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Charles M. Ziegler
State Highway Commissioner

MICHIGAN'S EXPERIENCES IN THE USE OF AIR ENTRAINING MATERIALS FOR CONCRETE PAVEMENT CONSTRUCTION

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By

E. A. Finney

RESEARCH LABORATORY
TESTING AND RESEARCH DIVISION

MICHIGAN'S EXPERIENCES IN THE USE OF AIR ENTRAINING MATERIALS FOR CONCRETE PAVEMENT CONSTRUCTION

Michigan's experience in the use of air entraining materials in concrete pavements dates back to the construction of the Michigan Test Road during the summer and fall of 1940. The Michigan Test Road was constructed in cooperation with the Federal Works Agency, Public Works Administration on M 115, between US 10 and M 66 in Clare and Osceola counties. Two types of air entraining materials were included in the construction of this test road. These air entraining materials have the ability to impart to a concrete mixture certain physical qualities which make the concrete highly resistant to scale. On the basis of the results obtained from the subsequent durability studies associated with the test road, the Michigan State Highway Department now requires that an air entraining material be used on every concrete pavement project. This paper is concerned primarily with the studies and experiences which have led the Department to adopt such a specification with the view of reducing scaling or progressive disintegration to a minimum and thereby increase the economic life of concrete pavements in Michigan.

THE SCALE PROBLEM IN MICHIGAN

One form of concrete deterioration prevelant in Michigan is surface scaling and subsequent disintegration from the surface downward. In 1939 a survey of concrete pavements on state trunk line highways in Michigan revealed that approximately 6.5% of the total pavement surface had scaled in varying degrees as follows: 6.3% light to medium surface scale, and 0.2% heavy scale to progressive disintegration. Typical examples of such scaling types are illustrated in Figure I. 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 unsightliness of scaled areas, the necessary subsequent maintenance and the added possibility of further deterioration is of immediate concern to the highway engineer.

Consequently in 1939, an investigation of scaling, to determine its causes and methods of prevention, was incorporated into the research program of the Michigan State Highway Department as a definite project under the title of "Durability of Concrete". The investigation was dedicated to the establishment of certain fundamental principles in concrete construction and to correlate certain laboratory studies with construction methods in order to develop more durable concrete pavements. To obtain this end, the investigation was divided into two separate studies: first, a laboratory study of concrete durability as related to scaling; and second, the construction of a special pavement for field observations which is widely known as the durability project of the Michigan Test Road.

The laboratory durability study was necessary in order to evaluate the various materials involved in the construction of the durability project, and to determine what effect these materials would have upon the design and physical characteristics of their respective concrete mixtures. Also the laboratory study was used to supplement the field study. Only those phases of the laboratory study intimately associated with the durability project and the subject of this paper will be discussed.

FIELD STUDY - DURABILITY PROJECT - MICHIGAN TEST ROAD

The natural approach to the scaling problem has been to find ways and means of improving the quality of the concrete. In this respect the problem

Figure 1

resolves itself into several phases: first, the acquisition of certain knowledge concerning the phenomenon of scaling; second, the improvement of the quality of the concrete constituents; third, improvement of workmanship as related to the finished product; fourth, the improvement of concrete by changing its character; and fifth, by the application of surface treatments. All of these factors have been considered to some degree in the scope of the research program pertaining to the durability project.

The durability project was constructed to furnish a field laboratory for the purpose of observing, under service conditions, certain important factors relevant to current highway construction practice which might be in some manner associated with scaling, or which might, when properly controlled, increase the resistance of the concrete to scaling. The factors receiving major consideration were proportioning and grading of aggregates with definite recognition of the material passing the 200 mesh; the relative effect of additives, including both physical and chemical varieties; the effect of natural cement blends and cements produced with grinding aids as air entraining materials; and the relationship of finishing operations and curing methods to scaling.

