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AMERICAN CONCRETE INSTITUTE

NEW CENTER BUILDING
DETROIT 2, MICHIGAN

The Institute's first post-war get-together is scheduled for Buffalo (Hotel Statler) this month—with general sessions Tuesday, Wednesday and Thursday, February 19, 20 and 21. Read details News Letter pages this JOURNAL.

To facilitate selective distribution, **separate prints** of this title (42-13) are currently available from ACI at 25 cents each—quantity quotations on request. **Discussion** of this paper (copies in triplicate) should reach the Institute not later than May 1, 1946

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Vol. 17 No. 4 7400 SECOND BOULEVARD, DETROIT 2, MICHIGAN **February 1946**

Maintenance of Heavy Concrete Structures
Minnesota Power & Light Company Practice*

By CLAY C. BOSWELL†
Member American Concrete Institute
and ALBERT C. GIESECKE‡

SYNOPSIS

The practice of The Minnesota Power & Light Company in repairing and restoring a concrete dam is described and illustrated and comparisons made with a much older structure, which has had no repair cost because construction methods were better.

The severity of the climate in the area of this company's operations produces a less frequent, but more severe type of frost damage, than that which occurs in a milder climate in the presence of a frequently reoccuring "cycle of freezing-thawing", such as is usually associated with concrete disintegration problems.

It is the deeper penetration of frost, into such concrete structures as are vulnerable to its damaging effects, which forms important reason for the practice developed by the Minnesota Power & Light Company, and which lends substantial meaning to the term "heavy concrete repair slab" as pictured in this article.

The practice of this company in dealing with problems of this type dates back to 1926 when the first major work of similar character was done. A number of comparable applications have since been made. Ages of two major applications are approaching 18 years, and results to date are most satisfactory.

In no sense is it the author's suggestion that the methods herein described be adopted in toto for other conditions; instead it is his conviction that conditions prevailing at each situation will require local decisions as to—

*Received by the Institute Nov. 5, 1945.
†Vice President and Chief Engineer, Minnesota Power & Light Company, Duluth.
‡Hydraulic Engineer, Minnesota Power & Light Company, Duluth.

1. Design of details of slab and reinforcing.
2. Design of concrete mix.
3. Spacing and detail of construction joints.

FOND DU LAC HYDRO ELECTRIC STATION DAM

If proof were wanted as to whether variations in technique used by the builder can make the difference between a *concrete dam of good quality*, as against one in which maintenance is a major item, it would be available by the simple process of inspecting the Thomson Dam and the Fond du Lac Dam, both on the St. Louis River, Minnesota, which, at this date, are 39 and 21 years old, respectively.

The excellent condition of the Thomson Dam was recognized in 1928 when it was described by H. C. Ash, in the A C I *Proceedings*, V. 25 of 1929.

Such lack of erudition as may have hindered the efforts of the builders of Thomson Dam, was in ample measure offset by diligent application of simple fundamentals. They used clean aggregate; mixed aggregate as densely as possible by combining pit gravel and lake gravel; they cleaned days-work planes, and, in the words of Mr. Ash "dry concrete requiring much tamping, and free water on the surface of placed concrete, were both discouraged with emphasis." The concrete, according to Mr. Ash, approximated proportions of 1:1.7:4.3.

The Fond du Lac concrete was crushed stone and pit sand, both of which were clean and sound. The mix was generally 1:3:6 and most concrete was placed by a system of chutes. Good practice was violated, principally in the wide variation and excessive use of mixing water, with consequent gross segregation which now is the obvious nucleus of most of the weakness requiring remedy within the decade ending approximately as the structure reaches the end of its first 25 years of service.

The 39-year-old Thomson Dam is in essentially a perfect state of preservation with no concrete maintanence expense "aft" or "forward." The 21-year-old Fond du Lac Dam, however, will, before it is 39 years old, have involved substantial maintenance costs in addition to those already incurred.

The Fond du Lac maintenance problem

Signs of impending concrete maintenance problems were seen as early as 1928, when the dam was but 4 years old, at which time disintegration was, in minor degree, noticeable in the taintor gate waterways. This was then, however, considered "*of no immediate concern.*" Greater concern was felt over the condition of two gate piers. Fig. 1, on close examination, will reveal that substantial evidence of disintegration was

Fig. 1 (above)—Downstream face of Fond du Lac Dam showing taintor gates numbers 4 to 17 inclusive. September, 1928

Fig. 2 (right)—Downstream face of Fond du Lac Dam in area of gates 8, 9 and 10. June 1936

visible on the downstream face of the dam, even when viewed from several hundred feet away.

Condition in 1936

Fig. 2 shows the condition near taintor gates 8, 9 and 10 in June 1936. Also, in October, careful field inspection revealed taintor gate waterway spalling as shown on Fig. 3. The lesser depth of spalling in taintor gate 16, and at several adjacent ones, is accounted for, at least in part, by the less frequent discharge through these gates as compared with those near the middle of the dam.

At this point, records of original construction were reviewed and it was found that concrete specifications were complied with, except as to

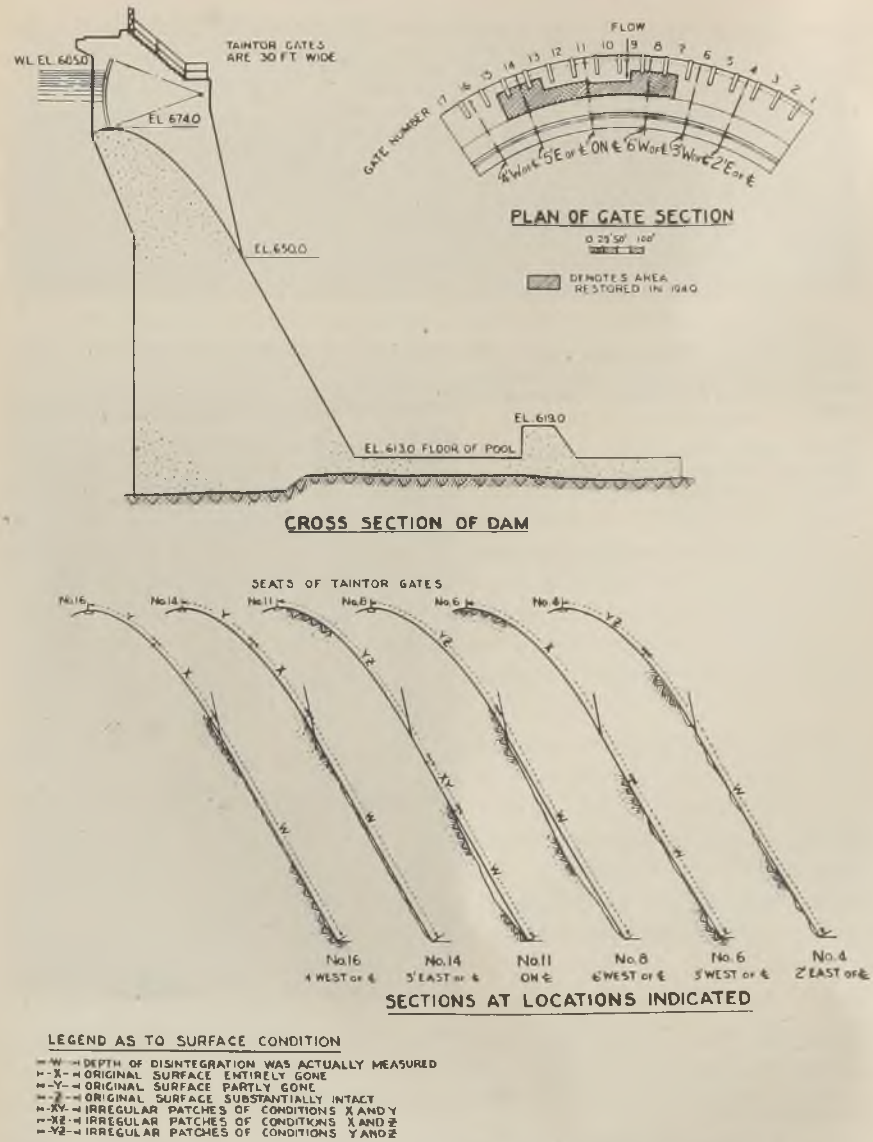

Fig. 3—Part record of inspection of downstream face of Fond du Lac Dam in October, 1936

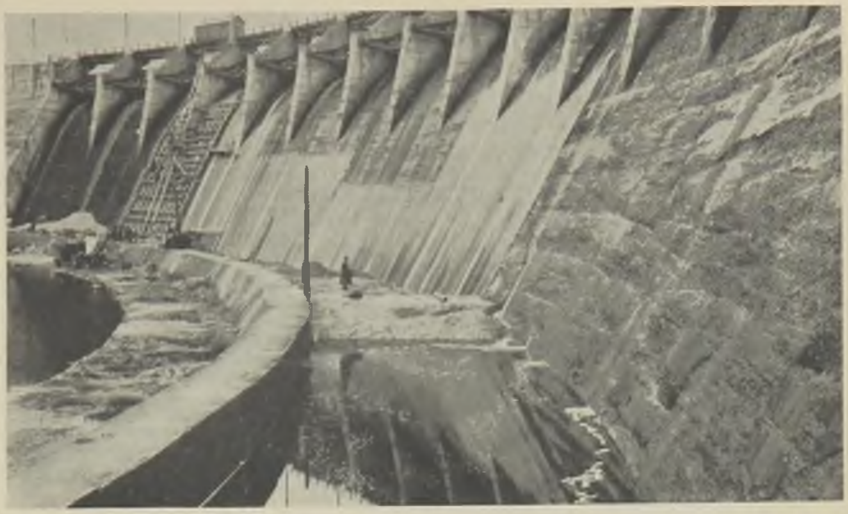

Fig. 4—Downstream face of Fond du Lac Dam in area of first concrete restoration. October, 1940

lavish use of mixing water; compressive strength tests were made as the work progressed, and these should have been warning enough to call for corrective measures. The chuting system of placing concrete was the occasion for excessive and varying moisture contents, and this resulted partly in defective conditions throughout large areas, and elsewhere in lenses of poorer concrete (and even sheet laitance) interspersed inside masses of somewhat better quality.

Repair program

Factors outside the Fond du Lac Dam were largely responsible for adopting the plan to which the job readily lent itself, namely, dividing the repair job into 3 blocks, one each for 1940, 1945 and 1948. This program permitted the work to be kept within the capacity of the company's repair crew, staggered with the periods in which similar work elsewhere had to be done. Further it accommodated in best possible degree, the coordination necessary between work of this kind and the requirements of power production.

1940 repair work

The area restored in 1940 is indicated on Fig. 3, as well as in Fig. 4, which shows the forms still in place at taintor gates 14 and 15, and in the right foreground, the interspersion of weaker lenses in otherwise fairly sound concrete. In the distance, (as well as at the upper right corner), the generally poor areas forming parts of subsequent repair blocks is shown.

Fig. 5—Downstream face of Fond du Lac Dam showing details of construction. October, 1940

Methods of dealing with similar problems, developed on other structures as much as 14 years earlier, were applied at Fond du Lac in 1940, and at this date, no indication of failure has manifested itself. While necessarily the remedy involves a cover over large areas, the cover is in no sense a "veneer" because it is far too heavy to be so designated.

Detail of heavy concrete repair slab

The concept of a "heavy repair slab" is descriptive of the substantial thickness of reinforced concrete which we use to treat such a surface. The slab is usually specified to have at least 24 in. average thickness and well reinforced with reinforcing connected mechanically by hooks to the dowel rods, which, in turn, by wedge and, or grout, provide anchorage to the underlying concrete at depth beyond the reach of frost penetration.

At Fond du Lac the vertical construction joints in the repair slab were spaced on the center line of each taintor gate. This placed a repair slab joint at each of the original structure joints which occurred at center lines of alternate gates. The placing of concrete was carried from the bottom to the very top of each section as a continous operation.

The new concrete is deposited on surfaces generally scrubbed by a heavy spray of high pressure air and water; then, shortly before concrete is placed, a grout wash is applied. All concrete is of clean, sound aggregate, of standard portland cement (without admixture or air entraining agent) and water sufficient to produce the minimum slump consistent with placing the concrete without honey-combing. Our general practice is to use about 6 to 6½ bags of standard portland cement per

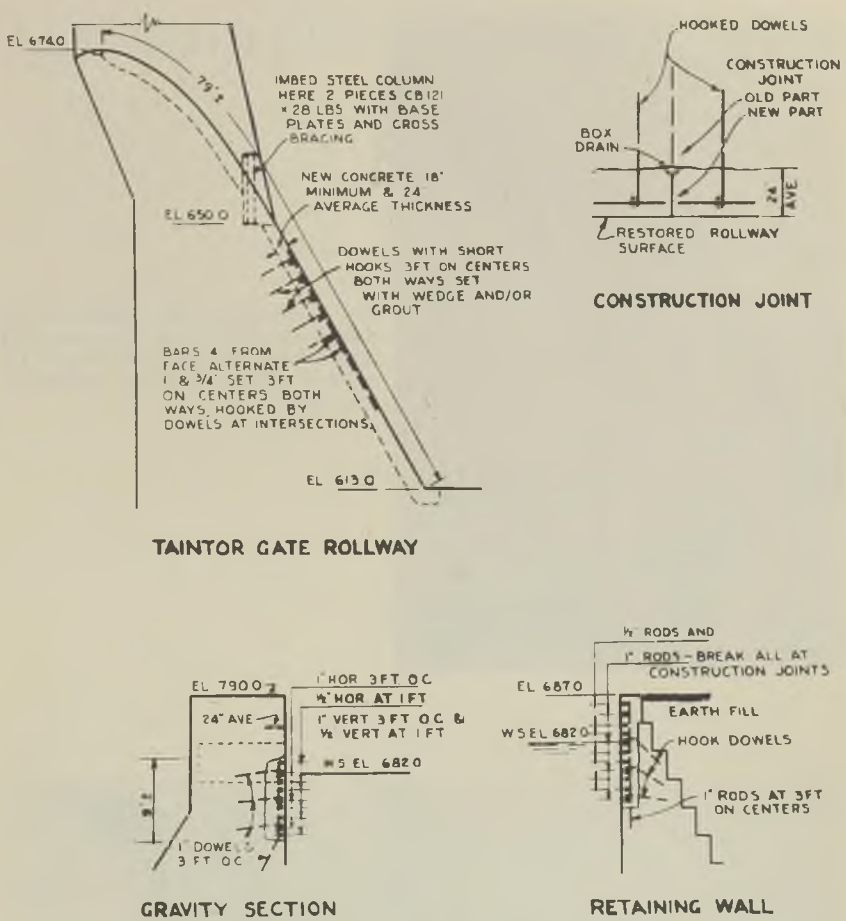

Fig. 6—Drawing from specifications governing the 1940 concrete restoration at Fond du Lac Dam

Fig. 6a, upper left; 6b, upper right; 6c, lower right; 6d, lower left

cubic yard and internal vibration is resorted to wherever it can be applied. In curing green concrete, the usual precautions of applying ample moisture are observed for from six to eight days.

Fig. 5 shows many items of interest. At the extreme right edge, new concrete from which forms have already been removed is visible. Next is the large area in which concrete is being placed, while on the left is an area which is being readied for concrete, with panel forms covering a portion of the area, and leaving to view the arrangement of dowels and reinforcing bars, as well as giving indication of thickness of the concrete slab being provided. Fig. 6 shows the details in drawing form.

Fig. 7—View of 1940 concrete in the right foreground and of a disintegrated area beyond the center line of gate 15, which is scheduled for 1945 restoration. July, 1945

Fig. 8—Typical pond face disintegration on vertical walls at Fond du Lac dam; trash gate pier to right of staff gage. September, 1941

Fig. 9—Typical pond face restoration, showing in profile, the pier appearing on Fig. 8.

Fig. 6a shows the arrangement of dowels and reinforcing steel. It also indicates the position and manner of placing steel columns at the heel of the taintor gate pier. Such a steel column is partly visible behind the incompleted forms in Fig. 5.

Fig 6b shows detail at location of original construction joints.

1945 repair work:

Work scheduled for 1945 embraced downstream face areas, as well as pond face items. Fig 6c shows details of restoration of the forebay retaining wall, and Fig. 6d shows manner of dealing with water line disintegration.

Fig. 7, at the left, shows an area scheduled for treatment in 1945, and at the right, a large part of the 1940 work. The dividing line between these two areas is the center line of taintor gate 15.

Fig. 8 shows water line disintegration suffered at the pond face. This particular view shows the trash gate pier just to the right of the staff gage, and the manner of treatment given it is indicated in Fig. 9 which shows the same trash gate pier in profile.

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Two Special Methods of Restoring and Strengthening Masonry Structures*

By J. W. KELLY† and B. D. KEATTS‡
Members American Concrete Institute

SYNOPSIS

Structures and foundations damaged by weather, erosion, scour, or settlement have been restored and strengthened by ingenious methods involving the pumping of cement-base stabilizing material into small interstices and the filling of larger spaces by aggregate which is then embedded in the stabilizing material under pressure. Herein are described several applications of the methods to various structures including bridge piers and abutments, reservoirs, dams, and underwater construction.

INTRODUCTION

It has been well said that greater engineering skill is required to restore an old structure than to build a new one. Certainly restoration challenges the engineer and calls for a high degree of experience and ingenuity. However, it is the only solution to many problems where the use of the structure must not be interrupted and where the cost of removal and replacement would be prohibitive.

Many cut-stone structures on this continent are now almost a century old, and many concrete structures are about a half-century old. As a class these structures are durable and stable, but one need not go far to find many that are in need of treatment. Some are defective because of faulty design or construction resulting in porosity, honeycombing, laitance, or cracking. Others, even if well built, are in unsatisfactory condition because of severe weathering, leaching, cracking, or exposure to fumes or other corrosive agents. Foundations have been subject to scour and to uneven settlement. In many cases the live loads

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have increased far beyond the original design loads, and new uses of the structure have been developed.

Special attention to these conditions has long been given by the construction organizations whose work is described herein, and hundreds of structures have been reconditioned through the use of two special techniques developed not only by field experience but also by extensive laboratory research. While these are proprietary processes, their application has been so widespread and so consistently successful that a factual account of their general nature and typical accomplishments will be of interest to all who have the responsibility for the maintenance and repair of masonry structures.

In order to avoid repetition in the descriptions of the work on individual structures, it is desirable first to explain the two general processes, intrusion and prepacking.

INTRUSION

Briefly, the intrusion process of stabilizing a structure or foundation consists in drilling holes at intervals and injecting an intrusion mixture which consists of portland cement, a powdered mineral filler, an intrusion aid, water, and in some cases a fine sand. The materials and proportions are necessarily varied to meet the particular conditions, within limits which are established by laboratory test and field experience. Features of the process are the characteristics of the intrusion mixture, special fittings and connections for intrusion, the sequence of solidifying various portions of the mass, and the determination of adequate penetration.

The mineral filler used in the intrusion mixture is a finely divided siliceous material called Alfesil. In the fresh mixture it tends to prevent agglomeration of the grains of portland cement and thus increases their effectiveness. In the hardened mixture, it combines with lime liberated by the hydrating portland cement to form calcium silicates which are relatively insoluble and which contribute to strength. The effect of this puzzolanic material becomes evident in the considerable development of strength at later ages, after a slow start.

The intrusion aid, or agent as it is commonly called, is used primarily for the purpose of increasing the pumpability or flowability of the mixture through the extremely small crevices and voids which must be traversed to secure thorough penetration of the structure by the solidifying material. The agent also assists in dispersal of the cement grains, and together with the filler it reduces settlement and eliminates early shrinkage of the mixture after it reaches its final location in the void spaces. Numerous test specimens cut from structures which have been

Fig. 1.—To prepare for intrusion, holes are drilled throughout structure and foundation.

intruded show that the spaces remain completely filled, without the partial separation from the walls and top of the cavity that is often observed in the case of portland-cement grouts.

Each structure presents distinctive problems, but in general the process of intrusion involves the following steps. Holes are drilled at various intervals and to various depths as required by the condition of the structure (Fig. 1). Care is of course taken not to damage the structure. Before a given section is treated it is tested under water pressure in order to determine whether the drilling is adequate and to select the proper consistency of the intrusion mixture.

The intrusion mixture is thoroughly mixed by mechanical stirring and agitation until a smooth slurry is obtained (Fig. 2). Where a high degree of penetration into small voids and passages is required, the mixing time may be as much as 20 minutes. The mixture is agitated continually in order to keep it uniform.

The intrusion mixture is injected by pumping under pressure sufficient to secure thorough penetration of the structure without displacement of structural parts (Fig. 2). The sequence of filling the various holes and, if necessary, the various depths in a given hole, is such as to expel the water and air from the cavities ahead of the intrusion mixture. When no

Fig. 2.—Materials from platform (center) are measured into mixing tanks. Piston pumps at left force intrusion mixture into structure.

Fig. 3.—A special expanding connection called an intrusion insert is used to connect pressure hose to hole.

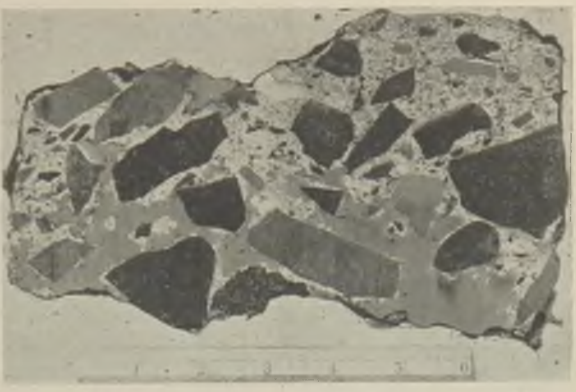


Fig. 4.—Piece of concrete cut from disintegrated tunnel lining 70 ft. from nearest point of intrusion. Note penetration of intrusion material (solid gray) into old structure.

additional material can be intruded immediately, pressure is maintained long enough to insure any additional penetration that may be made possible by slow flow of the mixture into cavities. The thoroughness of penetration at any given hole is judged by the inflow in relation to conditions observed during the drilling, by the pressure at which intrusion stops, and by the showing of intrusion mixture at distant cracks or other openings. When necessary, adjacent openings are calked to prevent loss of intrusion material. A special expanding connection has been developed to connect the pressure hose quickly and tightly to the drilled holes (Fig. 3).

The results obtained by intrusion become evident in the performance of the structure. If the structure is one which is exposed to water under pressure, the results can be observed visually at once. The amount of material intruded is of course one measure of solidification. Surprisingly large amounts can often be injected into structures which on the surface appear to be fairly sound (Fig. 4). Test cores may be taken to prove the completeness of penetration and to determine the strength.

Tests for strength and other physical properties of the intrusion mixture itself have been made by a number of laboratories. It must be emphasized that the mixtures are not standardized but are proportioned to meet the requirements of the particular job, and that any strength equal to that of comparable concretes can be produced. In one series of tests, 2-by 4-in. cylinders and standard tensile briquets were molded from a mortar which contained equal parts by weight of intrusion paste and sand, with a ratio of water to cement plus Alfesil of 0.47 by weight. The specimens were standard-cured. The following strengths were obtained.

	7 day	*28 day*	*3 mo.*	*1 yr.*
Compressive strength, psi	2510	4200	6860	9090
Tensile strength, psi	330	465	505	590

Comparative tests of intrusion pastes with portland-cement grout of equal consistency disclose (1) that the bleeding of the intrusion paste is negligible whereas under the same conditions the portland-cement grout bleeds as much as 4 per cent of water by volume; (2) the intrusion paste quickly passes through glass tubes filled with coarse sand, which cannot be penetrated with portland-cement grouts of corresponding consistency; and (3) the volumetric shrinkage during the first 24 hours is far less for the intrusion paste than for the portland-cement grout.

To summarize, the intrusion mixture maintains the solids in suspension, flows easily and without plugging, is low in setting shrinkage, and develops in the cavities a dense strong paste tightly bonded to the walls.

PREPACKING

Prepakt is concrete made by packing the forms with coarse aggregate and then pumping in a cement-base intrusion mixture to fill the voids under pressure. It is used both for restoration and, in special cases, for new construction.

One principal purpose of placing the aggregate in advance is to bring the pieces of aggregate into contact or near-contact, without the clearance which is required for plasticity in ordinary concrete. By this arrangement, even if the intervening mortar were normal in drying-shrinkage characteristics, overall shrinkage of the concrete would be relatively low because the pieces of coarse aggregate are in contact with one another. When the coarse aggregate is suitably graded the void spaces are relatively low, with correspondingly low requirement of mortar and therefore cement. The low cement content, together with the slow-hardening characteristics of the intrusion mixture, make for low and slow heat generation, which is of importance in mass concrete.

Packing the aggregate in advance also facilitates placing in difficult locations, and permits inspection before concreting in order to assure complete filling of the forms.

As in the case of intrusion mixtures, the strength of Prepakt concrete is made to meet the job requirements. The average compressive strength of 32 Prepakt concretes for which records are conveniently available, tested in the form of 6- by 12-in. cylinders, was 2,200 psi at 7 days, 3,540 psi at 28 days, and 4,330 psi at 3 months. Some of these concretes attained a compressive strength of 3,200 psi at 7 days and 6,700 psi at 3 months. The drying shrinkage of Prepakt concrete is less than that of ordinary concrete of the same cement content, and the resistance to cracking is correspondingly high. Resistance to weathering has been established as satisfactory not only by accelerated laboratory tests but also by field experience under several years of exposure. As in regular concrete, resistance to freezing and thawing may be markedly improved through the use of air-entraining agents.

The bond strength of Prepakt concrete to regular concrete, tested in the form of beams jointed at midspan, was found to be about 65 per cent greater than that for regular concrete cast against regular concrete; in fact, it was about 70 per cent of the strength of corresponding unjointed beams of regular concrete. In freezing-and-thawing tests of Prepakt concrete cast against air-entrained regular concrete, the joint between the two portions remained intact even after severe disintegration of the concretes themselves had taken place.

The general process of restoration with Prepakt is illustrated in Fig. 5a to 5c. Defective concrete of the structure is chipped out, a form is applied, and the space behind the form is packed tightly with coarse aggregate. Intrusion mixture is pumped in and, under pressure, not only fills the spaces within the prepacked aggregate but also penetrates into the pores of the underlying surface and into connecting cracks and void spaces. The cementing to and stabilizing of the underlying mass is a distinctive feature of this method of repair.

New construction with Prepakt is performed in a similar manner, with modifications as necessary. For example, in a larger mass the intrusion inlets which are placed at intervals horizontally and vertically may be perforated pipes embedded within the aggregate; and the intrusion mixture may be injected successively at various elevations. For underwater work it is usually not necessary to unwater the structure. Tests in field and laboratory have shown repeatedly that the rising mass of intrusion mixture displaces the water without mixing with it, and that satisfactory strengths and densities are uniformly obtained. Fig. 6 shows one laboratory test in progress; intrusion mixture is being forced in at the lower left edge of the form and is rising through $\frac{1}{2}$ to $1\frac{1}{2}$-in. aggregate previously submerged in water. In comparable tests with portland-cement grout, the zone of demarkation between grout and water is cloudy, and segregation and dilution of the grout occur.

APPLICATIONS

On many piers of the older railway bridges, surface disintegration has occurred due to weathering particularly at the water (and ice) lines. Fig. 7a and 7b show restoration in a typical case. First the foundation rock and the masonry base of the pier were intruded. Then the interior, which was filled with loose rock, was solidified as well as the mortar joints. Defective portions of the concrete pedestal cap and the facing stones were removed and replaced with Prepakt concrete; it was necessary to cast a Prepakt blanket completely around the lower portion. In another structure the pier footings were extended downward and outward with Prepakt concrete, providing not only a greater bearing area but also a bearing on firmer ground at the lower elevation.

Fig. 5a.—To prepare for restoration with Prepakt, old concrete is trimmed away to sound material.

Fig. 5b.—Forms are packed with coarse aggregate, and intrusion mixture is pumped in.

Fig. 5c.—Finished surface, before cleaning.

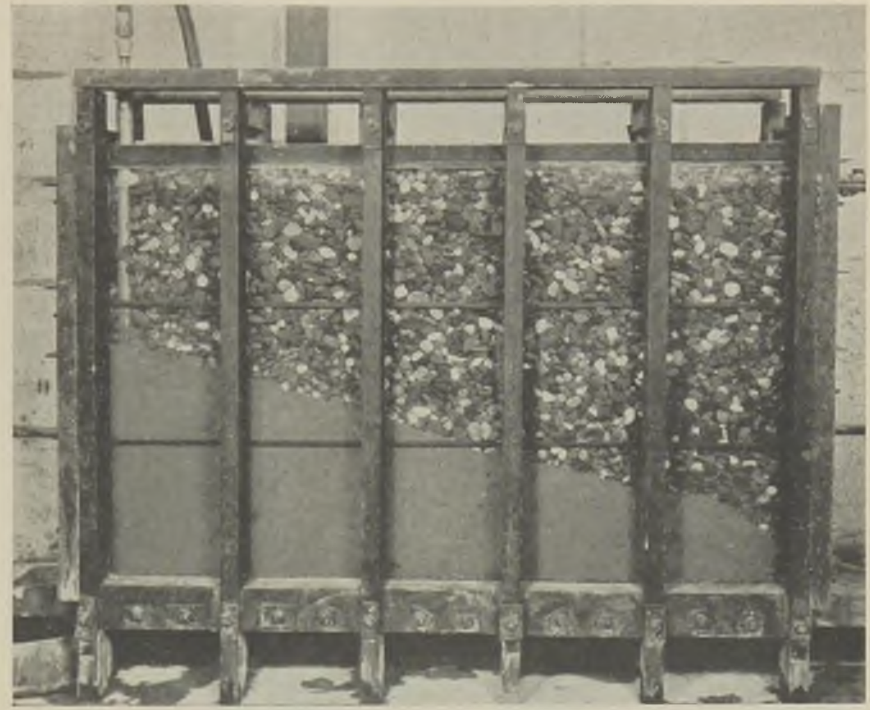
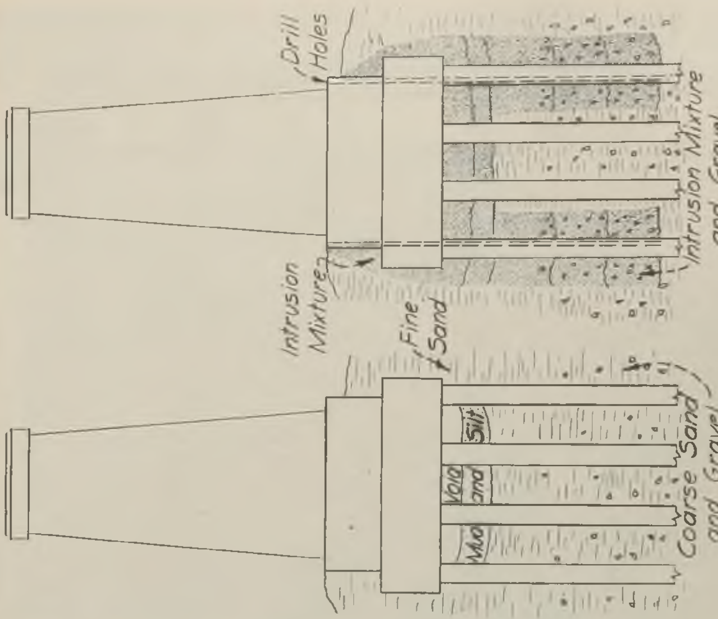


Fig. 6.—Laboratory test of placing Prepakt concrete under water. Note sharp line of demarkation between rising intrusion mixture and water being displaced.

During floods it is not unusual for mud or gravel to be washed from under piers which rest on piles. If the amount of material removed is considerable, the lateral support to the piles is lessened to such an extent that the structure weaves noticeably under load. One instance in which this condition was corrected by intrusion is illustrated in Fig. 8. Holes were drilled down through the footings, mud and sand were flushed out, and the space was filled with intrusion mixture, which also spread around the pier and stabilized an area greater than the original. The holes were extended further downward and were intruded to form a solid wall to prevent future scour. Still further down, the existing layer of coarse sand and gravel was flushed out and solidified by intrusion. The approximate final limits of intrusion, as determined by drilling, are indicated on the drawing. In stabilizing the piers of other bridges, in some cases the opening beneath the pier has been so large that it was filled with riprap or with prepacked aggregate in order to reduce the amount of intrusion mixture required.

Abutments and wing walls are restored in a manner similar to that previously described for piers. A typical case is illustrated in Fig. 9a



(A) Before Intrusion (B) After Intrusion

Fig. 8—Stabilization of railway bridge pier on piles.

Fig. 7a—(top left) Disintegrated concrete of pedestal block has been chipped away, and forms for Prepakt concrete are being erected

Fig. 7b—Disintegration of cut-stone facing was so severe at water line that Prepakt concrete blanket was built entirely around pier.

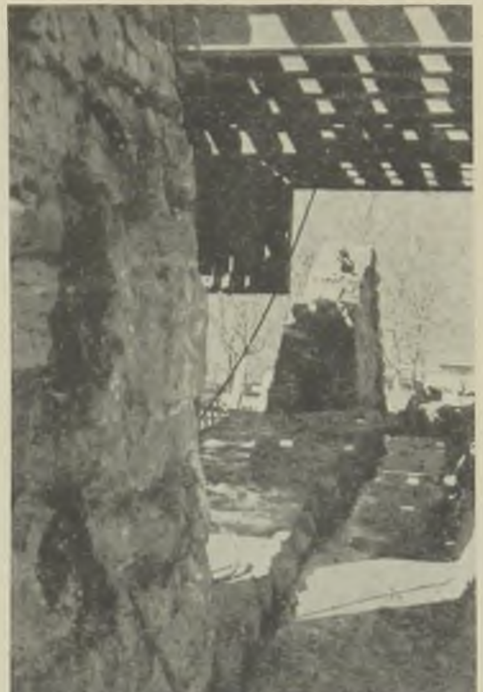


Fig. 9a (above)—Several courses of stone were removed from this old abutment, and a new bridge seat of Prepakt concrete was cast.

Fig. 9b (top right)—Prepakt concrete has replaced the old bridge seat and disintegrated facing stones of the old wing wall. During construction, bridge girders were supported on bent shown at left.

Fig. 10 (bottom right)—New construction with Prepakt. Forms for entire abutment and wing wall packed with local aggregate and intruded.

and 9b. In addition to the work shown, the entire interior of the masonry and joints was solidified by intrusion. In another case an entire abutment was built with Prepakt concrete which could be cast more economically with plant already at the site than by bringing in a conventional plant and casting ordinary concrete (Fig. 10).

A common type of early construction of small single-arch bridges consisted of cut-stone masonry to the spring line and brick masonry in the arch. Overcoating of the disintegrated masonry would lessen the opening of the waterway. Several bridges of this type have been restored by removing the stone in alternate lengths and casting Prepakt concrete to the original line of the structure (Fig. 11a and 11b). Solidification of the Prepakt under pressure assured tight contact and prevented settlement of the arch. In one case, the arches of a stone bridge were deepened over their entire area with a Prepakt-concrete arch which because of the pressure filling was able to share the load without settlement of the arch.

Restoration of the piers of a long railway bridge under heavy traffic and severe underwater conditions was accomplished by the intrusion and Prepakt methods in 1941-1943.* The piers, 70 years old, had been built by sinking watertight timber caissons in place and then building a concrete base and cut-stone pier on each base. Around some of the piers had been placed open-bottom caissons which were filled with riprap. Deterioration of the outer caissons eventually allowed much of the riprap to escape; in some cases damage to the timber of the central caisson had permitted erosion and disintegration of the concrete foundation; and the cut-stone portion of the pier was in bad condition particularly at the joints. At some of the piers, the water was as deep as 50 feet, and the current was as swift as 12 miles per hour. In spite of these adverse conditions, the entire restoration was accomplished at a cost estimated to be less than that for the construction of one new pier. In the upper portion of the piers, which were originally faced with ashlar masonry and filled with rubble masonry set in lime mortar, the volume of intrusion material pumped in was up to 12 per cent of the overall volume.

Another outstanding renewal, that of the 24 piers of a railway bridge 85 years old, was accomplished at a cost estimated to be one-tenth of the cost of replacement.† In no case was it necessary to unwater the piers; only a row of sheet piling was driven across the nose of the pier in order to slow the current and permit proper inspection and work by divers. Figure 12 is a winter view under this bridge.

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*"Substructure Repairs Under Difficult Underwater Conditions," *Roads and Bridges* (Toronto), Nov. 1943, pp. 36-40, 65-69.

†"Rejuvenates 85-Year-Old Bridge Piers," C. P. Disney, *Railway Age*, June 16, 1945, pp. 1049-1051.

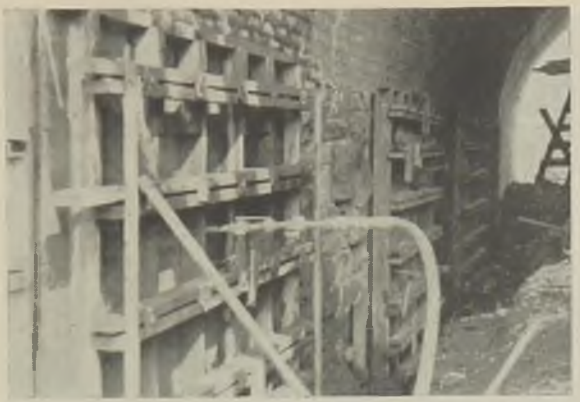

Fig. 11a (left)—Disintegrated stone masonry in bench walls of this single-arch railway bridge was removed in alternate 5-foot sections and replaced with Prepakt concrete.

Fig. 11b (right)—Second stage of replacement—Prepakt concrete sections permit full flow section and provide smoother surface than original construction.

The lining of several tunnels has been solidified and stabilized by the intrusion process, with Prepakt concrete used whenever required to replace displaced or damaged sections. One of the earlier jobs is described in *Western Construction News*, Feb. 1939, pp. 35-38 and in *Railway Age*, March 4, 1939, pp. 373-376.

Fig. 12.—One of two long railway bridges for which the piers were restored by intrusion and prepacking. Severity of ice conditions causing disintegration is apparent. Scaffolding for work interrupted by winter conditions is still on nearest piers.

A reservoir, shown in Fig. 13a and 13b, had been built in sandstone excavated to a depth of 14 feet and on the fill formed by the excavated sandstone to an additional depth of 14 feet. The sides were on a slope of 1 to 1. The entire area of the cut and fill had been surfaced with a blanket of clay, on which had been cast a concrete slab 4 to 6 in. thick. Settlement of the fill was so serious that it was impossible to fill the reservoir more than half full, and much of the clay blanket was eventually washed away leaving large voids and cavities. This condition was corrected by intrusion through and under the blanket, and the reservoir was rendered stable and watertight.

A large concrete dam built in the days of long gravity chutes, wet mixes, and consequent segregation and laitance formation, is shown in Fig. 14. Vertical construction joints were spaced 25 ft. apart, and lifts were about 5 feet deep. Leakage of water through both types of joint was extensive. In order to stop the leakage through the vertical joints, holes were drilled at intervals along each joint, extending into the rock foundation. Intrusion was completed in the early spring, when the width of the joints was a maximum due to seasonal contraction of the concrete blocks. The horizontal construction joints were also sealed

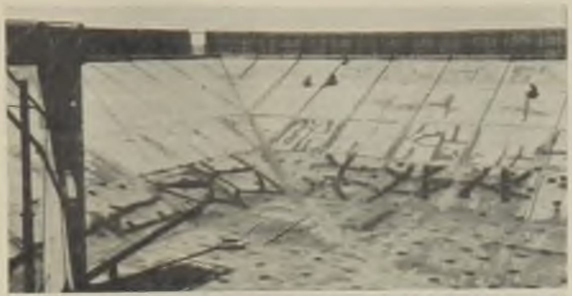

Fig. 13a.—Reservoir built half in excavation and half in embankment showed extensive leakage in spite of clay blanket.

Fig. 13b.—After intrusion to seal foundation and replace eroded portions of blanket, joints were sealed and entire surface treated with waterproofing compound.

Fig. 14.—Vertical and horizontal construction joints have since been sealed by intrusion. Downstream face will be restored later.

by drilling and intruding from the top, each laitance seam being thoroughly flushed out before intrusion.

One interesting development has been the solidification of rock-fill breakwaters and sea walls to prevent scour and break-up in heavy storms. Figure 15 shows a troublesome section of rock apron which has been stabilized by filling the spaces between the large stones with crushed-rock aggregate and then intruding the mass to form a five-foot apron and toe wall extending well below low tide. In a subsequent storm, much of the untreated rock section shown at the left of the photograph was washed out, whereas the treated section is still intact.

Inspection of a large concrete-lined spillway tunnel disclosed several eroded cavities in the invert. The largest of these breaks was about

Fig. 15.—Section of sea wall subject to heavy tide and wave action has been stabilized by intruding to form a solid blanket 5 feet thick. Rock fill at left has since been washed out by storm, leaving the intruded apron intact.

112 ft. long and 33 ft. wide, with a maximum depth of scour of 36 ft. A description of the repair work by the Prepakt method is given in "Erosion Causes Invert Break in Boulder Dam Spillway Tunnel," by Kenneth B. Keener, *Engrg. News-Record*, Nov. 18, 1943, pp. 762-766. Quoting from the description, " . . . investigations indicated that such a method had definite advantages in that the high bonding strength of prepacked concrete, its low cement content and low temperature rise, small shrinkage and therefore less inclination to cracking, would more than compensate for its slowness in attaining strength. However, the primary reason for adoption of that process was the conclusion that the repairs could be made more economically than by regular concrete placing methods."

A unique design for bridge piers in deep water has been devised by C. P. Disney.* In this design, steel H-piles set in the bed rock are encased in a Prepakt-concrete pier. Sheet piling is driven to the outline of the finished pier, the enclosure is washed clear of all material except that which is suitable for inclusion in the structure, the remaining space is packed with aggregate, and the pier is intruded to form a monolithic whole. While the operation is not that of reconditioning as are those previously described, it illustrates the possibilities for alterations of, and additions to, existing structures.

The work of restoration by either method discussed herein is conducted by Intrusion-Prepakt, and new construction using the Prepakt method by the Prepakt Concrete Co., both with offices in Chicago, Cleveland, and Toronto.

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*"Redesign of the Quebec Bridge," by C. P. Disney, *Roads and Bridges* (Toronto), Feb. 1943, pp. 17-22, 48.

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Laboratory Studies of Concrete Containing Air-Entraining Admixtures*

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Member American Concrete Institute

SYNOPSIS

The effects of the incorporation of each of nine different air-entraining admixtures in concrete were investigated by the making of a large number of batches of concrete under carefully controlled laboratory conditions. The results of tests on the plastic and hardened concrete specimens from batches made in parallel with and without each admixture are presented and discussed. An interpretation of the significance of the data and their application to the successful use of air entrainment in concrete is given.

INTRODUCTION

The practical advantages to be derived from the entrainment of well distributed minute spheroids of air in concrete mixtures were brought to the attention of the writer in 1939 by work performed by the Portland Cement Association on experimental pavements. Several field and laboratory investigations had been instituted by others during the previous decade with some vague idea of the benefit to the hardened concrete inherent in air entrainment. Search of the literature reveals a number of references to the use of fats, oils, and greases in cement earlier in this century as is indicated in the bibliography appended to this paper. Reference was found (2)‡ to the following specification for stucco as written by Marcus Vitruvius Pollio, the famous Roman architect, in the first century A.D.; "A mixture of well-hydrated lime, marble dust and white sand mixed with water, *to which mixture is added either hogs' lard, curdled milk or blood.*" The reference to the "blood" is sinister,

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(‡) The numbers in parenthese refer to the bibliography appended hereto.

but the reference to "hogs' lard" is illuminating in that it indicates that the practical use of the benefits of entrained air is not a twentieth-century discovery. This earlier work notwithstanding, the peculiar merit of purposeful entrainment of air in concrete has become generally known and made use of only in the past five years.

The data compiled by this laboratory from tests on field specimens and observations made in connection with the construction of numerous projects, using plain and air-entraining concrete, by the Corps of Engineers since April 1941 have been published (79). The results of studies by this laboratory of various forms of Vinsol resin interground with cement have also been published (30, 31, 45, 65, 71, 77, 81 and 82).

It is the purpose of this paper to present the results of the most recent laboratory studies of air-entraining admixtures which were authorized:

(a) To determine if the benefits were solely attributable to the agent used or to the air entrained or to a combination of both;

(b) To determine the most effective use of air entrainment and the optimum limits of such use, and

(c) To develop a specification for air-entraining admixtures and related methods of test.

The work was divided into an initial and secondary phase, the results of which are hereinafter reported in detail, and a tertiary phase, involving concrete containing large (6-in.) aggregate, which has not progressed sufficiently to warrant more than brief mention at the close of this paper.

INITIAL PHASE

Admixtures

It was decided that the investigation should not be limited to admixtures which had been interground with the cement, but should include those which are added at the mixer. For this purpose, the materials listed in Table 1 were included in the work.

TABLE 1—NATURE OF ADMIXTURES

Q—A combination of spent transformer oil and triethanolamine.

R—A neutralized form of gasoline insoluble resin of the pine tree.

S—R plus calcium chloride (non-proprietary).

T—Saponified beef tallow (non proprietary).

U—A combination of an alkali salt of a fatty alcohol sulfate and calcium lignin sulfonate.

V—A combination of R, calcium chloride and aluminum powder.

X—Paraffin-oil (non proprietary).

Y—A solution of calcium chloride in water containing a small amount of an unidentified organic material—not an air-entraining agent.

Z—A combination of fly ash, calcium chloride and calcium lignosulfonate.

NOTE: *In all cases the symbol P represents concrete without admixture.*

Preparation

The admixtures were prepared and used in the manner and in the amounts described below:

Admixture Q was used in the amount of 20 ml. per 100 lb. of cement or *0.015 per cent of the admixture solids by weight of cement.* The amount to be used, based on the weight of cement, was measured out by volume and then diluted with water to make 100 ml. of liquid to be added at the mixer. The amount of mixing water was decreased by 100 ml. when Admixture Q was used.

Admixture R. The proportions of the R solution were: resin powder: 249 g.; sodium hydroxide; 37.4 g.; water: sufficient to make two liters of the solution .

The $NaOH$ was dissolved in a small amount of water and then added slowly to a suspension of the resin powder in water. Stirring was continued until neutralization of the resin was complete. The solution contained 0.1245 g. of resin per ml. of solution. It was desired to use *0.01 per cent neutralized resin by weight of the cement,* so 34.3 ml. of solution was required per bag of cement. From the weight of cement to be used in each batch of concrete, the volume of the solution required was computed, measured, and then diluted with water to a total volume of 100 ml. for addition to the batch. The amount of mixing water was reduced by an equivalent volume.

Admixture S. The R admixture was prepared in solution and measured out exactly as described above except that it was not diluted. Commercial calcium chloride (77 - 80 per cent $CaCl_2$) was weighed out in the amount of 1 per cent by weight of the cement. A volume of cold water was measured out, as follows:

$$\text{Vol. of water, ml.} = \frac{W}{94} \times (473.17 - R)$$

where : W = weight in pounds of cement used,

R = volume of R solution to be used, in ml. and

473.17 = number of ml. in 1 pint.

Hence the volumes were such that the volume of the R solution + volume of water would be 1 pint per bag of cement.

The cold water was added to the $CaCl_2$ and it was stirred and heated until solution was complete. The $CaCl_2$ solution was then allowed to cool. Immediately prior to adding to the mixer the $CaCl_2$ solution was added to the R solution and the mixture stirred. The mixture was "stringy" when added to the mixer. When this admixture was used the amount of mixing water used was decreased by an amount equal to the combined volumes of the R solution and the water added to the $CaCl_2$

(i.e. by 1 pint per bag of cement). The admixture S was used in the amount of 1.06 per cent by weight of the cement.

Admixture T. The semi-liquid beef tallow was weighed out in four 120-g. batches. To each batch was added a solution containing 50 g. of $NaOH$, 150 ml. of H_2O, and 100 ml. of alcohol. The mixture was then boiled slowly (refluxed) until saponification was complete. The saponified mixture was then added to a cold saturated solution of $NaCl$ in water to "salt-out" the soap. The soap was then separated from the impurities and the salt solution by vacuum filtration. The soap was dried at 95 C. to constant weight and pulverized by grinding in a mortar. The powdered soap was weighed out in the amount of *0.01 per cent by weight of the cement* and then approximately 1000 ml. of water was added to the soap. This mixture was heated and stirred until the soap was completely dissolved. The soap solution was then diluted with warm water to a volume of 3000 ml. When this admixture was used, the amount of mixing water was decreased by 3000 ml.

Admixture U was obtained as a dry powder and the amount to be used was measured by weight so that *1.06 per cent was added by weight of the cement* used (equal to 1 lb. per bag of cement, as required by the manufacturer). The admixture was added to the batch in the powder form following the addition of first 2/3 of the water and before the cement.

