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Examining portland cement concrete slabs for scaling action

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Factors Affecting Resistance of Portland Cement Concrete to Scaling Action of Thawing Agents

BY THE PHYSICAL RESEARCH BRANCH
BUREAU OF PUBLIC ROADS

Reported by ALBERT G. TIMMS, Supervising Highway Physical Research Engineer

This report is a resume to date of investigations conducted to test materials and procedures for protecting concrete pavements against scaling and disintegration caused by calcium chloride and other thawing agents used for ice removal. A laboratory investigation by the Bureau of Public Roads was started in 1948 on methods of protecting the wearing surface of concrete against the action of calcium chloride. Later a similar study was made of the effect of outdoor weather conditions on small slabs placed on the ground. It was found that resistance to scaling was affected by air content, type of air-entraining admixture, surface treatments or coats, admixtures of oils, inhibitors, fly ash as a replacement for portland cement, rate of application of calcium chloride, curing methods, thawing agents other than calcium chloride or common salt, and by the vacuum method of placing concrete.

DURING the winter months when ice has formed on pavements and bridge decks, sodium chloride or calcium chloride or mixtures of the two are spread on surfaces to thaw the ice and make the riding surface safe for traffic. This practice has been common in many parts of the country for 25 years or more. The continued use of these salts, usually spread in flake, pellet, or crystal form, has frequently resulted in excessive scaling of the wearing surface of portland cement concrete. In some cases the action has been so severe as to cause complete disintegration.

In States where ice covers the pavements many times each winter, the problem of ice removal by chemicals and the attendant scaling and disintegration of the concrete is a serious one. Since sodium and calcium chlorides are very effective for melting ice, there is great interest in developing methods of making concrete resistant to their action. In New York, particularly, and in several of the other Northeastern States, climatic conditions, hilly terrain, and heavy traffic have intensified this problem of developing a concrete resistant to the scaling caused by chloride salts.

The Bureau of Public Roads began a laboratory investigation in 1948 of methods of protecting the wearing surface of concrete against the action of calcium chloride. Later because of the extreme severity of the laboratory test which caused doubt as to its similarity to field conditions, a similar study was made under outdoor weather conditions on small concrete slabs on the ground. This is a progress report of a continuing research program and has been prepared to summarize the information obtained on the laboratory tests and the outdoor exposure tests through the winters of 1951–52, 1952–53, and 1953–54.

Scope of Study

The laboratory investigation of scaling resistance was divided into five parts as follows:

1. The effect of increasing the air content of the fresh concrete beyond the 6 percent maximum limit now generally permitted in specifications for concrete for pavement construction was investigated.

2. The effect of delaying the scaling action by surface coatings of crankcase oil (undiluted and diluted) with various percentages of gasoline, and the effect of time of application of the oils were studied.

3. The effect on scaling action of using paraffin and asphaltic base lubricating oils (both new and used) as admixtures in concrete was studied, and also the effect of these materials on strength, shrinkage, and resistance to freezing and thawing in water.

4. An investigation was made of the following miscellaneous factors: Effect of using various amounts of calcium chloride applied to a given area for ice removal, of using a possible rust inhibitor mixed with calcium chloride, and of using urea for ice removal in place of calcium chloride.

5. A study of the improvement in the quality of the wearing surface produced by vacuum treatment of the concrete was undertaken.

The outdoor investigation to date covers tests over three winters. The variable studied during the first winter was type of air-entraining admixture. Twenty-seven commercial air-entraining admixtures were used in amounts that produced about the same air content in each of the concrete slabs. During the second and third winters the outdoor program was divided into four parts:

1. Tests made the first winter were repeated with most of the 27 air-entraining admixtures, but using two cements (brand A with high alkali content and brand B with low alkali content). Five more air-entraining admixtures were included which had been received too late for the first series. These concrete slabs were cast in molds both on a metal base and on a sand base.

2. The effect on the resistance to scaling of replacing part of the portland cement with fly ash was studied. A fine and coarse fly ash from each of two sources were used because previous experience indicated that the finer the fly ash from a given source the lower the carbon content. Two concretes, plain and air-entrained were used for each fly ash replacement, with each of the two different cements (brands A and B).

3. The effect of methods of curing the concrete on resistance to chloride attack was investigated. In connection with the curing study, surface applications of oil were also made following the curing period.

4. The effect of vacuum treating the surfaces of both plain and air-entrained concrete was studied.

Conclusions

The principal conclusions of the laboratory tests (artificial freezing) were as follows:

1. A scaling test which involved freezing of water on the surface of concrete test slabs and thawing with an application of flake calcium chloride showed that the resistance of the concrete was a function of the amount of entrained air. An air content in excess of 6 percent was more effective in making concrete resistant to the scaling action of calcium chloride than increasing the cement content.

2. Concrete which was cured and seasoned and then coated with mineral oil showed greater resistance to calcium chloride attack than similarly cured concrete which received no protective treatment. Multiple coats of oil were slightly more beneficial than a single coat of oil. Application of oil to freshly placed concrete decreased the resistance to scaling.

Table 1.—Chemical composition and physical properties of portland cements and fly ashes

	Portland cement		Fly ash			
	A	B	A	B	X	Y
Chemical composition (in percent):						
Silicon dioxide	22.0	22.3	47.1	49.2	41.2	38.5
Aluminum oxide	5.6	5.4	18.2	19.9	22.1	23.5
Ferric oxide	2.5	2.4	19.2	16.2	20.6	18.8
Calcium oxide	62.8	66.1	7.0	5.5	6.0	3.2
Magnesium oxide	3.0	1.0	1.1	1.4	1.2	1.0
Sulfur trioxide	2.0	1.7	2.8	2.7	.9	.6
Loss on ignition	.8	1.2	[1] 1.2	[1] 1.2	[1] 5.4	[1] 11.6
Sodium oxide	.40	.04	1.80	2.00	1.00	.60
Potassium oxide	1.05	.15	2.15	2.35	1.42	1.88
Total equivalent alkalies as Na_2O	1.09	.14	3.21	3.55	1.93	1.84
Insoluble residue	.16	.12	------	------	------	------
Chloroform-soluble organic substances	.009	.003	------	------	------	------
Free calcium oxide	.85	.56	------	------	------	------
Water-soluble alkali:						
Na_2O	.11	.01	------	------	------	------
K_2O	.63	.02	------	------	------	------
Computed compound composition (in percent):						
Tricalcium silicate	42	55	------	------	------	------
Dicalcium silicate	31	22	------	------	------	------
Tricalcium aluminate	11	10	------	------	------	------
Tetracalcium aluminoferrite	8	7	------	------	------	------
Calcium sulfate	3.4	2.9	------	------	------	------
Carbon	------	------	.2	.6	5.0	11.2
Carbon dioxide	------	------	.01	.04	.04	.03
Physical properties:						
Apparent specific gravity	3.20	3.17	2.49	2.52	2.51	2.43
Specific surface (Wagner) cm.²/g.	1,800	1,625	------	------	------	------
Specific surface (Blaine) cm.²/g.	------	------	3,075	4,305	2,565	3,220
Autoclave expansion percent	.32	.04	------	------	------	------
Normal consistency do	25.5	25.0	------	------	------	------
Time of setting (Gillmore test):						
Initial hours	3.2	4.2	------	------	------	------
Final do	5.2	6.4	------	------	------	------
Compressive strength (1:2.75 mortar):						
At 7 days p.s.i.	2,340	2,960	------	------	------	------
At 28 days do	3,670	5,070	------	------	------	------
Mortar air content percent	9.1	6.8	------	------	------	------

[1] Determination made at 600° C.

3. Neither paraffin nor asphaltic base oil used as admixtures were of much value in either delaying or controlling the progress of scaling. Used crankcase lubricating oil was effective in retarding the start of scaling, because of the air entrained in the fresh concrete by this material.

The use of one-third or two-thirds of a gallon of paraffin or asphaltic base oil per sack of cement as an admixture had no effect on the air entrained in the concrete. A slight reduction in shrinkage and in strength and a slight improvement in durability as measured by resistance to freezing and thawing in water resulted from the use of these oils.

The use of one-third or two-thirds of a gallon of used crankcase lubricating oil per sack of cement entrained air in the concrete. Concretes containing these admixtures showed a reduction in strength and an improvement in durability proportional to the amount of air entrained. The shrinkage of the concrete containing crankcase oil was about the same as the concrete without admixture.

4. Urea, reported to be a thawing agent non-corrosive to metals when used to thaw ice on concrete, was slower in thawing action than calcium chloride. It also caused scaling but not so quickly as calcium chloride.

Varying the amount of the thawing agent (calcium chloride or urea) had little effect either on the start or rate of progress of the scaling. The use of a metal corrosion inhibitor had only a slight retarding action on scaling of concrete when used with calcium chloride for ice removal.

5. Concretes containing 6 or 7 sacks of cement per cubic yard, both plain and air-entrained, were benefited in their resistance to scaling by the use of the vacuum treatment of the plastic concrete.

The principal conclusions of the outdoor exposure tests were as follows:

1. All the air-entraining admixtures tested in concrete were effective in delaying the start of serious scaling. As indicated by the preliminary tests of the first winter, the synthetic detergents and the salts of proteinaceous materials were less effective than the admixtures in the other groups. In the subsequent tests made the next two winters, the synthetic detergents were relatively more effective than they were in the preliminary tests. For the concrete containing aggregates with a 1-inch maximum size, the tests indicate that more satisfactory resistance is obtained when the air content is greater than 5 percent.

2. For the variables studied, the scaling of concrete was less pronounced when the concrete had been cast in a mold with a sand base than when cast in a mold with a metal base. The water retention of the concrete cast on the sand base is less than that cast on a metal base. The resulting decrease in the water-cement ratio accounts for the difference in resistance to scaling.

3. The two portland cements used did not produce concretes of equal resistance. The concretes made with cement B (low alkali content) were more resistant than the concretes made with cement A (relatively high alkali content). The different treatments of the concretes did not appear to change this relative difference between the cements in resistance to scaling.

4. Replacing portland cement in the mix with fly ash, regardless of the fineness or carbon content, was detrimental to the resistance of the concretes to attack by calcium chloride used for ice removal. Maintaining

Table 2.—Mix data for laboratory slabs, 6 by 12 by 2 inches thick [1]

Mix by dry weight	Admixture		Cement	Water	Slump	Air	Weight of plastic concrete
	Amount[2]	Type					
Part 1: Effect of Air Content							
Pounds			*Sack/cu. yd.*	*Gal./sack*	*Inches*	*Percent*	*Lb./cu. ft.*
94-210-320	----------	None	6.0	5.7	2.3	1.5	149.0
94-200-320	0.004	Vinsol resin	6.0	5.4	2.4	2.7	148.0
94-180-320	0.011	do	6.1	5.1	2.6	6.0	143.7
94-160-320	0.025	do	5.9	4.7	3.2	13.0	131.6
94-170-270	----------	None	7.0	4.8	2.6	1.5	149.3
94-155-270	0.005	Vinsol resin	7.2	4.5	2.4	2.7	148.9
94-140-270	0.011	do	7.2	4.2	2.2	4.9	143.8
94-130-270	0.022	do	7.1	4.1	2.2	7.2	139.6
Part 2: Effect of Oil Surface Treatment							
94-210-320	----------	None	5.9	6.1	3.5	1.9	147.3
Part 3: Effect of Oil Admixtures							
94-210-320	----------	None	5.9	6.1	3.0	2.0	146.6
94-170-320	⅔gal	Used crankcase oil	6.0	5.4	4.8	5.7	140.0
94-200-320	⅓gal	Paraffin oil	5.9	5.7	4.0	2.0	146.3
94-200-320	⅓gal	Asphalt oil	5.9	5.7	3.5	2.4	145.3
Part 4: Effect of Thawing Agent							
94-210-320	----------	None	5.9	6.1	3.5	1.9	147.3
Part 5: Effect of Vacuum Surface Treatment							
94-210-320	----------	None	6.0	5.7	----------	1.7	148.6
94-160-320	0.020	Vinsol resin	6.2	4.7	----------	7.4	141.1
94-170-270	----------	None	7.0	4.8	----------	1.7	148.6
94-130-270	0.022	Vinsol resin	7.1	4.1	----------	7.8	139.3

[1] Materials used: cement, brand A; siliceous sand, F.M. =2.70; siliceous gravel, ¾-inch maximum size.
[2] Per sack of cement. Except for oil admixtures, amounts are expressed as percent by weight of cement.

Figure 1.—Rating scale (0–10) of resistance of concrete to scaling after laboratory freezing and thawing with calcium chloride.

fixed air entrainment within the usual ›ecification limits did not balance the lowered ›sistance caused by the use of fly ash.

5. In general, the type of curing had little pparent effect on the resistance of the con- retes to calcium chloride attack. The mem- rane curing, when the film remained un- roken, had some protective action. Under raffic conditions such a film would probably e of little or no value.

6. The concrete cast in molds with metal ases and subjected to a vacuum treatment 'as little different in resistance to scaling om similarly cast untreated concrete. How- ver, when the concretes were cast in molds 'ith sand bases the concrete on which the acuum treatment was used was more resist- nt to scaling than the untreated concrete. 'his same relationship held for concrete with ir contents ranging from 1 to 10 percent.

Laboratory Exposure Series

The portland cement used was an ASTM 'ype I cement. It is designated as brand A ement and is the same cement as brand A sed in the outdoor investigation. Table 1 ives the chemical composition and physical roperties of the cement.

The aggregates used for all concrete mixes or the scaling tests consisted of a siliceous and having a fineness modulus of 2.70 and a vell-graded siliceous gravel of ¾-inch max- mum size. For the test specimens used for letermining strength, resistance to freezing nd thawing in water and volume change, rushed limestone was used as coarse aggre- ate. Concretes made from similar aggre- ates have good service records for durability. The concrete mix data are given in table 2.

The specimens used in the laboratory scaling est consisted of concrete slabs having a vearing surface of 6 by 12 inches and a thick- ness of 2 inches. The slabs were cast and the oncrete rodded and spaded in the usual nanner. In one group of slabs a vacuum treatment was applied to the plastic concrete after casting.