The durability project was constructed in conjunction with a complementary pavement project for the study of concrete pavement design. The two research projects constitute the Michigan Test Road. A map giving the general location of this project (in the State) is shown in Figure 2. The durability project is 7.7 miles in length. 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 project was constructed under regular contract

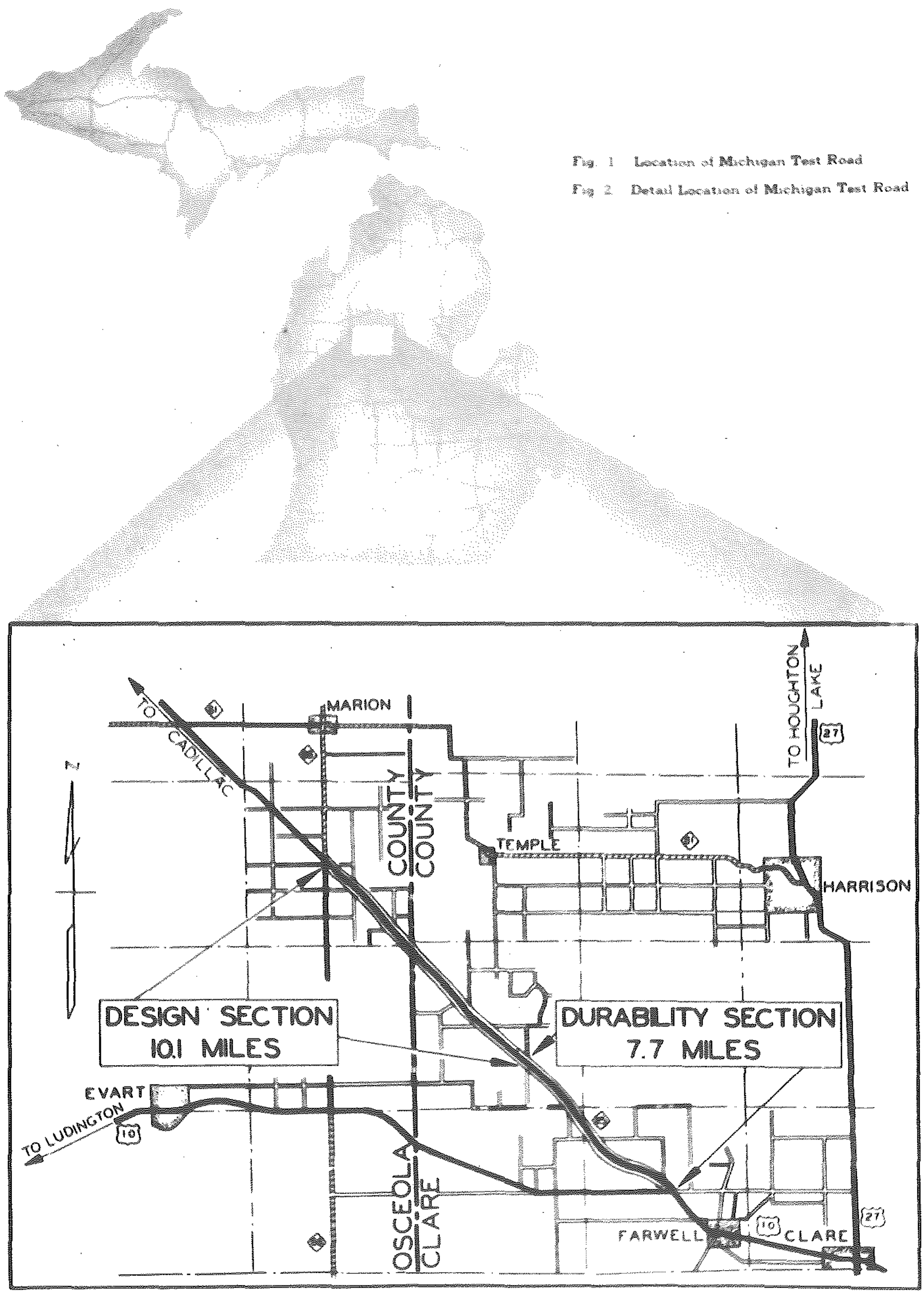

Fig. 1 Location of Michigan Test Road

Fig. 2 Detail Location of Michigan Test Road

Figure 2

and construction procedure using the Michigan State Highway Department's 1940 plans and specifications with necessary supplementals.