Admixture V (not used in initial phase of work). This admixture was developed by the writer during the progress of the work*. It was used in lieu of admixture S in all except the initial phase of the work and was added to the batch in the powder form in the amount of *1.06 per cent by weight of the cement.*

Admixture X. The paraffin oil (see list of properties below) was received as an oil in which precipitated lumps of paraffin were suspended. The mixture was heated on a water bath until the lumps were completely melted. An amount of the oil equal to *0.5 per cent by weight of the cement* was taken up in a graduated pipette and expelled in a thin stream into the weighed amount of cement. The amount of cement treated varied from 60 to 100 lb. per batch. The cement was then mixed in a modified Los Angeles Abrasion Machine (from which the shelf had been removed) for 500 revolutions with a weight of ¾-in. diameter steel balls equal to 4 times the weight of the cement. The cement was then removed from the drum, separated from the balls, and placed in 5-gal. cans which were sealed except for pressure-relief valves. The cans were placed in an oven, maintained at a temperature of 200 F. for two days, and allowed to cool with the oven for two days. They were

*Patent applied for.

removed from the oven and the cement weighed out for use in concrete on the day the concrete was to be made. This aging was stated to be necessary by the agency recommending the material.

PROPERTIES OF PARRAFIN OIL

Wax Content	20 to 25 per cent
Specific Gravity	0.850 to 0.857
Flash Point	230 F. to 260 F. (Cleveland Open Cup)
Cold Test	65 F. to 75 F.
Viscosity at 100 F.	43 to 48 (Saybolt Universal)

Admixture Y was purchased as a liquid from a local distributor and was added to the mixer in the amount of 1.5 gal. per cu. yd. (abs. vol.) of concrete as recommended by manufacturer for "mass" concrete. The amount to be added to a given batch was determined by weight so that for the following cement factors the per cent by weight of cement was, as follows:

C. F. (b. per cu. yd.)	Admixture, per cent
4.50	2.96
5.25	2.53
6.00	2.22

When admixture Y was used the amount of mixing water was decreased by an amount equal to the weight of solution added.

In view of the claim by the manufacturer that this material afforded integral curing, the concrete made with this material received no fog or water curing after molding.

Admixture Z was purchased as a dry powder from the manufacturer's commercial stock in August 1944 and the amount to be used was meassured by weight so that *1.06 per cent was added by weight of the cement* used (equal to 1 lb. per bag of cement, as required by manufacturer). The admixture was added to the batch in the powder form following the addition of the first 2/3 of the water and before the cement.

Cements

It was found to be impractical to obtain several brands of commercially produced portland cement containing the desired amounts (based on air entrainment) of the various intergrindable admixtures (Q, R, T, and X) and, as certain admixtures of the non-interground variety were to be used, it was decided to add all of the admixtures at the time of mixing the concrete (except X, see description of use above). The cement used was a blend of equal parts of four brands of cement manufactured commercially to meet Federal Specifications SS-C-206a (A.S. T.M. C 150 Type II). Proper quantities of equal parts of each of the cements were added to each batch of concrete at the time of mixing.

Aggregates

The fine aggregate used was from a single lot of natural siliceous sand from Long Island having a F.M. of 2.60. The coarse aggregate was Connecticut trap rock of 1½-in. maximum size and having a F.M. of 7.0. The characteristics of the aggregate are shown in Table 2.

TABLE 2—PHYSICAL CHARACTERISTICS OF AGGREGATES

Type	Bulk Sp. Grav.	Absorp. per cent	Soundness Loss-% (a)	Strength Ratio	Abrasion Loss-%(b)	Spec. Heat
Stone	2.93	1.3	0.5	....	9.6	0.208
Sand	2.62	0.5	2.5	109	....	....

(a) $MgSO_4$ 5 cycles.
(b) Los Angeles Machine.

Concrete

(a) *Mixtures and rounds.* Mixtures were designed with each of the admixtures to produce nominal cement factors of 4.5, 5.25 and 6.0 bags per cu. yd. of concrete with a nominal slump of 3 in. The W/C and sand-aggregate ratio were permitted to fluctuate as affected by the admixture. The properties of the mixtures used are given in Table 3.

In this initial phase of the work, one round of 4.5- and 6.0- bags cement-factor concrete and three rounds of the 5.25-bag cement-factor concrete were made. In each round, 3.3-cu. ft. batches of concrete were made for each of nine conditions of concrete.

Mixing was accomplished in a 3.5-cu. ft. Smith tilting drum mixer. The batches were mixed for two minutes, allowed to rest for three minutes followed by a one minute re-mixing. Timing of the mixing started when all materials including water had entered drum.

(b) *Specimens.* The specimens prepared from each 3.3-cu. ft. batch were; four 6-in. by 12-in. cylinders, one 6-in. by 6-in. by 30-in. column, one 6-in. by 6-in. by 30-in. beam, three 3½-in. by 4½-in. by 16-in. beams, two 6-in. by 6-in. by 8-in. prisms (for horizontal and vertical pull-out tests), and specimens for air content and bleeding. All specimens were consolidated in their molds by vibration, except for slump and air content tests. External vibration at 3600 r.p.m., was used except that internal vibration, at 7000 r.p.m., was used for the column specimens.

The specimens were cured and tested* as follows:

Cylinders. Stripped at 24 hr. and cured in fog to time of test. Tested at 10 and 30 days.

Columns and beams (large). Stripped at 48 hr. and cured in fog for 16 additional days, then stored in laboratory air pending shipment to Treat Island, Maine for installation on the tidal exposure rack in October 1944.

*The deviation from standard times of stripping, curing and testing was necessitated by the working schedule of the laboratory.

TABLE 3—CONCRETE MIXTURE DATA

Admixture	Cement Factor bags per cu. yd.		W/C g.p.b.	Sand % by Vol.	Unit Weight lb. per cu. ft.	
	Theoret.*	Actual			Theoret.*	Actual
P†	4.5	4.36	8.75	46	154.6	149.5
Q	4.7	4.35	7.40	40	158.0	145.2
R	4.7	4.36	7.40	40	158.0	145.7
S	4.7	4.47	7.40	40	158.0	149.7
T	4.7	4.54	7.45	40	157.9	152.5
U	4.7	4.30	6.75	37	160.1	145.0
X	4.7	4.37	7.50	40	157.8	146.0
Y	4.5	4.41	8.60	46	155.0	151.9
Z	4.7	4.49	6.70	37	160.3	152.8
P†	5.25	5.17	7.25	44.5	155.9	153.4
Q	5.50	5.16	6.25	39	158.7	148.4
R	5.50	5.15	6.10	37	159.4	148.2
S	5.50	5.10	6.10	37	159.4	147.1
T	5.50	5.29	6.35	39	158.4	152.0
U	5.50	5.09	5.85	36	160.3	147.5
X	5.50	5.29	6.30	39	158.5	152.4
Y	5.25	5.15	7.15	44.5	156.2	153.3
Z	5.50	5.24	5.85	36	160.3	152.5
P†	6.0	5.90	6.25	43.5	156.6	153.9
Q	6.2	5.84	5.60	38.5	158.8	149.1
R	6.2	5.82	5.60	38.5	158.8	148.4
S	6.2	5.83	5.60	38.5	158.8	148.6
T	6.2	5.98	5.70	38.5	158.5	152.8
U	6.2	5.85	5.25	35.0	160.5	150.9
X	6.2	5.87	5.60	38.5	158.8	149.9
Y	6.0	5.89	6.20	43.5	156.7	153.8
Z	6.2	5.85	5.20	35.0	160.7	151.0

*Theoretical cement factor and theoretical unit weight are based on calculations of the concrete mixture in an air-free condition.
†P = Concrete without admixture.

Beams (small). Stripped at 48 hr., then cured in fog for 14 days (for laboratory freezing and thawing) or until time of test (for flexural strength).

Prisms (pull-out). Undisturbed in mold and protected against vibrations for 96 hr. (exposed surface coated with membrane compound), then stripped and cured for additional 22 days in fog followed by seven days in laboratory air. Tested at age of 33 days.

Discussion of results—plastic concrete

The characteristics of the unhardened mixtures in this phase of the program are given in Tables 3 and 4. These characteristics are discussed briefly below:

(a) *Water demand.* The data indicate the large reduction in W/C made possible by use of the air-entraining admixtures with the cement factors, and aggregate type and size used. It was noted that due probably to higher air content, the reduction in W/C was greater with the addition of all air-entraining admixtures at the mixer than was practicable with

TABLE 4—CHARACTERISTICS OF PLASTIC CONCRETE MIXTURES

Admixture	Air Content of Mortar—% A.S.T.M. C185-44T	Air Content of Concrete—%			R*			Slump, Inches			Bleeding, per cent		
		Cement Factor[a]			Cement Factor[a]			Cement Factor[a]			Cement Factor[a]		
		4.5	5.25 b	6.0	4.5	5.25 b	6.0	4.5	5.25 b	6.0	4.5	5.25 b	6.0
P[d]	8.2	3.3	1.6	1.7	2.48	5.13	4.82	3	2.6	2.75	15.6	12.8	8.7
Q	17.4	8.1	6.5	6.1	2.15	2.68	2.85	4	3.25	3.50	8.0	7.0	5.6
R	19.2	7.8	6.5	6.5	2.46	2.95	2.95	4	3.1	2.75	8.4	6.7	4.2
S	19.1	5.2	7.8	6.4	3.67	2.45	2.98	2.50	3.25	3	3.2	3.2	2.9
T	17.0	3.4	4.0	3.6	5.00	3.86	4.72	2	3.0	2.75	8.7	7.9	5.6
U	17.6	9.4	8.0	6.0	1.87	2.20	2.93	3	3.2	2.50	5.9	4.6	2.9
X	12.3	7.5	3.9	5.6	1.64	3.15	2.20	5	2.7	2.75	11.2	8.9	4.8
Y	c	2.0	1.9	1.8	6.40	6.16	6.30	3.25	2.9	2.75	12.7	11.6	10.3
Z	20.2	4.7	4.9	6.0	4.30	4.12	3.37	2	2.75	3	6.1	6.7	2.4

Note: Determinations of air content of mortars run in duplicate.
R* = Ratio of Air in Mortar to Air in Concrete.
a : Cement factors are the designed nominal cement factors and are therefore approximate.
b : Values shown for C.F. = 5.25 bags are averages of 3 tests, except in the case of S, where they are averages of 2 tests.
c : C.F. = 4.5, 12.8%; C.F. = 5.25, 11.7%; C.F. = 6.0, 11.5%, due to the addition of three different quantities of admixture.
d : P = Concrete without admixture.

similiar mixtures containing neutralized Vinsol resin interground at the mill (65 and 82) even though, in the case of neutralized Vinsol resin, comparable quantities of the resin were used. It is to be noted, too, that practically no reduction in W/C resulted from the non-air-entraining admixture Y.

(b) *Consistency (slump).* The basic mixtures were designed to develop a slump of 3 in. The actual slumps obtained are shown in Table 4.

(c) *Bleeding (water-gain).* The large reduction in bleeding* developed by the mixture containing air-entraining admixtures is evident in Table 4. The largest reduction was obtained with admixture S. In general, the air-entraining admixtures reduced the bleeding of the plastic mixtures by at least 40 per cent of that resulting from the use of plain cement.

(d) *Air Content.* The air entrained in standard mortar (A.S.T.M. C 185-44T) and in the concrete mixtures, and the ratios between air-in-mortar and air-in-concrete are shown in Table 4. The particular value of the data is in the relative amounts of air entrained by the various materials in the several types of mixtures. Of value, too, is the record of the highly variable ratio of air-in-mortar to air-in-concrete as it reflects on the ability of A.S.T.M. Method C 185 to predict from air-in-mortar values the amount of air which will be entrained in concrete. The ratios are particularly divergent from the value of 2.54 determined as the average in previous work, in the cases of plain cement and admixtures, T, U, X, Y, and Z. It appears from these data that the amount of air which will be entrained in a given concrete mixture with a given amount of an air-entraining admixture can be determined accurately only by tests using the concrete and admixture involved. *It should be noted that the excessively high air contents of the concrete made with several of the admixtures were not corrected by reducing the amount of the admixture in the mixture because it was desired to use the admixtures in the amounts recommended by the manufacturer or common in previous practice.*

Discussion of results—hardened concrete

(a) *Compressive strength.* The influence of the various admixtures in the amounts used on the compressive strength of concrete containing three different cement factors is shown in Table 5. Admixture Z shows the most beneficial effect on strength with all cement factors and at both ages; as might be expected from the large reduction in water demand resulting from its use. Due, probably to the presence of accelerators, admixtures S and U show a beneficial effect of strength under all conditions of cement factor and age, with S showing the most beneficial result with the low cement factor, where such effect is most needed. None of the air-entraining admixtures shows a materially detrimental effect on

*Determined using method similar to that described in the "Handbook for Concrete and Cement" published by this office; Method CCL-CON-7, p. 127.

TABLE 5—RELATIVE COMPRESSIVE AND FLEXURAL STRENGTHS OF CONCRETE

Admixture	Strength—Per Cent								
	Age: 10 days			Age: 30 days					
	C.F.* = 4.5	C.F. = 5.25	C.F. = 6.0	C.F. = 4.5		C.F. = 5.25		C.F. = 6.0	
	Comp.	Comp.	Comp.	Comp.	Flex.	Comp.	Flex.	Comp.	Flex.
P†	100 (2210 psi)	100 (3030 psi)	100 (3720 psi)	100 (2985 psi)	100 (510 psi)	100 (4320 psi)	100 (635 psi)	100 (5420 psi)	100 (730 psi)
Q	99	99	104	95	101	109	97	99	88
R	90	101	92	95	100	105	100	90	100
S	132	117	105	129	115	109	107	103	102
T	86	111	101	107	108	108	72	101	94
U	101	115	112	108	97	115	96	105	101
X	95	127	107	96	108	116	116	103	97
Y	85	99	96	76	67	89	72	81	69
Z	143	152	132	149	130	131	121	125	111

*C.F. = Nominal cement factors in bags per cu. yd.
†P = Concrete without admixture.

strength under any of the conditions of age and cement factor despite rather high air contents.

(b) *Flexural strength.* The influence of the various admixtures on the flexural strength of concrete, containing three cement factors, is shown in Table 5. The results shown are the values obtained on the 3½-in. by 4½-in. by 16-in. beams made and tested in parallel with the durability test specimens, but cured for their entire age in water at 70 F. The data indicate that none of the air-entraining admixtures exerts an appreciably adverse influence on the flexural strength of concrete in spite of rather high air contents.

(c) *Modulus of elasticity.* The modulus of elasticity of the concrete was determined dynamically at an age of 16 days just prior to the freezing and thawing test. The values obtained are given in Table 6 as general information.

TABLE 6—AVERAGE DYNAMIC MODULI OF ELASTICITY

Age: 16 days

Admixture	Nominal Cement Factor b. per c.y. 4.50	5.25	6.00
	Dynamic E—psi x 10^6		
P	5.43	6.26	6.35
Q	5.05	5.66	5.75
R	5.15	5.73	5.68
S	5.78	5.49	5.80
T	5.80	5.98	5.98
U	4.95	5.67	5.86
X	5.27	6.24	5.98
Y	4.17	5.12	4.62
Z	6.41	6.27	6.16

(d) *Bond-to-steel.* The tests of bond of concrete, containing the various admixtures, to reinforcing steel were performed using ¾-in. high yield-point HI-BOND bars. However, these data were consolidated with more comprehensive data from subsequent tests and will be discussed later in this paper.

(e) *Durability.* (1) *Field.* Column and beam specimens were installed on the exposure rack at Treat Island in October 1944, but the deterioration of specimens has not progressed to the point permitting any comment or conclusions at this time.

(2) *Laboratory freezing and thawing.* The influence of the various admixtures on the resistance of concrete to rapid freezing and thawing (84) is summarized in Table 7 in terms of durability factors calculated as in Fig. 1. The saturated specimens immersed in water were subjected to reversals in temperature from 42 ± 2 F. to 0 ± 2 F. eleven times in 24 hr., commencing at an age of 16 days.

$$DFE = \frac{PN}{M}$$

where:

DFE = Durability factor in per cent of dynamic E at zero cycles.

P = Relative E of 50 per cent or greater at time of test based on E at zero cycles.

N = Number of cycles at which P reaches 50 cent *or* the ultimate number of cycles of the test prior to completion of test.

M = Ultimate number of cycles of the test.

Fig. 1—Calculation of relative durability factor—based on relative dynamic modulus of elasticity

The data in Table 7 indicate that at 215 cycles of quick freezing and thawing all of the concrete containing air-entraining admixtures is vastly more durable than concrete made with plain cement or with the non-air-entraining admixture Y. The concrete containing admixture R with each of the cement factors was at least slightly more durable than concrete containing any of the other admixtures, with admixture S being only very slightly less durable.

TABLE 7—INFLUENCE OF ADMIXTURES ON DURABILITY OF CONCRETE AS TESTED IN LABORATORY QUICK FREEZER

Durability Factor DFE at 215 cycles

	Nominal Cement Factors in bags per cu. yd.		
Admixture	4.50	5.25	6.00
P*	31	7	25
Q	82	86	86
R	85	88	89
S	84	87	86
T	77	81	83
U	74	81	88
X	84	82	86
Y	18	25	13
Z	76	81	88

*P = Concrete without admixture.

The history of the decrease in dynamic E of the specimens is shown in Fig. 2 to a maximum of 360 cycles of freezing and thawing. The order of decreasing durability is not changed appreciably from that which existed at 215 cycles, but the degree of deterioration is considerably greater, particularly in the case of admixture Z at 5.25 bags per cubic yard, and admixture U at 4.50 bags per cubic yard.

A check on the reliability of the durability factor based on decrement is dynamic E is afforded by the ratio of flexural strength of the frozen and thawed specimens at the ultimate number of cycles of the test, to the flexural strength of similar unfrozen specimens at equal age. The ratio is expressed as the D.F.M., or relative modulus of rupture. The relation-

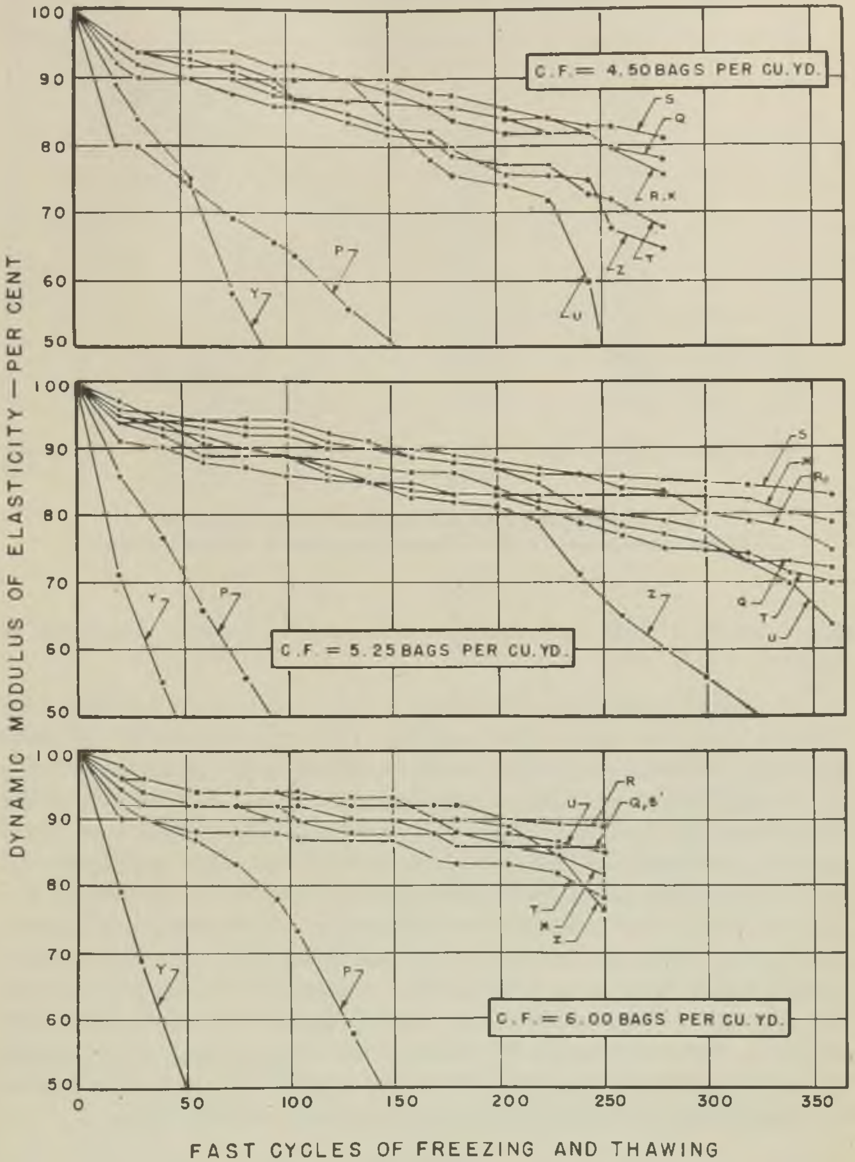

Fig. 2—Influence of type of admixture on resistance of concrete to accelerated laboratory freezing and thawing in terms of dynamic "E" in per cent

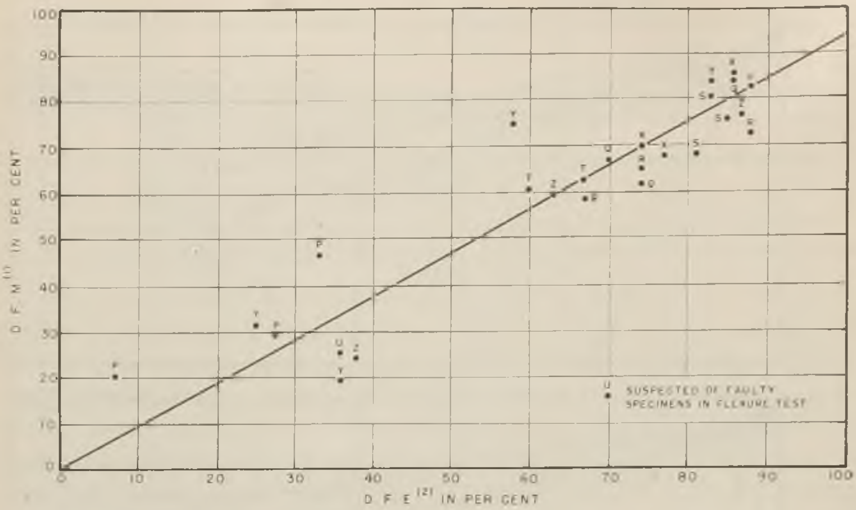

Fig. 3—Relationship between durability factors E and M
(1) Relative modulus of rupture M. (2) Durability factor based on decrement in dynamic E.

ship between D.F.E. and D.F.M. is reasonably good as indicated in Fig. 3.

The foregoing data were considered to be inadequate for final conclusions to be drawn but when considered in conjunction with the work previously accomplished, they were considered to be an adequate basis for the drafting of a tentative specification and methods for evaluating admixtures for concrete (77). The tentative specification was based upon the performance of an admixture with two cements meeting Federal Specification SS-C-206a but differing in reaction with certain of the admixtures. It was a further purpose of the specification to place admixtures in a definite category as a material for use in concrete subject to acceptance testing as are the other materials for concrete: cement and aggregate. The action appeared desirable in view of the beneficial effects on the performance of concrete inherent in the use of certain admixtures providing that protection was afforded against uncertainties of performance or sacrifice in rate and degree of strength gain.

SECOND PHASE

The previous work demonstrated the excellent effect of air-entraining admixtures on the durability, workability, and coherence of concrete mixtures, but additional data were required on the effect of various types of admixtures on these and other properties of concrete.

TABLE 7A—CHEMICAL ANALYSES OF CEMENTS "A" AND "C"

	Cement A	*Cement C*
Oxides:		
SiO_2	22.20	21.15
Al_2O_3	4.28	5.08
Fe_2O_3	3.42	4.05
CaO	64.96	63.42
MgO	1.26	2.09
SO_3	1.30	1.80
Ign. Loss	1.27	0.88
Ins. Residue	0.08	0.14
Free CaO	1.02	0.41
P_2O_5	0.150	0.229
Mn_2O_3	0.051	0.055
Na_2O	0.167	0.130
K_2O	0.463	0.727
H_2O Sol. Na_2O	0.031	0.083
H_2O Sol. K_2O	0.164	0.443
Compounds:		
C_3S	58.3	52.3
C_2S	19.8	21.3
C_3A	5.6	6.6
C_4AF	10.4	12.3
$CaSO_4$	2.2	3.1
Ratios:		
CaO Saturation	69.26	67.64
Colony's Ratio	2.68	2.65
Al_2O_3/Fe_2O_3	1.25	1.25
SiO_2/R_2O_3	2.88	2.32
CaO/SiO_2	2.93	3.00

Materials

For this purpose, an extended program was set up based on the tentative specification referred to above, using the following materials:

(a) *Cements.* Commercial SS-C-206a cements from two mills.*

(b) *Aggregate.* Natural siliceous sand (F.M. 2.60) and Connecticut trap rock (1½-in. max.) as used in the preliminary programs.

(c) *Admixtures*(†). The following admixtures were added at the mixer at the time of mixing in the form and proportions previously described: Q, R, U, V, and Z. The symbol P was again used to designate concrete made without admixture.

Mixtures, mixing and specimens

Except where special factors were to be determined requiring a deviation therefrom; the mixtures were designed to have nominal actual cement factors of 4.5 and 6.0 bags per cu. yd. with W/C and sand contents varying as made practicable by the characteristics of the admixtures to develop a nominal slump of 2½ in. Preliminary and small batches (0.8 cu. ft.) were mixed in a 1-cu. ft. tilting-drum mixer. The preponderant

*See Table 7A for chemical analyses of these cements.

†It is emphasized that the commercial admixtures used were of the composition and quality commercially available in August, 1944.

number of batches were 2.75 cu. ft. in volume and were mixed in a 3.5-cu. ft. tilting-drum mixer. Following the addition of all materials including water, all batches were mixed for 2 min. followed by a 3-min. resting period and a 1-min. re-mixing period. All batches were discharged into a metal pan or boat and turned over three times with a shovel and then covered with damp burlap to minimize loss of moisture during the molding of specimens. The molding of all specimens was accomplished by rigid adherence to standard practice and each operation was performed insofar as practicable by the same person throughout the program. All conditions and variables tested were repeated on at least three different days. The principal types of specimens were removed from their molds and cured, as follows, with deviations therefrom explained in the succeeding text as they occurred:

(a) *Cylinders.* Stripped at 24 hr., cured in fog at 70 ± 2 F. until time of test.

(b) *Beams (3½ by 4½ by 16 in.) and bars (2 by 2 by 11 in.)* Exposed surface coated with membrane compound 2 hr. after molding. Stripped at 48 hr., and cured in fog at 70 ± 2 F. until time of test.

(c) *Prisms (pull-out).* Exposed surface coated with membrane compound 2 hr. after molding. Stripped at 96 hr. and cured in fog at 70 ± 2 F. until time of test at 28 days.

Discussion of results—plastic concrete

The effects of the various admixtures on the principal properties of the plastic and hardened concrete duplicated with two cements are discussed in the following paragraphs. *No attempt was made to regulate the air content of the mixtures to an optimum amount by varying the amounts of the admixtures added, although such regulation is possible and most desirable in obtaining the optimum benefits from air entrainment.* Deviation from the standard procedures described above are explained whereever they occur.

(a) *Water demand.* Using mixtures having nominal actual cement factors of 4.5 and 6.0 bags per cu. yd., the influence of the admixtures on the W/C necessary to develop a nominal slump of 2.5 in., was determined in 0.8-cu. ft. batches of concrete. The water-cement ratios so determined were then used in the remainder of the program in 0.8 and 2.75 cu. ft. batches except where otherwise especially noted. The results were similar with both cements and are tabulated in Table 8 together with the sand-aggregate ratios used.

(b) *Cement demand.* The effect of the admixtures on the cement content of concrete mixtures having water-cement ratios of 5.5 and 6.5 gal. per bag and in which the slump was maintained at 2.5 in. is shown in Table 9. These mixtures were made in 0.8-cu. ft. batches and the values were verified by check tests on different days.

TABLE 8—EFFECT OF ADMIXTURES ON WATER-CEMENT RATIO

Admix.	Cement Factor = 4.5 b/cu.yd.			Cement Factor = 6.0 b/cu.yd.		
	S/A % by Vol.	W/C g.p.b.	Reduction g.p.b.	S/A % by Vol.	W/C g.p.b.	Reduction g.p.b.
P*	46	8.60	0	43.5	6.25	0
Q	41	7.35	1.25	37.5	5.60	0.65
R	41	7.40	1.2	37.5	5.65	0.60
U	39.5	6.90	1.7	37.5	5.30	0.95
V	41	7.35	1.25	37.5	5.60	0.65
Z	44	7.75	0.85	40.5	5.75	0.50

*Concrete without admixture.

TABLE 9—EFFECT OF ADMIXTURES ON CEMENT DEMAND

Admix.	W/C = 5.5 g.p.b.			W/C = 6.5 g.p.b.		
	S/A % by Vol.	C.F.*	Reduction b/cu.yd.	S/A % by Vol.	C.F.*	Reduction b/cu.yd.
P†	42	6.80	0	44	5.40	0
Q	38	6.12	0.68	40	4.86	0.54
R	38	6.16	0.64	40	4.90	0.50
U	37	5.55	1.25	38.5	4.25	1.15
V	38	6.15	0.65	40	4.90	0.50
Z	39	6.17	0.63	40.5	4.80	0.60

*Actual cement factor in bags per cu. yd.
†Concrete without admixture.

TABLE 10—EFFECT OF ADMIXTURES ON SLUMP

Admix.	Theo. Cement Factor = 4.6 b/cu.yd.			Theo. Cement Factor = 6.1 b/cu.yd.		
	W/C = 8.60 g.p.b. S/A = 46 per cent by vol.			W/C = 6.25 g.p.b. S/A = 43.5 per cent by vol.		
	Cement A Slump, in.	Cement C Slump, in.	Aver. Increase Slump, in.	Cement A Slump, in.	Cement C Slump, in.	Aver. Increase Slump, in.
P*	2.25	2.25	0	2.50	2.50	0
Q	6.25	4.00	3	4.75	5.00	2.5
R	5.50	4.25	3	5.75	4.75	3
U	8.00	7.25	5.5	7.00	6.50	4
V	6.75	4.00	3	5.75	5.00	3
Z	5.25	5.00	3	6.75	5.75	4

*Concrete without admixture.

(c) *Consistency.* The effect of admixtures on consistency (slump) of concrete mixtures, when the W/C, sand-aggregate ratio and cement content used with plain cement are held constant is shown in Table 10 for relatively lean and rich mixtures.

(d) *Bleeding.* The effect of admixtures on bleeding of concrete mixtures, in which the actual cement factors and slump remain constant and the W/C and S/A were as shown in Table 8 is shown in Table 11.

TABLE 11—EFFECT OF ADMIXTURES ON BLEEDING

	Cement Factor = 4.5 b/cu.yd.		Cement Factor = 6.0 b/cu.yd.	
Admix.	Cement A Bleeding —%	Cement C Bleeding —%	Cement A Bleeding —%	Cement C Bleeding —%
P	100 (14.8)	100 (14.1)	100 (9.7)	100 (7.4)
Q	52	49	42	34
R	59	56	49	49
U	25	25	19	15
V	42	33	36	30
Z	55	57	25	20

Note: Figures in parentheses are average values of bleeding by concrete containing no admixture.

(e) *Air content.* The effect of admixtures on the air content of concrete mixed for a total period of 3 min. as previously described but with differing conditions of design is shown in Table 12. These data indicate the considerable influence of type of mixture, type of cement, and amount of admixture on air content. These effects are subject to control by regulating the amount of admixture used.

(f) *Effect of mixing time on air content.* The effect of time of mixing on air content with various admixtures was studied concurrently with and as a part of this program. Even though the conditions of the test were somewhat different than those which have been described, it is felt that the data should be inserted in this position in the paper.

The influence of cement itself on air entrainment in the presence of an admixture (which did not depend on a chemical reaction with cement to become active) was tested by mixing large (approx. 2.75-cu. ft.) batches of Ottawa sand, neutralized Vinsol resin, and water in a 3.5-cu. ft. tilting mixer. The air content of the sand-water mixture was determined at frequent intervals and mixing was continued until the air content began to diminish from the maximum. A similar test was run in which calcium oxide was added to the water to determine whether possible precipitation of calcium salts might affect the air entrainment. The foregoing tests on cement-free sand-water mixtures were duplicated using a simulated concrete mixture with quartz pebbles ½-in. in size as coarse aggregate to determine the influence of such pebbles on air entrainment in the absence of cement. A third group of tests was conducted in which Cements A and C were added to the simulated concrete mixture. A fourth series of tests was made using Cements A, B, C, and D in regular concrete mixtures. In this fourth series, each of the cements

TABLE 12—EFFECT OF ADMIXTURES ON AIR CONTENT OF CONCRETE MIXTURES WITH VARIOUS CONSTANT BASES ON DESIGN

a

Constant Actual Cement Factor * b/cu. yd.	Cement	Air Content, per cent Admixture					
		P	Q	R	U	V	Z
4.5	A	1.6	6.2	5.2	10.7	6.0	5.3
4.5	C	2.3	7.6	6.5	10.7	6.6	5.5
6.0	A	1.5	4.7	4.5	7.7	4.4	4.6
6.0	C	2.1	5.6	5.7	9.7	4.4	4.7

b

Constant W/C & Slump†		Cement	Air Content, per cent Admixture					
W/C g.p.b.	Slump, in.		P	Q	R	U	V	Z
5.5	2.5	A	1.4	4.2	3.6	6.0	3.8	3.1
6.5	2.5	A	1.3	3.9	3.5	6.4	3.3	4.1
5.5	2.5	C	1.3	5.4	5.3	8.2	5.9	4.0
6.5	2.5	C	1.4	4.4	4.8	8.7	5.1	4.9

c

Constant Theo. Cement Factor, W/C, and S/A‡			Cement	Air Content, per cent Admixture					
Theo. C.F. b/cu. yd.	W/C g.p.b.	S/A % by Vol.		P	Q	R	U	V	Z
4.6	8.6	46	A	1.6	6.2	5.7	8.7	6.7	4.9
4.6	8.6	46	C	2.3	7.0	6.9	8.3	7.0	4.0
6.1	6.25	43.5	A	1.5	5.5	4.7	8.1	6.3	5.1
6.1	6.25	43.5	C	2.1	7.3	6.7	10.1	7.8	5.9

*See Table 8. †See Table 9. ‡See Table 10

was tested, (a) with no admixture, (b) with interground flake Vinsol resin, (c) with interground neutralized Vinsol resin, and (d) with a solution of neutralized Vinsol resin added to the batch at the mixer. A fifth series of tests was made in which Cements A and C were used in regular concrete mixtures with and without several other types of air-entraining admixtures. Samples were extracted from the mixer for air-content determination at regular intervals and mixing was continued until the air content diminished from the maximum. The mortar and simulated concrete batches were made with silica sand and quartz pebbles to minimize any possible opportunity for grinding action to affect the entrainment of air. The results of these tests are presented in Fig. 4 and 5.

The data in Fig. 4a indicate that the presence of $Ca\ (OH)_2$ in solution increases the tendency toward entrainment of air, but the influence of

MIXTURE DATA						
TYPE	AGGREGATE	CONSISTENCY	SAMPLE[1]	CEMENT	W/C g/b.	C.F b/c.y.
SIMULATED MORTAR	50% G.O.S. - S.O.S.	100-110% FLOW	LITER			
"	" " "	100-110% "	"			
" CONCRETE	G.O.S.-S.O.S.+1/2 IN QTZ. PEBBLES	WET- 6-10 IN SLUMP	1/10 CU FT	PLAIN	7.2	5.0
"	L.I. SAND-1½ IN. MAX. TRAP ROCK	4 IN. NOMINAL "	1/2 " "	A.E.	6.16	5.51

(1) FOR DETERMINATION OF AIR CONTENT MIXER: -3.5 CU FT SMITH TILTING

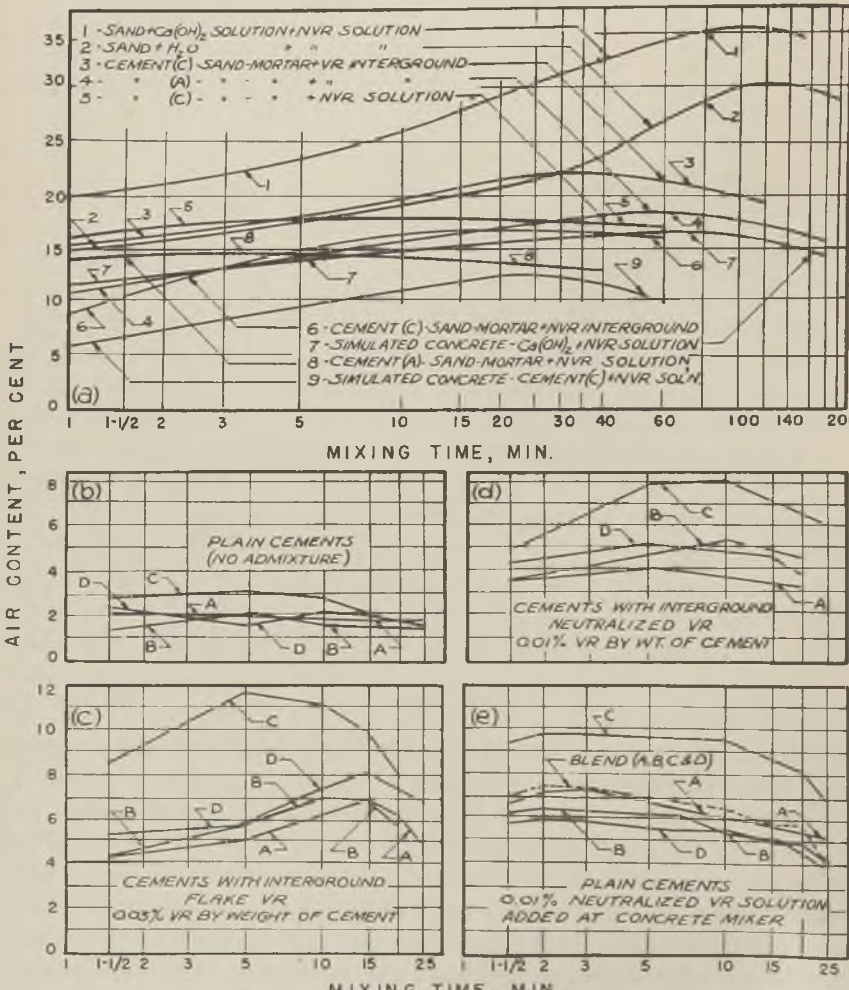

Fig. 4—Relation of air content to length of mixing time

the cement itself on air entrainment is negative, that is; the amount of air entrained and the duration of additional air entrainment are reduced appreciably by the presence of cement. This is in accord with the findings of others (65) that air entrainment is particularly a function of the amount and grading of the fine aggregate. As the fineness of the sand or the ratio of cement to sand increases, the tendency toward air entrainment is reduced. The simulated concrete batches entrained considerable air and were coherent and plastic mixtures despite the complete absence of cement.

The data in Fig. 4b indicate the amount of air entrained in concrete without admixture, containing four different brands of cement and the rate and degree to which the air is entrained. There is no evidence of increase in air content with continued mixing although there is some difference in the total amount of air entrained by the four cements used.

Fig. 4c shows the effect of time of mixing on the air entrainment of the concrete mixtures cited when the four basic plain cements are interground with 0.03 per cent flake Vinsol resin. In this case, air entrainment increases for an appreciable time before reaching a maximum and commencing to recede. This tendency is due, probably, to the continued reaction between the unneutralized Vinsol resin and the soluble alkalies present in the cements. Each of the four cements reacts differently under the influence of equal amounts of Vinsol resin.

Fig. 4d shows the effect of time of mixing on the air entrainment when the four basic plain cements are interground with 0.01 per cent neutralized Vinsol resin. Air entrainment continues with mixing time but the peaks are reached at an earlier period and the differences in air content are not as great as in Fig. 4c. The delay in air entrainment is due, probably, in this case to adsorption of the interground neutralized Vinsol resin by the particles of cement.

Fig. 4e shows the effect of time of mixing on the air entrainment when 0.01 per cent neutralized Vinsol resin is added at the mixer to similar concrete batches containing the four basic plain cements. In this case, the maximum air entrainment is reached early and recedes thereafter, and the differences between the cements are minimized. This action is due, probably, to the immediate and complete availability of all the admixture.

Fig. 5 shows the effect of time of mixing on the air entrainment when the recommended quantities of several of the admixtures are added at the mixer with two of the basic plain cements. The rate of air entrainment and the recession in air content is generally similar to that shown in Fig. 4e with neutralized Vinsol resin when added at the mixer.

The recession in air content in all cases where appreciable air is entrained is due, probably, to final exhaustion of the sudsing property

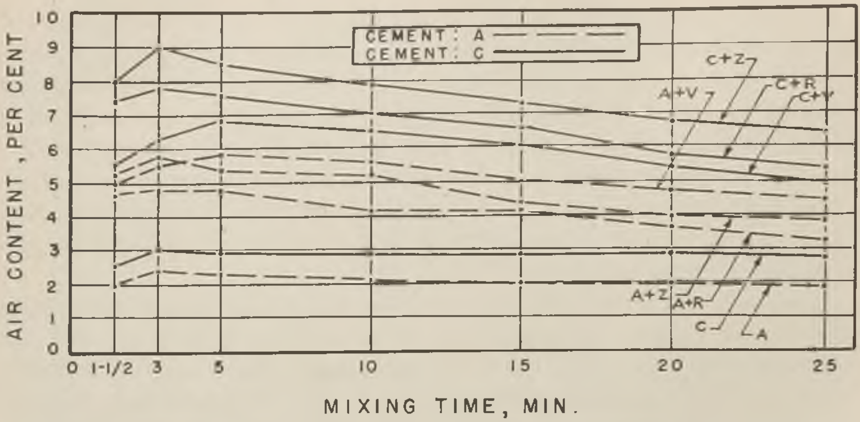

Fig. 5—Relation of mixing time to air content of concrete made with and without admixtures

of the admixture and escape or bursting of some of the air bubbles. In mixtures containing readily grindable aggregates, recession in air content may be accentuated by increased fineness of cement and aggregate due to the grinding action.

The data from the tests described above are important particularly as they reflect the influence of *time* of mixing on the air content of concrete. The particular amounts of air entrained are less important, because these *amounts* are regulable by adjusting the amount of the admixture used. Such regulation of amount of air and amount of admixture is most practicable when the admixture is added at the mixer.

It should be in mind, too, that these tests were made in a stationary tilting-drum mixer and the results may or may not have relationship to air entrained by transit mixers.

Discussion of results—hardened concrete

(a) *Compressive strength.* The effect of the admixtures on compressive strength of concrete mixtures made under various conditions is shown in Tables 13, 14, and 15; and in Fig. 6.

Under normal conditions of standard making and curing (70 ± 2 F.) and with the proportions given in Table 8, the admixtures affect the strength of concrete at the ages of 2 and 28 days as shown in Table 13, in terms of strength gained at equal ages with the two cements and no admixture. The effect of the accidental use of double quantities of each of the admixtures is also shown. It is apparent from these data that the large reductions in W/C made possible by addition of the admixtures at the mixer reinforced by the presence of accelerators in some of the admixtures resulted in superior strength, as compared to concrete without admixture, at the early age of two days in all cases except with ad-

TABLE 13—EFFECT OF ADMIXTURES ON COMPRESSIVE STRENGTH

Admixture	Cement A				Cement C			
	Recommended Amount of Admixture		Doubled Amount of Admixture		Recommended Amount of Admixture		Doubled Amount of Admixture	
	2 days	28 days	2 days	28 days	2 days	28 days	2 days	28 days
	Cement Factor = 4.5 b./cy. yd.							
	860 psi	2950 psi			1055 psi	3040 psi		
P‡	100%	100%	.....	.....	100%	100%	.....	.....
Q	137%	119%	107%	88%	110%	113%	112%	86%
R	133%	120%	87%	88%	100%	110%	96%	84%
U	119%	106%	85%	84%	93%	114%	95%	94%
V	190%	136%	160%	93%	144%	124%	127%	102%
Z	135%	122%	*	65%*	113%	119%	114%	106%
	Cement Factor = 6.0 b./cu. yd.							
	1630 psi	5260 psi			2235 psi	5525 psi		
P‡	100%	100%	.....	.....	100%	100%	.....	.....
Q	102%	100%	107%	83%	109%	96%	97%	84%
R	102%	99%	109%	82%	107%	94%	74%	73%
U	124%	96%	98%	79%	78%	84%	77%	81%
V	159%	150%	140%	87%	115%	105%	102%	86%
Z	109%	102%	*	92%*	107%	106%	88%	84%

*Specimens from one round crumbled on stripping at 24 hr.
‡P = Concrete without admixture.

mixture U combined with Cement C. The improvement in early strength is uniformly greater in the lean than in the rich mixtures; with admixture V developing the most marked improvement.

The effect on strength at the early age is considered to be most important due to its influence on the removal of forms, early use of the structure, and the fact that the thin and exposed sections of structures rarely if ever receive curing comparable with storage in fog at 70 ± 2 F. continuously for 28 days.

The effect of the admixtures on strength is beneficial in all cases with the lean mixture and both cements at the 28-day age. However, the effect is not marked in the rich mixture and is somewhat less than parity in several cases; particularly so with Cement C.

The effect of doubling the quantity of the admixtures is particularly variable at the early age, with admixture Z failing to harden sufficiently to resist the minor stress of form removal at an age of 24 hr., and admixture V maintaining a large improvement in strength except in the rich mixture with Cement C. At 28 days the variability of effect is not great and the strength is generally somewhat less than parity with concrete containing no admixture. It is evident from these tests that admixture Z is the only admixture tested which is adversely affected to a serious extent by the accidental use of a double quantity in a batch of concrete and this effect is noticeable with only one of the two cements used.

When advantage is taken of the workability contributed by the admixtures by reducing the cement content (Table 9) instead of reducing the W/C, the effect on compressive strength at the age of seven days* is as indicated by the data in Table 14.

*No tests made at other ages.

TABLE 14—EFFECT OF REDUCTION IN CEMENT CONTENT WITH ADMIXTURES ON RELATIVE COMPRESSIVE STRENGTH OF CONCRETE AT SEVEN DAYS AGE

	W/C = 5.5 g.p.b. Cement		W/C = 6.5 g.p.b. Cement	
Admix.	A	C	A	C
P*	4180psi. 100%	4395psi. 100%	2440psi. 100%	2550psi. 100%
Q	92	91	92	90
R	90	88	91	89
U	88	84	79	76
V	99	96	111	108
Z	105	101	113	108

*Concrete without admixture.

The influence of low temperature on the rate of early strength gain with and without admixtures, was tested by pre-cooling all ingredients and mixing the concrete at a temperature of 40 ± 2 F. and then storing one-half of the number of specimens in each batch in fog at 70 ± 2 F. and storing the other half of the specimens, sealed in their molds, at 40 ± 2 F. (rel. humidity 80 ± 10 per cent). Companion specimens were then tested in compression at ages of 1, 2, 3, and 7 days. The results are shown in Table 15 and in Fig. 6. The strength of the plain portland-cement mixture is reduced markedly by the lower temperature of mixing and curing and that the reduction in strength and the rate of strength gain for the first seven days is not affected appreciably by any of the admixtures except V. Admixture V exerts a marked beneficial effect on early strength even at a low temperature.

TABLE 15—INFLUENCE OF LOW TEMPERATURE ON STRENGTH DEVELOPMENT OF CONCRETE

Nominal cement factor = 6 bags per cu.yd. Cement A. W/C and S/A as shown in Table 8

	Strength Ratios — Age in Days							
Admix.	Strength at 40 F. as % of strength of plain concrete cured at 70 F. at equal age.				Strength at 40 F as % of strength of plain concrete cured at 40 F.			
	1	2	3	7	1	2	3	7
					89psi.	310psi.	505psi.	1470psi.
P*	18	26	28	45	100	100	100	100
Q	14	18	26	43	78	70	92	96
R	19	23	29	42	105	91	102	93
U	6	13	23	50	32	52	80	111
V	60	55	60	62	285	193	211	138
Z	9	23	34	60	52	91	121	134

*Concrete without admixture.

(b) *Flexural strength.* The effect of admixtures on the flexural strength of concrete mixtures, under standard conditions and with the proportions shown in Table 8, at the age of 28 days is shown in Table 16 in terms of the strength of plain concrete. The effect of a doubled quantity of the admixture is also shown. The data indicate that the strength developed in the presence of the admixtures is approximately equal to that of plain concrete, except that there is a uniform improvement in strength in the concrete containing the admixture V.

(c) *Bond-to-steel.* The effect of admixtures on the bond of concrete* (Table 8) to steel was tested by determining the unit load in lb. per sq. in. of steel embedment at a slip of 3 x 10^{-4} in. measured at the free

*Proportioned as shown in Table 8 and with air contents as shown in Table 12a.

