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GENERAL OBSERVATIONS ON CONCRETE SCALING

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A preliminary survey of all concrete pavements in Michigan shows that approximately 10 percent of the surface is scaled in varying degrees. Other states in corresponding climatic zones have experienced similar scaling conditions. This condition has become more apparent as the use of chemical salts has increased for the removal of ice from pavements. The use of concrete for pavements during the last 30 years has demonstrated its many desirable properties as a paving material. Scaling of concrete pavements in Michigan has not indicated that any of these properties have been seriously impaired by its action or that the use of chemical salts and resultant scaling have lead to any definite failure. Scaling has been common in most parts of the state, but on a whole the concrete is predominately good. But even so, the unsightliness of scaled areas, the necessary subsequent maintenance and the added possibility of further deterioration is of immediate concern to the highway engineer.

This concern leads the engineer to the consideration as to "what to do" about the problem. Logically in order to attack such a problem some information of a fundamental nature must be obtained as regards the cause of the scaling. Then on the basis of the information formulate corrective measures. The study of scaling and the use of preventative measures has not altogether followed this plan. Quite by accident certain admixtures when used in concrete have been found to arrest scaling for a period of time, the length of which must be determined by further research.

These admixtures have been used on a trial experimental basis with a certain amount of success, but all of the causes of scaling or any positive reason why these admixtures work has not as yet been definitely determined.

In studying the problem of scaling a definite philosophy should be adopted, as to whether ice control and methods now used should direct the basis of the investigation or whether new methods of ice control should be developed. It would appear that the most logical attitude to take is that the use of "salts" for ice removal is the cheapest and most efficient method we know and that the problem should be one concerned with what to do about the concrete to prevent scaling.

The Michigan State Highway Department was one of the pioneers in the development of ice removal methods, perhaps due to the geographical location of the state and the resultant ice formations on pavements. Abrasives, chloride salts, serrated blades and other methods have been used to control slippery conditions of pavements with satisfactory results. As an effect of the use of a considerable amount of salts in the control program an increased amount of scaling was noticed on the concrete slabs.

Consequently, in 1939, a study of scaling, its causes and methods for prevention was incorporated into the plans of the Research Division of the Michigan State Highway Department as a definite project under the title "Durability of Concrete".

This investigation has been divided into two separate studies; first, a field study including a survey of existent concrete pavements and a special study of a test road, and second, a laboratory study of concrete durability as related to scaling.

It has not been believed that salts are the only contributory factor to scaling of concrete pavements, since scaling has been frequently observed on pavements which never had any salts applied. But detailed observations indicate that salts accelerate incipient scaling. Therefore, it is necessary to study all factors which might contribute to scaling. To this end a detailed field survey of all concrete pavements constructed on the Michigan state trunkline system was made. This survey consisted of a visual examination to determine the amount of scaling and a subsequent study of the numerous factors incidental to pavement construction which might affect surface conditions and bear a relation to scaling. The various factors studied are shown in the sample coding sheet (Figure 1). The study covered about 1500 separate projects, some 290 sources of aggregates and 52 different brands of cement. Information obtained from this study assisted in setting up the various factors which should be studied in subsequent field and laboratory work. At present, the survey information is being coded and being made ready for tabulating cards for use in the standard business machine. The information obtained regarding these factors will be very interesting and should show some definite trends. The results of this study will be covered in a special report upon the completion of the work.

Soon after the completion of the field survey work, a test road project was built to assist in the further study of factors contributing to scaling as well as to study preventative measures. The construction of the test road project has been described in ROADS AND STREETS, May 1941 issue. Briefly, the project included an evaluation of the construction factors related to scaling both as regards materials and methods of construction, such as proportioning and grading of aggregates, physical and chemical additives, cement blends, cements produced with grinding aids, curing methods, and final finishing methods.

Prior to the construction of the test road and continuing to the present, investigational laboratory work has been carried on. Results of this laboratory work assisted also in determining the set up of the test road. These and other results obtained from later studies are being correlated with the results of the field study to the end that a comprehensive evaluation of all factors can eventually be made.

Although it will be some period of time before all of the field and laboratory work is completed, it is believed a report in the nature of a progress record will be of interest to those mutually interested in the problem. It is further hoped that such controversial issues which arise in the discussion of results will serve to incite arguments which will serve to clarify the issues as well as aid in the direction of further research activities.

To date the following phases of the "Durability of Concrete" study have been completed.

1. Preliminary studies on aggregates, cements and additives used on the Michigan Test Road.
2. Construction observations on the Michigan Test Road.
3. First year accelerated scaling study on the Michigan Test Road.
4. Laboratory studies on "scale" from existent pavements.
5. Action of chloride salts on concrete and its constituents.
6. Laboratory freezing and thawing of specimens from the Michigan Test Road.

Each of the above phases will be discussed briefly with an attempt to bring out methods used and any findings, to date, worthy of mention and at the same time to correlate them with other phases of the durability study. It should be understood that it is not intended there should be any finality to the findings, but rather they should be considered as indicators to what final results may be. It is felt that in a study of this type, long range in nature, progress results are interesting although not final.

Preliminary studies on aggregates, cements and additives used on the Michigan Test Road.

After a comprehensive study of all factors pertaining to the characteristics of materials and their relation to scaling had been made, a program was set up for the determination of those characteristics which were deemed most important. This program included a study of aggregates which would be used on the test road, all of the cements available on the Michigan market and the most promising additives which had been proposed for use in correcting scaling.

