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The abrasion samples tested in this study were cored from laboratory slabs constructed to simulate some of the field conditions and other factors encountered in placing, finishing, and curing of concrete bridge decks and pavement. Although the data presented are limited in scope, relative values of "abrasion losses" are established and are indicative of what might be expected in the field.

Results of these tests show that slump, curing, and time of finishing are the most important factors affecting the abrasion resistance of concrete surfaces. Concrete receiving an application of a mono molecular film to retard evaporation during the finishing period showed an increase in abrasion resistance. A two-coat surface treatment of linseed oil, applied when the concrete had partially dried, was found to increase abrasion resistance appreciably regardless of other variables.

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FACTORS AFFECTING DURABILITY OF CONCRETE SURFACES

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MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

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FACTORS AFFECTING DURABILITY OF CONCRETE SURFACES

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ABSTRACT

A laboratory research program on abrasion resistance of concrete surfaces, including the development of an impact-type abrasion test for testing of cored specimens, is described. Variables incorporated in this study were slump, finishing, curing, surface treatments (linseed oil and monomolecular film), and the use of admixtures. Sand with a low mortar strength was substituted for the laboratory stock sand in two tests. In addition to the abrasion tests on concrete cores, hardened concrete specimens were examined for air content and void distribution by the linear traverse method. A brief summary of reports by others on the causes and prevention of concrete wearing surface deterioration is also presented.

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INTRODUCTION AND BACKGROUND

In recent years, the deterioration of concrete wearing surfaces has become a major problem. This deterioration takes many forms, among which are scaling, ravelling, abrasion, spalling, pitting and cracking. A group of papers presented at the 41st Annual Meeting of the Highway Research Board in January, 1962[1], provides a comprehensive analysis of the problem and suggests preventive measures that may be taken both during and after construction. These papers deal predominantly with the effects of de-icing chemicals on concrete structures. The use of these chemicals is considered to have contributed to the observed increase in scaling and possibly other concrete defects as well.

Although air entrainment has been shown[1,2] to provide protection against damage from de-icing agents as well as from freezing and thawing, poor construction practices can negate much or all of this protection. Oleson[1-A] has cited an instance where the air content of concrete cores varied considerably between the surface and other height levels of the core. In this case, two cores were taken from adjacent lanes of a concrete pavement; one from a lightly scaled area, and the other from an undamaged area. Both cores had a total air content of over 5% as determined by the linear traverse method. However, a determination of top surface air content revealed 3.7% air in

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the core from the scaled area, while the core from the unscaled area had 7.6% air at the surface. Based on observations and photographs made during construction of the pavement, the low surface air content of the scaled area was attributed to the excessive use of water sprinkled on the surface as an aid in finishing.

Excessive floating and over-vibration can create a layer of surface mortar which will be weak and subject to early scaling and abrasion. These practices may also drive out entrained air making the surface susceptible to damage from de-icing salts and freezing and thawing. Rigid adherence to the specifications through proper inspection and control testing can eliminate much of the danger of concrete deterioration due to these and other poor construction practices.

There remains some doubt that improvements in concrete technology and construction methods will ever completely solve the problem of concrete deterioration. Mitchell[3] is of the opinion that water is the common denominator of all generally recognized types of concrete deterioration, and a high degree of imperviousness is necessary to achieve permanent durability. Since concrete is essentially a porous product, he believes that surface treatments are necessary to insure adequate imperviousness.

Numerous materials have been investigated for use in sealing concrete surfaces. Among these are bituminous products, silicones, latexes, epoxy resins, vegetable oils, and special curing compounds. The primary objective in most of the

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investigations of surface treatments was to determine the effectiveness of the product in the prevention of surface scaling caused by de-icing chemicals.

Linzell[1-B] has reported that the Ohio Department of Highways experimented with surface treatments in 1941. A mixture of linseed oil and kerosene was applied to five 1-mile sections of non-air-entrained concrete pavement. Remarkably improved resistance to scaling was claimed after repeated observations during subsequent years. Details concerning the mixture used and the rate of application are not reported.

In a study by the Ontario Department of Highways[1-C], various surface treatments were evaluated to determine their effect on freeze-thaw durability and scaling resistance of concrete. The study consisted of the examination of existing treated structures and pavements, controlled field trials, and laboratory tests. Some phases of the investigation were not complete at the time this report was made and only limited conclusions could be drawn. Both laboratory and field tests indicated that silicones did not give lasting protection to concrete. Laboratory and field results with a 50:50 mixture of linseed oil and kerosene were contradictory. Although laboratory tests indicated that ultimate durability was probably not improved, field tests showed that two coats of the linseed oil-kerosene mixture offered effective protection, at least during the first winter. Since 1959, all new concrete pavements in Ontario have been treated with two coats of the linseed oil mixture and the

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general conclusion is that this is an effective and economical method of protecting concrete against freeze-thaw damage and scaling.

Wisconsin[1-D] has used silicones as a preservative treatment during construction, but field observations indicate that such treatments are not particularly effective. They are now experimenting with other types of surface treatments such as linseed oil, rubberized asphalt seal coats, and epoxies.

In Iowa[1-E], pavements and bridge decks placed after October 15 and which will be subjected to de-icers, are treated with two coats of a linseed oil emulsion. Michigan[1-F] has experimented with various water repellants and surface penetrants. Laboratory tests indicate two coats of linseed oil to be as good or better in preventing surface scale than any of the proprietary products studied.

In controlled laboratory tests performed by the Bureau of Public Roads[4], the application of two coats of linseed oil was found to be beneficial in preventing or delaying scaling caused by the use of de-icing chemicals. The improvement in scaling resistance was minor for air-entrained concrete, but very pronounced for non-air-entrained concrete. The use of boiled linseed oil resulted in equal or slightly better resistance to scaling than raw linseed oil. The Bureau Office of Research and Development now recommends the use of linseed oil applications where de-icing chemicals are used.

The Texas Transportation Institute[5] has also conducted a study to determine the effectiveness of various

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waterproofing compounds. A total of eighteen products were evaluated by wetting and drying tests and freeze-thaw tests on non-air-entrained concrete. Results indicated that a two-coat treatment with linseed oil was the most effective of the products tested in reducing movement of water through concrete and in protecting against freeze-thaw damage.

California has also experienced problems with concrete surface deterioration in some mountainous areas. Some loss of surface has occurred in both pavement and bridge decks. Air entrainment was specified for all concrete in these freeze-thaw areas, but such defects as scaling and ravelling have appeared, suggesting the possibility that either not enough air was entrained, or that surface finishing removed air needed at the surface for frost protection. Deterioration of bridge decks was so extensive that in 1964, a contract was let to resurface 34 decks with an epoxy-type overlay to retard further deterioration. The average age of these bridges was about five years.