The cements used on the durability project included two brands of regular portland cement as normally used in the construction of concrete pavements in Michigan. Admixtures included the use of certain proprietary materials known as Plastiment, Pozzolith, Orvus and Vinsol resin. Natural cement, ground with and without the use of calcium stearate was also included as a blend with standard portland cement. Mineral fillers and natural fines were added in certain instances to increase the density and workability of the mix and as a possible factor in the reduction of scaling. Mix designs included the regular proportioning as determined by the material specifications and the mortar void design method of the Michigan State Highway Department. Short test sections 120 ft. in length were included to determine the relation of scaling to methods of curing.

The research information secured from the durability project may be divided into four groups: first, information obtained during construction; second, observations under service; third, special field accelerated scaling studies; and fourth, laboratory durability studies on field specimens.

<u>Construction Observations and Data</u>: The information procured during this period consisted of the following items:

1. Soil surveys including soil density and moisture content.
2. Meteorological observations.
3. Daily progress report including construction irregularities.
4. Moisture content and temperature of concrete on special sections.
5. Characteristics of concrete during placing.
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 predicted to a certain extent by laboratory tests and observations during construction, but the ultimate conclusions must be determined by observations made under actual service conditions. Therefore, it was planned to make periodic visual examinations, together with measurement of physical conditions, for an indefinite period of time. These observations will include a continuation of the measurement of moisture content, and temperature of slab, but for the most part they will be concentrated upon the comparative extent of surface scaling due to the action of traffic and climatic conditions.

Accelerated Scaling Study: For a period of 3 to 5 years it was planned to study or observe certain sections of the durability project under the action of ice and salts in an accelerated manner. These scaling studies have been completed, at least for the present.

Laboratory Durability Studies: The laboratory program included a microscopic study of scale and its constituents, as well as freezing and thawing of field specimens representing the same concrete mixtures and factors associated with the scaling studies, and in addition, similar freezing and thawing tests on pavement cores removed from the same test areas.

The complete description of the Michigan Test Road as well as certain findings derived from it have been published, (1) (2) (3), it is believed

(1) Michigan Test Road Bulletin, Michigan State Highway Department, July 1942.

(2) Investigational Concrete Pavement in Michigan, by J.W. Kushing, Proceedings of Highway Research Board, Vol. 20, 1940.

(3) General Observations on Concrete Scaling by J.W. Kushing, Roads and Streets, December 1941.

desirable to confine our attention to only those matters directly associated with air entraining materials.

THE EFFECT OF ENTRAINED AIR ON PHYSICAL PROPERTIES OF CONCRETE

Among the many different air entraining materials available for use are included fatty acids, wetting agents, oils and resins. The two air entraining materials which were selected for study on the durability project are a wetting agent called Orvus and a grinding aid of the resinous type commonly known as Vinsol resin.

