JOURNAL
of the
AMERICAN CONCRETE INSTITUTE

(ACI PROCEEDINGS Vol. 41)

Vol. 16 November 1944 No. 2

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to provide a comradeship in finding the best ways to do concrete work of all kinds and in spreading that knowledge

ADDRESS: 7400 SECOND BOULEVARD, DETROIT 2, MICH.

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Vol. 16—No. 2 November 1944 (Proceedings Vol. 41)

JOURNAL
of the
AMERICAN CONCRETE INSTITUTE

Published by the American Concrete Institute. The Institute was founded 1905; incorporated in the District of Columbia in 1906 as The National Association of Cement Users; the name changed 1913 by charter amendment. The Journal is issued six times yearly in the months of January, February, April, June, September and November under the authority of the

Papers and other contributions prepared with a view to Journal publication should be submitted in triplicate, addressed: Secretary, Publications Committee, American Concrete Institute, 7400 Second Boulevard, Detroit 2, Michigan. Publication of a contribution does not imply the acquiescence of critics (whose advice is sought by the Committee, prior to acceptance) or of the Institute in the opinions which it expresses nor the approval of data or practice which the contribution records. Institute authority attaches only to Standards formally adopted as provided in the By-Laws. A committee report implies merely the joint contribution of an appointed group.

Subscription price $7.50 per year payable in advance. To members, $7.50 per year, included in the annual dues. (A special dues rate of $3.00 per year applies for "a student in residence at a recognized technical or engineering school" and includes Journal subscription.

Bound volumes 1 to 40 of PROCEEDINGS OF THE AMERICAN CONCRETE INSTITUTE (1905 to 1943) are for sale as far as available, at prices to be had on inquiry of the Secretary-Treasurer. Special prices apply for members ordering bound volumes in addition to the monthly Journal.

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the ACI JOURNAL

is edited by the Secretary of the Publications Committee under the direction of the Committee

It is the policy of the American Concrete Institute to encourage participation by its members and others in the work of extending the knowledge of concrete and reinforced concrete as a basis for improved products and structures.

To this end the Board of Direction has assigned to the Publications Committee the responsibility of selecting for publication such papers, committee reports, discussions and other contributions or parts of such contributions, as in the judgment of the Committee, seem to offer most of value in attaining Institute objectives within space requirements, consistent with budget limitations.

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NEW CENTER BUILDING
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● The New York Convention, February 1945. (See News Letter p. 1)

● ACI Proceedings V. 40 now complete, ready for binding (see News Letter p. 2).

● The American Concrete Institute has announced the inauguration of the ACI Construction-Practice Award, to be given for a paper of outstanding merit on concrete construction practice. This award is established to honor the construction man—the man whose resourcefulness comes in between the paper conception and the solid fact of a completed structure.

The token of the award is a suitable Certificate of Award accompanied by $300 (maturity value) of United States War Bonds Series E. It is hoped to enrich the literature of concrete construction-practice.

● Five cash awards are also announced for contributions to the Job Problems and Practice pages September 1944 to June 1945. For the contribution judged by an ACI Committee to rank as the best of the volume year (V. 41)—$50.00; next best $25.00; to each of the three next best $10.00. See announcement of these awards, June JOURNAL or ask for a leaflet.

● Discussion of report and papers in this issue closes March 1, 1945.

A limited supply of separate prints of all papers and reports becomes available with the publication of each JOURNAL issue (usually 25 cents each). The paper by Mr. Gonnerman and the 16 contributions to the Symposium on air-entraining agents will be available in a separate pamphlet (96 p. and cover) at $1.25—ACI members 75 cents.

A part of PROCEEDINGS OF THE AMERICAN CONCRETE INSTITUTE Vol. 41

JOURNAL
of the
AMERICAN CONCRETE INSTITUTE

Vol. 16 No. 2 7400 SECOND BOULEVARD, DETROIT 2, MICHIGAN November 1944

Admixtures for Concrete*

A REPORT BY ACI COMMITTEE 212

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SYNOPSIS

With the aim of providing a perspective of the field of admixtures for the use of the engineer confronted with a need of modifying concrete to meet special requirements of a given job, Committee 212 has classified admixtures into 9 broad groups. Discussions are given of the factors which might indicate the usefulness of admixtures of each group, and of the important effects which may ordinarily be expected from the use of materials of each group. The 9 groups are as follows: (1) accelerators, (2) air-entraining agents, (3) gas-forming agents, (4) natural cementing materials, (5) pozzolanic materials, (6) retarders, (7) water-repelling agents, (8) workability agents, and (9) miscellaneous.

I—GENERAL

For the purpose of this report an admixture is defined as a substance other than portland cement, aggregate or water that is used as an ingredient for concrete. According to this definition, materials are included which are added to the mixing water, which are added to the batch before or during mixing or which, if their presence in concrete significantly affects the properties of the concrete, are interground with the clinker (excepting gypsum used in the normal manufacture of cement).

Usually the purpose of using an admixture is to modify the properties of the concrete in such a way as to make it more suitable for the work in hand. Under certain conditions, the use of a suitable admixture may impart desirable characteristics which cannot be secured as economically by other methods. It is strongly emphasized, however, that no amount

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*This report (received by the Institute Sept. 5, 1944), the first to be submitted by the Committee, is presented as information and for discussion only.

or kind of admixture should be considered as a substitute for the use of structurally sound well-graded concreting materials or good concreting practice.

Some of the more important modifications of properties of concrete which have been the objective of the use of admixtures are:

(a) Improvement of workability.
(b) Acceleration of the rate of strength development at early ages.
(c) Retardation of initial stiffening or increased time of set.
(d) Retardation or reduction of heat evolution.
(e) Increase in bond to steel reinforcement.
(f) Reduction in bleeding.
(g) Increase in the durability or in the resistance to special conditions of exposure to deteriorating elements.
(h) Decrease in capillary flow of water.
(i) Decrease in the permeability to liquids.
(j) In grout mixtures, the improvement of penetration and pumpability and the reduction of segregation.
(k) Prevention of settlement or creation of slight expansion in concrete and mortar used for filling blockouts or other openings in concrete structures, and in grout for seating machinery, columns, girders, etc.

In considering the role of admixtures in concrete it is pointed out that, (a) at times a change in type of cement or amount of cement used, or a modification of aggregate grading or mix proportions may offer the surest and most economical approach to the objectives desired; (b) many admixtures affect more than one property of concrete, sometimes affecting desirable properties adversely. (c) the effects of some admixtures are significantly modified by such factors as wetness and richness of mix, by aggregate grading, and by character and length of mixing. (d) The specific effects of some admixtures vary with the type and with the brand of cement used. (e) Accordingly, specific effects which will result from the use of an admixture can seldom be predicted accurately. Usually, tests of the particular lots of materials representative of those for a given job, sometimes tested under simulated job conditions, offer the only means for obtaining reliable quantitative information on the properties of concretes containing admixtures.

II—ECONOMIC ASPECTS OF THE USE OF ADMIXTURES

The use of an admixture may increase the cost of the concrete. Therefore, even though a given admixture may produce a desirable effect, the value of that effect should be weighed against its cost. Moreover, the effect of a given admixture can usually be obtained, at least in some degree, by other means or by other admixtures. Hence, whenever possible, the cost of an admixture should be compared with that of alternative materials or methods for getting the desired result.

In evaluating an admixture, its effect on the volume of a given batch should be noted. If adding the admixture changes the volume, as is often the case, the change in the properties of the concrete will be due not only to direct effects of the admixture but also to the changes in the amounts (per cubic yard of concrete) of the original ingredients. If the admixture increases the volume of the batch, the admixture must be regarded as effecting a displacement either of part of the original mixture or of one of the original ingredients—cement, aggregate, or water. All such changes in the composition of a unit volume of concrete must be taken into account when testing the direct effect of the admixture itself, and in estimating the cost of the admixture.

Other items entering into the evaluation are the cost of handling an extra ingredient, and any effect the use of the admixture may have on the cost of transporting, placing, and finishing the concrete.

Usually the evaluation of any given material should be based on the results obtained with the particular concrete in question. This is highly desirable since the results obtained are influenced to an important degree by the characteristics of the cement and aggregate and their relative proportions.

III—CLASSIFICATION AND DISCUSSION OF EFFECTS OF ADMIXTURES

The wide scope of the admixture field, the continuous entrance of new or modified materials into this field, and the variations of specific effects with different concreting materials and conditions, precludes a detailed listing of commercial admixtures and their effects on concrete. However, a division of the admixture field into 8 broad groups, according to type of materials constituting the admixtures, or to the characteristic effects of their use, and one convenient miscellaneous group is presented along with brief statements of the general purposes and expected effects of the use of materials of each group. Listed alphabetically these groups are as follows:

1. Accelerators
2. Air-entraining agents
3. Gas-forming agents
4. Natural cementing materials
5. Pozzolanic materials
6. Retarders
7. Water-repelling agents

8. Workability agents
    (a) Finely divided minerals
    (b) Water reducing agents
    (c) Aerating materials
9. Miscellaneous
    (a) Grinding aids
    (b) Unclassified

Commercial admixtures may contain materials of two or more of the above groups. For example, a workability agent which has a retarding action may be combined with an accelerator to compensate for the retarding action. Other admixtures have properties of more than one group. A finely divided mineral, for example, may also have pozzolanic properties, but the type of the resulting effect depends largely upon the amount of material added. These types of admixtures possessing properties identifiable with more than one class are considered in the discussion following as belonging to the class that describes the most prominent or important effect on the concrete.

1. Accelerators

Accelerators may be added to concrete to increase the rate of early strength development in concrete to: (a) Speed progress by permitting earlier removal of forms; (2) Reduce the required period for curing; (3) Advance the time when a structure can be placed in service; (4) Compensate for the retarding effect of low temperatures during cold weather concreting; (5) Reduce the period of protection required for initial and final set in emergency repair and other work. In many cases the engineer must decide on the alternative procedures of using an admixture or a high early-strength cement.

Chemical materials which accelerate the normal reactions between portland cement and water include the salt, calcium chloride (the most commonly used accelerator), some organic compounds such as triethanolamine, some of the soluble carbonates, silicates and fluosilicates, and aluminous cements.

Calcium chloride generally can be used safely in amounts up to 2 and not more than 3 per cent by weight of the portland cement. Although it is sometimes added at the mixer in flake form, the preferred way is in solution in the mixing water. Laboratory tests have indicated that the increase in strength resulting from the use of 2 per cent of calcium chloride may range from 400 to 1000 psi at 1 through 7 days for 70 F curing. Limited tests at 40 F indicate that although the strengths developed through 7 days are lower, the increases in strength obtained with 2 per cent calcium chloride are of the same order as those obtained at 70 F. The increase in strength usually reaches its maximum in 1 to 3 days and thereafter gradually decreases. At 1 year some increase still continues with concretes made with most cements and it is probable that no significant decrease in ultimate strength results from the use of this admixture. The specific effect of the use of calcium chloride varies, however, for different brands of cement, as indicated by the range of strength increases cited above for the early ages. Minor effects resulting from the use of calcium chloride include a small increase in the workability of the fresh concrete, a very early commencement of the initial stiffening with some cements and accordingly, a reduction in bleeding, and a probable increase in the drying shrinkage of the hardened concrete. Data are highly conflicting on the effect of calcium chloride on the drying shrinkage, however, and it may be dependent on such factors as size of specimen and curing procedure. The rate of heat evolution is increased materially at early ages and consequently, where temperature differentials within the concrete are important factors, the effect of this property of accelerators should be taken into consideration before they are used. Also the use of accelerators in warm concrete, such as may obtain in hot weather concreting, may result in such rapid stiffening as to impede placement or finishing. Test data are available which show that calcium chloride in concrete may aggravate any tendencies toward deterioration due to adverse alkali-aggregate reaction, and may slightly reduce resistance of concrete to cycles of laboratory freezing and thawing.

General recommendations on the use of accelerators other than calcium chloride cannot be given because sufficient information on other types is inadequate. In general, other types should be used only on the basis of competent technical advice, adequate preliminary tests, or satisfactory experience with the material in question. With some accelerators, small changes in amount added cause large differences in their effect. Some are capable of reducing the period during which the concrete remains plastic to less than 10 minutes. Such acceleration lowers the ultimate strength markedly however, and is used only for emergency patching or stopping of leaks.

2. Air-entraining agents

Air-entraining agents are used principally in concrete for paving that is to be subjected to severe frost action. They cause the entrainment of very small air bubbles during the period of mixing, the action of the agent being that of a foam or froth stabilizer.

Entrained air improves the workability of fresh concrete, especially its cohesiveness, and reduces the rate and amount of bleeding. It usually permits a reduction in water content without sacrificing workability. The specific weight of the concrete containing the air-entraining agent is less than that of the same concrete without the agent by an amount proportional to the difference in air content.

An increase in the amount of entrained air decreases compressive and flexural strength and the bond with reinforcing steel. However, by using a coarser aggregate-gradation (less sand) and by keeping the slump the same or slightly less than that required when not using an air-entraining agent, the desired strength can be maintained with little or no increase in cement content and usually with an improvement in workability. Apparently, also, such adjustments of the mix will serve to maintain the normal degree of bond with reinforcing steel. However, data on this point are meager and are not conclusive. Under average conditions the sand content can be reduced to 85 or 90 per cent of that required when not using an air-entraining agent, the decrease in sand and in the mixing water thus compensating for most or all of the volume increase attributable to entrained air.

The resistance to frost action of hardened concrete containing less than about 7 bags of portland cement per cubic yard is markedly improved by entrained air, the improvement being greater the lower the cement content. Entrained air is particularly effective in preventing surface scaling commonly caused by the use of calcium or sodium chloride for ice removal. Marked improvement is usually obtained when the entrained air is from 2 to 4 per cent of the volume of the fresh concrete.

The successful use of air-entraining agents requires some modification of usual procedures. When the agent is interground with the cement, the dry cement flows freely and sometimes is difficult to handle in conventional batching equipment and delivery trucks. After the concrete is placed in a pavement the entrained air may reduce the rate of bleeding below the rate of evaporation. When this happens, the surface soon becomes dry and sticky, making it necessary to shorten the interval between placing and finishing. Also, the number of lateral strokes per foot of forward travel of mechanical finishers can sometimes be increased to advantage. In hand finishing, steel tools are sometimes preferable to wooden ones.

The use of two air-entraining agents, Vinsol resin and Darex, is covered by The Proposed Revised A.S.T.M. Specification Designation C175—T, "Air-entraining Portland Cement for Concrete Pavements (Tentative)".*

This specification deals with air-entraining agents interground with the cement. Many other organic mixtures or compounds such as natural resins, tallows, oils, or sulfonated soaps or oils will serve as air-entraining agents in portland cement concrete. Such materials are usually effective in amounts ranging from about 0.005 to 0.05 per cent by weight of the

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*Presented to the annual meeting of the A.S.T.M. in June 1944 by Committee C-1 and accepted at the meeting.

cement. Water-insoluble resins, fats, and oils are not in themselves foaming agents, but depend upon a saponification reaction with the alkali constituents of the cement for development of the foaming (or foam-stabilizing) property. These materials are effective only when inter-ground with the cement. Water-soluble agents, however, such as "neutralized" Vinsol resin (a sodium hydroxide solution of Vinsol resin) or alkali-metal salts of sulfonated oils or fatty acids are in themselves foaming agents and can be either interground with the cement or added at the mixer. Some of the latter materials form the air-entraining ingredient of proprietary mixtures available for addition at the mixer. Some air-entraining agents have little or no influence on the hydration of the cements; others do influence the hydration, usually retarding it.

The amount of air that will be entrained with a certain kind and amount of air-entraining agent can be determined only by direct test under the prevailing job conditions. Different results are obtained with different cements and aggregates and with the same materials different results are obtained under different conditions of mixing, transporting, and placing. During the progress of the work it is necessary to determine the air content frequently and to make adjustments as required to keep the air content within suitable limits. This is usually done by determining the specific weight of the fresh concrete and taking steps to hold it between 3 and 5 lb. per cubic foot less than the weight of the concrete when the air-entraining agent is absent.

3. Gas-forming agents

Settlement shrinkage or "bleeding" in plastic concrete is caused by settling of the individual solid particles in the semi-liquid mixture due to the force of gravity. The extent of settlement or bleeding is dependent on many factors and in aggravated amounts or under certain concreting conditions may result in undesirable characteristics in hardened concrete or mortar. Accumulation of low-quality matrix films, laitance layers, and voids on the underneath side of forms, blockout cavities, reinforcing steel or other embedded parts, machinery bases and at the top surfaces of concrete layers or lifts, reduce bond, water-tightness, uniformity and strength in the concrete or mortar and necessitates, in some instances, costly cleanup and grouting operations.

Aluminum powder when added to mortar or concrete reacts with the hydroxides present in hydrating cement and forms minute bubbles of hydrogen gas throughout the cement-water matrix. Usually the unpolished powder is preferred, though when a slower action is desired the polished form may be advantageous. The amounts added are usually limited to 0.005 to 0.02 percent by weight of the cement, though larger amounts may be used in the production of light-weight concrete of low strength.

The action of aluminum powder when controlled to occur during the proper interval of time, causes a slight expansion in plastic concrete or mortar and thus reduces or eliminates settlement, and may accordingly increase bond to horizontal reinforcing steel and improve the effectiveness of grout in filling joints. Ordinarily the density is slightly reduced and the resistance of the hardened concrete to frost action improved. The effect on strength depends to a considerable extent on the degree to which the tendency of the concrete to expand is restrained; without restraint the loss in strength may be considerable, but with a proper degree of restraint imposed the strength may not be affected appreciably and in some cases may be slightly increased. In hot weather the action of aluminum powder may occur too quickly and its beneficial action be lost. In cold weather the action is much slower and may not progress far enough to produce the desired effect before the concrete has set. The delayed generation of gas may or may not be harmful, depending on the rate and amount of gas generation after the concrete has set and upon the degree of restraint imposed.