The problem of concrete distress is not limited to mountainous regions where it is thought that de-icing chemicals have contributed to the rapid deterioration of concrete surfaces. A highway near Los Angeles in the southern part of the State shows scaling and abrasion damage, although it is not subjected to freezing temperatures. Whether common factors exist which contribute to surface deterioration in these completely different environments, has not yet been determined.

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In a paper titled "Abrasion Resistance"[6], Kennedy and Prior summarize much of the work done on this subject with an emphasis on the methods of testing. They point out that cement factor, air content, and curing have all been shown to be important factors in abrasion resistance. They concluded that since these factors are related to compressive strength, it is reasonable to accept strength as a criterion of wear resistance. Witte and Backstrom[7] also state that compressive strength is the most important factor controlling the abrasion resistance of concrete; abrasion resistance increasing as compressive strength increases. If compressive strength could be accepted as the sole criterion for abrasion resistance, the solution to the problem would be relatively simple; merely specify high strength concrete wherever surfaces are subject to abrasion. However, abrasion has also been noted on surfaces of concrete with relatively high compressive strength (above 4000 psi). It appears, therefore, that other factors must be considered as affecting abrasion resistance, and compressive strength alone cannot be used as a criterion for durable concrete.

Concrete surfaces with poor durability have been a problem on some highways in California. In an effort to find means of improving surface durability, particularly of wearing surfaces, a research project was initiated by the Materials and Research Department. It was hoped that a test could be developed to measure the surface quality of concrete and to correlate this test with concrete performance in the field. Since this goal

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has not been fully realized, further work is planned to correlate the findings reported here with field performance.

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TEST METHOD DEVELOPMENT

From literature research, it was found that various test methods have been used by investigators to determine resistance of concrete to surface wear. Among these are the dressing-wheel, revolving disk, shot-blast, rolling steel balls under pressure, and a modified Los Angeles Rattler. These methods have met with varying degrees of success.

Since it was felt that an impact-type test might be more satisfactory for evaluating abrasion resistance, a test method of this type was devised. This was done by modifying an existing test which had been developed for determining the surface loss of a compacted bituminous mixture[8] when subjected to impact abrasion. The complete procedure, as adopted and used in this project, is described and illustrated at the end of this report. Briefly, the test consists of placing a 4-inch diameter by 2-inch high specimen in a 5-inch high container, adding steel balls and water, and shaking for three minutes on a mechanical shaker. (See photographs.)

In preliminary tests, specimens were fabricated individually in gang molds. However, with this method, it is difficult to duplicate fabrication and finishing procedures. Another method involved casting concrete slabs two inches thick from which a number of cores could be taken. This practice

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did produce more consistent results, but coarse aggregate near the surface could still cause a non-uniform finish. To improve on the uniformity of the concrete surfaces and more nearly simulate field conditions, the block thickness was increased to 5 inches. Although this necessitated sawing each core to the 2-inch test height, it is believed that more realistic results were obtained. The appearance of the concrete surfaces after the impact abrasion test is very similar to the abraded concrete surfaces observed in the field.

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TEST PROGRAM

A test program was designed to provide a comparison of the effects of various simulated field conditions, the use of certain admixtures, and the application of surface treatments on abrasion resistance. The test program included the following variables: slump, finishing, curing, admixtures consisting of one air-entraining agent and two water-reducing retarders, a fine aggregate which had failed the mortar strength test, and surface treatments with linseed oil. Blocks were also treated with a monomolecular film which is intended to retard water evaporation during the finishing period. A total of twenty-six 14x21x5-inch blocks were fabricated.

Since mixing had to be spread over an eight-day period, the variables to be mixed each day were selected by a statistically random method.

Fabrication

Test concrete was made using 3/4-inch maximum size aggregates from the American River near Sacramento. (See Table 11 for grading.) An exception was made in two of the mixes where a lower quality sand was substituted for the American River sand. Cement was Type II modified at 6 sacks per cubic yard. Mixing was done in an open tub-type mixer following a

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standard laboratory procedure. Slump, unit weight, and air content was determined and the concrete was then placed in 14x21x5-inch wooden molds. A 1-1/4-inch stinger-type vibrator was used for compaction by quickly inserting the tip of the vibrator into the concrete and removing just slowly enough not to leave a void. The same pattern of 20 vibrator strokes was used on each test slab.

Finishing

In an effort to simulate bridge deck finishing, the following procedures were followed for the two conditions indicated:

Time After Vibration	Early Finish	Delayed Finish
15 minutes	Strike off 1/8" high* with 2 passes of float. Alternate direction of each pass.	Same as Early
30 minutes	Float in 4 passes, removing approximately 1/2 of excess mortar.	Spray with water, float in 4 passes removing approx. 1/3 of remaining excess mortar.
45 minutes	Float in 4 passes, removing excess mortar down to top of form. Broom the surface.	Spray with water, float in 4 passes removing 1/2 of the remaining excess mortar.
180 minutes	No further treatment	Spray with water, float in 4 passes removing excess mortar down to the top of form. Broom the surface.

*1/8-in. high wood strips placed on top of forms, then removed after strike-off leaving excess material to be removed during subsequent finishing.

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Curing

For those blocks receiving a standard cure (indicated in tables as "Std."), wet mats were applied as soon as the surface sheen had left the concrete. Forms were removed the following day and the concrete blocks placed in the moist curing room. When the concrete was 7 days old, the test blocks were removed from the moist curing room and stored in laboratory air which is maintained at approximately 73°F and 50% relative humidity.

Three of the test blocks received a freezing treatment intended to simulate unexpected freezing conditions which might occur during construction. After approximately 24 hours of moist curing, the block was placed in a freezer and exposed to air at 15°F for 8 hours a day on three consecutive days. Blocks were covered with wet mats when not in the freezer. Thermocouples placed in the concrete indicated minimum temperatures of 24° at a 1-inch depth and 27° at 2 inches. At four days of age, the concrete blocks were stripped from the molds and placed in the moist curing room. They remained there for three days before being removed and stored in laboratory air.

To simulate a lack of proper curing (indicated in tables as "Adv." for adverse) during the first three days following placement, eight test blocks were left uncovered for the first 24 hours, then placed in a 100°F oven for eight hours a day on three consecutive days. Blocks were stored

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in laboratory air when not in the oven. After the "drying" period, blocks were stripped from the molds and placed in the moist curing room where they remained for three days before being removed and stored in laboratory air.