Orvus is a wetting agent manufactured by the Proctor and Gamble Soap Company for industrial use and it may be procured either in the paste or powder form. It is a sulphated fatty alcohol containing sodium lauryl sulfate as the active ingredient. Sufficient Orvus was added to the mix to produce a drop in weight of 4 to 6 pounds per cubic foot of concrete of the same consistency and cement content without the addition of Orvus. The approximate quantity of Orvus to give this desired drop in weight will be between 0.02 and 0.10 pounds per barrel of cement. This requirement will vary to some extent in accordance with the materials used on any given project. It was found that, for the particular materials used on the durability project, 0.06 pounds of Orvus per barrel of cement gave a reduction in weight of approximately 5 pounds per cubic foot. The Orvus paste was dissolved in warm 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 is a hard, high melting, dark colored resinous material manufactured by the Hercules Powder Company. It is available as a finely ground non-caking powder or in lamellar flakes. Chemically Vinsol resin is an impure abietic acid in powder form. When the acid comes in contact with portland cement and water it forms a calcium salt of abietic acid which has the characteristic properties of soap, and as such, favors the entrainment of air during the mixing of the concrete. Unlike Orvus, Vinsol resin must be added by the cement manufacturer before or during the clinker-grinding operation in order to achieve the proper results. On the durability project two cement manufacturers furnished Vinsol resin portland cement milled from the same clinker respectively as was used in manufacturing standard portland cement for the durability project. The Vinsol resin cement was manufactured under specifications furnished by the Portland Cement Association as follows: - "The cement shall be ground with 0.15 pounds (± 20 percent) of pulverized Vinsol resin per barrel which should be uniformly added to the clinker at time of grinding. The specific surface of the cement as determined in accordance with A.S.T.M. C 115-38T shall not be less than 1750 nor more than 2100 square centimeters per gram". Measurements of drop in weight in the field showed that this specification gave the proper weight drop of approximately 5 pounds per cubic foot for the materials used on the project.

Physical Characteristics of Plastic Concrete:

The concrete mixtures resulting from the use of either of the two air entraining materials (Orvus and Vinsol resin) were very similar in their physical characteristics during the plastic state. The workability of the concrete with entrained air was decidedly better than that of normal portland cement concrete. Practically no segregation or bleeding was experienced. Straight edging and floating of the plastic concrete containing entrained air was slightly more difficult than the standard portland cement concrete because it has an inherent characteristic of becoming somewhat sticky. The concrete mixture with entrained air has the appearance of being fatty or over sanded. It was also noted that its finishing characteristics were influenced somewhat by extreme fluctuations in temperature and relative humidity at time of pouring.

Strength Characteristics of Aged Concrete:

During the construction of the durability project 6"x12" compression cylinders and 6"x8"x24" beam specimens were prepared for subsequent strength tests in order to determine the effect of the various admixtures on the strength characteristics of the concrete. Average results from these tests are shown in Table I. The strength values are also compared on a percent basis with those of the concrete made with standard portland cement No. 1. This particular brand of cement was used as a reference throughout the project.

The data in Table I show a decided drop in strength characteristic of the concrete containing air entraining materials, as compared to normal portland cement concrete. The Vinsol resin cement on an average gave better strength characteristics than the Orvus material. Yet with but one exception the flexural strength of the concrete containing Orvus or Vinsol resin was below specification requirements by a considerable amount. This marked difference in strength values may be attributed to the high air content required in the concrete and to the inability of the engineer to consistently control within definite limits such factors as water content, uniform gradation and workmanship throughout the construction of the project.

TABLE I

SUMMARY OF CONCRETE STRENGTH DATA

Material	Cement	COMPRESSION STRENGTH: 6"x12" Cylinders, 7 Days, p.s.i.	% Var.*	6"x12" Cylinders, 28 Days, p.s.i.	% Var.*	Cores 6", 20 Months, p.s.i.	% Var.*	FLEXURAL STRENGTH**: Beams 6"x8"x24", 7 Days, Mod.of Rup. p.s.i.	% Var.*	Beams 6"x8"x24", 28 Days, Mod.of Rup. p.s.i.	% Var.*
Orvus	1	2608	74	3728	81	3962	74	389	69	562	80
Orvus	2	2324	66	3857	84	3820	71	425	75	602	86
Vinsol Resin	1	2845	80	3867	84	4010	75	508	89	529	75
Vinsol Resin	2	3580	101	3991	87	5420	101	576	102	771	110
Standard	1	3543	100	4587	100	5375	100	567	100	702	100
Standard	2	2837	80	4597	100	6600	123	546	96	659	94
Specification Strength				2500				550		650	

* Percent Variations Based on Standard Cement No. 1

** By Three Point Loading Method A.S.T.M. Designation C 78-39

In order to further evaluate the merits of the air entraining materials incorporated in the test road and to judge the relative performance of the resultant concrete in service, certain durability studies were made, including accelerated scaling tests on the slab surface and the freezing and thawing of field specimens as well as core segments.