Approximately 3 hours after molding, the top surface of each specimen was given a broomed finish to simulate the surface finish frequently given pavement slabs. Subsequent to brooming a mortar dam approximately one-half inch in height was cast around the perimeter of the specimen. In general, the concrete was cured in moist air, the bottoms and sides of the specimens were waterproofed with a heavy coating of paraffin, and then stored in the air of the laboratory before starting the freezing and thawing cycle. The exact period of curing is shown in the notes of tables 3–6 and 12–13.

The top surfaces of the slabs were first flooded with one-quarter inch of water, after which the specimens were placed in the freezer and the surrounding air temperature reduced to −10° F. The slabs were kept in the freezer approximately 15 hours, then removed from the freezer, and flake calcium chloride applied directly to the ice-covered surface. In general, the amount of calcium chloride applied was 2.4 pounds per square yard of ice-encrusted surface. This is the maximum amount usually applied in practice and is the amount used by other investigators. In one group of tests different amounts of calcium chloride were applied per square yard. After the ice had thawed, the calcium chloride solution was washed from the surface of the slabs, fresh water applied and the cycle repeated. One cycle was completed each 24 hours from Monday through Friday. The slabs remained in the freezer from Friday night until Monday morning.

In general, three slabs were made for each condition and two or more rounds of slabs made on different days for each condition of test. Only one round of slabs was photographed and since the rounds in general checked each other very closely the results of only one round are reported.

The various slabs were rated periodically for surface scale. The ratings were based on visual observation of the extent and depth of scale. The following tabulation describes the numerical significance of the rating:

0—No scale
1—Scattered spots of very light scale
2—Scattered spots of light scale
3—Light scale over about one-half of the surface
4—Light scale over most of surface
5—Light scale over most of surface, few moderately deep spots
6—Scattered spots of moderately deep scale
7—Moderately deep scale over one-half of the surface
8—Moderately deep scale over entire surface
9—Scattered spots of deep scale, otherwise moderate scale
10—Deep scale over entire surface

Typical examples of the various ratings are shown in figure 1, and figure 2 illustrates progressive scaling of three identical slabs as the number of cycles of freezing and removal of ice with calcium chloride was increased.

Outdoor Exposure Series

The portland cements used were ASTM Type I cements. Two cements were used, brand A and brand B. Brand A had a relatively high alkali content and brand B a very low alkali content. Table 1 gives the chemical and physical properties of the cements.

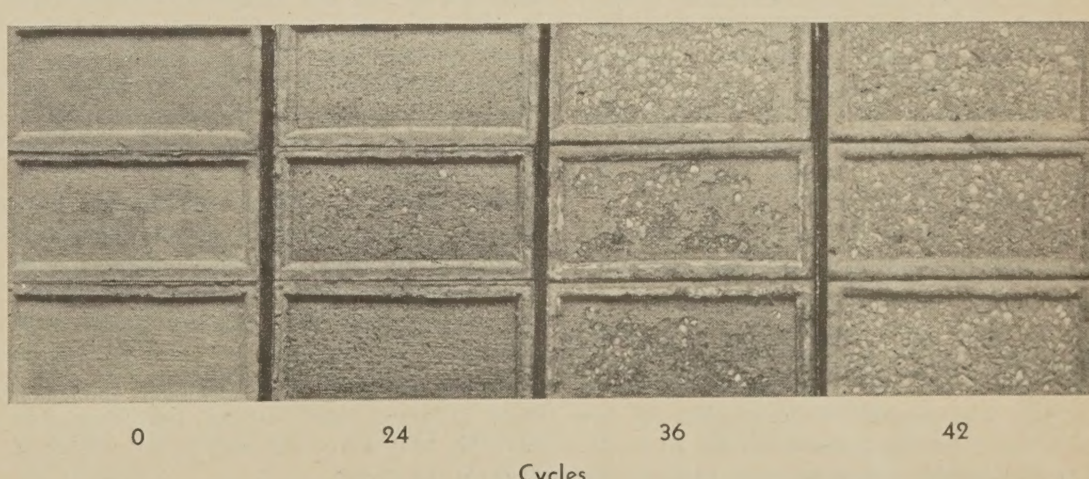


Figure 2.—Progressive scaling of non-air-entrained concrete after indicated cycles of laboratory freezing and thawing with calcium chloride.

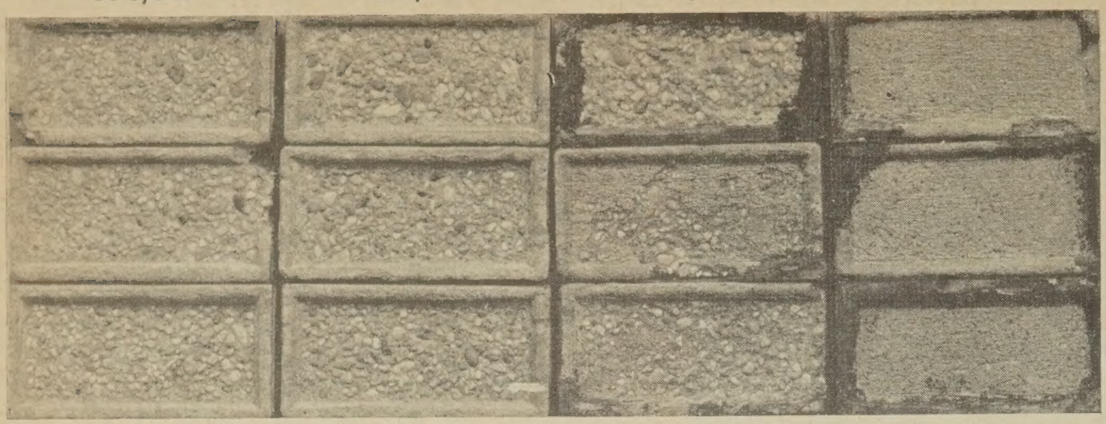


Figure 3.—Effect of percentage of entrained air on resistance of concrete to scaling after laboratory freezing and thawing with calcium chloride.

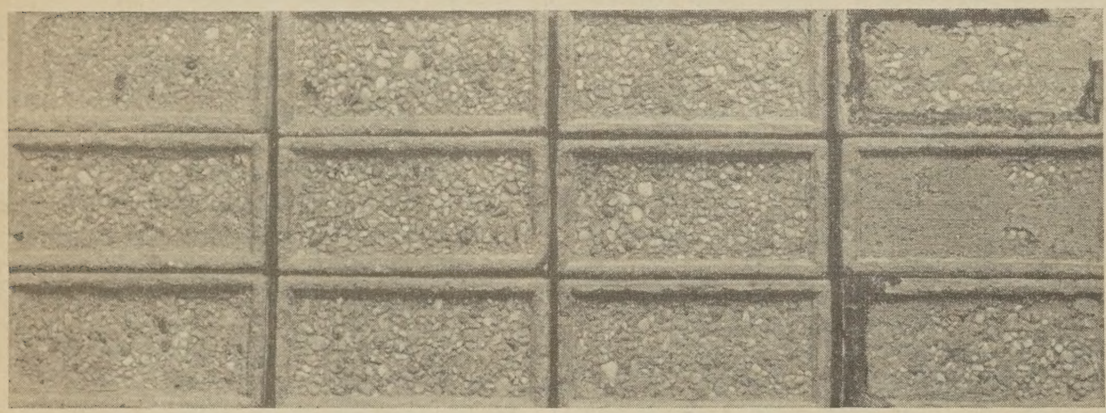


Figure 4.—Effect of percentage of entrained air on resistance of concrete to scaling after laboratory freezing and thawing with calcium chloride.

The aggregates used for all mixes consisted of a siliceous sand having a fineness modulus of 2.70 and a crushed limestone coarse aggregate of 1-inch maximum size. Concretes containing these aggregates have a good service record for durability.

The rapidity with which scaling started on the small slabs frozen in the laboratory freezer, suggested the possibility that the conditions were far more severe than those occurring under field applications of calcium chloride. In order to study this feature further, slabs 16 by 24 by 4 inches deep with raised edges or dams around the perimeters were made for outdoor exposure.

The surfaces of the slabs were given a broomed finish and most of them were then cured in the moist room from 28 to 90 days and then placed in the exposure area. The specimens were in the exposure area from 30 to 100 days before the first application of calcium chloride was made. A description of the treatment is in the notes to tables 15 to 21. Broomed finishing was selected because observations indicated that a broomed finish tended to hold the calcium chloride solution on the pavement surface and retarded its removal by drainage. In the fall and winter, the top surfaces of the test specimens were kept covered with water.

The first slabs were made in the laboratory in water-tight molds with a metal base. This condition simulates concrete placed on an impervious subgrade or on paper or asphalt seals placed on the subgrade. Later tests were made using a damp sand base which would be more nearly comparable to types of subbases often used under concrete pavements. With the exception of the series in which curing was studied, all other slabs were made in the laboratory.

When ice was frozen on the slabs, calcium chloride was applied to the surface at the rate of 2.4 pounds per square yard. After the ice was completely thawed, the surface was washed and fresh water left on the surface to await another freezing.

During the winter of 1951–52, 19 cycles were obtained, and during the winter of 1952–53, only 17 cycles, and in the winter of 1953–54, 34 cycles.

The slabs were rated periodically for surface scale. The ratings were based on visual observation of the extent and depth of scale. The numerical significance of the rating system used was the same as that shown for the small laboratory exposed slabs.

Discussion of Laboratory Tests

Air content, part 1

In this group of laboratory tests the object was to study the effect of increasing the air content beyond the maximum 6 percent limit now generally permitted for use in concrete pavements. Since the maximum size of aggregate used with the 6- by 12- by 2-inch slabs was three-fourths inch, this necessitated a higher air content for a given degree of durability than is required by a normal paving mix containing aggregate graded up to 2 inches. This increase in air requirement has been shown by a number of investigators to be necessary in maintaining the level of durability.[1]

Two different proportions were used, one containing 6 and the other 7 sacks of cement per cubic yard. The slump of the concrete was maintained at 2 to 3 inches. Where entrained air was desired, neutralized Vinsol resin was used to produce the quantity of air specified.

Table 3 shows the scale ratings of the surfaces of the slabs containing various percentages of air. These ratings are reported at 30, 36, 42, 50, and 60 cycles when the tests were discontinued. Some tests were discontinued sooner because of the condition of the slab. The slabs having a cement content of 6 sacks per cubic yard had a maximum air content of 13 percent instead of the 7 to 8 percent which was planned.

The surface condition of the slabs after various cycles of exposure to calcium chloride action is well illustrated in the photographs in figures 3 and 4. Figure 3 shows the condition of the surface of concrete made with 6 sacks of cement per cubic yard and various air contents ranging from 1.5 to 13.0 percent. In each case the three slabs in a vertical column were identical in composition and

[1] *Effect of entrained air on concretes made with so-called "sand gravel" aggregates*, by Paul Klieger, Journal of the American Concrete Institute, Oct. 1948.

Table 3.—Rating of resistance to surface scaling of concrete slabs containing various percentages of air, part 1 of laboratory tests [1]

Cement	Air [2]	Rating after freezing and thawing [3] for—				
		30 cycles	36 cycles	42 cycles	50 cycles	60 cycles
Sack/cu. yd.	*Percent*					
6.0	1.5	8	10	---	---	---
6.0	2.7	6	8	10	---	---
6.1	6.0	2	3	5	6	8
5.9	13.0	0	0	0	2	2
7.0	1.5	3	7	10	---	---
7.2	2.7	2	5	8	10	---
7.2	4.9	0	2	5	10	---
7.1	7.2	0	1	2	4	6

[1] Each value is average of 3 tests. Slabs cured in moist a[ir] for 21 days followed by 14 days storage in laboratory air.
[2] Air content determined by ASTM tentative metho[d] C231–49T.
[3] Freezing and thawing tests were discontinued whe[n] surface scaling rating was 10, or at 60 cycles.

No coating	1 coat		
	50% oil 50% gasoline	75% oil 25% gasoline	100% oil
No $CaCl_2$	$CaCl_2$ used as thawing agent		

igure 5.—Effect of single coat of mineral oil on resistance of non-air-entrained concrete to scaling after 40 cycles of laboratory freezing and thawing with calcium chloride.

No coating	3 coats		2 coats
	50% oil 50% gasoline	75% oil 25% gasoline	100% oil
No $CaCl_2$	$CaCl_2$ used as thawing agent		

'igure 6.—Effect of multiple coats of mineral oil on resistance of non-air-entrained concrete to scaling after 40 cycles of laboratory freezing and thawing with calcium chloride.

reatment. Under each column is shown the ir content of the fresh concrete.

The slabs in which no air-entraining admixture had been added (1.5 percent air) vere removed from test at 36 cycles because he surfaces were rated 10 after 36 cycles (see able 3), and the entire slab was almost completely disintegrated. Likewise the test of he concrete that contained only 2.7 percent ir was discontinued after 42 cycles, at which ime they were rated 10. It is interesting to note that at 60 cycles 6 percent of entrained air, which is the maximum for most specifications, was not enough to give adequate protection (rating of 8) for this type of exposure. However, 6 percent delayed the start of scaling and the rate of disintegration was less. The slabs shown in figure 3 containing 13.0 percent were rated 2 after 60 cycles which is little more than the start of scaling. The high air content was accidental as it was not the intention to exceed 8 percent. The test was made even though it was realized that the strength and wear resistance would be seriously affected by the very high air content.

Figure 4 shows the slabs made with concrete containing 7 sacks of cement per cubic yard. The range in air content was from 1.5 to 7.2 percent For a given air content the concretes containing 7 sacks of cement per cubic yard were only slightly more resistant than the 6-sack concretes.

The conclusion that can be drawn from the results of these tests is the importance of using as high an air content as possible without jeopardizing unduly strength or wear resistance. The tests also show that the air content is far more important in its influence on resistance to scaling than the cement content.

Surface treatments, part 2

In this group a study was made of the effect on scaling of coatings of crankcase oil, undiluted and diluted, with various percentages of gasoline. The effect of time of application of the oils on start of scaling was also investigated.

Observations made in the field on actual pavements indicate that scaling was less likely to occur on those areas in the middle of the traffic lane containing noticeable oil stain than in the wheel tracks. It is believed that the oil drippings from cars and trucks fill the voids and reduce the absorption of the calcium chloride solution.