Monomolecular Film Surface Treatment

A series of blocks were sprayed immediately after strike-off with a solution to produce a monomolecular film which retards evaporation of the water from the fresh concrete surface. The material was supplied in a concentrated form, but was diluted with water according to the manufacturer's directions to an 80:1 solution before applying. Rate of application was one gallon of solution to 250 square feet of concrete surface.

Linseed Oil Surface Treatment

A number of blocks received a two-coat treatment of linseed oil when the concrete was 14 days old. For the first coat, the linseed oil was diluted 1:1 with turpentine and the solution applied at the rate of one gallon per 360 square feet. The second coat was applied undiluted at one gallon per 600 square feet.

Admixtures

The air-entraining agent used for this project was a

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Vinsol resin product. Two water-reducing retarders were used; a hydroxylated carboxylic acid type at 3-fluid ounces per sack of cement, and lignosulfonate type at 0.25-lb per sack. No adjustments in aggregate proportions were made when the retarders were used, but sand was reduced 2% for the air-entrained mixes. (See Table 11 for grading of the aggregate.)

Low Quality Sand

In making two of the blocks, stock sand was replaced by sand of lower quality. The lower quality material had a relative mortar strength of about 80% as determined by Test Method No. Calif. 515 (a modification of ASTM C 109), compared to 95% for the stock sand.

Test Specimen Preparation

Test blocks were cored when the concrete was 17 to 19 days old. Five 4-inch diameter cores were taken from each block for the abrasion test. An additional core was taken from selected blocks for determining void characteristics by the linear traverse method.

Since the abrasion specimens were to be two inches high, the bottom three inches of each core was cut off and discarded. The cores for void determination were sliced horizontally so that sections at the top surface, 1/2-inch below the top surface, and in two cases, the center of the core, could be examined individually.

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Abrasion test specimens were placed in water to soak 24 hours before testing, in accordance with the standard test procedure.

Abrasion Test

At 21 days of age, specimens were tested according to the method described in the appendix. Results of the abrasion tests and other pertinent information can be found in Tables 1 through 11.

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DISCUSSION

A tabulation of fresh concrete properties, test variables, abrasion losses on the hardened concrete at 21 days of age, and the relative abrasion losses are shown in Table 1. The effects of each variable on abrasion loss are shown in Tables 2 through 8.

Effects of Slump - Table 2

Four of the five comparisons between slumps of three inches and six inches show that this increase in slump causes an increase in abrasion loss, the average increase being about 15%.

Effects of Finishing - Table 3

Results of tests on specimens which had received a delayed finish show that the average abrasion loss was decreased about 20% over similar blocks which received the early finish. This was contrary to expectations as it was thought that the addition of water to the surface before each floating would weaken the concrete, and that the delayed floating would prevent the forming of a dense surface. It is possible that the added water was entirely removed, together with some or all of the surface mortar during the finishing process, and thus had no detrimental effect.

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The above finding agrees with a report by Klieger[9] that to improve scaling resistance (and surface durability), it appears desirable to delay final finish as long as possible. Michigan[1-F] has adopted a procedure of this type for certain portions of bridge construction. Deep structural members are built up slightly higher than the finished dimension and struck off to proper elevation when bleeding has stopped. This is intended to eliminate a possible weak top layer of mortar formed with excessive water.

Effects of Curing - Table 4

The lack of proper curing resulted in a significant increase in abrasion loss. This was also noted during preliminary testing when different curing procedures were followed. Although the adverse cure might have been more severe than would occur in actual practice, the results clearly indicate the need for proper curing.

Effects of Freezing and Thawing During Curing Period - Table 4-A

The interruption of the curing cycle by intermittent freezing caused only a slight increase in abrasion loss.

Effects of Admixtures - Table 5

Abrasion test results on concrete containing air-entraining agents and water-reducing retarders are shown.

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The effect of these agents on abrasion loss is inconclusive, but does not appear to be significant.

Effects of Linseed Oil Treatment - Table 6

The application of two coats of linseed oil increased the abrasion resistance in every case, the average increase being about 30%. This supports the findings of others, as mentioned earlier in this report, that linseed oil improves the durability of concrete surfaces. It is evident that linseed oil strengthens the surface in addition to deterring the entry of moisture. The beneficial effects of the linseed oil treatment would be expected to be more pronounced for poorly cured or porous concrete surfaces than for high density, properly cured concrete.

Effects of Monomolecular Film - Table 7

The results of tests on concrete which had been treated with a monomolecular film are shown. Specimens which had received the treatment and an early finish, show an increase in abrasion resistance of approximately 20% when compared to untreated specimens. For some undetermined reason, the treated specimens with delayed finish did not show the increase. Possibly the additional manipulation destroyed the continuity of the film.

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Effects of Low Quality Sand - Table 8

The substitution of sand of low relative mortar strength (80%) for stock sand (95%) did not appear to have any significant effect on abrasion loss. However, it is probable that insufficient tests were made to provide conclusive data.

Cumulative Effect of Variables - Table 9

Variables that significantly increase abrasion losses can have a cumulative effect as shown by this table.

Linear Traverse Data - Table 10

Data obtained by linear traverse examination of core sections taken from different depths below the finished surface is presented. The top surface was ground and polished just enough to produce a plane surface. For each of the variables so examined, the air content at the surface was calculated to be considerably lower than that determined on the fresh concrete. Even at 1/2-inch below the surface, the air content was significantly lower. Air content determined at the center of cores from air-entrained concrete checked closely with that measured in the fresh concrete. It appears that vibrating the concrete drove off part of the air, especially from the surface. It is possible that this action contributes more to decreasing the durability of concrete surfaces (exposed to freezing and thawing) than has previously been realized. In

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certain instances, the top surface of air-entrained concrete placed in the field has likely been left with insufficient entrained air for protection against freezing.

The spacing factor of the air void system has been considered by some[10,11] to provide a criterion for determining satisfactory frost protection. Powers[10] has stated that the spacing factor should not exceed 0.01-inch. As shown in Table 10, the air-entrained concrete had spacing factors well below this figure at all three levels of the core. The surface sections contained the least amount of air but indicated the lowest spacing factors. However, since the percentage of paste content used in the calculations was that of the total mix, there is an inherent error in the values shown for the surface spacing factors. The paste content at the surface is higher than that for the mass; therefore, the actual spacing factors would also be higher if arbitrary corrections were made.