Accelerated Scaling Studies:

The accelerated scaling studies consisted of exposing test panels of the pavement surface on the durability project to the action of ice and calcium chloride under controlled conditions.

The first and second of the series of scaling studies were completed during the winter months of 1940-1941 and 1941-1942 respectively.

Originally two test methods were employed to ascertain the resistance of concrete pavement mixtures to calcium chloride attack. The methods have been designated as methods "A" and "B". Method "A" was discontinued after the first year's study because it was found that method "B" gave more accelerated results and was better adapted to control procedure. In test method "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, the slush was removed from the test area, the surface was flushed and allowed to rest one day before beginning the next cycle.

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, the slush 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 approximately a 10 percent solution.

Each test area was constructed 3 feet wide and 12 feet long. A dyke was formed around the perimeter of this area of sufficient height to confine the water and calcium chloride solutions. The test panels are illustrated in Figure 3.

At the end of each freezing and thawing cycle the amount of scale developed during the cycle was determined by superimposing over the test area a steel mesh grid with openings 12 inches square. By means of the grid the amount of scaled surface could be measured quickly and accurately.

During the first series of scaling studies in 1940-1941, two test panels were established for each factor studied. One test panel was subjected to test method "A" and the other to test method "B". In the second season's studies conducted in 1941-1942, test method "B" was repeated only on the test areas pertaining to those certain factors under comparative study where it seemed advisable to repeat the scaling observations for two reasons: first, to verify or check the results of the first season's observations; and second, to correlate the age factor with the resistance of the concrete to scaling. Scaling tests were discontinued on those sections under observation which showed abnormal tendencies toward scaling during the first season's tests, and on other sections which were believed to be of insignificant value to the research program.

The most significant fact brought out by the accelerated scaling studies was that the air entraining materials, Orvus and Vinsol resin, produced a concrete which was highly resistant to scale. This fact is clearly shown by the data presented in Table II. Figure 3 contains illustrations of the relative condition of the different pavement surfaces after a definite number of freezing and thawing cycles.

<u>Freezing and Thawing of Field Specimens</u>:

During construction of the durability project representative samples of concrete were molded into 3"x6"x15" beams for further examination in conjunction with the scaling studies. The beams were subsequently subjected to accelerated freezing and thawing tests to determine their relative resistance to disintegration by freezing and thawing action. The progressive deterioration of each specimen was measured by change in value of Young's modulus found by the sonic or dynamic method. The information sought was concerned primarily with the effect of the air entraining materials on the durability characteristics of the concrete, as compared with standard construction.

<u>Method of Exposure to Freezing and Thawing</u>: The specimens were placed in specially designed rubber containers having a wall thickness of 3/16 inches. Sufficient water was added to the containers to cover the specimens to a depth of 1/4 inch. The ratio of water in the container to the amount of concrete by weight was approximately 0.11. The number of containers in any one freezing compartment and the quantity of liquid in the freezing

TABLE II

COMPARATIVE RESULTS FROM SCALING STUDIES

Year		1940-1941		1941-1942	
Material	Cement	Cycle	% Scale	Cycle	% Scale
Orvus	1	33	0	* 93	0
Orvus	2	33	0	* 94	0
Vinsol Resin	1	33	0	* 93	0
Vinsol Resin	2	33	0	* 94	0
Standard	1	33	61	41	100
Standard	1	13	100	9	100
Standard	2	21	100	32	100
Standard	2	27	56	7	100

* 1942 studies continuation of studies on 1941 panels.

bath were adjusted so that, when the compartment was fully charged, the level of the freezing liquid was approximately equal to that of the water in the containers.