The concrete used in the tests was made with non-air-entrained cement and contained 6 sacks per cubic yard. The mix data are given in table 2.

The slabs in the first section of the group were given a single coating of unused lubricating or mineral oil (SAE No. 10 grade) either undiluted or diluted with gasoline. These surface treatments were quite similar to those used in New York State.[2] The combinations of oil and gasoline used for surface treatment and the scale ratings after 15 and 40 cycles of exposure are given in table 4. The condition of these slabs after 40 cycles of freezing and thawing is shown in figure 5.

In the second section of this group, specimens were given several coats of oil. Two coats of the undiluted oil were used and three coats of the diluted oils. The concrete would not absorb more than two coats of the undiluted oil within a reasonable period of time (24 hours) without leaving an appreciable residual film on the surface. The condition of these slabs is shown in figure 6.

The two columns on the left in figure 5 illustrate the condition of the slabs without surface treatment. Calcium chloride was not applied to the slabs shown in the first column from the left and the ice was thawed in laboratory air at about 75° F. These slabs on which no calcium chloride was used showed some action and were given a rating of 4. Calcium chloride was applied to all the other slabs including the three shown in the second column that were uncoated. The specimens were all subjected to 40 cycles before the tests were discontinued. The uncoated specimens to which calcium chloride was applied were seriously disintegrated at the end of 40 cycles and the surface scale rating was 8.

All of the single-coated specimens showed slight scale and one of each group of three identical specimens was badly disintegrated. There was no very marked difference in protection given by the undiluted oil as compared to the different dilutions as indicated by the ratings which varied from 2 to 4.

The surface ratings for the slabs given multiple coats of No. 10 oil or dilutions of the oil with gasoline are given in table 4, and the condition of the slabs after 40 cycles of freezing and thawing is shown in figure 6. The ratings indicate that at 40 cycles the multiple

[2] *Control of concrete pavement scaling caused by chloride salts,* by B. D. Tallamy, Journal of the American Concrete Institute, Mar. 1949, vol. 20, No. 7.

Table 4.—Effect of oil surface coatings on the resistance of concrete to scaling, part 2 of laboratory tests [1]

Number of applications	Surface treatment [2]	$CaCl_2$ for thawing	Rating after freezing and thawing for— 15 cycles	40 cycles
----	None	No	2	4
----	None	Yes	4	8
1	50% SAE 10 oil, 50% gasoline.	Yes	2	4
1	75% SAE 10 oil, 25% gasoline.	Yes	2	3
1	100% SAE 10 oil	Yes	2	2
----	None	No	2	4
----	None	Yes	4	8
3	50% SAE 10 oil, 50% gasoline.	Yes	2	2
3	75% SAE 10 oil, 25% gasoline.	Yes	2	3
2	100% SAE 10 oil	Yes	2	3

[1] Each value is average of 3 tests. Slabs cured in moist air for 21 days followed by 14 days storage in laboratory air.
[2] Surface treatment applied at the rate of 1 gallon per 20 square yards at age of 28 days.

oil treatment is slightly more beneficial in preventing scaling than the single coating.

Examination of all the slabs in the series indicates that no type of coating will prevent scaling from becoming progressive after a single break in the surface permits the calcium chloride solution to enter the concrete under the oil-impregnated layer. On pavements in service such breaks in the oil-protected surface may be caused by tire chains.

It was proposed in New York State that the oil coat could be applied to plastic concrete in lieu of a membrane curing compound. Therefore, to obtain information on the effect of such application, oil was applied to three slabs 3 hours after molding to simulate the time of application of a membrane curing compound. The other six slabs were given 7 days moist curing. Three of the six were given no further treatment. To the remaining three an oil surface coat was applied after 7 days drying. The ratings of these slabs after 15, 25, 50, and 60 cycles of freezing and thawing are shown in table 5. The application of oil to the surface of plastic concrete was definitely detrimental and resulted in much more severe scale than similar concrete that received no surface treatment. The slabs on which the oil was applied to the plastic concrete were rated 10 and the ones on which no oil was used were rated 6 after 60 cycles of freezing and thawing.

The concrete given an oil treatment after 14 days had far better resistance to scaling than that which received no earlier surface treatment. These slabs were rated 3. These tests indicate that the oil protective coat cannot be applied at an early age and still have value in improving resistance to scaling caused by application of calcium chloride.

Admixtures of oils, part 3

In this phase of the investigation, paraffin base oil, asphalt base oil, and used crankcase oil were used as admixtures in concrete. The mixes and the mix data for the concrete used in this group are given in table 2. The scale ratings of the slabs are shown in table 6 after 20, 30, 50, 65, and 75 cycles of freezing and thawing with calcium chloride. Figure 7 shows the specimens after 75 cycles of freezing and thawing.

The paraffin base oil and the asphalt base oil were ineffective in delaying the start of scaling or in controlling the rate of progress of the scaling. As may be seen from the table, the slabs containing these oils showed more scaling at 20 cycles than the slabs made without admixture. At 75 cycles the slabs containing the paraffin or asphaltic base oils were rated 10, the same as the concrete slabs without admixture.

The used crankcase oil was effective in retarding the start of scaling probably because of the air entrained in the plastic concrete. The concrete containing this material was rated 1 after 50 cycles and 4 after 75 cycles.

Since some of the materials used as admixtures are of value in delaying the start of scaling, the effect of these admixtures on other properties of concrete is important. To study these properties, concretes containing these admixtures were tested for flexural and compressive strength, durability as measured by freezing and thawing (specimens frozen in water), and volume change due to drying.

The mix data for the strength specimens are shown in table 7. Seven mixes were used, one a base mix without admixture containing 6.0 sacks of cement per cubic yard of concrete with a slump of approximately 3 inches. The other 6 mixes contained the admixtures and were similar to the base mix, except that the sand and water content was reduced to maintain approximately the same slump and cement content.

The one-third gallon of oil was selected because it was the amount used in previous tests for waterproofing concrete. Twice this amount was also used to determine if there were any harmful effects from using more than that recommended.

The air contents of the mix without admixture and of the mixes containing the paraffin and asphalt base oils ranged from 1.0 to 1.2 percent. The air content for the mix containing one-third gallon of used crankcase lubricating oil per sack of cement was 6.4 percent, and for the mix containing two-thirds of a gallon it was 5.0 percent. Air determinations were made using a pressur type air-meter.

The water required per sack of cemen for the mixes containing the paraffin base an asphalt base oils was only slightly less tha that required for the plain mix for the sam slump and cement content. For the mi containing one-third gallon of used crankcas lubricating oil, it was 0.3 of a gallon less, an for two-thirds of a gallon it was 0.5 of gallon less.

The workability of all of the mixes contain ing the admixtures was better than that o the plain concrete. This improvement wa greater for those mixes which entrained ai

For each mix, eight 6- by 6- by 21-inc beams and eight 6- by 12-inch cylinders wer made, two each on 4 different days. Fou beams and four cylinders were tested at 7 day and four at 28 days. All specimens wer stored continuously in moist air until teste

Strength Tests

The results of the strength tests are give in table 8. The table also shows the rati of the strength developed with admixture

Table 5.—Effect of time of application of oil coating on the resistance of concrete to scaling, part 2 of laboratory tests [1]

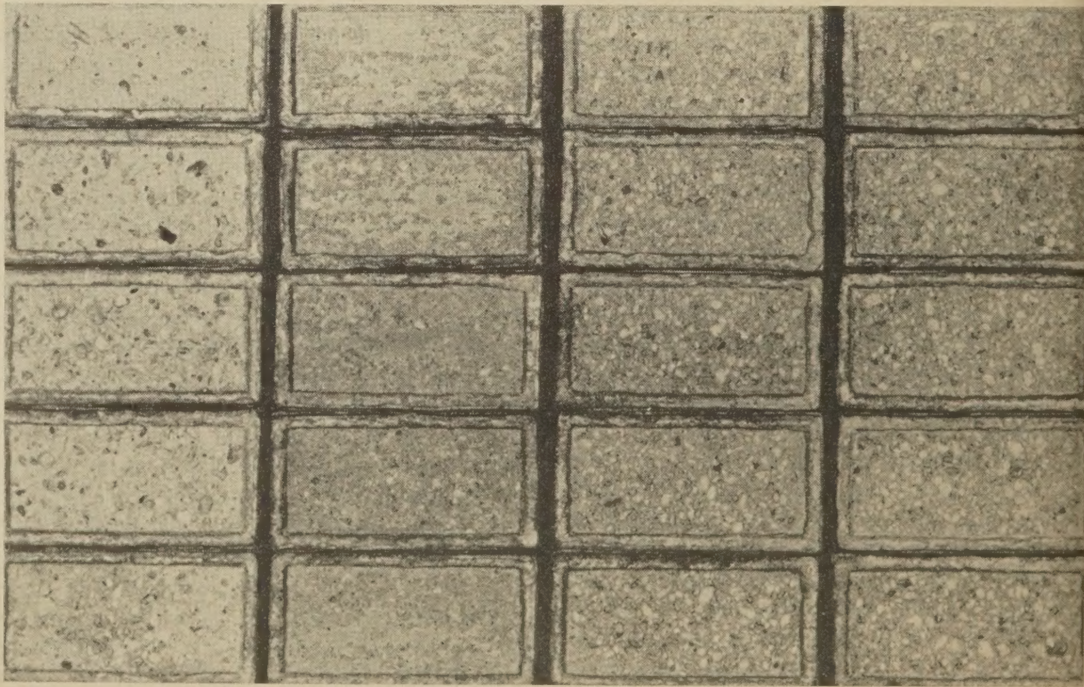
Surface treatment	Rating after freezing and thawing for—			
	15 cycles	25 cycles	50 cycles	60 cycles
None	3	4	5	6
Oil applied after 3 hours [2]	4	4	6	10
Oil applied after 14 days [3]	2	2	3	3

[1] Each value is average of 9 tests.
[2] Slabs cured in moist air for 7 days followed by 28 days' storage in laboratory air followed by 4 days' soaking.

Table 6.—Rating of resistance to surfac scaling of concrete slabs containing oil as admixture, part 3 of laboratory tests [1]

Admixture	Air [2]	Rating after freezing and thawing for—				
		20 cycles	30 cycles	50 cycles	65 cycles	75 cycle
	Percent					
None	2.0	1	2	3	9	10
Used crankcase oil	5.7	1	1	1	2	4
Paraffin oil	2.0	3	4	4	10	10
Asphalt oil	2.4	3	5	5	10	10

[1] Each value is average of 5 tests. Slabs cured in moist ai for 14 days followed by 40 days' storage in laboratory air.
[2] Air content determined by ASTM tentative metho C231–49T.



Plain — Used crankcase oil — Paraffin base oil — Asphalt base oil

Figure 7.—Effect of oil admixtures on resistance of concrete to scaling after 75 cycles laboratory freezing and thawing with calcium chloride.

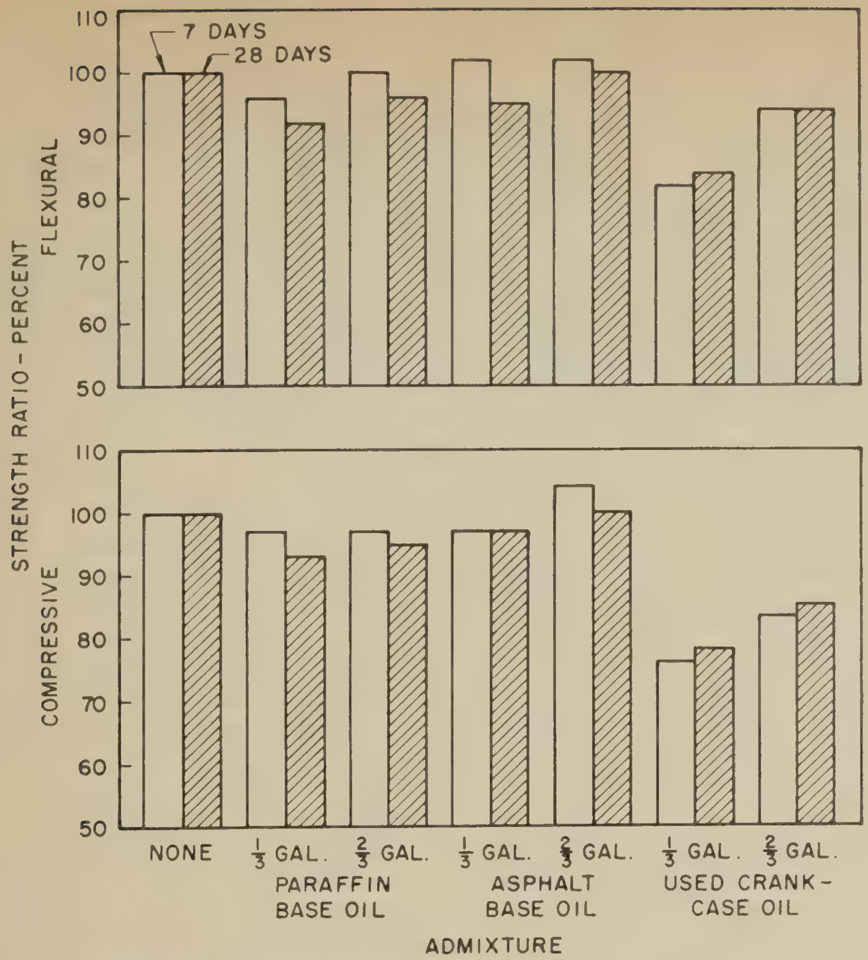


Figure 8.—Strength ratios of concrete containing oils.

approximately 6 sacks of cement per cubic yard of concrete with a slump of 3.3 inches. The other four mixes contained the admixtures and were similar to the plain mix except that sand and water contents were reduced to maintain approximately the same consistency and cement content.

The mixes and materials used were similar to those used in the strength tests except that the maximum size of coarse aggregate was 1 inch instead of 1½ inches, and the percentage of sand was increased. The use of a smaller maximum size coarse aggregate resulted in higher air contents in the concretes than those in the concretes used for the strength specimens. The greatest difference was in the mixtures containing two-thirds of a gallon of used crankcase oil. Five percent air was obtained for the concrete (1½-inch maximum size) for the strength specimens and 10 percent for the concrete (1-inch maximum size) for the freezing and thawing specimens. A mixture containing one-eighth gallon of used crankcase oil was included in the freezing and thawing series. This mix had an air content of 5.2 percent which is within the accepted limits.