Since the mortar concentration is greatest at the surface, it follows that the air content at that point should be considerably greater than that in the concrete to provide equivalent frost protection. Mortar is generally considered to need 9% to 10% air by volume for frost protection, this being about equivalent to 4-1/2% to 5% air by volume in concrete. Whether the surfaces of the air-entrained concrete in this test program had sufficient air to provide protection against freezing damage is questionable.

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General Comments

The results of the test program do not fully explain why concrete surfaces deteriorate under traffic. However, since the effects of the variables which decrease abrasion resistance are shown to be cumulative, it follows that one poor construction practice may only slightly reduce the durability of the concrete surface, while a combination of two or more poor practices may seriously lower the resistance of the surface to weathering and abrasion. Such combinations probably occur in a random manner in the field which would explain why only certain portions of a concrete surface show abrasion loss while others appear to be satisfactory. Further research is needed to determine the degree of correlation that exists between the laboratory findings reported herein and concrete surface deterioration in the field. Variables that have been found to affect abrasion resistance could be introduced into concrete bridge decks under rigid control to provide some of the answers. The dissipation of entrained air from the surface is a problem that should be studied both in the laboratory and in the field.

Throughout this report, references have been made to various types of concrete surface deterioration. The descriptive terms used are indicative of the lack of concrete surface durability. If the quality of a concrete surface is improved and made more resistant to impact abrasion, surface durability as affected by most factors, would also be improved. The test

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method described herein provides a means of measuring this resistance and establishes a basis for evaluating the effects of various contributing factors.

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SUMMARY

The data presented in this report show that each of the factors of slump, finishing techniques, and curing procedures, has an appreciable effect on the abrasion resistance of concrete surfaces as measured by an impact-type test. Of these three items, the broadest range of abrasion losses encountered were those associated with curing procedures. Concrete surfaces that have been cured with adequate moisture to provide for proper hydration of the cement will have a relatively higher resistance to abrasion.

The use of a monomolecular water retention agent during the finishing period had a measurable effect on improving the abrasion resistance of the surface. The use of admixtures in the concrete had no appreciable effect on abrasion resistance of the surface.

The findings of the laboratory test program corroborate the experience reported by others with respect to the impressive benefits, both preventive and remedial, that may be realized by the application of linseed oil treatments. Adhering to good construction practices will not, under all circumstances, provide a durable abrasion resistant surface. Since it has been shown that the factors adversely affecting abrasion resistance are cumulative, it is conceivable that the problem may manifest itself in virtually any environment. Therefore, general use

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of linseed oil application as a preventive maintenance measure appears justified. This procedure would be especially valuable in areas where de-icing agents are used. The treatment serves to seal the concrete surface, thereby deterring the entry of water, as well as creating a toughened wearing surface which greatly improves surface durability of the concrete.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

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TABLE 1

Abrasion Test Results

Test Slab No.	1	2	3	4	5	6	7	8	9
Nominal Slump, Ins.	3	3	6	3	6	3	6	6	3
Finish (1)	E	D	D	D	D	D	D	E	E
Cure (2)	Std.	Std.	Std.	Std.	Std.	Adv.	Adv.	Std.	Adv.
Admixture (3)	None	None	None	AE	AE	None	None	None	None
Surface Treatment (4)	None	None	None	None	None	None	None	None	None
Wt. Loss Range, Gms.	25-27	16-24	20-27	18-24	22-26	22-27	25-36	23-27	30-42
Avg. Wt. Loss, Gms.	26.2	20.4	23.0	20.2	24.0	24.0	30.0	25.4	37.6
% of Standard (No. 1)	100	78	88	77	92	92	115	97	144
Fresh Concrete Properties									
Slump, Inches	3.0	2.5	5.25	2.75	5.5	2.5	5.5	6.0	2.75
Air, Percent	1.4	1.4	0.8	4.9	6.0	1.4	1.3	1.2	1.2
Unit Wt., Lbs./Cu.Ft.	154.2	154.0	153.8	145.8	144.1	153.8	152.2	152.7	153.6
W/C, Lbs./Sk.	47.5	47.2	51.5	43.8	47.8	46.8	52.2	52.2	47.2

(1) E - Early
D - Delayed

(2) Std. - Standard
Adv. - Adverse
FT - Freeze-thaw

(3) AE - Air Entrainment
HC - Hydroxylated Carboxylic Acid Type
LS - Lignosulfonate Type

(4) LO - Linseed Oil
MM - Monomolecular Film

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Table 1 (Continued)

Test Slab No.	10	11	12	13	14	15	16	17	18
Nominal Slump, Ins.	3	3	3	6	6	3	3	3	3
Finish (1)	D	E	D	D	D	E	E	E	E
Cure (2)	FT	Std.	Std.	Std.	Adv.	FT	FT	Std.	Adv.
Admixture (3)	None	None	None	None	None	None	AE	None	None
Surface Treatment (4)	None	LO	LO	LO	LO	None	None	MM	MM
Abrasion Test Results									
Wt. Loss Range, Gms.	20-25	17-22	12-17	14-20	15-22	23-30	25-30	18-22	26-36
Avg. Wt. Loss, Gms.	22.4	18.6	14.4	18.6	17.6	26.2	27.8	20.2	31.2
% of Standard (No. 1)	85	71	55	71	67	100	106	77	119
Fresh Concrete Properties									
Slump, Inches	2.5	2.5	2.5	5.25	5.5	3.0	2.5	2.5	3.0
Air, Percent	1.4	1.4	1.4	0.8	1.3	1.3	5.2	1.2	1.2
Unit Wt., Lbs./Cu.Ft.	153.8	154.2	154.0	153.8	152.2	152.2	147.9	153.3	153.8
W/C, Lbs./Sk.	46.8	46.1	47.2	51.5	52.2	48.1	44.1	47.2	47.5

(1) E - Early
D - Delayed

(2) Std. - Standard
Adv. - Adverse
FT - Freeze-thaw

(3) AE - Air Entrainment
HC - Hydroxylated Carboxylic Acid Type
LS - Lignosulfaonte Type

(4) LO - Linseed Oil
MM - Monomolecular Film

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Table 1 (Continued)