The freezing liquid was glycerin diluted with water. The rubber containers were placed in the freezing compartment in such a manner that all sides of the containers were in contact with the freezing liquid and that circulation of the liquid would not be impeded. A charge in each of two freezing compartments consisted of approximately 18 beams. Such a charge constituted about 75% of full load capacity of the freezing unit. The specimens in the refrigerator unit are illustrated in Figure 4.

The freezing unit was usually charged during the afternoon of one day, allowing the specimens to freeze over night, and then removed the next morning for the thawing period. This procedure constituted a freezing and thawing cycle of 24 hours duration.

At the beginning of the freezing cycle, the temperature of the freezing liquid was -20° ±2°F rising to a maximum temperature of + 20°F under full load. The temperature upon removal of the specimens was approximately -10°F.

At the end of the freezing period, the containers with the frozen specimens were removed from the refrigerator and placed in a water bath at a temperature of 90°F to 100°F until the ice around the specimens was completely melted. The water was then drained from the containers, the specimens turned end for end in the containers, and fresh tap water at a temperature of approximately 80°F added to the containers to proper level after which the specimens were allowed to reach equilibrium in air at a room temperature of approximately 75°F. The total time required for complete thawing was approximately 6 hours.

The results from the freezing and thawing tests on the field specimens as presented in Table III indicate quite definitely that the air entraining materials Orvus and Vinsol resin imparted to their respective concretes the ability to resist disintegration by freezing and thawing action to a greater degree than that possessed by standard concrete mixtures.

Freezing and Thawing of Core Specimens:

A comparative durability study of core samples representing the various concrete mixtures embodied in the durability project was made in conjunction with the accelerated scaling studies and the laboratory freezing and thawing tests on molded field specimens. In conducting the core study three objectives were in mind: first, to gather additional data of value in evaluating the factors under consideration in the durability project; second, to observe the relative durability between the top and bottom of the pavement slab; and third, to determine the comparative merits of freezing and thawing concrete in a calcium chloride solution as compared to freezing and thawing in tap water.

The cores were removed from the pavement slab 4 months after completing pouring operations on the durability project, incidental to the Department's routine core check procedure for ascertaining the thickness of the pavement slab. Because of the large number of test areas involved in the study only one core from each test section was selected to represent the concrete in freezing and thawing. Companion cores from the same test areas were used to check pavement thickness and to determine the compressive strength of the concrete. At the time of conducting the tests on the core specimens the concrete had attained an age of 21 months.

TABLE III

COMPARISON OF RESULTS FROM FREEZING AND THAWING STUDY

Material	Brand Cement	Spec. No.	CYCLES OF FREEZING AND THAWING			
			Age 5 Months		Age 1 Year	
			50% Red. in Mod.	100% Red. in Mod.	50% Red. in Mod.	100% Red. in Mod.
Orvus	1	3	43	80	40	90
Orvus	2	4	30	62	30	100
Vinsol Resin	1	2	45	80	--	---
Vinsol Resin	2	4	47	75	25	80
Standard	1	2	30	60	20	85
Standard	2	4	32	55	15	75

Each core used in the durability study was cut transversely into three sections approximately 2 inches thick representing the top, middle and bottom portion of the pavement. The top and bottom sections were further divided into two equal segments. One segment from the top and bottom of each core was reserved for freezing and thawing in a 10 percent solution of calcium chloride. The remaining segments from the same cores were frozen and thawed in tap water for comparison with the calcium chloride treatment. The middle section of each core was retained for absorption and permeability tests.

Freezing and Thawing Tests: In conducting the freezing and thawing tests on the core segments, the same freezing and thawing cycle and equipment, as employed for the sonic beam specimens and previously described, were used. The specimens frozen and thawed in the 10 percent calcium chloride solution were kept in the solution during the entire freezing and thawing cycle. The calcium chloride solution was checked for concentration after each five cycles and thoroughly agitated at the beginning of each freezing period.