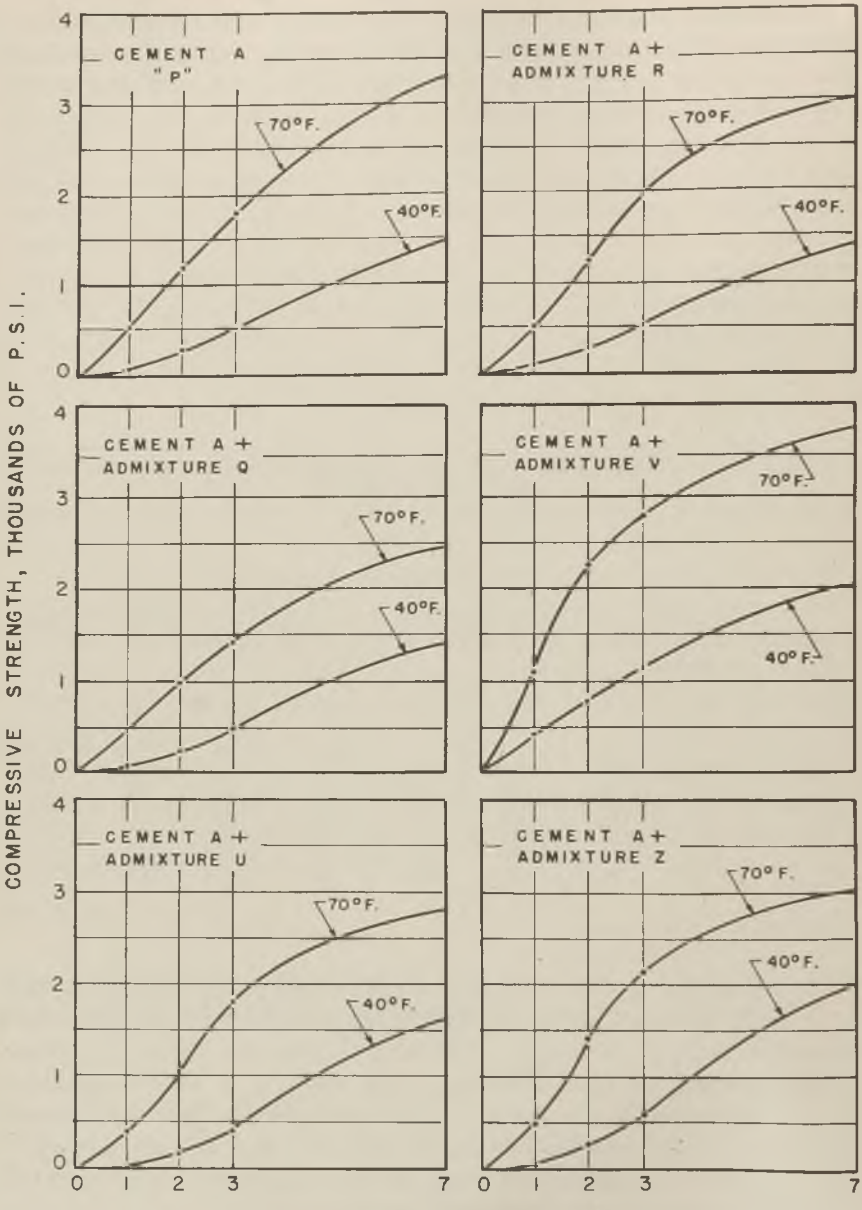

Fig. 6—Influence of temperature on strength development of concrete
Cement factor: 6 bags per cu. yd. Concrete mixed at 40 F., cured at temperatures shown.

TABLE 16—RELATIVE EFFECT OF ADMIXTURES ON FLEXURAL STRENGTH OF CONCRETE

Admix.	Cement A: Recommended Amt. of Admix.	Cement A: Doubled Amt. of Admix.	Cement C: Recommended Amt. of Admix.	Cement C: Doubled Amt. of Admix.
	Cement Factor = 4.5 bags per cu. yd.			
P[b]	495 psi 100%	—	555 psi 100%	—
Q	105	96	93	91
R	109	96	100	89
U	101	90	100	88
V	119	111	114	109
Z	109	67[a]	98	102
	Cement Factor = 6.0 bags per cu. yd.			
P[b]	705 psi 100%	—	740 psi 100%	—
Q	98	98	98	97
R	104	95	106	90
U	99	87	89	89
V	112	102	112	105
Z	101	73[a]	103	92

(a) Specimens from one round crumbled on stripping at 48 hr.
(b) Concrete without admixture.

end of ¾-in. round, high yield-point, Hi-Bond bars. The bars were cast in a horizontal position in 6-in. by 6-in. by 8-in. prisms and were left completely undisturbed for 96 hr. prior to removal of forms. The pull-out tests were made at an age of 28 days on a total of 454 specimens. The specimens were made in groups of three and repeated on three to seven different days.

The grand average results obtained from all the tests made with nominal cement factors of 4.5 and 6.0 bags per cu. yd. and two cements are shown in Table 17.

TABLE 17—BOND STRENGTH OF CONCRETE TO STEEL

	Cement A				Cement C			
	C.F. 4.5 bags per cu. yd.		C.F. 6.0 bags per cu. yd.		C.F. 4.5 bags per cu. yd.		C.F. 6.0 bags per cu. yd.	
Admix.	psi	%	psi	%	psi	%	psi	%
P*	354	100	412	100	423	100	470	100
Q	270	76	412	100	300	71	473	100
R	230	65	355	86	342	81	496	106
U	265	75	485	118	290	69	541	115
V	540	153	860	209	504	119	1054	224
Z	430	121	582	141	302	71	638	136

*Concrete without admixture.

TABLE 18—EFFECT OF ADMIXTURES ON LENGTH CHANGE IN CONCRETE

Length Change in Per Cent x 10^{-3}

Admix.	Initial Stor. in Fog, Cement A, 7	Initial Stor. in Fog, Cement A, 14	Initial Stor. in Fog, Cement C, 7	Initial Stor. in Fog, Cement C, 14	Drying at 70 F. — 25 ± 5 R. H., Cement A, 1	Drying, Cement A, 7	Drying, Cement A, 14	Drying, Cement A, 28	Drying, Cement C, 1	Drying, Cement C, 7	Drying, Cement C, 14	Drying, Cement C, 28	Resaturation at 70 F., Cement A, 1	Resat., Cement A, 7	Resat., Cement A, 14	Resat., Cement A, 28	Resat., Cement C, 1	Resat., Cement C, 7	Resat., Cement C, 14	Resat., Cement C, 28
							Cement Factor—4.50 b./cu. yd.													
P*	+5	+6	+4	+7	−10	−31	−50	−63	−9	−37	−60	−66	+37	+41	+46	+49	+38	+45	+50	+51
Q	+3	+6	+4	+5	−12	−38	−54	−61	−13	−41	−57	−63	+34	+43	+47	+50	+33	+46	+49	+52
R	+4	+6	+4	+6	−10	−31	−48	−58	−11	−36	−53	−61	+35	+43	+47	+49	+35	+46	+48	+51
U	+5	+8	+5	+8	−11	−36	−51	−57	−11	−39	−51	−57	+32	+45	+48	+48	+32	+44	+48	+50
V	+6	+7	+6	+7	−12	−33	−49	−58	−12	−38	−54	−62	+36	+47	+51	+53	+35	+48	+52	+54
Z	+4	+6	+7	+9	−11	−34	−50	−58	−11	−36	−50	−61	+34	+47	+49	+50	+36	+46	+49	+53
							Cement Factor—6.0 b./cu. yd.													
P*	+4	+6	+5	+5	−8	−29	−39	−48	−10	−33	−50	−56	+36	+41	+45	+46	+38	+44	+49	+55
Q	+5	+5	+6	+7	−11	−37	−46	−53	−11	−34	−46	−49	+36	+44	+49	+51	+33	+42	+46	+50
R	+3	+5	+5	+7	−11	−37	−48	−57	−10	−35	−52	−58	+37	+45	+50	+54	+39	+48	+53	+59
U	+5	+7	+8	+10	−12	−41	−42	−51	−13	−37	−50	−57	+28	+44	+46	+51	+29	+46	+51	+56
V	+8	+8	+8	+9	−14	−41	−50	−59	−10	−32	−46	−53	+35	+48	+51	+54	+33	+47	+50	+53
Z	+8	+9	+7	+8	−11	−38	−46	−56	−9	−32	−47	−54	+37	+48	+49	+53	+33	+44	+48	+51

*Concrete without admixture.

The deviation in individual results was considerably less than developed in previous tests using bars with diamond-shaped deformations and less careful handling of the specimens at the very early ages, however, the variability in results was sufficiently great to make the general average values of more importance in terms of relativity with plain concrete than in terms of specific strengths in lb. per sq. in. of steel embedment. Since this paper is concerned particularly with the relative effect of the admixtures on bond to steel, no special comment on bond strength as affected by type of bar or other factors will be made.

The data indicate that bond to steel is affected adversely to a serious degree in concrete containing a cement content of 4.5 bags per cu. yd. and admixtures Q, R, or U. With admixture Z, the bond is benefitted when used with Cement A but is relatively poor when used with Cement C. The admixture V has a markedly beneficial effect on bond with both cements.

The data indicate, also, that when used in concrete having a cement content of 6.0 bags per cu. yd., all of the admixtures except R achieve at least parity with plain concrete. Admixture R reduced bond with Cement A and slightly increased bond with Cement C. Admixtures V and Z caused a material increase in bond with both cements; the increase with admixture V being very large, and verified by seven separate runs of three specimens with each cement.

(d) *Volume change.* The effect of admixtures on volume change of concrete was tested in the manners and with the results described below:

(1) *Normal shrinkage and expansion.* The effect of wetting and drying on concrete made with and without the admixtures was tested by molding 2-in. by 2-in. by 11-in. beams from the mixtures referred to in Table 8, except that aggregate larger than ¾ in. was removed by hand picking. The beams were cured in fog (70 ± 2 F.) for 14 days and then stored in air (70 ± 2 F.) at 25 ± 5 per cent R.H., circulated over the specimens at a speed of 15 m.p.h. for 28 days. At the end of this period, the beams were stored in water at 70 ± 2 F. for an additional period of 28 days. The reversals of drying and wetting were continued for three cycles.

The results of the tests indicate that none of the admixtures exerts an appreciable influence on the reaction of the concrete to wetting and drying. Summarized data for the two cements and two cement contents are shown in Table 18 and typical expansion and contraction curves are shown in Fig. 7. Additional data are summarized in Table 19 to show the effect of three repeated cycles of wetting and drying on the length change of concrete made with and without the admixtures and with the blend of four cements as used in the initial phase of the work. The immaterial effect of the admixture on this property of concrete makes further presentation of detailed data of little value to this paper.

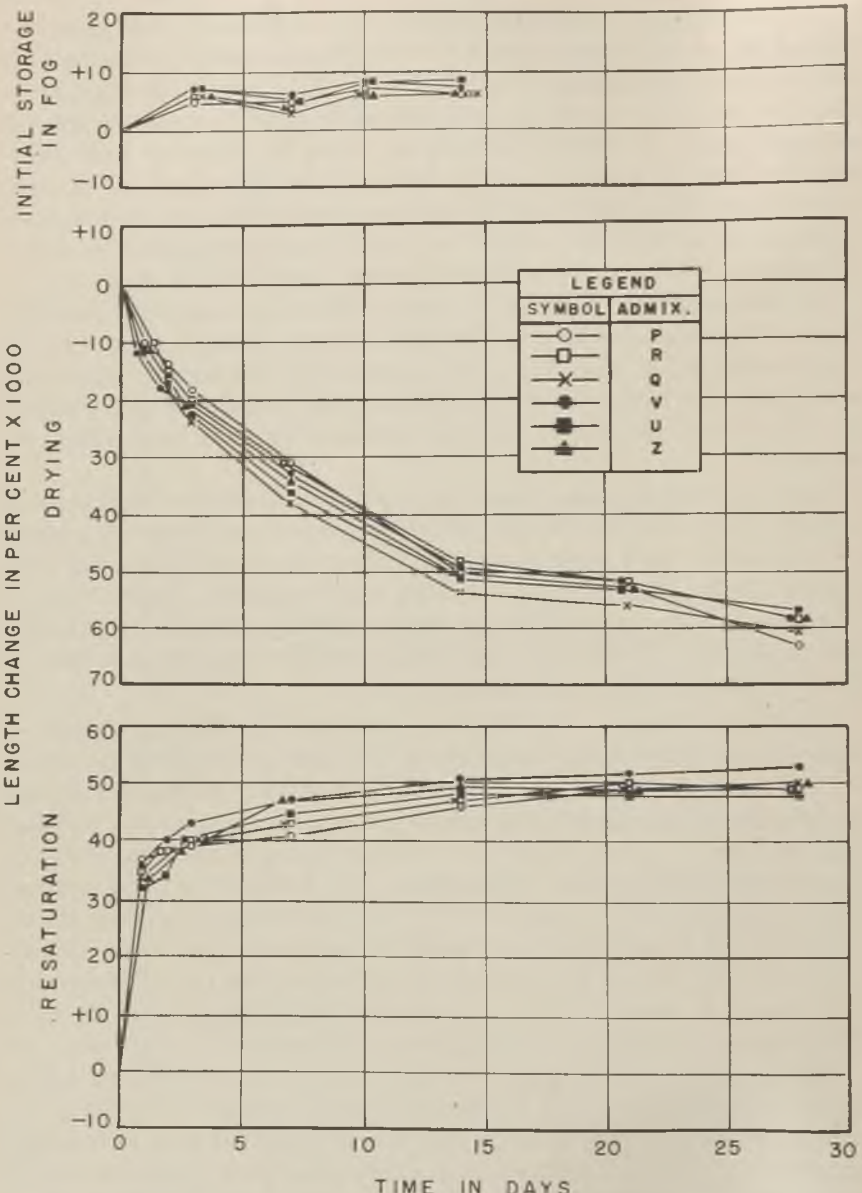

Fig. 7—The effect of wetting and drying on length change of concrete containing various admixtures with cement A

Cement factor: 4.5 bags per cu. yd.

TABLE 19—LENGTH CHANGE OF CONCRETE DUE TO WETTING AND DRYING

Admix.	Cycle	Length Change in Per Cent x 10^{-3}								
		After 14 days Fog Cure at 70 F.			After 28 days drying at 90 F. and 25 ± 5% Rel. Hum.			After 28 days saturation at 70 F.		
		Cement Content b./cu. yd. 4.50	5.25	6.0	Cement Content b./cu. yd. 4.50	5.25	6.0	Cement Content b./cu. yd. 4.50	5.25	6.0
P†	1	+ 5	+11	+ 4	−53	−63	−50	+40	+36	+45
	2				−32	−34	−32	+37	+33	+36
	3				−27	−29	−28	+32	+39	+34
Q	1	+ 6	+10	+ 2	−55	−57	−54	+47	+43	+44
	2				−37	−35	−34	+40	+43	+41
	3				−32	−32	−29	+38	+39	+36
R	1	+ 6	+10	+ 3	−53	−54	−50	+41	+41	+39
	2				−33	−33	−33	+36	+40	+40
	3				−28	−28	−38	+34	+35	+44
S	1	+12	+ 6	+ 7	−48	−61	−50	+41	+47	+41
	2				−31	−37	−36	+37	+42	+38
	3				−26	−32	−39	+36	+39	+48
T	1	+ 7	− 2	+ 4	−56	−77	−52	+34	*	+37
	2				−30	*	−34	+35	*	+42
	3				−25	*	−39	+31	*	+45
U	1	+10	+14	+ 5	−52	−52	−49	+33	+42	+47
	2				−32	−32	−43	+34	+39	+35
	3				−23	−29	−32	+34	+35	+43
X	1	+ 6	+14	+ 2	−49	−54	−49	+40	+41	+39
	2				−33	−32	−33	+39	+39	+40
	3				−27	−31	−37	+35	+35	+46
Y	1	No Initial Curing in Fog			−55	−51	−58	+42	+41	+53
	2				−33	−35	−37	+38	+31	+41
	3				−30	−27	−32	+35	+36	+37
Z	1	+ 8	+14	+ 5	−44	−48	−49	+39	+44	+43
	2				−29	−32	−29	+35	+38	+34
	3				−25	−33	−30	+35	+35	+36

*After 28 days drying pin became loose—hence no further length change measurement.
†P = Concrete without admixture.

(2) *Early shrinkage and expansion.* The effect of admixtures on the volume constancy of concrete mixtures in the transition from the plastic to the well-hardened state was tested experimentally by pycnometric means, as described below:

A sample of the mixed concrete (Table 8) of approximately 0.1-cu. ft. volume was placed in a synthetic-rubber basket-ball bladder* of approximately equal capacity when undistended. Loading was accomplished

*Darex No. B 21185 obtained from the Dewey and Almy Chemical Co.

in a manner designed to eliminate extraneous air. The bladder was corked tightly and placed on a wire-ring tripod support in a volumeter which consisted of a Pyrex vacuum desiccator (200 mm. I.D.) with a tubulated cover accommodating a No. 8 rubber stopper. The covered desiccator was filled with water until the level rose to a desired point in a burette inserted in the rubber stopper. Air trapped in the desiccator was removed by mild agitation and tapping.

The procedure of the test was arranged so that the initial reading of the water level in the burette was taken 20 minutes after the water was added to the cement in the mixture. Subsequent readings were taken by an observer at frequent intervals until the end of the working day. Readings were taken during the night and for the remainder of the 96-hr. test period at one-half hour intervals by an automatically operated moving-picture camera.

The apparatus was maintained at a constant temperature of 70 ± 2 F. throughout the test. The absence of volumetric influences caused by evolution of heat within the test specimen was observed by placing thermocouples in several test specimens and in the surrounding water. The temperature variation at the center of gravity of the specimen was inappreciable, being less than 4 F. in all cases.

Each of the curves shown in Fig. 8 represents the average of tests made in duplicate and repeated on two different days. The concordance between individual results was good up to the 40-hr. period but diverged somewhat thereafter from causes not yet determined. The data indicate marked differences in the influence of the several admixtures and the two cements on the early volume of concrete. The effect is most notable with admixture V in which the delayed generation of hydrogen gas causes an early tendency toward expansion and approximately zero net expansion at the end of the test.

Work with this test procedure will be extended both in combination of materials tested and in duration of the test. The data presented herein are of relative value only and a direct interpretation of the effects shown in terms of the volume constancy of restrained concrete cannot as yet be made.

(e) *Laboratory freezing and thawing.* The effect of the admixtures on the resistance to rapid freezing and thawing was determined with two cement contents and two cements. The mixtures were proportioned as indicated in Table 8. The 3½- by 4½- by 16-in. beam specimens were removed from the molds at an age of 48 hr. and stored in fog at 70 ± 2 F. for seven days. The beams were made in groups of three and each variable in the program was repeated on at least three different days. Freezing and thawing was commenced at an age of specimen of

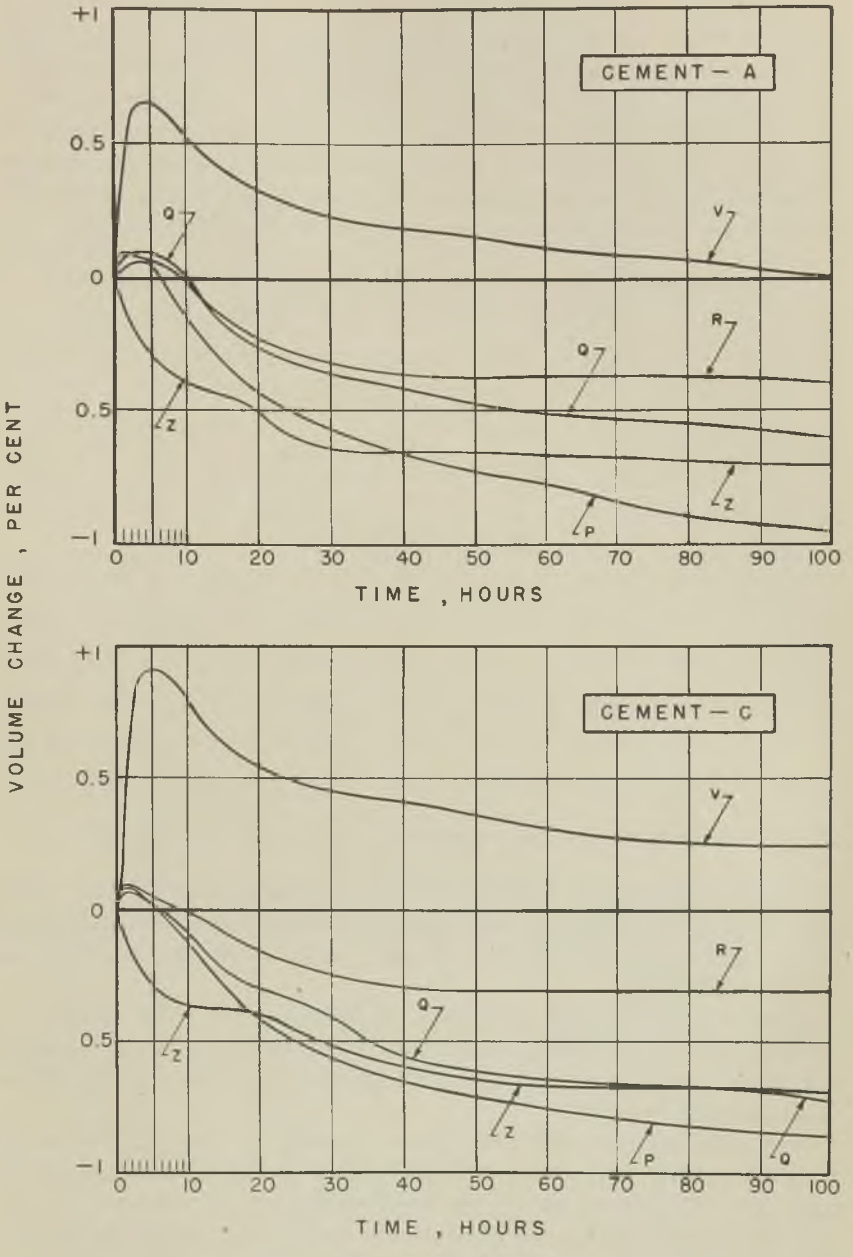

Fig. 8—Early unrestrained volume change of concrete made with and without admixtures

nine days, with the dynamic E at this age being taken as the zero or reference value (the averages of these references values of E and those for 28 days are shown in Table 20 as information). An additional series of specimens was prepared to duplicate the above in all respects except that they were subjected to freezing and thawing after a curing period of 28 days. The object of this second group was to determine whether subjecting the specimens to freezing at the early age of nine days would result in low or otherwise abnormal values for durability.

TABLE 20—DYNAMIC MODULI OF ELASTICITY—PSI.x10^6

	Nominal Cement Factor; bags per cu. yd. 4.50				6.00			
	Cement							
	A		C		A		C	
Admix.	Age at Test—Days							
	9	28	9	28	9	28	9	28
	Dynamic Moduli of Elasticity—psi x10^6							
P	4.85	5.68	4.82	5.53	5.86	6.54	6.03	6.36
Q	4.91	5.50	4.51	5.03	6.12	6.64	5.81	6.25
R	4.95	5.69	4.89	5.56	5.87	6.35	5.78	6.08
U	4.58	5.00	4.81	5.31	5.92	6.51	5.20	5.67
V	5.26	5.92	4.83	4.52	5.91	6.35	6.01	6.61
Z	5.08	5.68	5.06	5.67	5.89	6.39	6.03	6.32

Note: All values are average results for 9 specimens for each cement and admixture.

The nine-day age for commencement of freezing was chosen in order that at least 200 cycles of freezing and thawing, plus the curing period, could be accomplished in the 28-day period normally available for acceptance testing.

Concordance between the three specimens within each round and between each of the three or more rounds was sufficiently good to permit use of uncorrected values in the summarized data shown in Table 21 and plotted in Fig. 9 and 10.

The data indicate the remarkable increase in durability resulting from the use of each of the admixtures as compared to plain-cement concrete. The difference between the durability of the concrete containing the various admixtures is relatively small, with durability factors* for all admixtures except Z being above 75 at 250 cycles for the concrete cured for nine days.

*Calculated as in Fig. 1.

TABLE 21—RESISTANCE* OF CONCRETE TO FREEZING AND THAWING
(Laboratory fast cycle)

Ad-mix.	Cement A				Cement C			
	4.5 b./cu. yd.		6.0 b./cu. yd.		4.5 b./cu. yd.		6.0 b./cu. yd.	
	Cured 9 days	Cured 28 days	Cured 9 days	Cured 28 days	Cured 9 days	Cured 28 days	Cured 9 days	Cured 28 days
P‡	3.0	2.0	6.0	8.0	5.0	4.0	28.0	20.0
Q	89.0	80.0	88.0	83.5	92.0	82.0	91.0	92.5
R	89.0	73.5	87.0	86.5	92.0	82.0	92.0	93.5
U	86.0	79.0	83.0	79.0	82.0	78.0	91.0	91.0
V	91.5	82.0	92.5	91.5	93.5	88.0	94.0	95.0
Z	63.0	57.0	76.5	52.0	69.0	49.0	82.0	62.0

*Expressed as Durability Factor at *250 cycles* based on equation D.F.E. = $\frac{PN}{M}$ (see Fig. 1).

‡P = Concrete without admixture.

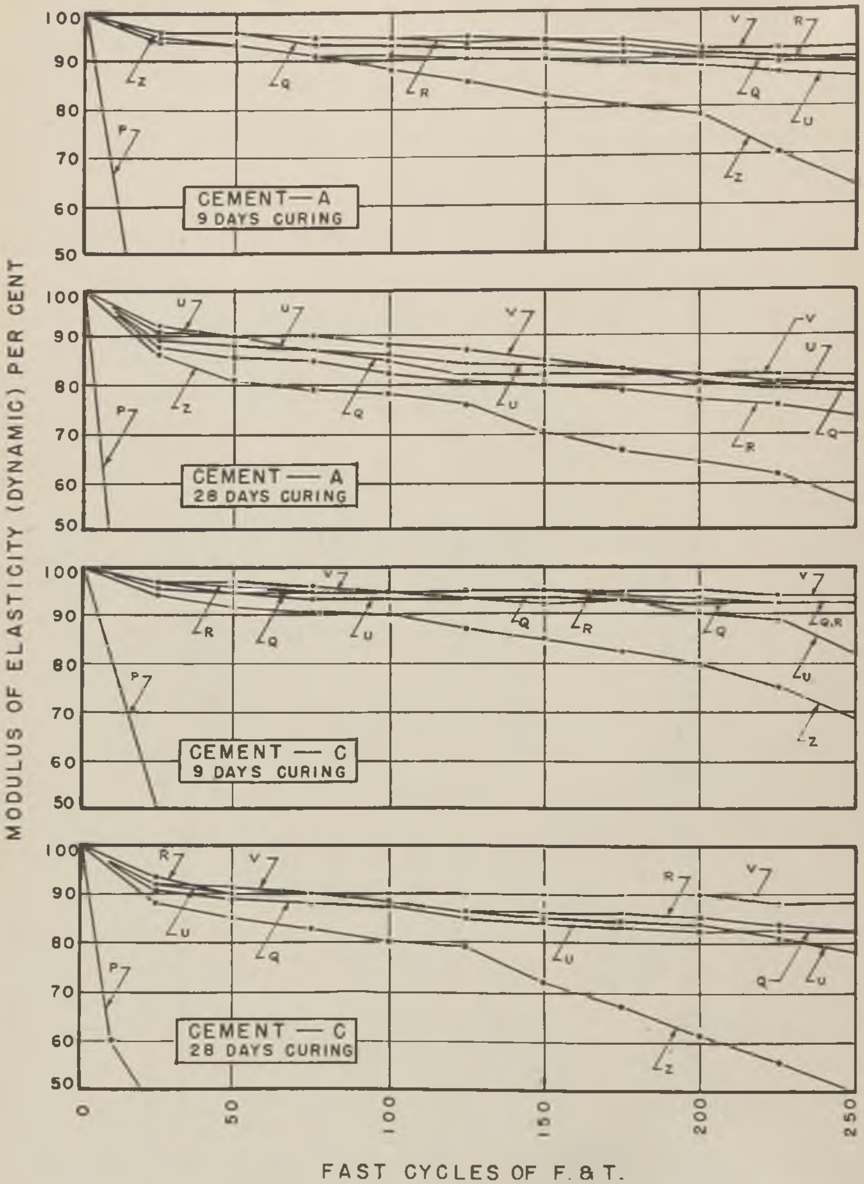

Fig. 9—Influence of admixtures on durability of concrete
Cement factor: 4.5 bags per cu. yd.

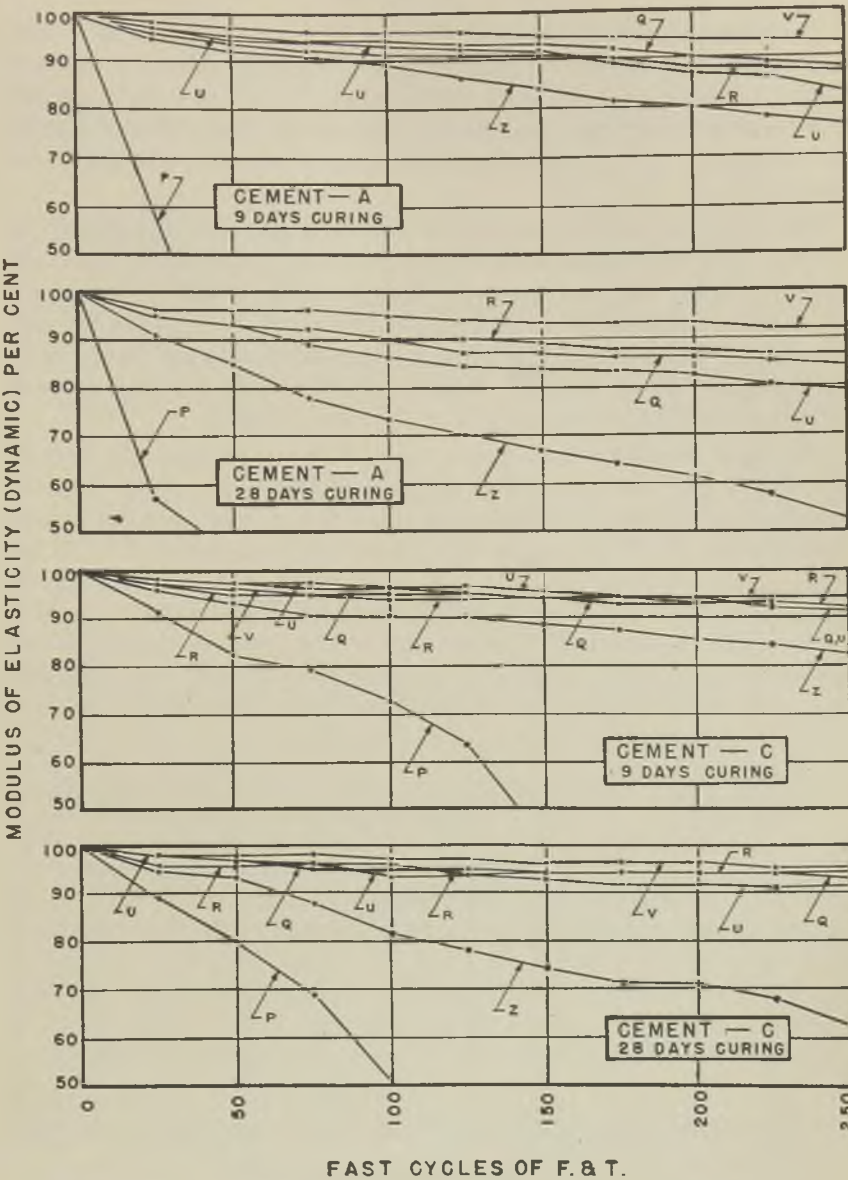

Fig. 10—Influence of admixtures on durability of concrete
Cement factor: 6.0 bags per cu. yd.

The effect of curing the specimens for 28 days instead of nine days was surprisingly small; tending toward a negative effect in all cases except the 6-bag mixtures made with cement C in which a slight positive effect was indicated with four of the admixtures. The adverse effect of the prolonged curing was most marked in all concrete containing admixture Z.

The effect of the higher cement content, with complementary reduction in W/C, was noticeable in the plain-cement mixtures with both ages of curing, but was generally inappreciable at 200 cycles in the mixtures containing the various admixtures which were cured for only nine days. The concrete cured for 28 days was moderately improved in durability at 200 cycles with reduction in W/C with the improvement being more marked with cement C than with cement A.

The large number of specimens to be tested prevented the number of cycles of the test being extended beyond 260 cycles except in a few cases toward the end of the program when it was found possible to continue certain of the specimens to a decrement in dynamic E of 50 per cent. These few data shown in Fig. 11 represent average values for the fourth and fifth rounds made with admixture V and cement A. The effect of the increased W/C, concomitant with reduced cement factor, becomes marked with prolonged freezing and thawing; the durability factor for the 4.5-bag concrete being 26 as compared to 49 for the 6-bag concrete, with both factors based on 1000 cycles.

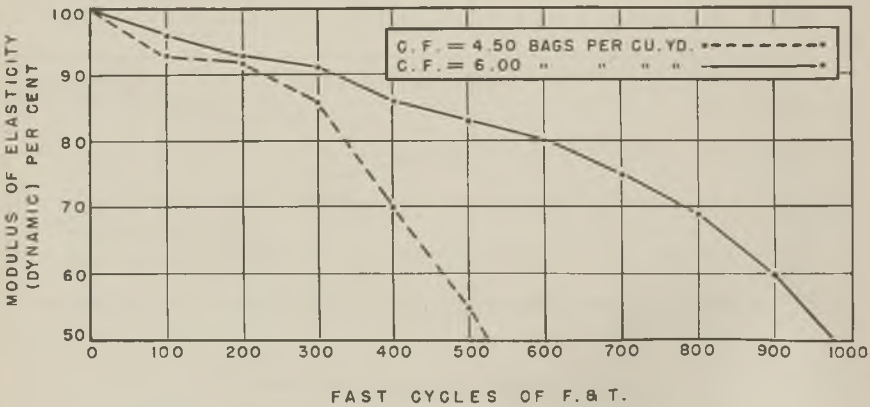

Fig. 11—Ultimate durability of concrete containing admixture V and cement A

A supplementary series of tests were made with admixture V and cement F* for the express purpose of determining the effect of W/C on durability of otherwise similar concrete. The results to 400 cycles are

*A cement meeting A.S.T.M. Specification C 150, Type I, not used previously in this work.

shown in Fig. 12 in which each curve represents the average of nine specimens made in groups of three on three different days. The anticipated influence of W/C on durability is apparent, but the full degree of difference was not developed at 400 cycles when the data were compiled for this paper.

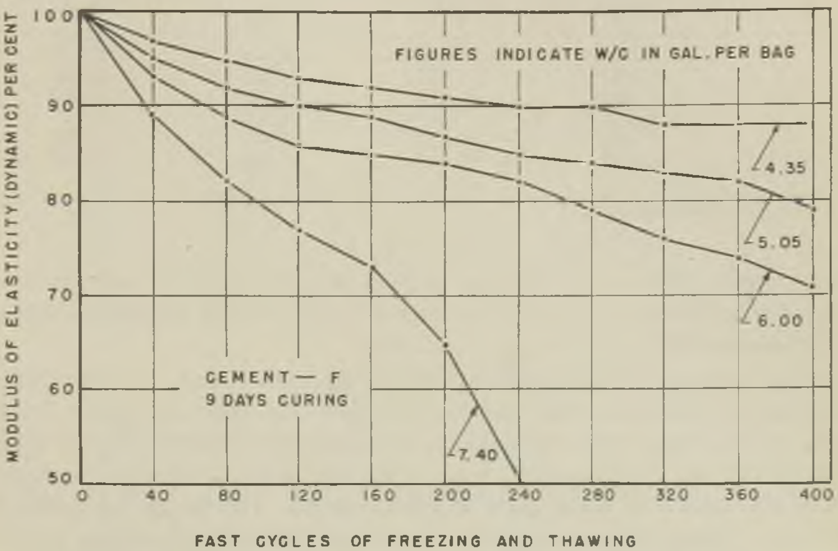

Fig. 12—Influence of variation in water—cement ratio on durability of concrete containing admixture V

(f) *Thermal properties.* The influence of the admixtures on the thermal coefficient of diffusion of concrete proportioned as shown in Table 8, appears to be entirely negligible as indicated by the results given in Table 22. It is evident that the presence of minute well distributed air voids should reduce the rate of heat diffusion, but this effect is not marked when the amount of air entrained is of the order which is optimum for the best results in concrete.

Discussion of results—supplemental studies

(a) *Effect of superimposed load.* The effect of a load equal to 2 psi imposed on the plastic concrete immediately after molding was studied by making duplicate cylinders, beams, and prisms from the batches of concrete (Table 8) made for determining compressive and flexural strength, bond-to-steel, and durability. Platens were made to fit each of these types of specimens and metal cans were prepared containing steel shot in quantities sufficient to apply a uniform load of 2 psi to the exposed surface of each specimen. Immediately after molding, the load

TABLE 22—THERMAL DIFFUSIVITY OF CONCRETE CONTAINING AIR-ENTRAINING ADMIXTURES

Diffusivity in sq. ft. per hr.

	Cement A		Cement C	
	Cement Factor—bags per cu. yd.		Cement Factor—bags per cu. yd.	
Admix.	4.5	6.0	4.5	6.0
P*	0.035	0.034	0.035	0.035
Q	0.034	0.033	0.033	0.032
R	0.034	0.032	0.035	0.032
U	0.033	—	0.033	—
V	0.034	0.032	0.035	0.032
Z	0.037	0.034	0.035	0.034

*Concrete without admixture.

was applied with a minimum of impact or vibration and permitted to remain in place for 24 hr. The effect of the loading is similar to testing the bottom third of specimens 3 ft. deep.

The influence of such loading on the strength, bond, and durability of the concrete made with and without the admixtures is shown in Table 23. It is evident from the data that the properties tested were all benefitted by the superimposed load, with the benefit varying markedly with the admixture used and with plain cement. The property benefitted to the greatest degree was bond-to-steel. Concrete containing admixture V, having developed an extraordinary improvement in the normal test (see Table 17) showed a minimum improvement in bond-to-steel under the loaded condition. Durability was the property least benefitted by the loaded condition.

(b) *Effect of vibration on air content.* The air content of concrete mixtures is determined normally by comparing the weight per cu. ft. of the plastic mixture with the theoretical unit weight in accordance with A.S.T.M. Method C 138-44. In this method, the plastic unit weight is determined by hand-rodding the mixture in the container. In view of the prevalence of consolidation of concrete by internal vibration in the field, it is important to know the effect of vibration on the air content as determined by the standard method. This problem was investigated by making a series of 20 mixtures with plain cements and with admixture V, and determining the unit weight in 1 cu. ft. measures simultaneously by the standard rodding method and by internal vibration. The air contents were determined by calculation and the average values obtained are given in Table 24. The vibration was continued beyond the time which would be optimum in the field for the mixtures used in order to accentuate rather than minimize the effect thereof on air content.

TABLE 23—EFFECT OF LOADING ON COMPRESSIVE, FLEXURAL, AND BOND STRENGTH, AND ON DURABILITY OF CONCRETE

(Load = 2 psi)

Admix.	Expressed as Per Cent of Value Obtained for Comparable Unloaded Concrete (See Tables 13, 16, 17, and 21 for unloaded values)									
	Cement A					Cement C				
	Comp. Str. 2 days	Comp. Str. 28 days	Flex. Str.	Bond-to-Steel	Durability D.F.E.	Comp. Str. 2 days	Comp. Str. 28 days	Flex. Str.	Bond-to-Steel	Durability D.F.E.
				Cement Factor = 4.5 b./cu. yd.						
P*	119	109	112	136	105	110	102	108	117	109
Q	112	102	104	208	102	106	104	108	172	103
R	113	103	112	216	103	120	107	116	163	103
U	115	105	105	203	101	116	103	107	168	101
V	108	99	117	153	110	118	107	114	174	112
Z	110	105	100	127	101	118	103	103	196	100
				Cement Factor = 6.0 b./cu. yd.						
P*	100	107	109	165	103	116	106	103	170	106
Q	110	110	103	176	102	109	109	111	182	102
R	109	106	101	234	101	106	108	98	147	102
U	103	113	107	140	100	110	101	111	140	100
V	116	117	106	117	108	125	116	110	120	108
Z	107	101	109	129	102	103	106	108	127	99

*P = Concrete without admixture.

TABLE 24—EFFECT OF VIBRATION ON AIR CONTENT OF CEMENT

Air Content in Per Cent

Plain Cement			Admixture V		
Rodded	Vibrated	Difference	Rodded	Vibrated	Difference
1.3	1.0	−0.3	3.3	2.9	−0.4
2.1	1.5	−0.6	3.7	3.2	−0.5
2.5	1.8	−0.7	3.9	3.6	−0.3
2.8	1.9	−0.9	4.2	3.7	−0.5
3.4	2.4	−1.0	4.4	3.7	−0.7

The data indicate that vibration does result in an apparent reduction in air content, with the degree of reduction being greatest in plastic mixtures of plain-cement concrete having relatively high air contents. This phenomenon is believed to be explained in part by the nature of the voids formed in plain concrete and in concrete with purposefully entrained air. The air entrained in plain concrete is present usually in relatively large voids of sufficient volume to develop buoyancy in sufficient degree to cause rapid upward migration under the influence of vibration. However, the widely distributed minute voids formed under the influence of a sudsing agent have inadequate volume to exert effective buoyant force. Little evidence of upward migration of the minute voids have been noted in hardened concrete under the microscope, whereas, the migration of large air voids under the influence of vibration is very evident to the naked eye in plain concrete. Therefore, it may be possible that the apparent reduction in air content in the concrete-with-admixture may be caused largely by loss of the large bubbles of incidentally entrapped air typical of plain concrete which are present also, in purposefully air-entraining concrete. A second partial explanation for apparent reduction in air content may be due to a compression of the air under the fluid pressure developed under effective vibration. It has been observed, too, that the unit weight of hardened concrete, as measured by displacement in water, is usually greater than that of the same plastic concrete. This reduction in apparent air content may be due in part to shrinkage of the concrete, evaporation of moisture, and by partial filling of some of the air voids with water.

In any case, the apparent reduction in air content caused by vibration is not sufficient in degree to cause alarm over the possible reduced effectiveness of air entrainment on the desirable properties of concrete. This has been demonstrated definitely by the fact that all concrete specimens reported in this paper were consolidated by thorough vibration and the beneficial effects of the purposeful air entrainment are very apparent in the freezing and thawing test.

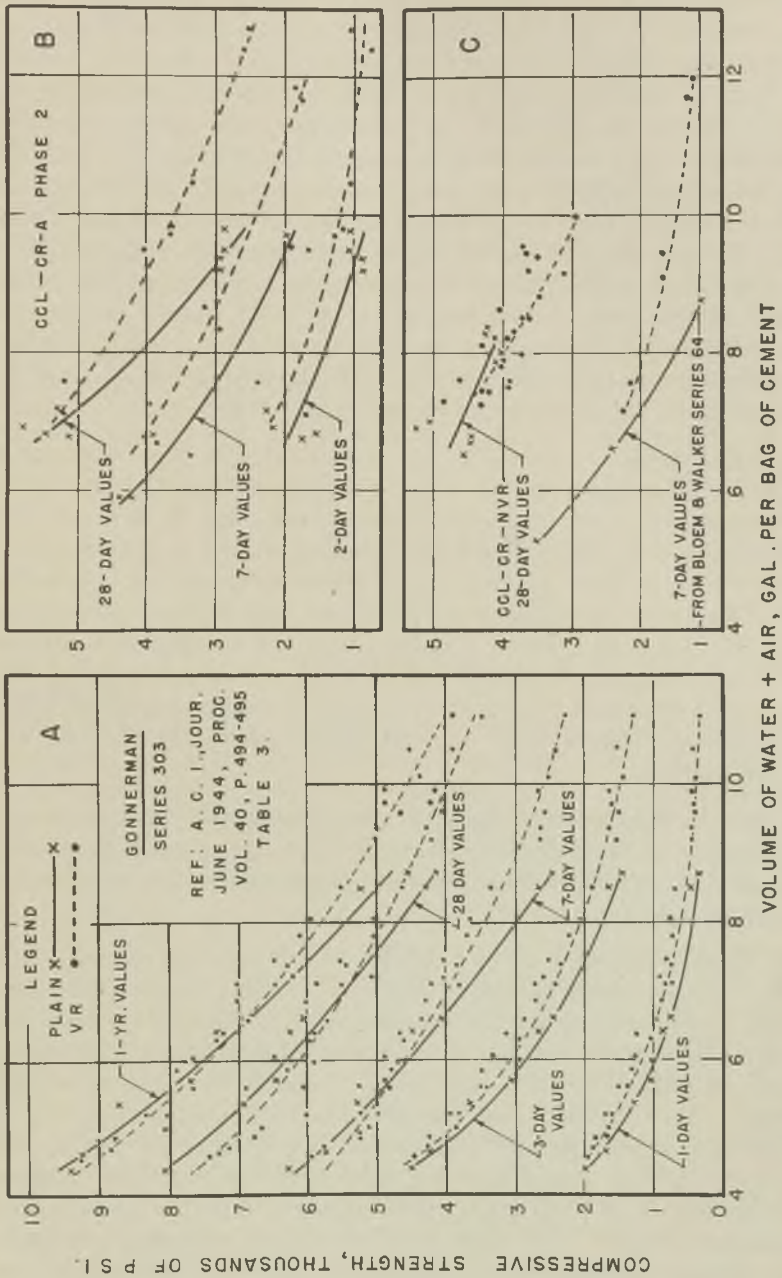

Fig. 13—Relation of total volume of water plus air in concrete to compressive strength at various ages of test

(c) *Effect of total volume of air plus water on compressive strength.* It has been suggested (47, 83) that the effect of entrained air in concrete on compressive strength is to cause a reduction similar to that which would have been induced by an increase in the mixing water in a volume equal to the volume of the entrained air. Gonnerman (47) shows a curve for voids-cement ratio vs. compressive strength at 28 days in which the curve represents both plain and air-entraining cement concretes and for which the factor "voids" represents absolute volume of air plus water. Since this curve was constructed on the basis of a plot using only 20 of the values given in his Table 3 at but one age, a new graph was drawn using 42 values for each of five test ages (Fig. 13A). Similar graphs were constructed for data developed in work conducted at this laboratory with admixture R (Fig. 13B and C). Also shown on Fig. 13C are the curves given in Fig. 3 of a paper by Bloem and Walker (83).

The relationships suggested by the data plotted in Figs. 13A and B have been indicated by curves. In both cases an increased air plus water volume resulted in an appreciably greater reduction in strength with plain cement than when an air-entraining admixture was used, except for low values of W + A/C at ages of seven days and over. A similar effect is suggested by the curves from Bloem and Walker. The curves in Fig. 13C for work done by this laboratory fail to show this relationship, due, principally, it is believed, to the fact that a number of different brands of cement were used with different coarse aggregates, under circumstances in which there was very little variation in W/C for any one combination.

In general, it is believed that there is an indication from these data that, except for low values for W + A/C at ages greater than seven days, air has less effect than water, in equal volume, on compressive strength of concrete.

(d) *Effect of entrained air on reduction in unit weight of concrete.* One of the methods which has been applied in certain specifications as a limiting requirement for the air to be entrained in concrete has been that the unit weight of the concrete shall be reduced by a specified number of pounds per cubic foot from that which would be obtained with plain concrete. This method leaves something to be desired because it does not take into account the effect of possible differences in the bulk specific gravity of the fine and coarse aggregate and the reduction in sand-aggregate ratio and W/C made practicable and desirable by purposeful entrainment of air. The data in Table 25 demonstrate the effect which different combinations of aggregates have on reductions in unit weight with air contents varying from 0 to 5 per cent.

TABLE 25—VARIATION IN UNIT WEIGHT OF CONCRETE AS AFFECTED BY AIR CONTENT AND SPECIFIC GRAVITY OF AGGREGATES

Bulk Sp. Gr.		W/C g.p.b.	Cement Factor bags per cu. yd.		S/A % by Vol.	Actual Unit Wt. lb. per cu. ft.	Air %	Reduc. in Unit Wt. lb. per cu. ft.
Sand	C. Agg.		Theo.	Actual				
2.50	2.90	6.00	4.50	4.50	35.0	159.4	0.0	0.0
2.50	2.90	5.80	4.54	4.50	33.7	158.6	1.0	0.8
2.50	2.90	5.50	4.59	4.50	32.4	157.9	2.0	1.5
2.50	2.90	5.25	4.64	4.50	31.1	156.9	3.0	2.5
2.50	2.90	5.00	4.68	4.50	29.8	156.1	4.0	3.3
2.50	2.90	4.75	4.72	4.50	28.5	155.2	5.0	4.2
2.65	2.65	6.00	4.50	4.50	35.0	154.2	0.0	0.0
2.65	2.65	5.80	4.54	4.50	33.7	153.0	1.0	1.2
2.65	2.65	5.50	4.59	4.50	32.4	151.9	2.0	2.3
2.65	2.65	5.25	4.64	4.50	31.1	150.9	3.0	3.3
2.65	2.65	5.00	4.68	4.50	29.8	149.9	4.0	4.3
2.65	2.65	4.75	4.72	4.50	28.5	148.8	5.0	5.4
2.65	2.50	6.00	4.50	4.50	35.0	149.3	0.0	0.0
2.65	2.50	5.80	4.54	4.50	33.7	148.1	1.0	1.2
2.65	2.50	5.50	4.59	4.50	32.4	147.0	2.0	2.3
2.65	2.50	5.25	4.64	4.50	31.1	145.8	3.0	3.5
2.65	2.50	5.00	4.68	4.50	29.8	144.8	4.0	4.5
2.65	2.50	4.75	4.72	4.50	28.5	143.5	5.0	6.0

FUTURE WORK

Mass concrete

The major use of air entrainment in concrete to date has been in pavements and relatively non-massive structures. However, the major contribution of purposeful air entrainment to increased plasticity, water-retentivity, and durability should not be ignored in connection with massive structures. It is apparent from all work performed to date that the leaner mixtures are benefitted more than are the richer mixtures by the use of air entrainment. It is apparent, too, that the very lean mixtures containing large aggregate used in massive concrete structures are relatively non-plastic and possess a low order of coherence. It is at least reasonable to expect that the plasticizing effect of air entrainment should improve the mobility and coherence of such mixtures. Pilot studies conducted in this laboratory in recent months, in which ½-cu. yd. blocks of lean concrete containing 4-in. and 6-in. aggregate have been cast, cored, and tested, indicate major improvements in placeability, coherence, and durability with no sacrifice in strength and *minor reductions in unit weight.* In cases where the admixture is added at the mixer, very close regulation and control of the amount of entrained air is thoroughly practicable.