4. Natural cementing materials

This group includes natural cements, hydraulic limes, water-quenched blast furnace slag and mixtures of blast-furnace slag and lime. Although blast-furnace slag itself is only weakly hydraulic, when combined with lime or other activators it becomes capable of developing significant strength.

When used, materials of this class are usually substituted for 10 to 25 per cent by weight of the portland cement, although substitution of larger amounts may sometimes be made when low strengths are not objectionable. Effects resulting from their substitution for part of the cement generally are an increase in workability, more pronounced for harsh mixes, and decreases in bleeding, in segregation, in heat of hydration and, for most of the materials, a decrease in strength. Natural cementing materials are generally considered as not having significant effect on frost resistance unless, as in the case with certain natural cements, a mild air-entraining agent is also present in the material.

The use of materials of this class may require an increase in mixing water, and accordingly, an increase in drying shrinkage may result. A relatively long curing period is needed for development of potential strength.

5. Pozzolanic materials

Pozzolanic materials are finely divided siliceous and aluminous materials which, though not cementitious in themselves, combine with hydrated lime at ordinary temperatures in the presence of water to form stable compounds of cementitious value. These materials are sometimes used in large hydraulic structures where it is desirable to avoid high temperatures or in structures exposed to sea water or sulfate-bearing soil solutions. When used, pozzolanic materials generally are substituted for 10 to 35 per cent of the cement. They have a lower specific gravity than portland cement; therefore if substitution is made on a weight basis a greater bulk volume of cementitious material results. Substitution of pozzolanic material for part of the cement generally improves workability, reduces bleeding and segregation, reduces heat of hydration, though not in proportion to the amount substituted, improves impermeability to water and increases resistance to aggressive attack of sea water, sulfate-bearing soil solutions and natural acid waters. These effects are greater for lean mixes than for rich mixes.

The effect of substitution of pozzolanic materials for part of the cement on the strength of the concrete varies markedly with the particular pozzolanic material used. Generally the strength development is slower and is retarded more by low temperatures with the pozzolanic materials. Under favorable curing conditions, later strengths, as a rule, will be higher, though large differences result from the use of different pozzolanas. In all cases, however, prolonged wet curing is necessary for development of potential strength.

The addition of pozzolanic materials to concrete (instead of substitution for part of the cement) affects workability, impermeability, and resistance to chemical attack in a manner similar to that resulting from substitution. The improvements in workability, impermeability, and resistance to chemical attack are most marked, however, when the pozzolana is added to a concrete originally deficient in the amount of fine material; if added to one already containing an abundance of fine material, the water cement ratio must be increased, and accordingly absorption and drying shrinkage may be increased.

The effects of addition on strength vary with the mix and with the material. Generally the strength of lean mixes may be increased and the strength of rich mixes decreased.

Example of materials used in amounts ranging from 10 to 30 per cent of the weight of the cement are: fly ash, volcanic ash, heat-treated diatomaceous earths, and heat-treated or raw shales or clays.

Requirements for cements containing pozzolana are given in Federal Specification SS-C-208a, "Cement; Portland, Pozzolana."

6. Retarders

The principal uses in concrete of admixtures having a retarding effect on the set of cement are to overcome the accelerating effect of temperature during hot weather concreting operations, to remove the tendency of some cements to exhibit premature stiffening, and to delay the early stiffening action of concrete for difficult conditions of placing. Solutions are sometimes applied to forms in order to inhibit the set of a surface layer of mortar so that it can be readily removed by brushing, thus exposing the aggregate and producing unusual surface texture effects. Retarders are especially useful in cement grout slurries, particularly where it may be necessary to redrill grout holes, for grouting over a prolonged period of time, in cases where the grout must be pumped for a considerable distance, and where hot water flows are encountered.

A wide variety of chemicals are mentioned in current literature as having a retarding influence on the normal setting time of portland cement. Others have been found variable in action, retarding the set of some cements and accelerating the set of others. Some chemicals act as retarders or inhibitors when used in certain quantities, and accelerators when used in other amounts. The effects of most of these materials on the other properties of concrete and mortar are not well known, although, in general, some reduction in strength accompanies the use of organic retarders. When used in proper concentrations, however, some retarders have been observed to have no adverse effect or to actually enhance strength.

Unless experience has been had with a retarder, its use as an admixture should not be attempted without technical advice or preferably advance experiment with the cement and other concreting materials involved, to determine the extent of its effects on the setting time and other properties of the concrete. The more commonly known retarders used as admixtures, such as carbohydrate derivatives and calcium lignosulfonate, are employed in only small fractions of a per cent by weight of the cement.

7. Water-repelling agents

Soaps or other fatty acid compounds, such as calcium, ammonium, aluminum, or sodium stearates or oleates, and petroleum oils or waxes are mixed with concrete at times to make the hardened concrete water-repellent. The water-soluble soaps are not water-repellent as added to the concrete mix, but they can become so by reaction with the hydrated lime formed during the hydration of the cement to form water-insoluble calcium soaps. The property of water-repellency may be useful in masonry mortars to decrease capillary rise of moisture, thus minimizing the discoloration and efflorescence which results at times from evaporation of capillary water. Concretes containing water-repellent materials also have application in floors or walls in contact with the soil, where the concrete is subject to capillary flow of moisture but not flow of water under a high pressure head.

Additions of water repellents in amounts usually ranging from 0.1 to 0.2 per cent, by weight of cement, increase workability of the fresh concrete, and in the hardened concrete decrease the absorption by capillarity, increase permeability under high pressure and decrease strength. The use of larger amounts increases these effects. The "waterproofed" portland cements and many of the masonry cements contain water-repellent materials.

The commercial admixtures of this class, intended to be added at the mixer, are in the form of liquids, pastes and powders containing water-repelling agents in amounts ranging from 5 to 25 per cent, the remainder being water and various fillers. Undiluted aluminum, ammonium and calcium stearates and butyl stearate emulsion are available as chemical compounds.

8. Workability agents

At times it may be desirable to increase the workability of a concrete (a) if the concrete is harsh because of aggregate grading or aggregate characteristics; (b) if the concrete must be placed around closely spaced reinforcement or in difficultly accessible sections; (c) where special means of placement are required, such as with tremie or pumping methods. It should be noted that frequently redesign of the mix or increasing the cement content may give the desired results. General effects of increasing the cement content are: increased workability, strength, impermeability, frost resistance, heat development, volume change, and increased surface crazing if the placed concrete receives much manipulation.

(a) *Finely divided minerals.* In mixes deficient in "fines" (particularly the material passing the No. 200 sieve) the addition of a finely divided mineral improves workability, reduces the rate and amount of bleeding and increases the strength. In general the higher the specific surface of the mineral the smaller the volume required to produce a given effect on workability. When an appropriate quantity of mineral powder is used, no increase in total water content of the concrete is required, and drying shrinkage and absorptivity of the hardened concrete are not much affected. The addition of a mineral powder to mixes *not* deficient in fines, particularly mixes rich in portland cement, generally decreases workability for a given water content. For that reason, the addition of mineral powders to such mixes generally entails an increase in the total water content of the concrete, and that may result in an increase in drying-shrinkage and absorptivity, and a decrease in strength.

Examples of materials added in amounts not exceeding 3 to 5 per cent by weight of the cement are bentonite clay and diatomaceous earth. Examples of materials added in larger amounts are fly ash, finely divided silica, clay, fine sand, hydrated lime, talc, and pulverized stone, some of which may be added in amounts up to 20 per cent.

(*b*) *Water-reducing agents.* Certain organic compounds or mixtures that have been marketed under proprietary names increase the slump of concrete of a given water content and, therefore, permit concrete of a given slump to be produced at a somewhat reduced water content. Only a few such materials have been examined; hence no broad statements can be made of the general effects of all materials in this group. The materials that have been examined to date, however, contain either sulfonated organic compounds or carbohydrate salts in combination with other active or inert materials. The sulfonated type generally caused some entrainment of air and decrease in bleeding, but not to the extent as caused by materials classed as air-entraining agents. This type had a proportionately greater effect in lean mixes than in rich ones. The carbohydrate type did not cause entrainment of air and did not reduce bleeding; some retardation of set was produced.

The effect on the hardened concrete of the use of these materials, when advantage of the possible water reduction was taken, was generally somewhat improved impermeability and compressive strength, and for the type causing mild air-entrainment, an improved resistance to freezing and thawing.

As with other chemically active admixtures, the specific effect of these materials varies with different cements, and tests should be made with the job cement and preferably job materials before their use is attempted.

(*c*) *Aerating agents.* Although air-entraining agents are considered for use principally because of their effect on the durability of concrete, their effect on the workability of leaner mixes is so pronounced as to merit mention in any discussion of workability agents. The incorporation of numerous small well distributed air bubbles in the concrete acts as a lubricating medium, generally increasing the "fatness" of the mix and markedly improving the placeability of otherwise harsh concrete. As noted in the discussion of Class *2. Air-entraining agents*, entrained air improves cohesiveness and accordingly reduces segregation, reduces rate and amount of bleeding, and usually permits reduction in mixing water without loss of workability. The initial stiffening of the concrete is frequently accelerated by air entrainment. The effects of aeration on the properties of the hardened concrete are discussed under Class 2.

9. Miscellaneous

(a) *Unclassified.* There are a number of commercial admixtures which do not fit into any of the foregoing classifications. This group includes materials for which the claim is made that they increase the resistance to wear or abrasion (integral floor hardeners) or they react with the cement or the products of hydration of the cement, filling pores, thus decreasing absorption and permeability. These materials are very difficult to evaluate, but in no case can they be considered a cure for poor workmanship.

(*b*) *Grinding aids.* Grinding aids, generally speaking, have not been considered as admixtures, and accordingly do not logically fall within the scope of this classification. By reason of their wide-spread use, however, and because of their indirect effect on concrete a brief discussion of them is included. The use of grinding aids has contributed to the finer grinding of cements. This in turn has led to higher early strengths or leaner mixes that were placeable and which yielded adequate strengths. Materials such as Vinsol resin and tallow, in amounts of the order of .03 to .06 per cent, are aids to grinding, but are generally used for the subsequent direct effect upon concrete rather than for their effect upon grinding. Water, coal and resin are the oldest used grinding aids. The commercial grinding aid TDA, when added in the amounts used as a grinding aid (limited by current A.S.T.M. and Federal specifications to .045 per cent by weight of the cement except in high-early-strength cement a maximum of .08 per cent may be used) is generally considered to have only little direct effect on concrete.

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(2) See also 4 (b)

(*b*) *Water-reducing agents*

(1) See 6 (a)

(*c*) *Aerating agents*

(1) See 2 (a), (b), and (c).

Discussion of this report should reach the ACI Secretary in triplicate by March 1, 1945 for publication in the JOURNAL for June 1945.

A part of PROCEEDINGS OF THE AMERICAN CONCRETE INSTITUTE Vol. 41

JOURNAL
of the
AMERICAN CONCRETE INSTITUTE

Vol. 16 No. 2 7400 SECOND BOULEVARD, DETROIT 2, MICHIGAN November 1944

The Effect of Alkalies in Portland Cement on the Durability of Concrete*

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SYNOPSIS

Field observations, now confirmed by laboratory tests, have demonstrated the reactive character of concrete aggregates derived from lavas of the volcanic cone of Mt. Rainier, Washington. Deterioration has been universal in concrete containing such aggregates and high-alkali cement but when low-alkali cements have been used structures are in excellent condition at ages up to 19 years. The rate of retrogression is dependent on the severity of climatic conditions.

Disintegration of another type is progressing in certain structures in Eastern Washington. Reactivity of the aggregates used is not exhibited in the sealed-can test but may be demonstrated by a combination of moist storage followed by cycles of freezing and thawing. The main, if not the sole, factor influencing disintegration in this test is the content of alkalies in the cement whether they are present initially or are added at the time of mixing.

These results point to the need of limiting the alkali content of cements for satisfactory use with many aggregates in Washington.

INTRODUCTION

In the discussion that follows, reference is made to the alkali content of cement as used in structures ranging from 6 to 19 years of age. Actual analytical data as to alkali content are not available for the cements used at that time. There are, however, good means of estimating fairly accurately the probable ranges in alkalies in the cements from the several mills involved. Since 1939, routine analyses have been made at frequent intervals and these show that the percentages of the alkalies, Na_2O and K_2O, are fairly constant in each brand and type of cement. In the absence of changes in sources of raw materials or in manufacturing processes, estimates of former alkali contents when based on analyses of recent production are more than mere guesses. References will be

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*Received by the Institute Aug. 9, 1944.
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made upon this basis to high-alkali cement as that containing more than 0.90 per cent alkalies; medium-alkali cement, from 0.60 per cent to 0.90 per cent alkalies and low-alkali cement, less than 0.60 per cent alkalies.

MT. RAINIER STRUCTURES

Field observations:

In 1941(1)* the writer described the condition of concrete structures containing reactive aggregates from the Cowlitz River in the vicinity of Mt. Rainier, Washington. It was stated that those structures in which low-alkali cements were used were in excellent condition. In view of the fact that some writers(2),(3) have questioned the permanent integrity of concrete containing reactive aggregates even though the cement was low in alkalies, it is of value to note that these structures, some of them now 19 years of age, remain in nearly perfect condition.

Since 1941 the structures containing high-alkali cements have continued to deteriorate and it is evident that the progress of retrogression has not yet stopped. This is indicated by comparison of photographs and by actual measurements of cracks over periods of several years. In the more protected parts of the substructures, new cracks have appeared recently. Newer structures now appear similar to the older ones at comparable ages.

The sand and gravel in bars of the Cowlitz River is derived in part from lavas of the volcanic cone of Mt. Rainier. These lavas, largely andesitic in composition, have been suspected as constituting the reactive portion of Cowlitz River aggregate. Recent evidence tends to confirm this theory.

Aggregates consisting of sand and gravel taken from the White River were used in the construction of Deadwood Creek Bridge, a concrete arch completed in 1938. The bar from which the aggregates were taken is close to the source of the river in glaciers on Mt. Rainier and is practically undiluted with rocks from other sources.

A high-alkali cement was used in Deadwood Creek Bridge. The concrete showed signs of abnormal cracking as early as 1940 but it was not until 1942 that it became evident that the rate of deterioration was greater and that the probable condition of the concrete would be worse at equal ages than that in the structures constructed with Cowlitz River aggregates.

Laboratory studies:

At the time of writing the 1941 report(1), laboratory investigations had not progressed to the point that definite conclusions as to basic

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*See bibliography at end of text.

causes were warranted. These studies now indicate rather positively that the deterioration is due to unfavorable reactions between high-alkali cements and aggregates containing Mr. Rainier lavas.

4-inch cores cut with a diamond drill from the substructures of Clear Fork Creek and Summit Creek Bridges (each constructed with high-alkali cement) were stored in the laboratory fog-room at 70 F. During a period of about one month, clear, viscous beads and small, white patches appeared in considerable number on the surfaces of the cores. The chemical analysis of these exudations is given in Table 1.

TABLE 1—CHEMICAL ANALYSIS OF EXUDED MATERIAL FROM CORES

Loss on ignition	16.1
Insoluble in water (ignited basis)	9.1
Water-soluble (ignited basis)	90.9
SiO_2	85.0
R_2O_3	2.2
CaO	2.0
Na_2O	4.4
K_2O	1 9
	95.5

It will be noted that the exuded material consisted essentially of silica and alkalies. The composition is similar to that obtained from the sides of cores from Parker Dam as reported by Meissner(4).

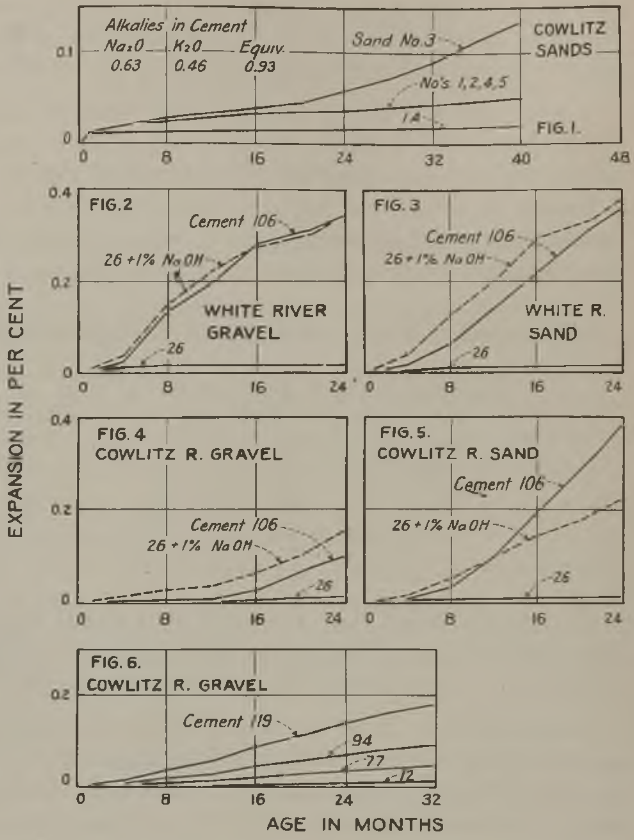
One core, 15 in. long, was found to have a modulus of elasticity determined dynamically of 4,800,000. This value indicates some retrogression in strength since laboratory-made specimens of similar mixtures have reached values of about 6,000,000 at the age of one year.

1x1x10-in. bars of 1:2 mortar containing sand or crushed gravel from the Cowlitz and White rivers have been stored in sealed containers, in the presence of moisture, for periods of from 24 to 40 months. Fig. 1 to 6 inclusive show the amount of expansion in these specimens. Fig. 1 gives the results to 40 months of the series previously reported(1) up to the age of 6 months.