At the end of each five or ten cycles of freezing and thawing, the specimens were removed from the rubber containers, wiped off and visually examined. The specimens were examined in particular for indications of scale development on their surfaces and failure of bond between mortar and aggregate. The visual inspection was supplemented by noting the sound or ring given forth when the specimen was struck lightly with a hammer. The test was continued to the point where the specimen had totally disintegrated as evidenced by complete crumbling of mortar or when the concrete could be easily broken apart by light tapping with a hammer.

The cycles of freezing and thawing necessary to obtain complete disintegration for each concrete segment have been summarized in Table IV.

The results in Table IV are further proof indicative of the superiority of concrete with entrained air to resist deterioration by freezing and thawing action as compared with concrete without the entrained air.

Another significant fact indicated by the data is that with but few exceptions, the concrete segments representing the top of the pavement were less durable than those representative of the bottom of the pavement. This is true for either method of freezing and thawing. However, the variation in durability of the top and bottom segments from the mixtures containing Orvus or Vinsol resin was considerably less than in the case of standard concrete.

In general, the data also indicate that the relative durability of the various concrete mixtures was not affected by the method of test. Only the rate of deterioration was changed.

CONSTRUCTION PROCEDURE WITH AIR ENTRAINING MATERIALS

On the basis of the encouraging results obtained from the durability studies associated with the test road, the Department authorized in 1941 the construction of 6 concrete pavement projects containing Orvus as the air entraining material. At that time Vinsol resin portland cement was not readily available for pavement construction. The 6 projects totaled approximately 18.5 miles in length.

The first of the six projects constructed in 1941 was of an experimental nature involving the use of Orvus with limestone aggregates, both fine and coarse. In the past Michigan had experienced considerable scaling

TABLE IV

COMPARATIVE RESULTS FROM CORE STUDY

Material	Brand of Cement	CYCLES FOR DISINTEGRATION					
		10% Calcium Chloride			Water		
		Top	Bottom	% Var.	Top	Bottom	% Var.
Orvus	1	140	206	- 32	205	205	0
Orvus	2	55	130	- 58	110	200	- 45
Vinsol Resin	1	145	186	- 22	175	170	+ 3
Vinsol Resin	1	185	165	+ 13	200	200	0
Vinsol Resin	2	130	165	- 21	205	200	+ 3
Vinsol Resin	2	130	145	- 10	215	200	+ 8
Standard	1	45	65	- 31	120	135	- 11
Standard	1	35	78	- 55	120	195	- 38
Standard	2	50	35	+ 43	80	110	- 27
Standard	2	45	70	- 36	70	135	- 48

from these materials. The Orvus admixture seemed to reduce the harshness of the concrete mixture, improved its workability, eliminated bleeding, and no scaling was obtained from subsequent accelerated scaling tests similar to those conducted on the test road.

From 1941 until the present time, there have been constructed approximately 75 miles of concrete pavements containing Orvus. During the summer of 1943 specifications for Vinsol resin portland cement were officially recognized by the American Society of Testing Materials and by the Federal Government. Consequently the various cement manufacturers prepared themselves to furnish Vinsol resin cement for highway construction upon request. There are now under construction approximately 20 miles of such pavements. Some of the reasons for the preference of Vinsol resin portland cement are:

1. The Orvus material plus labor cost to handle it is an item of expense to the contractor, whereas Vinsol resin portland cement is furnished to the contractor at the same cost as standard portland cement.
2. On account of the personnel influence in the method of handling Orvus there was encountered some difficulty in obtaining uniform mixtures.
3. Recently it was noted that the Orvus material appeared to vary in quality from time to time which influenced to a certain extent the yield and air content of the mixture.
4. In cold weather hot water is necessary to dissolve the Orvus and keep it in a fluid state.

On the project, Orvus was dissolved in water to produce a solution of known concentration so that a one quart measure of solution per batch of materials would contain the proper amount of Orvus to produce the required drop in weight. The Orvus solution was added at the skip but in some cases permission was granted to add it at the batching plant.

