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A STUDY OF DELAYED FINISHING OF CONCRETE SLABS

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SYNOPSIS

This investigation was undertaken to determine whether increasing the period of elapsed time before the second screeding operation would overcome the difficulties reported in the placement of air-entrained concrete during 1946. At the same time the resistance of the concrete to freezing and thawing was determined to ascertain whether concrete durability was adversely affected by the delayed finishing operations.

On the basis of the limited test data, it was indicated that:

1. The finishing operations can be delayed longer in the case of the concretes made with blended cement (15 percent natural, 85 percent portland) and air-entraining cement than with the concrete made with standard portland cement and vibrated blended cement concrete mixture.

2. The amount of shrinkage or swell in all cases is not of such magnitude as to seriously affect the finishing operations or the smoothness of the finished pavement.

3. The delay in finishing operations up to the point where finishing can be done properly does not reduce the resistance of the concrete to freezing and thawing.

4. More uniform concrete, as measured by resistance to freezing and thawing, and as indicated by the difference in resistance of the top and center discs, is obtained with the use of cements or cement blends which result in the entrainment of air in the amounts found in this study.

Upon resuming its concrete paving program in 1946, following the war years when little paving had been done, the Minnesota Highway Department adopted the principle of air-entrainment as a desirable requirement in all its paving. The air-entrainment was accomplished by the use of portland cement in which an air-entraining agent was interground at the mill or by the use of a blend of natural cement and portland cement in which case the air-entraining agent was incorporated in the natural cement at the mill. At times it was necessary to add air-entraining agent at the mixer in order to bring the air content within the specified limits.

No appreciable difficulty was encountered in obtaining the specified air content in the concrete paving mixtures although most projects showed a considerable variation from day to day. Some complaints were made concerning difficulties in finishing, particularly during the hot windy days.

However, the major item of concern was the fact that some of the newly completed pavements had rough riding surfaces. It was felt that the condition was a result of the difficulties of finishing which were reported as more evident with air-entrainment than had been previously found with standard-portland. Some observers stated that there was an apparent swell of the concrete during setting and that surfaces which had been finished smooth did not remain so. It was thought by some that if the finishing operations could be delayed for a period of time some of the difficulties could be overcome, particularly those of finishing and apparent change in volume of the concrete.

Scope of Investigation—An investigation was therefore set up to determine how much time could elapse between the first strike-off or screeding of the slab and the final screeding, without handicapping the finishing operations. It was further desired to measure the shrinkage and swell of the concrete, if any, and the effect of the delayed operations upon the durability of the concrete.

Laboratory Procedures—Four pavement mixtures were used involving three different cements or cement blends and one variation wherein the concrete was placed by vibration methods. Some of the properties of these cements are given in Table 1.

TABLE 1

Type	Air-Ent. Agent	Time of Initial Set	Time of Final Set	Air in Mortar	28 Day Str.
				%	psi.
Standard	None	3:15	4:05	8.4	432 Tens.
Natural	Darex	0:35	0.55		226 Tens.
85% Std. 15% Natural	Darex	3:15	4:35	15.2	3167 Comp.
Air-Ent. Port.	Darex	2:50	3:45	13.9	3583 Comp.

Sand—The sand was obtained from a local producer and had the following gradation:

		%
Passing	$\frac{3}{8}$-in. sieve	100
"	No. 4 "	97
"	No. 10 "	79
"	No. 20 "	49
"	No. 50 "	11
"	No. 100 "	2
"	No. 200 "	0.7

Coarse Aggregate—The coarse aggregate was gravel, obtained locally and was graded as follows:

		%
Passing	2-in. sieve	100
"	$1\frac{1}{2}$-in. "	95
"	$\frac{3}{4}$-in. "	58
"	$\frac{3}{8}$-in. "	13
"	No. 4 "	0

Proportions—The proportions by absolute volumes for the four paving mixtures are given in Table 2.

