RECENT TRENDS AND DEVELOPMENTS IN THE CONCRETE FIELD

Thesis for the Degree of B. S.

MICHIGAN STATE COLLEGE

John C. Bullock, Jr.

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RECENT TRENDS AND DEVELOPMENTS

IN

THE CONCRETE FIELD

A Thesis Submitted to

The Faculty of

Michigan State College

of

Agriculture and Applied Science

by

John C. Bullock, Jr.

Candidate for the Degree of

Bachelor of Science

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Dedication

The present legislation of the Civil Engineering Department of Michigan State College requires that this paper be classified as a "thesis." Therefore, it seemed only fitting that I investigate the aforementioned denotation, and ascertain the extent to which this paper qualifies as such.

The Webster's Collegiate Dictionary, 5th Edition, which has been my faithful companion for the past four years, was my source of reference. Without further comment, I quote from this source, "thesis---1. A proposition; specif., a position or proposition which a person advances and offers to maintain by argument. 2. A dissertation presented by a candidate for a degree or diploma----." It became apparent when I had read these lines that my faithful companion had again been my salvation in a time of need.

There is a story molded within these lines, a story of tyranny and oppression, of bitter struggles, climaxed by successful conquest. In years gone by, a prospective graduate, turning to his dictionary for the meaning of the very word which I have just defined, found but one definition, "thesis----a proposition which a person advances and offers to maintain by argument." What terrific chagrin it must have heaped on the many who were confronted with the titanic task of approaching this insurmountable attainment.

The irony of successfully facing four years of constant oppression only to be struck down with one last crushing blow!

Fortunately, there are those stalwart Joan-of-Arcs who do not shy away from giants, but who fight and fall that others might surmount their battered bodies to better strike the fatal blow. To these martyrs I bow down.

How the bells must have sounded, and the joyous echoes of laughter and hilarity filled all Christendom on the day the gates were finally felled and the crowds came surging in. The day the book was again opened and the victor's hand firmly wrote the liberation of posterity, "thesis--- a dissertation presented by a student for a degree or diploma----."

So, to the memory of those brave souls who struggled, fought, and perished that I might submit my thesis as a true fulfillment of the obligation which the word now represents, I hereby dedicate this endeavor.

Respectfully,

John C Bullock Jr.

Preface

The thesis, as applied to a candidate for a degree, may be thought of as having several different connotations. One, the material presented by a student who has endeavored to offer a new theory or idea, to present a new design or method, or solution to an existing or fictitious problem. A second, is the report of a student who has set about to investigate a theory or idea, a design, or a method, in order to determine its soundness or possible falacies. A third connotation is the material that is advanced by a student who has attempted to offer new evidence on a subject of which there is little information, or possibly a great deal of conflicting information. This paper does not qualify in any of these catagories.

It was my intention merely to investigate the concrete field, attempt to get some vague idea of what current progress is being made in the concrete field, to stimulate my own interest, and in general to further my own very vague knowledge of the subject. There has been little effort on my part to attempt any solutions, to formulate any definite opinions, or to determine the soundness of any material which has come to my attention in regards to the subject. In order to express a worthwhile opinion, a person should be thoroughly familiar with the subject under contemplation. This was not and could not be achieved for such a broad subject in the limited time available. Occasionally, an opinion is expressed, but these are generally for purposes

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of clarity, and in all cases may be subject to considerable alteration.

Approximately two hundred issues of about twenty periodicals were canvassed for material pertinent to the subject. In addition, thirty letters were written to various manufacturers and other possible sources of information with rather gratifying results. There were, however, several sources of information which could not be exploited for one reason or another in the time afforded.

Five weeks were spent in gathering information from current periodicals, and an additional week in reading the material received by mail. Approximately three weeks were spent in organizing the material and setting it down in the order in which it now appears. The required time of eighteen hours per week to be devoted to the thesis, was amply fulfilled.

The manner in which the material is organized warrants some comment. The amount of material under each heading and sub-heading is entirely dependent upon the amount of material found in the periodicals canvassed. This does not infer that the subjects of the greatest importance are necessarily those in which the greatest amount of material appears. Some of the more startling discoveries may be merely mentioned under the "Miscellaneous" heading. However, the topics most exploited in the last few years with the greatest amount of success, are necessarily represented by the greater amount of material. It is also very possible th

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that several important recent developments in the concrete field received no mention. Again it is only because they did not appear in the current periodicals canvassed.