(a) *Amount of air desired.* One of the principal features of the application of air entrainment to mass concrete mixtures is the fact that the total amount of entrained air need be less than in pavement or structural concrete mixtures for equal effect, because use of considerably larger coarse aggregate results in a reduction in the mortar component of the mass. It is the condition and air content of the mortar which affects the mobility, coherence, and durability of the concrete. It can be demonstrated that a total air content of 2.7 per cent in lean concrete mixtures containing 6-in. aggregate is comparable insofar as the mortar constituent is concerned to a total air content of 4.0 per cent in a pavement mixture containing 1½-in. aggregate. For this reason it is practicable to achieve full benefits from air entrainment in mass concrete with a minimum of reduction in unit weight.

(b) *Determination of unit weight of mass concrete.* The preliminary studies referred to above have included tests of unit weight. In these studies, *it was demonstrated that the usual procedure of wet-screening to remove aggregate larger than 1½-in. to permit use of standard containers was impractical and produced incorrect results.* The process of passing a concrete mixture over a sieve separates the ingredients and exposes a maximum of mortar surface to the air. The agitation of the separate mixture permits the loss of a considerable portion of the entrained air so that the anticipated relationship of air to the residual concrete mixture smaller in size than the sieve used is not obtained. Therefore, it is considered necessary to determine the air content of all mixtures with a minimum of disturbance and without wet-screening. When aggregate larger than 2 in. is used, it becomes necessary to determine unit weight in 2-cu. ft. measures. Such tests are being conducted currently in the laboratory.

It is proposed to expand the studies of purposeful air entrainment in lean concrete mixtures containing large aggregate sizes with the object of developing means for specifying and controlling air entrainment in massive structures.

GENERAL DISCUSSION

The data presented in this paper are summarized below with an interpretation of their significance and application to the successful use of air entrainment in concrete.

Action of air-entraining admixtures

Air-entraining admixtures will cause the formation of a foam composed of small to minute bubbles of air when shaken vigorously with water by reduction in the surface tension of the solution. The quantity, dispersion, and stability of the foam is increased in a mixture of sand, water, and a given amount of admixture as the quantity and coarseness (within the usual limits of fine aggregate) of the sand and the time and vigor of mixing are increased. The addition of cement to the mixture, with proportional reduction in sand, results in a decrease in amount of foam as the ratio of cement to sand increases to the ultimate point where very little air is entrained in a simple cement-water-admixture system. Therefore, cement may be considered to be a depressant of air entrainment. In a concrete mixture, the amount of air entrained varies inversely with the cement content and directly with the sand-total aggregate ratio. Further, the amount of air entrained increases with increased slump or flow of the mixture. The entrainment of air in concrete may be accomplished most satisfactorily when the admixture is not dependent upon chemical reaction with the cement to develop the requisite sudsing property.

From the foregoing, it is apparent that the term "air-entraining cement" is a misnomer, although evolved naturally from the fact that air-entraining admixtures were introduced to modern concrete practice as interground additions to cement.

Regulation of the amount of air entrained

The close regulation of amount of air to be entrained in a mortar or concrete mixture can be accomplished most practically by adjustment of the quantity of the given type of admixture used; as regulation by varying the cement or sand content, the time and type of mixing, or the consistency of the mixture is limited by economics, structural design factors; and available mixing, transporting, and placing equipment. When the admixture is interground with the cement, factors of adsorption, carbonization, volatilization, and metamorphism caused by the heat of grinding affect the quantity of the admixture necessary to be added to develop a given amount of air entrainment in a mortar or concrete mixture. By use of a standardized mortar test (A.S.T.M. C 185-44T), it is possible to regulate the amount of admixture necessary to entrain a given amount of air in that mortar and, when the admixture is interground with the cement, this method of control is superior to quantitative limitations based on chemical analysis. However, varying factors of cement content; amount and grading of sand; shape, grading, and size of coarse aggregate; time and type of mixing, and consistency vitiate largely the value of the standard mortar method as a means of predicting or controlling the air content in concrete mixtures.

Effect of air-entraining admixtures on the properties of concrete

The effect of the use of the so-called "air-entraining admixtures" on the properties of concrete appears to be a function of the amount and condition of the air entrained, that is; the number, size, and degree of distribution of the bubbles of air in the mortar component of the mixture, rather than on total volume alone. The chemical effect of these admixtures appears to be limited entirely to the possible presence and type of other than sudsing compounds, such as accelerators, deflocculators, or gas-generating agents. Considering only the sudsing agent, the effect of entrained air is cumulative, as indicated below:

(a) The entrained air acts as a very elastic and stable non-reactive fine aggregate of high lubricating value. Its presence permits:

(b) A marked reduction in the water-cement ratio necessary to produce the desired placeability of the mixture, and

(c) A reduction in the sand-total aggregate ratio normally required by approximately 1.3 times the amount of air entrained; thereby reducing the total surface area of rigid aggregate to be coated and lubricated by the cement-water paste.

(d) Reduction in the W/C effects a basic increase in the strength and durability of the cementing medium, and the reduction in the total water present in the mixture reduces the amount of excess water available for formation of channels through the matrix of the concrete; thereby reducing permeability and bleeding.

(e) Reduction in bleeding is increased beyond that effected simply by reduced W/C by immobilization of additional water through adsorption on the air bubbles. Reduction in bleeding results in diminished separation of the matrix from the under sides of coarse aggregate particles and in diminished flotation upward of laitance.

(f) Finally, the numerous well dispersed air voids provide reservoirs for the relief of pressure created in concrete due to differential volume movements in the concrete caused by temperature change and by the expansion accompanying the transition of water to ice. This contribution to durability is reinforced by the reduced W/C and lack of channelization of the matrix due to bleeding.

It appears that the entrained air is more closely related to the fine aggregate than to any other component of a concrete mixture and that the benefits inherent in purposeful air entrainment are related principally to that constituent of the mixture. Therefore, the optimum percentage of air entrained should be a function of the quantity of fine aggregate present in the mixture rather than a fixed percentage of the total mixture. In rich mixtures containing coarse aggregate of small maximum size, the total amount of air to be entrained for optimum results should be considerably greater than would be required in lean mixtures containing large coarse aggregate, because the sand component of the former is much greater in amount than in the latter.

(a) *Effect on strength and W/C.* From data which is based preponderantly on tests made with Vinsol resin interground with cement at the mill and concrete containing 1½-in. coarse aggregate (65, 71, 79, 82) the air entrained in concrete results in a reduction in strength which is related roughly in amount to that which would accompany an equal increase in volume of water, that is, the volumetric ratio of water plus air to cement is roughly but not quite equal to the volumetric ratio of water to cement in its effect on strength. Since the ratio of practicable reduction in W/C to increase in air content is reduced sharply beyond approximately 4 per cent air, increases in air content beyond that amount are accompanied by a rapidly increasing reduction in strength. Since a maximum increase in durability appears to be reached when the air content is approximately 4 per cent and the reduction in strength is not appreciable at that point, this amount of air entrainment is considered to be the optimum for use in concrete mixtures containing coarse aggregate up to about 1½ in. in maximum size.

The sacrifice in compressive and flexural strength and in bond of concrete to steel which is associated usually with the use of simple air-entraining admixtures in concrete may be minimized by addition of the admixture at the mixer where the quantity added may be regulated at will and controlled closely to produce the optimum air content. Data from the tests made with admixtures which are compounds of sudsing agents and various accelerators, deflocculators, and gas-generating agents indicate that the full benefits of the entrainment of air may be retained with an accompanying definite increase in strength and bond-to-steel. As would be expected, the degree to which the compound admixture affects the properties of the plastic and hardened mixture is a function of the composition of the admixture.

The benefits to concrete quality which appear to be available, potentially, through the use of compound air-entraining admixtures appear to be very great, but the competitive nature of such admixtures and the possible adverse influence of minor quantities of certain materials on concrete quality make evident the necessity for adequate laboratory performance tests to govern their acceptability for use. In recognition of these benefits and possible liabilities, a specification for air-entraining admixtures and a method of evaluating their performance in concrete have been formulated and submitted for the approval of the Department. They are not yet available for publication.

(b) *Effect on other properties.* When added to the concrete at the mixer so as to produce the optimum quantity of entrained air, the use of air-entraining admixtures will not result in *increased* retardation of set or early strength gain at temperatures above freezing. It is possible to achieve increased early strength at low temperatures by using a satisfactory accelerator with or as a part of the admixture with no sacrifice in the desirable properties of concrete.

Purposefully entrained and properly dispersed air will not be displaced upward or escape to a material degree from well designed concrete mixtures consolidated by proper application of vibration.

The thermal properties of concrete are not affected to a material extent by the entrainment of optimum quantities of air.

The volume constancy of concrete, due to moisture or temperature changes, is not affected materially by the entrainment of optimum quantities of air.

The degree to which the air content of a mixture will increase is a function of the nature of the admixture and the immediacy of its availability as a sudsing agent when introduced in the mixer. The entrainment of air is not likely to increase in concrete mixtures by continued mixing in stationary or paving-type mixers beyond a period of about three minutes when the admixture is added at the mixer. Continued increase in air with prolonged mixing is likely to occur beyond this period when the admixture is interground with the cement at the mill.

The air content of concrete resulting from the use of air-entraining admixtures should be considered as a definite ingredient and the design of mixtures should be based on ingredients of water, *air*, cement, fine and coarse aggregate.

In view of the benefits to be derived from mixtures of air-entraining agents, accelerators, and gas-generating agents, and the regulability of effect achievable by such use, the admixture should be added to the concrete mixture in the field at the batching plant or mixer.

The addition of admixtures should be made by mechanical batchers which will dispense the material in accurate and regulable amounts.

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BIBLIOGRAPHY

1. The Reaction of Cement Mixed with Tallow and with Clay, 1885, *Trans. Am. Soc. Civil Engrs.* v. 14, p. 164.

2. Uses of Mineral Oil Mixed Concrete, Albert Moyer, 1909 (Dec.) Reprint by Vulcanite Cement Co.

3. (Discusses soaps and calcium chloride admixtures), R. J. Wig and P. H. Bates, 1912, Nat. Bur. of Stds., Technical Paper No. 3.

4. Effect of Sugar on Cement Mortar (Discusses effect of paraffin oil and fatty acids also), J. Dautrebande, 1923 (Apr.) *Concrete,* v. 22, p. 161.

5. Soaps as Integral Waterproofings for Concrete, Alfred H. White and J. H. Bateman, 1926, ACI, *Proc.*, v. 22, p. 535.

6. Tests of Integral and Surface Waterproofings for Concrete, C. H. Jumper, 1931 (dated 1931 Oct.) printed 1936), Nat. Bur. of Stds. Research Paper No. 394.

7. Tests of Integral and Surface Wateproofings for Concrete, C. H. Jumper, 1932, ACI Jour., Dec. 1931, *Proc.* v. 28 (1932) p. 209.

8. The Chemistry of Cement and Concrete, F. M. Lea and C. H. Desch, 1935, Longmans, Green & Co., N. Y., pp. 15, 324-325, 354-355.

9. Chloride Salts—Resistant Concrete Pavements, Ira Paul, 1938, Am. Assoc. of Highway Officials of the No. Atl. Sts., 14th Ann. Proc., pp. 144-167.

10. The Effect of Using a Blend of Portland and Natural Cement on Physical Properties of Mortar and Concrete, W. F. Kellerman & D. G. Runner, 1938, Proc. A.S.T.M., v. 38, (II) pp. 329-350.

11. Durability of New York State Concrete Pavements, E. C. Lawton, 1939 (Jun.) June, 1939, ACI Jour., *Proc.* v. 35, p. 561.

12. The Bleeding of Portland Cement Paste, Mortar and Concrete (Especially "Effect of Entrained Air" pp. 95-97), T. C. Powers, 1939, (Jul.) Res. Lab. P.C.A. Bull. 2, Chicago.

13. A Report of Certain Properties of Concrete in which "Treated" Quick-Hardening Portland Cement Was Used, G. O. Gardner, 1940 (Mar.), Symposium on Specifications for and Additions to Portland Cement, Part II, ASTM Comm. C-1 (Unpublished).

14. Plasticizers and Grinding Aids, H. L. Kennedy and F. T. Mardulier, 1940 (Mar.), A.S.T.M. Symposium—see above.

15. Experimental Concrete Road, Hudson, N. Y. Plant of the Universal Atlas Cement Co., O. L. Moore, 1940 (Mar.), A.S.T.M. Symposium—see above.

16. A Discussion of Laboratory Studies Pertaining to the Grinding, Plasticizing and Waterproofing Materials Interground with Portland Cement Clinker, L. A. Wagner, 1940 (Mar.), A.S.T.M. Symposium—see above.

17. Report on Effect of Organic Additions to Portland Cement, M. A. Swayze, 1940 (Mar.), A.S.T.M. Symposium—see above.

18. Experimental Concrete Pavement in the City of Minneapolis, H. G. Erickson, 1940 (May), Bull. of Minn. Fed. of Arch. and Eng. Soc. pp. 9-11.

19. Experimental Data in Connection with Chloride Salts-Resistant Concrete Pavement, C. C. Ahles, 1940 (Sep.), *Explosives Engineer* v. 18, p. 267.

20. Pavement Scaling Successfully Checked, O. L. Moore, 1940 (Oct.), *Engineering News-Record*, v. 125, pp. 471-474.

21. Discussion of 20 above, D. W. Scully and I. L. Paul, 1940 (Nov.), *Engineering News-Record*, v. 12, p. 598.

22. Utah Studies Pavement Scaling, Anon, 1940 (Dec.), *Western Constr. News*, v. 15, pp. 107-108.

23. Extensive Research on Concrete Highway Project to Investigate Fundamental Principles and Factors Developed by the Michigan Test Road, J. W. Kushing, 1941 (May), *Roads and Streets*, v. 84, no. 5, p. 35.

24. More Durable Concrete with Treated Cement, M. A. Swayze, 1941 (Jun.), *Engineering News-Record*, v. 126, p. 946.

25. New Type of Cement for Scale Resistance, Anon, 1941 (Jul.), *Contractors and Engineers Monthly.*

26. General Observations on Concrete Scaling-Organic Admixtures Showed Satisfactory Results, J. W. Kushing, 1941 (Dec.), *Roads and Streets*, v. 84, no. 12, p. 23.

27. Ohio's Experience with Vibratory Methods of Placing Concrete and Tests with Grinding Aids, C. W. Allen and J. F. Barbee, 1942, *Proceedings, Highway Research Bd.*, v. 22, p. 306.

28. Cement Dispersion and Air Entrainment in Concrete Pavement Construction, E. W. Scripture, 1942, Master Bldrs. Res. Lab. Research Paper No. 39, Cleveland, Ohio.

29. Experimental Test Data in Connection with the Development of Chloride-Resisting Concrete by the Use of Treated Portland Cements and Blends with Natural Cement, A. A. Anderson, 1941, Proc. 17th Ann. Conv. of Assoc. of Hgy. Office of No. Atl. Sts., pp. 67-89 also *Explosives Engr.*, v. 20, pp. 10-14, 26-30, (Jan. 1942).

30. Cement Durability Program—First Interim Report, C. E. Wuerpel, 1942 (Jun.), Central Concrete Laboratory.

31. Effect of Vinsol Resin on Bond between Concrete and Steel, C. E. Wuerpel, 1942 (Nov.), ACI Jour., Nov. 1942 *Proc.*, v. 39, pp. 129-130.

32. Heavy-Traffic Plain Concrete Pavement Utilizes Resin-Treated Cement, 1942 (Dec.) *Concrete* v. 50, p. 33.

33. Effect of Air Entrapping Portland Cement on the Resistance to Freezing and Thawing of Concrete Containing Inferior Coarse Aggregate (discussion by C. E. Wuerpel, A. D. Conrow, and S. Walker), E. O. Axon, T. F. Willis and F. V. Reagel, 1943 A.S.T.M. Proc., v. 43, p. 981-1000.

34. The Function of Entrained Air in Concrete, H. L. Kennedy, 1943 (Jun.), ACI Jour. June, 1943, *Proc.*, v. 39, p. 592.

35. Grinding Aids for Portland Cement, E. R. Dawley, 1943 (Jul.), *Pit & Quarry*, v. 36, no. 1, p. 57.

36. The Elimination of Pavement Scaling by Use of Air-Entraining Portland Cement, Portland Cement Association, 1943 (Aug.), Highways & Municipal Bureau, P.C.A., Concrete Information Sheet No. HB-18.

37. The Frost Resistance of Concrete, A. R. Collins, 1943 (Aug.), Jour. of the Soc. of the Chem. Industry Trans. & Comm., pp. 113-116.

38. Tensile and Other Properties of Concretes Made with Various Types of Cements (9 cements with aerating agents), Louis Schuman and John Tucker, Jr., (1943 Aug.), Nat. Bur. of Stds., Jour. of Research, R. P. 1552.

39. Scale-Free Pavements Made with Air-Entraining Portland Cement, O. H. Gosswein, 1943 (Nov.), *Roads & Streets*, v. 86, no. 11, p. 57.

40. Concrete Protection Afforded by Freeze-Resistant Resin from Pine Wood, 1943 (Nov.), *Scientific American*, v. 169, p. 228-229.

41. Discussion of: The Function of Entrained Air in Concrete (cf. No. 34), M. Spindel, 1943 (Nov.), ACI Jour. Nov. 1943 Supplement, *Proc.*, v. 39, pp. 544-1 to 544-4.

42. More About Air-Entraining Cements—Suggested Specifications and Construction Procedure for Concrete involving this Cement, Anon, 1943 (Dec.), *Roads and Streets* v. 86, no. 12, p. 45.

43. Air-Entraining Cement Concrete Proves Scale Resistant, E. F. Young, 1943 (Dec.), *Engineering News-Record*, v. 131, no. 27, pp. 950-953.

44. (ref. by Farmer & Lindsay No. 68), 1944, (Jan.), *Concrete*, p. 103.

45. Aggregates for Concrete (Section headed: "Air-Entraining Cements"), C. E. Wuerpel, 1944 (Jan.), Nat'l Sand & Gravel Assoc. Circular 25, pp. 34-35.

46. Investigation of the Air-Entraining Properties of Portland Cements Effected by the Addition of Vinsol Resin, W. J. McCoy, 1944 (Mar.), Bull. A.S.T.M., No. 127, p. 22.

47. Tests of Concretes Containing Air-entraining Portland Cements or Air-entraining Materials Added to Batch at Mixer, H. F. Gonnerman, 1944 (Jun.), ACI Jour. June, 1944, *Proc.* v. 40, pp. 477-507.

48. An Introduction and Questions to Which Answers are Sought; Concluding Summary, F. H. Jackson, 1944, ACI Jour., June, 1944; *Proc.* v. 40, Symposium on Concrete Containing Air-entraining Agents, pp. 509-515, 567-569.

49. The Function of Entrained Air in Portland Cement, H. L. Kennedy, 1944 (Jun.), ACI Symposium pp. 515-517.

50. Laboratory Freezing and Thawing Tests on Concrete Containing Various Air-entraining Agents, H. S. Meissner, 1944 (Jun.), ACI Symposium pp. 517-522.

51. Air-Entrainment Calls for Changes in Mix Design and Mixing Practice, M. A. Swayze, 1944 (Jun.), ACI Symposium, pp. 522-524.

52. Methods of Entraining Air in Concrete, D. R. MacPherson, 1944 (Jun.), ACI Symposium, pp. 524-529.

53. Manufacturing and Use of Air-entraining Portland Cement, G. L. Lindsay, 1944 (Jun.), ACI Symposium, pp. 529-536.

54. Aeration, Offering Improved Concreting, Should be Used with Caution, H. F. Thomson, 1944 (Jun.), ACI Symposium, pp. 536-538.

55. Milwaukee's Experiences with Air-entraining Cements, R. A. Burmeister, 1944 (Jun.), ACI Symposium, pp. 539-547.

56. Air-entraining Cements in Ready Mixed Concrete Industry, Stanton Walker, 1944 (Jun.), ACI Symposium, pp. 547-552.

57. Entrained Air Beneficial in Freezing and Thawing Tests. R. E. Davis. 1944 (Jun.), ACI Symposium, p. 552.

58. Field Experiences with Concrete Containing Air-Entraining Cement, G. H. Larson, 1944 (Jun.), ACI Symposium, pp. 552-554.

59. Laboratory and Field Experiences, J. H. Chubb, 1944 (Jun.), ACI Symposium, pp. 554-558.

60. Effect of Air-Entraining Agents on Pumped Concrete, T. R. Sherrod, 1944 (Jun.), ACI Symposium, pp. 558-560.

61. Air-Entraining Agents in Ohio Highways, J. F. Barbee, 1944 (Jun.), ACI Symposium, pp. 560-563.

62. Air-Entraining Agents Not a Cure-All, F. V. Reagel, 1944 (Jun.), ACI Symposium, pp. 563-567.

63. Entrained Air—Its Effect on the Constituents of Portland Cement Concrete, H. L. Kennedy, 1944 (Jun.), A.S.T.M. Proc., v. 44, pp. 821-830 (also in part, in *Eng. News-Record*, v. 133, no. 2, 1944, p. 112 (July 13, 1944).

64. Discussion of Paper by Kennedy, C. E. Wuerpel, 1944 (Jun.), A.S.T.M. Proc., v. 44, pp. 831-834.

65. Report on Cooperative Studies of Proposed Method of Test for Air Content of Portland-Cement Mortar, C. E. Wuerpel, 1944 (Jun.), Appendix I, Report of Comm. C-1 on Cement A.S.T.M. Proc., v. 44, pp. 306-310.

66. Control of Quality of Ready Mix Concrete (especially: "Effect of Air-Entrainment on Proportions, Effect of Air-Entrainment on Strength") pp. 23-25, National Ready Mixed Concrete Association, 1944 (July), N.R.M.C.A. Wash., D.C., 71 pages.

67. Cement Industry Must Solve Problems, Bror Nordberg, 1944 (Aug.), *Rock Products*, (Editorial) v. 47, no. 8, p. 47.

68. Post-War Highway Cements, Bror Nordberg, 1944 (Aug.), *Rock Products*, v. 47, no. 8, pp. 78-79, 132, 134.

69. Compressive Strength at 28-Day Age of Job-Made Concrete Cylinders Containing Treated and Untreated Portland Cement, C. E. Wuerpel, 1944 (Aug.), Central Concrete Laboratory.

70. How to Use Air-Entraining Cements, H. G. Farmer and G. L. Lindsay, 1944 (Aug.), *Engineering News-Record*, pp. 64-67.

71. The Reaction of Vinsol Resin as It Affects the Air-Entrainment of Portland-Cement Concrete, C. E. Wuerpel and Albert Weiner, 1944 (Oct.), Bull. A.S.T.M. No. 130, pp. 41-43 (also, in part, in *Eng. News-Record*, v. 133, no. 2, 1944, pp. 111-112, (July 13, 1944).

72. Discussion of Paper by Wuerpel and Weiner, P. H. Bates, Duff A. Abrams, J. C. Pearson, Alexander Foster, Jr., and H. W. Leavitt, 1944 (Oct.), Bull. A.S.T.M., no. 130, pp. 43-37.

73. Air-entraining Cement Manufacture, J. F. Barton, 1944 (Nov.), *Rock Products*, v. 47, no. 11, pp. 39,112.

74. Admixtures for Concrete, ACI Comm. 212, F. B. Hornibrook, Chrm., 1944 (Nov.), ACI Jour. Nov. 1944, *Proc.*, v. 41, pp. 73-86.

75. Supplementary Data and Analysis of: (cf. no. 46) Tests of Concrete Containing Air-Entraining Portland Cements or Air-Entraining Materials Added to Batch at Mixer, H. F. Gonnerman, 1944 (Nov.), ACI Jour. Nov. 1944, Supplement, *Proc.*, v. 40, pp. 508-1 to 508-6.

76. Discussion of: Concretes Containing Air-Entraining Agents (cf. Nos. 47-61), M. Spindel, 1944 (Nov.), ACI Jour. Nov. 1944 Supplement, *Proc.*, v. 40, pp. 572-1 to 572-5.

77. Addendum No. 1 and Accompanying Inclosure entitled "Evaluation of Admixtures for Concrete," U. S. Army Corps of Engineers, Office, Chief of Engineers, 1944 (Dec.), "Guide Specifications for Concrete Construction for Civil Works" and "Engineering Manual for Civil Works" Chap. XII entitled: "Recommended Practice for Concrete and Reinforced Concrete".

78. Effect of Calcium Chloride on the Water Requirements, Specific Weights and Compressive Strengths of Concrete Made with Plain and Treated Cements, H. C. Vollmer, 1944, 23rd Ann. *Proc.*, Highway Research Board, p. 296.

79. Field Use of Cement Containing Vinsol Resin, C. E. Wuerpel, 1945 (Sept.), ACI Jour. Sept. 1945, Proc., v. 42, pp. 49-82; see also; Concrete Research as in No. 84 Second Interim Report, Part II, Central Concrete Laboratory.

80. Air-Entraining Portland Cement in Concrete Block, H. G. Farmer, 1945(Jan.), *Rock Products*, v. 48, no. 1, pp. 209-210, 217.

81. Concrete Including Air-Entraining Agents, Open Forum, 1945 (Mar.), Tech. Info. Ltr., No. 21, N.R.M.C.A, Wash. D. C.

82. Some Effects of Air-Entrainment and Coarse Aggregate Type on the Properties of Concrete, C. E. Wuerpel, 1945, Nat'l Crushed Stone Assoc., Wash., D. C.

83. Progress Report on Studies of Concrete with Entrained Air (Series 64), D. L. Bloem and Stanton Walker, 1945 (May), Circularized to N.R.M.C.A.

84. Automatic Accelerated Freezing-and-Thawing Apparatus for Concrete, C. E. Wuerpel and H. K. Cook, 1945, A.S.T.M. Proc., v. 45, (issued as a preprint); See also: Concrete Research, Second Interim Report, Part III, Central Concrete Laboratory.

85. The Testing of Portland Cements Containing Interground Vinsol Resin, R. L. Blaine, J. C. Yates and J. R. Dwyer, 1945, A.S.T.M. Proc., v. 45 (issued as a preprint).

86. Chloroform Soluble Content Control of Air-Entraining Portland Cement, E. S. Ernst and R. A. Loveland, 1945 (Jul.), *Pit and Quarry*, v. 38, no. 1, pp. 119-122, 128-129.

87. Effect of Heat on Portland Cements Containing Vinsol Resin, Leonard Bean and Albert Litvin, 1945 (Aug.), Bull. A.S.T.M., no. 135, pp. 30-32.

88. Laboratory Studies of Concrete Containing Air-Entraining Admixtures, C. E. Wuerpel, 1945 (Jul.), Concrete Research, Second Interim Report, Part I, Central Concrete Laboratory.

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Shrinkage Stresses in Concrete*

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Member American Concrete Institute

PART 2—APPLICATION OF THE THEORY PRESENTED IN PART 1 TO EXPERIMENTAL RESULTS

Carlson's results on prisms drying from one end

As mentioned in Part 1, Carlson[1] applied diffusion principles to the problem of computing both loss of moisture and distribution of shrinkage. The fundamental equations on which his computations were based are the equations to which Equations 5 and 22 of Part 1 reduce when the parameter B is set equal to infinity. In his experimental work the prisms were allowed to dry through one end only, the rest of the surface being sealed. Measurements were made over gage lines that were parallel to the direction of flow of moisture. These conditions appear to be most favorable for the direct measurement of the distribution of shrinkage tendency since in an unrestrained specimen shrinkage stresses should not have any appreciable effect on the unit shortening in the direction of moisture flow.

In Fig. 3 of his paper Carlson showed two diagrams. One diagram gave the distribution of shrinkage as measured after a definite period of drying and the other gave the computed "distribution of drying" (loss of moisture) for different assumed coefficients of diffusion for the same period of drying. The observed distribution of shrinkage and the computed "distribution of drying" are in good agreement when the proper coefficient is selected. However, as shown by Fig. 1 of his paper, the measured loss in weight was not in very good agreement with the theory. Carlson could have obtained slightly better agreement between theory and measured shrinkage if he had taken surface conditions into account,

*Part 1 of this paper was published in the ACI Journal, January, 1946, and includes (p. 194) the complete list of references.

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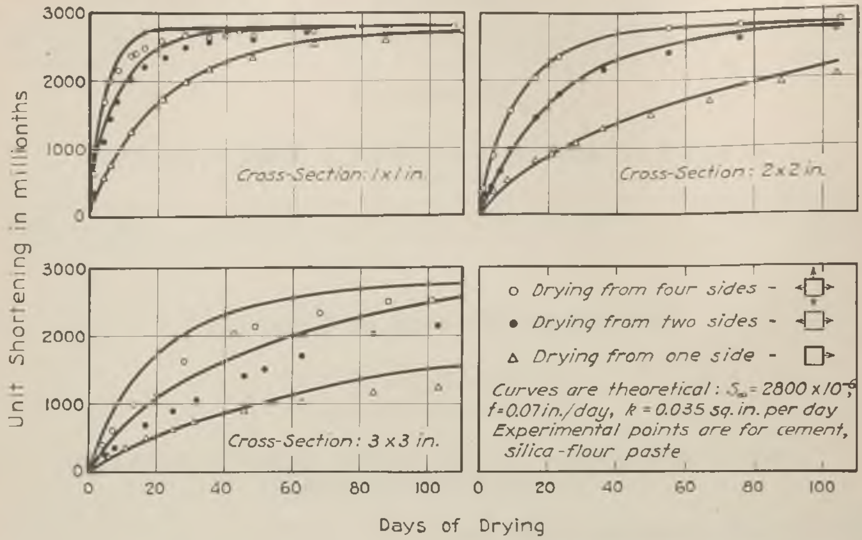


Fig. 15—Comparison of observed and calculated course of shrinkage

i.e., used a finite value for the parameter B. However, had he done so, the discrepancy between theory and measured loss in weight would have been greater than that shown.

Carlson's work is important evidence in support of the hypothesis that shrinkage of concrete approximately follows the laws of diffusion.

Shrinkage of prisms of various sizes drying from one or more sides

In the work done in this laboratory measurements were made on gage lengths transverse to the direction of moisture flow. Since variations in shrinkage along the path of moisture flow result in stresses transverse to the direction of flow, the measurements include the strains produced by these stresses. If, however, the specimens are long compared to their dimension in the direction of moisture flow and the stress-strain relation is linear, then as shown in Part I the shortening of the central axis will be equal to the average shrinkage. The results to be discussed provide a test of the theory for conditions in which both size of specimen and number of exposed sides are variable.

Fig. 15 shows the unit shortening versus days of drying for three different sizes of prisms made of the same mix and for the three different drying conditions discussed in Part 1. Mix A and cement M, described in the Appendix, were used. The specimens were cured seven days under water. Each point is the average of the results from two prisms. The curves were constructed from computations based on the theoretical equations developed in Part 1. These equations, which give the theoretical relationship between unit shortening, the constants of the material, and dimensions of the specimen have the form

$$\text{unit shortening} = S_{av} = F\left(S_\infty, \frac{fb}{k}, \frac{kt}{b^2}, \frac{c}{b}\right)$$

where S_∞ is ultimate shrinkage for the assumed final drying, f is the surface factor, k is the diffusivity factor, and b and c are dimensions of the specimen. The exact form of the function, especially the way in which c/b enters into it, differs with the drying condition.

The three constants S_∞, f, and k were evaluated from average experimental values for the pair of prisms of 2-in. square cross-section, drying from four exposed sides. From these same constants the curves were constructed, as shown in Fig. 15, not only for this pair but also for the theoretical unit shortening of the other eight pairs of prisms. The agreement between the experimental values and the calculated curves is fairly satisfactory except for two pairs of 3x3-in. specimens, which were observed to have cracked during drying and therefore could not be expected to shorten in accordance with the theory.

Discussion of the validity of the theory on the basis of the foregoing data

The data from those specimens that did not crack, together with the data given by Carlson, might seem to indicate rather conclusively that shrinkage does take place in accordance with the theory developed in Part 1. However, such a conclusion would not be justified. A good fit between an equation and experimental data is necessary but it is not sufficient proof of a theory. Although constants in the equations of Part 1 may be chosen so that the theory given there will be in good agreement with experiment for certain measurements on specimens under a few different conditions, the theory should be expected to fail under some other conditions since it rests on some assumptions that are not wholly correct. Shrinkage is not linearly related to change in moisture content; the flow of moisture in concrete does not follow the law of diffusion; and the stress-strain relation is not linear. Since the assumptions are not wholly correct, the factors S_∞, f, k, and E that are supposed to characterize the material must be empirical, and experimentally determined numerical values of these factors will be different for different tests on the same material. The good agreement between theory and the experimentally determined contraction of the specimens discussed above must be the result of the balancing of opposing effects. They will not necessarily balance the same way in another test.

The foregoing criticism means that however promising the theory may appear from the results of a few experiments, the application of the theory must be limited and extrapolation of the results to sizes of specimens or conditions of drying other than those for which the constants were determined cannot be made with confidence. The selection of these constants for given conditions constitutes the chief difficulty for the practical use of the equations. This does not mean that the theory is of little value; we believe it to be of considerable value.

True, the theoretical equations are not rigorously correct and the constants cannot have exactly the meaning attached to them. But the evidence is that shrinkage does follow the diffusion equation approximately and that the deformations and stresses are approximately those given by the theoretical equations if the empirical constants selected are such as to give fair agreement with experimental results.

Although the experimental results shown in Fig. 15 appear to be in good agreement with the theory, a close study shows the following in regard to those prisms drying from only one side: (1) After one or two months of drying the shortening of the prisms drying from one side becomes progressively less than that indicated by the theoretical curves. (2) The experimental results from the 2x2-in. prisms deviate more from the computed values than do those of 1x1-in. cross-section. (The 1x1-in. specimens drying from one side have the same b-values as the 2x2-in. specimens from which the constants S_∞, f, and k were determined.) (3) The 3x3-in. prisms drying from one side deviate still more from the computed values than do those of 2x2-in. cross-section. It is expected that extrapolation to still larger sizes would result in still greater discrepancies between experimental and computed values unless allowance is made for change in the constants with change in b-value.

Comparison of data on warping with data on shortening

A more critical test of the theory is provided by the results shown in Fig. 16. The abscissa for these diagrams is the square root of the period of drying divided by the thickness of the prism.* As mentioned in Part 1, using square-root-of-time as the abscissa gives a nearly straight line for an appreciable portion of plots of both shortening and warping. Dividing the square root of time by the thickness of the specimen puts all specimens on a more nearly comparable basis. Multiplying the warping (deflection of center of a 32-in. span) by the thickness puts the "free warping" specimens on the same basis in regard to unit deformation.

The plotted points in the upper diagram of Fig. 16 represent the shortening of those prisms of Fig. 15 that were drying from only one side. The points in the lower diagram represent the warping of the specimens made of the same kind of concrete, also drying from only one side. Although these two sets of data were not obtained on the same specimens at the same time, they are representative of what is obtained when both sets of measurements are made simultaneously on the same specimens.

*The dimension in the direction of drying is taken as the thickness.

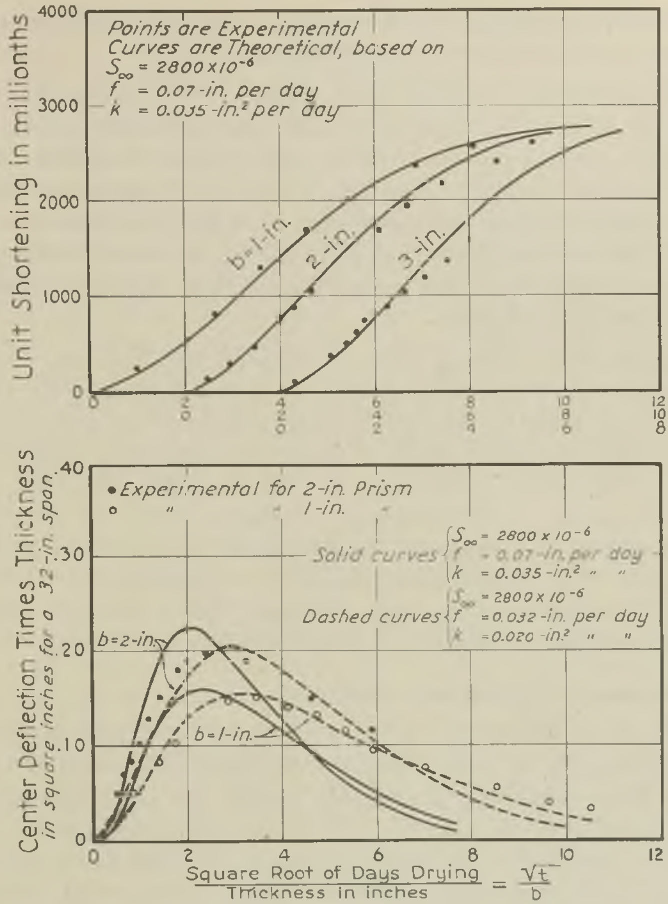


Fig. 16—Comparison of observed and calculated course in shortening and warping of prisms of mix A and cement M

The curves in the upper diagram and the solid curves in the lower diagram were constructed from the theoretical equations using the same values of the constants S_∞, f, and k as were used in constructing the curves of Fig. 15. Therefore, the three curves in the upper diagram of Fig. 16 represent the same equations as three of the curves in Fig. 15; they differ only in the abscissas. The solid curves in the lower diagram deviate considerably from the plotted points. This indicates even greater disagreement with theory than is shown in Fig. 15. However, the dashed curves obtained from the theoretical equation by using the same value of S_∞ but with f reduced by 54 per cent and k reduced by 43 per cent are in very good agreement with the experimental values.

The computed shrinkage stresses will be about the same whether the first or the reduced values of f and k are used.

The values of the constants S_∞, f, and k, used in constructing the dashed curves, were obtained from three measurements as follows: (1) maximum warping of the 1-in. specimen, (2) time at which this maximum warping occurred, and (3) final shortening of a companion specimen. The agreement throughout the course of drying between the experimental values for warping and those given by the theoretical equations when these constants are used is excellent for the 1-in. specimen and very good for the 2-in. specimen.

The above shows that if data on warping and data on shortening are analyzed separately, either group of data will appear to be in accord with the theory if the thicknesses of the specimens do not differ too much, but the values of f and k obtained from the two groups of data will be different. The fact that the factor k is an empirical rather than a fundamental property of the material is believed to be the chief reason why both groups of data cannot be represented satisfactorily by one set of constants. The empirical nature of f is considered to be of only secondary importance in this study because it has much less effect than k on the shortening-vs.-time and warping-vs.-time relations.

Effect of differences in k on warping and shortening

The effects of differences in diffusivity on the theoretical values of warping (Equation 23)* and shortening (Equation 22)* are shown in Fig. 17 where these quantities are plotted against the parameter $\sqrt{ft}/b$ for three different relative values of k. As shown, differences in k have practically no effect on the early warping; each curve follows the same course until it approaches its maximum point. The lower k, the greater the maximum warping. This effect on maximum value of warping, of course, would be anticipated because of the effect of k through the parameter fb/k ($= B$) as shown in Fig. 9.* As shown by the curves for shortening in Fig. 17, the effect of k upon shortening is entirely different from its effect on warping. The rate of shortening is materially reduced by a reduction in k, but the maximum shortening is unaffected.

This theoretical analysis of the different effects of changes in k on shortening and on warping has been useful in explaining differences in performances of concretes made with cements of different composition. For example, experimental results from concretes made with two different cements are shown in Fig. 18. Mix C was used. A comparison of Fig. 17 and 18 leads to the conclusion that the coefficient of diffusivity for concretes made with cement No. 5-1500-1.9 is lower than for con-

*See Part 1.

cretes made with cement No. 1-1500-1.9*. Concretes made with cement from clinker No. 5 shortened at a lower rate but according to data not plotted eventually shortened more than concretes from clinker No. 1.

Before this explanation was found, it seemed surprising that of two groups of specimens drying from one side only, subjected to the same exposure, one group would warp more and shorten less than the other group. In order that one specimen warp less than a second when the two specimens have the same average shrinkage, the distribution of shrinkage in the first specimen would have to be more nearly uniform. For the same surface conditions, a large value of k through the parameter fb/k, tends to make shrinkage more nearly uniform and therefore is accompanied by less warping. An increase in uniformity of shrinkage also reduces the shrinkage stresses in an unrestrained specimen and therefore reduces the tendency for spontaneous cracking. (Fig. 14 Part 1—shows how the theoretical maximum stresses depend on the parameter fb/k $(= B)$.)

Effect of alkali content on k and its possible effects on cracking

It had been observed from various laboratory tests designed to measure cracking tendencies that concretes made with cements from clinker No. 5 tended to crack more than those made with cement from clinker No. 1, even though measurements often showed less volume change at the end of a given period of drying for the concretes of clinker No. 5. This greater cracking tendency of cement from clinker No. 5 was attributed to its higher alkali content, since this appeared to be the only important difference in their chemical compositions. Attempts to evaluate k for concretes made with cements from these two clinkers showed that for the same mix proportions the value of k for concrete made with the cement of higher-alkali content was only one-half that made with the cement of lower-alkali content. These observations suggested the possibility that: alkali reduced k, a reduced k resulted in higher shrinkage stresses, and higher stresses resulted in more cracking.

To investigate this effect of differences in alkali content more fully, several tests were made using cement No. 1-1665-2.48. The procedure was to add 0.91 per cent Na_2O by weight of cement in the form of $NaOH$ to the mixing water of one of two companion mixes. The results of one test using mix B are shown in Fig. 19 where shortening and weight losses of prisms are plotted against period of drying.

The dimensions of the prisms were 2½x2½x11¼ in. They dried from all surfaces except the ends. By using for the specimens containing added alkali a time-scale equal to one-third the scale used for the regular specimens the corresponding curves for both sets of specimens approxi-

*[illegible]ed in the Appendix, the first number is the clinker number, the second is the specific surface [illegible]), and the third is the percentage of SO_3.

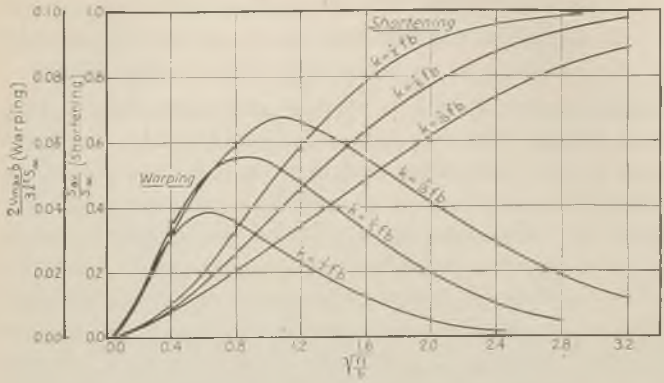
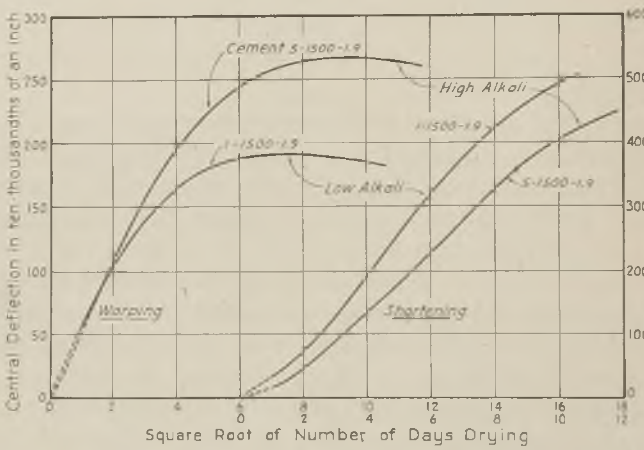


Fig. 17—Theoretical effect of k on the course of contraction and warping of prisms drying from one side only

Fig. 18—Warping and shortening of prisms that differ primarily in the alkali content of the cement used

Prisms 3-in. thick in the direction of moisture travel. Deflection measured over a 32-in. span. Mix C. Cured 7 days.



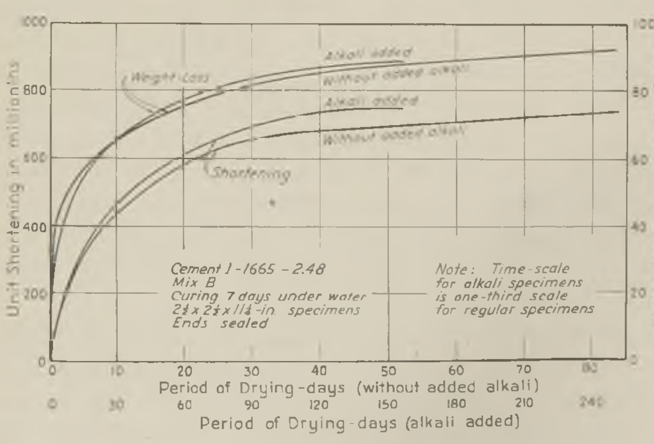


Fig. 19—Shrinkage and weight-loss for specimens with and without added alkali

mately coincided, indicating that the main effect of the added alkali was to reduce the diffusivities for both shrinkage and moisture flow to one-third the value without added alkali.

The effect of added alkali in reducing the diffusivity of shrinkage for cement of clinker No. 1 is in accord with data reported by Haegermann.[21] Haegermann was primarily interested in the effects on shrinkage of additions of various sulfates to cements of different C_3A contents. The sulfates tried were ferrous, calcium, magnesium, sodium, and potassium. The amounts added were such as to increase the SO_3, content 1 per cent, based on the cement. Five cements ranging from 15 per cent computed C_3A content to zero per cent C_3A were investigated.

The data were presented by Haegermann in the form of curves. For each cement, the curves representing the sodium and potassium sulfate additions are of noticeably different shape from the other curves for the same cement, the difference in shape being such as would result from a lower diffusivity. Since Haegermann did not give data on loss in weight during drying, it can only be inferred from the data on shrinkage that the sodium and potassium sulfates also reduced the diffusivity of moisture flow.

From theoretical consideration, it appears that any highly soluble material should reduce the relative rate of drying; i.e., should increase the time required to lose a given percentage of the total amount of moisture to be lost.* However, since many other factors affect the rate of shrinkage, and alkalies have many other effects which may indirectly affect shrinkage, one should expect many real and apparent contradictions to the above indication that an increase in alkali content will retard shrinkage.

The effect of the added alkali on cracking was investigated by means of the "wedge test"† and by the "restrained-shrinkage test" (subsequently described). The result was that specimens of higher alkali content showed a much greater tendency to crack, as measured by these tests.

Other tests made in this laboratory show that for cements containing an appreciable percentage of tricalcium aluminate, an increase in alkali content will increase final shrinkage of laboratory specimens unless the increase in alkali is accompanied by an increase in gypsum. The greater

*This reasoning is based on the supposition that at least part of the flow of water in concrete is by means of the following cycle: evaporation at an air-water interface, vapor diffusion across air space, capillary flow in liquid filled space, and again evaporation at air-water interface. Since the diffusivity of the soluble material within the liquid is finite rather than infinite, at any air-water interface at which water is evaporating, the concentration of soluble material will be higher than that for equilibrium with the adjacent liquid and thereby tend to restrict evaporation at this interface, and at any air-water interface at which water is condensing the concentration of soluble material will be lower than that for equilibrium with the adjacent liquid and thereby tend to restrict condensation at this interface. Therefore any highly soluble material should retard the drying by reducing the diffusivity of moisture flow.

†A specimen is cast in the form of a wedge and, after curing, is permitted to dry from the two non-parallel surfaces.

tendency to crack of the specimens with higher alkali content might have been due, at least in part, to a decrease in diffusivity and an increase in final shrinkage.

On the other hand, the possible benefits from alkali should not be overlooked. The lowered rate of moisture loss will permit the interior of concrete to retain sufficient moisture for additional hydration for a longer time after drying of the surface begins. Prevention of complete drying of the interior during the usual drying season should be especially advantageous in preventing cracking when restraints against shortening are present. Tests in this laboratory have also shown that concretes of higher alkali content have greater capacity for plastic flow, which is a favorable property.

Decrease in k as drying proceeds

As drying proceeds, the value of the coefficient of shrinkage diffusivity k apparently decreases. This decrease no doubt results from a progressive decrease in the apparent diffusivity of moisture, diffusivity of moisture probably being a function of the moisture content. If diffusivity of moisture is a function of moisture content, then the shrinkage diffusivity can be considered to be a function of the shrinkage S and the differential equation becomes non-linear. Adding particular solutions, as was done in Part 1, is then not permissible.