	Abrasion Test Results							
Test Slab No.	19*	20*	21	22	23	24	25	26
Nominal Slump, Ins.	3	3	3	3	3	3	3	3
Finish (1)	E	E	E	E	D	D	D	E
Cure (2)	Std.	Std.	Std.	Std.	Adv.	Adv.	Std.	Adv.
Admixture (3)	None	None	HC	LS	HC	LS	None	None
Surface Treatment (4)	None	LO	None	None	None	None	MM	LO
Wt. Loss Range, Gms.	24-29	13-18	22-25	23-29	26-31	20-27	20-25	23-34
Avg. Wt. Loss, Gms.	26.2	16.4	23.8	25.6	28.8	25.0	22.8	28.8
% of Standard (No. 1)	100	63	91	98	110	95	87	110
	Fresh Concrete Properties							
Slump, Inches	2.75	2.75	3.0	2.5	3.25	3.0	3.0	2.75
Air, Percent	1.2	1.2	1.2	2.4	1.2	2.3	1.3	1.2
Unit Wt., Lbs./Cu.Ft.	150.4	150.4	154.0	152.3	152.5	154.2	152.2	153.6
W/C, Lbs./Sk.	56.7	56.7	46.9	44.5	47.7	44.7	48.1	47.2

(1) E - Early
D - Delayed

(2) Std. - Standard
Adv. - Adverse
FT - Freeze-thaw

(3) AE - Air Entrainment
HC - Hydroxylated Carboxylic Acid Type
LS - Lignosolfonate Type

(4) LO - Linseed Oil
MM - Monomolecular Film

*Low Quality Sand

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TABLE 2

Effects of Slump on Abrasion Loss

Nominal Slump	Finish	Cure	Admix.	Surface Treatment	3-in. Slump		6-in. Slump	
					Slab No.	Abrasion Loss	Slab No.	Abrasion Loss
-------	D	Std.	None	None	2	20.4	3	23.0
-------	D	Std.	AE	None	4	20.2	5	24.0
-------	D	Adv.	None	None	6	24.0	7	30.0
-------	E	Std.	None	None	1	26.2	8	25.4
-------	D	Std.	None	LO	12	14.4	13	18.6
Average Abrasion Loss						21.0		24.2

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TABLE 3

Effects of Finish on Abrasion Loss

Nominal Slump	Finish	Cure	Admix.	Surface Treatment	Early		Delayed	
					Slab No.	Abrasion Loss	Slab No.	Abrasion Loss
3"	------	Std.	None	None	1	26.2	2	20.4
6"	------	Std.	None	None	8	25.4	3	23.0
3"	------	Adv.	None	None	9	37.6	6	24.0
3"	------	Std.	None	LO	11	18.6	12	14.4
3"	------	FT	None	None	15	26.2	10	22.4
3"	------	Std.	None	MM	17	20.2	25	22.8
Average Abrasion Loss						25.7		21.2

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TABLE 4

Effects of Standard vs. Adverse Cure on Abrasion Loss

Nominal Slump	Finish	Cure	Admix.	Surface Treatment	Standard Cure		Adverse Cure	
					Slab No.	Abrasion Loss	Slab No.	Abrasion Loss
3"	E	----	None	None	1	26.2	9	37.6
3"	D	----	None	None	2	20.4	6	24.0
6"	D	----	None	None	3	23.0	7	30.0
3"	E	----	None	LO	11	18.6	26	28.8
6"	D	----	None	LO	13	18.6	14	17.6
Average Abrasion Loss						21.2		28.2

TABLE 4-A

Effects of Freezing During Curing Period on Abrasion Loss

Nominal Slump	Finish	Cure	Admix.	Surface Treatment	Standard Cure		Freeze-Thaw Cure	
					Slab No.	Abrasion Loss	Slab No.	Abrasion Loss
3"	D	----	None	None	2	20.4	10	22.4
3"	E	----	None	None	1	26.2	15	26.2
3"	E	----	AE	None	---	----	16	27.8*
Average Abrasion Loss						23.3		24.3

*Not included in average

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TABLE 5

Effects of Admixtures on Abrasion Loss

Nominal Slump	Finish	Cure	Admix.*	Surface Treatment	No Admixture		Admixture	
					Slab No.	Abrasion Loss	Slab No.	Abrasion Loss
3"	D	Std.	AE	None	2	20.4	4	20.2
6"	D	Std.	AE	None	3	23.0	5	24.0
3"	E	FT	AE	None	15	26.2	16	27.8
Average Abrasion Loss						23.2		24.0
3"	E	Std.	HC	None	1	26.2	21	23.8
3"	D	Adv.	HC	None	6	24.0	23	28.8
Average Abrasion Loss						25.1		26.3
3"	E	Std.	LS	None	1	26.2	22	25.6
3"	D	Adv.	LS	None	6	24.0	24	25.0
Average Abrasion Loss						25.1		25.3

*Admixture type used in comparison

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TABLE 6

Effects of Linseed Oil Treatment on Abrasion Loss

Nominal Slump	Finish	Cure	Admix.	Surface Treatment	No Treatment		Linseed Oil	
					Slab No.	Abrasion Loss	Slab No.	Abrasion Loss
3"	E	Std.	None	---------	1	26.2	11	18.6
3"	E	Adv.	None	---------	9	37.6	26	28.8
3"	D	Std.	None	---------	2	20.4	12	14.4
6"	D	Std.	None	---------	3	23.0	13	18.6
6"	D	Adv.	None	---------	7	30.0	14	17.6
3"	E	Std.	None	---------	19*	26.2	20*	16.4
Average Abrasion Loss						27.2		19.1

*Concrete contained low quality sand.

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TABLE 7

Effects of Monomolecular Film Treatment on Abrasion Loss

Nominal Slump	Finish	Cure	Admix.	Surface Treatment	No Treatment		MM Film	
					Slab No.	Abrasion Loss	Slab No.	Abrasion Loss
3"	E	Std.	None	---------	1	26.2	17	20.2
3"	E	Adv.	None	---------	9	37.6	18	31.2
3"	D	Std.	None	---------	2	20.4	25	22.8
Average Abrasion Loss						28.1		24.7

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TABLE 8

Effects of Low Quality Sand on Abrasion Loss

Nominal Slump	Finish	Cure	Admix.	Surface Treatment	Stock Sand		Low Quality Sand	
					Slab No.	Abrasion Loss	Slab No.	Abrasion Loss
3"	E	Std.	None	None	1	26.2	19	26.2
3"	E	Std.	None	LO	11	18.6	20	16.4
Average Abrasion Loss						22.4		21.3

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TABLE 9

Example of Cumulative Effect of Variables

Slab No.	12	11	1	9
Nominal Slump, Inches	3	3	3	3
Finish	D	E	E	E
Cure	Std.	Std.	Std.	Adv.
Admixture	None	None	None	None
Surface Treatment	LO	LO	None	None
Average Abrasion Loss	14.4	18.6	26.2	37.6