Mixing and Placing—Mixing was done in a $2\frac{1}{2}$-cu. ft. rotating drum mixer. A separate batch was prepared for each of the twenty slabs made. The aggregate was stockpiled under damp burlap. It was remixed and sampled for moisture just before mixing operations. Free moisture was present in both the sand and gravel as used in all batches.

The mixer was first coated with mortar. The materials were then added, a portion of the gravel and water being temporarily withheld. After mixing for one minute the remaining gravel and water were added and mixing continued for two more minutes. A slump test and an air determination were then made.

TABLE 2

Batch Designation	Cement	Proportions by Absolute Volume			
		Cement	Sand	Gravel	Water
Standard	Standard	1	2.88	4.96	1.67
Air-Entraining	Air-Entraining	1	2.66	4.96	1.57
Blended	Std. 85.5% Natural 14.5%	1	2.66	4.96	1.60
Blend Vibrated	Std. 84.7% Natural 15.3%	1	2.81	5.35	1.57

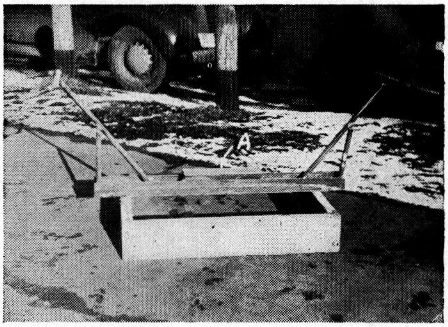


Figure 1. Slab Form and Screed

The forms were made of 2- by 6-in wood as shown in Figure 1. They were oiled and placed on subgrade paper on the concrete floor. The slab dimensions were 24 by 30 in. by 6 in. The concrete was puddled and the forms tapped lightly to insure proper placement.

Finishing Operations—The screed for striking off and finishing is also shown in Figure 1. It consisted essentially of a 42-in. length of 4-in. ship channel to which handles had been attached.

The edges of the forms were raised $\frac{1}{8}$ in. by means of shims to assure an excess of concrete after the first strike-off. The shims were removed before the second screeding operation. The screed was worked parallel to the 30-in. side of the slab in the screeding operations. The slabs intended for placement by vibration were finished by means of a Syntron electric type V-75 vibrator attached to the screed at the point marked "A". This vibration was carried out in the initial screeding operation only.

Five slabs were cast from each of the four paving mixtures described above and subjected to varying periods of delayed finishing. In each case the initial strike-off operation was done at three minutes after the placing of the concrete. The delays in the finishing of the various slabs were measured by the time interval between the first and second screeding operations. This interval was taken as 10 min. for the normal and increased by 30-min. increments for each of the succeeding slabs of the same mix, so that the maximum interval was 2 hr. and 10 min.

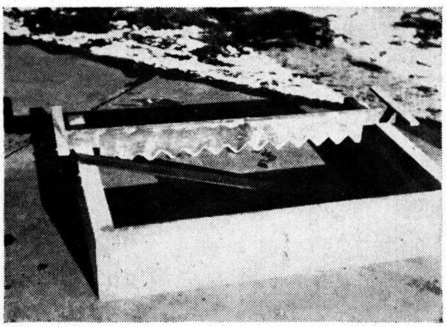


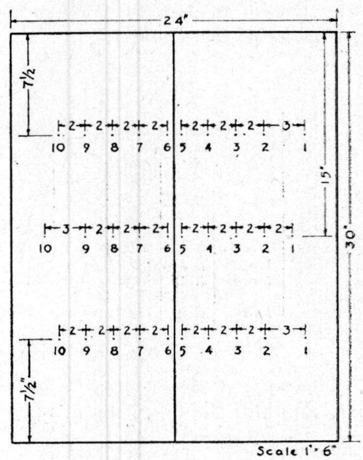
Figure 2. Joint Cutting Device

Bull floating was done 10 min. after the second screeding operation using the same apparatus but operating it parallel to the 24-in. side of the slab.