However, if in place of considering k to be a function of the dependent variable S it is considered to be a function of the independent variable t and of the dimensions of the body, then the differential equation remains linear. Furthermore, if the factor f is considered to vary with time in a like manner so that the ratio f/k remains constant (see, for example, Equation 2a), then all of the equations for displacements, stresses and strains developed in Part 1 still apply if the symbol t appearing in them is replaced by a function of t and the dimensions. The changes suggested above amount to a continual change in the time-scale so that the time required for given conditions to develop becomes progressively longer. By modifying the theory in this way better agreement with experimental results can be obtained.

Fig. 20 is an example of applying the foregoing analysis. The plotted points are from experimental data on the average warping of four 3-in. specimens of concrete of mix B with cement 1-2280-1.94. When an attempt was made to select constant values of f, k, and S_∞ to be used in the theoretical equation that would give curves in agreement with all of the experimental values, not all the data could be brought into agreement with the theoretical equation. But by taking the following values for the factors, a better fit was obtained.

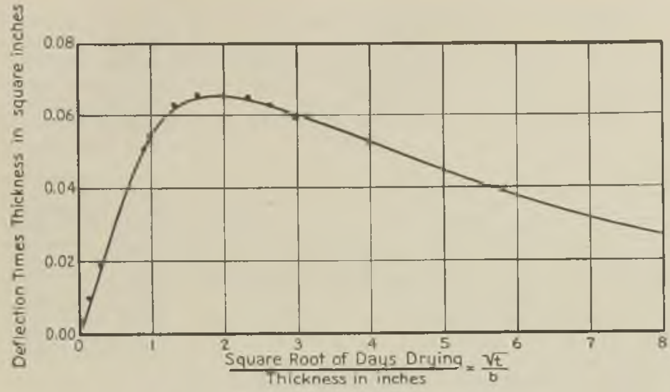


Fig. 20—Comparison of theoretical and experimental warping

Points are from the average warping of four 3-in beams. Span 32-inches. Mix B. Cement 1-2280 – 1.94. Cured 7 days.

$$k = 0.10 \sqrt{\frac{2}{2+t}} \text{ in}^2\text{/day}$$

$$f = 1.67\, k \text{ in/day, i.e., } \frac{fb}{k} = 5$$

$$S_\infty = 765 \times 10^{-6}$$

When these values are introduced into the differential equations and a solution made, the symbol T in the final equations for warping, etc., is replaced by

$$\frac{4k_o}{b^2}\left[\sqrt{\frac{2+t}{2}} - 1\right]$$

where k_o is the initial value of k or 0.10 sq. in. per day. For convenience in making computations preliminary to plotting of the theoretical curve, t was expressed in terms of T, or $t = \frac{b^2T}{k_o} + \frac{b^4T^2}{8k_o^2}$. The tabular values used for constructing the curve are given below:

From Table 4		Computed Values		
T	$\frac{2bv_{max}}{3l^2S_\infty}$	t	$\frac{\sqrt{t}}{b}$	$v_{max}b$
0.01	0.0152	1.00	0.333	0.0178
0.03	0.0326	3.61	0.635	0.0384
0.10	0.0538	19.1	1.46	0.0634
0.15	0.0557	36.4	2.01	0.0655
0.20	0.0539	58.5	2.55	0.0635
0.30	0.0470	118	3.62	0.0553
0.50	0.0336	298	5.75	0.0395
0.75	0.0219	639	8.41	0.0258

The better agreement that can be obtained by the modified theory probably would not compensate for the extra work in all cases. Since the

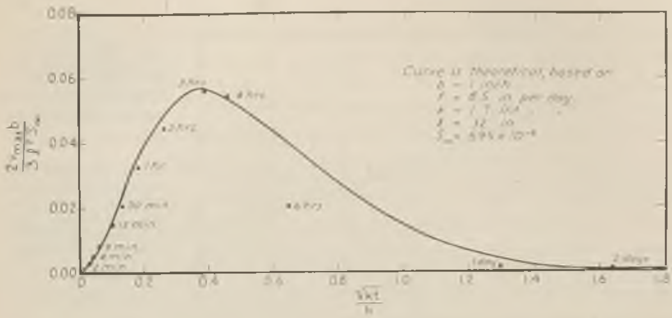
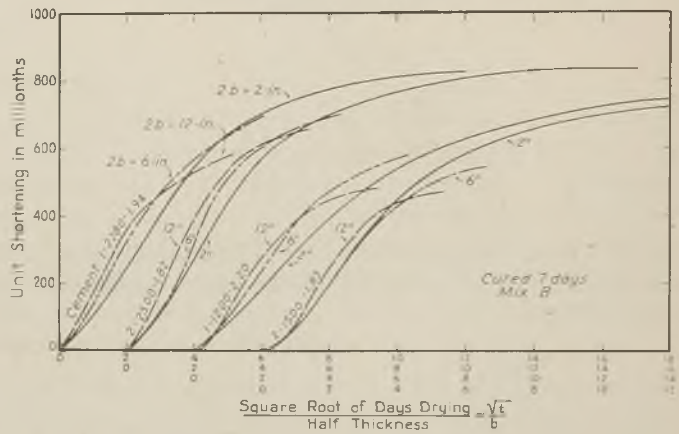


Fig. 21—Comparison of theoretical and experimental warping of beam absorbing moisture from one side

Points represent the warping of a 1-in. beam, having all but one of its surfaces sealed, during submersion in water. Cured 7 days and then dried at 50% R.H. for 10 months before testing. Mix B. Cement 1-2280-1.94. Span 32 inches.

Fig. 22—Shrinkage of slabs of different thicknesses drying from two opposite sides



forms of the resulting differential equations, rather than the reasonableness of the assumption used, were given first consideration, the value of such modification is greatly reduced.

Warping of prisms during absorption of moisture from one side

Expermental results indicate that the theoretical equations are as applicable to the swelling of concrete as they are to the shrinking. However, the factors f and k are different; they are much larger than for shrinking if the exposed surface is submerged in water. Agreement between theory and experiment that is somewhat better in most respects than that usually found in absorption tests in this investigation is shown in Fig. 21. The plotted points give experimental values and the curve gives theoretical values for a 1-in. prism of concrete, mix B with cement 1-2280-1.94. The specimen, which had all surfaces sealed except one, had previously been dried at 50 per cent relative humidity for ten months. This specimen reached a maximum warp after about three hours' absorption of water and at the end of 24 hours had returned to approximately zero warp where it remained for the rest of the test, a period of one month. The experimental value for the warp after 6 hours' exposure is considered to be in error. Other tests on 1-in. prisms did not show the indicated large decrease in warp between the fourth and sixth hours of exposure.

Although the amount of experimental data on swelling is yet small, the indications are that the application of the theory as developed in Part 1 is limited, first, because at the beginning of wetting the moisture already present will ordinarily not be uniformly distributed; second, because of having remained wet longer, the cement in the interior regions will have hydrated more than that closer to the drying surface; and third, as the concrete becomes wet again, hydration again starts. Agreement with diffusion theory is not expected while hydration is occurring at an appreciable rate, especially if the formation of hydration products causes expansion.

Effect of thickness on rate and amount of shrinkage of walls or slabs

In an investigation of the effect of wall or slab thickness on the rate and amount of shrinkage the results shown in Fig. 22 were obtained. The specimens from which the data were taken were made of mix B. Cements of two different compositions and a fine and a coarse grind of each are represented. The specimens were cured seven days under water. The specimens were 34 inches long and of either 2x6- or 2x12-in. cross section. By sealing all but two surfaces the prisms were made to represent slabs or walls of 2-, 6-, and 12-in. thicknesses drying from two opposite sides. For example, the specimens that represented a wall 12 in. thick were 2x12x34-in. and dried from only the 2x34-in. surfaces, there being 12 inches between these surfaces.

Sets of gage-points were cast in these pseudo slabs so that the shortening over three or four 30-in. parallel gage lines could be measured on each specimen. Details are shown in the Appendix. Each curve was obtained by averaging the results from four specimens of a kind.

As shown in Fig. 22, the results from these concrete specimens are in general similar to those obtained on the cement-silica mix discussed previously (see upper diagram, Fig. 16.). The curves have the characteristic S-shape found for similar plotting of data from smaller specimens. The thicker the slab the greater its fb/k $(=B)$ and, according to theory as shown by Fig. 8 (of Part I), the greater the shortening should be for a given value of the abscissa, $\sqrt{t}/b$. The experimental data are partly in agreement and partly in disagreement with the theory in this regard. In the middle, straight-line portions of the curves, the curves are in the correct positions relative to each other, but in every case the relative positions become reversed at larger values of $\sqrt{t}/b$. Also, the relative positions of the curves representing the two coarser grinds are reversed at the very beginning portion of the curves. This latter deviation from theory can be explained on the basis of a non-linear stress-flow relationship.

If the positive plastic flow* exceeds the negative, the specimen will not shorten as much as it would if plastic flow did not take place. Of course, if the total positive and negative flows are equal (algebraic average = zero), the length of the specimen is not changed by plastic flow and the algebraic average must be zero in an unrestrained specimen if the stress-flow relationship is linear. However, if the stress-flow relationship of the concrete is non-linear over the range of stresses developed, the flow increasing more rapidly than the first power of the stress, then, as explained in Ref. 20, shortening of the specimen is reduced by plastic flow. The reduction would be more pronounced for the thicker specimens (those of greater b) because, as shown by Curve B of Fig. 14 (Part I), an increase in the parameter fb/k $(=B)$ results in an increase in the maximum stresses. The above explanation (on the basis of a non-linear stress-flow relationship) as to why the relative positions of the first parts of the curves representing the two coarser grinds were reversed from what they should be according to theory is not entirely satisfactory because the question arises as to why the curves representing the finer grinds were not reversed also. This point will be mentioned again and an additional explanation given in a later section after other tests with these concretes are reported.

The reversal in relative position of the curves beyond the straight-line portion is attributed to the lesser final shortening of thicker specimens and to the reduction in diffusivity as drying proceeds. The thicker the specimen the less the final shortening because:

(1) The very low rate of drying from the interior of thick specimens is favorable for continued hydration and additional hydration reduces shrinkage tendency.

(2) In a thicker specimen the region losing moisture at an appreciable rate is under greater restraint and for a longer time than in a thinner specimen; consequently, more inelastic elongation is developed.

Plastic flow

Before discussing further the results of measurements of plastic flow, certain common usages of the term will be explained. The term usually calls to mind permanent deformations of the infinitesimal elements of a body as a result of stresses. In many cases, especially if shrinkage-stresses or thermal stresses are present, neither the actual stresses nor the deformations produced by them are known.

*The term "plastic flow" is synonymous with the term "creep" as used by many writers. It is used for either tensile (positive) or compressive (negative) inelastic deformation. See the section on "Plastic Flow" for further explanation of the term.

In the usual measurements of plastic flow the quantity measured is the inelastic deformation of a body that results from applied loads. From these measurements computations are made of the inelastic deformations of the individual elements, i.e., average unit deformation if the load is axial or unit deformation of the outer fiber if the load produces flexure. If stresses from other sources are not present, the computed values may be representative of the actual plastic flow. But if stresses from other sources are present, the computed and actual values may differ appreciably. Therefore, if in addition to load stresses a specimen is under stress as a result of non-uniform temperature or non-uniform shrinkage, it should be made clear whether the term plastic flow refers to the resultant plastic flows of elements or to only computed plastic flows produced by loads. Since the effects of load and the effects of drying are not simply additive, there is no clear basis for deciding how much of the total deformation is due to the stresses arising directly from the load. In agreement with previous writers, the deformations produced by loads will be taken as the difference between the deformations of loaded specimens and the deformations of identical specimens under the same drying conditions but not under load. Only the deformations produced by loads will be computed and represented by curves, but in the *interpretation* of results consideration will be given to what the *actual* inelastic deformations are believed to be.

As shown by the formulas for plastic flow used in this paper, the total deformation produced by load is divided into two parts, elastic and inelastic. The elastic part is considered to be that which would be recovered immediately if the load were removed; it is determined from the computed load-stresses and the "dynamic" modulus of elasticity. The remaining part is considered to be the plastic flow produced by the load.

Some investigators make a slightly different division in that the elastic deformation is considered to be that which was produced immediately upon application of the load rather than that which would be recovered immediately upon removal of the load. The two values are equal if the modulus of elasticity does not change during the test. Some writers prefer to divide the total deformation produced by load into three parts: (1) that recovered immediately upon removal of load, (2) that not immediately but eventually recovered, (3) the permanent deformation. McHenry[22] restricts the use of the term plastic flow to the third part. This division into three parts has merit, especially for those cases in which the second part is an appreciable percentage of the total. For the data given in this paper no separation of the second and third parts could be made, but the permanent deformation (3) is believed to be much greater than the temporary (2).

If the specimen is not shrinking while it is under load, then a considerable part of the inelastic deformation is probably only temporary and apparently the result of viscous flow in the adsorbed water films. After removal of the load, the elastic constituents of the gel-structure tend to restore the original shape but are retarded by the viscosity of the adsorbed water films. However, if an elemental volume* of cement paste is shrinking while under stress, the conditions are different. The loss of moisture introduces relatively large interparticle forces which tend to change the relative positions of the colloidal particles within an element. Some adjacent particles are pulled closer together but others are moved further apart. During this time of movement the directions of relative motion of the particles may be appreciably affected by stresses on the element. In this way stresses on an element during the time it is shrinking may produce comparatively large permanent deformations.

The foregoing is one explanation for the much larger amount of plastic flow that a load will produce on a drying specimen compared to what it would produce if either the specimen were prevented from drying or had previously been dried. It is also an explanation of the relatively great capacity for the concrete near the drying surface to deform plastically without cracking. If the analysis is correct, then a definite stress-flow relationship cannot be ascribed to a given element of concrete since the amount of plastic flow would depend not only upon the magnitude and duration of stress on an element but also upon the changes in moisture content that occurred while the element was under stress.

Because most of the inelastic deformation was considered to be permanent and because the increase in deformation with time was considered to be controlled chiefly by changes in distribution of shrinkage and shrinkage-stresses with relatively small lag in time after the development of shrinkage-stress, the term "plastic flow" rather than "creep" was selected for the inelastic part of the deformation.

It is important to know in what way the pastic flows of the individual elements contribute to the inelastic deformations of the body as a whole. For example, if a body is under axial load the plastic flow in tension or compression caused by the load is the difference in the *algebraic sum* of the inelastic deformation of each element and what the algebraic sum would have been if the body had not been under load. But the plastic flow of a body under flexural load depends on the *moment* of the inelastic deformation of each element with respect to the "neutral axis." Both plastic elongation on the tension side and plastic compression on the compression side of a beam under flexural load contribute to the measured plastic flow of the beam as a whole.

*In this discussion non-homogeneity of the cement paste is recognized and an element of paste is not infinitesimal but large enough to be essentially like adjacent elements.

Summary of remarks on plastic flow. The actual plastic deformation of elemental volumes of a specimen may be much different from that computed on the basis of laboratory experiments if shrinkage-stresses are present, but in this paper the plotted curves represent such computed values. Computed values are based upon the difference in the deformations of loaded and not loaded specimens. The term "plastic flow" is used in this paper to refer to either actual or computed plastic deformation. Plastic deformation is arbitrarily defined as that part of the total deformation produced by stress (either by actual stress or by load-stress as indicated by the text) that would not be immediately recovered upon removal of the stress.

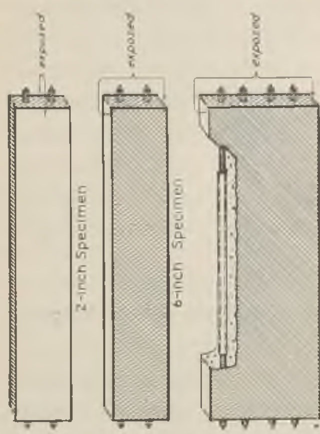
Effect of thickness on stresses and plastic flow when the slab is partially restrained against shortening

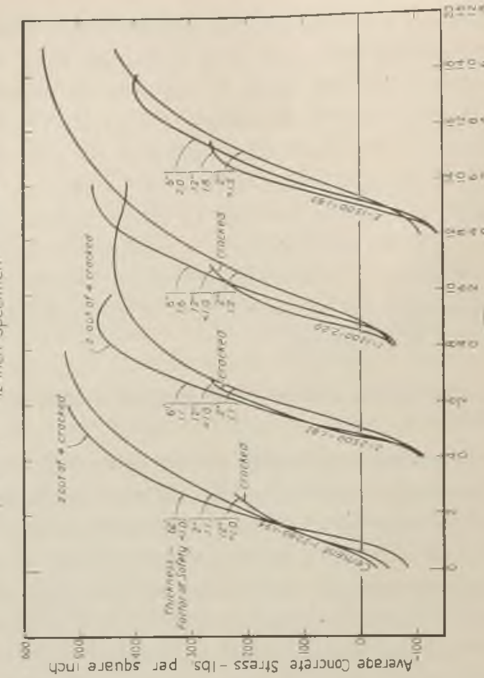
Companion specimens of the same size and sealed in the same manner as those represented in Fig. 22 were partially restrained against shrinkage by specially designed steel bars, somewhat as were those described by Carlson.[23] The main features of the steel bars are shown in Fig. 23. (The concrete specimen illustrated in Fig. 23, however, is from another test in which the concrete was allowed to dry from all sides and only one bar was used per specimen). Each specimen of 2x6-in. cross section contained two ⅝-in. diameter bars, and each specimen of 2x12-in. cross section contained four ⅝-in. diameter bars. The arrangement of bars is shown in the Appendix, and in Fig. 24.

A rubber tube covered the central 20 inches of each bar so as to prevent bond over a 20-in. gage length, thereby insuring the same axial force in the bar over all sections of the gage length. That part of each steel bar not covered with rubber was threaded and thus the bars were anchored to the concrete for a distance of 7 in. on each side of the gage length. Because of this anchorage the shortening of the steel bar over the gage length is equal to the shortening of the concrete over the same gage length. Moreover, as is obvious from considerations of equilibrium, the force in the concrete in this gage length is equal and opposite to the force in the steel in the same gage length. Therefore, the average unit stress in the concrete can be computed from the change in length, modulus of elasticity, and percentage of steel. The formula is

$$\sigma_c = \frac{A_s E_s}{A_c} \quad \frac{\Delta l}{l}$$

where σ_c is average stress in the concrete
A_s is cross-sectional area of the steel
A_c is cross-sectional area of the concrete
E_s is Young's modulus for the steel





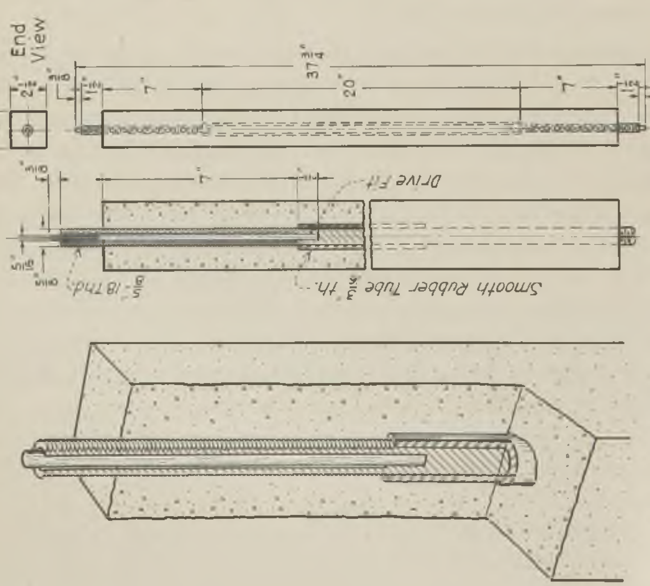


Fig. 23 (above)—Details of cracking—test specimen

Fig. 24 (right)—Average stress in partially restrained specimens (each curve the average of four)

Δl is net change in length over gage length after corrections have been made for any change in temperature.* Δl is negative if the specimen has shortened.

l is gage length.

Not only the average stress caused by the restraint but also plastic flow caused by this stress can be computed if the modulus of elasticity of the concrete is known and the assumption is made that the shrinkage tendencies of the restrained specimens are the same as those for companion unrestrained specimens of the same size. The formula is

$$c = S_{av} - \frac{\sigma_c}{E_c} + \frac{\Delta l}{l}$$

where c is unit plastic flow caused by restraint,

S_{av} is the unit shortening of the free-shrinkage specimens, and

E_c is Young's modulus for the concrete.

Performance of partially restrained specimens. As explained in the Appendix all specimens were cured under water. The specimens tended to expand during this storage and consequently the concrete in those partially restrained with restraining bars was compressed. Therefore, for a short time after drying began, the direction of the plastic flow produced by the restraining bars was in a negative direction. Shortly after drying began, the stresses in the restraining bars changed from tensile to compressive, and the average stress in the concrete changed from compressive to tensile.

Under the conditions of this test the average stress reaches a maximum and then slowly decreases if failure by spontaneous cracking does not occur. A specimen's average stress and its shortening necessarily reach their maximums simultaneously if the temperature remains constant. Therefore, the time of maximum average stress is the time when the rate of average shrinkage equals the rate of plastic deformation. During the decrease of average stress, the rate of plastic deformation exceeds the rate of shrinking.

Ordinarily in this test the specimens are not permitted to reach a final equilibrium state in regard to shrinkage, shrinkage-stress, and plastic flow. But just after the maximum restraining force has been developed additional tensile load sufficient to cause failure of the specimen is applied. This load is applied to the protruding threaded ends of the restraining bars by a machine designed for the purpose. While the load is being applied, measurements are taken so that the added stress in the concrete can be determined. Further details are given in Fig. 33 of the Appendix.

*All tests were conducted in a room maintained at 76 ± 1°F and a relative humidity of 50 ± 2%, except for occasional deviations from these limits.

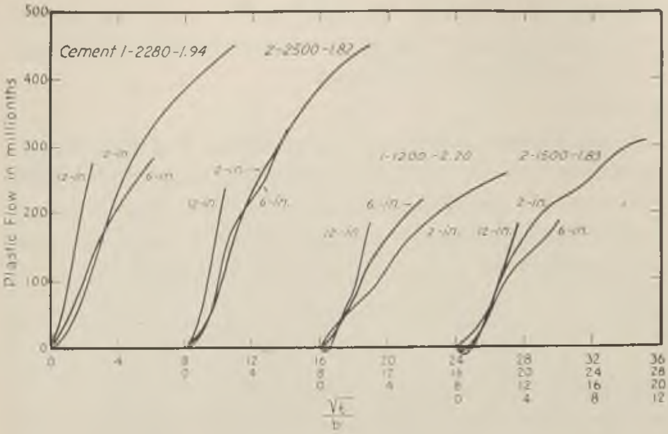


Fig. 25—Plastic flow in the partially restrained specimens of Fig. 24

Factor of safety. The purpose of the testing just described is to learn how close the specimen comes to cracking spontaneously. The ratio of the computed stress at failure to the maximum average shrinkage-stress is called a factor of safety. Specimens that crack spontaneously are reported as having a factor of safety less than unity. Results showing computed average shrinkage-stresses and plastic deformation are shown in Fig. 24 and 25, respectively. The record of the number of specimens of each cement that cracked spontaneously and of the average factors of safety (f.s.) of those that did not crack is also shown in Fig. 24.

Effect of thickness on plastic flow. Attention is called to the similarity of the three sets of curves in Fig. 22, 24, and 25. The similarity is not to be interpreted as necessarily indicating that the plastic deformation of an element is proportional to its stress. One is tempted to make this interpretation because, if it were true, then the plastic flow of a specimen would depend only on average stress and not on the distribution of stress. In general, the diagrams show that the 12-in. specimens developed considerably more plastic flow for the same amount of average stress than either the 2- or the 6-in. specimens.

There are several possible reasons for this: first, because of the lower rate of shortening, the larger specimens will have been under a given range of stress longer than the smaller specimens and therefore would be expected to have more plastic flow for the same stress. Since the time required for the same amount of shortening is approximately proportional to the square of the thickness, the 12-in. specimens will in general have been under a given range of stress about four times as long as the 6-in. specimens. Second, since the thicker specimens will have higher maximum stresses, the additional plastic flow could be accounted for by a non-linear stress-flow relationship whether or not this relationship for each element was modified while the element was losing moisture rapidly. Third, the assumption that shrinkage tendencies of the restrained-shrinkage and free-shrinkage specimens are equal is not entirely correct and consequently their computed plastic flow are in error. A difference in the shrinkage tendencies of the 12-in. free and restrained specimens might result since the arrangement of the four bars was such as partially to obstruct the flow of moisture.

Probably all factors listed above contributed to the results. Of the factors causing the computed plastic flow to be greater in the 12-in. specimens, the author is of the opinion that the non-linear stress-flow relation contributed much more than the difference in duration of given stresses.* That the maximum stresses in the larger specimens are higher is shown by the fact that all the 12-in. restrained specimens of three of the four cements cracked (see Fig. 24) whereas only a few of the 6-in. specimens and none of the 2-in. specimens cracked.

According to most of these arguments the 2-in. specimens should have less plastic flow than the 6-in. specimens, whereas in general they have slightly more for the same shortening and for the same average stress. A complete explanation for this is not at hand, but the lesser extent of hydration of the cement in the 2-in. specimens because of their more rapid drying may be a factor. Also, the exposed surfaces of the 2-in. specimens were the top and bottom surfaces as cast, whereas the drying surfaces for all the other specimens were the sides as cast. Bleeding and settlement of the plastic mix before initial hardening is complete always makes the concrete near the top and that near the bottom as cast different from that at the sides. It must also be remembered that the computed plastic deformation may be more or less than the real plastic deformation of the material.

Use of beams drying from only one side for determining probable stresses in slabs or walls drying from two opposite sides

To obtain information on plastic flow and on the magnitude and distribution of stresses in unrestrained walls or slabs drying from two opposite sides another set of specimens, also companion to those represented in Fig. 22, were made. These specimens differed from those of Fig. 22 in that they were permitted to dry from only one side instead of two opposite sides and in that the thicknesses of corresponding specimens were just half those of Fig. 22. Since they were half as thick and dried from only one side instead of two sides (see Appendix), any one of these specimens was considered to have the same conditions of drying and consequently the same distribution of shrinkage tendency as either half of a corresponding specimen represented in Fig. 22.

*Most contemporary writers on the inelastic properties of concrete apparently would take the opposite view. This difference in viewpoint is explained and an argument for the author's view is given in Ref. 20.

If the distribution of shrinkage tendency is the same and if the correct external forces are applied so as to make all the deformations the same as those of either half of the corresponding specimen, then the distribution of stresses will also be the same.

Eight specimens of a kind were made, four of which were allowed to warp freely and four were restrained against warping. It was not feasible to distribute the external restraining forces on the specimens to be restrained against warping in exactly the manner that the mutual forces between the two halves of the corresponding specimens were distributed. As shown in the Appendix, the method adopted was to support the specimen as a simple beam and to apply enough force at the quarter-points to prevent warping of the central half.

As discussed previously and as shown by Equation 19*, the amount of warping of a specimen free to warp is indicative of the non-uniformity of shrinkage tendency. From similar considerations it follows that the amount of moment necessary to prevent warping is indicative of the non-uniformity of stresses resulting from the non-uniformity of shrinkage tendency. Furthermore, the difference between the actual moment required to prevent warping and that computed from the amount of free warping, assuming no plastic flow, gives an indication of the distribution of plastic flow. The results for one of the four cements are shown in Fig. 26. The lower curves give the actual moment developed, M, divided by the section modulus, I/c, for beams of three different thicknesses. The upper curves show what the Mc/I would have been if the restraining moment had not produced plastic flow. The upper curves are obtained from the measured values of the warping tendency and Young's modulus of companion specimens. Young's modulus was determined from resonant frequency of vibration.

Stresses based on flexure formula. Since the ordinates in Fig. 26 are in terms of Mc/I, they represent the stress in the outer fiber according to the elementary flexure formula. According to the lower curves of Fig. 26 the computed stresses for the 1-in. specimens reached a maximum of 410 lb. per sq. in. by the end of the first day of drying. The computed maximum stress in the 3-in. specimen was 490 lb. per sq. in. and was reached in 14 days. The computed stress in the 6-in. specimens had reached 500 lb/in^2 after 36 days and the indications are that, had the test been continued, the computed stress would have reached a maximum of about 550 lb per sq. in. after about 100 days of drying. These computed stresses in the outer fiber, based as they are on the flexure formulas, are of course not the actual stresses. The actual stresses in the drying surface will build up very rapidly (see curve y/b = 1.0 in Fig. 12*) and

*See Part 1.

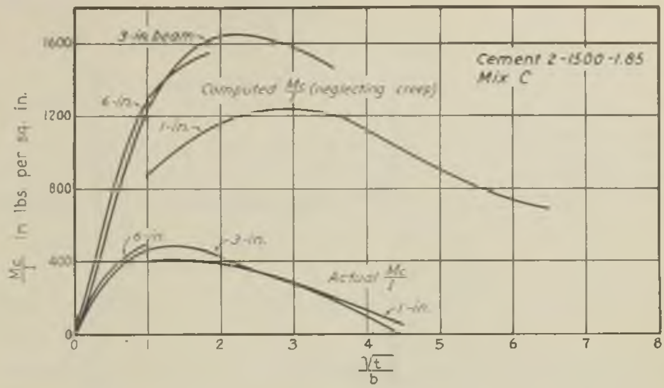


Fig. 26—Comparison of actual moment necessary to keep beams from warping with the conputed moment necessary to straighten companion beams that are free to warp. (Plotted in terms of $\frac{Mc}{I}$)

will build up as rapidly in the thicker slabs as in the thinner. The actual stresses are probably better represented by the solid curves of Fig. 27.

Stresses based on modified theory. The solid curves of Fig. 27 show stresses based upon a modified theory. These curves were obtained by substituting appropriate values of the parameters y/b, kt/b^2, fb/k, E, and S_∞ into Equation 20 of Part 1. For the construction of these curves the theory as presented in Part 1 was modified in that, instead of using constant values for the factors k, f, S_∞, and E, the following procedure was pursued:

(1) The ultimate shrinkage S_∞ was set equal to 750, 700, and 600 millionths, respectively, for the 1-, 3-, and 6-in. thick specimens. The selection of these separate values rather than one value for all specimens was governed by the apparent ultimate unit shortenings of the corresponding free-shrinkage specimens (Fig. 22).

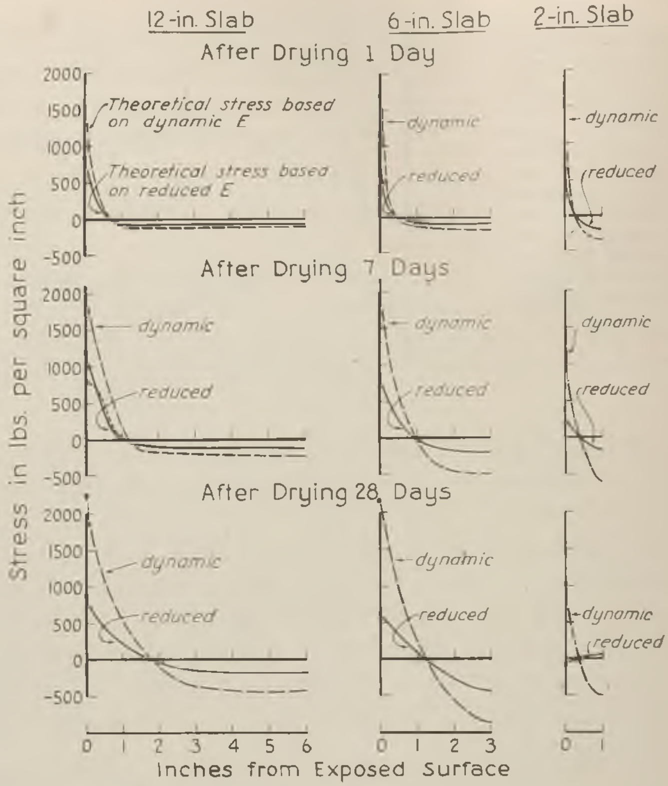
(2) The ratio f/k was set equal to 2.5 in.$^{-1}$, i.e., fb/k was 2.5 for 1-in., 7.5 for 3-in. and 15.0 for 6-in. specimens. When this value of f/k and the above values of S_∞ were used, the theoretical maximum values of warping as given by curve A of Fig. 14* were found to be in agreement with the experimental values of maximum warping for each of the three thicknesses of specimens.

(3) A value of kt/b^2 was selected for each period of drying (1, 7, and 28 days) and for each thickness of specimen, such that when substituted along with the above values of S_∞ and f/k in Equation 23* for warping the result would be in agreement with the experimentally determined values for these periods and these thicknesses.

(4) A value of E was selected for each period of drying and each thickness of specimen such that the theoretical moment given by Equation 27 would be in agreement with the experimentally determined values.

*See Part 1.

Fig. 27—Theoretical distribution of shrinkage stresses (modified theory) in slabs drying from two opposite surfaces for various drying periods and slab thicknesses



(5) The above values of S_∞, kt/b^2, fb/k, and E together with appropriate values of y/b, were substituted into Equation 20* and computations made for stresses. The solid curves were plotted from these computed stresses.

The dashed curves show the stresses that are obtained when the foregoing procedure of computing stresses is used except that the dynamic modulus of elasticity is used for E. The difference in the curves is a measure of the relief of stress by plastic flow and thus is a measure of the amount of plastic deformation that has occurred.

Although it is believed that for the most part the magnitude and distribution of stresses after the various periods of drying and for the various thicknesses of specimens are about as given by the solid curves of Fig. 27, the curves are probably in error in certain respects. The principal source of error lies in the assumption that the effects of plastic flow can be taken into account by using a reduced modulus of elasticity as is done when Equation 20 is used. Inelastic deformation is cumulative and depends on the past stress-history, not necessarily on the

*See Part 1.

stress at the moment. Furthermore, as explained in the section on plastic flow, the rate of flow for an element will depend on the rate at which the element is tending to shrink and may not be proportional to the stress on the element. Therefore, near the drying surface, where the stress has been relatively high from the beginning of drying, the plastic flow will be greater and the stress will be less than that indicated. Slightly farther inward where the stress has only recently changed from compression to tension the resultant plastic deformation will be less and the stress more than that indicated. The dotted curve in the one diagram of Fig. 27 represents an attempt to show a better estimate of the actual stress.

Reversal of stress by plastic flow. Fig. 26 indicates that eventually the stress in the outer fiber will become negative, i.e., compressive. In all restrained-warping tests that were continued until equilibrium of moisture content was nearly reached, the moment required to prevent warping decreased to zero and would have then become negative if restraint against negative warping had been provided. This means that when a wall dries from two opposite sides or a prism dries from all four sides, eventually the outer shell will be in compression and the inner core will be in tension.

Of interest in this connection is the fact that specimens of neat cement bars have been known to break spontaneously and audibly while resting in place in a storage rack. The explanation is that during the early part of drying large tensile stresses developed in the outer shell. As a result the outer shell was first permanently elongated and then caused to fail in tension, i.e., to crack. As drying proceeded inward, the inner core, which had not yet been stretched, tended to become shorter than the outer shell. The cracks closed, compression developed in the outer shell, and tension developed in the inner core. In some cases this tension was sufficient to cause failure of the core. A specimen would break spontaneously when failure of the inner core occurred at a section where the outer shell was already cracked.

Investigation of properties of concrete by means of slabs or prisms drying from one side only

As the foregoing has indicated, results from prisms drying from only one side have been very valuable for ascertaining in what ways the theory of diffusion is applicable to shrinkage of concrete. They are also valuable for investigating certain properties of concrete, especially if used in connection with the diffusion theory. The chief advantage of drying a prism from only one side is that it tends to warp as well as shorten as it dries and thereby makes possible measurements not obtainable on prisms drying from all surfaces.

As explained previously, the results from prisms drying from only one side indicated a cause for concretes of higher alkali content to show a greater tendency to crack under some conditions. Additional results in regard to fineness of grinding and percentage of gypsum will now be reported for the information they give to illustrate how such prisms may be used to investigate properties of concrete.

Effect of finer grinding on plastic flow. As explained previously, in addition to the one cement represented in Fig. 26 and 27, three other cements were tested at the same time and in the same manner. The results for the other cements were similar in most respects to those shown in Fig. 26 and 27 for the one cement. There were some differences, however. More plastic flow occurred in the specimens made with the two finer-ground cements. The differences in plastic flow with fineness of grinding in this test were similar to and in agreement with the differences shown for these cements in the restrained-shrinkage test (Fig. 25).

The effect of finer grinding on strength is similar to that produced by longer curing and therefore since longer curing decreases plastic flow we might expect that finer grinding would also decrease plastic flow. However, several cements tested in this way all showed that finer grinding increased plastic flow for both restrained-shrinkage and restrained-warping specimens. Other tests in this laboratory indicate that this effect of finer grinding on plastic flow is indirect. A given quantity of gypsum added at the time of grinding is less effective in retarding the early chemical reactions the finer the cement.[24] Lack of proper retardation of the early reactions because of insufficient gypsum results in a concrete of greater shrinkage tendency and greater capacity for plastic flow. Therefore, according to the indications, finer grinding, if unaccompanied by increase in percentage of gypsum, indirectly produces a concrete of greater tendency to deform inelastically.

This still leaves unanswered the question introduced in the discussion of Fig. 22 as to why the effects of plastic flow did not also reverse the relative positions of the curves for the finer-ground cements. Possibly at the very beginning of drying the coarser-ground cements, because of their relatively low strength, flow more readily but become less plastic than the finer-ground cements at the later ages when the strengths are more nearly equalized. However, since only slight differences in the way the different concretes deviate from the theory could account for the results and since concrete deviates from the theory in many different ways there are other possible answers to the question.

One possible answer is suggested in Fig. 24, according to which coarser grinding resulted in greater negative stresses at the end of the curing period. These negative stresses were produced by the tendency of the concrete to expand during curing, especially the tendency to expand after some resistance to plastic flow had developed. Any tendency for the interior of the free-shrinkage specimens to continue expansion after the surface begins to dry would reduce the rate of shortening at the beginning of the drying period. If, as seems quite probable, this tendency is greatest for the thicker specimens with the coarser-ground cements, then these specimens would shorten relatively less at the beginning of drying than would be indicated by theory.

Effect of added gypsum. The effect of the gypsum in the cement on the properties of the hardened concrete was observed in an investigation in which 21 cements were made from the five clinker compositions listed in the Appendix. By blending various grinds of these clinkers, cements of different finenesses and different gypsum contents were obtained from each clinker. Concretes (Mix C) made from these 21 cements were tested in the manner indicated previously for prisms drying from only one side. However, in this investigation only the 3-in. size of specimen was used.

Where the C_3A content of the clinker was moderate or relatively high, an increase in SO_3, content decreased shrinkage and warping and also decreased plastic flow. Where the C_3A content was low, an increase in SO_3 had relatively little effect. According to other data obtained in this laboratory, a still further increase in SO_3 would have increased the shrinkage.[24] Representative results for a cement of high C_3A content are shown in Fig. 28, 29, and 30. As shown by Fig. 28, the maximum warp of those specimens free to warp was reduced appreciably by increase in per cent of SO_3. The reduction in shortening with increase in SO_3 agrees with that reported previously by other investigators[21, 24, 25].

Fig. 29 shows that the restraint developed by the specimens restrained against warping was in general less with the higher percentages of SO_3. However, increasing the SO_3 from 1.5 to 2.4 per cent had only a very small effect on the amount of restraint developed in the restrained specimens compared to the effect on the warping of unrestrained specimens. The explanation is that although the increase in SO_3 reduced warping it also reduced the tendency to yield under stress. The net result is some reduction in stress but not as much as would be anticipated from the results of the free-warping specimens.

Fig. 30 shows the effect of SO_3 on the factor of safety against cracking as determined by this test of a cement of high C_3A.

SUMMARY AND CONCLUSIONS

The theory that shrinkage of concrete follows the laws of diffusion similar to those followed by the flow of heat is tested by means of specially

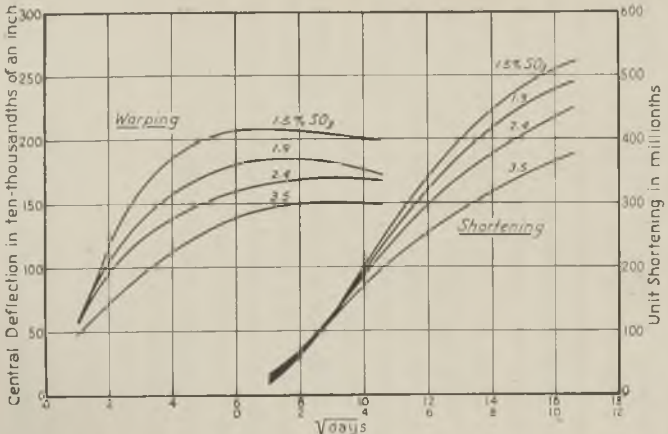
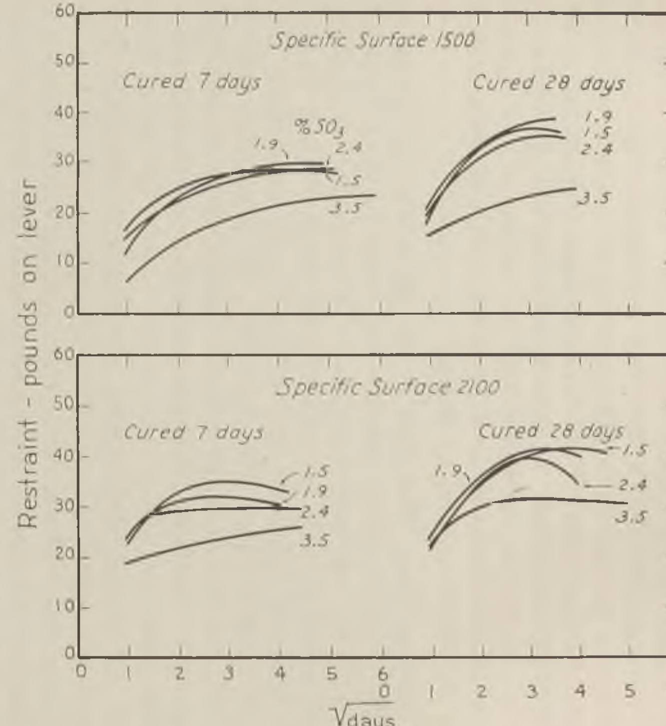


Fig. 28—Effect of gypsum an warping and shortening for a cement of high C_3A content

Cement from Clinker No. 1. Specific Surface 2100. Specimens 2 x 3 x 34-in. Cured 7 days. Sealed on all but one 2 x 34-in. surface. Central deflection over a 32-in. span.

Fig. 29 (right)—Effect of gypsum, period of curing, and fineness of grinding on restraint necessary to prevent warping

Cement from Clinker No. 1. Mix C. 3-in. beams $\frac{Mc}{I} = \frac{32}{3}(W + 4)$ where W is pounds on lever.



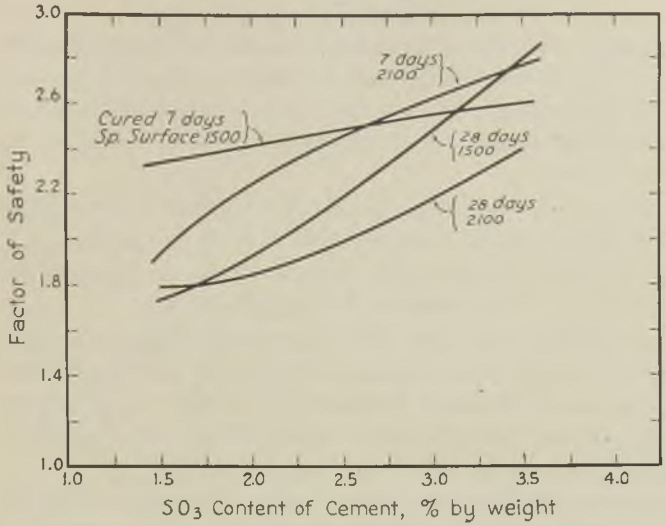


Fig. 30—Effect of gypsum, period of curing, and fineness of grinding on factor of safety against cracking

Specimens same as those represented in Fig. 29.

designed experiments. According to the theory that was developed in Part 1, the shrinking and development of stress in a given concrete under given conditions of drying is considered to be characterized by certain constants. These constants are diffusivity of shrinkage, surface factor, ultimate shrinkage, and Young's modulus of elasticity. Equations were derived in Part 1 giving shortening and warping of prisms versus period of drying in terms of these constants and the dimensions of the prisms.

In Part 2 it is shown that these constants can be selected so that the shortening of a prism as computed by the theoretical equations is in good agreement with experimental values of shortening. Furthermore, it is shown that by using the same constants the shortening versus period of drying of other prisms differing in size and number of sides exposed to drying can be predicted with fair accuracy if the difference in size is not too great. However, it is shown that the theory must be modified to take into account inelastic deformation and to permit the supposed constants to vary with moisture content and size of specimen if the theory is to be in agreement with all results on all types of specimens of a given concrete.

The theory is used to explain various things about concrete; in fact, paradoxically, it is used to explain some of the ways in which concrete does not perform as predicted by the theory. The tendency of large specimens to crack more and shrink less than smaller specimens and the effect of alkali content of the cement in increasing the tendency to warp while reducing the rate of shrinkage are explained on the basis of the theory. It is shown that when a saturated specimen is dried at 50 per cent relative humidity the stress developed would be much greater than the strength of the concrete if it were not for the effects of plastic flow. It is further shown that when a specimen is restrained against deforming the restraining forces are much less than they would be if plastic flow did not occur.

An example is given of the use of the theoretical equation in determining the distribution of stresses at various times during the drying of a specimen. In this example, consideration is given to plastic flow and to the decrease in diffusivity of shrinkage as the specimen dries.

The restrained-shrinkage test and the restrained-warping test are used to determine a factor of safety against cracking for concrete under conditions of drying and of restraint comparable to those under which the tests are made. These tests, together with tests on free-shrinkage and free-warping specimens, are used to measure plastic flow.

The various tests described in Part 2 and in the Appendix to Part 2 when used in conjunction with the theory given in Part 1 provide a means for studying some of the more fundamental properties of concrete and for predicting the performance of concrete under some conditions in the field.

ACKNOWLEDGMENTS

This paper developed during a study of the causes and the control of cracking of concrete. The author is indebted to many present and past workers in this field. E. A. Ripperger, now Lt. (j.g.) U.S.N. with the Pacific fleet, was responsible for a large part of the experimental work reported herein. He designed (or adapted from earlier designs) most of the special equipment used and was engaged in certain phases of the study previous to the author's participation. All of the work was done under the supervision of F. R. McMillan, Director of Research, and T. C. Powers, in charge of Basic Research.

The author is particularly indebted to Mr. Powers for assistance in preparing the manuscripts. His suggestions in regard to presentation of material and the wording of various paragraphs have been invaluable.

The author also wishes to thank Miss Adele Scott for preparing the diagrams and Miss Virginia Atherton for proofreading the manuscript.

APPENDIX TO PART 2

Mix proportions

Materials	Parts by Weight		
	Mix A	Mix B	Mix C
Water, net	0.5	0.355 to 0.388	0.487
Water added for absorption	...	0.048	0.083
Total water	0.5	0.403 to 0.436	0.570
Cement	1.0	1.0	1.0
Pulverized silica	0.6	....	....
Elgin sand	...	1.28	2.43
Elgin gravel (¾" max. size)	...	1.82	2.97

Consistency

Consistency of Mix B with different cements was maintained fairly constant at from 5 to 6 in. of slump with a 12-in. cone by varying the amount of mixing water. The consistencies of Mixes A and C were allowed to vary with the different cements. Mix C usually gave a slump of from 2 to 4 inches, but with some cements the slump was as little as 1.5 inches and with others as much as 6 inches.

Materials

Cements: One cement designated M was a mixture of four brands of Type I cement, purchased in Chicago. Its specific surface by the Wagner method was 1665 sq. cm. per g. The other cements were prepared from five different commercial clinkers. From each of these clinkers cements of three different finenesses, coarse, medium, and fine, were prepared by grinding at the plant. In addition, two cements, one of low and one of high gypsum content, were prepared from each clinker by grinding in a small laboratory ball mill. The purpose in preparing these five different cements from each clinker was to make it possible to obtain any desired fineness and gypsum content by blending different grinds of the same clinker. In referring to these cements in the text the first number in the designation is the clinker number, the second is the Wagner specific surface, and the third is the per cent SO_3 content by weight.

The chemical compositions of the five clinkers and of cement M are shown below.

Oxides	Cement Clinker No.					Cement M
	1	2	3	4	5	
	Chemical Analysis, per cent by wt. (corr. for minor components)					
SiO_2	21.54	20.67	23.05	27.82	22.56	21.25
Al_2O_3	6.52	5.48	4.14	1.93	5.00	5.98
Fe_2O_3	1.56	2.50	4.35	1.87	2.48	2.69
Combined CaO	64.32	65.00	64.28	65.38	64.06	62.56
MgO	2.17	1.31	1.36	1.75	3.35	3.04
SO_3	0.41	0.19	0.03	0.17	0.20	1.75
Loss on Ign.	0.15	0.85	1.05	0.26	0.37	1.13
Free CaO	0.98	2.71	0.73	0.23	nil	0.79
Na_2O	0.17	0.30	0.05	0.05	1.13	0.28
K_2O	0.16	0.40	0.17	0.22	0.44	0.63
Compounds	Computed Compound Composition per cent by wt.					
C_3S	50.73	66.57	52.37	38.58	51.61	44.15
C_2S	23.49	9.05	26.58	50.66	25.75	27.62
C_3A	14.72	10.29	3.61	1.95	9.06	11.30
C_4AF	4.75	7.61	13.24	5.69	7.55	8.19

Aggregate: Sand and gravel were from Elgin, Illinois. The gravel was screened to pass a ⅜-in. sieve and be retained on a No. 4 sieve.