Properties of the cements used in these tests (Fig. 2 to 6 inclusive), as well as those to be described later, are given in Table 2. For convenience in studying the data, the numbers assigned to the cements are the same as the content of equivalent alkalies expressed in hundredths of one per cent. The expression "equivalent alkalies" is used to denote the quantity "sodium oxide, Na_2O, plus 0.658 times potassium oxide, K_2O". The factor 0.658 is the molecular equivalent of K_2O in terms of Na_2O.

It will be noted in Fig. 1 to 6 inclusive that Cowlitz River aggregate when mixed with high-alkali cements expands continuously, with no

Fig. 1 to 6—Expansion of 1x1x10-in. bars of 1:2 mortar in sealed containers at 70 F.



indication of diminishing rate up to 40 months, the age of the oldest specimens. In general, aggregate from White River gives more rapid and greater expansion. It is worthy of note that in no case have specimens containing low-alkali cements expanded a significant amount. The addition of 1 per cent sodium hydroxide ($NaOH$) to low-alkali cement 26 has resulted in expansions comparable to those obtained with high-alkali cement 106.

Inspection of the group of structures containing Cowlitz River aggregate and high-alkali cement has indicated that the severity of exposure to climatic conditions has been a major influence in the rate, though possibly not the final degree, of deterioration of the concrete. Laboratory tests have been made to study the influence of freezing and thawing on the durability of concrete containing Cowlitz and White river aggregates when mixed with cements of varying alkali content.

Test specimens were 4x4x20-in. bars cast horizontally. There were four bars of each cement-aggregate combination. After 24 hours they

TABLE 2—PROPERTIES OF CEMENTS USED IN TESTS

Cement No.	26	69	84	96	106	12	39	49	68	77	94	119
SiO_2	23.55	21.80	22.00	22.04	20.69	22.61	22.33	24.67	20.53	22.33	22.43	21.01
Al_2O_3	4.40	5.36	4.92	5.12	5.89	3.86	6.36	4.24	5.37	4.82	4.97	5.55
Fe_2O_3	3.74	4.35	4.02	4.99	3.00	1.75	2.35	1.47	2.75	4.44	3.73	3.28
CaO	63.51	63.14	61.66	62.91	63.19	65.50	65.11	65.77	63.72	62.58	62.62	63.88
MgO	2.20	2.17	3.26	1.46	1.95	1.80	1.35	0.83	2.73	2.17	1.32	1.85
SO_3	1.83	1.75	1.56	1.69	1.58	2.70	1.47	1.44	2.65	1.91	1.60	1.62
Loss on Ignition	1.12	0.89	1.80	1.35	3.12	0.85	0.75	1.10	1.66	1.72	2.11	1.66
Insoluble Residue	0.20	0.27	0.28	0.10	0.20	0.25	0.30	0.20	0.27	0.50	0.32	0.28
Na_2O	0.14	0.50	0.55	0.68	0.80	0.09	0.26	0.27	0.20	0.50	0.70	0.93
K_2O	0.18	0.29	0.44	0.43	0.40	0.05	0.20	0.33	0.73	0.41	0.37	0.39
Equivalent Alkalies	0.26	0.69	0.84	0.96	1.06	0.12	0.39	0.49	0.68	0.77	0.94	1.19
C_3S	40	43	41	42	53	58	45	46	56	41	41	54
C_2S	38	31	32	32	19	21	30	36	17	33	33	20
C_3A	5	7	7	5	10	7	13	9	10	5	7	9
C_4AF	11	13	12	15	9	5	7	5	8	14	11	10
Specific Surface	1935	1600	1760	2240	1600	2520	1685	1855	1860	1790	1815	1500
Autoclave Expansion, %	0.00	0.07	0.03	0.02	0.30	−0.02	0.05	0.07	0.12	−0.01	0.04	0.17
Vicat, Initial	3-30	2-45	2-30	2-30	2-15	1-30	3-15	3-30	3-00	2-30	1-45	2-15
" Final	7-00	6-45	6-30	6-00	7-00	2-45	3-45	4-45	4-00	3-30	2-45	3-00
Gillmore, Initial	4-30	4-45	4-45	3-45	3-45	5-00	6-00	7-00	6-00	5-30	4-30	5-15
" , Final	8-00	8-00	8-00	8-00	7-30	6-30	6-30	8-00	7-00	6-30	6-00	6-15
Tensile Strength, 3 d	290	268	240	276	280	396	277	335	362	305	255	270
7 d	386	368	336	340	361	481	367	390	418	377	325	375
28 d	488	427	428	433	432		415	450	487	477	423	468
Comp. Strength 3 d	1400	1420	1385	1405	1585	3250	1455	1610	2100	1415	1100	1230
7 d	2105	2355	2325	2325	2340	4360	2490	2440	3410	2150	1895	2425
28 d	4150	4090	4575	4415	3550		4205	4060	4765	3495	3570	3890
Per Cent Floc (Paul)	0.3	0.7	0.5	0.7	0.8	1.2	0.3	1.0	2.7	0.3	0.8	0.6
Bleeding Capacity (Powers) ΔH' at w/c 6 gals. per sack, neat paste	0.024	0.047	0.052	0.034	0.039							
Sugar Test (Merriman)												
phenolphthalein, ml.	3.5	7.8	5.5	5.5	11.1							
clear point, ml.	3.9	8.8	5.9	6.0	12.7							

TABLE 3—PROPERTIES OF AGGREGATES USED IN TESTS

	Steilacoom	Irvin	Thorp	Rock Island	Cowlitz River	White River
Bulk Specific Gravity						
sand	2.67	2.65	2.67	2.66	2.62	2.66
gravel	2.67	2.66	2.75	2.72	2.64	2.59
Absorption, %						
sand	0.8	1.4	2.2	1.2	1.6	1.0
gravel	0.8	0.8	2.0	0.8	1.0	1.2
Loss in Los Angeles Machine, %						
after 100 rev.	1.4	2.1	3.3	2.5	2.4	2.9
after 500 rev.	7.0	12.0	12.1	13.8	12.3	20.2
Loss in Sodium Sulphate Soundness Test, 5 Cycles, %						
sand	0.6	0.3	1.4	0.7	1.6	0.4
gravel	0.0	1.1	0.5	0.0	3.5	0.0

were removed from the molds and stored in a fog-room at 70 F until freezing and thawing was started. They were then mounted vertically in racks with nearly unobstructed spaces of 1¼ in. between specimens. Freezing was in air to 0 F and thawing was under sprays of water to 45 F. These temperatures were at the centers of the bars as measured by thermocouples embedded in companion specimens. A typical temperature record for a 24-hour period is shown in Fig. 7. Two cycles were completed per day without interruption, except that on each seventh day one cycle was omitted while measurements were being made.

Properties of the cements and aggregates are given in Tables 2 and 3 respectively. Data of the concrete mixes are given in Table 4. The effects of freezing and thawing were measured by changes in natural frequency measured dynamically, by changes in weight, and at the conclusion of the tests, by flexural strength of the bars as beams. In this paper only the effects upon the dynamic modulus of elasticity, *E* (computed from natural frequency), are given because weight changes and flexural tests disclose nothing in contradiction of the dynamic results.

Fig. 8 and 9 show the results obtained with Cowlitz and White River aggregates and five cements when freezing and thawing was started at the end of a 30-day moist curing period. 77 cycles had little effect on any of the specimens. This is taken to mean that the aggregates from both sources are inherently sound and capable of producing durable concrete. After 77 cycles, freezing and thawing was discontinued and the bars were returned to moist storage at 70 F for a period of 7 months. During this storage, values of dynamic *E* increased from 10 to 20 per

TABLE 4—DATA OF CONCRETE MIXES FOR FREEZING-THAWING BARS

	A	B
Maximum Size of Aggregate	1¼″ square	1″ round
Fineness modulus		
sand	3.15	3.17
gravel	7.30	7.00
combined	5.51	5.53
Proportions per sack of cement		
lbs. of sand	250	190
lbs. of gravel	330	300
water, gallons added to room-dry agg't.		
Steilacoom	5.70	
Irvin	5.91	
Thorp	6.16	
Rock Island	6.06	
Cowlitz River	6.57	5.25
White River	6.57	
Sacks of cement per cu. yd. of concrete	5.75	6.5
Slump, inches		
minimum	3¼	1½
maximum	5½	3

Notes: Proportions shown are for bulk specific gravity of 2.67. Weights proportioned to bulk specific gravity of each material.

Each aggregate separated on ¾ in., ⅜ in., ¼ in., No. 4, 8, 16, 30 and 50 sieves and recombined to common grading.

A. Steilacoom, Irvin, Thorp, Rock Island, Cowlitz River and White River aggregates with cements 26, 69, 84, 96 and 106. Water in excess of absorption was added to prepared batches of aggregates which were stored in fog room for 24 hours prior to mixing concrete. Two 4x4x20-inch bars were molded from each batch. Two batches were made on different days. Mixed in Lancaster Type SW mixer. Bars were cast horizontally, removed from molds on following day and stored in fog room at 70 F. until freezing and thawing tests were started.

B. Cowlitz River aggregate and cements 12, 39, 49, 68, 77, 94 and 119. Aggregates in room-dry condition when concrete mixed. Four 4x4x20-in. bars from a single batch mixed in Lancaster Type SW mixer. Molded and cured as described under A.

cent above the 30-day values. Freezing and thawing was then resumed and resulted in considerable difference in durability among the concretes made with the five cements. The order of durability with either aggregate was the same for the cements. Cement 96 with 0.96 per cent equivalent alkalies was the poorest. Cement 106 was somewhat better. With this exception the order of durability is the same as that of the alkali contents of the cements. Cement 26 was virtually unaffected by freezing and thawing. The tests of part of the specimens were discontinued at the end of 155 cycles. Cement 26 was carried through 220 cycles to establish its superiority more definitely.

It is evident that some change, presumably chemical in nature, took place within the concrete during the 7-month moist storage period and

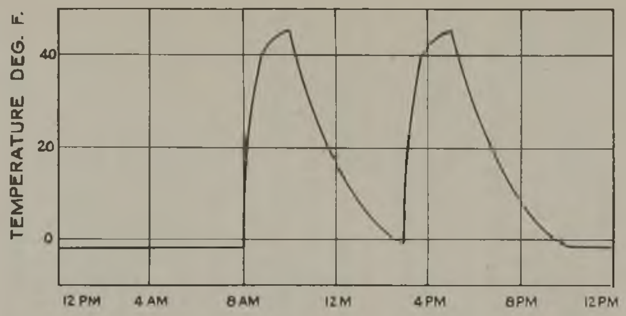


Fig. 7—Typical temperature record during freezing and thawing tests

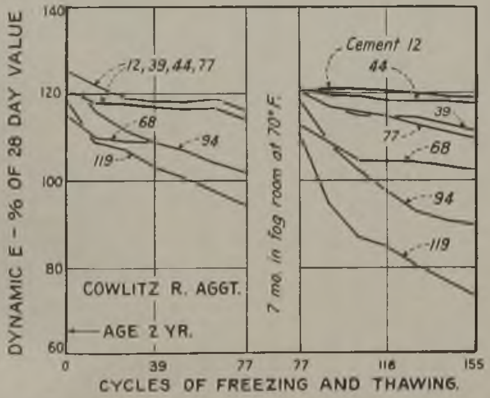


Fig. 10—Freezing and thawing tests of 4x4x20-in. concrete bars after 2 years moist storage

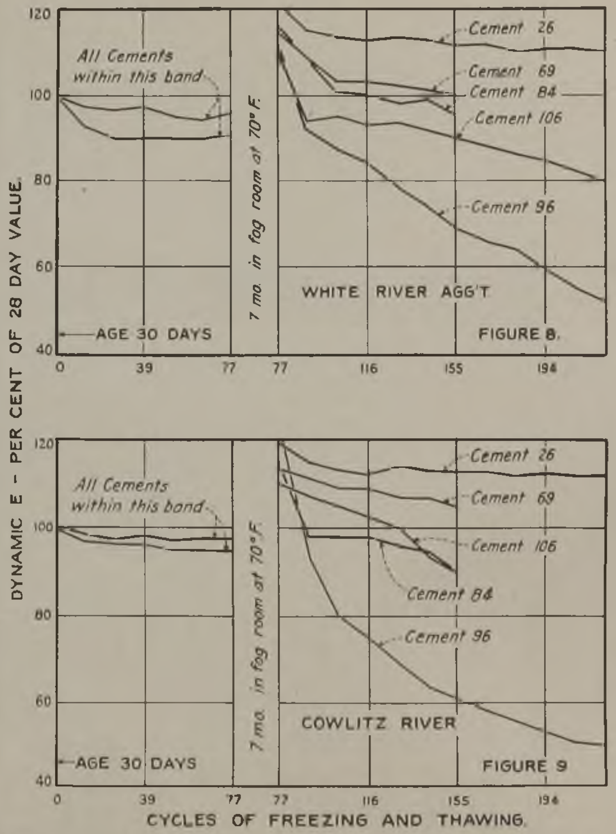


Fig. 8 and 9—Freezing and thawing tests of 4x4x20-in. concrete bars after 30 days moist storage that the alkalies in the cements took part in this change. It should be noted that, during the original 77 cycles, the bars were subjected to intensive leaching during thawing. It is known that alkalies are leached rather readily from small concrete members. It is entirely probable, therefore, that the full quantity of the alkalies originally in the cements was not present during the 7-month storage period. Leaching could account for the greater durability exhibited by cement 106 than by cement 96 since the alkalies in some cements are more readily soluble than in others.

There were 28 bars containing Cowlitz River aggregate on hand in the laboratory which had been stored continuously in the fog room for two years. This group included 7 cements of varying alkali content (4 bars of each cement). They had been tested periodically for dynamic modulus. All of these had gained at uniform rates proportional to the logarithm of the age.

Freezing and thawing was started on these bars (at the age of two years) with the results shown in Fig. 10. During the first 77 cycles differences in alkali content of the cements were more pronounced in their effect on durability than in the previous series (Fig. 9). In general, the degree of deterioration was proportional to alkali content. As in the previous series, the bars were stored an additional 7 months in moist air at 70 F, after which freezing and thawing was resumed. The curves show that the gain in dynamic modulus which took place during the 7-month period was approximately offset by the next 13 cycles, after which the progress of deterioration continued at approximately the rate obtaining before the moist storage. This fact may be interpreted as meaning that chemical action with the alkalies in the cement had been largely completed during the initial two years of continuous moist storage at 70 F. This does not mean similar completion of chemical reactions in two years' time under field conditions of lower average temperature and periodical drying.

EASTERN WASHINGTON STRUCTURES

Field observations:

Deterioration of concrete of the same type as in the structures in the vicinity of Mt. Rainier has not been found elsewhere on the State highway system of Washington. A number of structures containing disintegrating concrete of a different type, however, are in the eastern part of the State where climatic conditions are severe. Visible defects in the latter group have characteristics which differentiate it from that at Mt. Rainier. These differences are noted in the following tabulation:

	Eastern Washington	*Mt. Rainier*
Occurrence of cracks	In superstructure only	In all parts of structure
Pattern of cracks	Longitudinal only	Longitudinal and random
Relative width of cracks	Narrow	Wide
Character of concrete adjoining cracks	Visibly disintegrated	Apparently sound although dull and lifeless when fractured
Abnormal expansion	Occasional	Frequent
Scaling on decks	General, frequently of progressive type	Rare and in thin surface layer only
Exudations	Calcium carbonate, frequently heavy	Alkali carbonate efflorescence, occasionally
D-lines	Frequent	Of rare occurrence

Three areas in Eastern Washington in which deteriorating concrete is found will be discussed in this paper. The cements used in these structures have been high or medium high in alkalies. This fact has led to investigations to study the possibility that unsatisfactory durability resulted from unfavorable reactions between high-alkali cements and the aggregates involved. There is little field evidence to support or refute such a conclusion, however. There are no cases of use of low-alkali cement with the aggregates involved although low-alkali cement when used with other aggregates in one of the areas has given good service. Nor have the results been universally poor with all structures in which the troublesome aggregates have been used. Deterioration seems to have been conditioned by severity of exposure to moisture and cycles of freezing and thawing. The fact that disintegration has occurred nearly exclusively in handrails, sidewalks, decks and wing walls illustrates the effect of exposure.

Laboratory studies:

Lacking good field evidence, dependence has been placed upon the results of laboratory studies to determine the part that alkalies in cement have had in causing deterioration. The following three sand and gravel aggregates, one from each area under discussion, were selected for laboratory study:

1. Irvin—from the Spokane River Valley about ten miles east of Spokane supplemented by fine sand from Mead. Aggregates from this general vicinity have been used extensively and have been shipped for considerable distances. Abnormal expansion in pavements containing Irvin aggregate and a cement that evidently was extremely high in alkalies has been described previously(1).

2. Rock Island—from the flood plain of the Columbia River near the town of Rock Island. Aggregates from this pit have been used in the majority of highway structures in Stevens Pass.

3. Thorp—from a bar in the Yakima River near Thorp. Aggregates from this pit were used in bridges in Blewett Pass. Although other bars in the Yakima River have yielded durable concrete, the majority of highway structures containing Thorp aggregate have been faulty.

Characteristics of the latter which may distinguish it from other Yakima River aggregate are not obvious and have not been determined.

Properties of these aggregates are given in Table 3. It will be observed that they indicate characteristics usually associated with good durability.