From information obtained from past construction in Michigan and elsewhere, it has been held and substantially proven that over finishing and bleeding, due to characteristics of certain types of sands, aggravate scaling. Of course, both of these factors are closely related to the water content, but it is believed that the basic difficulty as regards bleeding and the necessity of over finishing can be attributed to the characteristics of the aggregate. The two most important characteristics in this connection are grading and shape of particles. As has been mentioned, water content is important but since it is a quantity which can be easily controlled, its importance was emphasized only in keeping water content as low as possible, consistent with satisfactory workability.

In designing the mixes for the Michigan Test road durability section the hypothesis of "improved grading" was accepted. The improvement of grading was to aid only in the workability of the mix with a resultant reduction in particle interference. With greater workability less effort would be expended in finishing a minimum of fines and excess water would accumulate on the surface. In the study to determine proper gradation of fine and coarse aggregate it was attempted to approach an "ideal grading" as near as possible and still be in the range of conservation as to cost and application. Only two general types of aggregates were used, namely, glacial gravel and crushed stone (coarse aggregate) and natural sand and manufactured stone sand (fine aggregate). The fine aggregate was supplemented, in some cases, with various "fines" including, limestone dust, silica dust and very fine natural sand. The approximate resulting gradations used are shown in Figure 3. In some cases, the total fines passing the 200 mesh sieve, on the basis of the total mix, amounted to about 5 percent. In connection with particle shape, a study of manufactured stone sand was made as to the character of the individual particles. No attempt was made to correct what was believed to be improper shape, but the material as received from the manufacturer was accepted and observations made in the field upon the characteristics of "bleeding". This preliminary study showed the necessity of further study of this subject to the end that the slabby, angular particles of manufactured stone sand may be very undesirable as regards "scaling". It was hoped that the supplementing of the stone sand with "fines" and certain admixtures would reduce the tendency to bleeding and scaling. The results obtained will be further discussed under "First Year Accelerated Scaling Study".

In the preliminary tests, 20 brands of cement which are used in Michigan were studied as regards to durability resistence. The tests on neat cements and mortars included freezing and thawing in water, freezing and thawing in air, action in 30 percent calcium chloride solution, with a cycle of rinsing with distilled water and drying. Studies were also made on expansion characteristics of cement mortars by use of the autoclave. The cements were rated as to their relative resistance to the various tests. Fortunately the contractor on the test road elected to use two brands of cement which showed in these tests to be widely separated in their characteristic behavior. Further similar laboratory studies are to be made on mortars and concrete using these same cements.

Concurrent with the cement tests, studies were made on several proprietary admixtures, natural cement blends and mineral fillers. These materials included Tricosal, Plastiment, Luxment, Pozzolith, Orvus, T.D.A., Vinsol Resin, Silica Dust, Limestone Dust, Bentonite and Fly Ash. In these studies the following tests were made on natural sand-cement mortars containing the admixtures:

1. Freezing and thawing (in water).

2. Freezing in air (saturated) and thawing (in water).

At the end of 50 cycles, in both tests, the loss in weight and reduction in compressive strength was determined. As on the cement mortars, expansion studies were also conducted on mortars containing the admixtures. From the relative results those admixtures with best resistance and physical characteristics were considered for use in the test road. However, some of these were finally eliminated because of unavailability, economic reasons and possible construction difficulties. The materials finally selected were Plastiment, Pozzolith, Orvus, Vinsol Resin, natural cement blend with and without grinding aid, silica dust, limestone dust and natural fine sand.

Construction observations on the Michigan Test Road.

In order to obtain a proper correlation of preliminary studies with field and laboratory scaling and durability studies, it was necessary to make a comprehensive comparative study of the physical characteristics of the various concrete mixes used in the Michigan Test Road. The following factors were considered and detailed data obtained during construction:

1. Subgrade conditions
2. General appearance of concrete
3. Workability
4. Segregation
5. Consistency
6. Bleeding
7. Finishing
8. Laitance
9. Curing
10. Appearance of concrete after removal of forms
11. Time and temperature during placing and curing of concrete.

12. Mechanical analysis of fresh concrete

13. Setting time of concrete.

14. Concrete test specimens for future laboratory work.

This information has been completely assembled for analysis and considerable data has been obtained for rating the various materials as regards construction practice. Such information is particularly valuable in studying peculiar conditions as well as correlating final results of laboratory and field durability studies.

<u>First year accelerated scaling study on the Michigan Test Road</u>

During the actual service life of the test road pavement and for a period of 3 to 5 years, it is 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 Research Division 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, as shown in Figure 4.

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 starting the next cycle. This produced a long period of contact of the concrete with the salt and introduced only a few freezing-thawing periods.

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 rate of 5 pounds per area. When the ice was decomposed, it was removed from 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 percent 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. Each winter the test areas will be established in the same section and adjacent to the previous test areas.

During the winter of 1940-41 a number of cycles of each "type cycle" were run on panels in sections containing each of the various materials and methods of construction as shown in Table 1. The table shows the results obtained on the various factors for each method of accelerated action. Since the results are not final until more data is obtained, it is felt that, at this time, it is only important to show that certain of the admixtures and construction methods were beneficial in resistance to the action of salts and freezing and thawing. It is to be noted that the "B" type tests were more severe, indicating that scaling is more severe with more freezing and thawing periods. It can be said in a general way, however, that those admixtures of an organic nature which increase the air content with resultant reduction in unit weight were most effective. These results are in agreement with findings of other investigators in the field. The results of the first years test, although very encouraging, have not warranted the acceptance of such materials on a general specification basis. In some cases, laboratory findings in freezing and thawing tests are not in agreement with findings in the field, and further, studies on the chemical action of "salts" on the constituents of concrete create certain reservations in the mind of the investigator as regards such findings. Further, it should be pointed out that some of the admixtures caused construction difficulties and delays because of poor workability, poor finishing and slow setting. Additional studies should be made in the field to determine the relative effect of the salts in the scaling action. It is proposed to make such a study during the coming winter.