The sand was graded as follows:

Sieve No.	Per Cent Passing
100	5
48	15
28	43
14	67
8	82
4	100

Pulverized Silica: The silica was from the same source as standard Ottawa sand, but ground to cement fineness. Its specific surface by the air-permeability method was 3200 sq. cm. per g.

Procedure

With some exceptions the procedure in preparing and testing the specimens was as follows:

Preparing the specimens: The materials were mixed in a power-driven open-tub mixer. The fractions of the various-sized aggregates and grinds of cement were weighed and placed in the tub. The mixing schedule was: mix ½ minute dry, 2 minutes wet, rest 3 minutes, mix 2 minutes. (Special tests showed that the grinds of cement were adequately blended in ½ minute of dry mixing in the presence of sand.)

The freshly mixed concrete was placed in steel molds and consolidated by light vibration by placing molds on a platform-type vibrator. Covers were fastened on the molds but not made water-tight. Each mold was equipped with restraining bars, gage inserts, etc., the details of assembly depending upon the tests to be made.

The molds and contents were stored under water at 74 F for one day. The molds were then stripped and the specimens returned to water at 76 $\pm$ 1 F in a covered tank where they were left for one hour. The specimens were then removed one at a time, dried with a cloth, and all initial measurements of length, deflection, and weight were made. All dimension measurements were made within 30 seconds after removal from water, and weighings were made as soon thereafter as practical. The specimens were then returned to the 76 F curing tank.

One day before the end of the curing period the specimens were removed for sealing of certain surfaces against the loss of moisture. The surfaces to be sealed were wiped with a cloth and then allowed to air-dry until the surface *just* changed color. During this time, scheduled measurements were usually made. After the color change and before any appreciable loss of moisture by evaporation, one coat of black, quick-drying brushing lacquer was applied. After the lacquer had dried a few minutes, the excess was removed with a cloth and one coat of hot paraffin was applied to the lacquered surface. While a second coat of paraffin was being applied, one thickness of newspaper of appropriate shape was pressed into the still soft paraffin somewhat in the manner in which a paper hanger applies wallpaper. Next, a final heavy coat of paraffin was applied. The layer of paper helped to eliminate pin holes. (When only the ends of prisms were sealed, the paper and final coat were omitted.)

After the specified surfaces were sealed, the unsealed surfaces and exposed steel parts were cleaned, vaseline was applied to the steel parts, and the specimen was returned to the curing tank for an additional day of curing. At the end of the curing period the specimens were transferred from the curing tank to a room maintained at 76 $\pm$ 1 F and

50 ± 2 per cent relative humidity. At this time the vaseline was removed from the steel parts and measurements for the beginning of the drying period taken.

Testing the specimens: The testing was considered to have begun in most of the tests with the beginning of the drying period. The specimens may be divided into classes, according to the tests made, as follows:

Free shrinkage specimens were measured for length changes, weight losses and resonant frequency of vibration. Reference plugs were cast in the ends of the specimens for the length-change readings. They were hex-head cap screws arranged to give the desired gauge length. Ordinarily these were single plugs centrally located in the ends. But for those prisms that represented slabs drying from two opposite sides the arrangement was as shown in Fig. 31.

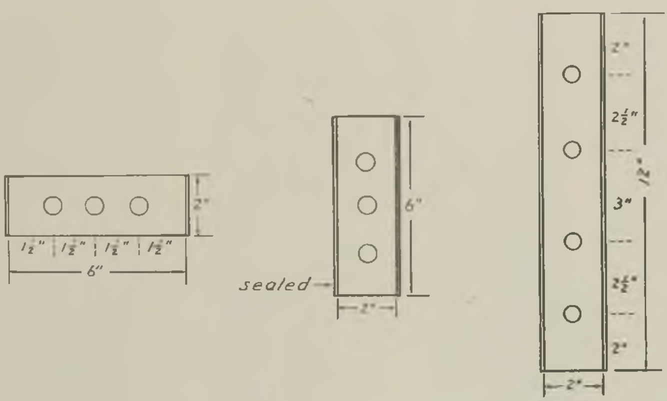


Fig. 31—End views showing arrangement of gage plugs in specimens representing 2-in., 6-in. and 12-in. slabs

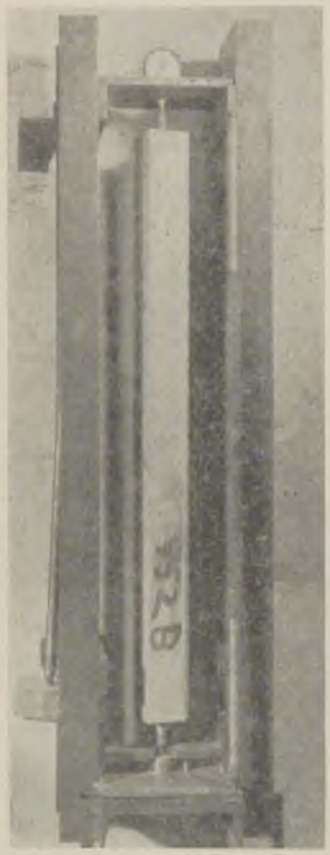
The gage plugs for these specimens were ⅜ in. bolts 4 in. long.

Restrained shrinkage specimens were partially restrained against shrinkage by steel restraining bars. The arrangement of the bars in those specimens that represented slabs drying from two opposite sides was the same as that shown in Fig. 31 for gage plugs except that only two bars 3 inches apart were cast in the 2x6-in. specimens. Square specimens that are permitted to dry from all four sides and that are partially restrained by one centrally located bar are used in routine testing of resistance to cracking. Further details in regard to restraining bars and the measurements for change in length of the restraining bar are shown in Fig. 32 and 33 as well as in Fig. 23 body of the text.

If the restrained-shrinkage specimen did not crack spontaneously before the maximum restraining force had been developed, additional increments of load were applied as shown in Fig. 33 until failure was produced.

Free warping specimens were measured for deflection over a 32-in. span. Most of these specimens were also measured for length change, weight loss and resonant frequency. Some of the free warping specimens made in the early part of the work were not equipped for length-change measurements. Cross sections of free warping specimens are shown in Fig. 34. See Fig. 35.

Restrained warping specimens companion to the free warping specimens were loaded, as shown by Fig. 36, so as to prevent warping between the loaded quarter-points. Readings of the load required were taken periodically and, after the maximum restraint had developed, the load necessary to produce failure was determined.



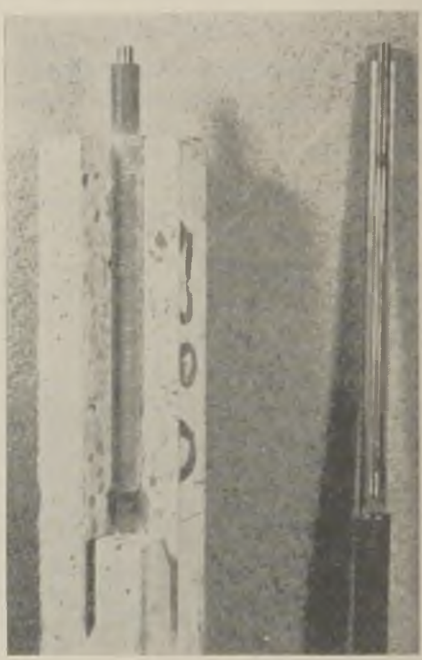


Fig. 32a (left)—Comparator
Fig. 32b (above)—Restraining Bar

Measurements of shrinkage-stress are made whether cracking occurs or not. The comparator (in Fig. 32a) is used to measure the changes in length of the steel restraining bar that result from the strains placed on it by the concrete. From these measurements and the known properties of steel, the average stress in the concrete is computed.

Important details of the restrained-shrinkage type of specimens are shown in Fig. 32b (See also Fig. 23 in the text.) Note that the concrete can grip the bar only in the end-region; contact in the 20-in. central section is prevented by a thick layer of rubber.

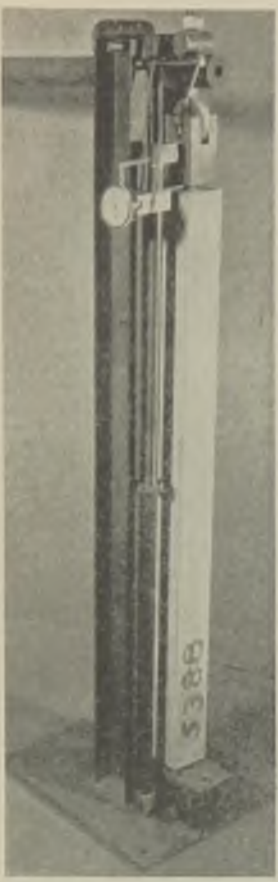


Fig. 33a

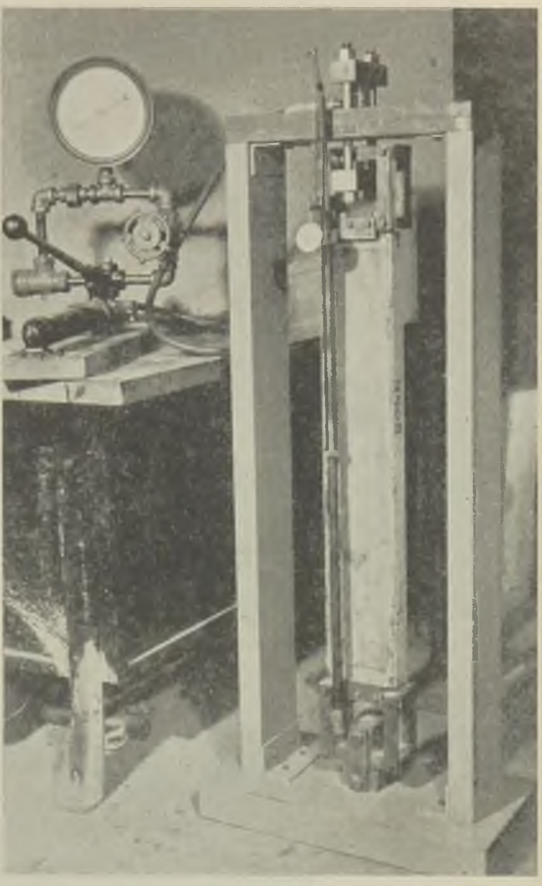


Fig. 33b

This method of test has been used to measure shrinkage-stress in specimens as wide as 12 in. and containing as many as four restraining bars.

Those specimens that do not fail under shrinkage-stress alone are given additional stress with the machines shown in Fig. 33a and 33b. The machine at the left (Fig. 33a) is used for most of the specimens; that at the right Fig. 33b is used if the capacity of the other one is exceeded and if the specimen contains more than one bar. The load is applied to the bar, and the extension of the bar at the time the concrete fails is determined by the strain-gage shown in the pictures. The net amount of load on the concrete at failure is computed from the magnitude of the load and the strain-gage reading. The factor of safety is the ratio of the load on the concrete at failure to the maximum load represented by the restraint against shrinkage.

"Sonic" testing: Most of the "unrestrained" specimens are tested periodically for frequency of vibration with the apparatus shown in Fig. 35a. Young's modulus is calculated from the resonant frequencies.

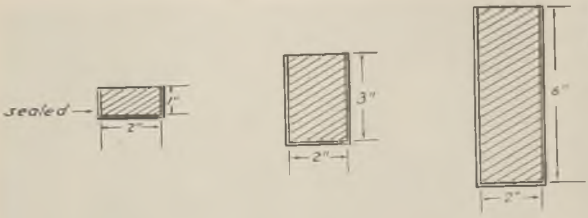


Fig. 34—Cross section of free warping specimens.

Fig. 35a—Sonic testing

Fig. 35b—Warping measurement

Fig. 36a (above)
Fig. 36b (left)
Restrained warping

Warping, length-change, and moisture-content: On specimens like that shown in Fig. 35a, the change in length is measured with the comparator shown in Fig. 32 and the warping is measured with the curvature-gage shown resting on a specimen in Fig. 35b. Results are correlated with concomitant changes in moisture-content.

Warping due to swelling: Previously dried specimens are placed, uncoated side down, in a trough of water as shown Fig. 35b or they are exposed to saturated air. The resulting warping due to absorption at one surface is more rapid than that due to shrinkage and can give rise to larger stresses.

The specimens shown Fig. 36 are supported only at the ends. They are coated on all but the bottom side and therefore as they dry they tend to bow upward. This tendency is opposed by the shackles at the quarter-points which are connected to a lever system below, one for each specimen. The levers are held by the fine-thread screw-adjustment seen best in Fig. 36b. The screws are turned downward until the force is just sufficient to prevent warping as indicated by the curvature-gage shown in both pictures. This instrument can be moved from specimen to specimen.

The force on the lever is measured periodically by finding the weight (bucket of shot) that will just hold the specimen in the position maintained by the screw. The force required reaches a maximum and then recedes slowly to zero as drying continues. When the maximum is reached, the specimens are loaded to failure. The ratio of the maximum force required to prevent warping to that required for failure is the factor of safety.

This test gives approximately the factor of safety against cracking of slabs of twice the depth of the specimens, drying equally from both sides.

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Job Problems and Practice

Five cash awards—$50.00, $25.00 and 3 of $10.00 each are to be made for the best contributions to this department in the current volume year—Sept. 1945 to June 1946.

In JPP many Members may participate in few pages. So, if you have a question, ask it. If an answer is of likely general interest, it will be briefed here (with authorship credit unless the contributor prefers not). But don't wait for a question. If you know of a concrete problem solved—in field, laboratory, factory, or office—or if you are moved to constructive comment or criticism, obey the impulse; jot it down for JPP. Remember these pages are for informal and sometimes tentative fragments—not the "copper-riveted" conclusiveness of formal treatises. "Answers" to questions do not carry ACI authority; they represent the efforts of Members to add their bits to the sum of ACI Member knowledge of concrete "know-how."

Influence of Mixing Water "Hardness" on Air-Entrainment (42-172)

By CHARLES E. WUERPEL*

The question has been raised as to the influence of the "hardness" of the mixing water on the entrainment of air in a concrete mixture containing an air-entraining agent or admixture; it being believed possible that hard water in certain sections of the country might decrease the sudsing or air-entraining properties of neutralized Vinsol resin or similar agents with the result that less than the desired amount of air would be entrained in concrete with the normal amount of the agent.

The absence of an effect on air entrainment caused by the degree of hardness of the mixing water was demonstrated in a series of experiments in which the following waters, running the gamut of hardness, were used:

Type of water	$CaCO_3$ *p.p.m.*
(a) Distilled	0
(b) Extreme softness in natural waters(1)	2.4
(c) Mount Vernon, N.Y. tap water	20.0
(d) Extreme hardness in natural waters(2)	1043.0

(1) Average lake water according to Data of Geochemistry by F. W. Clarke.
(2) Arkansas River. Data of Geochemistry, F. W. Clarke.

*Engineer in charge Central Concrete Laboratory, Corps of Engineers, Mt. Vernon, N. Y.

The waters (b) and (d) were prepared, in accordance with the method suggested and used by the Department of Water Supply, City of New York, by adding the equivalent amounts of calcium and magnesium in the form of $CaCl_2$ and $MgCl_2$ to distilled water.

Table 1 shows the results of tests made on mortar by A.S.T.M. Method C 185-44T using A.S.T.M. C 150-44 Type II cement with 0.010 per cent of neutralized Vinsol resin solution added to the water at the time of mixing.

Table 1

Water	Air Content—%
a	16.4
b	16.6
c	16.4
d	16.2

The lack of appreciable effect of the *Ca* and *Mg* ions present in the mixing water on the sudsing properties of the air-entraining agent is understandable when consideration is given to the much greater concentration of these ions which go into solution from the cement very rapidly after the water comes in contact with the cement. In other words, the hardness of the aqueous portion of a concrete mixture is so great as not to be appreciably affected by the hardness of the water supply.

Locating Points Along Beam Axis Corresponding to Known Moments (42-173)

By W. C. GOODWIN*

In the design of concrete building frames it is desirable to be able quickly to locate points corresponding to predetermined moment values. The location of points of inflection, points to bend or anchor reinforcement, or to change a concrete section are examples. The method submitted is not restricted to symmetrical† bending and applies to any combination of uniform and concentrated loads. It requires only that shears and moments be consistent with each other, the loading pattern, and conditions of restraint and continuity.

Notation

M moment at a support.
M' any part of M.
V shear at support, consistent with M.
P concentrated load at distance a from support.
x distance to section X-X from support.
w uniform load.

*Fabricated Steel Products Co., Boston.
†See Table V, "Continuity In Concrete Building Frames," Third Edition, Portland Cement Association.

Formulas

In Fig. 1, the moment at section X-X is

$M = Vx - P\,(x\text{-}a) - wx^2/2$ and

$x = (M - Pa) \,/\, (V - P) + \{(wx^2 \,/\, 2\,(V - P)\}$ (1)

If the load P does not occur within the distance x, then

$M = Vx - wx^2/2$ and

$x = M/V + wx^2/2V$ (2)

If neither the loads P nor w occur within the distance x, then

$M = Vx$ and

$x = M/V$ (3)

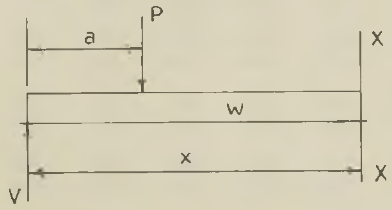


Fig. 1

Application

Case 1—When a beam in a building frame carries a concentrated load or loads near mid span and the weight of the beam is either negligible or for convenience included in the concentrations, formula (3) may be used directly for x.

Case 2—In the more common case where the beam carries a uniform load w either with or without concentrations, but where it may be seen by inspection that a is greater than x, formula (2) applies and x may be determined as follows:

Compute $q = M'/V$ and $r = 1000w/V$ separately. With their product rq enter Table 1 and select rx. Then $x = rx/r$.

Case 3—When a concentrated load occurs between the support and section X-X, formula (1) applies. Proceed as in Case 2 but substitute $M' - Pa$ for M' and $V - P$ for V.

$q = (M' - Pa) \,/\, (V - P)$ and $r = 1000w \,/\, (V - P)$.

In Table 1, values of $M/V = rq$ were computed for a constant $r = 1$ and various values of rx in the formula,

$x = M/V + wx^2/2V = q + rx^2\,/2000,$

When $r = 1$, $rx = rq + x^2/2000,$

For any value of r, $x = rx/r$.

Example 1—A beam with a span of 20 feet is loaded near mid span with a concentration of 100 kips which is assumed to include the weight of the beam. At one support the maximum negative moment is 300 foot kips and the shear is 52 kips. Find the point of inflection.

$x = M/V = 300/52 = 5.8$ feet.

TABLE 1

Values of rg and rx for $r = 1$

rg	10	20	30	39	49	58	68	77	86	95
rx	10	20	30	40	50	60	70	80	90	100
rg	104	113	122	130	139	147	156	164	172	180
rx	110	120	130	140	150	160	170	180	190	200
rg	188	196	204	211	219	226	234	241	248	255
rx	210	220	230	240	250	260	270	280	290	300
rg	262	269	276	282	289	295	302	308	314	320
rx	310	320	330	340	350	360	370	380	390	400
rg	326	332	338	343	349	354	360	365	370	375
rx	410	420	430	440	450	460	470	480	490	500
rg	385	394	403	412	420	428	435	442	449	455
rx	520	540	560	580	600	620	640	660	680	700
rg	461	466	471	476	480	485	489	492	495	500
rx	720	740	760	780	800	825	850	875	900	1000

Example 2—A beam with a span of 20 feet is loaded with 50 kips at each third point in addition to a uniform load of 2 kips per foot. At one support the maximum negative moment is 300 foot kips and the shear is 75 kips. (a) Find the point of inflection. (b) Find the point corresponding to 3/5 of the maximum negative moment.

(*a*) $q = 300/75 = 4.0$ $\quad r = 2000/75 = 27$ $\quad rq = 108$

$rx = 115$

$x = 115/27 = 4.3$ feet.

(b) $q = 3/5$ of $4.0 = 2.4$ $\quad r = 27$ $\quad rq = 65$

$rx = 67$

$x = 67/27 = 2.5$ feet.

Example 3—A beam with a span of 20 feet is loaded with a concentration of 50 kips located 2 feet from one support, in addition to a uniform load of 2 kips per foot. The negative moment at this support corresponding to the maximum positive moment is 140 foot kips, and the shear is 68 kips. Find the point of inflection for maximum positive moment.

$q = (140 - 50 \times 2) / (68 - 50) = 2.2$ $\quad r = 2000 / (68 - 50) = 111$

$rq = 245$

$rx = 287$ $\quad x = 287/111 = 2.6$ feet.

Fifth Annual

TECHNICAL PROGRESS SECTION

FOR COMMERCIAL PRODUCERS

February 1946

CONTENTS

FOREWORD

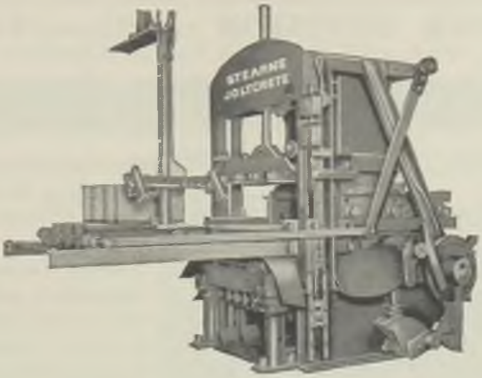
This is the Fifth Annual Technical Progress Issue of the ACI Journal and the first of the postwar period. It carries gratifyingly more advertising than any of its four predecessors.

To restate the original purpose and factors involved: Once a year in this section of the JOURNAL the seller of goods and services in the field of concrete would reach the potential buyer with an opportunity for mutual benefit. The technically trained engineer-buyer is scornful of ballyhoo, alienated by overstatement, breezy generalities or by any highly imaginative sales promotion. The man responsible for sales is likely to be close to the advertising department. To what degree can commercial advertising "copy" be made to read like engineering good sense? Could the salesman's claims be backed up with facts?

The Publications Committee has stood guard. The surprising facts of the experience are two: 1) The small percentage of "copy" submitted which has been sent back to its source for revision, and 2) the willingness of advertisers, almost without exception, to meet the Publications Committee's suggestions to reduce the "claims" for a product to statements which could be, at least partially, authenticated. Advertisers have seemed to see that claims for their products which put a severe strain on credulity of the intelligent reader *just aren't good advertising.*

This is not to say that the Publications Committee critics are hard-boiled—by no means. They are able to see that many claims which are a long way from *under*-statement still do not *deceive* anyone. These critics know, and know that the ACI public knows, that sales viewpoint *may* be arrived at through over-rosy spectacles. Can the copywriter be expected to put out a message that is as completely qualified as the typical researcher's well hedged conclusions!

Sometime there may be an accepted buyer-seller esperanto, or a basic English of the marts of trade. Until then buyers will have some vestigial reminder of the classic warning, "Let the buyer beware!" Seriously, however, while ACI endorsement of the pages which follow is neither given nor implied, most of our advertising seems to be written against a background of performance and with the knowledge that, in the long view, there are profits only where there is authentic "straight talk".



Stearns Improved
Joltcrete No. 9

THE EXCELLENCE OF PRODUCTION that won four Army-Navy "E" awards for Stearns is again at work in its own, its original field: the design and manufacture of concrete products plant equipment.

- STEARNS MACHINES, vibration and tamp-type block makers, mixers and material handling skip loaders will solve any post-war production problem that concrete products manufacturers may have.

- STEARNS ENGINEERS AND DEALERS will continue to give this vital industry the benefit of their mature experience.

- MAKE USE OF BOTH!

STEARNS

GENE OLSEN, PRESIDENT

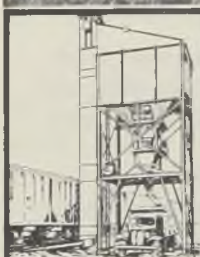
Pioneers in the development of new and improved equipment for the volume production of concrete masonry units.

BLAW-KNOX DIVISION of Blaw-Knox Company

Farmers Bank Bldg. • Pittsburgh, Pa.—New York, Chicago, Birmingham, Philadelphia, Washington

USE THIS UP-TO-DATE

Dry, harsh, concrete paving mix being handled by Blaw-Knox Transverse-Blade Automatic Type Concrete Paving Spreader equipped with vibratory attachment. Concrete tested ½ to ¾ inch slump. Contractor's production in spite of difficult concrete was in excess of 400 lineal ft. of 12 ft. wide slab 9" thick per hour. Spreader-Vibrator is one man operated. Vibration increased strength of concrete by 25 per cent.



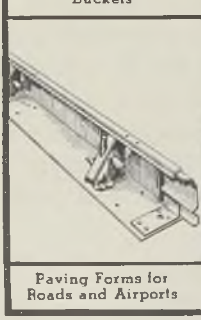
Bulk Cement Plants

Concrete Buckets

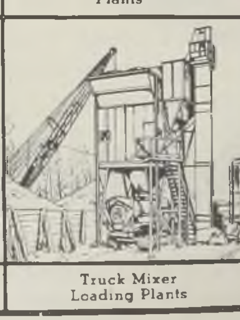
View behind Blaw-Knox Spreader-Vibrator shown in upper photograph. Concrete has been spread to required elevation and simultaneously compacted by vibratory attachment. Note uniformly smooth surface behind vibrator. Blaw-Knox Finishing Machine worked closely behind Spreader-Vibrator and kept pace easily. Cores drilled from completed pavement showed no honeycomb at bottom of slab or at joints and no excess mortar at surface of pavement.

Clamshell Buckets

Aggregate Batching Plants



Paving Forms for Roads and Airports



Truck Mixer Loading Plants

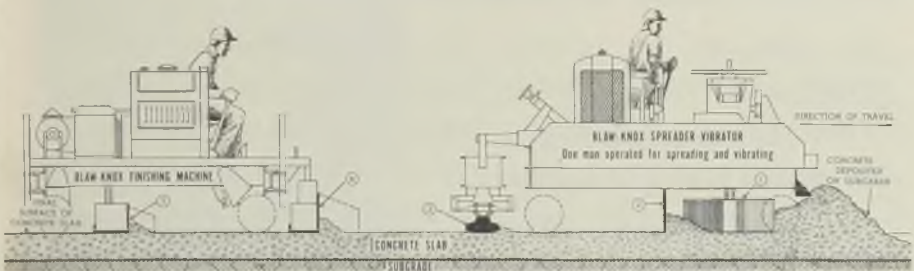
Steel Forms for General Concrete Construction

Steel Street Forms

• BLAW-KNOX •

PAVING METHOD

for greater production . . . lower cost and higher quality



1 Automatic Transverse Spreading Blade spreads concrete transversely and at the same time pushes excess concrete ahead of machine; adjustable for spreading height.

2 Strike-off shapes concrete to required height and crown allowing slight excess for compaction by vibrator, strike-off is hydraulically adjustable for elevation.

3 Vibratory attachment compacts concrete simultaneously with spreading operation; vibrator is spring suspended and does not rest on side forms. All vibratory effect is transmitted directly to the concrete. Vibrator is controlled by spreader operator and leaves slight excess of concrete for finishing machine.

4 Finishing Machine front screed strikes off excess of concrete to exact grade and crown. Finisher has easy and rapid operation; follows close behind Spreader-Vibrator.

5 Rear screed of Finishing Machine performs final finishing and smoothing operation.

The method of paving construction illustrated has been proved on hundreds of miles of concrete paving construction for roads and airports.

The dry and harsh concrete mixes frequently specified by engineers for modern pavements can be spread, compacted and surfaced most rapidly and efficiently by the combination of the Blaw-Knox Transverse-Blade Type Automatic Concrete Paving Spreader equipped with vibratory attachment and the modern Blaw-Knox Finishing Machine.

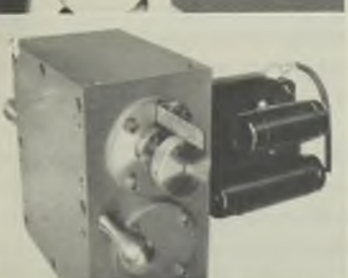
The Spreader-Vibrator spreads the concrete to the required depth and at the same time compacts the concrete by vibration. The Finishing Machine follows close on the heels of the Spreader-Vibrator and does a quick and easy surfacing job. The Blaw-Knox Spreader-Vibrator teamed with the Blaw-Knox Finishing Machine handles the output of two 34-E dual drum paving mixers.

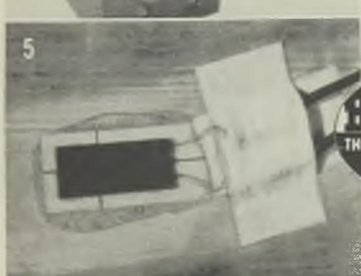
Difficult concrete is easily handled on a production basis by this up-to-date paving method and the contractor gains — in greater yardage, lower construction cost, minimum of manual operations and higher quality paving.

The Blaw-Knox Finishing Machine can also be equipped with a vibratory attachment. However, experience has shown that the paving vibrator mounted on the spreader provides better compaction, more practical operating procedure, and maximum production of paving slab. The Spreader-Vibrator always remains with the paving mixer and does not have to move back to aid in correction of high or low areas.

Blaw-Knox Spreaders and Finishers including vibratory attachments are available in standard sizes as follows: 10-15 ft. adjustable width, 20-25 ft. adjustable width.

Your Nearest Blaw-Knox Distributor Will Promptly and Efficiently Handle Your Inquiries for Construction Equipment.





TESTING EQUIPMENT FOR CONCRETE CONSTRUCTION

Today's construction projects classify their physical testing equipment three ways. One, testing materials of construction in plant laboratories; two, testing as a means of concrete quality control in field laboratories; three, testing in place.

The Baldwin Locomotive Works offers equipment for all three purposes: For materials of construction the 90,000# compression machine of Figure 1 is especially built for 2" x 2" cubes, small cylinders and beams and will be found in use wherever compression testing of cement and concrete cubes and cylinders is practiced.

Figure 2 is a typical 400,000# universal testing machine installation for plant laboratory service, fitted with the Emery capsule and the Tate-Emery null method multi-range dial indicator. This machine is designed for testing concrete in compression and reinforcing steel in tension.

For field laboratories the 400,000# compression machine in Figure 3 is small, accurate and convenient to handle. This is a single purpose machine of all welded plate construction with packless ram and Emery null method dial indicator which makes four revolutions of 100,000# per revolution.

For dynamic testing of structures in place we introduce the Lazan Mechanical Oscillator of Figure 4, useful not only for vibratory testing of a completed structure to simulate service but for consolidation purposes and any other use where high frequency mechanical vibrations will serve.

For experimental stress analysis in such structures, SR-4 strain gages, Figure 5, are pre-eminent and can be used in many ways. Baldwin is ready to furnish details on any of the above. The Baldwin Locomotive Works, Philadelphia 42, Pa., U. S. A. Offices: Philadelphia, New York, Chicago, Cleveland, Washington, Boston, Detroit, St. Louis, Houston, Pittsburgh.

BLH THE BALDWIN GROUP

BALDWIN

SOUTHWARK

TESTING EQUIPMENT

JACKSON—The RIGHT

For each and every purpose to which Vibrators are applicable in the concrete industry, we are confident we can supply the equipment that will give you not only the best and fastest placement, but also the maximum of dependability and trouble-free service. Pioneers and outstanding developers of vibratory equipment, our complete line includes internal and external vibrators for: General Construction ★ Light Construction ★ Mass Concrete Dam Construction ★ Hard-to-get-at Places ★ Form Vibrating ★ Floors, Streets and Highways ★ Pipe Manufacturing ★ Movement of Materials—Vibratory Tables, etc. Drop us a line for the best solution to any concrete vibrating problem.

JACKSON HEAVY-DUTY VIBRATORY PAVING TUBE

For speedy full width highway and airport concrete paving. Up to 25 feet widths. Submergible dual tubes energized by powerful vibratory motors quickly transform harsh mixes to plastic state. Assures complete compaction—easy finishing. Cement savings up to 10% through reduction in W/C ratio. Attaches to any modern finisher. Variable frequency 3000-5600 V.P.M. Hydraulic lift. Grouped controls.

HS-A1 HYDRAULIC CONCRETE VIBRATOR

This is a general purpose machine of the internal type adapted to a wide range of applications. Operated by light oil pumped through hose line 34 feet long to hydraulic motor in vibrator head. Valve on power plant adjusts frequency desired, from idling to top speed of 7200 V.P.M. All moving parts in the hydraulic medium (oil). Vibrator head 2¾" diameter, standard, gas engine, air cooled 4.7 H.P. A general favorite because of its wide range of application and low maintenance.

JACKSON PORTABLE POWER PLANTS

A new high in dependable portable power is now available in Jackson postwar Power Plants having permanent magnet generators in which all usual maintenance is eliminated except lubrication. Especially designed for severest service under continuous operating conditions. Simple, rugged construction and design, stripped of fussy control gadgets. Run all Jackson Vibrators, for lights, and all types of contractor's power tools. One to 7.5 KVA sizes available.

ELECTRIC TAMPER & EQUIPMENT CO.,

Paving Specifications . . .

2 VIBRATION ON THE FINISHER, not on the concrete spreader:

Although Jaeger can furnish a vibratory attachment for use on Spreaders, the recommended Jaeger method of vibration *on the Finisher* has proved superior for any true vibratory mix. On an efficiently run job, only the Finisher has time to go back for more than one vibratory pass, as often needed. Also, it is the machine which always finishes to form level, thus insuring an over-all vibrated surface.

It has been demonstrated that specifications for true vibratory mixtures can best be met by use of the Jaeger Vibratory Finisher with "bullnose" screed giving DEEP INTERNAL VIBRATION. For less difficult mixtures use of a vibratory tube, *on the Finisher,* is also satisfactory.

3 FAST, MECHANIZED PLACEMENT and FINISHING of quick-drying air-entraining cements:

The Spreader-Finisher "team", originated by Jaeger, which made it possible to handle stiff, vibratory concrete at the dual-drum paver pace, also equips road builders to handle quick-drying air-entraining cements.

Under hot, windy or dry air conditions, the Jaeger "team" provides the spreading and finishing capacity needed to keep close behind big pavers and complete the job before drying hinders a satisfactory finish.* Also, an exclusive feature of the Jaeger Finisher is that screed speeds can be independent of traction, permitting the use of fast screed speeds which has been found necessary to prevent tearing when the surface is sticky.†

* † Discussions of these two problems have appeared in previous issues of the Journal of the American Concrete Institute.

Manufacturers of Concrete and Bituminous Spreading and Finishing Equipment, Road Forms, Concrete and Bituminous Mixers, Truck Mixers, Pumps, Air Compressors, Hoists, Material Loaders.

FASTER CONSTRUCTION OF SUPER HIGHWAYS AND RUNWAYS

(A) Viber Vibrators extended in upward position, giving ample clearance to pass over joint, manhole covers or other obstacles.

(B) Position of Vibrators starting under oscillating screed.

(C) Position of Vibrators submerged under oscillating screed to full depth of concrete slab.

AS FAST AS IT CAN BE PLACED, even the stiffest concrete of super-thick slabs can now be economically vibrated *full depth*, for uniform density and strength. Higher quality concrete, with substantial savings in time, labor, construction and maintenance costs result from use of the VIBER SLAB. This multiple unit, high-speed internal vibrating machine is specially designed for *continuous full width*, full depth compaction of slabs up to 25 feet. The VIBER SLAB requires but a single operator and may be attached to most types and makes of spreading and finishing equipment. A battery of correctly spaced VIBER VIBRATORS give you the unequalled speed, *in concrete*, of 9,500 RPMs, and test borings prove their unmatched compacting efficiency. Full details will be furnished upon request.

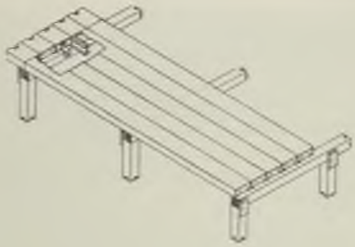
VIBER SLAB

MULTIPLE HIGH-SPEED INTERNAL VIBRATION

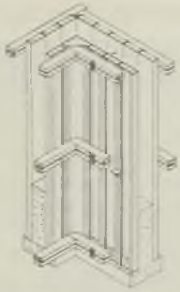
VIBER COMPANY • 726 South Flower St. • Burbank, California

ORIGINATORS OF INTERNAL CONCRETE VIBRATION!

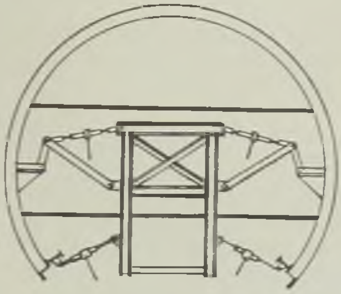
Labor-Saving Concrete Forms



Flat Slab Forms

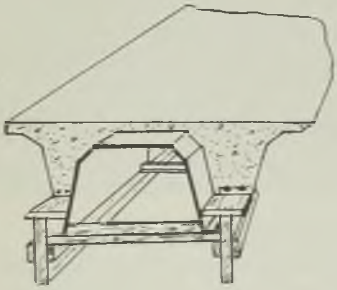


Travelling Wall Forms

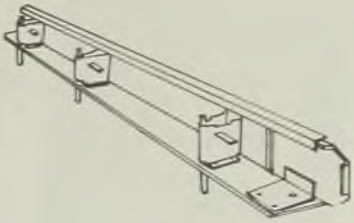


Tunnel Forms

Column Forms



Pan Forms



Road Forms

Also, Centering, Pipe Forms, Slide Forms, Shaft Forms, Manhole Forms, Etc.

Plants: Irvington, N. Y. Lancaster, Pa. Zanesville, Ohio

ATLAS STEEL CONSTRUCTION COMPANY

83 James Street - - - IRVINGTON, N. Y.

Atlas Steel Forms for every Purpose

FORMULA FOR CONCRETE

Mix Design + Batching + Transportation + Placing and Curing = ?

Engineers know how to analyze materials and make scientific mix-designs that will produce any desired qualities when mixed in the concrete laboratory

Modern transportation and placing equipment are available. The *weak link* is batching. Many plants still use equipment of the type first used when the change from volumetric to weight batching was made and concrete batched with such equipment frequently bears little or no resemblance to the carefully prepared mix-design.

Modern scientific batching equipment to fill this gap is available. Specify [SC]² PRECISION CONCRETE CONTROL and batching accuracy is assured. It includes:

The (SC)² Moisture Meter. The only unit capable of determining moisture content in less than 1 minute

The (SC)² Compensator which compensates for the moisture content in every ingredient and graphically records its every operation

MOISTURE DETERMINATIONS, accurate to ¼% made in one minute; one for every batch when necessary.

AUTOMATIC COMPENSATION FOR MOISTURE CONTENT in fine and coarse aggregates. Does not require calculations, charts or tables. With it, any intelligent weigh-man can produce remarkable uniformity.

PRECISION PROPORTIONING OF ALL INGREDIENTS using TOLEDO, the world's most accurate scales. Automatic cut-off is used for cement and water and is optional for aggregates.

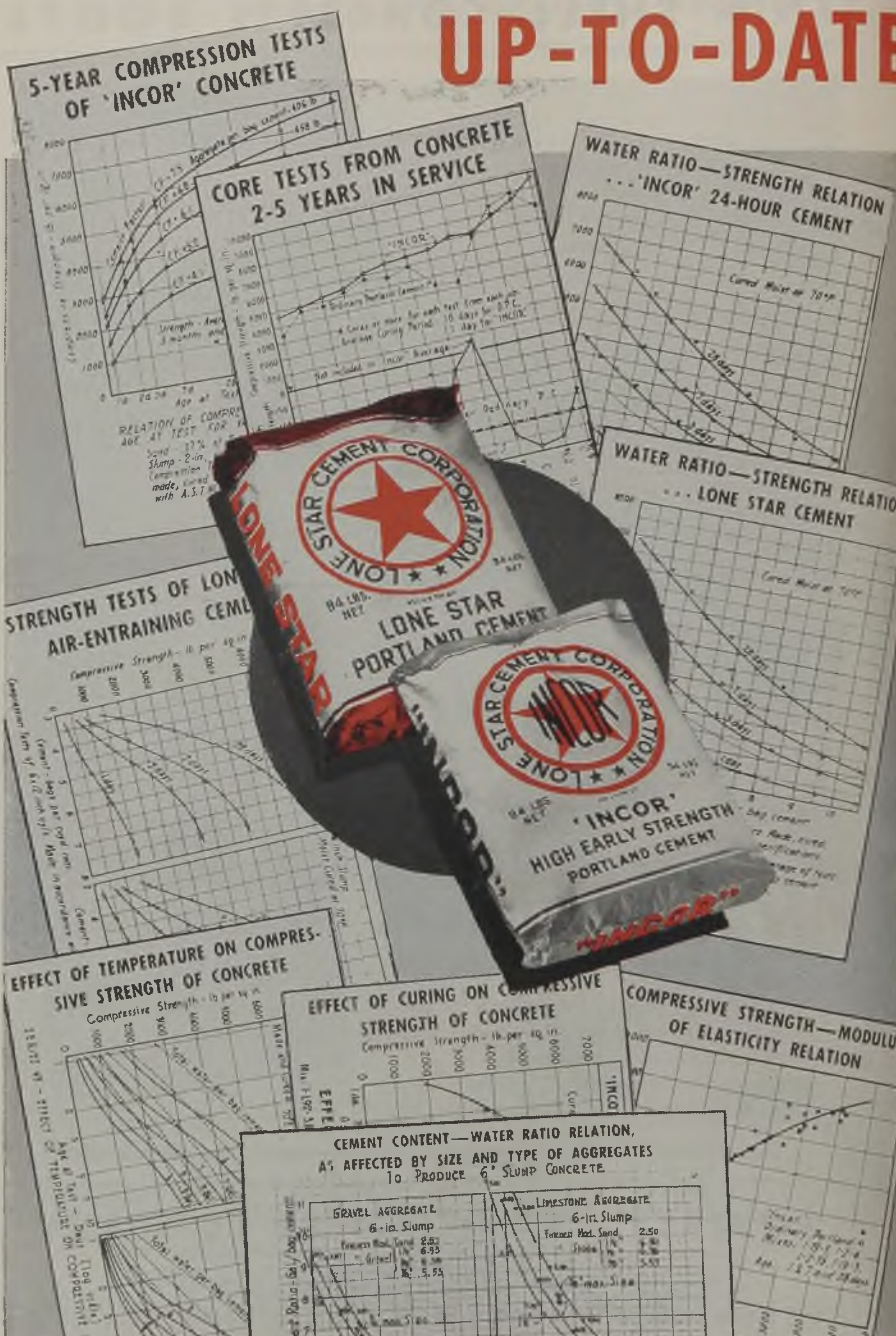
AUTOMATIC GRAPHIC OR PRINTED RECORDS OF EVERY BATCH showing the delivered weight of each ingredient.

[SC]² CONTROL is approved by every concrete engineer, ready-mix operator and contractor who has ever used it.

Write today for information on how engineers are specifying and getting accurately controlled concrete.

Scientific Concrete Service Corporation
724 Salem Ave. **Elizabeth 3, N. J.**

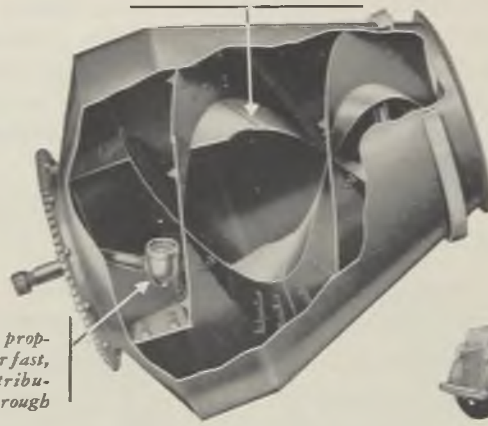
SCIENTIFIC [SC]² CONCRETE


UP-TO-DATE
5-YEAR COMPRESSION TESTS OF 'INCOR' CONCRETE
CORE TESTS FROM CONCRETE 2-5 YEARS IN SERVICE
WATER RATIO—STRENGTH RELATION ...'INCOR' 24-HOUR CEMENT
WATER RATIO—STRENGTH RELATION ... LONE STAR CEMENT
STRENGTH TESTS OF LON
AIR-ENTRAINING CEM
LONE STAR CEMENT CORPORATION
LONE STAR
94 LBS. NET
LONE STAR PORTLAND CEMENT
'INCOR' HIGH EARLY STRENGTH PORTLAND CEMENT
EFFECT OF TEMPERATURE ON COMPRESSIVE STRENGTH OF CONCRETE
EFFECT OF CURING ON COMPRESSIVE STRENGTH OF CONCRETE
COMPRESSIVE STRENGTH—MODULUS OF ELASTICITY RELATION
CEMENT CONTENT—WATER RATIO RELATION, AS AFFECTED BY SIZE AND TYPE OF AGGREGATES To Produce 6" Slump Concrete
GRAVEL AGGREGATE
6-in. Slump
LIMESTONE AGGREGATE
6-in. Slump

REX MOTO-MIXERS

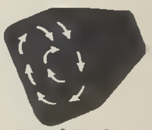
The Truck Mixers with the "LIVE" Hi-Lo Mixing Action

Large correctly shaped mixer blades are equipped with fillet the entire length of the blade to eliminate build-up and to aid in faster discharging.



Water nozzle properly located for fast, thorough distribution of water through the batch.

Rex has "Live" mixing



Not a "Dead Ending" action

An exclusive feature of the new Rex Moto-Mixer is the up-hill mixing action which has proved an outstanding improvement in truck mixer development. As a result of this action, plus large correctly designed mixing blades, it is now possible to mix low slump concrete—fast.

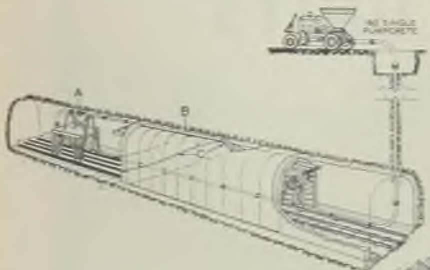
The full volume of the drum is utilized for mixing purposes. This is accomplished by rotating the drum in the discharge direction. The end to end reversing action, spiraling the batch to the top of the drum where it can cascade back to the lower end by gravity, more nearly approaches the efficiency of a large drum stationary plant mixer than anything yet developed in the truck mixer field.

Another important feature is the method of introducing water at a point where it can be distributed throughout the batch quickly. Water is ejected from the nozzle at a point where the mixing blades plow into the batch. The blades form a furrow; and through this furrow, water is more readily and quickly dispersed throughout the entire mix.

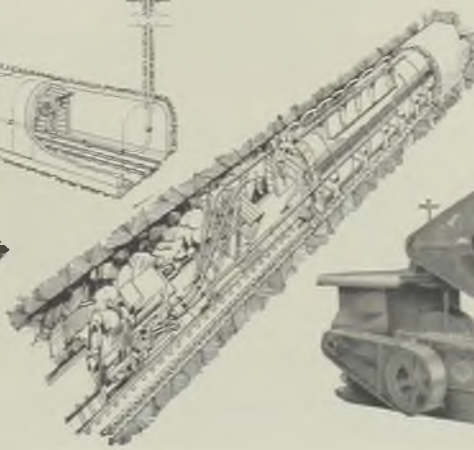
The up-hill mixing action and the more efficient distribution of water throughout the batch are two chief reasons why the new Rex Moto-Mixers produce a more uniform, thoroughly mixed concrete in less time than has formerly been possible with any type of truck mixer. For additional information on the Rex Hi-Discharge Moto-Mixer, send for a copy of Bulletin No. 467. Address Chain Belt Company, 1713 West Bruce Street, Milwaukee 4, Wisconsin.

REX CHAIN BELT COMPANY

TUNNEL LINING WITH THE REX PUMPCRETE



Lining a tunnel with Pumpcrete setup outside. Transporting equipment and labor in the hole are eliminated. Other tunnel operations can be carried on without interference.



Tunnel lining with Pumpcrete setup inside. Pumpcrete is equipped with horizontal remixer which provides storage and prevents segregation. Concrete can be deposited to sidewalls of large tunnels in horizontal layers where this method is desirable.

For tunnels from four feet in diameter up to the largest, the REX Pumpcrete offers a more flexible approach in meeting general tunnel construction problems than any other type of equipment. Its long placing range and general utility for any phase of the job provide the most economical method of concreting on the majority of tunnel projects.

Pumpcretes will handle stiffer concrete with much less loss of slump than other placers operating at an equal distance. In other words, less water per bag of cement is required for a given slump consistency. Discharge to the forms is more readily controlled which minimizes segregation and is another one of the reasons why a Pumpcrete, properly employed, will turn out a better job structurally than any other type of mechanical placer, i.e., by filling the forms tighter with denser, more impervious concrete. The pumping system is also applicable to a much wider variation of procedure in meeting the unusual placing problems that occur on many tunnel lining jobs. It will do a much better job of filling overbreaks; and in tight sections caused by squeezes or falls, where regular arch pipe cannot be installed, it will do a satisfactory job by pumping directly through the form.