Mortar bar tests conducted in the same way as described for Mt. Rainier aggregates were made with the sands and crushed gravels from these pits. Negligible expansion, generally less than 0.02 per cent has resulted in every case up to ages of 2 to 4 years. This has been true with both high- and low-alkali cements and with 1 per cent sodium hydroxide added to low-alkali cement. The tests indicate that these aggregates do not react with high-alkali cements in the same manner, or at least to the same degree, as those from Mt. Rainier and they confirm the field observation that the type of deterioration is different. They might well be considered as definitely non-reactive were it not for the results of laboratory freezing and thawing tests.

Freezing and thawing tests of concrete containing these aggregates were made concurrently with, and methods were the same as, those of the Cowlitz and White River aggregates. Sand and gravel from the glacial deposit near Steilacoom on Puget Sound was included in the group. This aggregate has an excellent service record and has been used to some extent under severe climatic conditions.

The results of freezing and thawing tests are shown graphically in Fig. 11 to 14 inclusive. These data show that with one exception, to be discussed later, the first 77 cycles had very little effect on any of the specimens. This result indicates that the aggregates and cements each had characteristics making for good initial durability.

Following the first 77 cycles the specimens were stored in a fog room at 70 F for seven months. Upon resumption of freezing and thawing it became evident that changes, presumably chemical in nature, had taken place in certain specimens with the result that they were no longer resistant.

A study of the curves shows that in every case of poor resistance the cement was one of the three of highest alkali content. Good durability resulted in every case with cements 26 and 69, the lowest in alkalies. These were followed consistently in order by cements 106, 84 and 96.

The cements themselves were capable of making durable concrete as shown by the results with Steilacoom aggregate. Even cement 96 which gave such poor durability with the other aggregates was only slightly affected with Steilacoom aggregate.

Particular attention is called to the results obtained with cement 106 and Thorp aggregate. Two of the bars, No. 40 and 41, failed rapidly

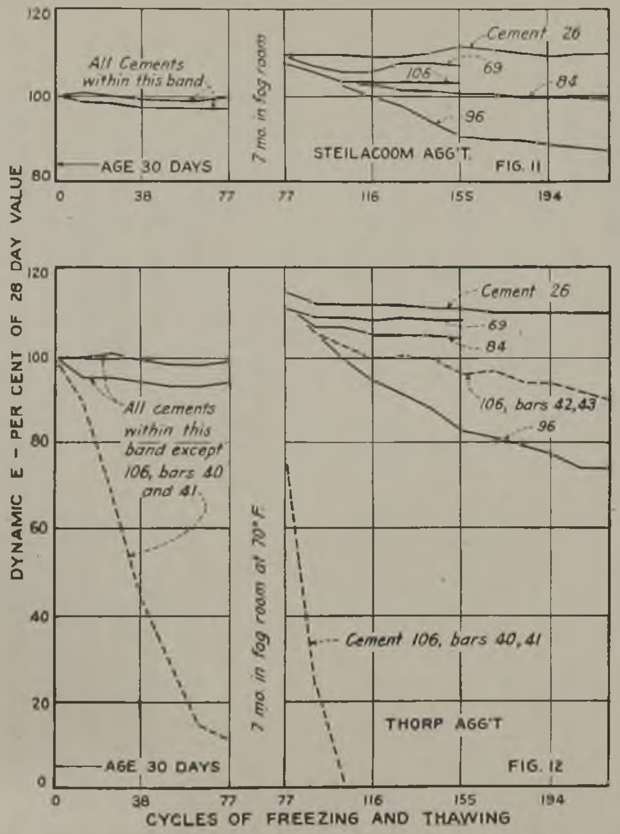


Fig. 11 and 12—Freezing and thawing tests of 4x4x20-in. concrete bars after 30 days moist storage

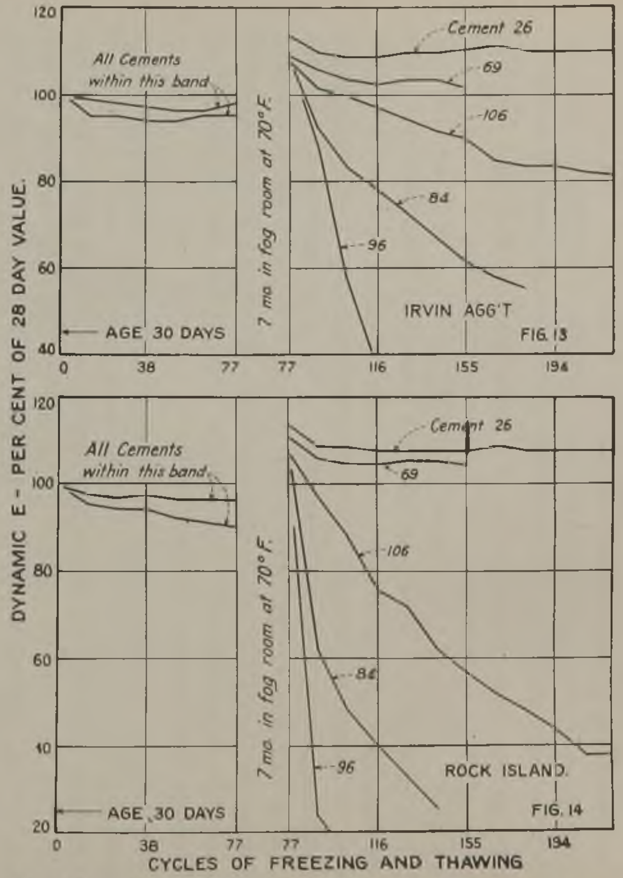


Fig. 13 and 14—Freezing and thawing tests of 4x4x20-in. concrete bars after 30 days moist storage during the first 77 cycles. Companion bars, 42 and 43, were not appreciably affected. Bars 40 and 41 were from one batch of concrete, bars 42 and 43 from another. This is the only instance in the series of marked difference between the bars of a group. There is no apparent reason in the mix data that explains the difference in behavior of the two batches. The most plausible explanation that comes to mind. and one that has not been confirmed, is that the aggregate carries a few particles of highly reactive material that in some way were concentrated in the batch used for bars 40 and 41. These two bars presented peculiarities in appearance that have not been observed with any of the other concrete specimens. During the 7-month period of fog room storage heavy exudations, identified as calcium carbonate, appeared on the surfaces. These were similar in appearance to those observed on the Blewett Pass bridges which contained aggregate from the same source. At the conclusion of 103 cycles, when these bars were broken as beams, crystals were noted in great profusion over the entire fractured faces. Some of the crystals were in the form of hexagonal plates, others in long slender shapes. Both have been identified as calcium hydroxide. The reason for part of the calcium hydroxide crystallizing in needle form instead of the customary hexagonal plates is not known.

Summarizing the results of the freezing and thawing tests, it was found that

(1) Good resistance resulted with each cement when combined with Steilacoom aggregate.

(2) Good resistance resulted with the two cements of lowest alkali content when combined with each of the aggregates.

(3) Poor resistance resulted with the three cements of highest alkali content when combined with each of the three aggregates from Eastern Washington.

These results appear to preclude the possibility that lack of durability with the latter aggregates was influenced appreciably by factors other than high-alkali content in the cement. The tests described below also point to the alkali content of the cement as the main, if not the sole, factor determining durability.

Mention was made of 1x1x10-in. mortar bars containing sand and crushed gravel from the three eastern Washington pits which had been stored for from 2 to 4 years in sealed containers without appreciable expansion. A number of these bars were subsequently subjected to 52 cycles of freezing in air to 0 F and thawing in water to 45 F. Changes in length, weight and frequency were measured at 13 cycle intervals. The degree of deterioration indicated by the three sets of measurements

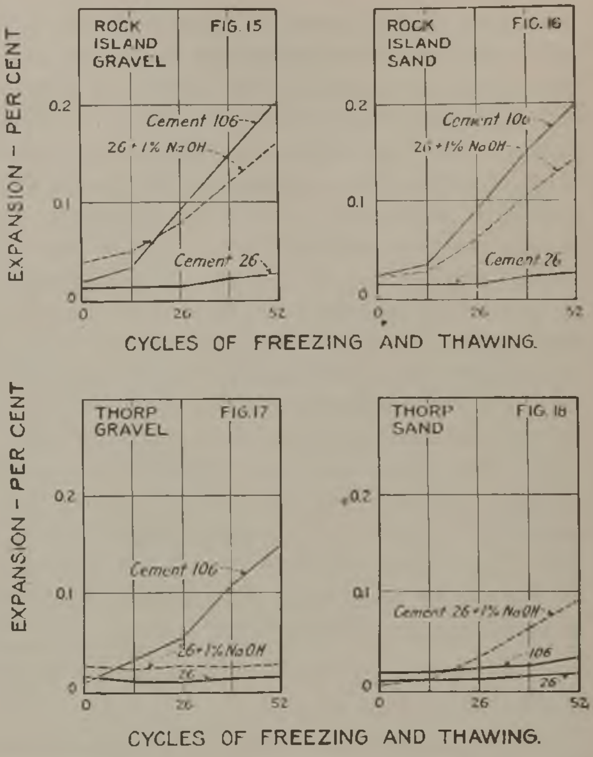


Fig. 15 to 18—Freezing and thawing tests of 1x1x 10-in. bars of 1:2 mortar after 25 months sealed storage

was in excellent agreement. Since length changes were recorded during original sealed storage these measurements only are reported for freezing and thawing. In these tests an expansion of 0.1 per cent is roughly equivalent to a loss of 20 to 25 per cent in dynamic modulus. Bars containing Irvin aggregates were not affected appreciably in these tests. This result may be due to the fact that the aggregates were crushed and graded to pass a No. 30 sieve. Sand and crushed gravel from the Thorp and Rock Island pits was graded up to the No. 4 sieve and in these specimens the effect of alkalies is well shown. These data are given in Fig. 15 to 18 inclusive. It will be noted that the expansion due to freezing and thawing was very slight when cement 26 was used with either aggregate but that cement 106 caused large expansions in three cases out of four. The addition of 1 per cent sodium hydroxide to cement 26 raised its alkali content to a value approximately equal to that of cement 106, and caused expansions of the same order as the latter cement. The inconsistencies among the specimens containing Thorp aggregate seem to be a reflection of the erratic results obtained with this aggregate in the concrete bars described earlier. Similar instances of non-conformity to type have been noted in the structures in which this aggregate was used.

The data of the mortar bar tests bring out strongly the fact that it is the high content of alkalies and not some other property of the cement that lowers resistance to freezing and thawing. A study of Table 2 indicates a number of properties of cement 106 that might be considered to be indicative of lower quality than cement 26. It is significant, therefore, that through the addition of alkali alone the resistance of cement 26 was reduced to a degree approximating that of cement 106.

Discussion:

The aggregates from the three sources in Eastern Washington exhibit reactivity of a type different than that found at Mt. Rainier or that described by Stanton(5), Meissner(4), Kammer and Carlson(6) and others. In the laboratory, mortar bars containing these aggregates with high-alkali cement or low-alkali cement, with or without added alkali, did not expand significantly during storage at 70 F in sealed containers. Yet, among these bars, those of high-alkali content, when subjected to cycles of freezing and thawing after prolonged sealed storage, did expand appreciably.

Results similar to those of the mortar bars were obtained in freezing and thawing tests of larger concrete specimens. The cycle used in this study has been found by test to be milder than that described by Reagel(7) although conducted at similar temperatures. The difference in severity was mainly the result of thawing under sprays of water instead of by direct immersion. The latter procedure, used by Reagel and others, seems to force more water into the specimens because of the hydrostatic head involved. The cycle used in these studies was adequate in severity to disclose marked differences in durability and seems to approximate the effect of rain and melting snow during natural exposure to weather.

It is indicated, therefore, that better results would be obtained in service if cements of low-alkali content were used with aggregates similar to those of Eastern Washington that were investigated.

Reactivity of the type found in these aggregates has not been described previously. It should be noted that a period of approximately one year was the shortest time in which evidence of reactivity was ,established by laboratory test. It is desirable, therefore, to conduct further studies designed to develop a more accelerated test method.

CONCLUSIONS

Aggregates containing rock types derived from the lavas of Mt. Rainier react detrimentally with high-alkali cements and the type of reaction is similar to that reported by other investigators in a number of locations. These aggregates do not react harmfully with low-alkali cements as indicated by laboratory tests and by excellent results in existing structures, some of which have reached the age of 19 years.

Aggregates from three sources in eastern Washington have produced concrete that is lacking in resistance under severe climatic exposure. Laboratory studies indicate that poor resistance is primarily a function of the alkali content of the cement. The type of reaction, however, is distinctly different from that occurring with Mt. Rainier aggregates.

These results point to the need of limiting the alkali content of cements for use with many aggregates in Washington. The present tests, however, do not furnish sufficient data to determine definitely the safe upper limit of alkalies.

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A part of PROCEEDINGS OF THE AMERICAN CONCRETE INSTITUTE Vol. 41

JOURNAL
of the
AMERICAN CONCRETE INSTITUTE

Vol. 16 No. 2 7400 SECOND BOULEVARD, DETROIT 2, MICHIGAN November 1944

The Effect of Curing Conditions on Compressive, Tensile and Flexural Strength of Concrete Containing Haydite Aggregate*

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Members American Concrete Institute

SYNOPSIS

Lightweight concrete has been given a severe test in the U. S. Maritime Commission's present concrete ship construction program. In its use, problems arose that could not be solved by the application of sand-gravel concrete data. This paper describes some of the strength characteristics of this type of concrete. Data herein are consistant in showing that rapid moisture loss from Haydite concrete produces a serious retrogression in the tensile and flexural strengths, regardless of the length of moist curing. This decline in strength, caused by drying shrinkage stresses developing in the outer fibers as the moisture content becomes unbalanced, is of a temporary nature and apparently can be curbed by the application of paint or membrane seal following the moist curing period. The drying shrinkage may well contribute to serious cracking in some types of structures if control is not maintained.

INTRODUCTION

This paper discusses the results of some tests of lightweight concrete made at the Belair Shipyard during the construction of twenty ship-shape concrete barges built by Barrett and Hilp under a contract with the U. S. Maritime Commission. The study was undertaken to determine the cause of extensive cracking of the concrete experienced elsewhere in similar structures.

Specific data covering the strength characteristics of Haydite concrete were meager and results obtained by different laboratories could not always be correlated. It was natural, therefore, that there should be conflicting theories regarding the cause of the cracking. The authors had designed the mix being used in the ship concrete at Belair to include 25 to 35 per cent fine Haydite and were getting highly satisfactory

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*Received by the Institute—June 19, 1944. This paper does not have the endorsement of the U. S. Maritime Commission.

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compressive strengths. There was much concern therefore upon receipt of information that laboratory results indicated that the inclusion of fine Haydite (0 to No. 4) in the mix seriously reduced the tensile strength of the concrete. The use of a minimum of 15 per cent natural sand by solid volume of the total aggregate had been specified by the Maritime Commission. This specification was included because previous tests* had shown that use of some natural sand in lightweight concrete tended to increase resistance to shattering on impact.

Cracking of the ship concrete had been negligible and for this reason the authors were reluctant to replace the fine Haydite with natural sand, and thereby reduce the cargo carrying capacity of the barges, without further proof of the necessity for doing so.

While experimenting with different proportions of natural sand in the mix, it was discovered quite by accident that the normal tensile and flexural strength of Haydite aggregate concrete is greatly dependent upon an even distribution of internal moisture at the time of testing, in fact, far more so than any strength variance influenced by the natural sand content. Data included in this paper therefore are not the results of a well planned test series based on any preconceived theory on what the results might be, but rather a series of small investigations, each individual test based on evidence newly discovered in the one just preceding it. This procedure necessitated duplication of much work in order to tie the tests together. Unfortunately the authors were not in possession of the excellent paper on this subject by W. F. Kellermann† until much of this work had been completed. Otherwise time allotted to finding the cause could have better been given to seeking a practical cure.

Few long time tests have been started because of the probability of insufficient time to complete them. Data included herein, with one exception, are based on tests requiring not more than 60 days.

TEST PROCEDURE

The Haydite used in the tests was manufactured at San Rafael, Calif., except that the fine Haydite in some batches was from Kansas City, Mo. The natural sand was a blend of 75 per cent Kaiser Top sand from Radum, Calif. with 25 per cent of a fine sand from Antioch, Calif. With few exceptions standard hull concrete, containing 50 percent coarse aggregate of size $\frac{3}{16}$ to ½ in. and 50 per cent total fine aggregate was batched in the proportion of materials currently on hand giving a suitable grading combination. A few tests were made on mixes containing all Haydite and a few were made with no fine Haydite.

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*Kluge, Ralph W. "Impact Resistance of Reinforced Concrete Slabs." ACI JOURNAL, April, 1943, *Proceedings*, V. 39, pp. 397 to 412.

†Kellermann, W. F., *Public Roads*, May, 1937.

Plastiment was added in the amount of ⅜ lb. per sack of cement. The cement was type II from the Permanente and Yosemite corporations.

Specimens

Whenever practicable, a large number of specimens were cast from a routine test batch of ship concrete and divided into groups subjected to the various curing treatments. This was done to eliminate the possibility of unwanted variables between numerous small batches with a few specimens from each. Compression specimens were 6 by 12 in. cylinders, rodded and tested in accordance with standard methods. Values given are average results of from two to four tests.

Tensile specimens were cast in standard mortar briquette molds. The briquettes were cured at this laboratory and tested by a commercial testing laboratory of San Francisco. The full mix was used in the briquettes and thorough compaction was obtained by rodding with a 60 penny spike in conjunction with finger puddling. Reported results are based on averages of from two to four specimens. Briquettes breaking more than 15 per cent out of line with the average of the group were not considered in the graphs.

The procedure used in testing flexural strength was, in so far as practicable, that suggested by A. T. Goldbeck, Director, Bureau of Engineering, National Crushed Stone Association, Inc., Washington, D. C. in his paper, "Tensile and Flexural Strength of Concrete."*

The specimens were 6 x 6 x 20 in. beams, placed in two layers and compacted by rodding. The amount of rodding was varied with different consistency, but was sufficient always to assure good compaction. Loading was done as a simple beam with the load applied at third points over an 18-in. span. The finished surface was always placed in tension. The rate of loading throughout developed a maximum fiber stress of 200 psi per minute.

