaces. Consequently, in the durability project of the Michigan Test Road consideration was given to crushed limestone aggregates with special attention to stone sand.

Series 8A and 8B contain limestone aggregate, meeting Michigan State Highway Specifications for 4A and 10A coarse aggregate and Stone Sand 2SS. Both materials were obtained from the Manistique Quarry. In Series 8A, limestone dust mineral filler 3MF was added to the concrete mixture at the rate of 85 lbs. per cubic yard of concrete, for comparison with standard limestone aggregate construction, as well as standard gravel and sand construction.

The results obtained from the accelerated scaling treatments are tabulated below in Table VII. Figure 11 illustrates the condition of the pavement surface upon completion of the freezing and thawing cycles.



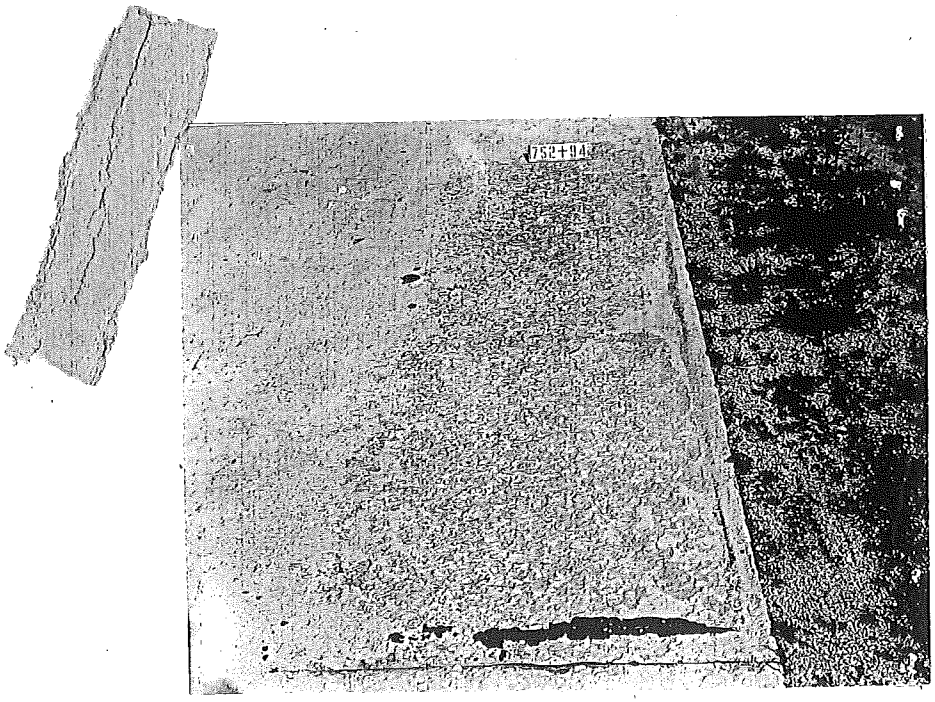
A. Limestone Aggregate, No Filler, 100% Scale, 22 Cycles, 1940-1941, Series 8B, Panel 29



B. Limestone Aggregate, No Filler, 100% Scale, 6 Cycles, 1941-1942, Series 8B, Panel 31

Figure 11

C. Limestone Aggregate with Limestone Dust, 100% Scale, 13 Cycles, 1940-1941, Series 8A, Panel 28



D. Limestone Aggregate with Limestone Dust, 100% Scale, 6 Cycles, 1941-1942, Series 8A, Panel 30

Figure 11

TABLE VII

LIMESTONE AGGREGATE STUDY

Panel	Season	Aggregates	TEST METHOD A Cycle	A % Scale	B Cycle	B % Scale
25	1940-1941	Standard Construction Natural Aggregates	3	100%	13	100%
27	1941-1942	Standard Construction Natural Aggregates	-	-	9	100%
29	1940-1941	Limestone Aggregate No Filler	5	100%	22	100%
31	1941-1942	Limestone Aggregate No Filler	-	-	6	100%
28	1940-1941	Limestone Aggregate Limestone Dust	3	100%	13	100%
30	1941-1942	Limestone Aggregate	-	-	6	100%

Discussion of Results:

The use of limestone dust in crushed limestone aggregate concrete has a tendency to increase scaling rather than decrease scaling.

Comparative Study of Cement Brands:

In the construction of the durability project two different brands of Portland cement were included for a comparative study in conjunction with the various factors which were included in the project. The cement brands used have been designated as Brand No. 1 and Brand No. 2. Brand No. 1 was manufactured by the Petoskey Cement Company located at Petoskey, Michigan. Brand No. 2 was manufactured by the Aetna Portland Cement Company located at Bay City, Michigan. The results obtained from the accelerated scaling studies are presented in Table VII A.

Discussion of Results:

From the results presented in Table VII A it is quite evident that Brand No. 2 produced a concrete with a higher degree of scaling than Brand No. 1.

Effect of Age on Scaling:

The scaling panels on the Durability Project were established with the intent of making scaling studies each winter to determine the effect of age upon the resistance of concrete to scaling. The results from the scaling studies of 1941 and 1942 were so irratic that no relationship between degree of scaling and age of concrete can be established. This fact is clearly illustrated in Figure 22.

TABLE VII A

COMPARISON BETWEEN BRANDS OF CEMENT

Panel	Season	Brand Cement	TEST METHOD A Cycle	A % Scale	B Cycle	B % Scale
4	1940-1941	Brand No. 1	6	6%	28	19%
14	1940-1941	Brand No. 1	7	11%	33	61%
11	1941-1942	Brand No. 1	-	-	41	100%
25	1940-1941	Brand No. 1	3	100%	13	100%
27	1941-1942	Brand No. 1	-	-	9	100%
17	1940-1941	Brand No. 2	6	33%	27	56%
16	1941-1942	Brand No. 2	-	-	9	100%
20	1940-1941	Brand No. 2	5	100%	21	100%
21	1941-1942	Brand No. 2	-	-	32	100%
34	1941-1942	Brand No. 2	-	-	7	100%

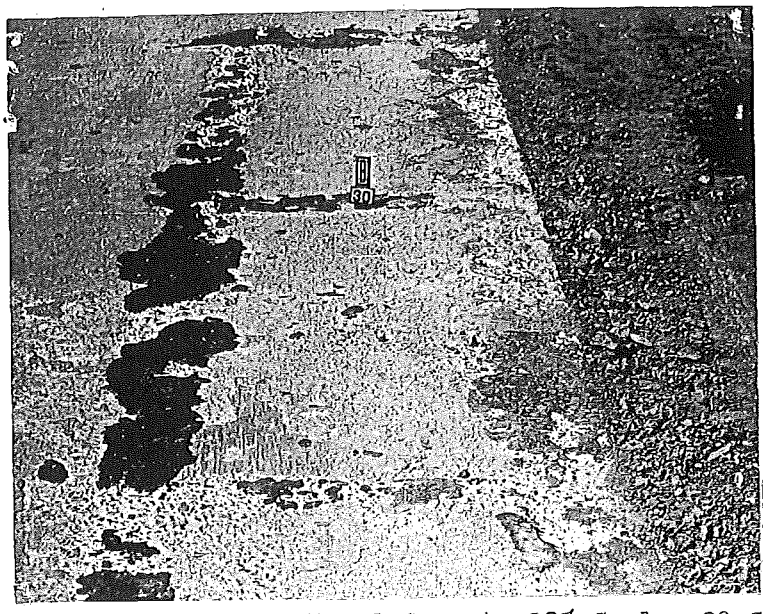
SUPPLEMENTARY SCALING STUDIES ON DESIGN PROJECT

In conjunction with the scaling studies on the Durability Project several scaling panels were installed on the design project. The scaling studies included a comparison between a section of pavement which was rain marked during construction and a section not rain marked. The tests were conducted to determine if the beating action of the rain on the surface of the fresh concrete might change the physical characteristics of the top mortar coat in such a manner as to make the surface of the pavement slab highly resistant to scaling as caused by chloride salts. The panels were located at Station 778+20, 783+08 and 790+0, Design Project. The panels were subjected to the same accelerated freezing and thawing tests as performed on the Durability Project. The results obtained from these studies are presented in Table VIII. Figure 12 illustrates the condition of the pavement surface after termination of the freezing and thawing tests. Brand No. 2 Cement (Aetna) was used throughout the Design Project.