Pumpcrete is the answer for most tunnel lining and for many other types of construction work. For detailed information, send for a copy of either TUNNEL LINING WITH THE REX PUMPCRETE or Bulletin No. 466 for general construction work. Address Chain Belt Company, 1713 West Bruce Street, Milwaukee 4, Wisconsin.

of MILWAUKEE REX

OUTSTANDING ROAD BUILDING UNITS

'FLEX-PLANE' Finishing Machines—have finished a complete surface in one pass with a compound screed—3115 lineal feet of 9″ concrete 24 feet wide in one 11 hour day—a world record!

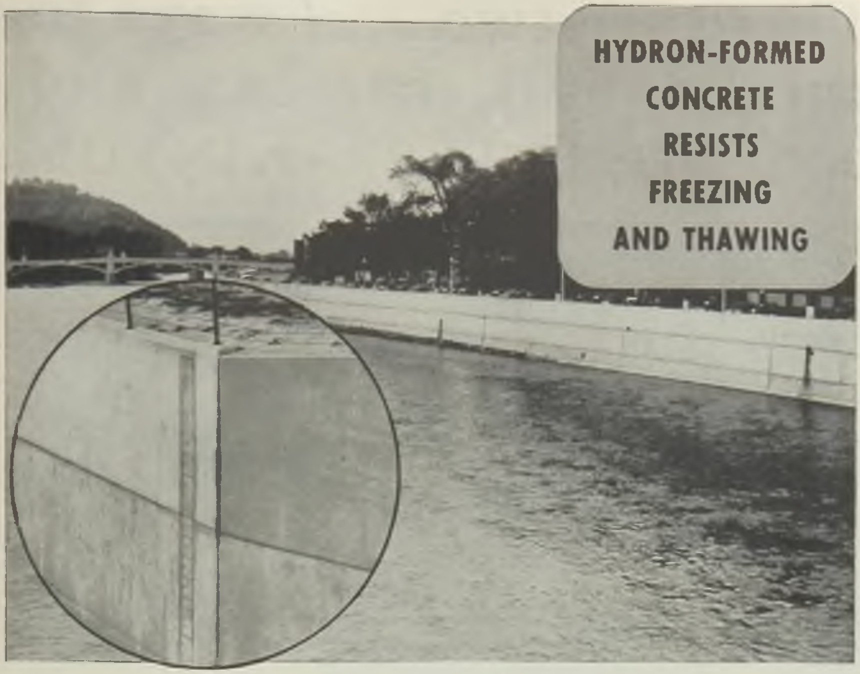
'FLEX-PLANE' Joint Installing Machines for installing joints automatically or semi-automatically—we now provide electric vibration so the concrete around the joint is thoroughly compacted to prevent scaling.

'FLEX-PLANE' Spraying Machines—for curing concrete—an entirely automatic machine—each square yard of surface is double sprayed with proper amount of material.

'FLEX-PLANE' Traffic Line Marking Machines—used in a number of States for dividing or marking traffic lanes.

FLEXIBLE ROAD JOINT MACHINE CO.

WARREN, OHIO, U. S. A.



SUSQUEHANNA FLOOD WALL LIKE NEW AFTER FOUR YEARS OF FREEZE-THAW CYCLES

These are pictures of the Susquehanna flood wall at Binghamton, N. Y. taken last summer. Despite four years of frequent freeze-thaw cycles, the wall still looks like new.

It was cast against Hydron absorptive lining, which reduces by 30% the absorption of water by concrete. Hydron also greatly reduces or eliminates such surface defects as air pits, water channels, and sand streaks.

Tests show conclusively that Hydron produces a case-hardened concrete surface that withstands four times as many freeze-thaw cycles as samples cast against wood.

Before its use on the Susquehanna Flood Wall, or the new MacArthur locks in the "Soo" Canal, or the Norfork Dam, Hydron underwent years of analysis and testing.

Hydron's case-hardening effect is at least one inch deep with a gradual change in the water-to-cement ratio and density from the surface into the bulk concrete.

Made in thin, flexible sheets, Hydron is mounted to forms with rapid-fire staple guns, strips cleanly, needs no tedious finishing.

Send for your copy of informative booklet on Hydron.

Serving Through Science

UNITED STATES RUBBER COMPANY

1230 Avenue of the Americas • Rockefeller Center • New Yo.k 20, N. Y.

Restore the Old--
with Build the New--
INTRUSION-PREPAKT

INTRUSION

Pressure-filling of spaces within masonry and concrete structures, foundations, and riprap with cement-base binding paste, to solidify the mass.

PREPAKT

Concrete made by packing forms with coarse aggregate and then solidifying by intrusion.

Fine seams in sandstone of ashlar masonry dam filled by intrusion. Mortar joints are likewise solidified.

As mortar is pumped in from below, spaces in prepacked coarse aggregate become completely filled.

APPLICATION

These processes have been successfully used for years on hundreds of projects including

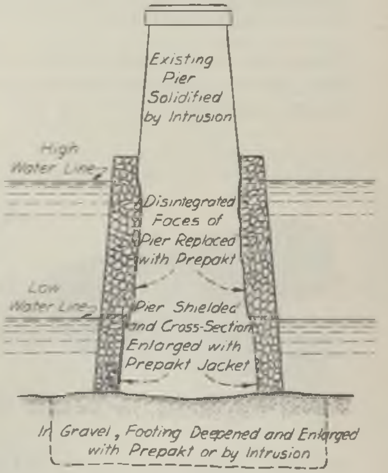
PIERS	WALLS	DAMS
FOOTINGS	VIADUCTS	BREAKWATERS
ARCHES	TUNNELS	ROCK FILLS

BRIDGE PIERS

Scour of stream beds, abrasion by floating debris and ice, and weathering tend to damage bridge piers by causing inadequate support, unequal settlement, reduction of cross-section, and loss of mortar from joints. Each pier requires special treatment, but all are capable of being restored and protected against attack, through the combined processes of intrusion and prepacking as required. Typical cases are illustrated in the photographs below, together with a drawing showing various means of repair which have actually been used with success. By jacketing with Prepakt, it is possible even to increase the strength and stability of the pier beyond its original capacity, to provide for the heavier loads of modern traffic.

Typical restoration of abutment and wing wall. Bridge seat and disintegrated stones replaced with Prepakt. Interior of masonry intruded down to bed rock.

Scour of river bed exposed timber grillage and piles supporting pier. View shows pier ready for jacketing with Prepakt, after interior has been solidified by intrusion.



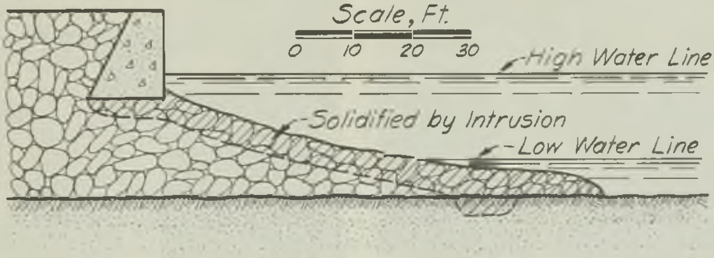
Composite sketch from various jobs, illustrating restoration and strengthening of pier.

BREAKWATERS

Breakwaters, sea walls, rock fills, dams, and gravelly soil bases have been stabilized by intrusion to form monolithic structures. Impervious blankets are provided wherever the full thickness of the structure need not be solidified.

An outstanding example of this type of work is illustrated below. A sea wall subjected to heavy tides, up to 14 ft., and severe storms was periodically washed out and required extensive repairs. To stop this condition and to provide permanent protection to the embankment, the upper portion of the rock fill, 3 to 5 ft. thick, was packed with coarse aggregate and was intruded to form a solid blanket. The cut-off wall was intruded to a depth of 8 ft. The work was accomplished in two construction seasons. During the winter between seasons, severe storms and tides washed out part of the untreated rock fill, but left the treated portion entirely undamaged as shown.

Similarly, an earth fill dam is being treated by flushing out the finer fraction of soil and intruding the gravel.



Section of sea wall, showing stable imprevious blanket and cut-off wall formed by intrusion.

Completed portion of sea wall. Note (in foreground) aggregate used to fill interstices of larger stone, and wooden plugs projecting from vertical intrusion pipes.

Untreated portion washed out by storms; treated portion undamaged. Construction was completed during following year.

See Also Preceding Three Pages

Hand Puddling Can't Compete

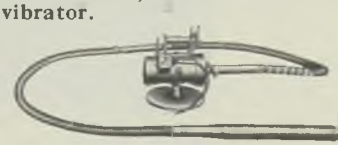
with a Mall
REG. U.S. PAT. OFF.

CONCRETE VIBRATOR

A Size and Type For Every Job!

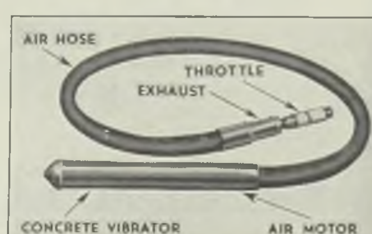
Fewer hands—faster placing—stiffer mix—uniform strength and density—better bond with reinforcement—no voids or honey-combs—water-tight job that permits an earlier stripping of forms—these are just a few of the advantages you get with a Mall Concrete Vibrator. In addition, for their size Mall Vibrators place more concrete than any other vibrator.

When not being used to vibrate concrete, the Mall Vibrator can be adapted to Surfacing, Form Sanding, Wire Brushing, Grinding and Drilling. Attachments for these operations are easily and quickly interchanged with the vibrating element which is constructed of the toughest materials. Tips are welded with special metals to withstand the severe abrasive action which occurs during operation.



MALL 1½ H.P. UNIVERSAL ELECTRIC CONCRETE VIBRATOR. Delivers 9000 vibration frequencies per minute under load. Like other MALL units, it is available with 14 ft., 21 ft., or 28 ft., of flexible shafting. Has low round base mounting and convenient carrying handle.

MALL CONCRETE VIBRATOR POWERED WITH 3 H.P. GASOLINE ENGINE. Delivers 7000 vibration frequencies per minute. Has variable speed, single cylinder, four cycle, air cooled gasoline engine that runs all day on 1½ to 2 gallons of gasoline. The wheelbarrow type mounting provides unusual portability. Attachments can be furnished for CONCRETE SURFACING, WIRE BRUSHING, FORM SANDING, DRILLING in concrete, brick, iron or steel, and SHARPENING TOOLS and BITS.



7500 r.p.m. PNEUMATIC MODEL. For placing concrete in tunnels, caissons, and other deep construction. All parts are easily renewable in the field and no special tools are required. Equipped with twist-hand throttle for easy operation.

MALL TOOL COMPANY, 7703 South Chicago Avenue, Chicago 19, Illinois

● 25 Years of "Better Tools for Better Work"

Mall REG. U.S. PAT. OFF. **PORTABLE POWER TOOLS**

Whiteman FLOATING-FINISHING MACHINES produce better concrete surfaces. The ideal method for color application.

Eliminate back-breaking kneework with this modern mechanical troweling machine. It produces a dense, wear-resistant slab, free from riffles and depressions.

MODEL "B" DUAL PURPOSE FLOATING-FINISHING MACHINE

Floating is done with the "Heavi-Duti" 10' x 18' flat float trowels. This operation compacts the slab; drives out air pockets; brings up moisture; produces an excellent traction surface for warehouse floors, walks, airplane runways or vehicular traffic. To finish, attach 6" x 18" crucible steel trowels. While machine operates control handle is turned to obtain correct trowel pitch. Available with gas engine or electric motor drive. 46" diameter.

NEW MODEL "J" LIGHTWEIGHT FLOATING-FINISHING MACHINE

Same principle as Model B . . . but smaller capacity. The trowel diameter of 34" (guard ring 35") permits operation in small crowded areas and through 36" doorways. The Model "J" weighs only 105 lbs.; provides easy portability . . . even an inexperienced operator can finish 1000 square feet in fifteen minutes. Available with gas engine only.

METAL AND WOOD SCREED STAKES

For quick placing in any kind of soil . . . used with 2" x 4" wood or 2½" pipe screeds. Final grade obtained by sliding head up or down. The best method of screeding against walls or curb.

WHITEMAN EQUIPMENT is sold only through established American and Foreign distributors. Write for name of nearest dealer.

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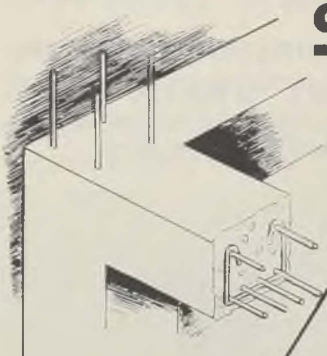
LOS ANGELES CALIF. U.S.A.

Whiteman MANUFACTURING COMPANY
3249 Casitas Avenue
Los Angeles 26, California

HI-BOND*

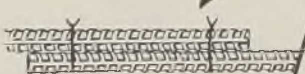
a More Efficient



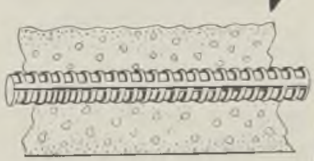
. At Splices

. In Concrete

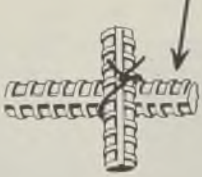
. For Installations



When HI-BOND bars are spliced, they will develop their tensile strength in splices with a shorter lap than commonly used.



Irrespective of the position in which they are cast HI-BOND bars provide a greater mechanical grip in the concrete and, therefore, offer higher resistance to slippage.



HI-BOND bars stay anchored when they are crossed and wired because the ribs key into each other and hold firmly.

*TRADEMARK-REG. U. S. PAT. OFF.

INLAND HI-BOND

REINFORCING BAR

HI-BOND bars provide the designer with an effective means to utilize more of the potential strength of the steel in reinforced concrete. The design of the helical ribs produces greater bearing area in concrete. This develops higher bond stresses, which permit more efficient load transfer at splices. This is demonstrated in tests reported in research paper 1669 issued by the National Bureau of Standards in their September, 1945, Journal.

These tests prove that HI-BOND bars will develop their tensile strength in splices with a shorter lap than commonly used, whether bars are wired together or spaced apart.

Placing of reinforcing steel is done more speedily and securely with HI-BOND bars. The helical ribs dovetail so well at intersections that the simplest wire tie will hold HI-BOND bars firmly fixed even in difficult wall positions. The saving in time, labor and wire makes possible more economical construction.

With HI-BOND, deflections in beams are reduced, width of cracks minimized, and the possibility of steel corrosion is less. All these advantages result in better, stronger, more efficient installations —no premium is assessed for HI-BOND's improved design—when you specify HI-BOND *you get extra value at no advance in cost.* Inland Steel Company, 38 South Dearborn Street, Chicago 3, Illinois.

REINFORCING BAR

HUNT PROCESS

THE ORIGINAL CONCRETE MEMBRANE CURE SINCE 1926

EVIDENCE OF THE EFFICIENCY OF HUNT PROCESS CURING

Views of San Fernando Road, (U. S. 99 to San Francisco and North) was cured with "Hunt Process Black" in the summer of 1929. It is one of the most heavily travelled truck and passenger car highways in the City of Los Angeles. The top picture was made July 1929 shortly after pavement was opened to traffic; the center picture was made December 1945.

Contractors stamp, as photographed December 1945, was originally placed in pavement during construction. It shows the complete curing obtained from Hunt Process, with little evidence of surface erosion from 16 years of very heavy traffic. This particular stamp is near a "Stop & Go" intersection where traffic abrasion is particularily severe.

Since 1929 more than 170,000,000 square yards of concrete surface have been cured with Hunt Process Company Curing Compounds, equivalent of more than 13,000 miles of 22-foot concrete.

DISTRIBUTORS

The Lofland Company	Dallas, Texas
The Colorado Builders' Supply Co.	Denver, Colorado
Grace Brothers, Limited	Honolulu, T. H.
The Carter-Waters Corporation	Kansas City, Missouri
The R. C. Hardcastle Company	Oklahoma City, Oklahoma
Baker-Thomas Lime & Cement Co.	Phoenix, Arizona
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A. R. Reid Company	San Francisco, Calif.
Charles R. Watts & Co.	Seattle, Washington
A. E. Foreman & Sons	Vancouver, B. C.

HUNT PROCESS COMPANY

"Spray It & Forget It"

HUNT PROCESS CLEAR
HUNT PROCESS BLACK
HUNT PROCESS PIGMENTED-(WHITE)

Main Office & Plant
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Kansas City Mo. Plant
Carter-Waters Corp.
2440 Pennway

provide an equivalent slump, little or no decrease in strength will result. In fact, in lean mixes (less than 5 sacks per cubic yard) there is usually an increase in strength.

To both engineers and contractors there are many intangible savings which may assume major importance under certain conditions, such as ease of placing, speed of finishing, overcoming irregularities in aggregate gradation, etc.

The above facts have all been proved in the field with Darex Air Entraining Agent, which already has been used in over four million yards of concrete. This material comes in solution form ready to use and lends itself to simple proportioning at the mixer.

★ ★ ★

IN AIR-ENTRAINED CONCRETES
IT'S THE
"Controlled Air"
THAT COUNTS

Use DAREX AEA with confidence wherever air entraining concretes are specified.

Write for booklet and manual on the use of DAREX AEA.

DEWEY AND ALMY CHEMICAL COMPANY

Department T - - Cambridge 40, Massachusetts

Calcium Chloride Curing Provides Maximum Hardness for Concrete, According to Abrasions Tests at National Bureau of Standards

Greater concrete hardness is provided by calcium chloride curing than by other methods of curing tested, according to tests of resistance to abrasion made at the National Bureau of Standards by H. C. Vollmer and reported in his paper appearing in the proceedings of the 24th Annual Meeting of the Highway Research Board.

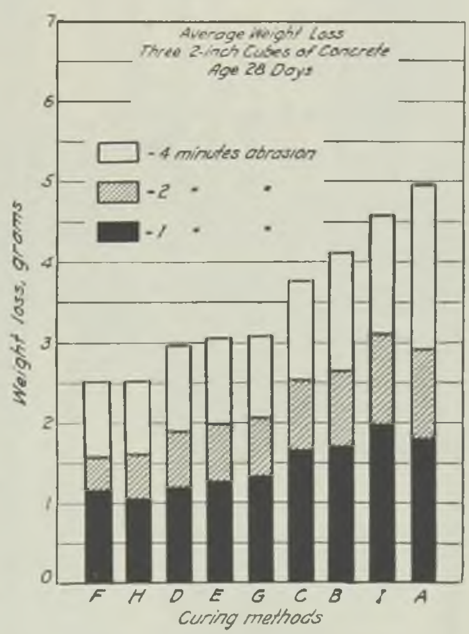
These results are most important to concrete engineers interested in the enormous building program ahead in which emergency restrictions no longer apply and the best of materials and methods of construction will be used.

Mr. Vollmer describes the results of his tests of resistance to abrasion of concrete specimens cured by various means, as follows:

"Tests of the resistance to abrasion of the top surface (cured surface) of the specimens indicated that the use of 1½ *per cent calcium chloride integrally* (equal to 1½ lbs. per bag of cement in the mix) and 1½ *lbs. per sq. yd.* applied to the surface as soon as the bleeding water disappeared (no burlap) and all specimens cured by employing the surface application of *calcium chloride* whether in conjunction with burlap or not, *resulted in a higher resistance* than specimens cured with wet burlap applied for three days; however, the wear resistance of specimens with *liquid curing membranes or with no curing were somewhat less* than specimens cured with wet burlap applied for three days."

Copies of Mr. Vollmer's complete report will be sent on request.

RESISTANCE TO ABRASION



F—1½ lbs. calcium chloride per sq. yd. surface and 1½% calcium chloride integral.

H—2 lbs. calcium chloride per sq. yd. surface with 18 hrs. wet burlap.

D—2 lbs. calcium chloride per sq. yd. surface (no burlap).

E—2% integral calcium chloride with 18 hrs. wet burlap.

G—3 days wet burlap.

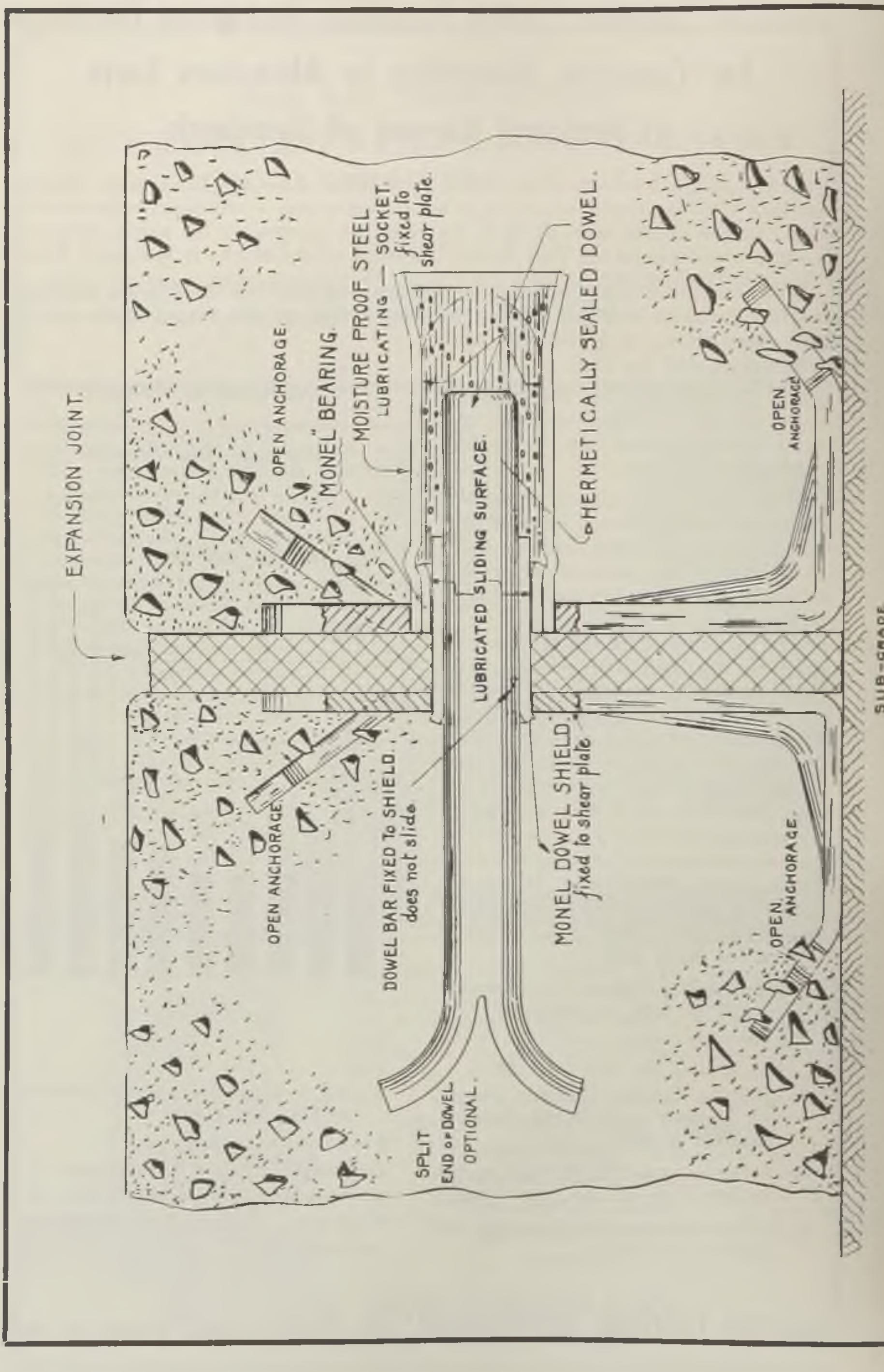
C—Surface coating (Membrane C).

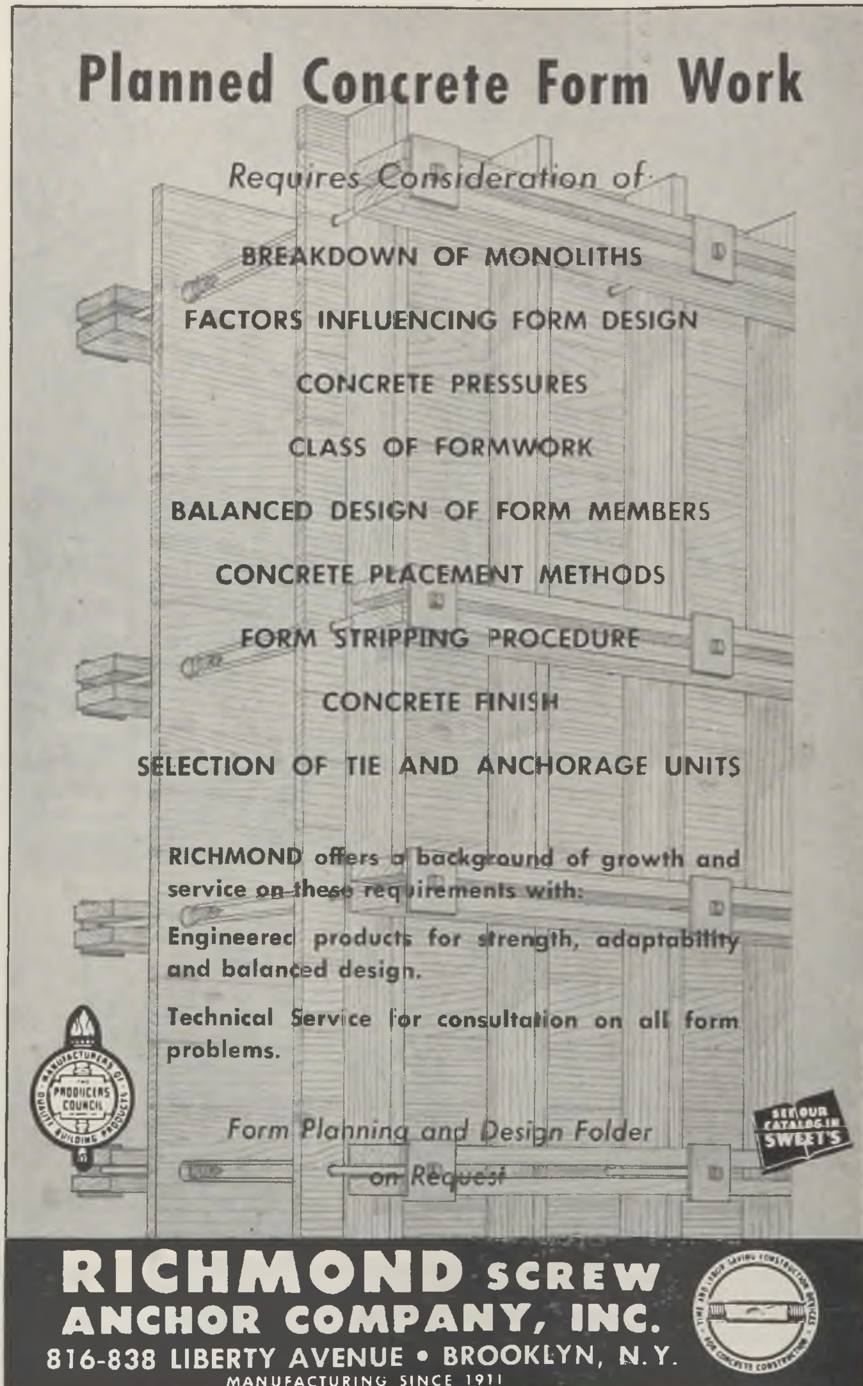
B—Surface coating (Membrane B).

A—Surface coating (Membrane A).

I—No curing.

CALCIUM CHLORIDE ASSOCIATION, 4145 Penobscot Bldg., Detroit 26, Mich.


EXPANSION JOINT
OPEN ANCHORAGE
"MONEL" BEARING
MOISTURE PROOF STEEL
LUBRICATING — SOCKET fixed to shear plate
HERMETICALLY SEALED DOWEL
LUBRICATED SLIDING SURFACE
OPEN ANCHORAGE
SUB-GRADE
OPEN ANCHORAGE
DOWEL BAR FIXED TO SHIELD does not slide
MONEL DOWEL SHIELD fixed to shear plate
OPEN ANCHORAGE
SPLIT END OF DOWEL OPTIONAL


Planned Concrete Form Work
Requires Consideration of:
BREAKDOWN OF MONOLITHS
FACTORS INFLUENCING FORM DESIGN
CONCRETE PRESSURES
CLASS OF FORMWORK
BALANCED DESIGN OF FORM MEMBERS
CONCRETE PLACEMENT METHODS
FORM STRIPPING PROCEDURE
CONCRETE FINISH
SELECTION OF TIE AND ANCHORAGE UNITS
RICHMOND offers a background of growth and service on these requirements with:
Engineered products for strength, adaptability and balanced design.
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MANUFACTURING SINCE 1911

PORTLAND CEMENT DISPERSION
and ADSORPTION OF CALCIUM LIGNOSULFONATE
with POZZOLITH

Pozzolith, which applies the well known principle of dispersion to Portland cement, was developed by Master Builders Research Laboratories following their discovery of the cement dispersing action of calcium lignosulfonate.

Cement dispersion reduces the water-cement ratio required for a given workability, increases strength, and greatly improves durability as well as having a number of other beneficial effects. [1]

A study of cement dispersion recently reported by Fred M. Ernsberger and Wesley G. France of Ohio State University provides evidence of the actions and results of cement dispersion as well as a mechanism by which it may be accomplished. [2]

This article —"Portland Cement Dispersion by Adsorption of Calcium Lignosulfonate", establishes two points: (A) that cement when placed in water normally flocculates and is dispersed by the action of calcium lignosulfonate so that the full cement area is subject to hydration. Through microscopic examination this study established the fact that cement particles clump together or flocculate when placed in water; that there are many more discreet particles, particularly small particles when the water medium contains about 0.1% of calcium lignosulfonate. Application of Stokes' law to falling cement particles in a water medium provided a method for measuring the degree of dispersion with and without calcium lignosulfonate. The comparison is shown in the following table. (B) that the mechanism by which cement dispersion is accomplished is mutual repulsion due to the adsorption of like electric charges on the surface of the cement particles. Dispersion of small particles in aqueous suspensions is usually due to mutual repulsion resulting from particles bearing a like electrostatic charge. Use of the following technique determined that cement dispersion is due to the same principle: By examining under the microscope the electrophoretic migration of suspended cement particles, it was observed that when suspended in *distilled water* there was no movement of the particles toward either electrode; that when suspended in *calcium lignosulfonate* solution there was a readily observable movement toward the anode.

Specific Surface of Portland Cement Suspended in Water, with and without Calcium Lignosulfonate

Ca Lignosulfonate Adsorbed, G./100 G. Cement	Av. Sp. Surface, Sq. Cm./Gram	Apparent % Increase
Type I Cement: 90% Passing 325-Mesh Sieve; Sp. Surface in Kerosene, 1690 Sq. Cm./Gram		
None	1150	..
0.2	(1505)	31
0.3	1570	37
0.4	(1685)	47
0.5	1705	48

Calcium lignosulfonate is a colloidal electrolyte which ionizes in solution to give metallic cations and lignosulfonate anions. The study showed that it is the adsorption of the lignosulfonate anions by the cement particles that gives them the negative charge. Having a like electrostatic charge, the particles repel each other, resulting in cement dispersion.

1 A.C.I.Journal Feb. 1943, pages 358-362 for fulller description and effects of cement dispersion.

2 Industrial and Engineering Chemistry — June 1945, pages 598-600.

FLOCCULATED

PHOTOMICROGRAPHS
OF
CEMENT SUSPENSIONS
Illustrating Dispersion

Magnified 200 times

DISPERSED

Showing how cement particles clump together or flocculate when placed in water. By flocculating, many of the cement particles are only partly wetted and some are not wetted at all. Furthermore, when cement flocculates it bottles up a small amount of water inside the clumps.

Cement dispersion causes the clumps to break up and particles to separate. The first result of cement dispersion is that many more of the particles get wetted all over. This puts more of the cement to work. In addition, by breaking up the clumps the entrapped water is released and becomes part of the mixing water.

Truman Bridge, Kans. City, Mo. Consltg. Engrs. — Howard, Needles, Tammen & Bergendorff, Kans. City, Mo. Sub-Structure. Contrs.—Massman Const. Co., Kans. City, Mo. Super-structure Contrs.— American Bridge Co., Chicago, Ill. Pozzolith Concrete.

T.V.A. Bridge, Almond, N.C. 6,000 cu. yds. Pozzolith Concrete.

Fort Stanton Park Reservoir, Washington, D.C. Design Engrs.— Whitman, Requardt & Associates, Baltimore, Md. Contrs.— Baltimore Contractors, Baltimore, Md. 6,500 cu. yds. Pozzolith Concrete.

AUTHORITATIVE TESTS
show

POZZOLITH gives VASTLY GREATER DURABILITY with INCREASED STRENGTH

In an exhaustive investigation employing a range of cements typical of all U. S. Cements — (Full reports available for examination.)

1. Pozzolith increased DURABILITY —

SEA WATER — after 142 Cycles of Outdoor Freezing and Thawing

Nominal Cement Factor — Sacks		
6	Plain Concrete — of 39 beams tested	15 survived
6	Pozzolith " — " 77 " "	76 survived

FRESH WATER — In Laboratory — Freezing and Thawing

		After Average No. Cycles	Average Durability Factor	Average Change in Dynamic E
4½	Plain Concrete	49	17	—31
4½	Pozzolith "	139	63	—21
6	Plain "	50	20	—32
6	Pozzolith "	176	80	—10

	6 Sack Mixes	4½ Sack Mixes
2. Pozzolith increased STRENGTH —		
3-day Compressive	50%	70%
28-day "	12%	25%
3. Pozzolith cut BLEEDING	55%	60%
4. Pozzolith cut WATER-CEMENT Ratio	14%	15%

TEST REPORTS FROM OTHER SOURCES

Strengths at Later Ages

Pozzolith concrete, cement dispersed, continues to increase in strength over the long periods. The following compressive strength tests on Pozzolith concrete employed on Ansco Buildings, Binghampton, N. Y., are reported by Cornell University.

C/F	W/C	SLUMP	COMPRESSIVE STRENGTH — DAYS 3	7	28	90	6 mos.	12 mos.
5.85	5.69	5"	3115	4440	5765	7580	8320	8370

Tests of Pozzolith Concrete made and reported by Milton Hersey Co., Ltd., Montreal, Canada, industrial chemists, engineers and inspectors are:

Lbs. Cement	Lbs. Water	Slump	COMPRESSIVE STRENGTH — DAYS 3	7	14	28	12 mos.
355	273	4"	1115	1575	1995	2335	3285
680	282	4"	3750	4265	4910	5370	7070

Tests of Pozzolith Concrete made and reported by Smith-Emery Co., Los Angeles, inspecting and testing engineers are:

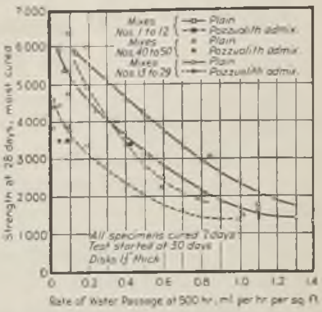
C/F	W/C	SLUMP	MODULUS OF RUPTURE — P.S.I. — DAYS 3	7	28	60	6 mos.	12 mos.
5.50	5.44	2.25"	515	537	658	716	750	791
4.95	6.00	2.00"	507	517	625	680	708	735

Pozzolith Reduces Bleeding

	PERCENT BLEEDING			
	Cement Factor—4.5 sacks/cu. yd.		Cement Factor—6.0 sacks/cu. yd.	
ADDITION	Cement Y	Cement Z	Cement Y	Cement Z
None	100	100	100	100
Air-entraining Agent A	52	49	42	34
Air-entraining Agent B	59	56	49	49
Pozzolith	55	57	25	20

POZZOLITH DECREASES PERMEABILITY

"With the same water-cement ratio, a change in the water percentage (space occupied by water at the time of mixing) by the use of water-reducing agents or by varying the aggregate characteristics will have little effect upon watertightness when measured by low-head (liquid) flow. This leakage varies with the strength of the concrete. In the tests shown herein, a commercial admixture "Pozzolith" permitted a reduction in mixing water; this permitted a reduction in cement content for the same strength. An improvement was noted in the capillary resistance of the concrete containing the Pozzolith (even at the same strength)". *1*



PLOTTED SUMMARY OF TESTS[1]
Relationship between 28-day strength and rate of water loss at 500 hr. Since all tests were made from concrete of plastic consistency, these data indicate an improvement in resistance to capillary movement of water with increase in strength. Pozzolith, used because it reduced water requirement, made an added improvement.

POZZOLITH INCREASES BOND STRENGTH

Bond Strength of Concrete To Steel
Lbs./Sq. In. of embedment at Slip of 3 x 10—

	CEMENT Y		CEMENT Z	
Addition	4.5 sks/cu. yd.	6.0 sks/cu. yd.	4.5 sks/cu. yd.	6.0 sks/cu. yd.
None	354	412	423	470
Air-entraining Agent A	270	412	300	473
Air-entraining Agent B	230	355	342	496
Pozzolith	430	582	302	638

POZZOLITH HOLDS THE CONCRETE IN A PLASTIC STATE WHILE THE CONCRETE IS STANDING OR IN TRANSIT

"Concrete aggregates were shipped by rail from Portland to a point on Clatsop spit about 3½ miles from the end of jetty, where the concrete was mixed. Transportation to the work was in 4-cu. yd. bottom dump buckets, four being placed on each of 3 standard gauge railroad flat cars.

The grading of aggregates and the mix were in accordance with standard government specifications, and provided for at least 4½ sacks of cement (Fed. Spec. SS-C-206) per cu. yd. The contractor was allowed to use an admixture of Pozzolith, at his own expense, to provide greater workability, as the long journey over the rough railroad track otherwise made it difficult to dump the concrete on arrival at the work. The finished concrete structure has now been through three severe winter seasons and does not show any deterioration or cracks." *2* See photograph opposite page.

1 Methods for Measuring the Passage of Water through Concrete. W. M. Dunagan, Associate Professor of Theoretical and Applied Mechanics, Iowa State College, Ames, Iowa. Proc. ASTM Vol. 39, 1939, pages 866-880.

2 Pacific Builder and Engineer, April 1944 issue, Pages 41-44 on "Placing a Heavy Concrete Terminal on the South Jetty of the Columbia River" by R. E. Hickson, Head, Rivers and Harbors Division, Portland District, U. S. Army Engineers.

AIR ENTRAINMENT

. . . In Structural Concrete

Pozzolith in addition to its basic action of cement dispersion, automatically entrains 3% to 4% total air which is the optimum amount with respect to increased durability and strength and improvement of the other properties of concrete, including economy These advantages are obtained with Pozzolith *without the need of constant watching on the job.*

The authoritative tests previously referred to, made by the Nation's highest testing authority, show that with Pozzolith, using 13 different cements in 6 sack and 4½ sack mixes, the total average air, regardless of slump, ranged from 3.07% to 3.75%.

. . . In Flat Slab Construction

For pavement in freezing climates some believe that air contents greater than 3% would be desirable, sometimes even if it means the sacrifice of other desirable properties of the concrete. These higher air contents can be entrained by the use of our HP-7 with no increase in cement content, yet without any loss in strength or other essential value as has been demonstrated in highway pavements and on aircraft landing strips laid with HP-7 in Ohio and Michigan. [1]

HP-7 is a combination of the cement dispersing agent calcium lignosulfonate and the effective wetting agent, sodium lauryl sulfate (Orvus), and successfully meets current air-content and durability requirements with increased strengths due to the more effective utilization of the cement.

← Concrete Terminal on the South Jetty of the Columbia River. U. S. Army Engineers. Pozzolith Concrete.

Gulf, Colorado & Santa Fe Railway Underpass, Ft. Worth. Tex. Engrs.—Private Plans. Gen. Contrs.— Martin & Grace, Dallas, Tex. Pozzolith Concrete furnished by Ft. Worth Sand & Gravel Co., Ft. Worth, Texas.

↓

1 A.C.I. Journal, Feb. 1944, pages 358-361 for data on HP-7.

BENEFITS OF CEMENT DISPERSION IN CONCRETE FLOOR CONSTRUCTION, MASONRY MORTARS, EQUIPMENT GROUTING & CONCRETE REPAIR

Concrete Floor Wearing Surfaces: Metallic aggregates (Master Builders Metallic Hardner and Metalicron) have been widely used for industrial concrete floor wearing surfaces for over thirty years. The useful life of this type of floor was vastly increased through the development in 1938 of Masterplate, a combination of scientifically graded metallic aggregates with cement dispersion. One hundred and twenty pounds of this wear-resisting metal aggregate is now incorporated easily with low water cement ratio where formerly the limit was approximately 40 lbs. per square. This heavily armored surface vastly increases the durability of concrete floors,[1] so that Masterplate concrete floors have been adopted in many industries where previously concrete floors had not been adequate.

Furthermore, a Masterplate floor provides for static dissemination and reduces sparking to a minimum. This has resulted in the wide use of Masterplate in areas requiring maximum safety, particularly in industries with explosive processes, and in Army and Navy magazines and storehouses.[2] Masterplate floors meet the safety requirements of leading fire insurance companies.[3]

1 National Bureau of Standards Research Paper No. 1252, November 1939.

2 Construction Methods, Sept. 1945, Page 98 for use of Masterplate in rocket plant as protection against sparking.

3 "Handbook of Fire Protection"— 1941 Edition, National Fire Protection Ass'n.

The Aluminum Co. of Canada, Ltd., Arvida, Que. Plans by Owners Engrs. Contrs.— Foundation Co. of Canada, Ltd., Montreal, Que. 300,000 cu. yds. Pozzolith Concrete.

LESS HAZARDOUS AREAS in hazardous buildings are given monolithic metallic finish on concrete floors as protection against sparking. In accordance with specifications, dry mixture consisting of metal aggregate (free from non-ferrous metal particles), cement dispersing agent and pozzuolanic material capable of combining with free lime to form water-insoluble compound is applied to freshly screeded concrete surface at 90 lb. per 100 sq. ft., and floor is finish-compacted by motor-driven disk-type float.

MASTER VIBRATORY FINISHING SCREED

- **How it provides accurate strike-off and compaction in a single easy operation.**
- **How it finishes over 6,000 sq. ft. per hour.**

Note. Hand-drawn Vibratory Finishing Screed, in the main photograph, control throttle at right end provides easy regulation of vibrating speed. The small illustration above shows a 26′ Vibratory Finishing Screed working in California on a 25′ pavement strip of 11″ thickness . . . and finishing strip in one pass. Pavers are 34-E single and 34-E dual drum.

Master Vibratory Finishing Screed works only part time to take care of pavers' output. Moves forward at 6′ per min. One screed should handle two dual drum pavers for maximum efficiency on this type of strip. Reports indicate that finishing done by Master screed equals two screed type tamper-equipped finishing machines obtaining better compaction and requires less cement finishers.

★ ★ ★

Master 25′ Vibratory Finishing Screed, below on the job at San Bernardino, Cal. Note. Screed is attached to box spreader by two cables.

PURPOSE AND RESULTS OBTAINED THEREBY

Here, at last, is a machine so simple that the average laborer with little mechanical knowledge can understand . . . yet get desirable results never obtained before by other methods. The Master Vibratory Finishing Screed is so designed that through the application of vibration on concrete slabs, maximum density, strength and minimum surface variations are obtained. It also allows the placing of concrete with low water content, thereby gaining greater internal strength in the concrete structure.

The Screed in striking off operation rests on pre-set forms or guides and leaves the surface of the slab with corresponding true alignment The Master Screed vibrates uniformly throughout its entire length up to maximum sizes built, assuring uniform compaction and eliminating the element of error due to labor.

The light weight of the Master Vibratory Finishing Screed makes it satisfactory for manual operation on such work as: Highways, concrete floors and other types of slabs; Airport runways, aprons, hangar floors; Warehouse floors; Dock decks; City street paving; Sidewalks; Industrial plant drives; Canal inverts; Bridge decks; Concrete roofs; and many other applications. In addition, the Master Screed is the only highway slab finishing screed that can produce a true parabolic curve crown. All sizes of Master Screeds can be built for any type of crown or invert.

DESIGN: The Master Vibratory Finishing Screed is a simple, sturdy all-steel, vibrating strike-off screed, consisting of a steel Tee-shape and vibrating member spanning the slab, supported at either end by adjustable spring-mounted steel shoes which travel on the forms or guides between which the concrete is deposited.

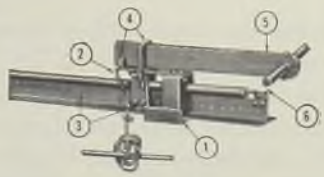
MASTER VIBRATOR FINISHING SCREED *(Continued)*

Centrally located is a vibrating element securely fastened to the Tee section and driven by an air cooled gasoline engine or electric motor through a Master automatic clutch and Vee belt drive. Vibrations are adjustable from 2000 to 6400 per minute through the use of the engine throttle, thereby providing means of applying the number of vibrations per minute that produces the most satisfactory results in the concrete being used. The spring-mounted end shoes are adjustable for various widths by close drilled holes in the main member (see diagram at right).

The screed is furnished with Draw Ropes at either end for forward or backward movement. Generally on units up to 16 feet long, two laborers are all that are required. Longer screed may require up to four laborers. Weights have been reduced to the minimum, a 20 foot Vibratory Finishing Screed weighing 380 pounds and smaller sizes correspondingly lighter. Movement of the screed from one location to another is quickly made by use of the carrying handles furnished with screed.

Vibratory screeds to finish slabs of 6 ft., 10 ft., 13 ft., 16 ft., 20 ft., 25 ft., and 26 ft. are standard—longer lengths built to order. All standard screeds adjust down 7′ 6″ from maximum length, except VS-6 (6′ screed), which adjusts down 3′ 6″. More adjustment can be obtained by drilling vibratory beam in field.

For further details write for Master Bulletin 596



1. Adjustable spring mounted shoes. 2. 2-way draw. 3. Easy adjustment for length. 4. Yoke for lifting. 5. Lifting handle. 6. Remote engine control.

MASTER COST-SAVING EQUIPMENT—FOR IMMEDIATE DELIVERY

Gas or Electric Concrete Vibrators (Catalog No. 689)

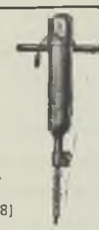
Hand Tools for operating from all Master Vibrators and BIG-3 (Catalog No. 683)

BIG-3 for Generation, Tool Operation and Concrete Vibration (Catalog No. 687)

Portable Gas-Electric Generator Plants. Sizes 500 to 17000 Watts (Catalog No. 594)

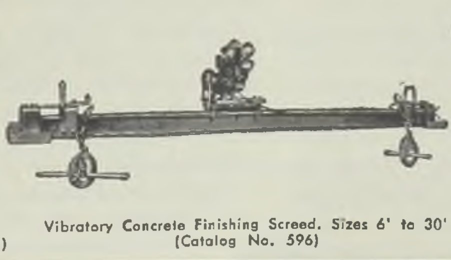
General Purpose Floodlights

"Power-Blow" Electric Hammer and Spade (Catalog No. 688)

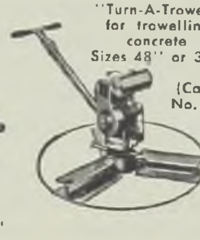


Electric Pavement Breaker (Cat. No. 718)

Gas or Electric Back-Fill Tampers (Catalog No. 699)



Vibratory Concrete Finishing Screed. Sizes 6' to 30' (Catalog No. 596)



"Turn-A-Trowel" for trowelling concrete Sizes 48" or 34" (Catalog No. 685)

Send for illustrated catalog on any item to

MASTER VIBRATOR COMPANY

DAYTON 1, OHIO

Test No.	Without "Anti-Hydro"				With 1½ Ga. "Anti-Hydro" Per Cu. Yd.			
	Slump, Inches	Wt. (Lbs.) Per Cu. Ft.	Strength psi. 7 Days	Strength psi. 28 Days	Slump, Inches	Wt. (Lbs.) Per Cu. Ft.	Strength psi. 7 Days	Strength psi. 28 Days
1	2.0	151.1	2440	3560	2.75	150.1	2650	3780
2	2.0	151.1	2420	3820	3.00	150.6	2670	3700
3	2.25	151.1	2440	3540	3.00	151.7	2560	3640
Avg.	2.08	151.1	2433	3640	2.92	150.8	2627	3707

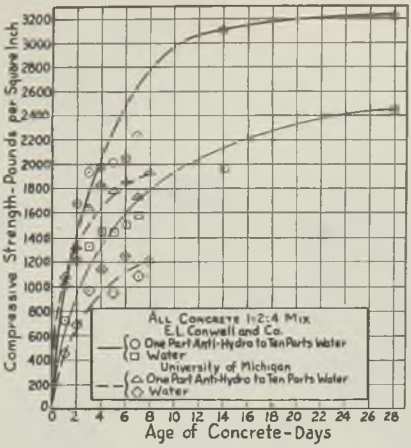
"Anti-Hydro" also increases the tensile strength of portland cement mixtures. This has important bearing upon the bonding qualities of "Anti-Hydro," which were tested by Raymond G. Osborne Laboratories of Los Angeles, California. "This test was made for the purpose of determining the degree of bond possible between a layer of poured concrete to be used as topping and the old concrete floor slab." Smith-Emery Company of Los Angeles reporting on the shear tests state that "the failure in all cases was in the old concrete. There was no apparent failure of the bond." N. B. The bonding material was a thin portland cement grout mixed with "Anti-Hydro" according to specifications.