Approximately 3 min. after bull floating the transverse joint was cut using the apparatus shown in Figure 2. The joint was cut parallel to the 30-in. side of the slab. The joint marker was then placed and the slab finished with a wood float and straight edged. The joint was included because much of the difficulty encountered in the 1946 work appeared to be associated with the joints.

The layout of reference points is as shown in Figure 3. As soon as the concrete was set sufficiently to hold the gage points they were placed at the points designated as 1, 2, 3, 8, 9 and 10. Large carpet tacks were used for gage reference points, the tack point being cut to a length of $\frac{1}{4}$ in.

When visual observation indicated that the concrete was in a condition similar to field conditions the joint marker was removed and the joint edged. The inside gage points 4, 5, 6 and 7 were then placed and Ames dial readings taken on these points and those previously



POINTS 1-2-3-8-9-10 PLACED IMMEDIATELY AFTER STRAIGHT EDGING

POINTS 4-5-6-7 PLACED IMMEDIATELY AFTER EDGING OF JOINT

Figure 3. Location of Gage Points

placed. Readings were taken at intervals until no further change was indicated.

Room temperature was kept at approximately 80 F. during the finishing operations and a battery of fans kept air moving over the slabs continuously.

Slabs were covered with damp burlap at about 4 hours and were kept so covered until the curing compound was applied at 10:00 PM of the day of pouring. The slabs were then kept in laboratory air until 14 days at which time cores were drilled.

The sequence of finishing operations for all slabs is shown in Figure 4.

Mix Data—The data relating to the concrete mixtures are given in Table 3.