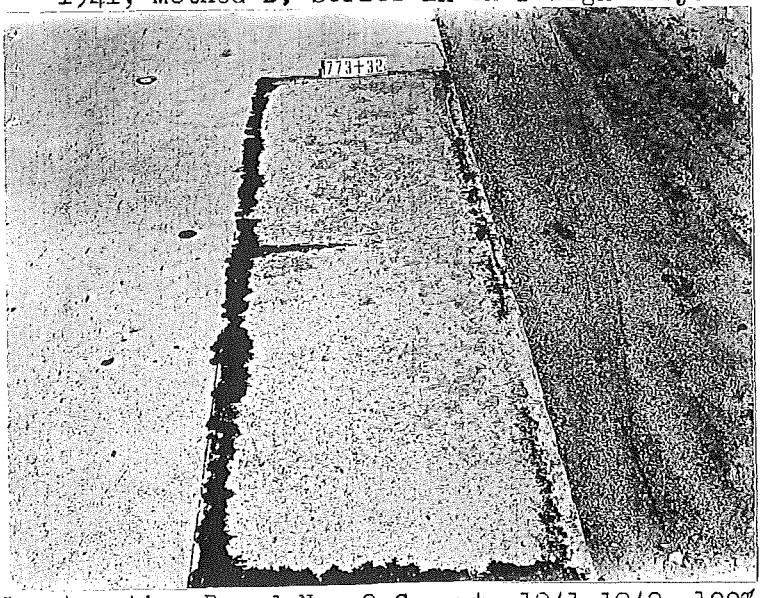
TABLE VIII

Results of Studies on Design Project

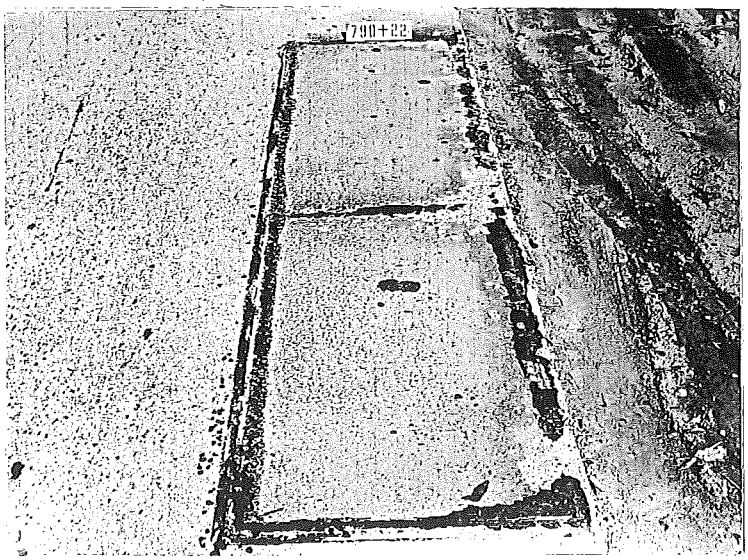
			TEST METHOD			
			A		B	
Panel	Season	Condition	Cycle	% Scale	Cycle	% Scale
30	1940-1941	Standard Construction	6	47%	29	92%
33	1941-1942	Standard Construction	-	-	9	100%
34	1941-1942	Standard Construction			7	100%
32	1941-1942	Rain Market			61	4%



A. Standard Construction Brand No. 2 Cement, 92% Scale, 29 Cycles, 1940-1941, Method B, Series 1A on Design Project Panel 30



B. Standard Construction Brand No. 2 Cement, 1941-1942, 100% Scale, 9 Cycles Method B, Series 1A Design Project Panel 33



C. Rain Marked Concrete Standard Construction Brand No. 2 Cement, 1941-1942, 4% Scale, 61 Cycles, Method B, Design Project Panel 32

Figure 12

Discussion of Results:

The rain marked panel showed a much higher resistance to scale than the panels of standard constructions. This interesting finding is not entirely a surprise, since it is generally believed that if the surface of the fresh concrete could be reworked at the proper time after laying, the physical characteristics of the top layer of mortar will be changed in such a manner that the durability of the concrete surface will be materially improved.

SUMMARY OF SCALING STUDIES

Complete tabulated summaries pertaining to the results of the scaling studies conducted on the Durability Project of the Michigan Test Road during the winter of 1940-1941 and 1941-1942 are presented in Tables 9 and 10. Table 9 presents all of the factual data relevant to each scaling panel whereas Table 10 is a classified summary giving the results of the scaling studies in the order of degree of scaling.

TABLE IX

SUMMARY OF CONCRETE SCALING STUDY

MICHIGAN TEST ROAD - 1940-1941 and 1941-1942

SERIES	DIVISION	PANEL NUMBER 1940-41	PANEL NUMBER 1941-42	LOCATION OF PANELS 1940-41 Method A	LOCATION OF PANELS 1940-41 Method B	LOCATION OF PANELS 1941-42 Method B	ESTIMATED SCALE 1940-41 Method A Cycles	ESTIMATED SCALE 1940-41 Method A % Scale	ESTIMATED SCALE 1940-41 Method B Cycles	ESTIMATED SCALE 1940-41 Method B % Scale	ESTIMATED SCALE 1941-42 Method B Cycles	ESTIMATED SCALE 1941-42 Method B % Scale ≠	DESCRIPTION OF CONCRETE Finish	Curing	Cement	Admixture	b/bo
Durability Project																	
1	B	1	1	381+30	381+42	381+60	5	100	33	94.5	23	100	Broom	Wetted Straw	Brand No. 1	None	0.76
2	A	2	-	393+64	393+76	- -	6	22	28	92	-	-	Broom	Asphalt Emulsion	Brand No. 1	None	0.76
3	A-1	3	2	394+84	394+96	395+40	6	42	28	61	47	100	Burlap	*Asphalt Emulsion	Brand No. 1	None	0.76
	A-2	4	-	396+00	396+12	- -	6	6	28	19	-	-	Burlap	Wetted Straw	Brand No. 1	None	0.76
	A-3	5	3	397+22	397+34	#397+34	6	Trace	28	Trace	61-(89)	68	Burlap	*Paper	Brand No. 1	None	0.76
	A-3	-	4	- -	- -	397+54	-	-	-	-	47	100	Burlap	*Paper	Brand No. 1	None	0.76
	A-4	6	-	398+43	398+55	- -	6	14	28	33	-	-	Burlap	Wetted Earth	Brand No. 1	None	0.76
	A-5	7	-	399+64	399+76	- -	6	Trace	28	28	-	-	Burlap	Ponding	Brand No. 1	None	0.76
	A-6	8	-	400+84	400+96	- -	6	Trace	28	14	-	-	Burlap	Double Burlap	Brand No. 1	None	0.76
	A-7	9	-	402+04	402+16	- -	6	0	28	3	-	-	Burlap	Paper	Brand No. 1	None	0.76
	A-8	10	5	403+24	403+36	403+50	6	Trace	28	16.67	61	73	Burlap	2% $CaCl_2$	Brand No. 1	None	0.76
	A-9	11	6	404+44	404+56	#404+56	6	0	28	0	61-(89)	36	Burlap	*Membrane Curing	Brand No. 1	None	0.76
	A-9	-	7	- -	- -	404+73	-	-	-	-	61	12	Burlap	*Membrane Curing	Brand No. 1	None	0.76
4	B	12	8	417+30	417+42	#417+42	7	0	33	1.4	60-(93)	6	Burlap	Wetted Straw	Brand No. 1	Pozzolith	0.76
	B	-	9	- -	- -	417+60	-	-	-	-	61	8	Burlap	Wetted Straw	Brand No. 1	Pozzolith	0.76
	D	13	10	443+60	443+72	443+90	7	0	33	22.2	61	56	Burlap	Wetted Straw	Brand No. 1	Plastiment	0.76
	E	14	11	463+80	463+92	463+38	7	11.2	33	61	41	100	Burlap	Wetted Straw	Brand No. 1	None	0.76
	F	15	12	464+42	464+54	#464+54	7	0	33	0	60-(93)	0	Burlap	Wetted Straw	Brand No. 1	Orvus	0.76
	F	-	13	- -	- -	464+70	-	-	-	-	60	Trace	Burlap	Wetted Straw	Brand No. 1	Orvus	0.76
	H	16	14	497+70	497+82	#497+82	7	Trace	33	0	61-(94)	0	Burlap	Wetted Straw	Brand No. 2	Orvus	0.80
	H	-	15	- -	- -	498+00	-	-	-	-	61	0	Burlap	Wetted Straw	Brand No. 2	Orvus	0.80
	I	17	16	500+10	500+22	510+76	6	33	27	56	9	100	Burlap	Wetted Straw	Brand No. 2	None	0.76
5	A	18	17	514+50	514+62	#514+62	7	0	33	Trace	60-(93)	Trace	Burlap	Wetted Straw	Brand No. 1	Vinsol Resin	0.76
	A	-	18	- -	- -	514+80	-	-	-	-	60	Trace	Burlap	Wetted Straw	Brand No. 1	Vinsol Resin	0.76
	C	19	19	563+70	563+82	#563+82	7	0	33	0	61-(94)	Trace	Burlap	Wetted Straw	Brand No. 1	Vinsol Resin	0.76
	C	-	20	- -	- -	564+08	-	-	-	-	61	Trace	Burlap	Wetted Straw	Brand No. 2	Vinsol Resin	0.76
	D	20	21	574+24	574+36	575+04	5	100	21	100	32	100	Burlap	Wetted Straw	Brand No. 2	None	0.76
6	A	21	22	590+10	590+22	#590+22	7	6	29	Trace	61-(90)	44	Burlap	Wetted Straw	Brand No. 1 with natural cement	No grinding aid	0.76
	A	-	23	- -	- -	590+42	-	-	-	-	31	100	Burlap	Wetted Straw	Brand No. 1 with natural cement	No grinding aid	0.76
	C	22	24	618+92	619+04	#619+04	7	0	33	0	61-(94)	0	Burlap	Wetted Earth	Brand No. 1 with natural cement	Beef tallow in natural cement	0.80
	C	-	25	- -	- -	619+20	-	-	-	-	61	0	Burlap	Wetted Earth	Brand No. 1 with natural cement	Beef tallow in natural cement	0.80
2	B	23	-	623+70	623+82	- -	7	42	33	83	-	-	Broom	Cutback Asphalt	Brand No. 1	None	0.76
7	A	24	-	642+90	643+02	- -	7	17	33	70	-	-	Burlap	Wetted Earth	Brand No. 1	Silica Dust	0.76
	A	-	26	- -	- -	654+90	-	-	-	-	33	100	Burlap	Wetted Straw	Brand No. 1	Silica Dust	0.80
	B	25	27	666+90	667+02	665+12	3	100	13	100	9	100	Burlap	Wetted Straw	Brand No. 1	None	0.76
	C	26	28	669+30	669+42	679+38	7	59	33	94.4	8	100	Burlap	Wetted Straw	Brand No. 1	Limestone Dust	0.76
	E	27	29	706+50	706+62	712+20	3	100	21	100	12	100	Burlap	Wetted Straw	Brand No. 1	Modified Sand	0.76
8	A	28	30	753+16	753+28	752+82	3	100	13	100	6	100	Burlap	Wetted Straw	Brand No. 1	Lime Dust with Lime Agg.	0.76
	B	29	31	753+76	753+88	754+30	5	100	22	100	6	100	Burlap	Wetted Straw	Brand No. 1	Limestone Aggregate	0.76
Design Project																	
1	A	30	33	771+20	771+32	773+20	6	47	29	92	9	100	Burlap	Wetted Straw	Brand No. 2	Not Rain Marked	0.76
1	C	-	34	- -	- -	783+08	-	-	-	-	7	100	Burlap	Wetted Straw	Brand No. 2	Not Rain Marked	0.76
1	C	-	32	- -	- -	790+10	-	-	-	-	61	4	Burlap	Wetted Straw	Brand No. 2	Rain Marked	0.76