The temperature of specimens at the time of testing was 70 F. The testing apparatus was one of local design and construction in which consideration had to be given economy as well as the elimination of unwanted lateral forces. While it is recognized that a more elaborate device might not duplicate the actual results, it should nearly duplicate the ratio between the strength of the various groups. Moist curing was the standard 70 F. fog. Those specimens painted following the moist curing period were given 3 coats of the special concrete paint used on the ships. Three coats, applied by brush, approximated the depth of coverage the ships received.

Air curing was accomplished by storage in the laboratory in which the temperature averaged 70 F. and relative humidity 60 per cent.

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*See A.S.T.M. "Report on Significance of Tests of Concrete and Concrete Aggregates".

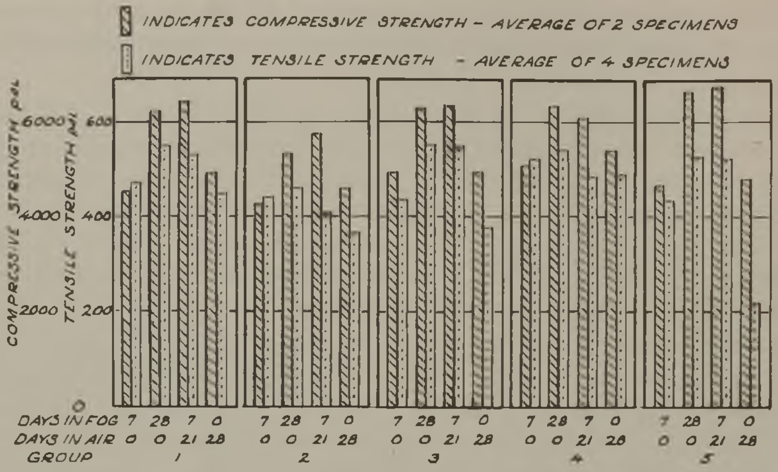


Fig. 1 (above)—Effect of drying on tensile and compressive strengths

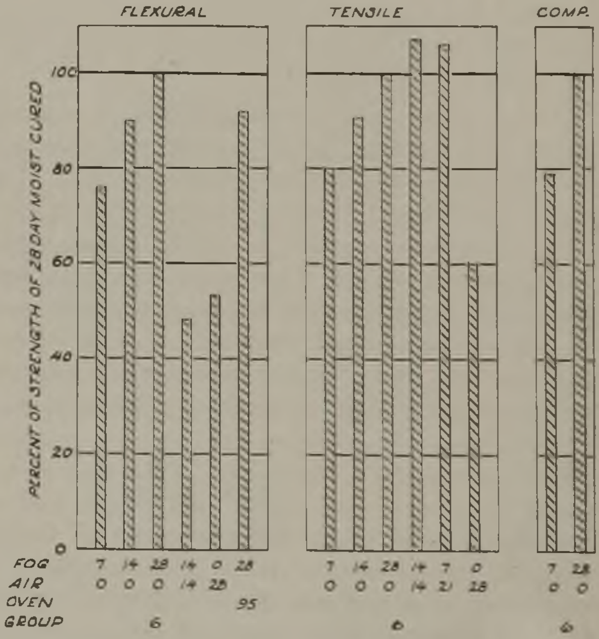


Fig. 2 (right)—Effect of drying on tensile and flexural strength of Haydite aggregate concrete after various periods of moist cure

DISCUSSION OF RESULTS

There is no evidence in any of the groups in Fig. 1 to indicate the tensile strength would be adversely effected either by drying or by variance in the amount of fine Haydite used. Likewise Fig. 2 shows no loss in tensile strength. However, Fig. 2 does show the flexural strength after 14 days of drying to be only 48 per cent of the continuously moist

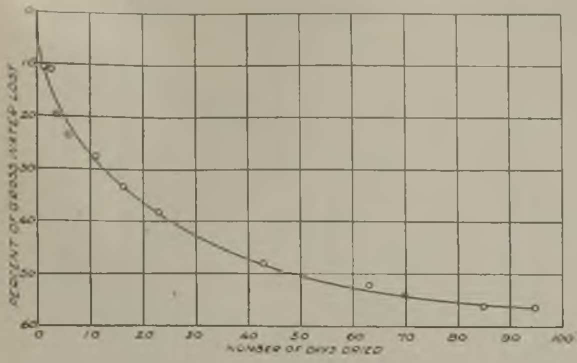


Fig. 3—Rate of moisture loss from two beams oven dried at 135 F

cured specimens. This was the first indication that an unbalanced moisture content might be at least partially responsible for the cracking in structures examined elsewhere.

Two of the beams from the group in Fig. 2, dried to constant weight at a temperature of 135 F., are shown to have recovered all but 8 per cent of their strength before drying in spite of the fact that the accelerated drying caused stress sufficient to create a myriad of minute surface cracks within two days. Undoubtedly there would have been less cracking under normal drying conditions and at constant weight the flexural strength would have been as great as, or greater than, before drying. Kellerman found specimens dried to constant weight in an electric oven at 170 F., after 360 days moist curing, to be 67 per cent as strong as they were at the end of the curing period. The condition of the surface of these beams was not noted, however.

Referring to Fig. 6, it will be seen that the moisture remaining within the small briquettes after one day of drying is approximately equivalent to that in the beams after a month of drying and that by the end of three weeks they are approaching constant weight. This explains why no recession in strength due to drying was revealed by tensile tests shown in Fig. 1 and 2. Fig. 4 shows that a decline in strength does occur in the briquettes, but because of the high ratio of surface area to volume the moisture is lost and strength regained rapidly.

It appears significant that with the short curing period of 7 days the loss in strength during drying was neither as great nor did it occur as quickly as in those specimens cured 14 days. This is shown in Fig. 4 to be true for both the beams and briquettes and is in agreement with Kellerman who found a 38 per cent retrogression in strength of beams moist cured 353 days followed by 7 days drying in conditions less acute than here. A plausible explanation is that since the modulus of elasticity increased with age, the outer fibers of the younger group, being more

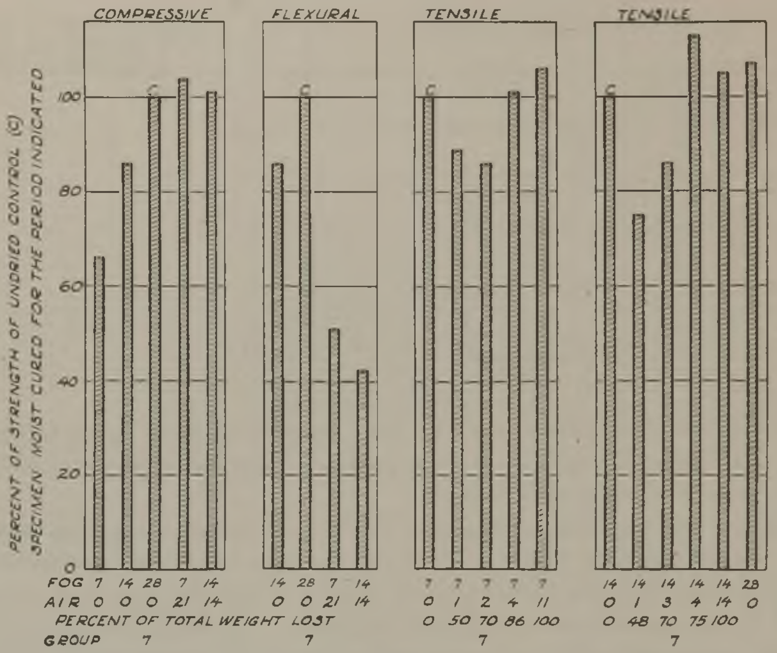


Fig. 4—Effect of drying on compressive, flexural and tensile strength of Haydite aggregate concrete and the relation of strength decline to moisture loss

plastic, yielded to deformation without developing as much stress as those in the group cured 14 days. Further evidence was observed in the aforementioned oven-dried beams which cracked much more after 28 days moist curing than did a test panel made at the start of the program in this yard. The test pannel was made with wetter concrete; it received no water curing; and it was exposed from the beginning to drying winds and sun.

As the tensile and flexural strength recedes during drying, the compressive strength increases. Fig. 1 and 4 show the strength of cylinders moist cured 7 and 14 days followed by 21 and 14 days respectively of drying to be consistently higher than of those continuously moist cured. This is not in strict agreement with Kellermann's findings, but the different storage conditions were possibly responsible for this variance. Although the strengths of Kellermann's dried specimens were lower than those moist cured at any given age, they continued to gain strength only slightly slower at a considerably lower temperature than his moist cured cylinders. Hydration of cement would naturally be somewhat retarded.

Evidently some initial compression loading on the partially dried cylinders serves only to bring stresses in the outer shell back into equili-

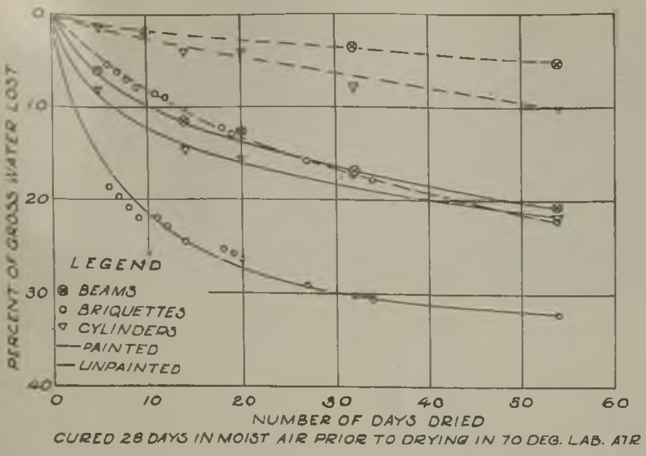
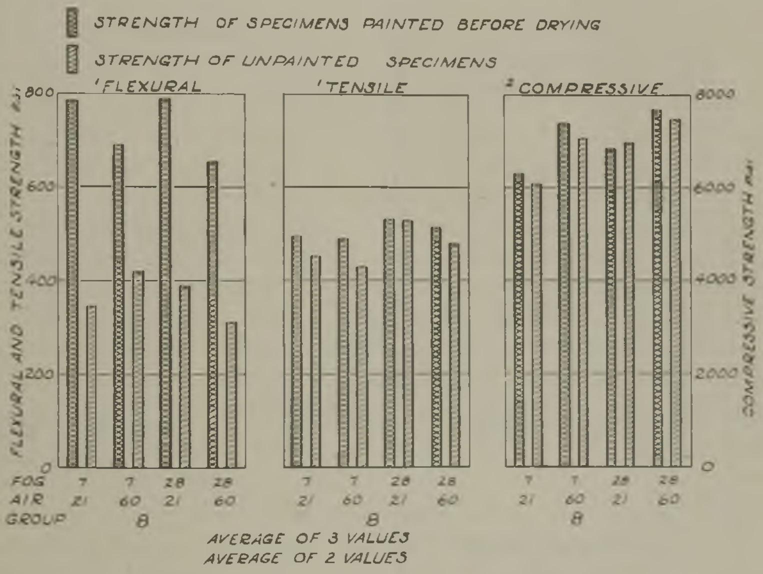


Fig. 5 (at left)—Effect of drying on the strength of specimens painted after moist curing

Fig. 6 (below)—Comparative rates of drying between specimens painted and unpainted



brium, and since at final rupture the outer portion must be first to yield, the result is a higher than normal strength. The effect on strength properties of painting the concrete immediately following the moist curing period is shown in Fig. 5 and the effectiveness of the paint in retarding the moisture loss is given in Fig. 6. Fig. 7 shows the relative appearance between the cross section of a painted and unpainted specimen after each had been dried 60 days. The photograph was taken immediately after breaking the beams. Note the even dark shading over the entire area of the painted beam in contrast with the light peri-

TABLE 1—SUMMARY OF MISCELLANEOUS DATA OF THE VARIOUS MIXES USED IN THE TEST SERIES

Test Group No.	Mix Proportions Percent of Solid Volume of Total Aggregate					Cement Content Sks. Per Cu. Yd.	Slump In Inches	Weight of Fresh Concrete Lbs. Per Cu. Ft.	Average Compressive Strength at 28 Days
	Nat. Sand	Haydite Aggregate							
		S.R ½	S.R ⅜	S.R $\frac{3}{16}$	K.C $\frac{3}{16}$				
1	0	30	20	50		9.17	4.0		6410
2	0	30	20		50	9.17	4.0		5780
3	15	30	20	35		9.17	4.0		6335
4	25	30	20	25		9.17	4.0		6085
5	50	30	20			9.17	4.0		6770
6	20	30	20	30		9.07	4.2	119.7	6300
7	15	30	20		35	9.20	4.0	115.0	5680
8	15	30	20		35	9.16	2.7	118.6	6130

TABLE 2—GRADING AND PHYSICAL PROPERTIES OF AGGREGATE

% Pass. Screen Size	Nat. Sand	$\frac{3}{16}$ K. C.	Haydite Aggregate		½ S. R.
			$\frac{3}{16}$ S. R.	⅜ S. R.	
½ Inch					86
⅜ Inch				99	38
No. 4			99	24	6
No. 8	87	86	72	5	
No. 16	62	46	40	1	
No. 30	43	25	23		
No. 50	20	15	14		
Pan					
F. M.	2.82	3.22	3.47	5.71	6.66
PHYSICAL PROPERTIES					
Sp. G. (Dry)	2.56	1.53	1.69	1.56	1.46
Absorption	2.4%	13%	15%	13%	13%
Wt. per Cu. Ft. (Dry-loose)	94	57	63	49	45

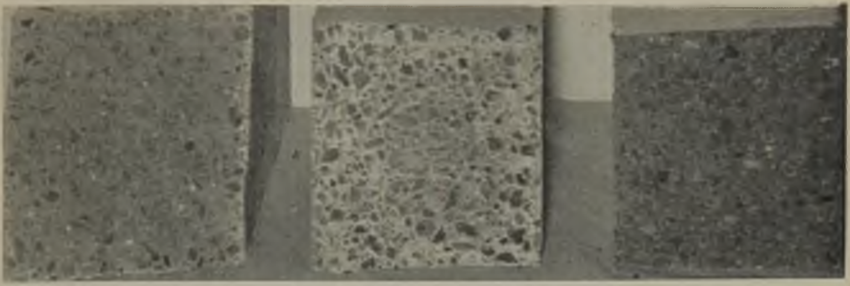


Fig. 7—Relative appearance of cross-section of painted and unpainted specimens

Specimen at left, unpainted, dried 60 days in air at 70 F.; center, ovendried to constant weight; specimen at right, painted, dried 60 days in air at 70 F.

meter of the unpainted one. It is evident from the photograph, and from Fig. 6 which shows the painted beams to have dried slowly and at a nearly even rate throughout the 60 day period, that at no time could the moisture content have been greatly out of equilibrium.

There is no proof in the data that the paint is not merely delaying the recession in strength and that it would not occur later and extend over a longer period; in fact the loss in strength noted in Fig. 5 between 21 and 60 days of drying is evidence that the paint does not entirely check the development of stress. However, the behavior of the painted briquettes, having had time to dry more than the beams within the test period, indicates that the painted beams will never drop as low in strength as the unpainted ones. Fig. 6 shows that the 28 day moist cured painted briquettes had lost approximately the same percentage of moisture after drying 21 days as had the unpainted ones after drying 3 days. If there were ever to be an appreciable decline in strength it should be in evidence at this time, yet Fig. 5 shows the strength to be normal for continuously moist cured concrete.

The importance of preventing a rapid loss of moisture from Haydite aggregate concrete, particularly in such thin walled structures as ships, cannot be too greatly emphasized. Let us assume for instance, locked shell or skin stress great enough that the shell is not quite capable of withstanding the additional working stress. Slight impetus, developed through failure of the shell might be sufficient to carry the crack completely through the section possibly with less loading than would be needed to cause failure had the shell already been cracked and stress relieved. This can be likened to the bursting of a ripe watermelon when the skin is cut.

The writers regret having to give up further search for a practical means of curbing this temporary retrogression in strength, however another approach has suggested itself as being worthy of investigation. While experimenting with batching of the highly absorbitive Haydite in a dry instead of the normal prewetted condition we were able to reduce substantially the gross water content and thereby reduce the weight of fresh concrete by 4.0 lb. per cu. ft. After a year of moist curing there remained a 3.5 lb. differential in weight, due entirely to the difference in absorbed water. No flexural strength tests were made, but compressive strength of the dry aggregate concrete was consistently higher than that of the prewetted aggregate concrete. The water absorbed within the aggregate is strongly indicated to be responsible for the temporary loss of flexural and tensile strength. Any reduction in absorbed water that is effected by dry batching or by coating the aggregate to resist absorption might be beneficial.

CONCLUSIONS

1) It is important to prevent rapid drying of concrete made with Haydite (lightweight) aggregate regardless of the length of the moist curing period. This is particularly true for the type of structures receiving maximum loading within a few weeks after the moist curing and in which high tensile and flexural strength is a prime consideration.

2) The compressive strength of Haydite concrete is no criterion of the flexural strength except during the moist curing period. During this time the flexural strength is normally 12 per cent of compressive but it can temporarily recede to under 5 per cent during a transitional period in which drying shrinkage stress develops in the outer fibers of the concrete. This stress is subsequently relieved by continued drying to the center of the mass and the flexural strength is regained.

3) The application of paint or other membrane to the concrete following moist curing serves to maintain uniformity of moisture throughout a long drying period and is beneficial, not only in promoting continued hydration of the cement, but also in preventing development of high stresses that reduce the strength.