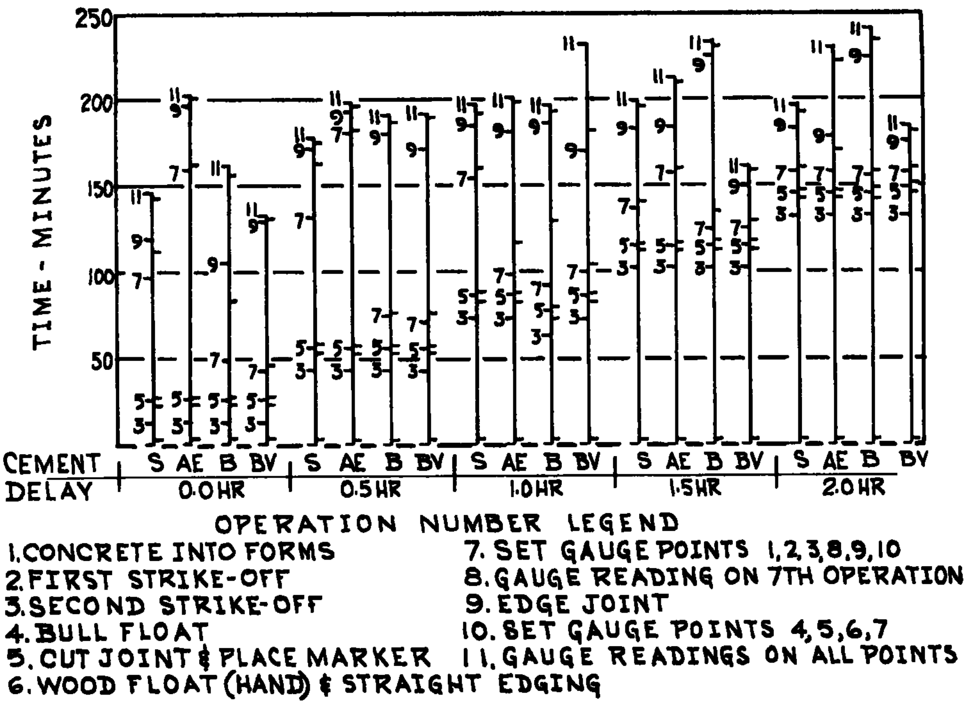


Figure 4. Finishing Operation Interval

TABLE 3

TEST DATA RELATING TO THE VARIOUS CONCRETE BATCHES

Cement	Test	Delayed Finishing Period—Hours					Aver.
		0	0.5	1.0	1.5	2.0	
Standard (1-11-47)	Slump, in.	2	1.8	3.5	1.6	2.2	2.22
	Air,[a] %	1.9	2.1	1.9	1.9	1.8	1.92
	Air Temp. *deg. F.*	75	78	81	80	81	
	Rel. Hum., %	21	25	25	22	24	
	Time Poured	8:18 AM	9 02 AM	9:55 AM	10 45 AM	11:17 AM	
Air Entraining (1-11-47)	Slump, in.	3.8	4.0	5.0	4.0	4.5	4.26
	Air,[a] %	5.2	5.4	5.0	5.4	5.7	5.34
	Air Temp., *deg. F.*	79	78	79	81	80	
	Rel. Hum., %	20	21		22	24	
	Time Poured	3:36 PM	2:39 PM	1 41 PM	12:55 PM	12:06 PM	
Blended (1-10-47)	Slump, in.	4.1	4.8	4.5	5.5	4.0	4.58
	Air,[a] %	5.1	6.0	5.3	5.8	6.5	5.74
	Air Temp., *deg. F.*	80	85	86	82	80	
	Rel. Hum., %				41	38	
	Time Poured	8:25 AM	8:45 AM	9.29 AM	10:16 AM	11:08 AM	
Blended and Vibrated (1-10-47)	Slump, in.	1.8	2.2	1.2	1.6	0.8	1.52
	Air,[a] %	5.1	5.8	4.2	5.5	4.4	5.00
	Air Temp., *deg. F.*	77	76	78	80	83	
	Rel. Hum., %					40	
	Time Poured	5:02 PM	3:52 PM	3:03 PM	2:12 PM	1:25 PM	

[a] Percent air was measured by the pressure method using a pressure of 30 lb.

Finishing Properties of Slabs—The following notes were made concerning the finishing properties of each of the slabs:

Standard Cement

No Delay—Considerable bleeding after bull floating, becoming apparent 5 min. after floating and very bad at 15 min.

0.5-Hour Delay—Not so much bleeding after floating. Some of free water removed in delayed screeding operation.

1.0-Hour Delay—Works very well on second screeding and floating. Some hair checking was visible on this slab before it was covered.

1.5-Hour Delay—Some of the mortar from this batch was left in the mixer. The surface was honeycombed after the second screeding and only fair after bull floating.

2.0-Hour Delay—Surface was marred and torn from second screeding operation. Concrete too hard to work well under bull float. No free water on surface. Too dry to straightedge.

Air Entraining Cement

No Delay—Easy screeding on second screeding and on bull floating. Too soft for good straight edging.

0.5-Hour Delay—Soft surface on slab with a paper thin film at time of second screeding. Mortar soft at time of bull floating. Finishing and straight edging O.K.

1.0-Hour Delay—Some water loss under form. Soft enough for straight edging after bull floating. Good finishing. Some air bubbles behind straight edge.

1.5-Hour Delay—Some water loss under form. Surface tore on second screeding. Workability O.K. after second pass of bull float. Straight edging O.K. Mass of concrete movable by jarring straight edge.

2.0-Hour Delay—Some water loss under form. Too dry to work well on second screeding and bull floating, and surface tore. Extreme limit for straight edging. Air bubbles behind straight edge.

Blended Cement

No Delay—Concrete very soft at second screeding and bull floating. Too soft to straight edge.

0.5-Hour Delay—Concrete soft at second screeding. Too soft for good straight edging.

1.0-Hour Delay—O.K. at second screeding. Straight edging improved but still a little too soft.

1.5-Hour Delay—Still workable at second screeding. Gave a very good surface after straight edging.