In order to cope with the size of the subject chosen, it was necessary to provide some limitations, and to make some omissions. Any information dealing with the design of standard sand-gravel mixes or their proportioning was not considered, since it was felt that this material was of a comparatively minor nature. This limitation was also applied to conventional reinforcement design, except in the instances where the novelty was such as to remove the design from its conventional classification. There has been a great deal of work done with waterproofing applications, and paints for concrete, in the past few years. These were also omitted because they are extraneous to the actual concrete ingredients and their design.

Some topics that I had planned to encounter in my reading were found strangely absent. Soil-cement concrete was scarcely mentioned, and there was also very little mention of bituminous-cement combinations, except for the small section herein included.

An attempt has been made to credit the material included to its proper source. However, in the event that several sources covered the same topic with about the same completeness, no reference is listed. Also, some averages were calculated on items from different sources which had slight variance. No references are listed for these figures.

The evaluation of the various materials and methods included are in many cases those of the manufacturer, and are necessarily quite one sided. It is rather difficult to obtain a clear picture of the exact worth of these materials or make accurate comparisons, by comparing very opinionated reports. A great deal of the so called "facts and figures" of the manufacturer which appeared to be obvious exaggerations or special cases, were omitted; or if included, the source was also given.

The enormity of the topic chosen has necessitated a very great degree of incompleteness both in the nature of the material included, and in its organization. However, a great deal of knowledge was acquired.from the endeavor, and my interest was very greatly stimulated. Therefore, the purpose of the undertaking was fulfilled. Perhaps at some future date the author can present a more comprehensive and complete report. Concrete is definitely an interesting subject, and one which is certainly worthy of future study.

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LIGHTWEIGHT AGGREGATES

The Lightweight Aggregate Field

The lightweight aggregate field is perhaps the field in which the greatest strides are being made today, and the field that may have the greatest effect on the future design principles of buildings both from an engineering and an architectural standpoint.

Lightweight aggregates are not new. They have been known since the time of the Romans. They have been used for construction purposes in southern Germany and other parts of Europe for many years. However, their introduction into this country is relatively new.

The concrete masonry industry was the first to realize the advantages of a lightweight aggregate in their products, with the chief saving seen in the ease of handling which could be afforded. In 1946, the production of lightweight block reached 386,389,000 8 x 8 x 16 inch equivalent units, as compared with 553,718,000 of the heavier variety, or approximately 41% of the total block output.

However, the most recent developments of lightweight aggregates have been in the monlithic field where great success has been achieved, principally on the west coast, where natural aggregate is readily available. So great have been the savings and advantages of lightweight concrete in projects already completed, that it threatens to supercede stone and gravel concrete in this part of the country almost entirely.

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Lightweight aggregates, in general, offer the advantages of reduced dead load, ease in handling, heat insulation, and sound absorption qualities and increased earth quake resistance. On the other hand, they present the problems of floating out of the aggregate, bleeding, and an increased cost factor. The advantages have been found to outweigh the disadvantages, except where long haulage will make the cost factor prohibitive. Specific advantages and disadvantages will be discussed for each aggregate in turn, as there is a wide range of characteristics in the different classes and specific aggregates.

The lightweight aggregate field promises to offer a keen rivalry between the ingenuities of aggregate producers and processors. Formerly, with stone and gravel aggregates, the local outfit had much the advantage, since the freight charges constituted the only principle difference in price, as the mining and processing of the material was on a relatively standardized basis. Now, with a whole new field of aggregates opening up, and new methods of processing being developed, producing better products, there promises to be some interesting competitive marketing. In fact, this competition has already begun.

According to Stuart H. Ingram (Pasadena, California mining engineer), "A lightweight aggregate, in order to hold a marketing position, should have these qualifications:"

(1) Be well graded in size

(2) Have minimum voids to be filled with mortar

(3) Have good compressive strength

(4) Be firm, so that particles won't break down in handling

(5) Bond well with cement and be inert

(6) Must not be affected by weather, time, moisture, insects and fungi

(7) Be as light as possible (to be economical, should not be more than 50% of the weight of rock or gravel, or weigh less than 50 pcf.)

Lightweight aggregates may be classified into the following classes:

(1) Aggregates of volcanic origin

(2) Micaceous materials

(3) Expanded clays and shales

(4) By-products of manufacturing processes

(5) Vegetable fibers

Each class will be discussed in turn with its various group members.

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Pumice

Foremost among the natural lightweight aggregates, now in the process of rapidly increasing production, is pumice. Professor Raymond E. Davis of the civil engineering department, University of California, has described pumice as having "real potentialities" in the lightweight aggregate field.[28] Pumice has proved itself in recent years to be of great value, and the demand has increased tremendously in the past two or three years.