For each mix, nine 3- by 4- by 16-inch beams were made. Three beams were used for freezing and thawing, three were used for control and were tested for flexural strength along with the freezing and thawing specimens, and three were used for drying shrinkage tests.

expressed as percentages of the strengths of the corresponding concrete without admixture. The strength ratios are shown graphically in figure 8.

It should be noted that the use of the admixtures included in this series resulted in reductions in the 28-day flexural and compressive strengths. The 28-day ratios for the paraffin and asphalt base oils series ranged from 92 to 100 for flexural strength and 93 to 100 for compressive strength. These reductions would not be considered serious if the use of the admixture resulted in an improvement in the durability of the concrete.

There was a greater reduction in the strengths of the mixtures containing used crankcase oils. The use of these admixtures resulted in the entrainment of air in the concrete; therefore the strength ratio of 85 percent specified in the Tentative Specifications for Air-Entraining Admixtures for Concrete, ASTM Designation C260–52T will serve as a basis for comparison.

The strength ratios for the mixtures containing one-third gallon of used crankcase oil per sack of cement were lower than the ASTM Standard, and for those containing two-thirds of a gallon the ratios were all above 85 percent except the compressive strength ratio at 7 days which was 83 percent. The lower strengths of the ⅓-gallon mixtures were probably due to the air content of 6.4 percent as compared to 5.0 percent for the ⅔-gallon mixtures.

The mix data for the freezing and thawing specimens and the volume change specimens are given in table 9. Five mixes were used, one base mix without admixture, containing

Table 7.—Effect of oils on properties of concrete, mix data for strength specimens [1]

Mix by dry weight	Admixture: Amount	Admixture: Type	Cement	Water	Slump	Air [2]	Weight of plastic concrete
Pounds	*Gal./sack*		*Sack/cu. yd.*	*Gal./sack*	*Inches*	*Percent*	*Lb./cu. ft.*
94–195–350	------	None	6.0	5.6	2.7	1.1	153.2
94–195–350	⅓	Paraffin base oil	6.0	5.5	3.2	1.0	152.8
94–190–350	⅔	do	6.0	5.3	2.7	1.2	152.3
94–195–350	⅓	Asphalt base oil	6.0	5.5	2.7	1.0	152.6
94–190–350	⅔	do	6.0	5.3	2.8	1.0	152.1
94–180–350	⅓	Used crankcase oil	5.8	5.3	3.1	6.4	145.0
94–170–350	⅔	do	6.0	5.1	2.5	5.0	146.4

[1] Materials used: cement, brand A; siliceous sand, F. M.=2.70; crushed limestone coarse aggregate, 1½-inch maximum size.
[2] Air content determined by ASTM tentative method C231–49T.

Table 8.—Effect of oils on the strength of concrete [1]

Admixture: Amount	Admixture: Type	Air [2]	Modulus of rupture [3]: 7 days Strength	7 days Ratio	28 days Strength	28 days Ratio	Compressive strength [4]: 7 days Strength	7 days Ratio	28 days Strength	28 days Ratio
Gal./sack		*Pct.*	*P.s.i.*	*Pct.*	*P.s.i.*	*Pct.*	*P.s.i.*	*Pct.*	*P.s.i.*	*Pct.*
------	None	1.1	605	100	765	100	3,560	100	4,990	100
⅓	Paraffin base oil	1.0	580	96	705	92	3,450	97	4,660	93
⅔	do	1.2	605	100	735	96	3,450	97	4,720	95
⅓	Asphalt base oil	1.0	615	102	730	95	3,440	97	4,840	97
⅔	do	1.0	615	102	765	100	3,690	104	4,990	100
⅓	Used crankcase oil	6.4	495	82	640	84	2,720	76	3,880	78
⅔	do	5.0	570	94	720	94	2,940	83	4,250	85

[1] Each value is the average of 4 tests.
[2] Air content determined by ASTM tentative method C231–49T.
[3] Specimens were 6- by 6- by 21-inch beams tested in accordance with ASTM standard method C78–49. Beams tested with side as molded in tension. Ratio values for relative strength are based on the strengths for the mix without admixture.
[4] Specimens were 6- by 12-inch cylinders tested in accordance with ASTM standard method C39–49. Ratio values for relative strength are based on the strengths for the mix without admixture.

Table 9.—Effect of oils on properties of concrete, mix data for freezing and thawing and drying shrinkage specimens [1]

Mix by dry weight	Admixture		Cement	Water	Slump	Air [2]	Weight of plastic concrete
	Amount	Type					
Pounds	*Gal./sack*		*Sack/ cu. yd.*	*Gal./sack*	*Inches*	*Percent*	*Lb./cu. ft.*
94-220-320	------	None	5.9	6.3	3.3	1.2	149.9
94-205-320	⅔	Paraffin base oil	6.0	5.8	3.9	1.3	148.7
94-205-320	⅔	Asphalt base oil	6.0	5.8	3.8	1.3	148.9
94-200-320	⅛	Used crankcase oil	5.9	5.6	4.1	5.2	144.5
94-190-320	⅔	do	5.6	5.6	4.2	10.0	137.0

[1] Materials used: cement, brand A; siliceous sand, F. M.=2.70; crushed limestone coarse aggregate, 1-inch maximum size.
[2] Air determined by ASTM tentative method C231-49T.

The bars containing one-eighth of a gallon of used oil and two-thirds of a gallon of used oil showed a loss in N^2 of 17 and 22 percent, respectively, after 70 cycles of freezing and thawing. The flexural strengths were 66 and 55 percent of that of the unfrozen specimens. However, these concretes contained 5.2 and 10.0 percent air. The durability factors for these bars were 83 and 78 representing very good resistance to freezing and thawing.

The results of the volume change tests are shown in table 11 and in figure 10. The bars for the volume change tests were made with stainless steel gauge plugs cast in the ends.

The results of the freezing and thawing tests are shown in table 10 and figure 9. The bars (3 by 4 by 16 inches) for the freezing and thawing tests were stored in moist air for 28 days prior to the start of the test. The freezing and thawing tests were made in a manner similar to that described in a previous article.[3]

The sonic modulus (N^2) was determined on the specimens prior to freezing, and then after regular intervals of freezing and thawing the percentage decrease in N^2 was determined.[4] When a group of specimens showed an average decrease in N^2 of 40 percent, they were considered disintegrated, and freezing and thawing was then discontinued and flexural strength tests were made. On the remaining specimens freezing and thawing was discontinued at 70 cycles and flexural strength tests were made.

In table 10 are given the losses in N^2, the durability factors, and the results of flexural strength on both the unfrozen control bars and the bars which had been frozen and thawed. The durability factor (DF) was calculated as follows:

$$DF=\frac{(100-L)n}{70}$$

Where:

L=loss in N^2 at n cycles.

n=number of cycles at which N^2 reaches 40 percent or 70 if loss of 40 percent is not reached by end of test (70 cycles). Durability factors of 70 or greater for the particular conditions of this test are considered satisfactory.

The concrete without admixture showed a loss in N^2 of 56 percent after 6 cycles of freezing and thawing. The freezing and thawing bars had a flexural strength of 24 percent of the unfrozen control bars. The durability factor was 3.

The concretes containing two-thirds of a gallon of paraffin base oil per sack of cement and two-thirds of a gallon of asphalt base oil showed a reduction in N^2 of 53 percent and 54 percent, respectively, after 11 cycles of freezing and thawing, and the flexural strengths were 30 and 31 percent of the corresponding control bars. The durability factor was 7 for both concretes.

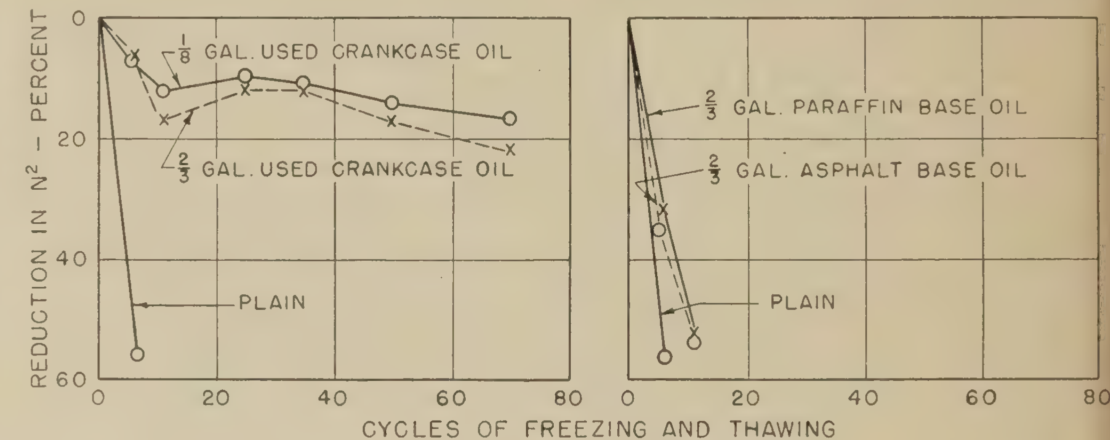


Figure 9.—Effect of admixtures of oils on the resistance of concrete to freezing and thawing.

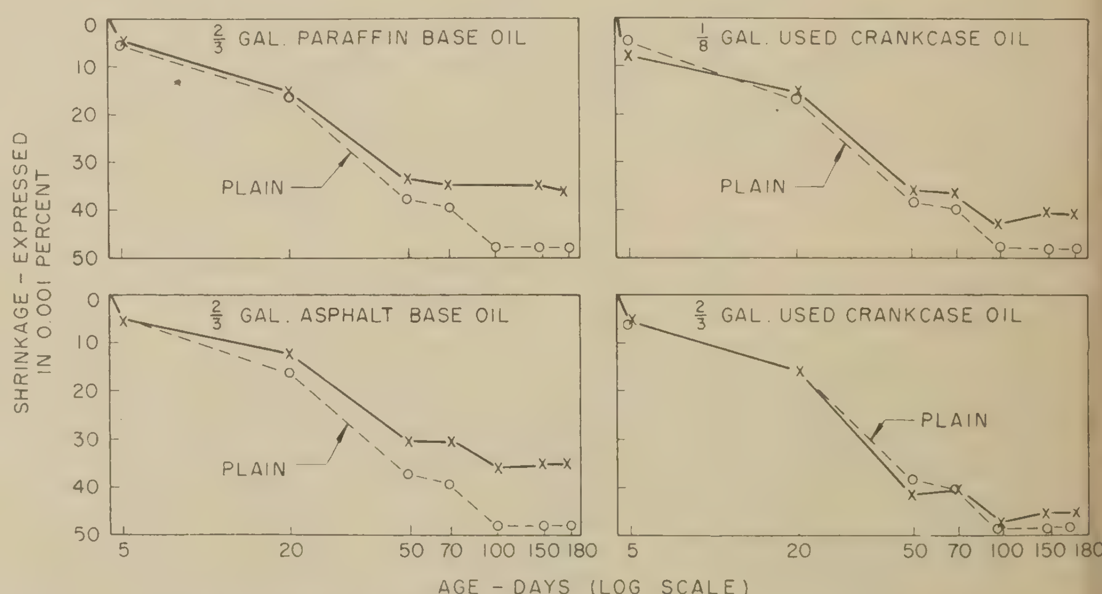


Figure 10.—Effect of admixtures of oils on the shrinkage of concrete.

Table 10.—Effect of oils on the resistance of concrete to freezing and thawing in water

Admixture		Air [2]	Loss in N^2 at—						Durability factor [3]	Flexural strength, 3- by 4- by 16-inch beams [4]	
Amount	Type		6 cycles	11 cycles	25 cycles	35 cycles	50 cycles	70 cycles		Control	Freezing and thawing
Gal./sack		*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*		*P.s.i.*	*P.s.i.*
------	None	1.2	56	---	---	---	---	---	3	970	235(24)
⅔	Paraffin base oil	1.3	32	53	---	---	---	---	7	1,030	305(30)
⅔	Asphalt base oil	1.3	35	54	---	---	---	---	7	895	285(31)
⅛	Used crankcase oil	5.2	7	12	10	11	14	17	83	905	600(66)
⅔	do	10.0	6	17	12	12	17	22	78	740	410(55)

[1] Each value is average of 3 tests on 3 beams.
[2] Air content determined by ASTM tentative method C231-49T.
[3] Durability factor calculated at 70 cycles of freezing and thawing.
[4] Beams tested with bottom as molded in tension (4-inch depth). Figures in parentheses indicate the percentage of th strength of the corresponding unfrozen control specimens.

[3] *Evaluation of air-entraining admixtures for concrete,* by F. H. Jackson and A. G. Timms, PUBLIC ROADS, Feb. 1954, vol. 27, No. 12

[4] *Application of sonic method to freezing and thawing studies of concrete,* by F. B. Hornibrook, ASTM bulletin No. 101, Dec. 1939, p. 5.

Figure 11.—Effect of thawing agent on the resistance of non-air-entrained concrete after 17 cycles of laboratory freezing and thawing.

'hey were stored in moist air in the molds or 2 days. After removal from the molds, hey were stored in laboratory air at 72° F. nd 50 percent relative humidity. The bars vere measured when they were removed from he moist room and then after regular intervals f drying. The percent reduction in length vas calculated from these measurements. After 180 days storage, the test was discon-inued. All the concretes containing admix-ures showed less shrinkage than the plain oncrete.

se of urea, part 4

Urea, an organic compound, which is eported to be non-corrosive to metals, had been suggested as a thawing agent to replace he more commonly used chlorides particularly on streets with underground streetcar cables. The tests in this investigation were made to compare the ice-melting properties of urea with calcium chloride and to study the effect of urea on the surface of non-air-entrained concrete when used for ice removal.

A comparison was made of concrete slabs on which no thawing agent was used with slabs on which either calcium chloride or urea was used. The rate of application of the thawing agent was varied from 1 to 3 pounds per square yard of exposed surface of the slab. Table 12 shows the scale ratings at 10, 15, and 17 cycles of freezing and thawing, and figure 11 shows the slabs after 17 cycles. The slabs shown in the figure were thawed with 2 pounds per square yard of either salt applied to the surface of the slabs.