2.0-Hour Delay—Surface tore at second screeding and bull floating. Too dry to work well.

Blended and Vibrated

No Delay—Too soft to straight edge.

0.5-Hour Delay—Second screeding good. Plenty of mortar for straight edging.

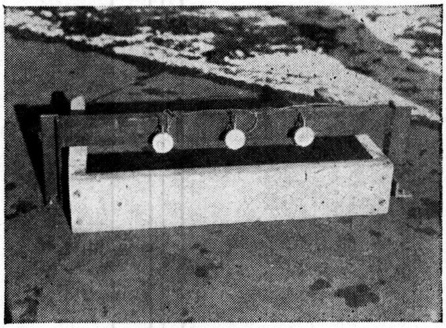


Figure 5. Device to Measure Surface Movement

1.0-Hour Delay—O.K. at second screeding. Straighted edged very well. Slab had good body. Did not move much when worked.

1.5-Hour Delay—Too dry at second screeding. Not much mortar on surface. Too dry to work with straight edge after bull floating.

2.0-Hour Delay—Workability very poor. Very dry after bull floating. Beyond limit for good straight edging.

Measurements of Slab Movement—As soon as the gage points were set in the slabs, readings were taken at intervals to observe shrinkage and swell of the slabs. The Ames dial assembly, shown in Figure 5 was used for this purpose. During the first two hours after the setting of the points, readings were taken at approximately half-hour intervals. Readings were taken at intervals of 4 to 10 hours during the remainder of the first 24 hours and thereafter at intervals of 24 hours.

Since no measurements could be started until the slab had set sufficiently to hold the gage points it is apparent that only a portion of the total shrinkage could be measured. Furthermore, the magnitude of the measured portion obtained depended upon the delay interval in the finishing operation. Measurements taken during the shrinkage period serve to establish the low point from which to determine the ensuing swell rather than to constitute a quantitative measure of shrinkage. Values of vertical shrinkage obtained ranged from 0 to 0.045 in.

It was found that the swell, as indicated by the measurements, continued at a reduced rate beyond the first 24-hr. period. Since it is not reasonable to assume that the hardened concrete should continue to swell at an appreciable rate it was felt that some of the measured swell may have been a result of some swell in the wooden forms, although they had been well oiled prior to use. The data obtained in the swell measurements was compiled to include only that portion up to an age of 24 hours. As indicated above, this is the measured swell from the low or maximum shrinkage point to the height at age 24 hours. These data are shown in Figure 6.

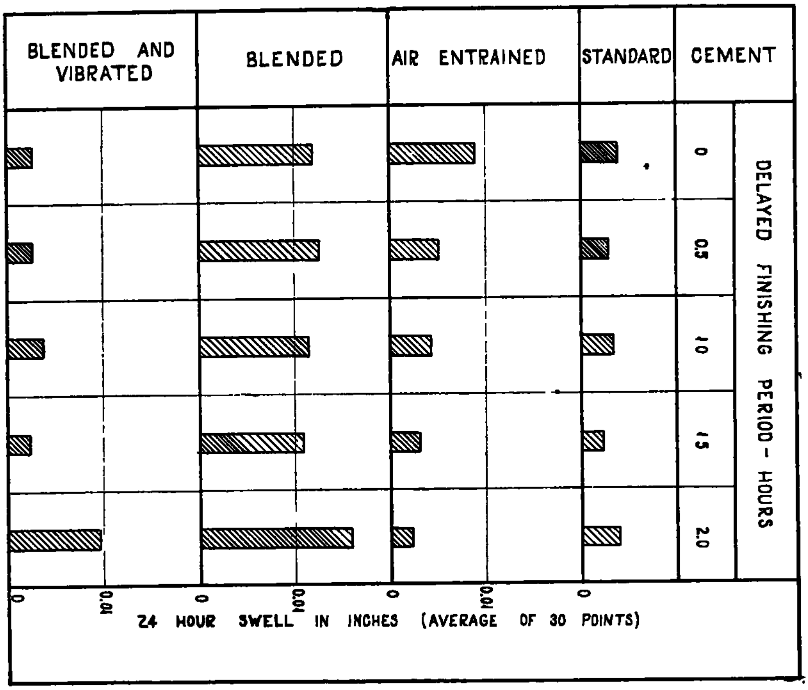


Figure 6. 24-Hr. Swell of 6-In. Concrete Slabs—Various Cements and Periods of Delayed Finishing