Pumice has been defined as an acidic, volcanic glass, produced from a granitic magma during explosive volcanic eruption.[22] Pumice, a glassy froth, honeycombed with elongated parallel cavities, is formed as gases are released from the lava particles as they cool to solidity.[12]

Essentially, pumice is composed of complex amorphous silicates of aluminum.[22] A typical analysis of a pumice ore is given in the accompanying table (table 1)[1]

Silica (dioxide)	72%
Alumina	14%
Potassium oxide & Sodium oxide	7%
Calcium oxide & Magnesium oxide	2.5%
Iron oxide	1.0%
Loss on Inition	3.5%

Table 1.[1] Components of a typical pumice deposit.

Pumice is found near the surface of the earth with little or no overburden. Deposits are in layers of varying thickness, which would apparently be governed by the frequency, duration, magnitude, and type of volcanic action of the particular volcano from which the deposit has originated. Deposits in Washington vary in depth from 2 feet to 14 feet with 6 feet being an average deposit (see Table 2).[6] Other states have somewhat larger deposits, with 10 feet to 25 feet being a common deposit in New Mexico.[51]

Material	Depth (inches)
Silty soil	13
Buff colored pumice	25
Sand	3
Gray pumice (older layer)	35
Silt, sand, and rock fragments	64

Table 2.[6] Typical pumice deposit in Washington.

Due to its volcanic origin, pumice deposits are confined to western states with volcanic or formerly volcanic mountains. Pumice deposits are found in Bishop and Imyoken, California; Bend, Oregon; Sante Fe and Albuquerque, New Mexico; and near Mount St. Helens and Glacier Peak in Washington. Other deposits have also been located. New Mexico probably contains 40% of the nation's pumice supply.[1] It is interesting to note that all volcanos do not have pum

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pumice deposits. Mts. Baker, Rainier, and Adams in Washington, for example, are apparently devoid of pumice.[6]

Pumice has been known since the time of the Romans.[22] It has been used for polishing, as an abrasive, and in puzzolanic cements to increase the resistance to penetration and corrosion by fresh or sea water, and provide long continuous age hardening of concrete. However, this has been on a relatively small scale as compared to the huge quantities in use today.

The first use of pumice as an aggregate, of any importance, was the building of several concrete ships for World War I.[13] However, it was not until 1940 that the huge strides in the production and use of this natural volcanic material began to be made. Production has probably doubled in the last five years.

California produced 7,170 tons of pumice and pumicite (discussed later) in 1926. This was used almost entirely as an abrasive. In 1946, the same state produced 109,191 tons of pumice and pumicite, with over 90% being used as an aggregate in the building industry.[22]

The use of pumice in the manufacture of concrete blocks has accounted for the major portion of its utilization in the past. Blocks have been produced from pumice aggregate under a large number of trade names, such as: Pyrolite,[58] Pumalite,[4] White Lava Block,[1] etc. However, pumice is now being used in place of regular stone mixes in on-the-job monolithic pourings, and in prefabricated panel production, in both cases with great success.

Pumice has nearly all of the advantages of an ideal lightweight aggregate. It is light, has high insulation properties, is of uniform quality, is incombustible, and has a surface texture to which plaster readily adheres. In addition, it requires little processing prior to actual use as an aggregate; it is relatively strong; and it is easily mined.

The weight of pumice aggregate ranges from 25 to 55 pounds as found in its natural state of gradation. It is found in sizes up to about one inch, being very nearly of design mix gradation. However, it is usually screened and very often crushed to meet specificational demands.

Pumice is generally white to gray in color, although newer deposits may be of various colors.

Pumice absorbs considerable water, and may require as high as five days to become inundated.[1] It must, therefore, be saturated before or during mixing. Several methods of presaturating the aggregate have been used, including: spraying the aggregate as it stands in piles; presaturating the aggregate in a mixer prior to actual addition of cement; or actual addition of extra water to the mix to compensate for the absorption. Either of the former methods is to be preferred.

One of the important advantages of pumice is its very high insulation property. A pumice concrete will have about six times the insulation ability as compared to a concrete using regular stone or gravel as an aggregate. Table 3[22] gives a fairly representative idea of the "K" factor (thermal conductivity factor) of well proportioned pumice mixes.