In general, the rate of application of the thawing agent appeared to have only a slight effect on the scale resistance of the concrete, After 10 cycles, the slabs on which 1 pound of calcium chloride was used had a rating of 7 and the ones on which 2 or 3 pounds were used had ratings of 9. After 15 cycles all specimens on which calcium chloride was used had a rating of 10.

The specimens on which urea was used, in general, showed slightly less scaling than those on which calcium chloride was used. The use of smaller amounts of urea per square yard of surface caused less depth of scaling and also appeared to retard the start of scaling slightly as may be seen from the ratings in table 12.

The rate of thawing of the ice on the slabs on which urea was used appeared to be slower than the thawing rate when calcium chloride was used. The slabs on which no thawing agent was used showed only light scale after 17 cycles of freezing and thawing in the air of the laboratory.

Use of rust inhibitor

It is claimed that the corrosive effect of calcium chloride on steel such as automobile fenders can be greatly retarded by inhibiting the action with buffer materials. Two different percentages of an inhibitor were mixed with calcium chloride and applied to the surface of the concrete slabs. The mix-ture containing 1 percent inhibitor by weight of the calcium chloride was used at three different rates of application, 1, 2, and 3 pounds per square yard, and the mixture containing 5 percent inhibitor was used only at the rate of 1 pound per square yard of sur-face.

Table 11.—Effect of oils on the drying shrinkage of concrete [1]

Admixture: Amount	Admixture: Type	Air [2]	Reduction in length (0.001 percent) after storage in laboratory air at 72° F. and 50 percent relative humidity for—: 5 days	20 days	50 days	70 days	100 days	150 days	180 days
Gal./sack		*Pct.*							
------	None	1.2	6	17	38	40	48	48	48
⅔	Paraffin base oil	1.3	6	16	34	35	36	35	36
⅔	Asphalt base oil	1.3	6	12	31	31	36	35	35
⅓	Used crankcase oil	5.2	8	16	37	37	43	41	41
⅔	-----do	10.0	4	17	40	40	47	44	44

[1] Each value is average of tests of 3 beams.
[2] Air content determined by ASTM tentative method C231-49T.

Table 12.—Effect of urea and inhibitor for calcium chloride on the resistance of concrete slabs to scaling, part 4 of laboratory tests [1]

Rate of application and thawing agent	Rating after freezing and thawing for—: 10 cycles	15 cycles	17 cycles
None	2	3	3
1 lb. per sq. yd.:			
$CaCl_2$	7	10	10
$CaCl_2$+1 % inhibitor	7	8	8
$CaCl_2$+5 % inhibitor	7	8	8
Urea	5	8	8
2 lb. per sq. yd.:			
$CaCl_2$	9	10	10
$CaCl_2$+1 % inhibitor	8	9	10
Urea	6	8	9
3 lb. per sq. yd.:			
$CaCl_2$	9	10	10
$CaCl_2$+1 % inhibitor	10	10	10
Urea	8	9	10

[1] Each value is the average of 3 tests. Slabs cured in moist air 14 days and then laboratory air for 90 days. Concrete was non-air-entrained.

In table 12 are shown the relative scaling ratings determined after 10, 15, and 17 cycles of freezing and thawing. It will be noted that the rust inhibitor had little effect on the scaling action of the concrete caused by calcium chloride and its use as a rust inhibitor with calcium chloride would have no practical significance as far as the resistance of the concrete is concerned. There appeared to be no difference in the extent of scaling on the slabs between those on which mixtures of 1 percent and 5 percent inhibitor were used with the thawing agent.

Vacuum treatment, part 5

It has been demonstrated that the use of vacuum mats consolidates plastic concrete with the consolidation probably being greater at the surface than in the body of the concrete.

Vacuum treatment was applied to two types of concrete, air-entrained and non-air-entrained. Two cement contents, 6 and 7 sacks per cubic yard, were used with and with-out air. The details of the mixes and the air contents are shown in table 2. The method of using simulated the commercial method of application to flat slabs using a vacuum pad and pump. The scale ratings are given in table 13.

The non-air-entrained concrete containing 6 sacks of cement per cubic yard and subjected to a vacuum treatment showed a much improved surface resistance to the action of the chloride as compared to the untreated concrete. The slabs made from concrete containing 6 sacks of cement, non-air-en-trained, and untreated were rated 10 at 30 cycles, whereas those with the vacuum treat-ment were rated only 4 after 55 cycles. Photographs of the slabs for the concrete containing 6 sacks of cement per cubic yard are shown in figure 12 and for the 7-sack concrete in figure 13.

In the case of the concrete containing 7 sacks of cement without entrained air, the improvement was very much less than that observed for similar concrete containing 6 sacks of cement per cubic yard. The vacuum-treated slabs were rated 8 at 30 cycles and 10 at 55 cycles as compared to the 6-sack concrete rated 3 at 30 cycles and 4 at 55 cycles. This is in agreement with other tests of vacuum placing of concrete. It has been observed that the leaner mixes are compacted more because of the greater quantity of water removed.

It was found that concretes with air entrainment and containing both 6 and 7 sacks of cement per cubic yard were greatly improved in resistance to the chloride attack by use of the vacuum method. This was not anticipated as it was believed that the vacuum treatment would not benefit air-entrained concrete because such concrete has inherent resistance in the first place, and secondly the vacuum treatment would lower the air content at the surface. The only explanation that appears reasonable is the probable reduction in the water-cement ratio at the surface of the concrete.

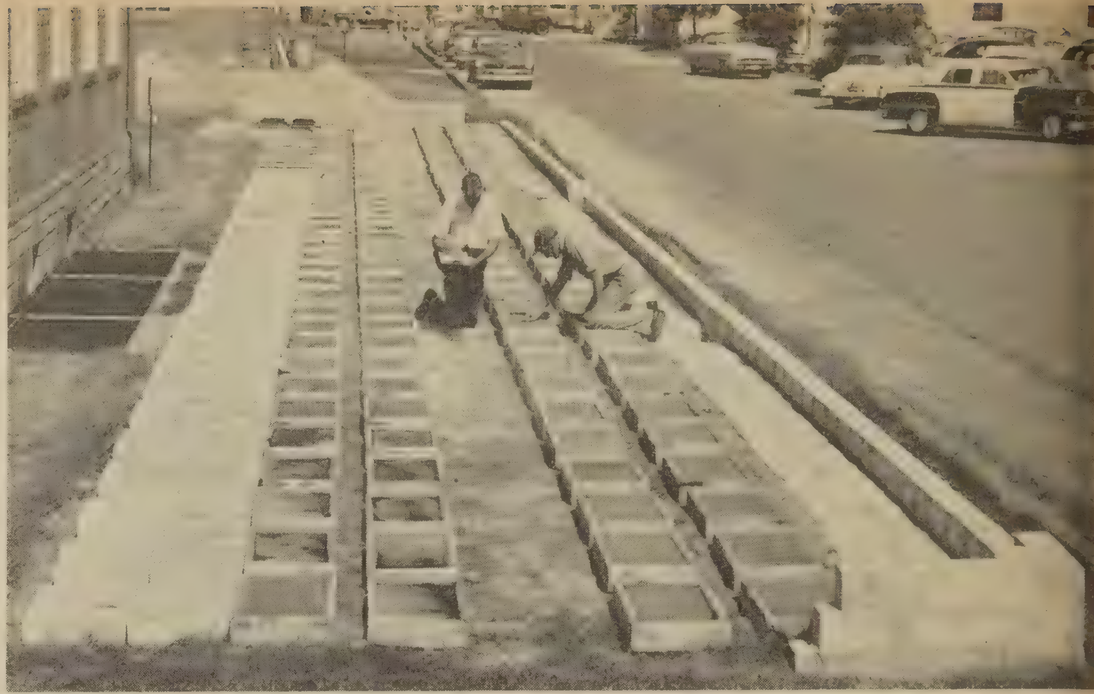


Figure 14.—Exposure area for test specimens

Discussion of Outdoor Tests

As mentioned earlier in this report, the concrete specimens for the outdoor exposure test were 16 by 24 by 4 inches deep. The concrete contained approximately 6 bags of cement per cubic yard and the maximum size of aggregate was 1 inch. Further details of the concrete proportions are given in table 14. Two cements were used, a high and a low alkali cement; table 1 shows the chemical analyses of the cements.

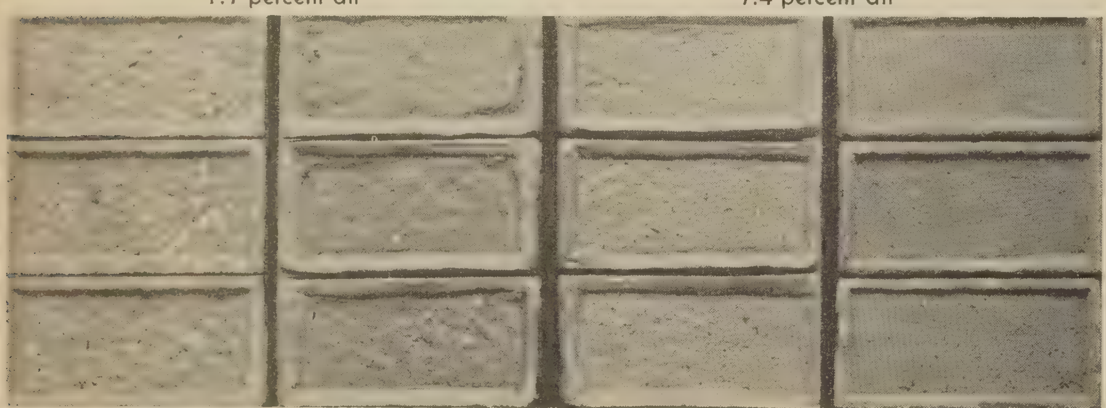


Figure 12.—Effect of vacuum-surface treatment on resistance to scaling of concrete after indicated cycles of laboratory freezing and thawing with calcium chloride.

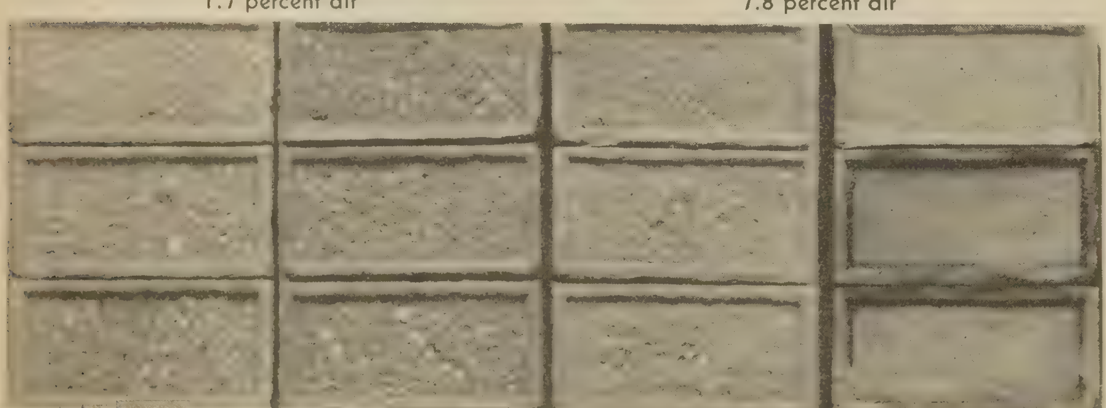


Figure 13.—Effect of vacuum-surface treatment on resistance to scaling of concrete after indicated cycles of laboratory freezing and thawing with calcium chloride.

The specimens exposed outdoors during the winter of 1951–52 were cast in water-tight wooden molds with metal bottoms. The concrete specimens were made in the laboratory during the spring of 1951, and cured in the moist room until the summer of 1951. They were then placed outdoors and in the fall when freezing was expected, the surfaces were covered with from one-fourth to one-half inch of water. The water was held on the surface by the raised edge on top of the specimen. On those slabs tested during the winter of 1951–52, 19 cycles of freezing and thawing were obtained. Any freezings that occurred on weekends are not included in the tests because in general no salt application was made on either Saturday or Sunday during this series.

Figure 14 shows the exposure plot photographed in the spring of 1954. The method of examining and removing any loose mortar before rating the slab is shown on the cover page. The same scale of rating was used for the large slabs as for the small laboratory slabs. A rating of 5 or more was considered major scaling.

Air-entraining admixture, part 1

One slab was made for each admixture tested. As a basis of comparison two non air-entrained slabs were made. The thawing agent used was calcium chloride and it was applied at the rate of 2.4 pounds per square yard in a manner similar to that used on the laboratory specimens.

Table 15 shows the ratings of the slabs after 7, 12, and 19 cycles. The different admixtures have been arranged in the table in seven groups corresponding to the grouping in the evaluation tests of air-entraining ad

Table 13.—Effect of vacuum treatment on the resistance of concrete to scaling, part 5 of laboratory tests [1]

Cement	Air [2]	Surface treatment	Rating after freezing and thawing for—			
			15 cycles	25 cycles	30 cycles	55 cycles
Sack/cu. yd.	*Percent*					
6.0	1.7	None	3	9	10	--
6.0	1.7	Vacuum	2	3	3	4
6.2	7.4	None	0	2	3	5
6.2	7.4	Vacuum	1	1	1	2
7.0	1.7	None	3	9	10	--
7.0	1.7	Vacuum	3	8	8	10
7.1	7.8	None	1	3	3	5
7.1	7.8	Vacuum	0	0	0	0

[1] Each value is average of 3 tests. Slabs stored in moist air 14 days followed by 21 days in laboratory air.
[2] Air content determined by ASTM tentative method C231–49T.

mixtures described in a previous report and with the same identification numbers.[5]

The non-air-entrained concretes used as a basis of comparison had light scale over most of the surface and some moderately deep scale at 7 cycles (ratings of 5 and 6) and both were badly scaled (rating of 10) at the end of 19 cycles.

With one exception, the use of air-entraining admixtures consisting of salts of wood resin resulted in concretes having very good resistance to the action of calcium chloride. The one exception, admixture No. 6, was rated 6 at the end of 19 cycles.