A limited amount of work was done later to check the above measurements of concrete swell. In this work the same four mixes of concrete were used again, but the periods of delayed finishing were omitted. The concrete was placed in steel beam forms to avoid any possible change in height of the forms. The gage points consisted of a raised point on 2- by 2-in. metal plates to permit earlier placement. Height measurements were made by means of an Ames dial using the surface of the steel form as a base. The laboratory air temperature ranged from 70 to 72 F. during the time the concrete was in a plastic state. No swelling action was observed. The shrinkage as given in Table 4 was measured from a time 30 min. after placing the concrete.

Freezing and Thawing Tests—Four 6-in. diameter cores were cut from each slab at an age of 14 days. The cores were then cut into discs 2 in. thick by means of a carborundum wheel. The top and center discs were subjected to freezing and thawing tests starting at 21 days of age. The discs were frozen for 3¼ hr. while immersed to a depth of ¼ in. in a pan of water and exposed to an air temperature of −10 F. following which they were thawed in water at 80 F. for 1¼ hr. The center of the specimens reached 32 F. in 45 min. and 0 F. in 2 hr. and 25 min.

TABLE 4
MEASUREMENTS OF SHRINKAGE

	Concrete Types			
	Standard	Air Entr.	Blended	Blended & Vibrated
Slump	3.5	4.2	4.1	2.0
Air, %	2.20	5.30	5.32	4.75
Shrinkage at 1 Hr., in.	.020	.016	.011	−.001
" " 2 Hr., in	.025	.019	.021	.006
" " 3 Hr., in	.025	.020	.022	.007
" " 5 Hr., in	.026	.020	.024	.009

The end point of the test was determined by testing the discs in flexure. The disc was supported on three $\frac{13}{16}$-in. rounded steel pegs paced at 120 deg. and located ½ in. from the circumference. A load of 276 kg. was then applied at the center through a $\frac{15}{16}$-in. diameter plunger. This load was intended to produce a stress equivalent to approximately 25 percent of the average 14-day strength under similar test conditions. The resistance of the core discs to freezing and thawing as measured under the above conditions is shown in Figure 7. This figure shows minimum and average number of freezing and thawing cycles necessary to reach the established end point. The top discs, representing the surface of the slab, are shown separately from the center discs. The values are average values of four test specimens in each case.