≠ Average of two independent observations
* Initial burlap cure
\# 1942 scaling tests continued on 1941 panels
() Accumulated cycles at end of 1942 tests

Method A. Weekly cycle of 10% $CaCl_2$ solution.
Method B. Daily cycle of freezing water on surface and thawing with $CaCl_2$.

TABLE X

CLASSIFIED SUMMARY OF TEST RESULTS FROM CONCRETE SCALING STUDY

CONCRETE CHARACTERISTICS				SCALING DATA 1940-1941		1941-1942		
Cement	Admixture	Finish	Curing	Cycles	% Scale	Cycles	% Scale	
Brand No.1	Orvus	Burlap	Wetted Straw	33	0	#60-(93)	0	
Brand No.1	Orvus	Burlap	Wetted Straw	--	-	60	Trace	
Brand No. 2	Orvus	Burlap	Wetted Straw	33	Trace	#61-(94)	Trace	Repeat
Brand No. 2	Orvus	Burlap	Wetted Straw	--	-	61	0	
Brand No. 1	Vinsol Resin	Burlap	Wetted Straw	33	Trace	#60-(93)	Trace	Repeat
Brand No. 1	Vinsol Resin	Burlap	Wetted Straw	--	-	60	Trace	
Brand No. 2	Vinsol Resin	Burlap	Wetted Straw	33	0	#61-(94)	Trace	Repeat
Brand No. 2	Vinsol Resin	Burlap	Wetted Straw	--	-	61	Trace	
Brand No. 1	Beef Tallow in Natural Cement	Burlap	Wetted Straw	33	Trace	#61-(94)	Trace	Repeat
Brand No. 1	Beef Tallow in Natural Cement	Burlap	Wetted Straw	--	-	61	0	
Brand No. 2	Rain Marked Surface	Burlap	Wetted Straw	--	-	61	4	
Brand No. 1	Pozzolith	Burlap	Wetted Straw	33	1.4	#60-(93)	6	Repeat
Brand No. 1	Pozzolith	Burlap	Wetted Straw	--	-	61	8	
Brand No. 1	None	Burlap	Rite-Cure	28	0	#61-(89)	36	Repeat
Brand No. 1	None	Burlap	Rite-Cure	--	-	61	12	
Brand No. 1	Nat.Cement no Grinding Aid	Burlap	Wetted Straw	29	Trace	#61-(90)	44	Repeat
Brand No. 1	Nat Cement no	Burlap	Wetted Straw	--	-	31	100	
Brand No. 1	None	Burlap	Paper	28	3	-	-	
Brand No. 1	None	Burlap	Double Burlap	28	14	-	-	
Brand No. 1	None	Burlap	Ponding	28	28	-	-	
Brand No. 1	None	Burlap	Wetted Earth	28	33	-	-	
Brand No. 1	None	Burlap	Paper Initial	28	Trace	#61-(89)	68	Repeat

TABLE X

CLASSIFIED SUMMARY OF TEST RESULTS FROM CONCRETE SCALING STUDY

CONCRETE CHARACTERISTICS				SCALING DATA			
				1940-1941		1941-1942	
Cement	Admixture	Finish	Curing	Cycles	% Scale	Cycles	% Scale
Brand No. 1	Plastiment	Burlap	Wetted Straw	33	22	61	56
Brand No. 1	2% $CaCl_2$ Intermixed	Burlap	See Admixture	28	17	61	73
Brand No. 1	None	Burlap	Wetted Straw	28	19	---	---
Brand No. 1	Silica Dust	Burlap	Wetted Earth	33	70	---	---
Brand No. 1	None	Broom	Cut Back Asp.	33	83	---	---
Brand No. 1	None	Burlap	Asp.Emulsion	28	61	47	100
Brand No. 1	None	Burlap	Paper Initial Curing	---	---	47	100
Brand No. 1	None	Burlap	Wetted Straw	33	61	41	100
Brand No. 1	Silica Dust	Burlap	Wetted Straw	---	---	33	100
Brand No. 2	None	Burlap	Wetted Straw	21	100	32	100
Brand No. 1	None	Burlap	Wetted Straw	33	94.5	23	100
Brand No. 1	Modified Sand	Burlap	Wetted Straw	21	100	12	100
Brand No. 2	None	Burlap	Wetted Straw	27	56	9	100
Brand No. 2	None	Burlap	Wetted Straw	13	100	9	100
Brand No. 2	None	Burlap	Wetted Straw	29	92	9	100
Brand No. 1	Limestone Dust	Burlap	Wetted Straw	33	94.4	8	100
Brand No. 2	Limestone Dust	Burlap	Wetted Straw	---	---	7	100
Brand No. 1	**None**	**Broom**	**Asp.Emulsion**	28	92	-	
Brand No. 1	Limestone Dust plus Limestone Agg.	Broom	Asp.Emulsion	13	100	6	100
Brand No. 1	None	Broom	Asp. Emulsion	22	100	6	100

Note # - 1942 treatments continued on 1941 Panel
() Accumulated Cycles at end of 1942 Tests.

PART TWO

OTHER CONCRETE SCALING STUDIES

In addition to the scaling studies conducted on the Durability Project of the Michigan Test Road, three other special supplementary scaling studies have been made on selected pavement projects. These projects are located in the Upper Peninsula. The scaling studies were supervised and reported by W. A. Keranen who at that time was in charge of the cooperative research activities at Houghton, Michigan. The Maintenance Division furnished men and materials with which to carry out the work. Part Two presents the results of these scaling studies.

The field scaling projects include a comparative study of calcium chloride salt versus natural freezing and thawing, the effect of calcium chloride on concrete containing stamp sand, and the effect of calcium chloride on concrete consisting of limestone aggregates, including stone sand, with and without silica dust and containing orvus.

CALCIUM CHLORIDE VERSUS NATURAL FREEZING AND THAWING

In connection with the concrete durability studies now in progress it was believed desirable to obtain more pertinent data relative to certain factors which are known to cause scale such as chloride salts and natural freezing and thawing. Consequently, the purpose of this particular study was to conduct comparative scaling studies on a concrete slab not previously treated with calcium chloride to determine in what degree calcium chloride or natural freezing and thawing are inducive to scaling of concrete surfaces.

For the study a pavement built during the 1941 construction season was selected.

Location and Character of Test Pavement:

A section of concrete pavement was selected on Project SN-FAP.3 (10) on US-41 North of the Village of L'Anse, in Baraga County. The test sections were located on the left edge of the pavement at Station 34+00. The concrete pavement was constructed under standard procedure using Champion natural aggregates, Duluth Universal - Portland Cement without admixtures. Finishing and curing consisted of bull float, burlap drag, wet burlap and earth curing respectively. After preliminary instructions, the actual test procedure was conducted by the Highway Department Maintenance Division at L'Anse under the direction of Mr. George Forrest, Maintenance Superintendent.