The use of the air-entraining admixtures, consisting of synthetic detergents, in concrete was ineffective in reducing scaling. The concretes had poor resistance with all but two showing complete scaling of the surface (rating of 10) at 19 cycles. Even the two exceptions were rated 4 and 6 at 19 cycles.

Admixtures of the sulfonated lignin type were effective in preventing major scaling up to 19 cycles at which time the tests were discontinued. All specimens were rated 1 at 19 cycles.

There were only two admixtures in the group of salts of petroleum acids. One of these in concrete had good resistance to scaling and the other admixture in this group was fair (rating of 6 at 19 cycles).

Neither of the two admixtures made from salts of proteinaceous acids had much value in reducing scaling of concrete even though these admixtures entrained air comparable with the other air-entraining admixtures. At the end of 19 cycles the surfaces of the concretes were nearly as bad as those concretes containing no air-entraining admixtures. However, major scaling was delayed to 10 or 12 cycles.

[5]See footnote 3, p. 150.

Table 14.—Mix data for slabs exposed outdoors, (16 by 24 by 4 inches deep) [1]

Concrete	Mix by dry weight	Cement	Water	Slump	Air
	Pounds	*Sack/cu.yd.*	*Gal./sack*	*Inches*	*Percent*
Non-air-entrained	94–215–315	6.0	6.1	3.0	1.8
Air-entrained	94–200–315	6.0	5.6	3.0	6.0

[1] Figures given are average values for parts 1 to 4 inclusive. In part 2, 33⅓ percent of the cement was replaced by equal solid volume of fly ash. Materials used: Type I cement, brands A and B; siliceous sand, F. M.=2.70; crushed limestone coarse aggregate, 1-inch maximum size.

The four admixtures consisting of fatty and resinous acids and their salts were very effective and all the concretes in which they were used showed excellent resistance to calcium chloride attack. Likewise the admixture containing organic salts of sulfonated hydrocarbons was of value in concrete in preventing scaling caused by the surface application of calcium chloride.

These tests are of particular interest because they show that the percentage of entrained air alone may not be the controlling factor in determining the degree of resistance to calcium chloride attack. Some of the concrete having air contents below 4.5 percent showed good resistance and some containing air contents over 5 percent showed rather poor resistance.

After the 19 cycles of freezing and thawing with calcium chloride, the slabs were sawed into five 4- by 4- by 16-inch beams. These beams were tested for flexural strength on a 12-inch span with center-point loading. The tops as molded (the surface on which calcium chloride was used) were in tension. The strengths were relatively high with only one value below 700 p.s.i. modulus of rupture which indicates that the concrete under the scale was structurally sound.

Other Variables Considered

Because a single slab was made for each condition in the preliminary investigation, it

Table 15.—Effect of air-entraining admixtures on resistance of concrete to scaling, preliminary tests of cement brand A molded on a metal base and exposed outdoors [1]

Admixture number	Air	Rating after freezing and thawing for—			Modulus of rupture [2]
		7 cycles	12 cycles	19 cycles	
BASE MIX: NO AIR-ENTRAINING ADMIXTURE					
	Percent				*P.s.i.*
None	1.1	6	8	10	905
Do	1.3	5	7	10	755
SALTS OF WOOD RESIN					
1	5.5	1	1	2	830
2	6.2	1	1	1	710
3	6.4	1	2	2	650
4	5.2	1	2	2	810
5	5.6	0	1	3	775
6	5.0	1	4	6	800
7	4.5	0	1	2	830
SYNTHETIC DETERGENTS					
12	6.4	1	3	6	705
13	5.0	1	2	4	780
14	4.0	4	8	10	815
15	4.8	3	8	10	770
16	4.8	3	7	10	750
17	4.8	2	7	10	750
26	5.4	1	6	10	790
SALTS OF SULFONATED LIGNIN					
18	5.8	0	1	1	940
20	6.7	0	1	1	870
21	6.4	0	1	1	935
22	3.2	0	1	1	1080
SALTS OF PETROLEUM ACIDS					
11	6.5	0	0	1	790
27	5.0	2	4	6	860
SALTS OF PROTEINACEOUS MATERIALS					
24	5.1	3	5	8	790
25	5.6	2	6	9	750
FATTY AND RESINOUS ACIDS AND THEIR SALTS					
8	4.2	1	1	1	860
9	5.6	0	1	1	815
10	4.8	0	1	2	810
28	6.4	1	1	2	825
ORGANIC SALTS OF SULFONATED HYDROCARBONS					
23	5.3	0	1	1	810

[1] Slabs made Feb. 1951, stored in moist air about 100 days. Outdoor freezing and thawing with $CaCl_2$ for 19 cycles during the winter of 1951–52.
[2] After 19 cycles of freezing and thawing each slab was sawed into five 4- by 4- by 16-inch beams. The beams were tested by center loading on a 12-inch span with the top as molded in tension.

Table 16.—Effect of air-entraining admixtures on resistance of concrete to scaling, part 1, cements A and B molded on a metal base and exposed outdoors [1]

Admixture number	Cement A					Cement B				
	Air	Rating after freezing and thawing for—				Air	Rating after freezing and thawing for—			
		12 cycles	17 cycles	39 cycles	51 cycles		12 cycles	17 cycles	39 cycles	51 cycles
Base Mix: No Air-Entraining Admixture										
	Percent					*Percent*				
None	1.8	6	10	10	10	1.0	4	8	10	10
Do	2.1	1	5	10	10	2.1	8	10	10	10
Do	1.8	8	10	10	10	1.1	8	10	10	10
Do	1.9	6	10	10	10	1.1	8	10	10	10
Do	1.0	8	10	10	10	0.6	3	10	10	10
Salts of Wood Resin										
1	6.1	1	1	1	2	5.7	0	1	1	1
2	7.3	1	1	3	6	5.8	1	1	2	3
3	6.0	1	1	2	2	6.5	1	1	2	2
4	6.1	1	3	6	7	6.0	1	1	2	3
6	4.9	1	1	1	2	6.6	1	1	2	2
7	6.3	1	1	1	1	5.1	1	1	2	3
30	5.7	1	1	1	1	7.8	2	2	2	2
31	4.0	1	2	2	3	5.6	1	2	2	3
32	6.4	0	1	1	1	6.4	1	1	1	2
Synthetic Detergents										
12	6.7	1	2	2	4	5.6	0	1	1	2
14	5.4	1	1	2	3	4.6	1	2	2	2
17	6.3	0	1	3	5	4.9	1	5	7	8
26	8.4	0	1	1	1	4.8	1	1	1	1
26 [2]	5.6	1	1	7	9	------	----	----	----	----
Salts of Sulfonated Lignin										
18	7.0	1	1	1	2	5.5	1	1	1	1
19	3.7	1	1	1	2	2.8	2	4	5	7
21	5.1	1	1	1	2	5.5	0	1	2	2
Salts of Petroleum Acids										
11	7.4	0	1	2	4	6.7	1	1	1	1
27	6.5	1	1	1	1	4.1	1	1	1	3
27 [2]	------	----	----	----	----	5.1	1	1	2	2
Salts of Proteinaceous Materials										
24	5.5	1	1	4	9	4.3	1	2	4	8
25	6.3	0	1	3	6	4.1	1	1	2	6
Fatty and Resinous Acids and Their Salts										
8	7.6	0	1	1	3	8.4	1	1	1	1
8 [2]	----	----	----	----	----	4.3	1	1	1	5
9	6.8	1	1	1	2	5.6	1	1	2	2
10	6.7	0	1	1	2	5.5	1	1	1	2
Organic Salts of Sulfonated Hydrocarbons										
23	7.5	1	1	1	2	5.6	1	1	1	3
Miscellaneous										
33	5.7	1	1	1	2	4.5	1	2	2	2
34	5.7	1	1	1	2	6.9	1	1	1	1

[1] Cement A slabs made Feb.–May 1952, and cement B slabs, Mar.–June 1952, then stored in moist air 30 to 120 days and placed in exposure area. Outdoor freezing and thawing with $CaCl_2$ during the winter of 1952–53 for 17 cycles and winter of 1953–54 for 34 cycles.

[2] Repeat of admixtures, 8, 26, and 27 with correct amount of air.

was considered desirable to repeat the early work and extend it to cover other variables. In the spring of 1952 most of the same 27 air-entraining admixtures and a few other admixtures received too late to be used the first year were used with each of two different portland cements to make two series of exposure slabs similar to those made the previous year. The two cements are identified as cements A and B. The winter of 1952–53 was very mild and the 17 cycles obtained were not nearly so severe as those obtained the previous winter. Under the conditions of test all the concretes regardless of the air-entraining admixture or brand of cement gave good resistance after the first year of exposure. These slabs remained in the exposure area during the summer of 1953 and were all tested again during the winter of 1953–54 and were subject to an additional 34 cycles of freezing and thawing, making a total of 51 cycles. Thirty-four cycles were obtained by making tests on Saturdays and Sundays. However, this was also a mild winter with the temperature seldom falling below 25° F.

The ratings of the slabs made with cements A and B are given in table 16. It is interesting to note that the extent of scaling at the end of 51 cycles in general was not as severe as that obtained in the earlier test in 1951–52 where the concrete was exposed to only 19 cycles of severe freezing. The two mild winters and the greater age of the slabs at the time of the second exposure probably accounted for the better resistance of the second series of tests.

Two slabs were made using admixture No. 26 and cement A. In the first the air content was 8.4 percent which was greater than intended. For this reason another slab was made with an air content of 5.6 percent. The slabs with 5.6 percent air were badly scaled (rating of 9) at 51 cycles, whereas the slab with 8.4 percent had a rating of 1 at 51 cycles. This was an indication that slight differences in air contents may account for differences in the scaling on different slabs containing the same admixture. However, when this admixture was used in concrete with cement B and the air content was only 4.8 percent, the resistance to attack by calcium chloride was very good.

A comparison of the results obtained with the two cements used indicates that the slabs containing type B cement were not as severely attacked as those made from type A. In the group of wood resins the concretes containing admixtures 2 and 4 showed ratings of 3 for type B cement at the end of 51 cycles, and the same admixture made with type A cement had scale ratings of 6 and 7, respectively. In the case of concretes containing synthetic detergents, all the slabs with cement A showed extensive scaling except the one containing 8.4 percent air, whereas with those made with cement B only one of the four slabs showed more than slight (rating 2) scaling.

The concrete slab containing cement B and admixture No. 19, sulfonated lignin, and having an air content of 2.8 percent had a rating of 7 at 51 cycles, whereas all the other slabs with higher air contents containing sulfonated lignin had ratings of 2 or less. The lack of resistance to salt action of the one slab in this group may be attributed to the low percentage of entrained air.

The concretes containing salts of petroleum acids, fatty acids and resinous acids and their salts, and the miscellaneous air-entraining admixtures showed satisfactory resistance when used with both cements.

The concretes containing salts of proteinaceous materials showed major scaling with both cements.

One or two representative air-entraining admixtures of each group were used in concrete cast on a sand base. Comparable slabs were cast for both cements A and B. The ratings of these slabs are shown in table 17. Only one slab with cement B had a rating of 3, two had a rating of 1, and the others were rated at 51 cycles.

Table 18 shows a direct comparison between metal and sand bases. In general, the action

Table 17.—Effect of sand bases on resistance of air-entrained concrete to scaling, part 1, cements A and B molded on a sand base and exposed outdoors [1]

Admixture number	Cement A					Cement B				
	Air	Rating after freezing and thawing for—				Air	Rating after freezing and thawing for—			
		12 cycles	17 cycles	39 cycles	51 cycles		12 cycles	17 cycles	39 cycles	51 cycles
BASE MIX: NO AIR-ENTRAINING ADMIXTURE										
	Percent					*Percent*				
None	1.1	1	8	10	10	0.6	2	4	8	10
SALTS OF WOOD RESIN										
2	5.0	1	2	2	2	6.0	1	1	1	2
SYNTHETIC DETERGENTS										
12	3.7	1	2	2	2	4.5	1	1	1	2
15	6.7	1	2	2	2	4.8	1	1	1	1
SALTS OF SULFONATED LIGNIN										
19	3.5	1	1	2	2	2.6	1	1	2	3
SALTS OF PETROLEUM ACIDS										
27	4.3	1	2	2	3	4.3	1	1	1	2
SALTS OF PROTEINACEOUS MATERIALS										
24	4.5	1	2	2	3	3.7	1	1	2	2
FATTY AND RESINOUS ACIDS AND THEIR SALTS										
10	4.3	1	2	2	2	4.2	1	2	2	2
ORGANIC SALTS OF SULFONATED HYDROCARBONS										
23	5.3	1	2	2	3	6.1	1	1	1	1

[1] Slabs made in June 1952, stored in moist air for 30 days, and then stored in exposure area. Outdoor freezing and thawing with $CaCl_2$ during the winter of 1952–53 for 17 cycles and during the winter of 1953–54 for 34 cycles.

Table 18.—Comparison of metal and sand bases on the resistance of air-entrained concrete to scaling, part 1 of outdoor tests [1]

Admixture number	Rating at 51 cycles			
	Cement A		Cement B	
	Metal base	Sand base	Metal base	Sand base
None	10	10	10	10
2	6	2	3	2
12	4	2	2	2
19	2	2	7	3
27	1	3	2	2
24	9	3	8	2
10	2	2	2	2
23	2	3	3	1

[1] These data also appear in tables 16–17.

of calcium chloride is less severe on air-entrained concrete that is cast on a sand base than when the concrete is cast in a watertight metal based mold that does not allow any of the water to escape from the plastic concrete.

Use of fly ash, part 2

Four fly ashes, a fine and coarse fly ash from each of two sources, were each used to replace 33⅓ percent of the cement in a 6-sack mix. The fly ashes (A and B, table 19) from one source had carbon contents of less than 1 percent and those from the other source (X and Y, table 19) had carbon contents of 5.0 and 11.2 percent. From each source the coarser material had the lower carbon content. Two cements were used, cement A and cement B. Cement B had a very low alkali content and cement A a high alkali content. Table 1 contains a comparison of the chemical analyses and calculated compound composition.

The concrete for the exposure slabs was cast in molds with metal bases. Two types of

No fly ash | Fly ash A | Fly ash B | Fly ash X | Fly ash Y

Cement A Non-air-entrained

Cement A Air-entrained

Cement B Non-air-entrained

Cement B Air-entrained

Figure 15.—Effect of fly ash on resistance of concrete to scaling. Test panels photographed in 1954 after 51 cycles of outdoor freezing and thawing with calcium chloride.