Discussion of this paper should reach the ACI Secretary in triplicate by March 1, 1945, for publication in the JOURNAL for June, 1945

A part of PROCEEDINGS OF THE AMERICAN CONCRETE INSTITUTE Vol. 41

JOURNAL
of the
AMERICAN CONCRETE INSTITUTE

Vol. 16 No. 2 7400 SECOND BOULEVARD, DETROIT 2, MICHIGAN November 1944

A Limited Investigation of Capping Materials for Concrete Test Specimens*

By THOMAS B. KENNEDY†
Member American Concrete Institute

SYNOPSIS

An investigation was made of the influence of type and age of cap on the apparent strength of concrete cylinders. The capping materials tested consisted of 2 types of commercial sulfur-silica compounds and 2 commercial plasters which had been in general use for this purpose. A total of 252 tests were made of concrete ranging in strengths from 2800 to 7500 psi.

The results indicate that the age of the caps has an important bearing on the apparent strength of the concrete with one hour being the minimum time required for the best of the materials to develop the full strength of the concrete.

1. INTRODUCTION

There are many factors which affect the apparent compressive strength of concrete test cylinders, and it is highly important that the testing laboratory fully develop the inherent strength of the specimens submitted to it for testing. Others have shown that concavity, convexity, irregularity and beveled-end conditions affect the apparent strength to varying degrees depending upon the capping material used.

This paper reports features of a laboratory investigation undertaken to clear up certain particular aspects of the problem of concrete-cylinder capping, and their effects on the apparent strength of the specimen tested. In some respects the work parallels features investigated by Troxell(1)‡ and confirms his work, while other points investigated were different.

This laboratory had been using, for almost two years, a certain commercial sulfur-silica compound, called herein compound "A", for capping

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*Received by the Institute, March 10, 1944.

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‡See references at end of paper.

test specimens, when through an odd circumstance it was discovered that specimens capped with this compound did not attain the strength at ages up to 5 hr. after capping that they did when the caps were 20 to 24 hr. old. The fact was discovered when a series of relatively high-strength specimens 147 to 235 days old, were being tested. All the specimens were capped on one day, but only half were tested that day, the remainder being tested the day following. It was found that those tested the day after capping had attained an average relative strength of 123 per cent when compared with those tested the same day capped. The compressive strength of the specimens on the day capped was nominally 4800 psi.

2. DESCRIPTION OF TESTS AND MATERIALS

The observation mentioned led to a limited program in which the following features were investigated:

(a) Two sulfur-silica compounds were compared: compound "A" and compound "B", the latter being a sulfur-silica product of known high strength, which had been used in the laboratory prior to the use of compound "A". Both these sulfur-silica compounds are proprietary materials. Compound "A", as ordinarily purchased, is in the form of 10 lb. bricks, while compound "B" is purchased as a powder in 100 lbs. bags. Both materials were used to cap a series of specimens comparing two end conditions, one with plane parallel ends, and the other with the bottom end plane and the top end stepped. The step was ¼ in. deep and comprised one half of the end area. Specimens were tested at varying time intervals after capping to determine the rate of strength gain of the two materials.

(b) Compound "B" was compared with two gypsum products: one, called compound "C", was a "medium-strength" material, and the other, called compound "D", was a "high-strength" material as identified by the manufacturer. Both compounds "C" and "D" were similar in appearance and in general action to plaster-of-Paris. The effect of varying time intervals between capping and testing was studied for each material.

(c) Compounds "B", and "D" were used in determinations of the difference in apparent strength caused by variation of thickness of caps.

All the concrete tests were performed on standard 6-in. by 12-in. concrete cylinders, which were tested using a 300,000-lb. capacity Baldwin-Southwark Universal testing machine.

The concrete used for the test specimens was varied according to plan. The coarse aggregate was a ¾ in. maximum size, uncrushed siliceous gravel, and the fine aggregate was a natural siliceous sand. The cement used complied with Federal Specification E-SS-C-191b and the water-cement ratio and cement factor were varied to attain whatever strength was desired. The slump ranged between 2 and 3 in. Each batch was mixed for 5 min. in a Smith 3 1/2S tilting mixer. A total of 252 cylinders was made and tested.

Capping with the sulfur-silica compounds was done using a Nardiello capping machine. All sulfur-silica caps were ¼ in. thick except on those cylinders which were capped with varying thickness of caps to study the effect of thickness upon the apparent strength.

The sulfur-silica compounds were heated in electric, thermostatically-controlled pots to a temperature of 248 F. ± 5F. The plaster caps were formed using squares of ⅜ in. thick plate glass pressed into the plaster to produce as thin caps as possible not exceeding 1/16 in. in all cases except, of course, where thicker caps were desired in the study of the effect of the thickness of caps. These thin caps could be made on laboratory specimens formed in molds with machined bottoms and having troweled top surfaces. Compound "C" was mixed in the proportion 1 part of water to 3 parts of "C" by weight, and compound "D" in the proportion 1 part of water to 3.57 parts of "D" by weight.

All concrete cylinders were cured in a fog room in an atmosphere of 100 per cent relative humidity and a temperature of 70 F.

3. DISCUSSION OF RESULTS

To compare the two sulfur-silica compounds, a total of 40 cylinders were made from two presumably identical batches of nominal 4500-psi. compressive-strength concrete. Half of the cylinders of each batch had plane parallel ends and half had stepped ends. Alternate cylinders from each batch were taken for capping with each compound. The twenty specimens capped with compound "A" then contained ten with plane ends and ten with stepped ends. The same was true of specimens capped with compound "B". Of each of the four groups of similar specimens, half were tested when the caps were 15 min. old and half when the caps were 2 hr. old. Relative compressive strength was based on the highest strength attained by any group. Table 1 gives the results of this series.

The stepped-end condition did not seem to have much effect on the compressive strength. There was an indication that compound "B", at an early age, gained strength somewhat faster than compound "A".

To determine the rate of strength gain for the two sulfur-silica compounds, a total of 46 specimens of nominal 3800-psi. compressive-strength concrete was made from two presumably identical batches of concrete.

TABLE 1—COMPARISON OF SULFUR-SILICA COMPOUNDS "A" AND "B" AT AGE OF CAP AND END CONDITION OF CYLINDERS BEFORE CAPPING AS SHOWN

End Condition and Type of Cap	Age of Cap, Relative Compressive Strength and Per Cent Deviation in Strength Nominal 4500-psi. Concrete 5 Cyls. each test							
	15 Min.				2 Hr.			
	Rel. Comp. Str. %	Max. Dev. %	Min. Dev. %	Av. Dev. %	Rel. Comp. Str. %	Max. Dev. %	Min. Dev. %	Av. Dev. %
Plane End, Compound "A"...	84	5.0	0.5	2.6	92	3.0	0.0	1.2
Plane End, Compound "B"...	85	4.5	1.5	2.8	100 (1)	3.5	1.5	2.2
Stepped End, Compound "A"	84	4.0	0.0	2.3	88	3.0	0.0	1.6
Stepped End, Compound "B"	88	8.0	0.5	4.2	99	4.5	0.5	2.8

(1) 100% equals 4445 psi.

All the cylinders from one batch were capped with compound "A" and all from the other batch with compound "B". Each batch of 23 cylinders was split into five groups, each group contained five cylinders except one which contained three. One group of five was tested when the caps were 1 hr. old, one when the caps were 2 hr. old, one at 18 hr., one at 24 hr., and the group of three when the caps were 40 hr. old. The 46 specimens comprising both groups were tested during one afternoon. All 46 were removed from the fog room simultaneously (48 hours before the time they were due to be tested) and remained in the laboratory air until tested. The capping was scheduled so that on the afternoon of testing some caps were 40 hours old, some 24 hours, some 18 hours, etc. This procedure insured that all specimens were alike relative to curing and drying. The highest strength attained by any group of the compound "A" specimens was with caps 40 hours old and this was considered 100 per cent relative compressive strength for that compound. For compound "B", the highest strength was attained by the 5 hour group and this was considered 100 per cent. Table 2 gives the results of this series.

It appeared from the results shown in Table 1 and Table 2 that compound "A" did not develop its strength as rapidly as compound "B". Compound "B" appeared in all cases to give specimen strengths at 1 hr. after capping approximately equal to strengths at later ages up to 40 hr.

One more set of cylinders was made for check on compound "A". These were of nominal 5000-psi. compressive strength concrete. There were 20 cylinders in the set, and they were divided into groups of five

TABLE 2—RELATIVE COMPRESSIVE STRENGTH IN PER CENT AND PER CENT DEVIATION OF NOMINAL 3800-PSI. CONCRETE CYLINDERS CAPPED WITH SULFUR-SILICA COMPOUNDS "A" AND "B" AND TESTED AT AGE OF CAP SHOWN

	Age of Cap																			
	1 hr.				5 hr.				18 hr.				24 hr.				40 hr.			
Type of Cap	Rel. Str.	Max. Dev.	Min. Dev.	Av. Dev.	Rel. Str.	Max. Dev.	Min. Dev.	Av. Dev.	Rel. Str.	Max. Dev.	Min. Dev.	Av. Dev.	Rel. Str.	Max. Dev.	Min. Dev.	Av. Dev.	Rel. Str.	Max. Dev.	Min. Dev.	Av. Dev.
Compound "A"...	83	7.0	3.0	5.0	84	6.0	2.0	3.6	93	6.0	1.0	3.2	96	7.0	1.5	4.4	(2) 100	5.0	0.5	3.2
Compound "B"...	99	2.5	0.5	1.7	100 (1)	6.0	0.5	2.8	98	5.0	1.0	2.9	97	6.0	0.5	3.4	98	1.8	0.5	1.0

(1) 100% equals 3800 psi. (2) 100% equals 3860 psi.

to be tested at 30 min., 1 hr., 2 hr., and 19 hr. after capping. All the specimens were removed from the fog room 24 hr. before the end of the testing period. The results are shown in Table 3. The strength at 19 hr. was taken as 100 per cent relative compressive strength. The relative results are also shown where the assumption is made that the strength at 19 hours was only 93 per cent of the ultimate, assuming again that the ultimate strength for compound "A" would be reached at 40 hr. (Table 2).

TABLE 3—RELATIVE COMPRESSIVE STRENGTH IN PER CENT, NOMINAL 5000-PSI. CONCRETE CAPPED WITH COMPOUND "A" AND TESTED AT AGE OF CAP SHOWN

	Age of Cap				
	30 min.	1 hr.	2 hr.	19 hr.	40 hr.
Relative Comp. Strength at 19 hr. = 100%.....	89	88	88	100 (1)	—
Relative Comp. Strength at 40 hr. = 100%.....	83	82	82	93	100

(1) 100% equals 5065 psi.

The same tendency toward delayed strength gain using compound "A" was again evident. The use of compound "A" was then discontinued by the laboratory in favor of the use of compound "B".

Compound "B" was compared with the medium-strength plaster compound called herein compound "C". A total of 44 cylinders was made from two presumably identical batches of nominal 7500-psi. compressive strength concrete. Alternate cylinders were taken from each batch and grouped in fours making 11 groups for the 44 specimens. Four groups were capped with compound "B" and seven groups with compound "C". These groups were tested when the caps were of various ages. The relative strength was based on the group attaining the highest strength. The same procedure as to curing was followed with all the plaster-capped specimens as with sulfur-silica-capped specimens, that is; all the specimens were removed from fog-curing at the same time, then the designated groups were capped at the appropriate time and allowed to remain in the laboratory air until time of testing. Table 4 shows results for the compound "B" and "C" comparison.

TABLE 4—RELATIVE COMPRESSIVE STRENGTH IN PER CENT AND PER CENT DEVIATION OF NOMINAL 7500-PSI. CONCRETE CYLINDERS CAPPED WITH COMPOUNDS "B" AND "C" AND TESTED AT AGE OF CAP SHOWN

Type of Cap	Age of Cap						
	15 min.	30 min.	45 min.	1 hr.	3 hr.	20 hr.	40 hr.
Compound "B"	83	86	87	95	—	—	—
Max. Dev.	1.5	3.0	7.0	5.5	—	—	—
Min. Dev.	0.5	0.5	0.5	0.0	—	—	—
Av. Dev.	1.1	1.6	3.4	2.8	—	—	—
Compound "C"	89	93	91	93	100 (1)	99	97
Max. Dev.	19.0	4.0	6.5	3.0	3.0	3.5	3.0
Min. Dev.	1.0	1.5	1.0	0.0	0.5	1.0	1.0
Av. Dev.	9.1	2.9	3.8	1.5	1.8	1.9	1.9

(1) 100% equail 7360 pss.

The data presented in Table 4 shows that the specimens capped with compound "C" tested at 3 hr. gave the highest strength; however, the difference was not marked.

It is thought that the higher strength for compound "C" over compound "B" shown in Table 4 was due to the very thinness of the compound "C" caps. They were not over 1/16 in. thick while the caps of compound "B" were 1/4 in. thick. Troxell(1) shows a relative strength of 96.9 per cent for plane normal end cylinders capped with plaster-of-paris for nominal 3000-psi. concrete, and 96.6 per cent for cylinders capped with Castite, a high strength sulfur-silica compound. He also shows a relative strength of 86.8 per cent for plaster-of-paris capped cylinders of nominal 8000-psi. concrete compared to 102 per cent for Castite capped cylinders.

The strength of plaster-of-paris, according to Troxell, when tested as 2 x 4 in. cylinders is 1700-psi. at 1 hour.

Using three classes of concrete of nominal 3000, 4500, and 5500 psi. compressive strength, sulfur-silica compound "B" was compared at a cap age of 1 hr. with plaster compounds "C" and "D" at various cap ages. There was one batch of cylinders for the 3000 and 4500-psi. concrete and two batches for the 5500-psi. concrete. Alternate specimens of the 5500-psi. concrete were taken from each batch and grouped for testing. The number of specimens for each class of concrete, the number in each group and the age of cap at which tested are listed below:

TABLE 5—NUMBER OF SPECIMENS TESTED PER CLASS OF CONCRETE AT VARIOUS AGES OF CAPS FOR COMPOUNDS "B", "C", AND "D"

Strength Class of Concrete	Nom. 3000-psi.		Nom. 4500-psi.				Nom. 5500-psi.		
Age of Cap	1 hr.	3 hr.	½ hr.	1 hr.	3 hr.	40 hr.	½ hr.	1 hr.	3 hr.
Compound "B"	6	—	—	4	—	—	—	10	—
Compound "C"	—	6	—	—	—	—	4	—	10
Compound "D"	—	6	4	3	3	3	3	—	10
Total No. Specimens		18				17			37

Relative compressive strength for each class of concrete was based on the highest group strength attained within that class. The relative results for this series are set forth in Table 6.

TABLE 6—RELATIVE COMPRESSIVE STRENGTH IN PER CENT, OF CONCRETE OF NOMINAL STRENGTH SHOWN, CAPPED WITH COMPOUND "B", "C", OR "D" AND TESTED AT AGE OF CAP SHOWN

Type of Cap and Per Cent Deviation	Nominal 3000-psi.		Nominal 4500-psi.				Nominal 5500-psi.		
	Age of Cap		Age of Cap				Age of Cap		
	1 hr.	3 hr.	½ hr.	1 hr.	3 hr.	40 hr.	½ hr.	1 hr.	3 hr.
Compound "B"	98	—	—	98	—	—	—	99	—
Max. Dev.	4.0	—	—	5.0	—	—	—	3.5	—
Min. Dev.	0.0	—	—	0.5	—	—	—	0.5	—
Av. Dev.	1.5	—	—	2.9	—	—	—	2.1	—
Compound "C"	—	100(1)	—	—	—	—	97	—	99
Max. Dev.	—	6.5	—	—	—	—	2.5	—	5.0
Min. Dev.	—	0.0	—	—	—	—	0.5	—	0.5
Av. Dev.	—	3.3	—	—	—	—	1.5	—	2.8
Compound "D"	—	99	95	100(2)	100(2)	98	99	—	100(3)
Max. Dev.	—	9.0	2.0	2.0	1.0	1.0	2.0	—	6.5
Min. Dev.	—	0.0	0.5	0.5	0.5	0.5	1.0	—	0.0
Av. Dev.	—	3.3	1.0	1.7	0.7	0.7	1.5	—	2.8

(1) 100% equals 2830 psi.
(2) 100% equals 4655 psi.
(3) 100% equals 5310 psi.

From the data set forth in Table 6, it would appear that there was an insignificant difference in strength between any of the three capping materials with the classes of concrete at the age-of-cap used in the test.

To determine the difference in strength caused by different thicknesses of caps, two batches of nominal 4500-psi. compressive-strength concrete were made comprising a total of 30 cylinders. These cylinders were cast in lengths of 11½, 11 and 10½ in. When capped, all the cylinders were 12 in. long. One batch of specimens was capped with compound "B" and the other with compound "D". There were seven cylinders in the 11½ in. group, four of them being capped on both ends with caps as thin as could be made (approximately ⅛-in. for the sulfur-silica and 1/16-in. for the plaster caps) and three with caps ¼ in. thick. There were four 11-in. and four 10½-in. cylinders in each batch yielding four with ½-in. and four with ¾-in. caps for each batch. The highest strength attained by any group capped with the same compound was counted as 100 per cent. Table 7 shows the results for this phase of the work.

TABLE 7—RELATIVE COMPRESSIVE STRENGTH, PER CENT OF NOMINAL 4500-PSI. CONCRETE WITH COMPOUND "B" AND "D" CAPS OF VARYING THICKNESS

Capping Material and Per Cent Deviation from Average	Cap Thickness			
	1/16 to ⅛ in.	¼ in.	½ in.	¾ in.
Compound "B" (1 hr. old)	90	100 (1)	96	92
Max. Dev.	12.0	4.0	5.0	5.0
Min. Dev.	0.0	1.0	1.0	0.0
Av. Dev.	6.3	2.7	2.5	2.5
Compound "D" (3 hr. old)	100 (2)	99	96	96
Max. Dev.	3.0	3.0	8.0	6.0
Min. Dev.	0.0	1.0	0.0	1.0
Av. Dev.	1.5	2.0	4.2	3.0

(1) 100% equals 4745 psi.
(2) 100% equals 4440 psi.