In reference to the various organic admixtures which showed satisfactory resistance, it might be pointed out that in construction operations those admixtures which could be added at the mixer were more desirable. The criterion of drop in unit weight of the concrete mixture has been used for determining proper amount of material to add. The reaction of the admixture to the mixes with aggregates from different sources will vary. Therefore, those admixtures which can be controlled in quantity at the mixer should prove to be more advantageous, since no corrective measure can be taken after an admixture is ground with the cement.

The action of the admixture in the concrete is of considerable interest and the present knowledge is ably summarized by M.A. Swayze in CONCRETE, August 1941. "The effect of air content of concrete and especially that part contributed by the organic admixtures on the physical properties of hardened concrete is a relatively new subject. It is recognized that very small quantities of these additives, such as resins, and fats, markedly increase resistance to frost action and concrete workability. They also increase air content and generally decrease strength ..
....

"Two schools of thought exist as to why these foam producing materials increase resistance to freezing and thawing. One considers the cause to be air cells themselves which furnish relief from the pressure built up by the freezing of water in concrete. The other holds that the high durability is attributable to a dispersing action in the cement gel, thus decreasing the size of capillaries in the hydrated paste. While the author is inclined, toward the latter opinion, final decision must await the results of research."

Whatever the reason, it is apparent in the use of the better admixtures (Figure 5), workability is increased, over finishing is not necessary, water contents are kept to a minimum and there is no gravitational separation with resultant "bleeding". The elimination of these undesirable characteristics is associated with increased resistance to action of freezing and thawing and for a period of one year to the action of chloride "salts".

Laboratory studies of "scale" from existent pavements.

Prior to the construction of the Michigan Test Road, several minor studies were made in the laboratory and field on scaled areas of concrete. Scale was collected and studied, cores were taken from the same project on scaled and unscaled areas and detailed analysis was made in comparing the characteristics of surface and parent concrete. Several microscopic and petrographic studies were made which aided in collecting information to determine what factors were related to scaling. The results of these preliminary studies showed that the cement content of the scale is 4 to 8 percent higher than the cement content of concrete underneath. As is well known, the mechanical strength of the scale was very low. These examinations indicated that the scale was the result of setting in the presence of excess water, the result of bleeding and had been weakened by contact with calcium chloride solution.

The petrographic studies of hydrated concrete yielded information concerning only the calcium hydroxide and calcium carbonate. Definite observations on the distribution of these products could be made and there was a definite relation between scaling and the presence of crystalline calcium hydroxide. Micrographic studies of the action of calcium chloride on mortars consisting of portland cement and Ottawa sand were interesting. Figure 6 is of a sample, "not treated" and figure 7 a sample, "treated" with calcium chloride. The effect is obvious. There has been a considerable amount of expension with resultant fracturing and breaking out of the sand grains. Many of the cracks tend to follow the outlines of the grains and others pass beneath them appearing only when the grains are forced out and broken.

All of the preliminary studies indicated that several factors were responsible for scaling including the action of salts. It was recognized that many might be excluded by proper construction methods, closer inspection and improved specification requirements. As many as possible of these factors were eliminated in the construction of the Michigan Test Road.

In the rigid control of all factors, it is interesting to note the sections containing supplemental fines. Care was taken in the grading of the aggregates, water content was held to a minimum, workability improved, bleeding was eliminated, yet, undesirable amounts of scaling was produced in the "accelerated scaling studies". This observation led to a detailed study of the probably action of chloride salts on concrete.

Action of chloride salts on concrete and its constituents.

In the investigation of the action of chloride on concrete, the answer to "how, when and where" such action might occur was sought. Since calcium chloride was used in the accelerated studies and this salt is only used in ice control on concrete pavements in Michigan, no consideration was given to sodium chloride at this time.

In the preliminary laboratory work, it has been noted how calcium chloride acted upon portland cement - Ottawa sand mortars. If mortars could be disintegrated, the natural question is, "how does this take place?"

The rather voluminous literature available on the action of calcium chloride when added to the concrete mix before setting does not yield appreciable information on the action of calcium chloride on set cement. It is believed that the action is both physical and chemical. In further laboratory work it was found that set neat cement plates immersed in calcium chloride solutions of 20 percent to 30 percent concentration lost all coherence inside of 2 to 3 months at room temperature. Crystalline needles of calcium oxychloride grew in the liquid immediately over the material resulting from the destruction of the cement. If the calcium chloride solution was frequently submitted to temperature changes between 0°C and 35°C the crystals of oxychloride appeared even before the plates were destroyed. If freshly prepared calcium hydroxide is immersed in 30 percent calcium chloride, it appears under the microscope, at first quite amorphous. Inside of a month, especially with frequent changes in temperature needles of calcium oxychloride appear in the clear liquid and under the microscope the whole mass is found to consist of crystals of calcium oxychloride.

The conversion of amorphous calcium hydroxide into crystalline form in the scale was also noted in the petrographic studies with none apparent in the underlying concrete. The calcium hydroxide in the parent concrete was still in the amorphous state.

These observations are very interesting and indicate that scaling must be both chemical as well as physical in character.