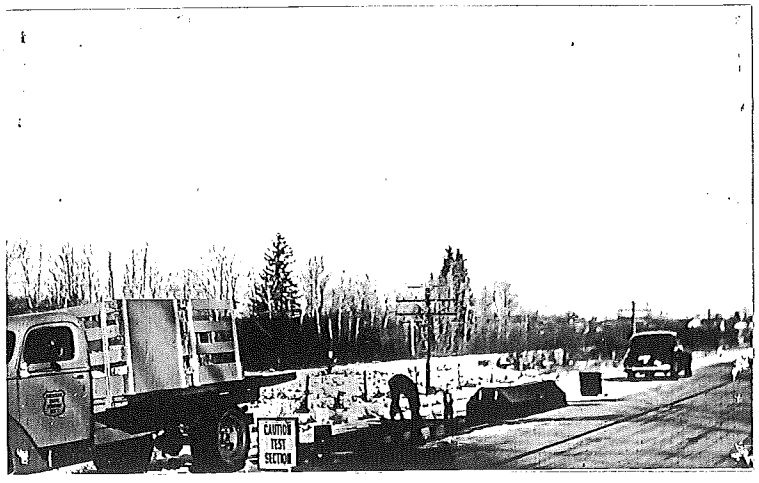
The Test Areas:

Two separate test panels were established by securing wooding strips 1/2 inches thick to the pavement with bituminous material to form dykes. The two panels were 12 feet long and 3 feet wide and separated from each other by a distance of 3 feet. See Figure 13.

Method of Test:

In both panels water was applied to a depth of 1/4 inch and permitted to freeze overnight. The following morning calcium chloride flakes were applied to one panel at the rate of 10 percent of the ice formed. This would have amounted to 5 pounds of calcium chloride, but it was found in every case that when the panels were solidly frozen more than one application was necessary. Actually it required from 7 to 10 pounds for complete decomposition. The chloride was evenly distributed over the entire surface of the ice. Immediately following decomposition of the ice, the panel was cleaned, flushed, and fresh water again applied for the next freezing and thawing cycle. This test procedure was designated as "Method A".

A. Panel Layout, Baraga Project US-41



B. General View Showing Metal Hood used in "Method B", Baraga Project US-41

Figure 13

The ice in the other panel was thawed, the following morning, by applying heat from an ordinary 4 inch kerosene torch placed under a metal hood until water was formed, See Figure 13. After thawing, the water was then permitted to freeze for the successive cycle. Replacement of the water was made twice weekly. The heat application was made under a hood constructed of galvanized sheet metal, the top of which was approximately two feet above the surface of the pavement. Inasmuch as the intent was to simulate natural thawing, the flame of the torch was directed upwards so as to prevent concentrated heat application to the surface of the pavement. The torch was alternated from one end of the hood to the other during the thawing operation in order to obtain an uniform heat distribution over the entire surface of the panel. It was found, by using this procedure, that when thawing was complete the resultant water was still cool. This test procedure was designated as "Method B".

Observations and Reporting of Results: Following the decomposition of the ice by either method "A" or "B" any scale area was accurately measured daily and the result recorded on a specially prepared form. The scale was designated at light (thin mortar scale), medium (surface scale exposing coarse aggregate), or heavy (disintegration of the concrete by the removal of coarse aggregate). The tests were continued for the duration of the freezing temperatures in that particular locality.

Protection to the Traveling Public: The test areas were adequately signed and lighted for the safety of the driving public both day and night.

Observations:

This project was started at a time when the snow and ice covered the pavement and considerable difficulty was encountered in making these panels watertight. It was necessary to melt the snow and ice and dry the pavement with a torch before applying the rai-seal. Even though care was taken in drying, the pavement may have been heated enough to affect the result of the test.

Test Procedure A: Fine sand and fine mortar started to come off the "A" panel after the 12th cycle, but there was no change in the appearance of the surface until after the 51st cycle. At this time a 1 sq. ft. area in the NW corner of the panel showed medium scaling, with no change in the remainder of the panel. No change was noticed in this NW corner previously, unless it was a slight roughening of the surface in this spot. This panel remained in the same condition until the 40th cycle at which time 25% of the surface of the panel appeared speckled -- light scale. After 62 cycles the light scale increased to 30% and the medium to 10%.

It seems that there was an inherent weak spot in the NW corner or the pavement was overheated at this spot when drying to place the dyke. This was also the deepest section of the panel and the corner from which the decomposed ice was broomed. We think this spot should be eliminated from the final results. Consequently, 9% medium scaling and 30% light scaling after 63 cycles is a fair result for this test.

Test Procedure B: On test "B" difficulty was experienced in keeping the strips watertight.

This panel showed 50% light scaling after the 42nd cycle and remained unchanged during the remainder of the test. The south one-half of the panel scaled and the north one-half did not. This scaling has been

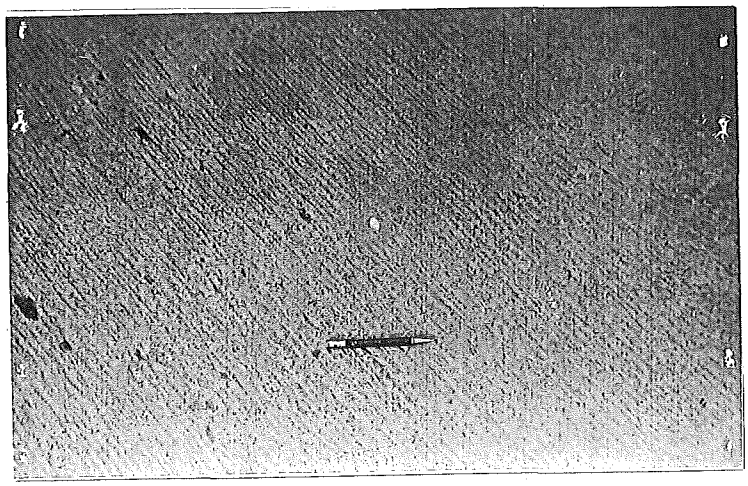
attributed to the overheating of the pavement when replacing strips, but upon close scrutiny after the test was completed, and upon a perfectly dry pavement, it was noticed that there was a definite line of demarcation clear across the pavement at this point, south of which the surface of the pavement had an entirely different texture. South of this line the full width of the pavement had scaled to the same degree as the section under test. This line of demarcation was slightly curved and looked as though it had been caused by the burlap drag being stopped at this point during finishing operations. Similar lines were noticed throughout the entire project upon investigation. Therefore, it is believed that this light scaling on the "B" panel should not be attributed to our test, as it is believed it would have scaled to the same degree under normal freezing and thawing due to normal weather conditions. This condition is illustrated in Figure 16.

A brief summary of comparative data is presented below. The condition of the surface after treatment is illustrated in Figures 14, 15 and 16.

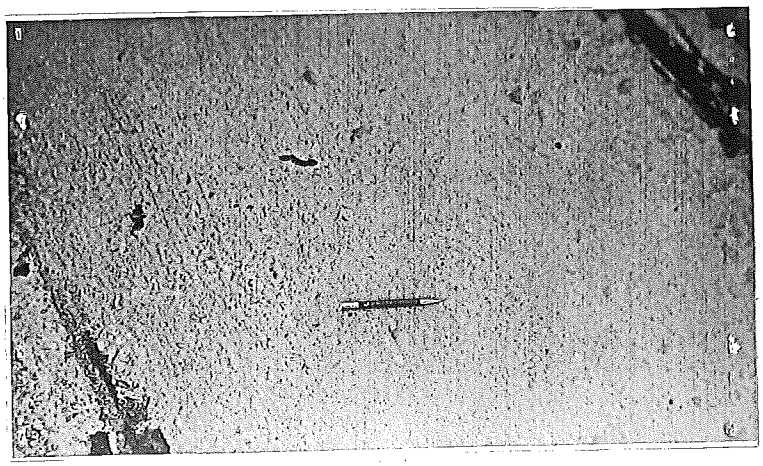
		% Scale		
	Cycle	Light	Medium	Heavy
1941-1942 $CACl_2$ (A)	63	30	9	0
1941-1942 Natural Freezing and Thawing (B)	63	50	0	0

Results of Tests:

The above results show that scaling of concrete surfaces may be caused by the natural freezing and thawing of water on the pavement surface or when the surface is highly saturated with moisture. This same phenomenon