The strength of the specimens increased as the caps became thinner for both capping materials, except in the case of the sulfur-silica caps 1/16 to ⅛-in. thick. To obtain these thin caps, the molten sulfur-silica compound was poured into a machined-out area of a steel plate and the specimen immediately pressed down into it. The steel plate was 10 in. square by ¾ in. thick and the machined-out area was 7 in. in diameter and ¼-in. deep with slightly sloping sides. It is thought that possibly some air bubbles might have been trapped under the caps contributing to lowered strength and erratic results.

Using the Nardiello capper and sulfur-silica compounds, 1/4 in. was as thin as it was found practicable to make caps.

Using plate glass and the plaster compounds, caps may be made "wafer" thin, 1/16-in. or less, on a plane smooth cylinder end. It is thought that this element of thinness contributes to the merit shown by the caps of compound "C" and "D".

4. CONCLUSIONS

1. From the work done in this series it was discovered that all sulfur-silica compounds do not act alike. Compound "B" developed adequate strength within 1 hr. after capping while compound "A" continued to gain strength up to 40 hr. and possibly longer. The strength at 1 hr. to 5 hr. was approximately 84 per cent what it was at 40 hr.

2. The stepped-end condition did not appreciably alter the apparent compressive strength developed when the capping was done with either compound "A" or "B" and an appropriate age of cap.

3. For the three classes of concrete tested (nominal 3000-psi., 4500-psi., and 5500-psi., compressive strength) there seemed little to choose between compounds "B", "C" or "D". It would appear that 1 hr. is sufficient time to allow all three capping materials to harden. However, both compound "C" and "D" gave slightly higher results at an age of 3 hr. Of the two gypsum materials compared, "C" is cheaper, but somewhat less desirable to use than compound "D". "C" hardens in approximately 15 min. after the addition of water and occasionally sticks to the glass plates. "D" hardens in approximately 30 min. and no trouble was experienced with sticking.

4. Caps of either sulfur-silica compound "B" or the gypsum compounds "C" and "D" should be made as thin as possible.

5. A minimum period of 1 hr. between capping and testing appears to be essential in order that the caps may be strong enough to distribute the load evenly to the specimens.

6. Ease of operation, speed with which specimens can be capped, and the fact that compound "B" may be reused, make it the most economical and desirable of the four materials tested for capping standard 6-in. by 12-in. concrete test specimens.

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Discussion of this paper should reach the ACI Secretary in triplicate by March 1, 1945, for publication in the JOURNAL for June, 1945

A part of PROCEEDINGS OF THE AMERICAN CONCRETE INSTITUTE Vol. 41

JOURNAL
of the
AMERICAN CONCRETE INSTITUTE

Vol. 16 No. 2 7400 SECOND BOULEVARD, DETROIT 2, MICHIGAN November 1944

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. 1944 to June 1945.

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."

Cement Paint for Steel Water Tanks (41-158)

Q—The report, "The Nature of Portland Cement Paints and Proposed Recommended Practice for Their Application to Concrete Surfaces" (ACI JOURNAL, June, 1942) is full of valuable suggestions and covers the subject well as far as the title indicates; namely, application to concrete surfaces.

We encounter the question of using cement paint on metal surfaces; it has been recommended for use on the inner surface of steel tanks for drinking water such as are installed on board ships. We have not been able to find anything to answer our question: will cement paint give a durable coating on the inside of steel tanks to prevent rusting and give no taste to drinking water?

By R. B. YOUNG*

A—We have in two of our buildings hot water tanks of about 1000-gal. capacity used for supplying water for domestic purposes. These tanks were ungalvanized and it was necessary to give them some treatment which would prevent corrosion. For several years now we have been painting them annually with a portland cement and water mixture, and

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our experience would indicate that their corrosion is considerably retarded by the treatment.

A treatment that has to be repeated each year would probably not be considered a desirable coating but in this particular case the holding temperature of the water is fairly high, varying up to 160 F. Better results could be expected with tanks in which cooler water was stored. However, our general experience with paints for under water use has not shown any of them to have considerable life.

By M. B. KLOCK*

Walter Hughes of our Municipal Testing Laboratory (Rochester, N. Y.) reports that steel tanks at the Rochester garbage reduction plant are lined with gunite. The tanks are 16 ft. in diameter; the gunite was applied about ½ in. thick, reinforced with wire mesh; the surface was clean, but no special pretreatment was given to the steel. This work was done 10 or 12 years ago, and the tanks are still in good condition, which we think is a good record.

A good way to apply a portland cement paint to any surface would be by a siphon which would blow the material on under high pressure. We use such a gun here for patching concrete surfaces with mortar. (Illustrated in "Concrete in Factory Construction" by L. F. Fairchild, ACI Journal, Nov.-Dec. 1934, p. 152.) In any case the steel should be thoroughly cleaned of all loose particles.

A portland cement paint is said to have been used "in the early days" to prevent or to overcome the taste of rust in water stored in metal tanks. The method was used by shipbuilders years ago for lining drinking water storage tanks. A receptacle was practically filled with whole barley grain, then filled to the top with clear warm water. When the mixture had thoroughly soured (the action could be speeded up by the addition of yeast) the water was drawn off, mixed 50-50 with clear water, and this used to mix a neat cement paint. There is a very choice variation to this: You may use stale beer instead of barley water. We tried this on a small tank and it is okay after two years.

A survey made by the Structural Bureau of the Portland Cement Assn., about 10 years ago prompted the following conclusions:

(1) Neat cement paste or a grout of cement and fine sand may be made to adhere to the inside of steel water tanks and protect them against corrosion.

(2) Whether a neat cement paste or a cement sand grout is used is largely a matter of application. The use of fine sand in the mix may tend to reduce shrinkage and therefore preserve the integrity of the coatings.

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(3) If the coating is always submerged or always wet, no appreciable shrinkage will occur, but rather the coating will expand and thus make cracks practically impossible .

(4) The use of admixtures that will not materially reduce the strength of the coatings and hence their bond to the steel is a matter of facility in application.

At that time the PCA acknowledged sources, chiefly railroads.

One set of specifications called for a mix of two parts of cement to one part of sand, all of which passes a No. 16 screen; the tank must be clean, the grout fresh, mixed in small batches, of a consistency of heavy cream and applied with a bristle brush that is kept clean by frequent washings. Two coats are applied, each coat being 1/16 in. thick and the second following the first after 12 hours. In case the two applications do not produce a coating 1/8 in. thick, a third coat is applied, allowing 12 hours time between the second and third coats. The coats are kept constantly moist from the time of application until water is admitted into the tank. This curing is accomplished by introducing a very small amount of steam into the tank.

Another source used a mix of one cement to one of fine sand applied with a brush in two coats—the second coat following the first by from four to ten hours. When the work is done from a raft it proceeds downward as the water is drawn from the tank. Ordinarily the use of scaffolding is more practical. The consistency of mix is such as to give it body and as great a thickness of coat as practicable in application with a brush. The "paint" is constantly stirred using a neat cement grout with the addition of about 5 per cent of hydrated lime to facilitate application.

One user prefers to defer painting new tanks until about one year to allow loosening of mill scale.

Still another uses neat cement grout in two brush coats about 12 hours apart, and about the same time is allowed after the second coat before placing the tank in service. A small jet of steam is allowed to enter the tank continuously while the cement grout is hardening.

"Painting Steel Portable Water Tanks" is the title of National Bureau of Standards letter circular 744 (Feb. 26, 1944) which presents a considerable digest, based on investigations and recommendations of the Army Engineer Corps, the Navy's Bureau of Ships and the New York Club of the Federation of Paint and Varnish Production Clubs. This letter covers rust inhibitors, preparation of surfaces and coatings—which do not include portland cement paint.

Long-time Shrinkage of Concrete (41-159)

By WALTER H. WHEELER*

I have been designing, supervising and sometimes also constructing reinforced concrete structures since 1908. During all of that time the problem of long-time shrinkage of concrete has been with us, and we still do not know the basic principles or mechanics of how it operates and why it operates. It causes cracks in otherwise perfect structures, which are unsightly and lead to eventual necessity for repairs. It causes permanent deflections and changes in slabs, beams and arches and is then called plastic flow. In other words it is the bane of the concrete engineer's existence.

It matters not that wood also shrinks, or that grave stone slabs which have leaned against a building for a century have been deformed by their own weight. Structural metal does not shrink and does not deform under normal stress so that it is permanently deformed.

It seems to me that we have not attacked this problem of shrinkage in concrete with the vigor and intelligence that is needed to find out just how and why it works that way and knowing that the remedies that can be applied to overcome it. It seems to me and it seems to others that I have talked with that this problem must be solved soon if reinforced concrete is to retain the high favor which has heretofore been given it, and that the cement companies should furnish the money to finance the necessary research to the extent that is necessary to solve it, and do it promptly. It is believed that this is mainly a problem for the chemist.

It also seems to me that the ACI should urge with all the energy at its command that such a research program be instituted forthwith on a scale that will get the results and get them speedily. The cement and concrete industry cannot laugh this problem off any longer.

[EDITOR'S NOTE—The gist of much correspondence on the subject discussed by Mr. Wheeler is about like this: When and if all the ills of concrete are cured, all the problems solved (and the answers appear in widely available texts), the field of concrete will cease to be interesting. Mr. Wheeler is not alone in wanting more answers to unsolved problems. Large appropriations are being invested in studies to find the answers Mr. Wheeler wants—the money supplied by those who also recognize the need for those answers. When the answers are found—or even likely clues to the answers, ACI will hope to make them known.]

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*Designing & Consulting Engineer, Minneapolis

Concrete Tanks for Storage of Wine (41-160)

Q—I should like information as to the use of concrete tanks for the storage of wine.

A—Comments made by A. G. Timms, see p. 291, "Concrete tanks for wine and grapejuice?" (No. 35-27) in your JPP section of ACI JOURNAL for Feb. 1939 are still appropriate. Reference is also made to "A Comparison of Various Treatments of Cement and Steel Wine-Tank Surfaces" by W. V. Cruess, T. Scott, H. B. Smith, and L. M. Cash of the Fruit Products Division, University of California, Berkeley, Calif., in *Food Research*, 1937, Vol. 2, No. 5. The authors describe tests made at the University and among other conclusions are the following:

> Treatment of the concrete surface with strong tartaric acid solution greatly reduced the amount of calcium dissolved by the wine. Two treatments, one with ½ per cent and one with 25 per cent solution gave better protection than one treatment with 25 per cent solution. A coating of insoluble calcium tartrate is formed.
>
> Of the commercial preparations tested in these experiments Pioneer Flintkote asphalt emulsion and Bass-Hueter (made by the National Lead Co.) black enamel gave best results.
>
> Gilsonite, 25 per cent, plus paraffin, 75 per cent, gave a highly protective coating. It is inexpensive and easily applied but is somewhat more brittle than the asphalt emulsion coating.

Precautions Against Deterioration of Concrete Exposed to Briny Air (41-161)

Q—What special precautions are advisable in reinforced concrete construction subject to the wind-driven briny air of the southeast coastal region?

A—There are many concrete structures, including exposed spandrel concrete frame buildings, along our sea coasts successfully withstanding the exposure to the wind-driven briny air. It is important, of course, to provide concrete of good quality and adequate cover over all steel. It is not only important to specify the proper thickness of concrete over the steel but also to have close supervision to see that the specifications are carried out in this respect. The following is quoted from the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete:

> At those surfaces of footings and other principal structural members in which the concrete is deposited directly against the ground, metal reinforcement should have a minimum covering of 3 in. of concrete. At other surfaces of concrete exposed to the ground or to severe weathering conditions, metal reinforcement should be protected by not less than 2 in. of concrete. At undersides of slabs exposed to weather 1 in. should be provided.

Where metal fabric in the form of wire mesh or expanded metal is used as reinforcement for protective coatings on columns, beams, or girders, it should have a minimum covering of 1½ in. for structures exposed to water, ground, or weather, and a minimum of ¾ in. for structures not so exposed.

We believe that if the minimum of 2 in. of concrete is provided, as recommended by the Joint Committee, that adequate protection will be obtained. Too often considerably less than this is used and particularly over the stirrups. In many cases the specifications provide sufficient cover, but the reinforcement is not properly tied into place and maintained in position during the placing of the concrete, and consequently is too close to the surface. Steel with insufficient cover will corrode even under normal exposure but corrosion is much more rapid when exposed to moist air laden with salt.

Wire form ties should be avoided. Tie rods which are completely removed should be used or at least a type of tie rod which leaves no metal within 2 in. of the surface. Holes left by the tie rods should be carefully filled with mortar.

In making construction joints care should be taken in preparing the hardened surface and in placing the new concrete to secure good bond.

Vibrating Concrete in Test Cylinder Molds (41-162)

Q—What is the best current practice for the consolidation of concrete in test cylinder molds by means of mechanical vibration?

By H. F. GONNERMAN*

A—While a number of investigations have been conducted to determine the effects of vibration on concrete, we know of no specification or procedure recognized as standard for the consolidation of concrete test cylinders. The best rocedure in a given case will depend on a number of factors, such as the type and properties of the vibrator, the proportions, water-cement ratio, grading, consistency and other properties of the mix. The time of vibration should be just sufficient thoroughly to consolidate the entire mass, since continuing the vibration after consolidation has occurred is likely to produce segregation.

In recent years the procedure in this laboratory in consolidating concrete in 6 x 12-in. test cylinders by means of vibration has been as follows:

The mold is half-filled with concrete which is then consolidated with an internal vibrator (9,000 rpm). When consolidation of this layer is about completed and as the vibration proceeds an assistant fills the balance of the mold. The operator gradually withdraws the vibrator

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*Manager of Laboratory, Portland Cement Assn., Chicago.

as consolidation takes place, care being taken to avoid leaving vibrator in mold too long as this will tend to give a core of mortar, particularly when the maximum size of coarse aggregate is 1½ in.

In a paper[†] giving results of tests of 6 x 12-in. vibrated concrete cylinders, Prof. M. O. Withey makes the following statement:

> With the machine running at the normal speed of 3500-3600 rpm and the maximum amplitude setting, a vibration period of one minute gave best results. At speeds approximating 6500 rpm, the actual amplitude for ⅓ and ⅔ setting was less than at 5000 rpm but the time required to consolidate the concrete properly was only 20 seconds.

An illustration (p. 529) shows the arrangement of the vibrator and platform used for molding the test specimens.

The New Jersey Highway Department has made tests for compressive strength of concrete by means of vibrated specimens. The New Jersey specification for this test required the molds to be mounted firmly on a vibrating steel channel, arranged so that six can be vibrated simultaneously. The vibrator was adjusted to 3500 impulses per minute and the vibration continued for 1¼ minutes.

[†] "Freezing and Thawing, Permeability and Strength Tests on Vibrated Concrete Cylinders of Low Cement Content," ACI JOURNAL, May-June, 1935; *Proceedings* V. 31, p. 528.

ACI NEWS LETTER

Vol. 16 No. 2 JOURNAL of the AMERICAN CONCRETE INSTITUTE November 1944

AS TO THE PROGRAM, FEBRUARY MEETINGS

41st Annual Convention—New York, Feb. 13-16, 1945

Much good material is in prospect for the ACI Convention in New York in February. Live, discussable subject-matter is in preparation, including many things of active concern to the structural engineer. But, since the Publications Committee, under the chairmanship of Douglas E. Parsons, wants to be sure that the convention grist *is* definitely a contribution to the progressive thinking of the convention audience, names and titles are not yet ready for announcement.

Not since the 1941 Convention in Washington has the Institute met in the East and not since 1939 has a convention been held in New York. The 1945 meetings should bring many of our eastern Members back into more active participation in ACI affairs.

Between now and mid-February much new War and World political history may well be written. It is not inconceivable that by February the War in the West may have reached the final clean-up stages and many of our energies be in process of reconversion to the task of overtaking our civilian needs. War accelerations of thought and act have not been without their contributions of knowledge which a peace economy will be quick to use. Certainly, construction for private and peace-time public use will be high on the list of potentials "after Germany."

Right now it can only be repeated that Tuesday, February 13 will be a day of administrative affairs—meetings of the Board of Direction and of Administrative committees.

Wednesday, February 14 will provide Technical Committees opportunity to further their tasks. To these committees we must look for correlations and interpretations that will put our scattered data from laboratory research and from field experience into terms for improved design, construction and manufacturing practice.

Thursday and Friday, February 15 and 16—and *perhaps* the evening of Wednesday the 14th—will be given over to general convention sessions.

All meetings will be at Hotel New Yorker where all those attending the ACI Convention are assured accommodations at a low maximum rate.

A New ACI Proceedings Volume is Complete with the November Supplement

Title Page, Contents, Closing Discussion and Indexes

—How to Assemble

The regular November Supplement is sent to all ACI Members and all non-member subscribers with the November JOURNAL each year. It is the answer to the scores of requests that come to the Institute every summer, autumn and winter for Title page, Contents and Index to the JOURNAL volume which is otherwise completed with the issue for the previous June.

When the JOURNALS for September and November of *last* year and the issues for January, February, April and June of this year are pulled apart (after removing the wire stitches) and the covers, "masthead" (two pages just inside the front cover of each JOURNAL issue) and the News Letter sections are all discarded, the remaining parts may be assembled with the parts of the November Supplement (after discarding its cover) to complete a new Proceedings volume.