Concrete Mix Design with Air Entraining Materials:

In designing the concrete mixture to contain an air entraining material the following procedure is generally followed. The proportions for a standard portland cement mixture are determined under the Department's regular procedure using the mortar void method and employing a consistency of 1 1/2 to 2 1/2" slump. The relative water content is then reduced to maintain the same slump when a certain quantity of air entraining material is used. In the case of Orvus, .02 to .10 pounds per barrel of cement has been found to work satisfactorily for Michigan's aggregates, while for Vinsol resin cement we find that 0.15 ± 20% pounds per barrel of cement is giving desired results. The drop in weight per cubic foot of concrete is held between 3 and 6 pounds.

In the field, the proper air content in the mixture is determined by checking the yield. Any discrepancy between actual weight and design weight per cubic foot is corrected by adjusting the amount of Orvus added, or in some cases the Orvus content has remained fixed and the quantity of sand changed. In the case of Vinsol resin cement the only adjustment possible will be in the quantity of sand per batch.

Certain construction procedures must be closely observed in order to obtain maximum benefit from the use of air entraining materials. In the first place it is important that the water content be controlled to very narrow limits. The water content of the mixture greatly influences the amount of entrained air which can be incorporated into the concrete. Also the mixing time should not exceed the normal time of approximately 1 minute. Prolonged mixing may cause excessive air entrainment.

The use of Vinsol resin cement requires special attention as to its handling at the batching plant, especially so when furnished in bulk form. Because it flows more freely than standard portland cement there can be considerable loss in handling at the plant or during the transportation of materials in the batch trucks. It has been found desirable to place the cement between layers of aggregates in the batch truck to prevent such losses. When it is necessary to add calcium chloride to the concrete containing Orvus during periods of low temperatures the setting properties of the concrete, as influenced by the presence of the calcium chloride, are not materially changed provided the amounts of water and Orvus are maintained at their proper values.

Since the use of air entraining admixtures materially shortens the time interval between placing and finishing, the concrete mixer now becomes the controlling factor in production instead of the finisher, as in the case of plain concrete mixers.

SUMMARY

The data discussed in this report concerning the experiences of the Department in the use of air entraining materials as associated with the Michigan Test Road and the laboratory studies on concrete durability indicate the superior qualities of concrete containing a certain amount of entrained air over that of standard portland cement concrete. Concrete containing entrained air within definite limits possesses remarkable resistance to surface scaling, as well as unusual resistance to disintegration due to freezing and thawing action.

Concrete with entrained air also possesses during the plastic state, better workability than normal concrete and practically no segregation or bleeding are experienced. However, its finishing characteristics are somewhat influenced by extreme fluctuations in air temperature and relative humidity. Also, there is a tendency for the concrete to become sticky and thus cause trouble during straight edging and floating operations. These difficulties may be overcome to a certain extent by proper manipulation of material quantities and finishing operations.

At the present time it is an inherent property of concrete with entrained air to have lower compression and flexural strengths than normal concrete. This reduction in strength, under properly controlled conditions, is not considered a serious factor in highway construction because in general concrete strengths usually exceed design requirements. It is believed that this condition will be minimized in the future by the proper adjustment of present concrete design methods to include air entraining materials.

An air entraining material ground into the portland cement at the mill is preferred over adding air entraining materials at the mixer for several reasons, the most important of which is that it eliminates the personal influence at the mixer resulting in a saving in operation costs and providing some assurance that the mixture may be more uniform in quality.

Certain construction procedures must be closely observed in order to obtain maximum benefit from air entraining materials especially with respect to water content and time of mixing.

It is generally acknowledged that the use of air entraining materials in concrete pavement construction is a distinct step forward in the development of better highways for the future and indicates the successful solution of just one of the many problems confronting the highway engineer today. The Department, recognizing the advantages to be gained by this new development, now requires that air entraining materials be used on every new concrete pavement project in Michigan constructed under its jurisdiction.