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TABLE 10

Void Distribution of Hardened Concrete Cores by Linear Traverse

Test Slab No.	Location of Bubble Count	Air Content %		Voids per Lineal In.	Avg. Chord Intercept	Spacing Factor
		Fresh	Linear Traverse			
1	Surface	1.4	0.3	0.88	.0039	.0148*
1	1/2" below surf.		0.8	0.69	.0112	.0300
2	Surface	1.4	0.2	0.74	.0025	.0122*
2	1/2" below surf.		0.8	0.74	.0109	.0293
4	Surface	4.9	2.1	13.14	.0016	.0028*
4	1/2" below surf.		3.5	9.97	.0035	.0049
4	2-1/2" below surf.		4.8	11.47	.0042	.0050
16	Surface	5.2	3.6	17.1	.0021	.0029*
16	1/2" below surf.		4.0	12.37	.0032	.0043
16	2-1/2" below surf.		5.3	14.09	.0038	.0044
21	Surface	1.2	0.2	0.66	.0033	.0152*
21	1/2" below surf.		0.7	0.73	.0102	.0283
22	Surface	2.4	0.6	2.08	.0028	.0085*
22	1/2" below surf.		0.8	1.30	.0064	.0170

*Actual paste content at surface not determined, so calculated spacing factors are low.

TABLE 11

Aggregate Grading*

Sieve Size	Percent Passing
3/4-inch	100
3/8-inch	65
No. 4	44
No. 8	35
No. 16	26
No. 30	17
No. 50	8

*Sand was reduced 2% for air-entrained mixes.

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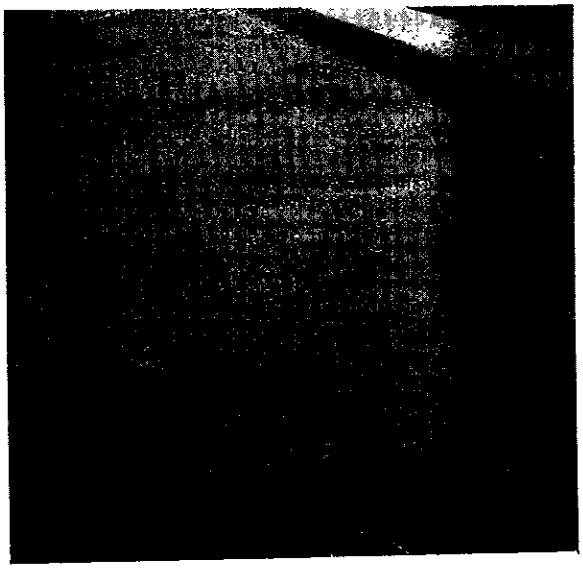
1

2



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4

Bridge deck deterioration

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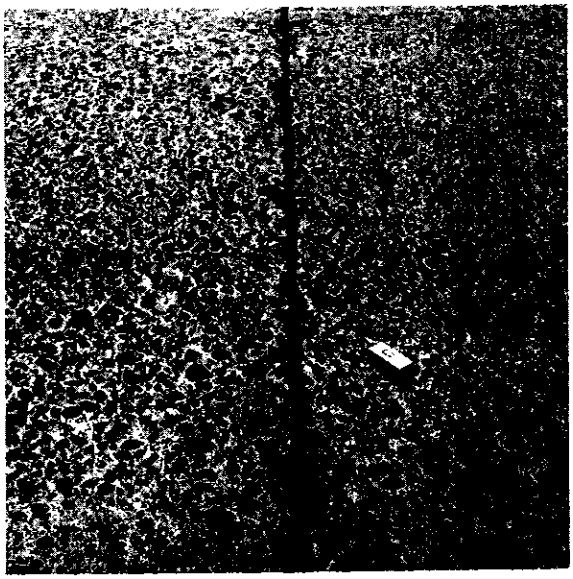

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6

Concrete pavement surface deterioration

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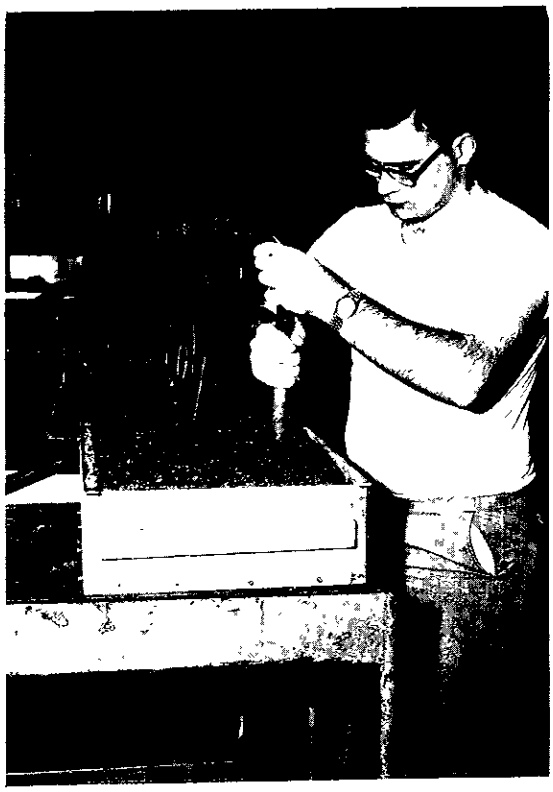
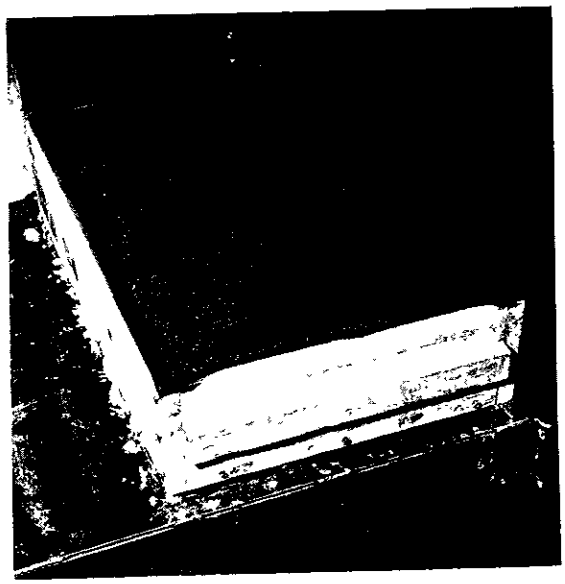