Increased compressive strength of all ages may be obtained with any standard brand of portland cement through the addition of "Anti-Hydro" to the concrete mix.

The graph shows comparative curves with and without "Anti-Hydro" in the mix as reported by E. L. Conwell & Company, Philadelphia, and Dept. of Engineering Research, University of Michigan, which are representative of innumerable comparative "Anti-Hydro" tests.

"Anti-Hydro" protects reinforcing steel from corrosion. E. L. Conwell & Company, Philadelphia, state in their report of October 9, 1928, "Specimens exposed to the weather up to four weeks showed no sign of corrosion on the steel in mixes containing 'Anti-Hydro.'"

Another function of "Anti-Hydro" is its added protection against frozen concrete and masonry in



winter construction, and the earlier use of the concrete. The H. C. Nutting Company reports on a series of cylinders which, during the initial 24 hours, were kept at 15° F. Of 7 without "Anti-Hydro," 3 were frozen. One (1) containing "Anti-Hydro" out of a total of 7 tested, was found "slightly frozen," but subsequently reached its normal strength.

It is in place to refer to permeability tests on mortars and to permeability and compressive strength tests in which "Anti-Hydro" gauged mixtures were shown to be impermeable while increasing the compressive strength of the concrete, at all ages reported. Many calcium chloride products in these same reports were shown to produce more permeable concrete than the standard untreated concrete of the same mix.

Many admixtures and Special types of cement have been offered from time to time for specific purposes of increased workability, strength, impermeability, dispersion or surface curing. Anti-Hydro has produced impermeable concrete of increased strength and has functioned as a durability and internal curing agent over a long period of years with uniformly satisfactory results.


PLASTIMENT
"The Concrete Densifier"
Sika
SIKA CHEMICAL CORPORATION

T. P. S. ADVERTISERS

ACI NEWS LETTER

Vol. 17 No. 4 JOURNAL of the AMERICAN CONCRETE INSTITUTE February 1946

—To provide a comradeship in finding the best ways to do concrete work of all kinds and in spreading that knowledge.

42nd Annual Convention

Monday, Tuesday, Wednesday and Thursday February 18, 19, 20 and 21, 1946

HOTEL STATLER

ADMINISTRATIVE MEETINGS

Advisory Committee, STANTON WALKER, Chairman.
9:30 a. m., Monday, February 18, Grover Cleveland Room

Board of Direction—12:30 (noon) Monday, February 18, Grover Cleveland Room for lunch and continuing afternoon and evening.
(The newly elected Board) 1 p. m. Thursday, Feb. 21, or immediately following adjournment of convention.

TECHNICAL COMMITTEE MEETINGS

(see also Bulletin Board at Registration Desk)

Committee 318, Standard Building Code, A. J. Boase, Chairman, Roy R. Zipprodt, Secretary, 9:30 a. m. Tuesday, February 19, with the expectation of continuing its labors the afternoon of the 21st following the adjournment of the convention and possibly through Friday, the 22nd.

Committee 318, Sub-committee 5, John R. Nichols, Chairman, will meet following first general convention session.

Committee 604, R. W. Spencer, Chairman, will meet—see bulletin board.

Committee 711, Precast Floor Systems for Houses, F. N. Menefee, Chairman, 10:30 a. m. February 19.

CONVENTION REGISTRATION

(All registered non-member visitors are welcome at general sessions—no registration fee)

9.30 A. M. TUESDAY, FEBRUARY 19 TO NOON FEBRUARY 21

Foyer, Niagara Room

in charge of

ETHEL B. WILSON, Assistant Secretary

See Bulletin Board for special notices.

Buy your tickets Tuesday if you wish to attend Luncheon, Wednesday noon
(tickets $2.00, include tips)

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12 noon sharp, LUNCHEON for all announced **program participants** in the sessions of Tuesday afternoon and evening. Presiding officers, Session Leaders, Chairman and Secretary Publications Committee and those who are to present papers or committee reports at the **Tuesday General Sessions of the Convention.**

2.00 P. M. TUESDAY, FEBRUARY 19

President DOUGLAS E. PARSONS, Chairman

Appointment of Tellers, to canvass ballots of the Annual Election.

"Proposed Minimum Standard Requirements for Precast Concrete Floor Units"

Report of Committee 711, F. N. MENEFEE, Charman
Presented by reference (ACI Jl. January, 1946) on a motion for adoption as an ACI Standard

NEW DEVELOPMENTS IN CONCRETE DESIGN METHODS

A. J. BOASE, Session Leader
Manager Structural Bureau, Portland Cement Association

"Radiant Heating by Reinforced Concrete"

JOHN R. NICHOLS
Consulting Engineer, Boston

There is evidence, Mr. Nichols believes, that radiant heating pipes in structural concrete will not be as destructive as an atomic bomb. Since there is great value and convenience in this heating method, he believes the prohibiting codes must be scrutinized to make sure that progress is not needlessly impeded.

"The Lattice Analogy in Concrete Design"

DOUGLAS McHENRY,
U. S. Bureau of Reclamation

The author will show that many complicated problems in stress distribution can be solved by a method which involves only simple arithmetic. The field of application of the lattice analogy is comparable to that of the photoelastic polariscope, but the elaborate equipment of photoelasticity is replaced by an ordinary computing machine.

"The Use of Prestressed Concrete in Floating and Land Structures"

HENRI MARCUS,
Bureau of Yards and Docks, Navy Department

This paper describes the design and construction of a concrete barge in which prestressed reinforcing steel was used. It includes a brief discussion of laboratory tests of prestressing which preceded the design.

"Hipped Plate Construction"

GEORGE WINTER,
Assistant Professor of Civil Engineering, Cornell University

The author will describe a method of design which utilizes effectively the monolithic continuous character of concrete. This type of construction, known abroad as "Faltwerke," has been little used in this country. Professor Winter has had occasion to design and see several substantial structures of this type erected during a number of years spent as a consultant in Russia.

8.00 P. M. TUESDAY, FEBRUARY 19

Vice President, HARRISON F. GONNERMAN,
Chairman

ENTRAINED AIR IN CONCRETE

F. H. JACKSON, Session Leader
Principal Engineer of Tests, Public Roads Administration

"Laboratory Studies of Concrete Containing Air-Entraining Admixtures"

By C. E. WUERPEL,
Engineer in Charge, Central Concrete Laboratory, North Atlantic Division, U. S. Corps of Engineers

Mr. Wuerpel's lead contribution to the symposium will epitomize the high points of two recent papers published in the ACI Jl.: in September, 1945, field experiences of the War Department; in the current February issue the results of a considerable laboratory investigation (both papers available in separate prints; copies available at registration desk for those who wish to participate in discussion).

TEN—10-MINUTE CONTRIBUTIONS TO THE SESSION THEME

"INDIANA EXPERIENCES IN HIGHWAY CONSTRUCTION"
S. W. BENHAM, Indiana Highway Commission.

"RESULTS OF RECENT LABORATORY STUDIES"
STANTON WALKER, Director of Engineering, National Sand and Gravel Association.

"FIELD EXPERIENCES IN THE NORTHEASTERN STATES"
LEE ANDREWS, Portland Cement Association.

"A MECHANICAL DISPENSING DEVICE FOR AIR-ENTRAINING AGENT"
E. M. BRICKETT, Dewey and Almy Chemical Co.

"A DEVICE FOR MEASURING ENTRAINED AIR IN CONCRETE"
W. H. KLEIN, Vice-President and General Manager, Pennsylvania-Dixie Cement Corp.

"ENTRAINED AIR—A FACTOR IN THE DESIGN OF CONCRETE MIXES"
W. A. CORDON, Engineer, U. S. Bureau of Reclamation.

"EXPERIENCES IN READY MIX OPERATIONS"
ALEXANDER FOSTER, Jr., Warner Company.

"EXPERIENCES IN PENNSYLVANIA HIGHWAYS"
W. H. HERMAN, Chief Research Engineer, Pennsylvania Department of Highways.

"TESTS WITH BLENDS OF NATURAL AND PORTLAND CEMENTS"
W. F. KELLERMANN, Senior Materials Engineer, Public Roads Administration.

"RECENT TEST RESULTS"
HENRY L. KENNEDY, Manager Cement Division, Dewey and Almy Chemical Co.

8 A. M. WEDNESDAY, FEBRUARY 20

8 A. M. BREAKFAST for announced program participants in the session of Wednesday afternoon: Presiding officers, Session Leaders, Chairman and Secretary Publications Committee and those who are to present papers or Committee reports at the general session Wednesday afternoon.

9.30 A. M. WEDNESDAY, FEBRUARY 20

CONCRETE RESEARCH

An Open Session of ACI Committee 115, Research

MORTON O. WITHEY, Chairman; FRANK E. RICHART, Vice-Chairman, S. J. CHAMBERLIN, Secretary

Past-President FRANK E. RICHART, Presiding

This annual session has grown in importance since its inauguration at the Institute's 33rd Annual Convention in New York in 1937. As in former years there is no stenotypist to record the series of brief papers or informal reports on concrete technics and initial results in projects under way. Most of those contributing are doing so with the understanding there will be

no published record except as specific release is made to the Institute for its subsequent publication. Some laboratories do not want publicity until investigations are complete for a fully considered record. With this understanding Members and non-members attending the convention will be welcome at this open committee session. The only way to be sure of what the session develops is to be there.

12 O'CLOCK NOON, WEDNESDAY, FEBRUARY 20, ACI LUNCHEON

This luncheon is for ACI Members and friends who bought their tickets Tuesday or early enough Wednesday morning to "get their noses in the pot" as the old saying goes. The price is $2.00 and that includes the "tip." Gather around the board with your old or new friends and save time in these restaurant-crowded days.

2 P. M. WEDNESDAY, FEBRUARY 20

MAINTENANCE AND REPAIR OF CONCRETE

Vice-President STANTON WALKER, Chairman

RODERICK B. YOUNG, Session Leader
Hydro-Electric Power Commission of Ontario

presenting an introductory paper on the general theme

"Two Special Methods of Restoring and Strengthening Concrete Structures"

J. W. KELLY
Associate Professor of Civil Engineering, University of California

and B. D. KEATTS
Engineer, Intrusion-Prepakt Inc.

See ACI JOURNAL, February, 1946 (or separate print) where Messrs. Kelly and Keatts descrive methods of repairing masonry structures, by which the old deteriorated mortaris washed from the masonry, in successive steps, and replaced with firm grout. Other restorations are made by consolidating aggregate, placed in patched areas of defective concrete,with grout forced into the voids of the aggregate.

"Maintenance of Heavy Concrete Structures"

CLAY C. BOSWELL and ALBERT C. GIESECKE
Minnesota Power & Light Co.

See ACI JOURNAL, February 1946 (or separate print) for the paper describing repair methods on a dam and contrasting the construction methods with those which have made repair unnecessary on a similar but older structure.

"Maintenance and Repair of Portland Cement Concrete Pavements"

A. A. ANDERSON

Manager Highways and Municipal Bureau, Portland Cement Association

Maintenance and repair methods and the equipment used are described and well illustrated.

"Repair of Concrete Chimneys with Minimum Boiler Operation Interference"

W. M. BASSETT

Engineer of Structures, New England Power Service Co.

and MILES N. CLAIR

Vice-President, The Thompson & Lichtner Co., Inc.

The title carries an important consideration of the job reported—the effort to avoid, so far as possible, stoppage of operations while repair was under way.

"Hydraulic Structure Maintenance Using Pneumatically Placed Mortar"

W. L. CHADWICK

Chief Civil Engineer, Southern California Edison Co.

Mr. Chadwick's contribution features methods which are the subject of study by ACI Committee 805, assigned to the preparation of practice recommendations for the application of mortar by pneumatic pressure—a committee of which the author is chairman. The paper, giving the experiences of the Southern California Edison Company, which maintains concrete structures high in the Sierra Mountains, will be presented by R. W. Spencer, Civil Engineer of the company.

"Maintenance and Repair of Concrete Bridges on the Oregon Highway System"

G. S. PAXSON

Bridge Engineer, Oregon State Highway Department

See ACI Journal, November, 1945 (or separate print) where this illustrated paper was published. It describes restoration procedures, followed by waterproofing treatments which have effectively stopped progressive deterioration of the concrete. This paper will be presented by R. F. Blanks, U. S. Bureau of Reclamation.

DINNER 6.15 P. M. WEDNESDAY, FEBRUARY 20

DINNER for announced participants in the sessions scheduled for Wednesday evening and Thursday morning:] Presiding Officers, Session Leaders, Chairman and Secretary Publications Committee and those whose names appear as contributors to these two sessions.

8.00 P. M. WEDNESDAY, FEBRUARY 20

President DOUGLAS E. PARSONS, Chairman

Report of Tellers on the Annual Election of Officers and other members of the Board of Direction and of the members of the 1946 Nominating Committee.

Presentation of Awards by President Parsons:

LEONARD C. WASON, Medal for "Noteworthy Research" to

BARTLETT G. LONG, HENRY J. KURTZ and THOMAS E. SANDENAW

for the work reported in their 1945 paper:
(January JOURNAL)

"An Instrument and a Technic for Field Determination of the Modulus of Elasticity and Flexural Strength of Concrete (Pavements)"

LEONARD C. WASON Medal for the "Most Meritorious Paper" of ACI Proceedings Volume 41 (February, 1945, JOURNAL) to

CLARENCE RAWHOUSER
for his paper

"Cracking and Temperature Control of Mass Concrete"

American Concrete Institute Construction Practice Award for "a paper of outstanding merit" on concrete construction practice to

LEWIS H. TUTHILL

for his contribution to the January 1945 JOURNAL of the American Concrete Institute:

"Concrete Operations in the Concrete Ship Program"

The HENRY C. TURNER Medal
"for notable achievement or service" to

JOHN LUCIAN SAVAGE

"in recognition of long and distinguished service in the design of hydraulic structures, including some of the world's most notable dams."

ROBERT F. BLANKS, Chairman Publications Committee, Presiding

Address by the Retiring President

DOUGLAS E. PARSONS,
Chief, Division of Clay and Silicate Products,
National Bureau of Standards

"Curing Concrete with Sealing Compounds"

ROBERT F. BLANKS, H. S. MEISSNER and LEWIS H. TUTHILL

United States Bureau of Reclamation

This paper to be presented by Mr. Meissner supplies data evaluating concrete curing by membrane treatment in terms of equivalent moist curing. It discusses the preferred methods of curing by use of sealing compounds and outlines a specification and acceptance test for their purchase.

"Behavior of Concrete Structures under Atomic Bombing"

CAPTAIN E. H. PRAEGER (CEC), USNR

Captain Praeger, formerly design manager of the Bureau of Yards and Docks, has recently returned from Japan, where he inspected the results of atomic bombing. His paper will be illustrated by steropticons and the ACI audience will have an opportunity to learn what the effects are of the world's greatest weapon of destruction.

"Should Portland Cement Be Dispersed?"

T. C. POWERS

Manager of Basic Research, Portland Cement Research Laboratory

a brief epitomization of a paper published in The ACI JOURNAL for November 1945—also available in separate prints.

9.30 A. M. THURSDAY, FEBRUARY 21

ROBERT F. BLANKS, Chairman

NEW DEVELOPMENTS AND WAR EXPERIENCES IN CONCRETE CONSTRUCTION METHODS

LEWIS H. TUTHILL, Session Leader

"Proposed Recommended Practice for the Construction of Concrete Farm Silos"

Report of Committee 714, WILLIAM W. GURNEY, Chairman

Presented by reference (see ACI JOURNAL Jan. 1944 and revisions Jan. 1946) on a motion for adoption as an ACI Standard.

"Using Coral Aggregates at the Advanced Bases of the Navy"

Commander I. S. RASMUSSEN (CEC) USNR

Commander Rasmussen has been on many projects where coral aggregates have been used in the construction of advanced bases. The Navy has made best use of the materials at hand as our armed forces fought the hard road back and Commander Rasmussen will tell us about it.

"Precast Concrete Structures"

A. AMIRIKIAN,

Principal Engineer, Bureau of Yards and Docks, U. S. Navy

This paper will deal with the application and principles of precasting to such specific structures as storehouses, barges, floating caisson gates, drydocks and hangars.

"Thin Wall Concrete Ship Construction"

F. R. MacLEAY,

Chief Engineer, Corbetta Construction Co.

As a sequel to Mr. Amirikian's paper the author presents the developments of construction methods for pouring thin concrete walls. These methods (illustrated) were successfully used in the construction of concrete leading craft.

"H-Beam and Prepakt Method of Pier Construction"

C. P. DISNEY,

Bridge Engineer, Canadian National Railways

Mr. Disney will discuss a projected plan of rebuilding the Quebec Bridge and reconstruction of many bridges, using a novel method for building piers around central H-beam piles.

"Harnessing the Atmosphere for Concrete Construction"

V. S. MURRAY,

Bridge Engineer, Ontario Department of Highways

With film, this author will illustrate how vacuum methods are used to precast and erect light-weight precast structural units.

"Observations on a Post-War European Journey"

MYRON A. SWAYZE,

Director of Research, Lone Star Cement Corp.

Mr. Swayze was in Germany last summer and members of ACI will enjoy hearing this informal report by one who would note the things that other engineers would like to hear about.

— Adjournment —

ACI Awards Announced

Acting on the report of its Medals Award Committee, the Board of Direction announces:

To John Lucian Savage, a member of the staff of the United States Bureau of Reclamation for 34 years and since 1924 it's Chief Designing Engineer:* the Henry C. Turner Medal (founded 1927 by Past President Turner) "to be awarded annually, but not more often, for notable achievement in or service to" the field of concrete.† The medal is of gold and is accompanied by a certificate of award bearing, in the present instance, this citation:

> *"in recognition of long and distinguished service in the design of hydraulic structures including some of the world's most notable dams."*

To Bartlett G. Long, Henry J. Kurtz and Thomas E. Sandenaw,‡ the Leonard C. Wason Medal for noteworthy research as reported in their Institute paper:

> *"An Instrument and a Technic for Field Determination of the Modulus of Elasticity and Flexural Strength of Concrete (Pavements)."*

published ACI JOURNAL January 1945. The bronze medal (in triplicate) is accompanied in its presentation to each of the authors, by a certificate of the award.

To Clarence Rawhouser, of the Bureau of Reclamation, the Leonard C. Wason medal for each year's "most meritorious paper" on the basis of his

> *"Cracking and Temperature Control of Mass Concrete"*

published ACI Journal, February 1945. The bronze medal is in its presentation accompanied by a certificate of the award.*

The Wason medals were founded by Past President Wason (the Institute's second president, 1915-1916) in 1917.

To Lewis H. Tuthill, of the Bureau of Reclamation* the first American Concrete Institute Construction Practice Award, founded 1944 for "a paper of outstanding merit on concrete construction practice": This is based on Mr. Tuthill's paper:

> *"Concrete Operations in the Concrete Ship Program"*

Mr. Tuthill will receive with his certificate of award U. S. Series E Bonds of a maturity value of $300.00.

Presentation of these awards will be from the hands of President Parsons, the evening of February 20, at the Institute's 42nd Annual Convention (see program in these pages).

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*See brief biographical sketch in pages which follow.

†Previous Turner Medalists: Arthur N. Talbot, 1928, William K. Hatt, 1929; Frederick E. Turneaure, 1930; Duff A. Abrams, 1932; John J. Earley, 1934; Phaon H. Bates, 1939; Ben Moreell, 1943.

‡For biographical notes on the authors see following pages.

The Medalists

John Lucian Savage—Turner Medal

John L. Savage was born on a Wisconsin farm near Cooksville, Dec. 25, 1879. In 1903 he received a B. S. degree in Civil Engineering at the University of Wisconsin. For 34 years he has been a member of the Bureau of Reclamation staff, and since 1924 has been its Chief Designing Engineer. His service with the Bureau began on the Minidoka Project in Idaho after graduation from school. For four years he worked in the Boise office designing irrigation structures under the guidance of Arthur P. Davis, Chief Engineer, and A. J. Wiley, Consulting Engineer. In 1908 Mr. Savage left the Reclamation Service to become associated with Mr. Wiley in an engineering practice in Boise. He has been an ACI member since 1928.

During this time, he designed many important structural works including the Salmon River Dam, the Swan Falls Power Plant on the Snake River, the Barber Power plant on the Boise River, the Oakley Reservoir Dam, and the American Falls Power Plant. He also received a special assignment from the Reclamation Service to design gates for the Arrowrock Dam on the Boise River.

In 1916 Mr. Savage re-entered the Reclamation Service in charge of civil engineering designs in the newly organized office of the Chief Engineer at Denver, Col., where important design work of the Bureau is done. In 1924 he was placed in charge of all electrical and mechanical designing with the title of Chief Designing Engineer, the position which he held until his retirement, April 30, 1945.

Mr. Savage was the designing engineer on the three largest concrete dams in the world—Grand Coulee, Shasta, and Boulder. Other famous dams that he has designed include the Norris Dam in the Tennessee Valley, and the Wheeler, another of the key structures in the basis-wide development of that area; Friant Dam, important co-worker of Shasta Dam in the Central Valley Reclamation Project (California); and Madden Dam at the Panama Canal. The Marshall Ford Dam in Texas, Imperial Dam on the Arizona-California border, Parker Dam on the Colorado River, and American Falls Dam (Idaho) are among the numerous Reclamation dams he has designed.

At the request of the Chinese government, Mr. Savage in 1944 made extensive surveys for the postwar development of China's great natural resources, including the huge Yangtze Gorge Project to irrigate 10,000,000 acres of land and develop some 10,000,000 kilowatts of electric power capacity. He also spent several months in India, visiting projects for irrigation and other developments in the United Provinces, Bengal, Madras, Mysore, and the Punjab.

When a cable came from London in 1940 asking the United States for Mr. Savage's assistance in connection with the Burrinjuck Dam in Australia, attention was directed to the law which prohibits officials of the United States from accepting emoluments from foreign countries. Rather than delay the voyage in this emergency Mr. Savage wired former Commissioner John C. Page of the Bureau of Reclamation: "Any assistance given Government

John Lucian Savage

of New South Wales will be gratis and I shall not accept any fee or other form of compensation or any reimbursement." He said he needed a vacation, anyway.

In 1940, Congress passed a bill specifically authorizing the President to send Mr. Savage to Australia and India as an engineering consultant. He spent four months in Australia in 1941-42 as consultant on two projects—the Upper Yarra Dam for the Melbourne and Metropolitan Water Board of Works and the Kiewa Dam for the State Electricity Commission of Victoria.

Engineer Savage has been honored many times for his achievements. On his recent visit to China he received a gold medal from the Ministry of Economic Affairs for Humanitarian Services. The American Society of Civil Engineers last year awarded him the John Fritz medal, one of the highest honors of the Engineering profession. In 1934, the University of Wisconsin conferred upon him the honorary degree of Doctor of Science. He was presented in 1937 with one of the most prized awards given to anyone in the engineering profession—the Gold Medal for Outstanding Engineering Service of the Colorado Engineering Council, which represents all engineering organizations in the State. The award had been made but once in the previous ten years.

"Jack Savage in a very real sense has epitomized the Bureau of Reclamation. He grew up with the organization. His extraordinary gift is the ability to bring a fresh mind to new problems in engineering. His approach is daring, but his plans are sound. Neither the necessity of building the highest dam in the world in Boulder Canyon nor the requirement for the construction of the most massive concrete dam so far conceived at Grand Coulee on the Columbia River dismayed Jack Savage. He simply proceeded to design the dams, and they now are the pride of the engineering world."—Comments of Commissioner of Reclamation Harry W. Bashore on Mr. Savage's decision to retire at 65.

Mr. Savage has now been appointed Consulting Engineer for the Bureau of Reclamation, and is serving as Consulting Engineer for several foreign governments. One of the important works on which he will advise is the Yangtze Gorge Dam near Ichang, China, which structure will be larger than Grand Coulee.

Lewis Hamilton Tuthill—ACI Construction Practice Award

Lewis Tuthill was born in Philadelphia, November 24, 1899. He was graduated from Oregon State College with B. S. degree in Engineering in 1920. Since graduation, he has been continuously engaged in design and construction work on irrigation, water supply projects and the building of dams, with the technique and control of concrete as his primary and absorbing interest. His first employment was with the Grants Pass Irrigation District, in Oregon; next the Merced Irrigation District in California, where he was associated with the control of concrete on Exchequer Dam; and, following this, the same detail on Malones Dam for the Oakdale and South San Joaquin Irrigation District. After a year of private consulting practice, concrete control work on Pardie and Hogan Dams for the East Bay Municipal District and City of Stockton, California, next occupied his attention. During seven years with the Metropolitan Water District of Southern California, he prepared specifications for 4½ million yards of concrete work and materials, passed upon the acceptance of cement and various materials for the immense aqueduct from the Colorado River to the Los Angeles area, and prepared a manual of inspection. Since 1939 he has been a member of the staff of the Bureau of Reclamation, still pursuing the profession of concrete engineer, and assisting in editing the Bureau's Concrete Manual. During a leave of absence from the Bureau, he spent two of the war years supervising concrete quality on the U. S. Maritime Commission's concrete ship construction program. For a description of this work, he now receives the first A.C.I. Construction Practice award based on its record of good practice applicable to many other types of structure than ships.

Mr. Tuthill was Chairman of Committee 614, whose report on "Recommended Practice for Measuring, Mixing and Placing Concrete" became an ACI Standard in 1942. The ACI Honor-Roll records attest the fact that he has been a very active worker for new ACI members. His contributions to and wide knowledge of concrete construction practice led to his recent appointment to the Advisory committee, as Chairman of Department 600, Construction. He has been an ACI member since 1926.

Clarence Rawhouser—Wason Medalist

Clarence Rawhouser was born York, Pa., February 1, 1902. He entered the University of Cincinnati in 1921, and enrolled in the cooperative course in Civil Engineering. After an interruption by illness, of his formal training, he returned to the University and received the CE degree in 1930. His cooperative educational training extended even farther back than college days; through alternate work and school periods he completed apprenticeship in wood patternmaking with the York Ice Machinery Corp. while attending the Industrial Course in York High School.

In 1929 he received the Cincinnati Engineers' Club annual award to the outstanding senior of the U. of C. College of Engineering. He was employed by the U. S. Engineers Office of the War Department in Cincinnati for a year, where he was engaged in studies of flood control of the rivers of the Cincinnati District. He has been in the dam engineering division of the Bureau of Reclamation in Denver, since 1930. Since that time he has been directly concerned with the problems of temperature control, artificial cooling, and observation of structural behavior of all concrete dams constructed by the Bureau, beginning with the pioneering work of that nature on Boulder Dam. He has contributed materially to the plans and methods used for controlling the temperature of Seminole, Bartlett, Parker, Grand Coulee, Marshall Ford, Shasta, Friant, and Altus dams. For suggestions made for special temperature-control measures at Friant Dam he received a Department of Interior Award of Excellence. He has been an ACI member since 1937.

He obtained the MS degree in Civil Engineering from the University of Colorado in 1943. He is an Associate Member of the American Society of Civil Engineers and a member of Tau Beta Pi.

Bartlett G. Long, Henry J. Kurtz and Thomas Sandenaw—Wason Medalists

The three collaborating authors are all ACI members—Long since 1934, Kurtz since 1942, Sandenaw since 1943, all of them until recently actively identified with the Army Engineer Corps' Cincinnati Testing Laboratory, at Mariemont, Ohio.

"Bart" Long, well known to many ACI members, severed his connection with the laboratory in 1944 and he and Mrs. Long have since been at their ranch at Pecos, N. M.

Mr. Long was born in St. Louis, Missouri, Apr. 3, 1892. He attended the University of Missouri, from Sept. 1911 to June, 1912, and the Washington University, from Sept. 1912 to June, 1914. He was a first lieutenant in World War I from July 26, 1917 to May 2, 1919, having served as an instructor in the Air Service.

His professional experience includes employment by Nelson Cunliff, Engineer, and Park Commission, St. Louis, Missouri; Florida State Road Dept., Tallahassee; Woods-Hoskins-Young Co., Chicago; State Highway Department, Santa Fe, New Mexico; Bureau of Reclamation, Denver, Colo.; War Department, U. S. Engineers, Seattle; U. S. National Park Service, San Francisco; War Department, U. S. Engineers, St. Louis, and Mariemont, Ohio.

Mr. Kurtz was born in Flint, Mich., Jan. 8, 1897; was graduated from Michigan State College, B.S. in 1921, M.S. in 1928.

His professional experience includes employment by Consumers Power Co., Battle Creek, Mich.; Commonwealth Power Corp., Jackson, Mich.; Pacific Telephone & Telegraph Co., Sacramento, Calif.; Bell Telephone Laboratories, New York City; Remler Radio Co., Inc., San Francisco; National Bureau of Standards, Washington, D. C.; American Society for Testing Materials, Washington, D. C.; U. S. Coast Guard, Cambridge, Mass.; War Department, U. S. Engineers, Mariemont, Ohio.

Mr. Sandenaw took his B. S. in industrial chemistry from Montana State College in 1934; attended Ohio State University for graduate work in chemistry in 1935-36; was employed in the chemistry section United States Engineers laboratory Fort Peck, Montana; 1936-38, took an M. S. degree in chemistry from Carnegie Institute of Technology in 1939; analytical chemist in the U. S. Navy Inspection Laboratory, Marshall, Penna., 1939-41; employed in the chemical section of General Materials Laboratory, special engineering division, the Panama Canal, Diablo Heights, C. Z. 1941-43; in the concrete section Cincinnati Testing Laboratory, Mariemont, Ohio, 1943-44. From there he went to the RCA Victor Division of Radio Corp. of America as a chemist in the engineering department of the vacuum tube manufacturing plant.

WHO'S WHO

Clay C. Boswell and Albert C. Giesecke

collaborate in a paper describing repair methods on a dam (p. 377)—part of a 1946 convention session on concrete maintenance and repair.

Mr. Boswell, an ACI Member since 1934, is Vice President and Chief Engineer of Minnesota Power & Light Co. Graduating from Missouri University in electrical engineering in 1915, Mr. Boswell has been identified with various public utility operations almost continuously since that time. He served his country during World War I, spending almost a year in France in command of an anti-aircraft searchlight detachment.

Mr. Boswell is a Member, American Institute of Electrical Engineers, and active in many other professional and civic organizations.

Mr. Giesecke, has served as Hydraulic Engineer for Minnesota Power & Light Co. Duluth, Minnesota since 1923. Prior to that time he was identified with important work in Latin America; also with Utah Power & Light Co., Pacific Power & Light Co., and several irrigation projects in Utah, Washington and California. Mr. Giesecke served overseas in a machine gun combat unit during World War I,—also on General Staff assignments. His ability to speak both German and Spanish has been of substantial advantage to him in the practice of his profession. He is an Associate Member of American Society of Civil Engineers.

J. W. Kelly and B. D. Keatts

collaborated in the paper (p. 289), which is one of a series to be presented at the ACI Convention this month, on maintenance and repair of concrete structures.

Professor Kelly, who has much work to his credit in his 20 years of ACI Membership (see p. 69 ACI 1945 Directory) needs no introduction to his present audience.

Mr. Keatts has been an ACI member since 1942, was graduated from the University of Illinois in 1924 with the degree of B. S. in General Civil Engineering. His first work after graduating was in the planning and specification's office of the Illinois State-Highway Department at Springfield for one year, and then with the Bridge Department of the Missouri Pacific Railroad at St. Louis where a small part of his time was in preparing plans for concrete structures; most of it as Resident Engineer on bridge construction under contract. He also had charge of maintaining the railroad's two river ferries for freight train service at St. Louis, Missouri and at Natchez, Mississippi. After four and a half years with Missouri Pacific Railroad he went to Stone and Webster Engineering Corp. at Chicago for four years on the construction of equipment which was manufactured in the Chicago territory for installation in dams and industrial plants.

In the depression, he found haven with other engineers at the Century of Progress world's fair at Chicago, three years during the construction period, two years of operation, and part of the demolition period.

Next he was with the Portland Cement Association in the States of Illinois and Wisconsin—his engineering work with PCA on contacts and instruction with engineers, technicians, and builders in the construction field.

He has been with Intrusion-Prepakt, Inc. for six years in the field locating proper sources of materials and getting them to the various jobs, establishing new field, laboratory-developed methods, and working with customers' engineers on special reconstruction problems. On January 1, 1946 he was given charge of the company's activities in the Eastern States.

Charles E. Wuerpel

is already well known to the ACI audience. His paper (p. 305) his second recent contribution on air-entrainment—field experience (September 1945) and now laboratory results. He will draw from both for a brief epitomization to lead the convention session on that subject.

Gerald Pickett

appeared in the January Journal with part 1 of "Shrinkage Stresses in Concrete;" Part 2 starts page 361.

Honor Roll

February 1, 1945 to January 24, 1946

Rene Pulido y Morales, in Havana, Cuba heads the list with 24 new Members proposed since Feb. 1, and only a week to go to end the Honor Roll year.

Rene Pulido y Morales	24
Roy Zipprodt	10
H. F. Gonnerman	7
Harry B. Dickens	5
A. Amirikian	3
J. A. Croft	3
Ernst Gruenwald	3
Dean Peabody Jr.	3
J. H. Spilkin	3
Charles S. Whitney	3
Francis MacLeay	2½
D. E. Parsons	2½
Charles E. Wuerpel	2½
J. B. Alexander	2
C. Blaschitz	2
H. W. Cormack	2
J. W. Kelly	2
Calvin C. Oleson	2
O. G. Patch	2
C. H. Scholer	2
Stanton Walker	2
J. M. Wells	2

J. C. Witt 2
Ben E. Nutter 1½
F. E. Richart 1½
O. A. Aisher 1
Michel Bakhoun 1
H. C. Bruce 1
H. Victor Carman 1
W. Fisher Cassie 1
A. R. Collins 1
R. F. Dierking 1
H. F. Faulkner 1
P. J. Freeman 1
B. F. Friberg 1
J. K. Gannet 1
Arturo Gantes 1
Stanley S. Haendel 1
W. S. Hanna 1
G. H. Hodgson 1
F. B. Hornibrook 1
V. P. Jensen 1
L. I. Johnstone 1
William G. McFarland 1
Denis Matthews 1
Charles E. Morgan 1
H. W. Mundt 1
Y. G. Patel 1
J. R. Pattilo 1
A. F. Penny 1
Kenneth Powers 1
Guy Richards 1
A. T. Rogers 1
Simeon Ross 1
John A. Ruhling 1
Herman Schorer 1
Byram Steel 1
G. W. Stokes 1
H. D. Sullivan 1
H. W. Sullivan 1
Wm. Summers Jr. 1
M. A. Timlin 1
J. W. Tinkler 1
Lewis H. Tuthill 1
Maxwell Upson 1

The following credits are, in each instance "50-50" with another Member—"half a member" to each name listed.

Birger Arneberg
E. E. Bauer
E. W. Bauman
P. G. Bowie
C. H. Chubb
J. H. Chubb
Miles N. Clair
Arthur P. Clark
R. R. Coghlan
R. B. Crepps
R. A. Crysler
Harmer E. Davis
J. L. Drueke
P. M. Ferguson
Alexander Foster
G. L. Freeman
Grayson Gill
E. A. Gramstorff
N. M. Hadley
W. C. Hanna
Carl W. Hunt
A. Dovali Jaime
W. R. Johnson
Paul A. Jones
H. J. McGillivray
R. E. McLaughlin
Adolph Meyer
A. F. Moore
O. F. Moore
E. Nennigar
M. D. Olver
C. E. O'Rourke
Raymond Osborne
Lucien Perrault
Milos Polivka
Jerome Raphael
Chas. S. Rippon
D. F. Roberts
D. O. Robinson
Kanwar Sain
J. L. Savage
Oskar Schreier
A. L. Strong
A. C. Trice
K. Tsutsumi
J. H. de W. Waller
S. J. Warberg
A. R. Waters
David Watstein
H. J. Whitten
George Winter
Harry C. Witter
S. H. Woodward
K. B. Woods
L. Zeebaert

New Members

The Board of Direction approved 22 applications for Membership (18 Individual, 3 Junior, 1 Student) received in December as follows:

Charters, C. M., c/o British American Oil Co. Ltd., 703 Royal Bank Bldg., Toronto, Ont., Canada

Dixon, Frederick R., 43 Fairlight St., Five Dack, Sydney N. S. W., Australia

Englander, Harry, 58 Campbell Ave., Williston Park, New York N. Y.

Ferulano, Paolo Emilio, Lista de Correo, Caracas-R de Venezuela, S. A.

Frank, Jacob, c/o R. S. Noonan Inc., 11 East Market St., York, Pa.

Gondolfi, D. E., 707 W. Main St., Ottawa, Ill.

Haller, Karl H., 824 Claremac Dr., West Palm Beach, Fla.

Jameson, R. O., 5519 McComas Ave., Dallas 6, Texas

Johnston, W. R., 1403-W. 45th Street, Seattle, Wash.

Kauer, T. J., Wire Reinforcement Institute, 1049 National Press Bldg., Washington 4, D. C.

Kilkenny, Paul E., 2575 Le Conte Ave., Berkeley 4, Calif.

Kinne, Raymond C., 329 Fountain Ave., Dayton, Ohio

Koo, Hia chang Benjamin, 214 Linden Ave., Ithaca, N. Y.

Martinez, Milton R., 301 Bryant Ave., Ithaca, New York

Mauldin, W. O., 412 R. A. Long Bldg., 928 Grand Ave., Kansas City 6, Mo.

Parme, Alfred L., 5234 S. Dorchester Ave., Chicago 15, Ill.

Pichel, Ernest, 105 W. 72nd St., New York 23, N. Y.

Plum, Niels M., 17 ved dammen, Bagsevaerd, Denmark

Quilty, Thomas Patrick, 884 Riverside Dr., New York 32, N. Y.

Shotwell, J. G., Box 888, Albuquerque, New Mexico

Tamanini, Flory J., 191 Yale Drive, Alexandria, Va.

Wood, Reginald Escott, Narriott & Wyhna Sts., Holland Park, Brisbane S. E. 3, Queensland, Australia

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Fred F. Van Atta Joins ACI Staff

Fred F. Van Atta

Erstwhile Major, now Mr. Fred F. Van Atta joined the Institute staff January 16, three weeks home from the Philippines, where as an army engineer, he applied himself to bridge reconstruction near Manila. Previously he had spent four and a half years with T. V. A. (Kentucky Dam) and later as a reserve officer in the Army was identified as assistant to The District Engineer, Charleston, S. C. with various projects in the Charleston area.

Since January 16 he has been doing research work—finding out about ACI, its objects, policies, practices, how it works, its organization and the varied details of producing Journals and other ACI publications. He is finding out what makes ACI tick; has learned something of why it doesn't always *click* on time. To *that* he will shortly begin to put his weight (and for that ACI isn't counting on mere avoirdupois). He will attend the convention in Buffalo this month to get acquainted; to see ACI in action.

Here are further details of his record:

Mr. Van Atta was born in Detroit, Mich., July 26, 1912; was graduated from Michigan State College, 1934 with a degree of B. S. in C. E. "with high honor". That summer he worked as technical assistant in research work on aggregate in the concrete laboratory of Michigan Engineering Experiment Station, Michigan State College. Next he was with the Coast and Geodetic Survey for ten months in five western states on precise level surveys; then Tennessee Valley Authority, Gilbertsville, Ky., September 1935 to January 1940, on foundation investigations and the early stages of construction of Kentucky Dam. Next, to vary his experience, January 1940 to March 1941 with U. S. Engineer Dept., Los Angeles, Calif. as Junior Civil Engineer (Hydraulic) in the development of hydrology and hydraulic design, followed by related work in hydraulic model studies.

Just before the war broke, he was with Jarvis Engineering Works, Lansing, Mich. for about five months on structural steel design and field work.

He entered the army Oct. 13, 1941 from the Officers Reserve Corps. As assistant to the District Engineer, Charleston, S. C., he was in charge of the preparation of plans and the construction of Aircraft Warning stations, concurrently assisting in the preparation of plans and specifications on fortifications for the Harbor Defenses of Charleston. Later he was Assistant Chief of the Military Engineering Section for Construction of airports and cantonments, and still later Assistant Chief of the Operations section of the District.

In June 1942 he was transferred to the North Charleston Area Office as chief of the Engineering Section in charge of engineering design and the preparation of plans and specifications for railroad facilities, concrete and timber wharves, earth fill, concrete and asphalt paving, roads, hospitals and cantonments at an army airbase, port of embarkation and general hospital.

War Department orders transferred him to Ft. Belvoir, Va., July 1, 1944 for ten weeks of training. Then followed short tours of duty at Fort Leonard Wood, Camp Gordon Johnston and Ft. Belvoir, prior to going overseas. From April to November 1945 he served in Manila with the General Engineer District in the Bridge Reconstruction section, first as Assistant and then as "Officer in Charge".

Van Atta has these society memberships: Tau Beta Pi, Phi Kappa Phi, Associate Member American Society of Civil Engineers

Lone Star Changes

Lone Star Cement Corp., announces the appoint of Purd B. Wright, Jr. as Manager "Incor" and Technical Service; Ernest Gruenwald as Chief Engineer, Technical Service (both are ACI members) and James F. Callery, as Manager, Publicity Department effective January 1, this year.

Awards to JPP Contributors

Awards of \$50.00, \$25.00 and three of \$10.00 were set up by the Institute for the five contributions to the Job Problems and Practice pages of the ACI Journal for the volume year Sept. 1944 to June 1945 judged best for the period. (They are continued in the current volume year to and including June 1946). First year awards are as follows:

The top award of \$50.00 to Ralph Lewis, Power Engineer in charge of Broken Hill Associated Smelters, Fort Pirie, South Australia, his contribution being one of those on the subject of "Setting Heavy Machinery on Concrete Bases" p. 362, February 1945.

The second, a \$25.00-award goes to Paul A. Jones, Construction Engineer, Bureau of Reclamation, for his contribution "Precast Concrete Irrigation Pipe Jacked under Railroad Tracks" p. 705, June, 1945.

The third, fourth and fifth awards—\$10.00 each—go to Walter H. Wheeler for his contribution to the Sept. 1944 JPP section; Charles Macklin for his contribution to the June 1945 Journal, and Capt. K. K. Hansen for his contribution to the JPP section in April 1945.

Definitions Pertinent to Concrete

At a meeting of Sub-Committee V, Committee C-9, American Society for Testing Materials, held in Washington January 15, 'twas voted that three revised definitions (admixture, gravel, sand) be referred to Committee C-9. The three definitions are as follows:

Admixture—A material other than portland cement, aggregate or water that is used as an ingredient of concrete, including materials added to the batch before or during mixing and materials interground with the clinker for the purpose of affecting the properties of concrete, excepting gypsum used in the normal manufacture of cement.*

Gravel—The coarse granular material, larger than sand, resulting from the erosion of rock by natural agencies.

Sand—The fine granular material, usually smaller than about ¼ inch, resulting from the erosion of rock by natural agencies or from the mechanical reduction of weakly cemented sandstone. The term is often used with a qualifying adjective to denote the product of mechanical crushing, as for example, "stone sand" or "slag sand."

*See paragraph 1 "Admixtures for Concrete" reported by ACI Committee 212, ACI JOURNAL, Nov. 1944; *Proc.* V. 41, p. 73.

The program of the sub-committee includes the development of definitions for the following—curing, laitance, water segregation, bleeding or water gain, workability.

The committee is also keeping informed of the status in ASTM committee E-8 of definitions for concrete, consistency, and plasticity.

This work of subcommittee V is reported to the Institute by the ACI representative on the committee, Dr. J. C. Witt.

THE AMERICAN CONCRETE INSTITUTE

is a non-profit, non-partisan organization of engineers, scientists, builders, manufacturers and representatives of industries associated in their technical interest with the field of concrete. The Institute is dedicated to the public service. Its primary objective is to assist its members and the engineering profession generally, by gathering and disseminating information about the properties and applications of concrete and reinforced concrete and their constituent materials.

For nearly four decades that primary objective has been achieved by the combined membership effort. Individually and through committees, and with the cooperation of many public and private agencies, members have correlated the results of research, from both field and laboratory, and of practices in design, construction and manufacture.

The work of the Institute has become available to the engineering profession in annual volumes of ACI Proceedings since 1905. Beginning 1929 the Proceedings have first appeared periodically in the Journal of the American Concrete Institute and in many separate publications. (Pamphlets presenting brief synopses of Journal papers and reports of recent years, most of them available at nominal prices in separate prints, are available for the asking.)

ACI publications in large current demand

ACI Standards—1945

148 pages, 6x9 reprinting ACI current standards: Building Regulations for Reinforced Concrete (ACI 318-41); three recommended practices: Use of Metal Supports for Reinforcement (ACI–319-42); Measuring, Mixing and Placing Concrete (ACI 614-42); Design of Concrete Mixes (ACI 613-44); and two specifications: Concrete Pavements and Bases (ACI 617-44) and Cast Stone (ACI 704-44)—all between two covers, $1.50 per copy—to ACI Members, $1.00.

Air Entrainment in Concrete (1944)

92 pages of reports of laboratory data and field experience including a 31-page paper by H. F. Gonnerman, "Tests of Concretes Containing Air-entraining Portland Cements or Air-entraining Materials Added to Batch at Mixer," and 61 pages of the contributions of 15 participants in a 1944 ACI Convention Symposium, "Concretes Containing Air-entraining Agents," reprinted (in special covers) from the ACI JOURNAL for June, 1944. $1.25 per copy; 75 cents to Members.

ACI Manual of Concrete Inspection (July 1941)

This 140-page book (pocket size) is the work of ACI Committee 611, Inspection of Concrete. It sets up what good practice requires of concrete inspectors and a background of information on the "why" of such good practice. Price $1.00—to ACI members 75 cents

"The Joint Committee Report" (June 1940)

The Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete submitting "Recommended Practice and Standard Specifications for Concrete and Reinforced Concrete," represents the ten-year work of the third Joint Committee, consisting of affiliated committees of the American Concrete Institute, American Institute of Architects, American Railway Engineering Association, American Society of Civil Engineers, American Society for Testing Materials, Portland Cement Association. Published June 15, 1940; 140 pages. Price $1.50—to ACI members $1 00

Reinforced Concrete Design Handbook (Dec. 1939)

This report of ACI Committee 317 is in increasing demand. From the Committee's Foreword: "One of the important objectives of the committee has been to prepare tables covering as large a range of unit stresses as may be met in general practice. A second and equally important aim has been to reduce the design of members under combined bending and axial load to the same simple form as is used in the solution of common flexural problems."—132 pages price $2.00—$1 00 to ACI members

Concrete Primer (Feb. 1928)

Prepared for ACI by F. R. McMillan, it had five separate printings by the Institute alone (totalling nearly 70,000 copies). By special arrangement it has been translated and published abroad in many different languages. It is still going strong. In the foreword the author said "This primer is an attempt to develop in simple terms the principles governing concrete mixtures and to show how a knowledge of these principles and of the properties of cement can be applied to the production of permanent structures in concrete." 46 pages, 25 cents (cheaper in quantity).

For further information about ACI Membership and Publications (including pamphlets presenting Synopsis of recent ACI papers and reports) address:

AMERICAN CONCRETE INSTITUTE 742 New Center Building Detroit 2, Michigan

Let your HEAD take you

(The average American today has a choice of just going where "his feet take him", or choosing wisely the course to follow. Let's skip ahead 10 years, and take a look at John Jones—and listen to him . . .)

"SOMETIMES I feel so good it almost scares me.

"This house—I wouldn't swap a shingle off its roof for any other house on earth. This little valley, with the pond down in the hollow at the back, is the spot I like best in all the world.

"And they're mine. I own 'em. Nobody can take 'em away from me.

"I've got a little money coming in, regularly. Not much—but enough. And I tell you, when you can go to bed every night with nothing on your mind except the fun you're going to have tomorrow—that's as near Heaven as man gets on this earth!

"It wasn't always so.

"Back in '46—that was right after the war and sometimes the going wasn't too easy—I needed cash. Taxes were tough, and then Ellen got sick. Like almost everybody else, I was buying Bonds through the Payroll Plan—and I figured on cashing some of them in. But sick as she was, it was Ellen who talked me out of it.

"'Don't do it, John!' she said. '*Please* don't! For the first time in our lives, we're really saving money. It's *wonderful* to know that every single payday we have *more* money put aside! John, if we can only keep up this saving, think what it can mean! Maybe some day you won't have to work. Maybe we can own a home. And oh, how good it would feel to know that we need never worry about money when we're old!'

"Well, even after she got better, I stayed away from the weekly poker game—quit dropping a little cash at the hot spots now and then—gave up some of the things a man feels he has a right to. We didn't have as much fun for a while but we paid our taxes and the doctor and—we didn't touch the Bonds.

"What's more, we kept right on putting our extra cash into U. S. Savings Bonds. And the pay-off is making the world a pretty swell place today!"

Read the report of the Buffalo Convention the April 1946 Journal—News Letter section.