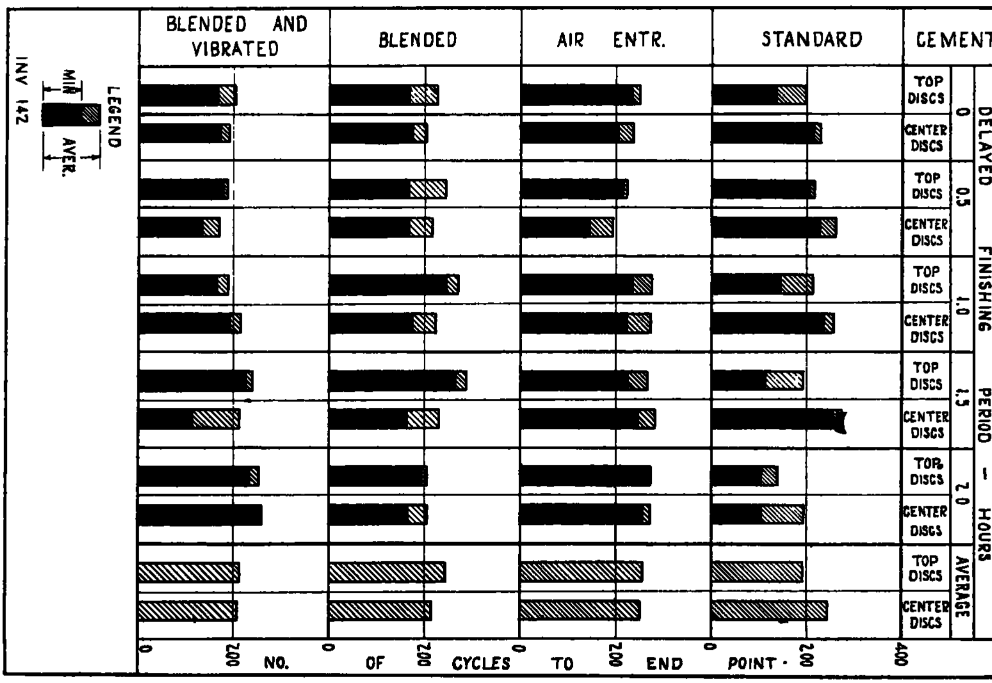


Figure 7. Freezing and Thawing Cycle at End Point for Core Discs

Absorption Tests of Core Discs—Absorption determinations were made on the bottom discs of the cores referred to above. The cores were dried to constant weight at a temperature of 150 to 160 F. and at the age of 23 days were immersed in a water bath at 70 F. for a period of 7 days. The data obtained are given in Table 5.

Discussion of Data—

1. Effect of Delayed Screeding on Ability to Finish. A study of the notes shows that in the case of the standard portland there was considerable bleeding of the slab with normal sequence of finishing operations but a reduced amount of bleeding when the finishing was delayed 30 min. Bleeding was not reported on those slabs where the delay ranged from 1 to 2 hr. It was apparent that under the conditions of test the maximum delay in finishing for the standard portland should not exceed 1 hr. if satisfactory finishing is to be obtained.

There was no bleeding noted in any of the other three mixtures although there was loss of water under the form in the case of the air-entraining cement where the finishing was delayed 1 hr. or more. It appeared that proper finishing consistency could be obtained with a 90-min. delay when air-entraining and blended cements were used. It should be noted that the slump in the case of the air-entraining and blended cements was about 2 in. greater than in the case of the standard which may have contributed to the longer time of workability. At the same time this should increase the tendency to bleeding but this did not occur.

2. Shrinkage and Swell. Swell was obtained with all cements in the original study but this may have been at least partially affected by the fact that wooden forms were used. The effect of the forms should be the same in all cases and it is therefore of interest to note that the swell is consistently higher in the case of the blended cement with all periods of delay. In any event the amount of shrinkage or swell is of no great consequence in the case of any cement insofar as its effect on pavement smoothness is concerned.

In the case of the later work when steel forms were used no swell was found in any case. It was of interest here to note that the shrinkage of the vibrated concrete was substantially less than for the other three types with not much difference in the latter except at one hour.

3. Freezing and Thawing Tests. The primary objective in the freezing and thawing tests was to determine what effect the delay in finishing operations would have on the resistance of the concrete to freezing and thawing. There appears to be no relationship between time of finishing and resistance to freezing and thawing. An interesting observation, however, is that in the case of the standard portland cement for every finishing time the top disc is less resistant than the disc from the center of the core. This would appear to be related to the tendency of the standard portland mixture to bleed at the time of finishing. On the other hand, the concrete made with the air-entraining cement and the blend vibrated and to a lesser degree that made with the blended cement, show a rather uniform resistance to freezing and thawing in the top and center discs with top discs, in most cases, being more resistant than the center disc.

It may be observed that the concrete made from air-entraining cement was somewhat more resistant in this freezing and thawing test than the other concretes and that it was more uniform in that the minimum values were in general higher than those for the other cements.