Start the assembly with Title page and "Contents" which together make up the first section of the Supplement and follow with the first section (the first subject unit, whether paper or report) from the first issue of the volume of the previous September and so on, following the order of listed items as shown in the Table of Contents, and being careful to insert sections of discussion immediately following the papers or reports discussed. Don't be confused by blank pages; count them as though they bore page numbers consecutive with the last numbered page of a subject unit. Blank pages are necessary for several reasons: to make possible an orderly assembly of JOURNAL subject units with subsequently published units of discussion and to provide separate prints of reports and papers from the same press run which provides the JOURNAL issues. Discussion units bear supplemental series of page numbers identifying them with the last page of the original matter discussed.

All this is a bit complicated, but it *does* meet Institute publication needs. If it is too complicated for your local bindery—or too expensive (and the Institute cannot undertake the binding of individual Member sets of JOURNALS), then it might be a good idea to do as hundreds of Members and subscribers already do: Place a "continuation order" with the Institute for its annual bound volumes. The price to non-members is $10.00 each; to ACI Members $5.00 each. The Member price is subject to a 40 percent discount (making a net price of $3.00) per volume, *provided* each volume is paid for before the first parts of that volume are manufactured, that is, *before* the publication of the September JOURNAL each year which starts a volume and all of whose parts are ready for binding only with the availability of the November supplement 14 months later.

New Members

The Board of Direction approved 41 applications for membership in August and September (36 Individuals, 3 Corporations, 1 Contributing,* 1 Junior) as follows:

Arnoldson, Carlos, Jr., P. O. Box 697, Havana, Cuba

Bansemer, Roland E., Koehring Co., 3026 W. Concordia Ave., Milwaukee 10, Wisc.

Berta, Carlos E., San Jose 1171, Montevideo, Uruguay, S. A.

Constructora General, S. A., Apartado 697, Panama, Rep. de Panama.

Coons, Kenneth Wm., Dept. of Chemical Engineering, University of Alabama, University, Ala.

Crawshaw, Arthur C., c/o Holmes & Narver, 639 S. Spring St., Los Angeles 14, Calif.

Danielson, Lloyd C., c/o J. A. Jones Construction Co., Box 299, Knoxville, Tenn.

Davis, E., "Cottesmore" 180 Rede Court Road, Rochester, Kent, England

Doanides, Peter J., Royal Greek Consulate, 30 Rockefeller Plaza, New York 20, New York.

Dole, C. Russell, Columbia Engineering Corp., 323 Plum St., Cincinnati 2, Ohio

*Florida Portland Cement Co., Box 1528, Tampa 1, Fla. (Attn. G. D. Brown)

Girlings Ferro-Concrete Co. Ltd., Great West Road, Feltham, Middlesex, England

Hatch, H. P., The Ohio Power Co., P. O. Box 137, Brilliant, Ohio

Helton, John J., Universal Atlas Cement Co., 630 Brown-Marx Bldg., Birmingham, Ala.

Hjorth, Lawrence R., 14 East 47th St., New York 17, N. Y.

Kaufer, Fred P., Varsovia No. 23—C., Mexico, D. F.

Kini, K. V., Lakshmi Bldg., Sir Pherozsha Mehta Rd., Fort, Bombay, India

Klein, Harold E., c/o Edward Ehebar Inc., 29 Meserole Ave., Brooklyn 22, N. Y.

Kloppenburg, George J., 1015 Troost Ave., Forest Park, Ill.

Lash, Stanley D., Civil Engineering Dept., Queen's University, Kingston, Ont. Canada

Lees, Henry M., 600 Benson Ave., Fox Chase, Philadelphia 11, Pa.

Master Builders Co., 7016 Euclid Ave., Cleveland 3, Ohio

McElrath, Albert J., P. O. Box 29, Murray, Kentucky

Meyer, John H., 4330 Ellenwood Ave., St. Louis 16, Mo.

Millikan, Oliver H., c/o Bureau of Reclamation, Denver 2, Colo.

Ott, John E., APO 722, ASF, NWSC, Area Office, Minneapolis, Minn.

Patel, Y. G., c/o Western India Engineering Co., 45/47 Apollo St., Fort, Bombay, India

Peterson, Carlyle W., 201 Laboratory of Mechanics, Iowa State College, Ames, Iowa

Peterson, Ellis J., 1106 E. Smith St., Tucumcari, N. Mex.

Reeves, Horace A., c/o J. A. Jones Construction Co., P. O. Box 299, Knoxville, Tenn.

Roehner, T. G., 412 Greenpoint Ave., Brooklyn, N. Y.

Rogers, Franklyn C., Dept. of Civil Engineering, Rutgers University, New Brunswick, N. J.

Sami, Sabri, 23 Sabri Street, El-Daher, Cairo, Egypt

Sanchez, Dario (Vickers), Casilla 1721, Santiago, Chile, S. A.

Smith, John William, 1405 Highland Ave., Chicago 26, Ill.

Summers, William T., Jr., 2327 Cedar Ave., Long Beach 6, Calif.

Thompson, Warren H., 130 Tremaine Ave., Kenmore, N. Y.

Uncles, William J., c/o The Edward Bale Co., 171 State St., Hartford 1, Conn.

Watson, J. D., P. O. Box 299, c/o J. A. Jones Construction Co., Knoxville, Tenn.

Welton, Richard E., P. O. Box 601, Honolulu, T. H.

Young, C. B. F., c/o Clark Babbitt Ind. Inc., 630 5th Ave., New York 20, N. Y.

WHO'S WHO

Bailey Tremper
well known as a contributor to this Journal, continues his pursuit of a solution of aggregate-alkali reactions in his present paper, p. 89.

E. B. Hanson, Jr., and W. T. Neelands
who record experiences with Haydite aggregates in Concrete Ship Construction (p. 105), were both with the Bureau of Reclamation until the War inspired another concrete ship program.

Mr. Hanson started with the Bureau of Reclamation in 1933 as a rodman and between then and 1942, when he went to Barrett and Hilp, concrete ship contractors, he worked on four Bureau of Reclamation Projects—The Hyrum Dam, Hyrum, Utah; The French town project, Missoula, Mont.; The Upper Snake River, in Idaho, and the Shasta Dam, Redding, Calif. From the Shasta Dam he went to the Belair Shipyard as concrete control engineer.

On this job Mr. Neelands became assistant concrete control engineer. He had received his training with the Bureau of Reclamation starting at Grand Coulee Dam in 1936, and transferred in 1940 to Shasta Dam. His work in the Belair Shipyards began in the spring of 1943.

Thomas B. Kennedy

received his degree of A.B. in Chemistry from the University of Illinois in 1930. He was employed by the U. S. Engineers in 1931 and was connected with field concrete work in lock and dam construction on the Upper Mississippi River, during the period 1934 to 1939. He has been employed in the Central Concrete Laboratory since that time as head of the section responsible for testing of aggregates, the design of concrete mixtures and the physical test of concrete specimens—whence his present contribution, p. 117.

Honor Roll

Feb. 1 through Oct. 25, 1944

ACI Members listed have proposed new ACI Members as shown after their names. There should be more names on this list and more new members tallied. It is all a matter of being "Member Conscious".

F. E. Richart	13
Mehmet Tokay	8
J. W. Kelly	6
Lewis H. Tuthill	6
Jacob J. Creskoff	5
William A. Jones	4
Charles E. Wuerpel	3½
Kenneth K. Knight	3
F. W. Panhorst	3
H. F. Gonnerman	2½
Hugh Barnes	2
Elmer B. Belt	2
R. F. Blanks	2
Harry Erps	2
P. J. Freeman	2
Ernst Gruenwald	2
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Walter H. Price	1
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John R. Ruhling	1
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Ralph A. Sherman	1
R. T. Sherrod	1
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Charles Snyder	1
E. Viens	1
J. J. Waddell	1
Chas. P. Williams	1
Benjamin Wilk	1
M. O. Withey	1
E. B. Wood	1
T. Van Dyke Woodford	1

Sources of Equipment, Materials and Services

A reference list of advertisers who participated in the Third Annual Technical Progress Issue of the ACI JOURNAL—the pages indicated will be found in the February 1944 issue and (when it is completed) in V. 40, ACI Proceedings. **Watch for the 4th Annual Technical Progress Section in the February 1945 JOURNAL.**

Concrete Products Plant Equipment

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Besser Manufacturing Co., 800 44th St., Alpena, Mich. —Concrete products plant equipment	349
Stearns Manufacturing Co., Inc., Adrian, Mich. —Block machinery	339

Construction Equipment

Baily Vibrator Co., 1539 Wood St., Philadelphia 2, Pa. —Concrete vibrators	352
Blaw-Knox Division of Blaw-Knox Co., Farmers Bank Bldg., Pittsburgh, Pa. —Truck mixer loading and bulk cement plants, road building equipment, buckets	340-1
Butler Bin Co., Waukesha, Wis. —Central mix, ready-mix and bulk cement plants, cement handling equipment	379
Chain Belt Co., Milwaukee, Wis. —Mixers, pavers, pumps	376-7
Electric Tamper & Equipment Co., Ludington, Mich. —Concrete vibrators	366-7
Fuller Co., Catasauqua, Pa. —Unloading and conveying pulverized materials	343
Heltzel Steel Form & Iron Co., Warren, Ohio —Pavement expansion joint beams	388-9
Jaeger Machine Co., The, Columbus, Ohio —Concrete paving equipment	344-5
Kelley Electric Machine Co., 287 Hinman Ave., Buffalo 17, N. Y. —Floor finishing equipment	368-9
Koehring Co., Milwaukee, Wis. —Tilting and non-tilting construction mixers	347
Mall Tool Co., 7703 So. Chicago Ave., Chicago 19, Ill. —Concrete vibrators	365
Master Vibrator Co., 200 Davis Ave., Dayton, Ohio —Concrete vibrators	394
Ransome Machinery Co., Dunellen, N. J. —Paving mixers	378
Smith Co., The, T. L. 2897 No. 32nd St., Wilwaukee 10, Wis. —Mixer and truck mixer efficiency	374-5
Viber Co., 726 So. Flower St., Burbank, Calif. —Concrete vibrators	355
Whiteman Manufacturing Co., 3249 Casitas Ave., Los Angeles 26, Calif. —Floor construction and finishing equipment	392-3

Contractors, Engineers and Special Services

page

Kalman Floor Co., Inc., 110 E. 42nd St., New York 17, N. Y. 370-1
—Floor finishing methods

Prepakt Concrete Co., The, and Intrusion-Prepakt, Inc., Union Commerce Bldg., Cleveland 14, Ohio 381-4
—Pressure filled concrete

Raymond Concrete Pile Co., 140 Cedar St., New York 6, N. Y. 354
—Pile foundations

Roberts and Schaefer Co., 307 No. Michigan Ave., Chicago, Ill. 342
—Thin shell concrete roofs

Scientific Concrete Service Corp., McLachlen Bldg., Washington, D. C. 353
—Mix controls and records

Vacuum Concrete, Inc., 4210 Sansom St., Philadelphia, 4, Pa. 357
—Suction control of water in the concrete

Westberg Co., The, 611 No. Alvardo St., Los Angeles 26, Calif. 362-3
—Pneumatically applied concrete

Materials and Accessories

Calcium Chloride Assn., The, 4145 Penobscot Bldg., Detroit 26, Mich. 372
—Calcium chloride

Carey Manufacturing Co., The Philip, Lockland, Cincinnati, Ohio 385
—Expansion joint material

Concrete Masonry Products Co., 140 W. 65th St., Chicago, Ill. 364
—Non-shrink metallic aggregate

Dewey and Almy Chemical Co., Cambridge, Mass. 390-1
—Air-entraining and plasticising agents

Horn Co., A. C., Long Island City 1, N. Y. 346
—Waterproofing

Hunt Process Co., 7012 Stanford Ave., Los Angeles 1, Calif. 380
—Curing compound

Inland Steel Co., 38 So. Dearborn St., Chicago 3, Ill. 395
—Reinforcing bars

Lone Star Cement Corp., 342 Madison Ave., N. Y. 350-1
—Portland cements

Master Builders Co., The, Cleveland, Ohio 358-61
—Cement dispersing and air-entraining agents

Richmond Screw Anchor Co., Inc., 816 Liberty Ave., Brooklyn, N. Y. 348
—form tying devices

Sika Chemical Corp., 37 Gregory Ave., Passaic, N. J. 386-7
—Waterproofing and densifier

Solvents and Plastics Co., 8032 Forsythe Blvd., St. Louis 5, Mo. 356
—Concrete curing compound

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ACI Construction-Practice Award

The American Concrete Institute announces the inauguration of the ACI Construction-Practice Award, to be given for a paper of outstanding merit on concrete construction practice. This award is established to honor the construction man — the man whose resourcefulness comes in between the paper conception and the solid fact of a completed structure.

The token of the award is a suitable Certificate of Award accompanied by $300 (maturity value) of United States War Bonds Series E. The object is the enrichment of the literature of concrete construction practice.

★ ★ ★

Five cash awards are also announced for contributions to the Job Problems and Practice pages September 1944 to June 1945.

For further particulars address Secretary American Concrete Institute, New Center Building, Detroit 2, Mich.

Statement of Ownership, Management, Circulation, Etc., Required by the acts of Congress of August 24, 1912, and March 3, 1933 of Journal of the American Concrete Institute published 6 issues a year at Detroit, Michigan, for September 1944.

STATE OF MICHIGAN...}ss
COUNTY OF WAYNE....}

Before me, a Notary Public in and for the State and county aforesaid, personally appeared Harvey Whipple, who, having been duly sworn according to law, deposes and says that he is the Editor of the Journal of the American Concrete Institute and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management (and if a daily paper, the circulation), etc., of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, as amended by the Act of March 3, 1933, embodied in Section 537, Postal Laws and Regulations, printed on the reverse of this form, to wit:

1. That the names and addresses of the publisher, editor, managing editor, and business managers are:

Publisher, American Concrete Institute, 742 New Center Bldg., Detroit 2, Mich.

Editor, Harvey Whipple, 742 New Center Bldg., Detroit 2, Mich.

Managing Editor, None.

Business Managers, None.

2. That the owner is: (If owned by a corporation, its name and address must be stated and also immediately thereunder the names and addresses of stockholders owning or holding one per cent or more of total amount of stock. If not owned by a corporation, the names and addresses of the individual owners must be given. If owned by a firm, company, or other unincorporated concern, its name and address as well as those of each individual member, must be given.)

American Concrete Institute, 742 New Center Bldg., Detroit 2, Mich.

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Douglas E. Parsons, Vice-President, National Bureau of Standards, Washington 25, D. C.

3. That the known bondholders, mortgagees, and other security holders owning or holding 1 per cent or more of total amount of bonds, mortgages, or other securities are: (If there are none, so state.)

NONE.

4. That the two paragraphs next above, giving the names of the owners, stockholders, and security holders, if any, contain not only the list of stockholders and security holders as they appear upon the books of the company but also, in cases where the stockholder or security holder appears upon the books of the company as trustee or in any other fiduciary relation, the name of the person or corporation for whom such trustee is acting, is given; also that the said two paragraphs contain statements embracing affiant's full knowledge and belief as to the circumstances and conditions under which stockholders and security holders who do not appear upon the books of the company as trustees, hold stock and securities in a capacity other than that of a bona fide owner; and this affiant has no reason to believe that any other person, association, or corporation has any interest direct or indirect in the said stock, bonds, or other securities than as so stated by him.

5. That the average number of copies of each issue of this publication sold or distributed, through the mails or otherwise, to paid subscribers during the twelve months preceding the date shown above is ...... (This information is required from daily publications only.)

Sworn to and subscribed before me this 16th day of October, 1944.

HARVEY WHIPPLE,
(Signature of editor)

ETHEL B. WILSON, Notary Public
(My commission expires Aug. 10, 1946)

[SEAL]

Perhaps I'm one war older than you are!

Believe me, after the last war I saw what happened. Will you let me give you some advice?

•

If you've got a job today—for your own sake, fellow, be smart! Think twice before you fight for a wage increase that might force prices up and land you behind the eight-ball in the end.

Salt away as much as you can out of your present wages. Put money in the bank, pay up your debts, buy more life insurance. Above all, put every extra penny you can lay your hands on into Uncle Sam's War Bonds and *hold* 'em!

Nobody knows what's coming when the Germans and the Japs are licked. Perhaps we'll have good times. Okay. You'll be sitting pretty. Perhaps we'll have bad times. Then they're sure to hit hardest on the guy with nothing saved.

The best thing you can do for your country right now is not to buy a thing you can get along without. That helps keep prices down, heads off inflation, helps to insure good times after the war.

And the best thing you can do for your own sake, brother, if there *should* be a depression ahead, is to get your finances organized on a sound basis of paid-up debts—and have a little money laid by to see you through!

4 THINGS TO DO to keep prices down and help avoid another depression

1. Buy only what you really need.

2. When you buy, pay no more than ceiling price. Pay your ration points in full.

3. Keep your *own* prices down. Don't take advantage of war conditions to ask for more—for your labor, your services, or the goods you sell.

4. *Save.* Buy and hold all the War Bonds you can afford—to help pay for the war and insure your future. Keep up your insurance.

HELP US KEEP PRICES DOWN

A United States war message prepared by the War Advertising Council; approved by the Office of War Information; and contributed by this magazine in cooperation with the Magazine Publishers of America.

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In addition, John and Mary and the other people on the Payroll Plan have been among the biggest buyers of *extra* Bonds in every War Loan Drive.

When this war is finally won, and we start giving credit where credit is due, don't forget John and Mary. After the fighting men, they deserve a place right at the top of the list. They've earned it.

You've backed the attack—now speed the Victory!

This is an official U. S. Treasury advertisement—prepared under auspices of Treasury Department and War Advertising Council

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