Other investigators have noted the complete disintegration of portland cement specimens cured in saturated calcium chloride solutions. In our laboratory, plates 1/2 inch thick sawed out of the middle of a 6 inch core, from a 2 year old concrete pavement, were immersed in a 30 percent calcium chloride solution and in 2 to 3 months all plates suffered complete disintegration. No heating or large variation of temperature was employed. (Figure 8).

Another phase studied in the investigation was the determination of the probable concentration of calcium chloride reached on the surface of a pavement after it has been subjected to the standard treatment for ice control. Results of this study showed that concentrations as high as 40 percent could be obtained under such conditions and the depth of penetration did not exceed over 1/2 inch.

The study of the salt action indicates that chemical and physical action takes place particularly under conditions where concentrations reach about 30 percent. However, lower concentration down to 10 percent have reacted upon concrete at a slower rate. It is further indicated that under standard ice control treatments where approximately 1/30 to 1/20 pound of salt is applied per square yard of pavement per application, concentrations as high as 40 percent will exist.

Further study of salt action and the effect of admixtures in the reduction of scaling should aid in producing a concrete which will be completely resistant to scaling. Accelerated field and laboratory studies will assist materially in evaluating the benefits derived. However, it is felt that freezing and thawing studies in the laboratory must be supplemented with calcium chloride action.

Laboratory freezing and thawing of specimens from the Michigan Test Road.

During the construction of the Michigan Test Road durability section specimens for freezing and thawing studies were molded. The first series of specimens of all different concrete mixes were subjected to cycles of freezing and thawing at the age of 5 months. These specimens were cylinders 4 inches in diameter and 16 inches in length and beams 3 by 6 by 15 inches cast under field control. The specimens were placed in tight fitting rubber boots, covered with water and placed in freezer chamber containing glycerin solutions. A minimum temperature of -20°C was attained in 4-1/2 hours, although freezing was conducted from 4 p.m. to 9 a.m. the following day. The thawing cycle was performed between 9 a.m. and 4 p.m. in a water bath of 70°F. A typical relationship of the number of cycles to change in modulus of elasticity for standard concrete is shown in figure 9.

Comparison of the laboratory freezing and thawing tests to the field accelerated scaling studies did not show the same relative resistance to "breakdown". However, a few significant relations were obtained. In general, those mixes which showed a greater resistance to breakdown in freezing and thawing did not scale in the field tests. It was also noted that the addition of the "fines" silica dust, natural "fine" sands, and limestone dust did not improve resistance when compared to normal standard mixes. And, further, the limestone dust when used both with natural coarse and fine aggregate and limestone coarse and manufactured fine aggregate, the resistance was very inferior. This might suggest that although "fines" will reduce "bleeding" in construction other characteristics are developed in the concrete, such as increased capillary attraction for liquids, either water or salt solutions. It may be possible, also, that the fine condition of the calcium carbonate with high specific surface may allow formation of other chemical compounds in combination with calcium hydroxide and calcium chloride which cause a rapid breakdown.

Conclusions

A review of the many factors which have been attributed to the cause of scaling indicates how difficult relative rating of each factor can be, since it is almost impossible to control all but one factor at a time in research investigations. Nevertheless there are certain points which have left definite impressions upon the minds of our research investigators while working on this problem up to its present stage of progress. Important among these points are the following:

1. Surface mortar scale does not appear unless certain conditions are obtained in construction and design of the mix which promote the development of a mechanically and chemically weak zone at the surface of the concrete slab.

2. Elimination of "bleeding" will not prevent action of certain chemical salts on the surface of standard Portland cement concrete.

3. Increase of "fines" with cement content remaining the same does not increase resistance to scaling over a standard portland cement concrete mix.

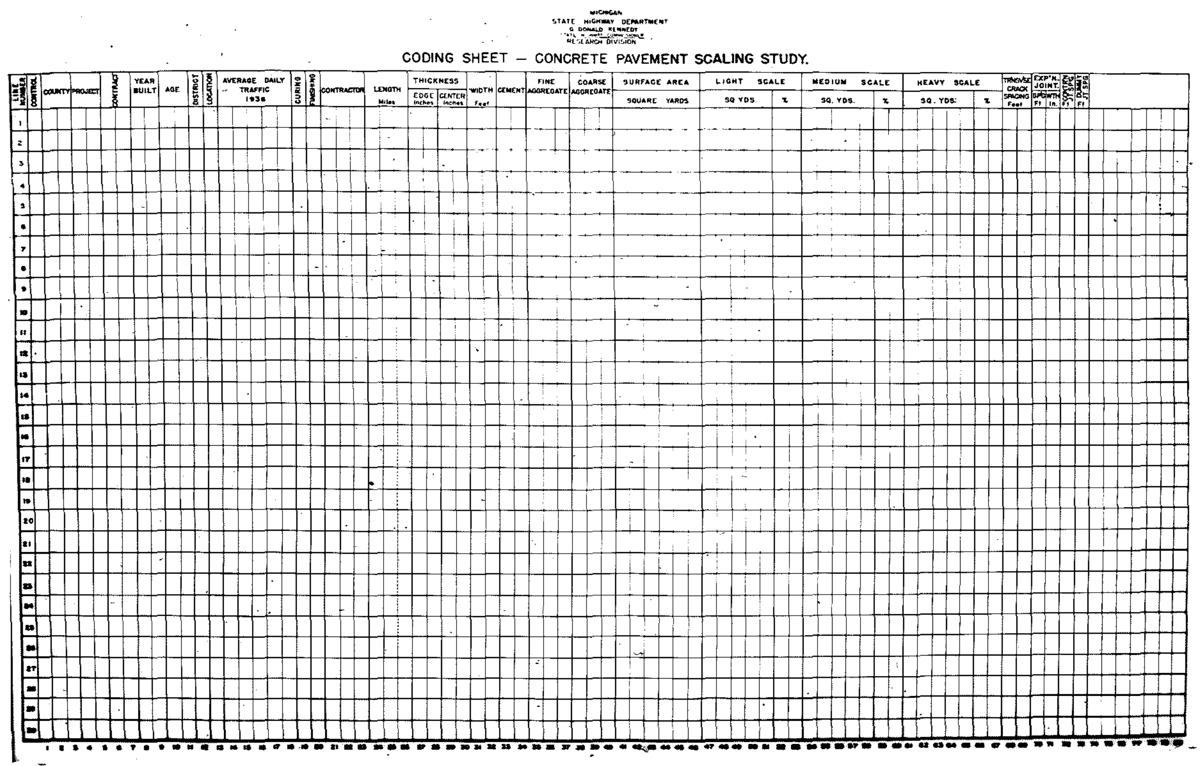
4. Certain organic admixtures seem to increase resistance to accelerated scaling by action of calcium chloride, as well as resistance to freezing and thawing.