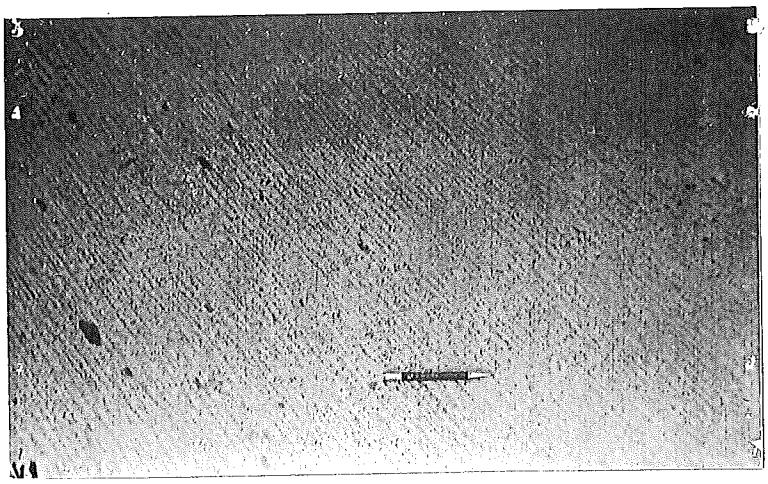


A. Pavement Before Test Method "A", Baraga Project - US-41

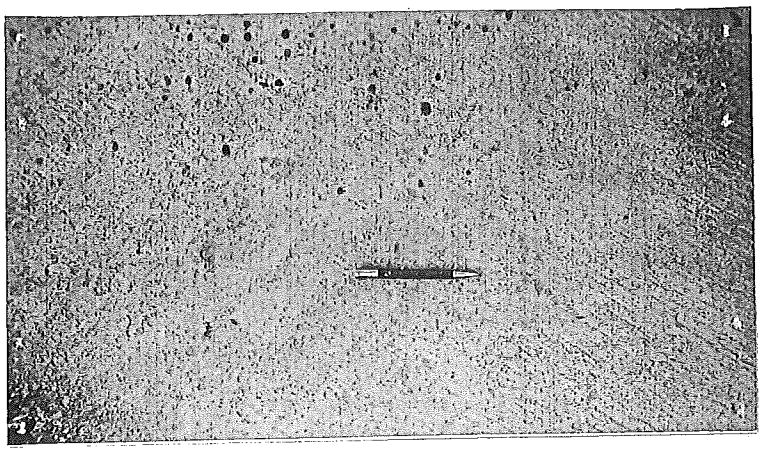


B. Pavement After Test Method "A", Baraga Project - US-41

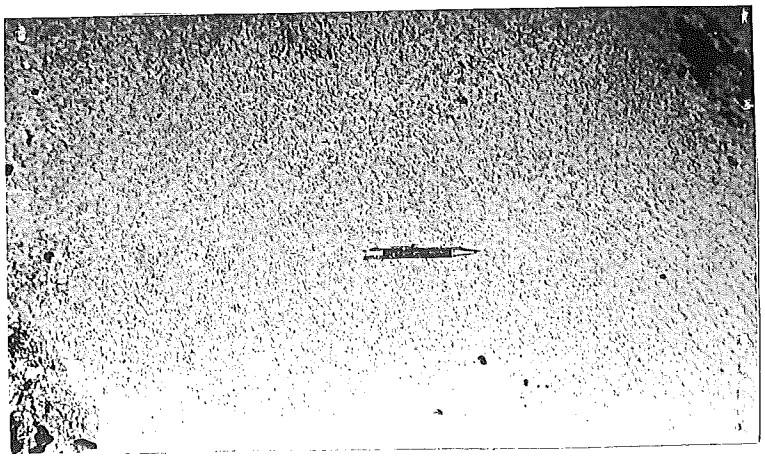
Figure 14



A. · Pavement Before Test Method "B", Baraga Project US-41

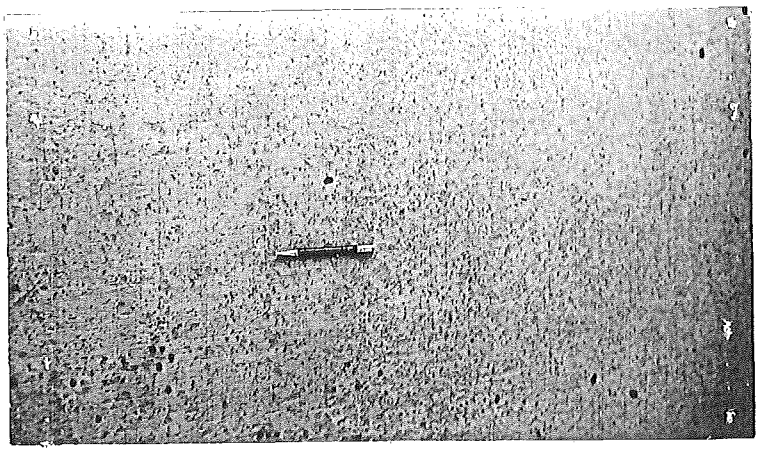


B. North Half Panel After Test Method "B", Baraga Project US-41

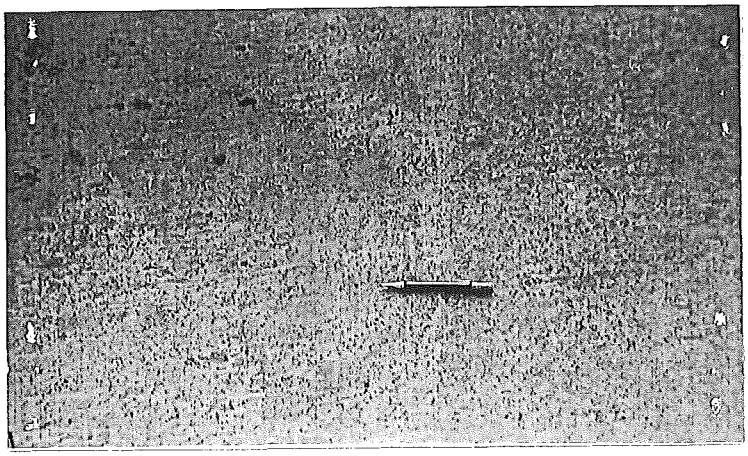


C. South Half Panel After Test Method "B", Baraga Project US-41

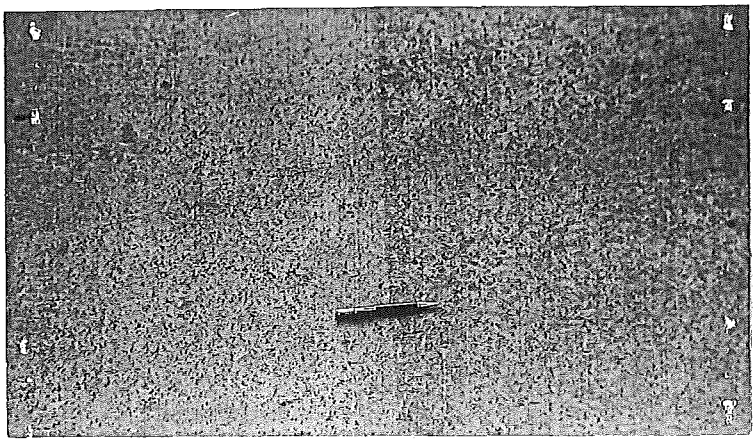
Figure 15



A. Line Through Pencil Separates Scaled from Unscaled Portion Test Panel
"Method B", Baraga Project
US-41



B. Same Condition as in A Except an Untreated
Portion of Pavement



C. View Showing Line of Demarcation on Edge of Pavement
Opposite from Test Panel

Figure 16

has been known to occur on other pavement surfaces which have not received calcium chloride treatments for ice removal. The scaling process is usually more severe when calcium chloride is present.

EFFECT OF CALCIUM CHLORIDE ON PAVEMENTS CONTAINING STAMP SAND

A separate study was made to determine the relative resistance to scaling of concrete pavements containing stamp sand as a fine aggregate. The study was made on a pavement constructed during 1938. This particular project was the most recently constructed pavement containing stamp sand.

Location of Test Area:

The section of concrete chosen for the test area lies on US-41 approximately 8 miles North of the City of Hancock in Houghton County. It is further identified as being at Station 440+00 right side of pavement Construction Project FA 175, Section J. The particular section did not have any previous scale development.

Size of Test Area: Only one test area was established 3 feet by 12 feet constructed in the manner described in report of Baraga Project.

Method of Test: "Method A" consisting of freezing water and thawing with calcium chloride was used in this test. "Method A" has been explained previously under Baraga Project. The tests were continued until 100% scaling of the surface had been obtained.