7 Vibration of test block

8 Floating process

9 Fog spray being applied to concrete during delayed finishing process



10 Finished block showing broomed surface

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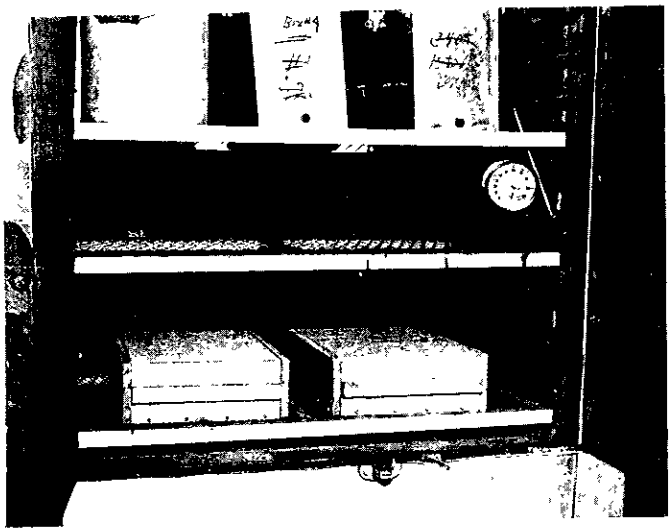
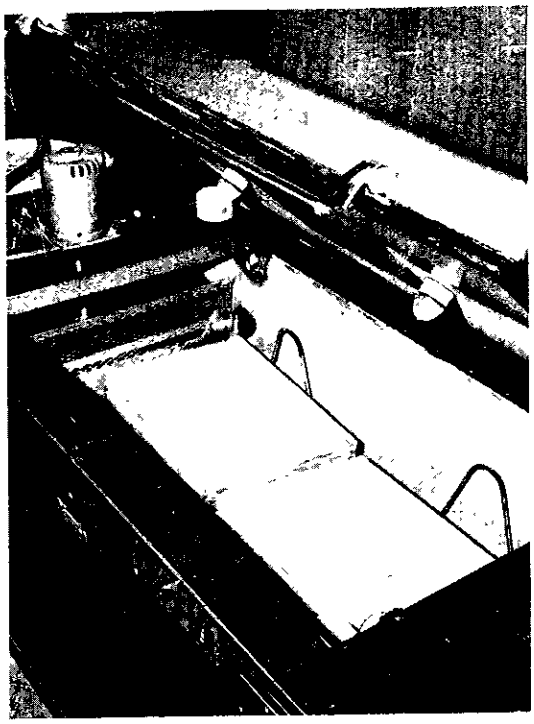
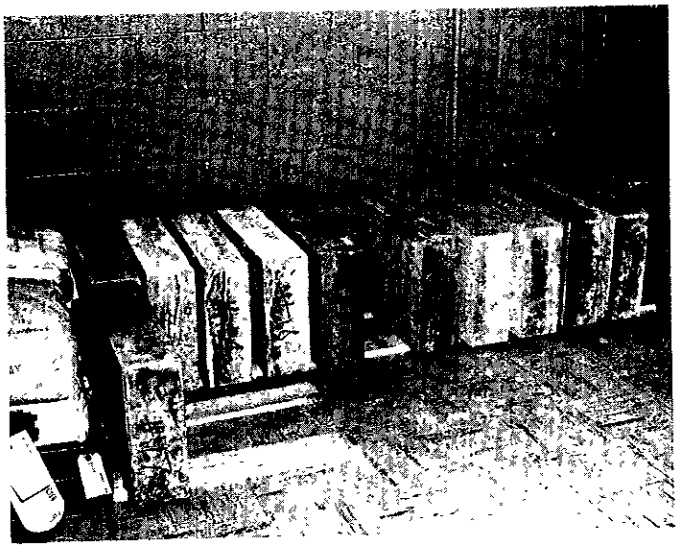


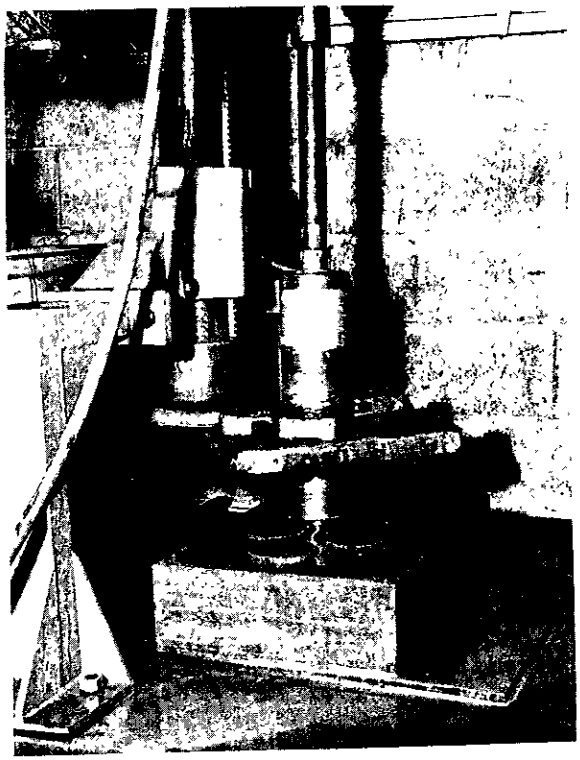
11 Test blocks in 100°F oven



12 Blocks being frozen during early curing period



13 Storage in laboratory air



14 Coring operation

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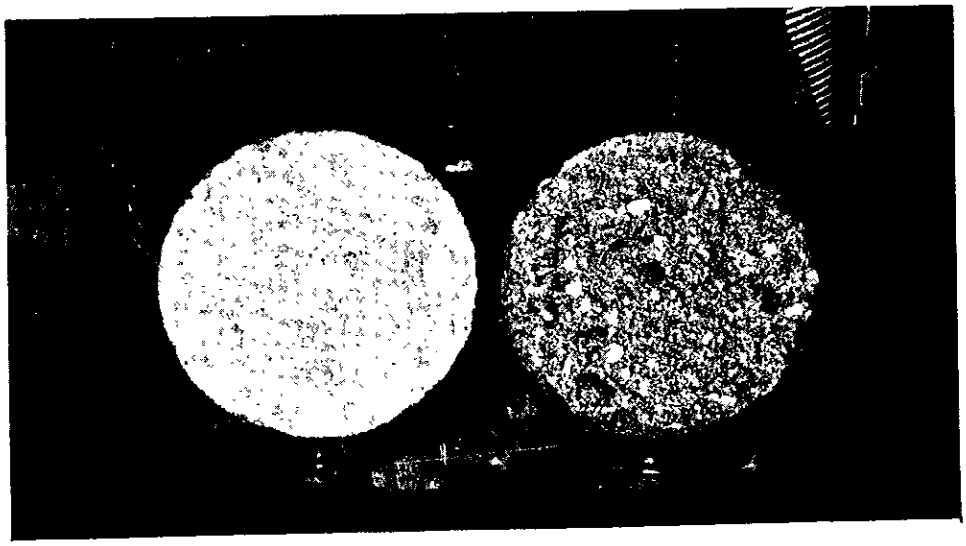
15 Specimens before and after sawing to 2-inch test height