5. The action of certain chloride salts on concrete accelerates scaling. It is believed that this action is both chemical and physical.

CEMENT	ADMIXTURE	FINISH	CURING	FREEZE-THAW CYCLES	FREEZE-THAW %SCALE	CaCl2 SOLUTION CYCLES	CaCl2 SOLUTION %SCALE
BRAND 1	LIMESTONE AGG. & LIMESTONE DUST	BURLAP	WET STRAW	5	100.0	3	100.0
BRAND 1	NONE	BURLAP	WET STRAW	13	100.0	3	100.0
BRAND 1	MODIFIED SAND	BURLAP	WET STRAW	21	100.0	3	100.0
BRAND 2	NONE	BURLAP	WET STRAW	21	100.0	5	100.0
BRAND 1	LIMESTONE AGG.	BURLAP	WET STRAW	22	100.0	5	100.0
BRAND 1	NONE	BROOM	WET STRAW	28	94.5	5	100.0
BRAND 1	LIMESTONE DUST	BURLAP	WET STRAW	27	94.4	7	59.0
BRAND 1	NONE	BROOM	ASP. EMULSION	25	92.0	6	22.0
BRAND 1	NONE	BROOM	ASP. CUT. BACK	33	83.0	7	42.0
BRAND 1	SILICA DUST	BURLAP	WET STRAW	30	70.0	7	17.0
BRAND 1	NONE	BURLAP	24 HR. BURLAP	27	61.0	6	42.0
BRAND 1	NONE	BURLAP	WET STRAW	33	61.0	7	11.2
BRAND 2	NONE	BURLAP	WET STRAW	27	56.0	6	33.0
BRAND 1	NONE	BURLAP	WET EARTH	28	33.0	6	1.4
BRAND 1	NONE	BURLAP	PONDING	28	28.0	6	TRACE
BRAND 1	TYPE # 1	BURLAP	WET STRAW	33	22.2	7	0.0
BRAND 1	NONE	BURLAP	WET STRAW	27	19.0	6	6.0
BRAND 1	NONE	BURLAP	CaCl2 INTREGAL	24	16.7	6	TRACE
BRAND 1	NONE	BURLAP	DOUBLE BURLAP	24	14.0	6	TRACE
BRAND 1	NONE	BURLAP	PAPER	28	3.0	6	0.0
BRAND 1	TYPE # 2	BURLAP	WET STRAW	33	1.4	7	0.0
BRAND 1	TYPE # 3	BURLAP	WET STRAW	29	TRACE	7	6.0
BRAND 1	NONE	BURLAP	24 HR. BURLAP & PAPER	28	TRACE	28	TRACE
BRAND 1	TYPE # 4	BURLAP	WET STRAW	33	TRACE	7	0.0
BRAND 2	TYPE # 5	BURLAP	WET STRAW	33	TRACE	7	TRACE
BRAND 1	NONE	BURLAP	RITE-CURE	28	0.0	6	0.0
BRAND 1	TYPE # 6	BURLAP	WET STRAW	33	0.0	7	TRACE
BRAND 2	TYPE # 6	BURLAP	WET STRAW	33	0.0	7	0.0
BRAND 1	TYPE # 5	BURLAP	WET STRAW	33	0.0	7	0.0

Table I - Showing Materials Used on Durability Section of Michigan Test Road

Figure 1 - Typical Scaling of Concrete Pavement



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CODING SHEET — CONCRETE PAVEMENT SCALING STUDY.