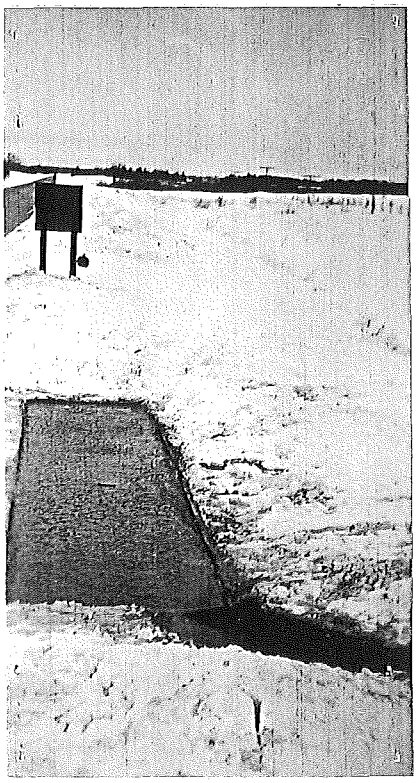
Results of Test:

Scaling started after the second cycle and proceeded to 100% medium scale at the end of the 25th cycle. Scaling started in a strip across the center of the panel, progressing to the deepest end of the panel first and then back to the other end. The fact that the pavement was uneven at this particular location accounted for one portion of the parcel being deeper than the other. There was also a depression in the center of the panel. The final results from scaling study are summarized as follows:

			% Scale		
		Cycle	Light	Medium	Heavy
1941-1942	Method A	35	-	100%	-

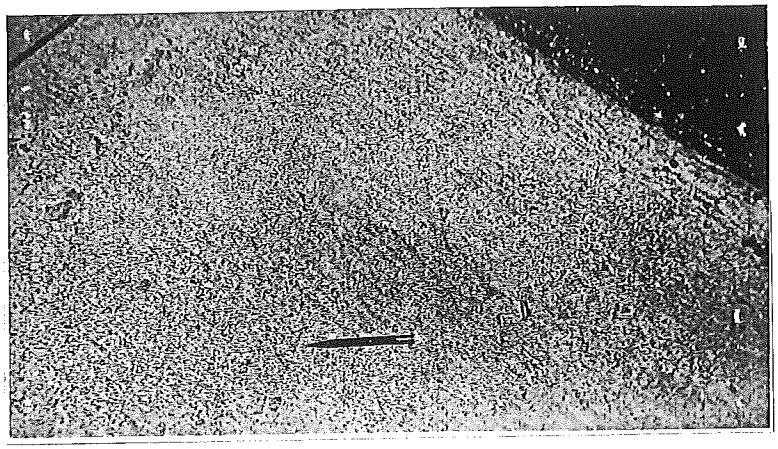
Pictures in Figures 17 and 18 illustrate condition of surface after 35 cycles.

A. Installing Dykes - Houghton Project



B. Scaling of Surface after 35 Cycles - Houghton Project

Figure 17



A. View of Pavement Surface Before Test - Houghton Project

B. Condition of Surface After Scaling - Houghton Project

Figure 18

EFFECT OF CALCIUM CHLORIDE ON CONCRETE CONTAINING STONE SAND, WITH AND WITHOUT SILICA DUST AND CONTAINING ORVUS

On the basis of results obtained from scaling studies conducted on the durability section of the Michigan Test Road during the winter of 1940-1941, relative to the use of admixtures to improve the physical characteristics of stone sand concrete and its ability to resist scaling, it was proposed to experiment further with the use of admixtures in the stone sand concrete mixtures. Consequently, Construction Project M-75-28, C2 located on M-94 in the City of Manistique, Schoolcraft County, was chosen for conducting the experiments on stone sand.

The purpose of this work was an attempt at improving the objectionable characteristics of stone sand in concrete, such as bleeding, poor workability, difficult finishing and excessive scaling by the addition of wetting agents and addition of fines.

The project was constructed with limestone aggregates obtained from the Inland Lime and Stone Company quarries located at Manistique, Michigan. Orvus, wetting agent paste admixture, was added in specified amounts approximately .05 lb. per barrel of cement throughout the entire project. In the north half of the pavement only, silica dust was added in addition to "Orvus" at the rate of 11.81 pounds per sack of cement. The silica dust was obtained through the Garco Products Inc., Co., Butler, Pa. from their Ottawa, Illinois source. The grading characteristics of the aggregates will be found in Table XI.

The results of the Manistique stone sand studies will be discussed from two different standpoints, first, under construction observations as presented by E. S. Anderson, Project Engineer in charge of the Project, also by Roy Fulton, Engineer on Special Assignment and under special scaling studies

carried out by the Maintenance Division at Manistique, Mr. Frank Peake, Maintenance Superintendent in cooperation with Mr. Kerenan, representative of the Research Laboratory.

Construction Observations:

The south half of the pavement was constructed with Orvus only. The north half contained both Orvus and Silica Dust.

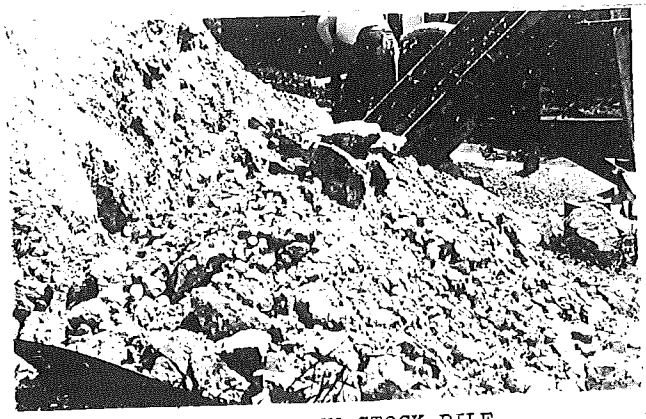
It was observed that Orvus alone reduced considerably the bleeding so typical of stone sand projects and slightly improved the workability of the concrete over that of untreated stone sand projects. With the use of fines (Silica Dust) in addition to the Orvus, there seemed to be a complete lack of bleeding and the workability of the mixture was materially improved.

Beam tests on both areas indicate that the concrete in both cases was up to specification requirements both for 7 day and 28 day periods.

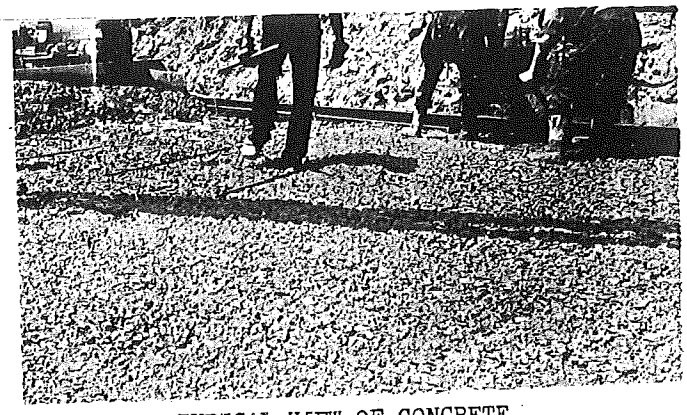
The pictures in Figure 19 illustrate the character of the concrete containing Silica Dust and Orvus. No pictures are available showing the concrete mixture with Orvus alone.

Accelerated Scaling Studies:

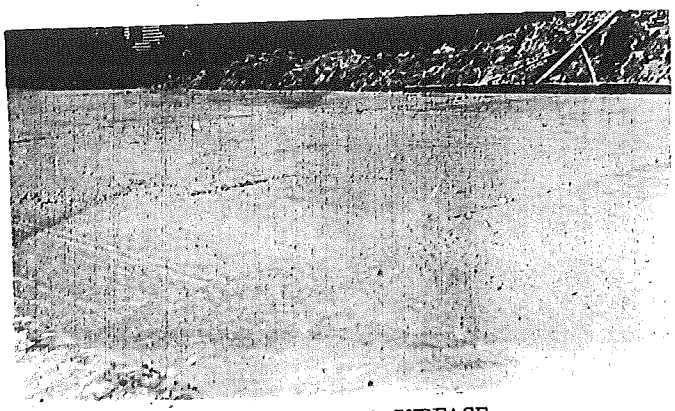
The test panels for scaling study were 3 feet by 12 feet so constructed to hold a layer of water 1/4 inch deep over the surface of the concrete. One panel was located at Station 53+00 on the north side of pavement consisting of Orvus and Silica Dust while the second panel was located at Station 54+15 on the south side of pavement containing the Orvus only.