16 Untested (left) and tested specimens

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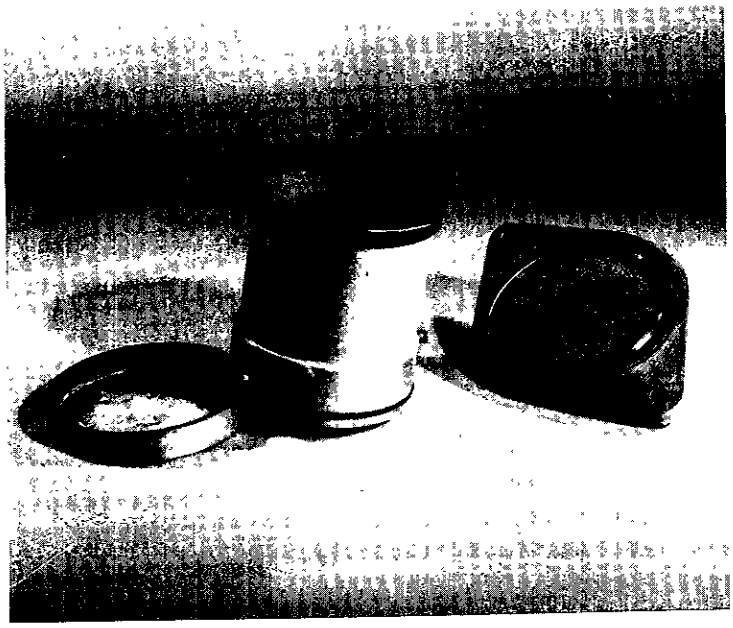
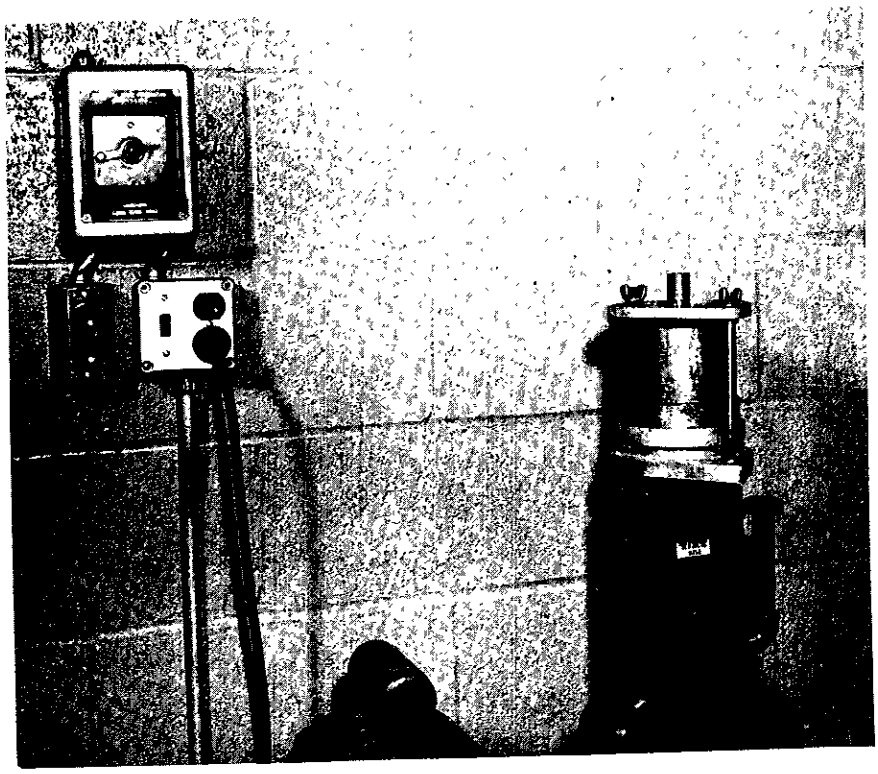


17 Container for abrasion test

18 Specimen in place for abrasion test



19 Abrasion test in progress

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APPENDIX

Test Method No. Calif. _____
(Proposed)

METHOD OF TEST FOR DETERMINING THE SURFACE ABRASION RESISTANCE OF CONCRETE SPECIMENS

Scope

The surface abrasion test measures the ability of a concrete specimen to resist surface abrasion by impact in the presence of water.

Procedure

A. Apparatus

1. A mechanical shaker capable of agitating a mold assembly containing the test specimen, water, and steel balls, in a vertical direction of 1200 cycles per minute with a 1-inch stroke. (Drawings are available from the Materials and Research Department.)

2. 1 - steel test mold, 4 inches ID by 5 inches high, fitted with a watertight base and cover. Three set screws are tapped through and positioned evenly around the perimeter of the mold 1-1/2-inch from the bottom.

3. 8 steel ball bearings, 13/32-inch diameter, weighing 4.5 grams each.

4. 1 - 200 ml graduated cylinder.

5. Balance sensitive to 1 gram.

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B. Specimens

The test specimens shall be cylindrical in shape, 4 inches in diameter and 2 inches high, and may be either cores cut from hardened concrete or specimens molded from concrete. They shall be soaked in water for a minimum of 24 hours prior to testing.

C. Test Procedure

1. Surface dry the specimen, weigh, and record weight to the nearest gram.

2. Place specimen in the test mold with the surface to be tested facing up and secure the specimen in a level position by means of the set screws. Place the mold with specimen on the base and add 8 steel ball bearings and 200 ml of water. Attach the cover making sure rubber gaskets are in place and clamp the assembly to the mechanical shaker.

3. Agitate the assembly at 1200 $\pm$ 10 CPM for three minutes and remove from the mechanical shaker.

4. Remove the specimen from the test mold. Flush off the abraded material, wash the specimen, surface dry, weigh, and record to the nearest gram.

D. Calculations

The abrasion loss in grams is calculated by subtracting the weight of the surface-dry specimen after the test from the weight of the surface-dry specimen before test.

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Reporting of Results

Report the amount of abrasion loss in grams. This amount shall be the average of at least three test specimens. Age of the concrete shall be included in the report.

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