Table 19.—Effect of fly ash on resistance of concrete to scaling, part 2, cements A and B molded on metal bases and exposed outdoors [1]

Cement	Fly ash [2]	Air [3]	Rating after freezing and thawing for—			
			12 cycles	17 cycles	39 cycles	51 cycles
NON-AIR-ENTRAINED CONCRETE: CEMENT A						
		Percent				
A	None	1.0	5	8	10	10
A	A	1.0	6	8	10	10
A	B	1.0	6	8	10	10
A	X	1.0	7	8	10	10
A	Y	1.0	6	8	10	10
AIR-ENTRAINED CONCRETE: CEMENT A						
A	None	4.0	1	2	2	3
A	A	4.6	2	3	3	4
A	B	5.4	3	4	4	4
A	X	4.9	4	6	7	7
A	Y	4.3	4	6	6	7
NON-AIR-ENTRAINED CONCRETE: CEMENT B						
B	None	1.0	3	8	10	10
B	A	1.0	4	8	9	10
B	B	1.0	4	8	10	10
B	X	1.0	6	8	10	10
B	Y	1.0	5	8	10	10
AIR-ENTRAINED CONCRETE: CEMENT B						
B	None	6.8	1	2	2	2
B	A	4.0	1	2	4	4
B	B	3.3	5	6	7	7
B	X	3.9	6	8	8	8
B	Y	5.8	6	8	8	8

[1] Slabs made June 1952, stored in moist air 30 days, then stored in exposure area. Outdoor freezing and thawing with $CaCl_2$ during the winter of 1952–53 for 17 cycles and during the winter of 1953–54 for 34 cycles.
[2] Where fly ash was used, 33⅓ percent of the cement was replaced by an equal volume of fly ash.
[3] Air in non-air-entrained mixes calculated, others measured by ASTM tentative method C231–49T.

concrete were used, non-air-entrained and air-entrained concrete. The ratings at 12, 17, 39, and 51 cycles are shown in table 19, and photographs at 51 cycles are shown in figure 15.

The plain concretes without air-entrainment and without fly ash replacements for part of the cement had very poor resistance to attack by the chloride salt. None of the fly ashes used as replacements for part of the cement were effectual in improving the resistance of non-air-entrained concrete to attack by calcium chloride.

Entrained air greatly increased the resistance of the plain concrete. In air-entrained concrete all the fly ash replacements for cement were detrimental to the resistance to scaling of the concrete, as indicated by the ratings of 4 to 8. The alkali content of the cement appeared to have had no relation to the resistance of the resulting concrete to attack by calcium chloride used for ice removal. The extent of attack by calcium chloride did not appear to differ much with the brand of cement or with the fly ash used as a replacement for cement.

Type of curing, part 3

Table 20 gives the ratings of concrete slabs cured by different methods. Portland cement A was used in all slabs. The slabs were cast outdoors in wood molds on sand bases and remained in the molds for 3 days. They were then removed from the molds, the sides painted, and the slabs placed in the exposure area. Two rounds of slabs were made for the non-air-entrained concrete on different days, and one round for the air-entrained concrete. For purposes of comparison, slabs given no curing were cast in molds with metal bases and with sand bases.

Table 20.—Effect of curing on resistance of concrete to scaling, part 3, cement A molded on bases indicated and exposed outdoors [1]

Type base	Initial curing[2]	Surface treatment [3]	Admixture	Rating after freezing and thawing for—			
				12 cycles	17 cycles	39 cycles	51 cycles
NON-AIR-ENTRAINED CONCRETE [4]							
Metal	None	None	None	1	1	1	1
Do	do	do	do	1	2	4	6
Sand	do	do	do	0	1	1	1
Do	do	do	do	1	2	2	3
Do	Burlap	do	do	0	1	1	1
Do	do	do	do	1	3	3	4
Do	do	Lubricating oil	do	0	1	1	1
Do	do	do	do	0	1	1	1
Do	do	None	Lubricating oil	0	1	1	1
Do	do	do	do	1	1	2	2
Do	Paper	do	None	0	1	1	1
Do	do	do	do	1	2	4	9
Do	do	Lubricating oil	do	0	1	3	5
Do	Membrane A	None	do	1	1	1	1
Do	do	do	do	0	1	1	4
Do	Membrane B	do	do	1	1	1	1
Do	do	do	do	0	1	1	2
Do	Lubricating oil	do	Lubricating oil	0	1	2	2
Do	do	do	do	1	1	1	5
Do	do	do	do	0	1	2	3
AIR-ENTRAINED CONCRETE [5]							
Metal	None	None	Vinsol resin	0	1	1	2
Sand	do	do	do	0	1	1	1
Do	Burlap	do	do	1	2	2	2
Do	do	do	Used crankcase oil	1	1	1	1
Do	Paper	do	Vinsol resin	0	1	1	1
Do	Membrane A	do	do	0	1	1	2
Do	Membrane B	do	do	0	1	2	2
Do	Used crankcase oil	do	Used crankcase oil	0	0	2	2

[1] All slabs made outdoors in July 1952, removed from molds after 3 days, and then stored in exposure area. Outdoor freezing and thawing with $CaCl_2$ during the winter of 1952–53 for 17 cycles and the winter of 1953–54 for 34 cycles.
[2] Curing applied after 1½ hours of placing of slab and if removed, removed after 3 days.
[3] Surface protective treatment applied after 28 days.
[4] Air content of non-air-entrained concrete approximately 2 percent.
[5] Air content of air-entrained concrete approximately 4½ percent.

Considerable difference in resistance was observed between the two rounds of test slabs, regardless of curing treatment. All the slabs in round 1, even the slab given no curing, showed better resistance than those cast in round 2 except burlap plus oil. This difference in rounds is a common experience in curing studies carried out under the humidity conditions which prevail in the Washington area. Because of the greater attack on the slabs in round 2, differences due to curing are more apparent. In the discussion that follows only the second round is considered.

In general, the different methods of curing had little effect on the scale resistance of the resulting concrete. Wet burlap curing for 3 days followed by a lubricating oil surface treatment at 28 days was effective in reducing scaling. Concrete containing an admixture of lubricating oil and cured 3 days under wet burlap was also effective in reducing scaling.

With air-entrained concrete little or no scaling occurred, and it is not possible to distinguish between the relative effect of any of the curing methods tried.

Vacuum treatment, part 4

Comparisons were made between the regular method of finishing concrete and the vacuum method. The ratings of the slabs after various cycles are shown in table 21. These specimens were made and cured outdoors. After curing under wet burlap for 3 days the sides were waterproofed and the slabs were then placed in the exposure area.

Non-air-entrained concrete was cast in molds with metal bases and in molds with

[able 21.—Effect of vacuum surface treatment on resistance of plain and air-entrained concrete to scaling, part 4, cement A molded on bases indicated and exposed outdoors [1]

Air	Type base	Surface treatment [2]	Rating after freezing and thawing for—			
			12 cycles	17 cycles	39 cycles	51 cycles
Percent						
1.0	Metal	None	1	1	8	10
1.0	do	do	1	4	10	10
1.0	do	Vacuum	1	2	4	6
1.0	do	do	1	4	7	10
1.0	Sand	None	1	1	9	10
1.0	do	do	1	4	10	10
1.0	do	Vacuum	1	1	2	4
1.0	do	do	0	1	2	3
2.6	do	None	1	1	2	4
2.6	do	Vacuum	0	1	2	2
3.2	do	None	1	1	2	2
3.2	do	Vacuum	0	1	1	1
5.2	do	None	0	1	2	2
5.2	do	Vacuum	0	1	1	1
6.1	do	None	1	1	2	2
6.1	do	Vacuum	0	1	1	1
7.0	do	None	1	1	3	3
7.0	do	Vacuum	0	1	1	2
10.0	do	None	0	1	1	1
10.0	do	Vacuum	0	0	0	0

[1] Slabs made outdoors in September 1952, cured with wet burlap for 3 days, and then stored in exposure area. Outdoor eezing and thawing with $CaCl_2$ during the winter of 1952–53 for 17 cycles and the winter of 1953–54 for 34 cycles.
[2] Vacuum applied to surface of plastic concrete for ½ hour.

amp sand bases. One-half of the specimens ast in each type base were finished in the reg- lar manner by brooming and the other half ere subjected to vacuum finishing using a vacuum pad covering the entire surface of the concrete. A vacuum of 18 to 25 inches of mercury was applied for about 30 minutes. The vacuum pad was removed and the specimen given a final trowel finish. The vacuum-placed slabs were covered with wet burlap 1 hour after they were cast and the others were covered after 2 hours.

The concrete cast in molds with metal bases and subjected to vacuum treatment had about the same resistance to scaling as that placed by the conventional methods. One of the two vacuum-placed specimens had a little better resistance than the other. In the case of the non-air-entrained concrete cast in molds with sand bases, there was a marked improvement in the resistance to scaling of the vacuum-placed specimens. It seems likely that the metal base mold inhibits the removal of the water normally withdrawn by the vacuum process.

The air-entrained concrete specimens for vacuum treatment were cast on sand bases. The air content varied from 2.6 to over 10 percent. The lowest air content of 2.6 percent for the untreated concrete had a rating of 4 at 51 cycles while the comparable vacuum-treated concrete had a rating of 2. The untreated concrete with an air content of 10+ percent had a rating of 1 and the corresponding treated concrete had a rating of 0. In every case the vacuum-placed concrete had a slightly greater resistance to the action of calcium chloride than its untreated counterpart.

REFERENCES

(1) *Experimental use of oil-solvent treatment to control salt scale of concrete pavement,* Illinois Department of Public Works and Buildings, Division of Highways, Illinois Highway Research Project No. 17, Progress Report No. 1, Apr. 1954; also Highway Research Abstracts, July 1954, vol. 24, No. 7.

(2) *Effect of age of concrete on its resistance to scaling caused by using calcium chloride for ice removal,* by W. C. Hansen, Journal of the American Concrete Institute, Jan. 1954, vol. 25, No. 5, p. 341.

(3) *Salt and phosphate to fight snow problems,* American City, Sept. 1952, vol. 67, No. 9, p. 108. (Article describes use of Banox, a phosphate rust inhibitor.)

(4) *Scarboro test road* (a picture), The Maine Trail, Aug. 1952, vol. 12, No. 5, p. 20. (West lane has air-entrained cement and shows hardly a surface blemish; other three lanes have normal cement which is badly scaled and patched. The scaling is due to freezing and thawing and use of salts.)

(5) *Control of concrete pavement scaling caused by chloride salts,* by B. D. Tallamy, Journal of the American Concrete Institute, Mar. 1949, vol. 20, No. 7, p. 513; also discussion by L. E. Andrews, H. F. Gonnerman, Eivind Hognestad, Ira Paul, and A. G. Timms, Journal of the American Concrete Institute, Part II, Dec. 1949, vol. 21, No. 4, p. 520–1.

(6) *Requisites and specifications for curing concrete,* by H. C. Vollmer, Proceedings of the 23rd Annual Convention of the Association of Highway Officials of the North Atlantic States, 1947, p. 176. (Approximately 100 miles of concrete pavements in three New England States, constructed with integral or surface calcium chloride curing, show no scaling after 15 to 20 years of service even though subjected to annual salt treatments for removal of ice.)

(7) *Experimental test data in connection with the development of chloride resisting concrete by the use of treated portland cements and blends with natural cement,* by A. A. Anderson, Proceedings of the 17th Annual Convention of the Association of Highway Officials of the North Atlantic States, 1941, p. 67; also Explosives Engineer, Jan. 1942, vol. 20, No. 1, p. 10.

(8) *The use of common salt for the removal of ice on concrete roads,* by A. R. Collins, Roads and Road Construction, May 1940, vol. 18, No. 209, p. 98; also Journal of the American Concrete Institute, Jan. 1941, vol. 12, No. 3, p. 305.

(9) *Pavement scaling successfully checked,* by O. L. Moore, Engineering News-Record, Oct. 1940, vol. 125, p. 471.

(10) *Experimental data in connection with chloride salts-resistant concrete pavement,* by C. C. Ahles, Explosives Engineer, Sept. 1940, vol. 18, No. 9, p. 267.

(11) *Chloride-salts-resistant concrete in pavements,* by Ira Paul, Proceedings of the 14th Annual Convention of the Association of Highway Officials of the North Atlantic States, 1938, p. 144.

(12) *Effect of calcium and sodium chlorides on concrete when used for ice removal,* by H. F. Gonnerman, A. G. Timms, and T. G. Taylor, Journal of the American Concrete Institute, Nov.–Dec. 1936, vol. 8, No. 2, p. 107.

(13) *Treatment of icy pavements,* by B. C. Tiney, Proceedings of the 13th Annual Meeting of the Highway Research Board, Part I, 1934, vol. 13, p. 330.

New Publication

The Bureau's *Highway Statistics, 1953*, the ninth of the bulletin series presenting annual statistical and analytical tables of general interest on the subjects of motor fuel, motor vehicles, highway-user taxation, financing of highways, and highway mileage is now available.

The 142-page publication may be purchased from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., at $1.00 a copy. The full series of the annual bulletins are available from the Superintendent of Documents, as indicated on the inside back cover of PUBLIC ROADS.

Traffic Article Postponed

The article *Trends in Traffic Volumes, Vehicle Types, and Weights* which has appeared annually in PUBLIC ROADS magazine since 1946 will not be included this year.

The comprehensive study of highways, begun in 1954 in accordance with section 13 of the Federal-aid Highway Act of 1954, was given preference over the work of reporting and analyzing the 1953 traffic trends data. The consequent postponement of this work has delayed the publishing of the usual traffic trends article for this one year. Tabular material, which would have been a part of the report had it been published, is available to subscribers of PUBLIC ROADS, and a set of tables giving 1953 traffic information will be furnished upon request.

Traffic data furnished in conjunction with the Section 13 study will undoubtedly result in revisions being made in tables now being made available for 1953. Furthermore, the new information resulting from the Section 13 study will make it possible to check a series of estimates of total rural and urban travel. These estimates have not been published since 1948, because the many circumstances affecting travel made it inadvisable to publish the information without a sufficient body of current basic data to check the es mates of rural and urban travel prepared o a trend basis.