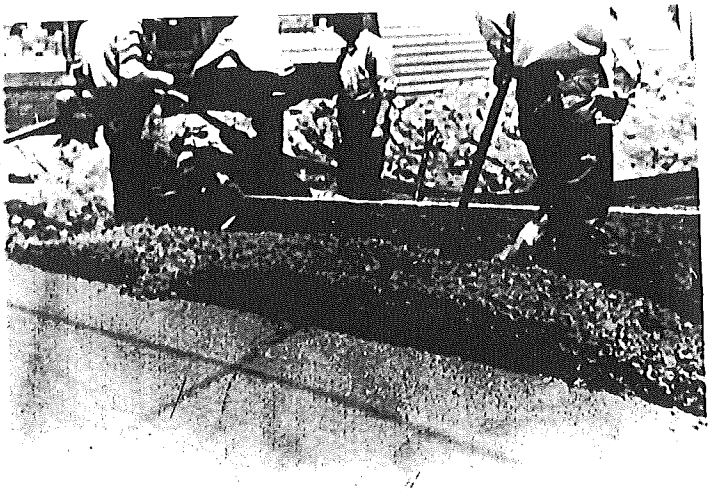
SILICA DUST IN STOCK PILE



TYPICAL VIEW OF CONCRETE

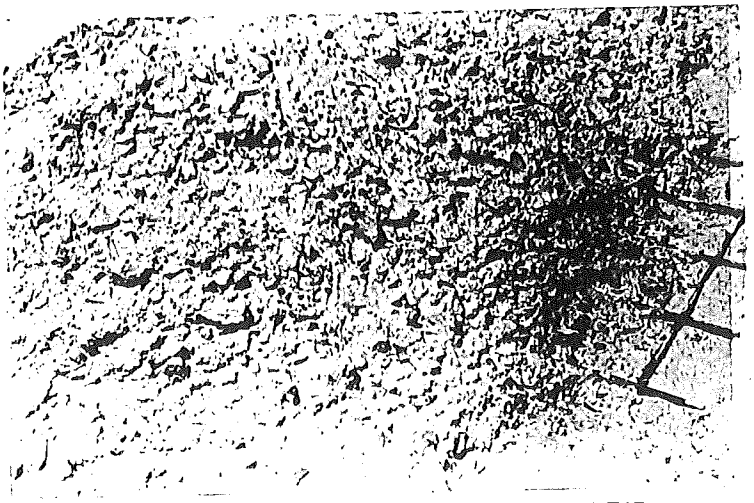


NO BLEEDING AT SURFACE



VIEW SHOWING PLASTICITY OF CONCRETE MIXTURE

SCALING PANEL



COATING OF STONE PARTICLES WITH MORTAR PASTE

LIMESTONE AGGREGATE CONCRETE WITH SILICA DUST AND ORVUS
FIGURE 19

Test Method "A" was performed on each panel. The test procedure consisting of freezing of water at night and thawing during the day with an application of calcium chloride as fully explained under the Baraga County tests. As previously mentioned the actual work of conducting the tests was performed by the Maintenance Division at Manistique.

Results of Tests:

At the completion of sixty-six cycles of freezing and thawing there was no indication of scaling either in the section containing orvus or the section containing both orvus and silica dust.

	TEST METHOD A	
1941-1942	Cycle	% Scale
Limestone Aggregates with Orvus	66	0
Limestone Aggregates with Orvus and Silica Dust	66	0

TABLE XI

TYPICAL GRADING ANALYSIS OF LIMESTONE AGGREGATES

Passing % By Weight	4A	10A	2SS	Silica Dust 3MF
2 Inch	100			
1 1/2 Inch	80	100		
1 Inch	28	98		
1/2 Inch		36		
3/8 Inch	2.3	19		
No. 4 Sieve		1.7	100	
No. 8			82	
No. 16			48	
No. 30			26	
No. 50			12	
No. 60				100
No. 100			3.3	
No. 140				99
No. 200				98
No. 270				93
Loss by Washing	0.4	0.7	3.3	

CONCLUSIONS

As mentioned in the introduction of this report the primary objective of the concrete durability study is to determine methods for improving the constituents of concrete and construction practices in such a manner as to eventually develop a concrete pavement surface totally resistant to scaling. To accomplish this objective, the research project was divided into three phases of study, namely; survey of existing concrete pavements, laboratory studies on concrete durability, and field studies on specially constructed concrete pavements.

This study of the results of the accelerated scaling studies made in conjunction with the field observations on specially constructed concrete pavements, over a two year period, justifies the following conclusions with reference to the extent to which the various factors studied affect the scale resistant properties of the concrete surface and the qualifications of the accelerated scaling tests.

1. The admixture Orvus and the grinding aids Vinsol Resin in Portland cement and beef tallow in natural cement produced a concrete surface entirely free from scale.

2. Of the two proprietary admixtures, Pozzolith and Plastiment which were included in the study, Pozzolith was considerably the better of the two products, producing a concrete highly resistant to scaling.

3. The blending of natural cement without grinding aid with Portland cement decreased scaling considerably but not totally. However, when grinding aid (beef tallow) was used with the natural cement complete scale resistant concrete was obtained. Therefore, it may be assumed that

the grinding aid is the desirable element in such mixtures for producing scale resistant concrete.

4. The addition of fines to the fine aggregate, while they improved workability, had no beneficial effect as far as reducing scale is concerned.

5. Concrete containing both coarse and fine crushed limestone aggregates showed very definitely to have the lowest scale resisting properties of any concrete.

6. Of the various curing methods studied those methods which tend to restrict moisture loss at the early stages of curing showed up the best during the scaling studies. For example, the membrane curing material and paper applied without initial curing seemed to impart durability to the concrete surface.

7. The type of finishing method or the use of bituminous membrane curing agents showed no advantage over standard construction practice.

8. The use of Orvus in limestone aggregate mixtures improves the workability of the mixture, practically eliminates the characteristic bleeding of such mixtures and produces a limestone aggregate concrete entirely free from scaling.

9. There was a marked difference in scaling characteristics of the concrete from the standpoint of brands of cements used. Those sections containing Brand No. 2 cement had a higher rate of scaling than the sections of concrete containing Brand No. 1 cement.

10. No definite conclusion, relative to the effect of age on scaling, can be drawn from the results obtained so far. This is believed due mainly to two reasons, first the time element of one year is too short

to bring in the age factor, second the test procedure as conducted during the 1941-1942 period was believed superior to that of the 1940-1941 series and consequently the final results are not ideal for comparing the age factor.

11. A graphical presentation illustrates the facts set forth above will be found in Figures 20, 21 and 22. These graphs illustrate the relationship between degree of scaling and factors studied as well as the effect of age on degree of scaling.

In conjunction with the field observations, laboratory studies are in progress pertaining to the durability of the various concrete mixtures under accelerated freezing and thawing conditions. The results from these laboratory studies must be correlated with the field studies before definite and final statements can be made.

The results from the laboratory freezing and thawing studies will be presented in a separate progress report.

RELATIONSHIP BETWEEN FACTOR STUDIED AND DEGREE OF SCALING

MICHIGAN TEST ROAD
1940-41, 1941-42

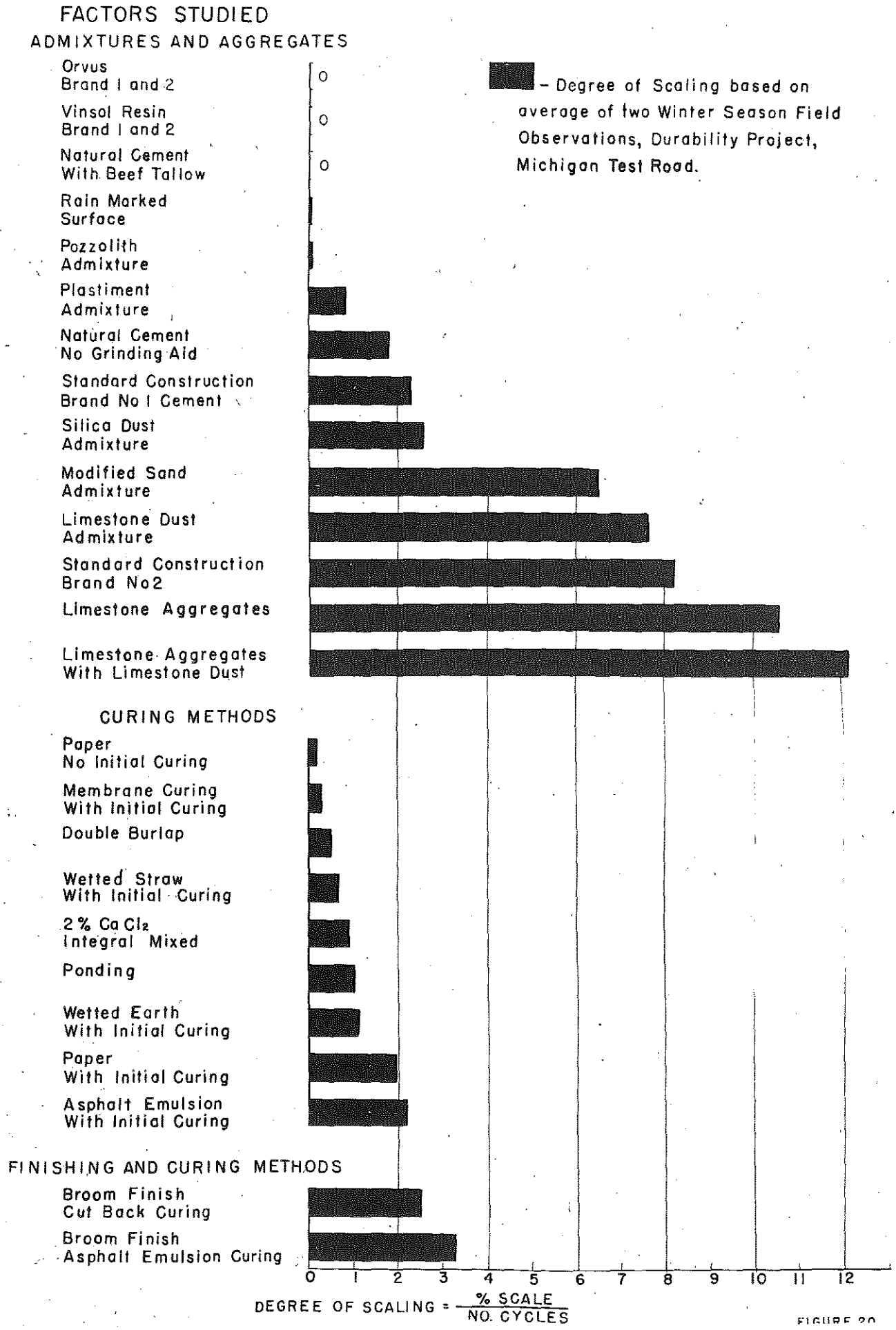
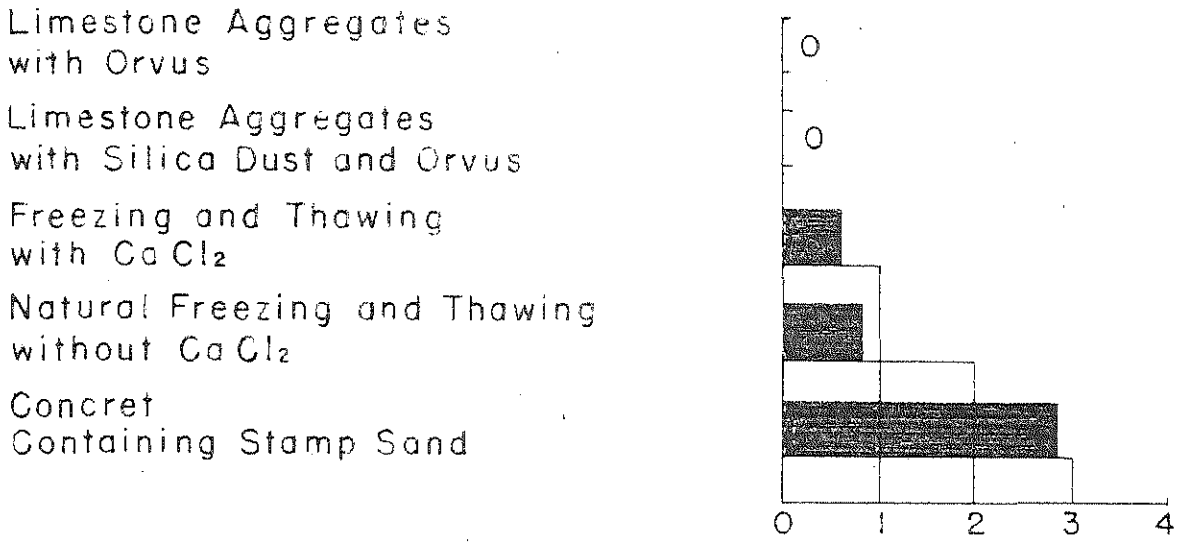