LINE NUMBER	CONTROL	COUNTY	PROJECT	CONTRACT	YEAR BUILT	AGE	DISTRICT	LOCATION	AVERAGE DAILY TRAFFIC 1936	CURING	FINISHING	CONTRACTOR	LENGTH Miles	THICKNESS EDGE Inches	THICKNESS CENTER Inches	WIDTH Feet	CEMENT	FINE AGGREGATE	COARSE AGGREGATE	SURFACE AREA SQUARE YARDS	LIGHT SCALE SQ YDS.	LIGHT SCALE %	MEDIUM SCALE SQ. YDS.	MEDIUM SCALE %	HEAVY SCALE SQ. YDS.	HEAVY SCALE %	TRNSVSE CRACK SPACING Feet	EXP'N. JOINT SPG Ft	EXP'N. JOINT WTH In.	CONTR. JT. SPG Ft	DUMMY JT. SPG Ft	
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Figure 2 - Coding Sheet for Pavement Survey Study

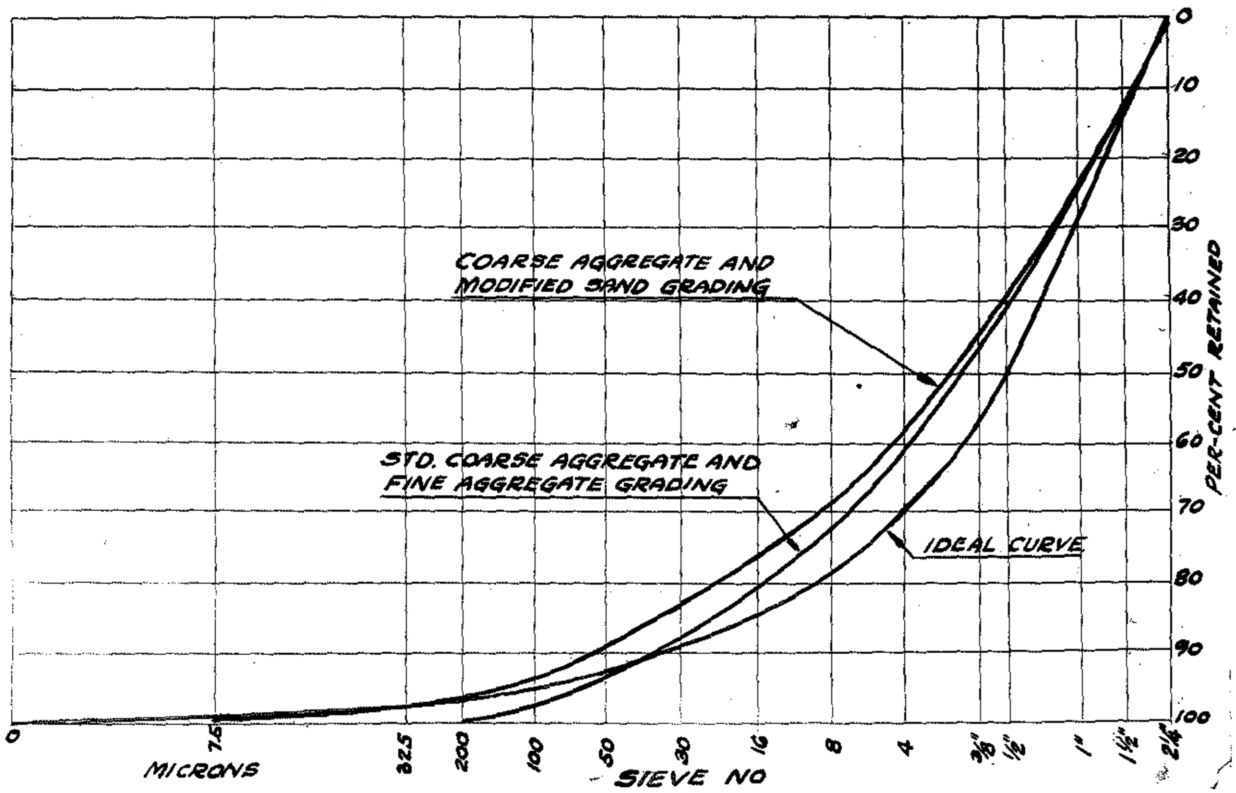

Figure 3 - Typical Grading Curves

Figure 4 - Panel Used in Scaling Studies

Figure 5 - Characteristics of Concrete Containing Additives

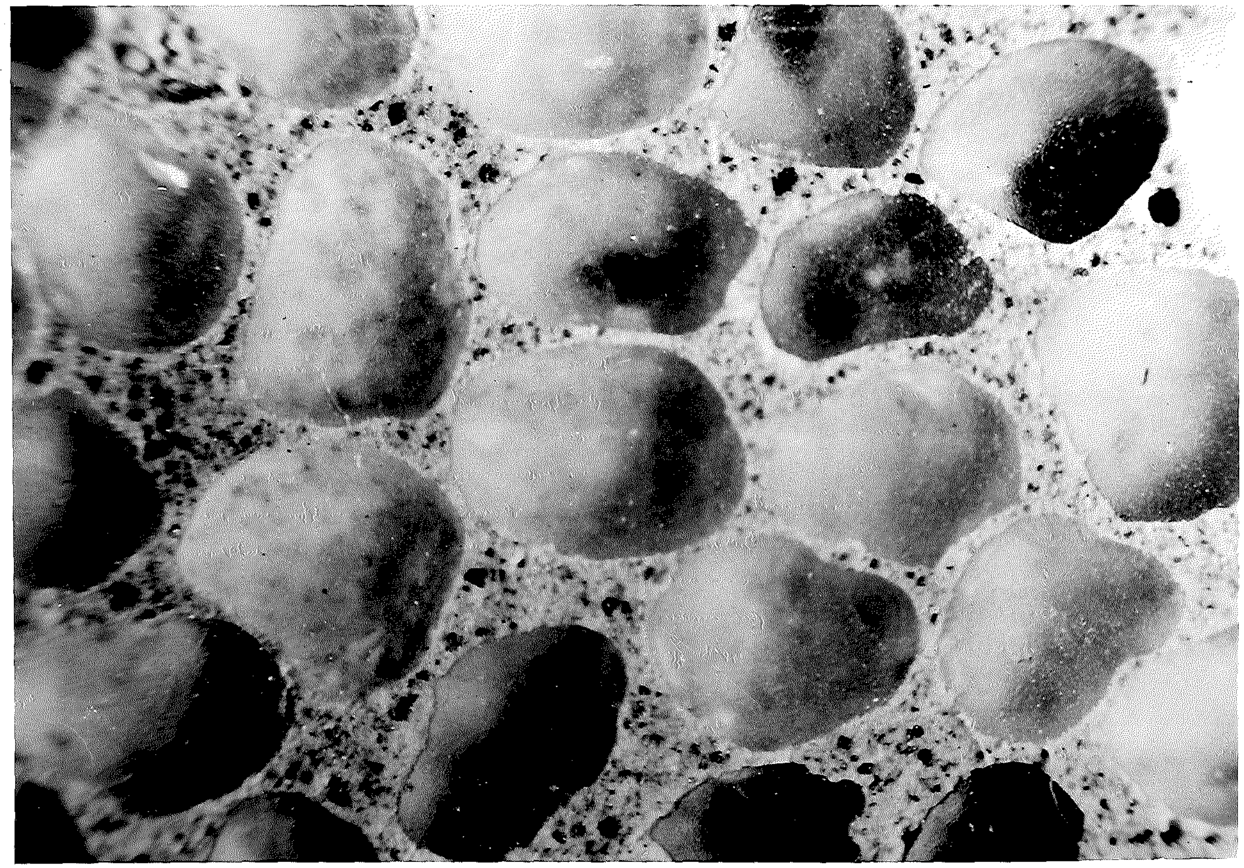