TABLE 5

WATER ABSORPTION

	Delayed Finishing Period—Hours					
	0	0.5	1.0	1.5	2.0	Ave.
	%	%	%	%	%	%
Standard	4.84	4.96	5.01	4.40	4.57	4.76
Air Entrained	4.51	4.70	4.57	4.52	4.61	4.58
Blended	5.20	5.22	4.90	5.18	5.43	5.19
Blended and Vibrated	4.80	4.73	4.64	4.64	4.86	4.73

It will also be observed that the blended cement concrete was slightly less resistant than the air-entraining cement concrete. This may be partly explained by the somewhat lower probable strength of the blended cement concrete particularly at the age of test with the resultant effect upon the end point test.

4. Absorption Tests. No significant differences are noted in the absorption test except that the absorption of the blended concrete is somewhat higher than for the other three.

Conclusions—On the basis of the limited test data the following conclusions are indicated:

1. The finishing operations can be delayed longer in the case of the concretes made with blended cement and air-entraining cement than with the concrete made with standard portland cement and the vibrated blended cement concrete mixture. It is again pointed

out that the slump in the case of the standard portland was 2-in. less than for the air-entraining or blended cements.

2. The amount of shrinkage or swell in all cases is not of such magnitude as to seriously affect the finishing operations or the smoothness of the finished pavement.

3. The delay in finishing operations up to the point where finishing can be properly done does not reduce the resistance of the concrete to freezing and thawing.

4. More uniform concrete, as measured by resistance to freezing and thawing, and as indicated by the difference in resistance of the top and center discs is obtained with the use of cements or cement blends which result in the entrainment of air in the amounts found in this study.

5. In view of the fact that the same load was used in all cases for the determination of the end point the data does not accurately measure the relative resistance to freezing and thawing of the different cements used in the study.

1947 Field Results—While the final finishing operations on the 1947 jobs were not delayed as much as this study would indicate to be possible, they were carried on, in general, somewhat later than was the case in 1946. The riding qualities of the 1947 jobs are generally much better than the 1946 jobs. It may be significant that on the best 1947 job, the longitudinal power-floating and the straightedge finishing were both carried on later than on the other jobs.

A DISCUSSION OF CEMENT HYDRATION IN RELATION TO THE CURING OF CONCRETE

T. C. Powers, *Manager of Basic Research, Portland Cement Association*

SYNOPSIS

The question of the amount of water required to hydrate cement is somewhat irrelevant to the question of proper curing. Cement hydration is discussed to show why this is so. The minimum amount of water required to bring cement to its ultimate degree of hydration (which may not be complete hydration) is, for an average cement, about 0.44 gram of water per gram of cement, plus the curing water that must be added to keep the paste saturated. This amount of water is the minimum that will provide space for the hydration products.

Curing procedures should be such as to keep the concrete as nearly saturated as possible until the originally water-filled space has become filled with hydration products to the desired minimum extent. For maximum hydration concrete must be kept saturated or nearly so because hydration products can form only in water-filled space and only in that part of the water-filled space that is outside the gel-substance, that is, only in the water-filled capillaries in the paste. Concrete sealed against evaporation must initially contain more than about 0.5 g. of water per g. of cement to assure full hydration, since self-desiccation progressively reduces the space available for hydration products. Even if full hydration may ultimately be reached, self-desiccation greatly reduces the rate of hydration.

Samples stored in water vapor (or in water vapor and air) in which the vapor pressure is about 80 percent of the saturation pressure, or less, will practically cease hydrating when the water evaporable at this pressure is lost, apparently because the capillaries become emptied at that pressure.

Procedures required to produce maximum cement hydration, namely, those that would produce and maintain the maximum degree of saturation, would not generally be justified. Self-desiccation, and even some loss by evaporation, is beneficial in some respects. Membrane curing will not assure full hydration but may be adequate and desirable, especially for concrete members in contact with soil.