FIGURE 20

RELATIONSHIP BETWEEN FACTOR STUDIED AND DEGREE OF SCALING

SPECIAL STUDIES

1941-1942



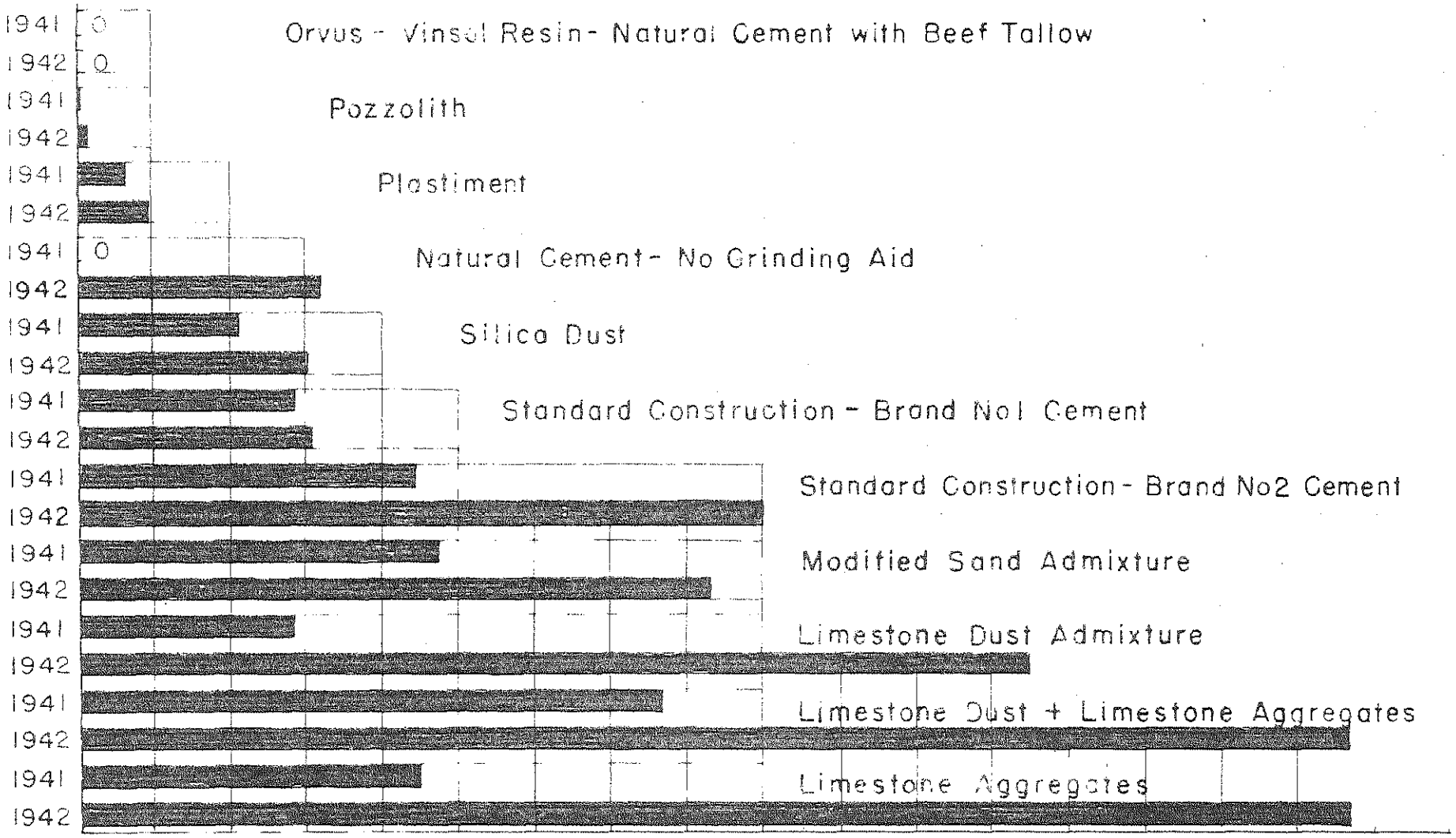
$$\text{DEGREE OF SCALING} = \frac{\%\ \text{SCALE}}{\text{NO. CYCLES}}$$

FIGURE 2

RELATIONSHIP BETWEEN DEGREE OF SCALING AND AGE OF CONCRETE

MICHIGAN TEST ROAD

1940-41 1941-42



DEGREE OF SCALING = $\frac{\%\ \text{SCALE}}{\text{NO. CYCLES}}$

FIGURE 22

SCALING STUDY

Record of Degree of Scale

Degree of Scaling	Factor Studied
0	Orvus
0	Vinsol Resin
0	Natural Cement with Beef Tallow
.06	Rain Marked Surface
.09	Pozzolith
.79	Plastiment
1.84	Natural Cement - No Grinding Aid
2.31	Standard Construction - Brand 1
2.61	Silica Dust
6.50	Modified Sand
7.63	Limestone Dust
8.23	Standard Construction - Brand 2
10.62	Limestone Aggregates
12.20	Limestone Aggregates with Limestone Dust
.17	Paper - No Initial Curing
.29	Membrane Curing - Initial Curing
.50	Double Burlap
.67	Wetted Straw
0.90	2% $CaCl_2$ Integral Mixed
1.00	Ponding
1.10	Wetted Earth - Initial Curing
1.93	Paper with Initial Curing
2.19	Asphalt Emulsion - Initial Curing

Degree of Scaling	Factor Studied
2.5	Broom Finish - Cutback Curing
3.28	Broom Finish - Asphalt Emulsion
0.62	Freezing and Thawing with $CaCl_2$
0.79	Natural Freezing and Thawing without $CaCl_2$
2.85	Concrete with Stamp Sand
0.0	Limestone Aggregates with Orvus
0.0	Limestone Aggregates with Orvus and Silica Dust

RELATIONSHIP BETWEEN AGE AND SCALING

Factor Studied	1941	1942
Orvus	0	0
Vinsol Resin	0	0
Natural Cement with Beef Tallow	0	0
Pozzolith	.04	.13
Plastiment	.66	.92
Natural Cement - No Grinding Aid	0.0	3.2
Silica Dust	2.12	3.1
Standard Construction Brand 1	2.86	3.1
Standard Construction Brand 2	4.42	9.0
Modified Sand	4.76	8.3
Limestone Dust	2.86	12.5
Limestone Dust with Limestone Aggregates	7.7	16.7
Limestone Aggregates	4.54	16.7