The present plan is to publish in PUBL ROADS the 1953 traffic trends data along wi that for 1954 when it becomes available. is expected that the consolidated article w include an analysis of all rural and urb travel, similar to that reported in 1948.

Errata

The new pamphlet *Revisions to the Manu on Uniform Traffic Control Devices for Stre and Highways*, announced in the Februa issue of PUBLIC ROADS on page 141 and i cluded with the list of publications on t inside back cover of the magazine, was i correctly priced. The correct amount f the Manual (including the 1954 revisio supplement) is $1.00 instead of 90 cent The price of the Revisions pamphlet alo is 15 cents.

U. S. GOVERNMENT PRINTING OFFICE: 1955

A list of the more important articles in PUBLIC OADS may be obtained upon request addressed , Bureau of Public Roads, Washington 25, D. C.

PUBLICATIONS of the Bureau of Public Roads

The following publications are sold by the Superintendent f Documents, Government Printing Office, Washington 25, . C. Orders should be sent direct to the Superintendent of ocuments. Prepayment is required.

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/ork of the Public Roads Administration:
- 1941, 15 cents. 1948, 20 cents.
- 1942, 10 cents. 1949, 25 cents.

ublic Roads Administration Annual Reports:
- 1943; 1944; 1945; 1946; 1947.
- (*Free from Bureau of Public Roads*)

nnual Reports of the Bureau of Public Roads:
- 1950, 25 cents. 1952, 25 cents. 1954, (out of print).
- 1951, 35 cents. 1953, 25 cents.

UBLICATIONS

ibliography of Highway Planning Reports (1950). 30 cents.
raking Performance of Motor Vehicles (1954). 55 cents.
onstruction of Private Driveways, No. 272MP (1937). 15 cents.
riteria for Prestressed Concrete Bridges (1954). 15 cents.
esign Capacity Charts for Signalized Street and Highway Intersections (reprint from PUBLIC ROADS, Feb. 1951). 25 cents.
ectrical Equipment on Movable Bridges, No. 265T (1931). 40 cents.
ictual Discussion of Motortruck Operation, Regulation, and Taxation (1951). 30 cents.
deral Legislation and Regulations Relating to Highway Construction (1948). Out of print.
nancing of Highways by Counties and Local Rural Governments, 1931–41. 45 cents.
ighway Bond Calculations (1936). 10 cents.
ghway Bridge Location No. 1486D (1927). 15 cents.
ighway Capacity Manual (1950). 75 cents.
ighway Needs of the National Defense, House Document No. 249 (1949). 50 cents.
ghway Practice in the United States of America (1949). 75 cents.
ghway Statistics (annual):
- 1945, 35 cents. 1948, 65 cents. 1951, 60 cents.
- 1946, 50 cents. 1949, 55 cents. 1952, 75 cents.
- 1947, 45 cents. 1950 (out of print). 1953, $1.00.

ghway Statistics, Summary to 1945. 40 cents.
ghways in the United States, *nontechnical* (1954). 20 cents.
ghways of History (1939). 25 cents.
entification of Rock Types (1950). Out of print.
erregional Highways, House Document No. 379 (1944). 75 cents.
gal Aspects of Controlling Highway Access (1945). 15 cents.
cal Rural Road Problem (1950). 20 cents.
anual on Uniform Traffic Control Devices for Streets and Highways (1948) (*including 1954 revisions supplement*). $1.00.
- Revisions to the Manual on Uniform Traffic Control Devices for Streets and Highways (1954). *Separate*, 15 cents.

athematical Theory of Vibration in Suspension Bridges (1950). $1.25.
odel Traffic Ordinance (revised 1953). 20 cents.

PUBLICATIONS (Cont'd)

Motor-Vehicle Traffic Conditions in the United States, House Document No. 462 (1938):
- Part 1.—Nonuniformity of State Motor-Vehicle Traffic Laws, 15 cents.
- Part 2.—Skilled Investigation at the Scene of the Accident Needed to Develop Causes. 10 cents.
- Part 3.—Inadequacy of State Motor-Vehicle Accident Reporting. 10 cents.
- Part 4.—Official Inspection of Vehicles. 10 cents.
- Part 5.—Case Histories of Fatal Highway Accidents. 10 cents.
- Part 6.—The Accident-Prone Driver. 10 cents.

Principles of Highway Construction as Applied to Airports, Flight Strips, and Other Landing Areas for Aircraft (1943). $2.00.
Public Control of Highway Access and Roadside Development (1947). 35 cents.
Public Land Acquisition for Highway Purposes (1943). 10 cents.
Results of Physical Tests of Road-Building Aggregate (1953). $1.00.
Roadside Improvement, No. 191MP (1934). 10 cents.
Selected Bibliography on Highway Finance (1951). 60 cents.
Specifications for Construction of Roads and Bridges in National Forests and National Parks, FP–41 (1948). $1.50.
Standard Plans for Highway Bridge Superstructures (1953). $1.25.
Taxation of Motor Vehicles in 1932. 35 cents.
Tire Wear and Tire Failures on Various Road Surfaces (1943). 10 cents.
Transition Curves for Highways (1940). $1.75.

MAPS

State Transportation Map series (available for 39 States). Uniform sheets 26 by 36 inches, scale 1 inch equals 4 miles. Shows in colors Federal-aid and State highways with surface types, principal connecting roads, railroads, airports, waterways, National and State forests, parks, and other reservations. Prices and number of sheets for each State vary—see Superintendent of Documents price list 53.
United States System of Numbered Highways together with the Federal-Aid Highway System (also shows in color National forests, parks, and other reservations). 5 by 7 feet (in 2 sheets), scale 1 inch equals 37 miles. $1.25.
United States System of Numbered Highways. 28 by 42 inches, scale 1 inch equals 78 miles. 20 cents.

Single copies of the following publications are available to highway engineers and administrators for official use, and may be obtained by those so qualified upon request addressed to the Bureau of Public Roads. They are not sold by the Superintendent of Documents.

Bibliography on Automobile Parking in the United States (1946).
Bibliography on Highway Lighting (1937).
Bibliography on Highway Safety (1938).
Bibliography on Land Acquisition for Public Roads (1947).
Bibliography on Roadside Control (1949).
Express Highways in the United States: a Bibliography (1945).
Indexes to PUBLIC ROADS, volumes 17–19 and 23.
Title Sheets for PUBLIC ROADS, volumes 24–27.

UNITED STATES
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OFFICIAL BUSINESS

STATUS OF FEDERAL-AID HIGHWAY PROGRAM

AS OF FEBRUARY 28, 1955

(Thousand Dollars)

STATE	UNPROGRAMMED BALANCES	ACTIVE PROGRAM											
		PROGRAMMED ONLY			PLANS APPROVED, CONSTRUCTION NOT STARTED			CONSTRUCTION UNDER WAY			TOTAL		
		Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles
Alabama	$15,053	$13,116	$7,035	337.5	$2,308	$1,494	9.3	$43,649	$21,859	665.1	$59,073	$30,388	1,011.9
Arizona	5,301	7,194	4,814	93.7	1,159	823	25.3	8,360	5,821	139.3	16,713	11,458	258.3
Arkansas	11,022	10,932	5,996	429.6	1,924	1,122	29.8	17,112	8,458	423.5	29,968	15,576	882.9
California	8,687	23,260	12,881	161.2	17,301	9,284	38.6	117,811	58,098	333.7	158,372	80,263	533.5
Colorado	14,182	7,109	4,105	104.4	3,243	1,771	62.8	13,950	7,758	164.8	24,302	13,634	332.0
Connecticut	16,170	537	268	1.7	2,822	1,401	3.2	10,080	4,840	8.1	13,439	6,509	13.0
Delaware	4,523	767	389	4.0	2,064	1,032	7.0	6,866	3,793	23.9	9,697	5,214	34.9
Florida	10,604	20,407	10,425	242.0	10,303	5,260	61.6	20,118	10,345	316.9	50,828	26,030	620.5
Georgia	18,615	12,504	6,329	182.1	10,748	4,590	45.8	52,654	25,197	1,000.0	75,906	36,116	1,227.9
Idaho	3,863	8,635	5,516	112.9	3,427	2,139	61.1	11,940	7,506	186.1	24,002	15,161	360.1
Illinois	15,239	66,585	36,654	678.2	16,657	8,747	116.3	64,405	33,817	298.2	147,647	79,218	1,092.7
Indiana	18,930	34,874	17,657	144.6	22,949	11,692	133.8	28,397	15,203	111.9	86,220	44,552	390.3
Iowa	11,451	15,680	8,399	580.8	10,282	5,614	168.9	15,965	8,928	654.8	41,927	22,941	1,404.5
Kansas	14,989	9,321	4,757	692.8	3,639	1,855	62.7	19,989	9,996	881.9	32,949	16,608	1,637.4
Kentucky	12,956	12,902	6,893	89.3	4,537	2,393	75.7	26,719	13,407	254.0	44,158	22,693	419.0
Louisiana	12,884	13,772	6,875	156.8	8,463	4,231	42.7	26,245	11,960	117.4	48,480	23,066	316.9
Maine	5,939	6,861	3,738	31.8	559	283	4.5	14,942	7,574	128.8	22,362	11,595	165.1
Maryland	6,604	22,663	11,807	65.2	5,398	2,598	13.2	9,427	5,097	52.0	37,488	19,502	130.4
Massachusetts	16,409	5,809	2,894	19.2	3,494	1,740	6.4	47,845	22,347	38.8	57,148	26,981	64.4
Michigan	16,755	40,783	21,175	626.3	13,915	7,004	193.5	36,977	18,658	228.2	91,675	46,837	1,048.0
Minnesota	18,128	12,030	6,285	929.0	8,055	4,096	279.7	14,659	7,948	369.2	34,744	18,329	1,577.9
Mississippi	6,888	15,421	7,521	502.3	8,153	4,241	217.6	20,284	10,436	386.3	43,858	22,198	1,106.2
Missouri	14,373	16,767	8,845	843.1	13,403	7,118	89.9	64,519	33,285	1,002.9	94,689	49,248	1,935.9
Montana	15,580	11,714	7,047	289.5	1,549	960	24.2	22,745	14,048	442.8	36,008	22,055	756.5
Nebraska	11,593	28,847	15,116	1,116.3	4,907	2,458	100.5	17,273	10,080	486.2	51,027	27,654	1,703.0
Nevada	10,548	3,965	3,379	122.0	1,706	1,355	22.6	4,727	3,870	50.7	10,398	8,604	195.3
New Hampshire	5,611	2,168	1,259	11.7	381	194	1.7	6,297	3,074	36.9	8,846	4,527	50.3
New Jersey	22,098	5,556	2,471	45.2	5,473	2,228	5.8	19,965	9,345	27.3	30,994	14,044	78.3
New Mexico	6,769	4,600	2,860	119.9	2,754	1,706	66.3	10,200	6,531	160.3	17,554	11,097	346.5
New York	45,905	46,750	24,523	84.9	17,338	8,640	7.1	196,625	91,559	292.6	260,713	124,722	384.6
North Carolina	17,081	19,912	9,922	339.2	3,932	1,903	64.7	39,841	18,554	531.4	63,685	30,379	935.3
North Dakota	8,023	11,736	5,994	1,217.9	3,478	1,762	303.2	4,916	2,456	272.5	20,130	10,212	1,793.6
Ohio	28,200	31,503	15,432	83.4	13,502	5,643	25.6	56,251	26,775	117.6	101,256	47,850	226.6
Oklahoma	21,303	6,144	3,258	206.4	10,597	5,701	124.6	20,758	10,833	310.3	37,499	19,792	641.3
Oregon	9,347	3,978	2,379	68.9	399	244	14.3	13,847	8,567	171.4	18,224	11,190	254.6
Pennsylvania	19,141	56,049	28,013	194.4	12,489	6,029	7.2	87,274	43,138	166.5	155,812	77,180	368.1
Rhode Island	3,563	5,700	2,850	16.9	3,535	1,768	14.9	7,259	3,624	18.1	16,494	8,242	49.9
South Carolina	12,234	8,506	4,665	175.4	2,062	1,112	21.3	14,290	7,497	255.0	24,858	13,274	451.7
South Dakota	5,586	18,755	10,603	978.9	2,352	1,317	155.2	6,631	3,747	336.7	27,738	15,667	1,470.8
Tennessee	14,843	18,237	9,072	419.0	9,183	4,592	102.3	30,933	13,483	340.1	58,353	27,147	861.4
Texas	39,078	16,251	9,330	224.5	11,275	6,078	185.0	75,991	40,170	1,191.3	103,517	55,578	1,600.8
Utah	6,325	5,606	4,172	131.4	2,963	2,211	68.0	3,601	2,826	21.0	12,170	9,209	220.4
Vermont	4,847	1,125	565	17.6	129	74		7,377	3,675	64.2	8,631	4,314	81.8
Virginia	16,871	10,666	5,418	171.6	4,764	2,303	61.2	19,168	9,318	207.3	34,598	17,039	440.1
Washington	11,845	9,259	5,362	177.9	3,256	1,743	35.2	18,934	9,750	142.6	31,449	16,855	355.7
West Virginia	12,065	9,889	5,026	44.1	4,857	2,443	38.2	13,053	6,551	48.6	27,799	14,020	130.9
Wisconsin	14,324	27,883	13,692	431.0	1,162	597	16.2	27,407	13,906	273.6	56,452	28,195	720.8
Wyoming	1,857	9,269	6,077	234.5	2,369	1,548	70.2	8,184	5,150	147.4	19,822	12,775	452.1
Hawaii	4,031	3,514	1,757	3.2	1,441	527	2.8	5,436	2,559	15.1	10,391	4,843	21.1
District of Columbia	5,497	5,694	2,847	8.3	2,170	1,069	1.1	13,521	6,430	1.1	21,385	10,346	10.5
Puerto Rico	9,586	5,755	2,804	34.0	1,792	862	5.9	13,515	6,007	41.7	21,062	9,673	81.6
TOTAL	663,316	766,960	407,151	13,996.5	306,618	157,595	3,294.7	1,458,932	735,854	13,956.1	2,532,510	1,300,600	31,247.3