Figure 6 - Ottawa Sand Mortar - Untreated

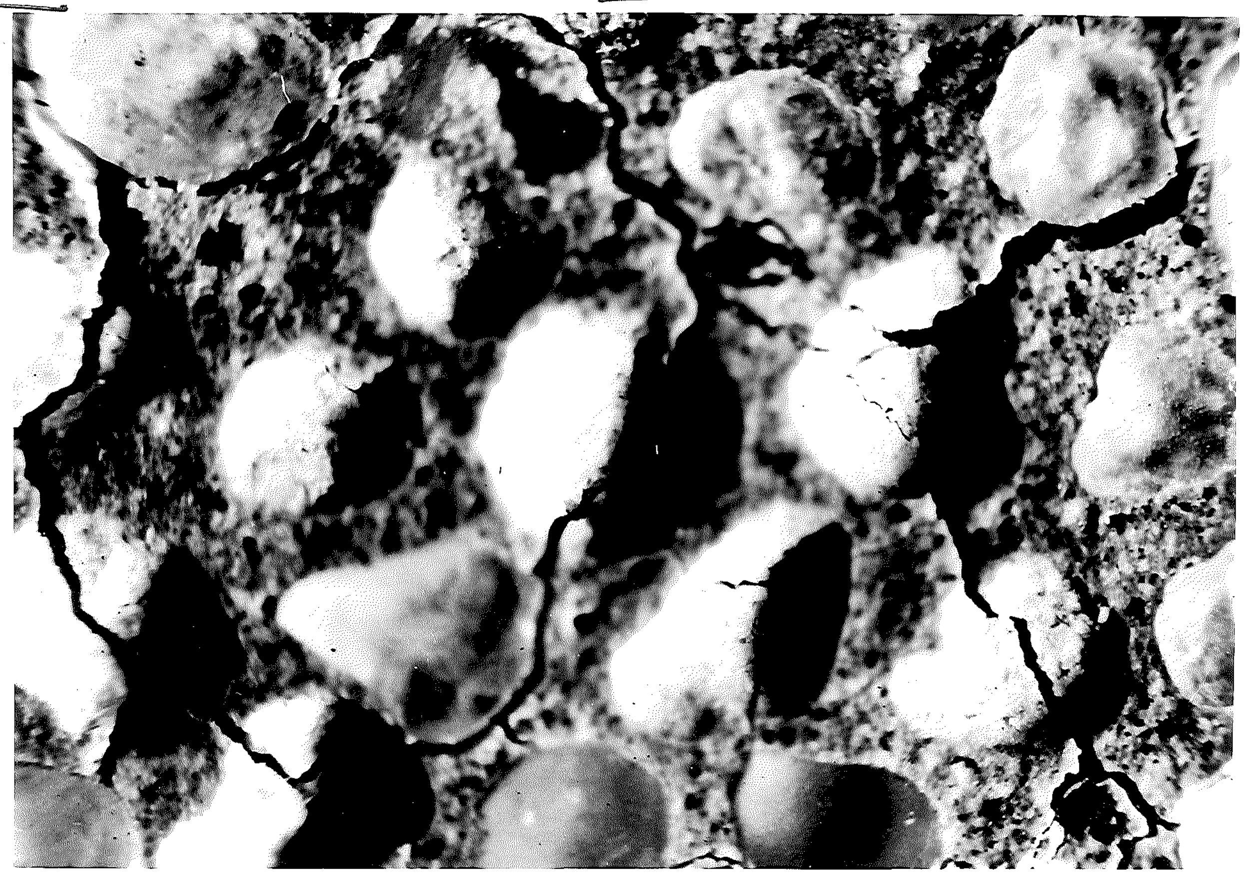

Figure 7 - Ottawa Sand Mortar - Treated with 30% Calcium Chloride 24 Hours

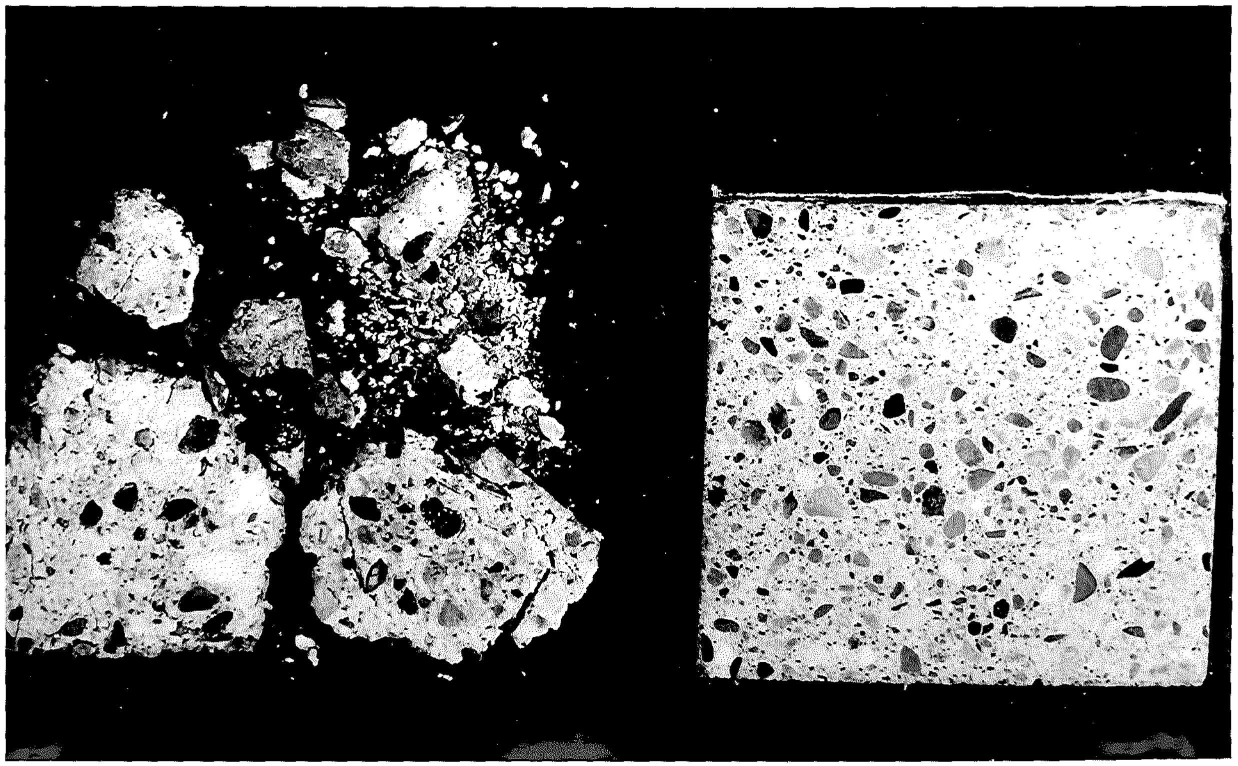

Figure - 8 - Concrete Disintegrated by Calcium Chloride Solution

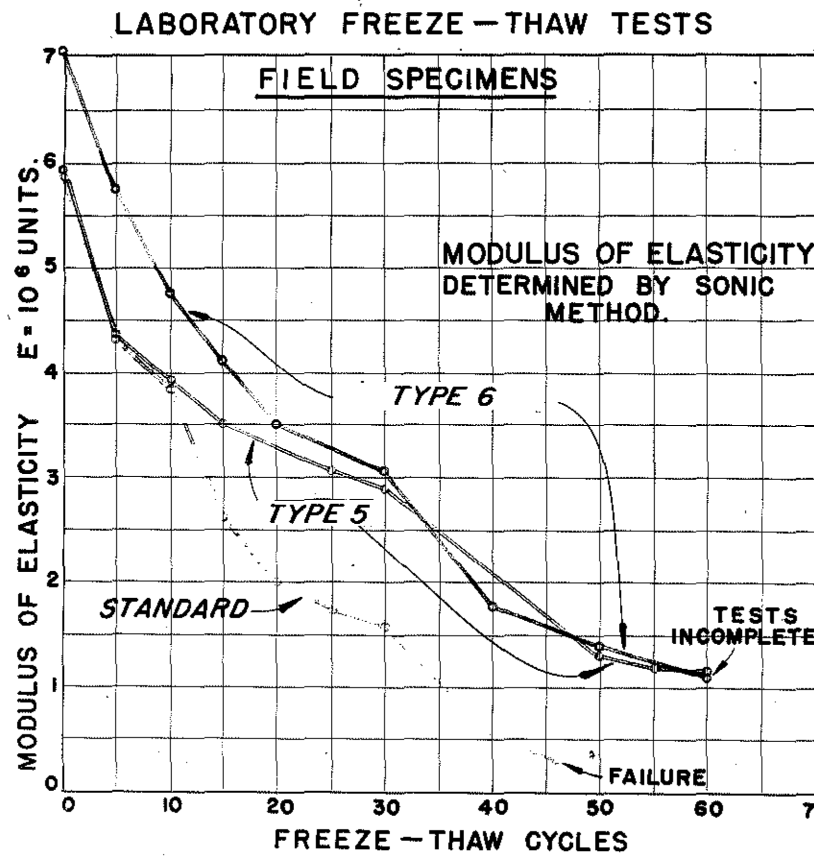

Figure 9 - Graph Showing Effect of Freezing and Thawing of Field Specimens