Compressive strength (psi)	"K" factor (Btu/sq. ft./in/°F/hr) Pumice concrete	Rock concrete
3500	2.25	13.00
3000	2.20	12.50
2500	2.15	12.00
2000	2.00	11.50
1500	1.95	11.00
1000	1.85	10.50

Table 3.[22] Thermal conductivity of typical pumice and rock concrete mixes.

The Albequerque (N.M.) Gravel Products Company has conducted many tests on pumice concrete. They have discovered[1] that workable mixes can be designed as easily and with the same scientific approach as so-called hard rock concrete; that pumice concrete definitely follows the water-cement ratio law for strength.

As is the case with most lightweight aggregates, pumice, because of its lightness, has a tendency to float out of the mix, producing segregation and bleeding.[1] It is recommended, therefore, that the mix be kept as dry as possible (with a slump of 2 inches or less) and that no troweling be done until the mix has partially set; even then dusting should

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precede finished troweling. Pozzolith (discussed later) has been added successfully to prevent bleeding and increase workability.[1]

Pumice concrete can be designed for a compressive strength up to about 3500 psi.[22] This is largely dependent upon the gradation of the aggregate and the water cement ratio, of course. The larger sizes of pumice aggregate have the lighter weight but the fines have the greater strength factor.[1] The addition of fine pumice in increasing quantities will give increased strength at the expense of an increase in weight.[22] Sand has been added to correct for the fineness modulus and increase the strength;[4] however, it too sacrifices weight for its strength gain. Addition of fine pumice is said to also give less permeability to water and greater corrosion resistance to sea water, fresh water, and organic acids.[22]

If pumice were melted down, it would have about the specific gravity of granite, or 2.4 to 2.6. The hardness is 5.5 to 6.0, the same as the feldspars and almost as hard as quartz which is 7.0.[1]

Professor Davis, of the University of California, claims that pumices can be improved a great deal by heat treatment, to reduce absorption in pumice concrete, and to increase its strength.[23] However, the demand for pumice without this treatment is, at the present time, great enough that the extra expense of this heat treatment is not warranted.

The Pumice Aggregate Sales Corporation, of Albequerque, N. M. (most modern and one of the larger producers of pumice) has sponsored the testing of its aggregate at the University of New Mexico, and the Pittsburg Testing Laboratory of San Francisco.[1] Tests have also been conducted at the Universities of Texas, Oklahoma and California (to mention a few). These tests have so far indicated, that pumice concrete has equal shear, bond, and tensile strength with that of conventional concrete.[1]

Table 4 gives a comparison of the unit weights of stone and pumice concretes for desired strengths, and also a comparison of the cement required to obtain these strengths. In each case a well graded aggregate mix is inferred.

Compression desired (psi)	Unit weight (pcf) pumice	rock	Cement required (sacks/yd) pumice	rock
3500	110	155	7.5	6.5
3000	102	152	7.0	6.0
2500	90	150	6.5	5.5
2000	87	148	6.0	5.0
1500	75	145	5.0	4.0
1000	66	142	4.5	3.5

Table 4.[22] Comparison of unit weights and cement required for pumice and rock concrete mixes

That the strength of pumice concrete increases with age is illustrated in tests performed on pumice ships of World War I which have been since broken up. These tests gave strengths of 8,000 psi, when standard cylinders were cut from the broken hulls.[2] This is believed to be due in part to the puzzolanic action of the pumice aggregate, plus a more complete hydration due to the porous nature of the aggregate.

Fire and heat resistant tests have been conducted on pumice products with very good results. As an example,[1] the Utah-Idaho Concrete Pipe Company conducted tests according to A.S.T.M. Specifications on a concrete block wall made of their product (which has pumice as an aggregate.)

In the first test, the inner face of the wall was brought to 2000 F. in four hours under a load of 80 psi at all times. In another test, the entire wall was placed in a gas furnace and heated to 1700° F. in one hour. A fire hose was then sprayed on the wall immediately. When the wall was cool, it was loaded to 160 psi. These tests were performed successfully with no failure resulting. Numerous other tests have proved that pumice concrete will meet all the standard requirements of heat resistance.

Pumice has other characteristics which add to its desirability. It can be sawed, nailed, and drilled with little more difficulty than wood. Pumice concrete is also vermin proof, which is an important property in states like California, where termites can be a menace.[51] Pumice concrete has greater acoustic qualities than regular concrete. In addition, concrete made of pumice has a greater ability to take a change of shape, or resist stress without cracking, than regular concrete; its modulus of elasticity is between 750,000 and 1,500,000 as compared to between 3,000,000 and 4,500,000 for conventional concrete.[51] This is especially important in parts of the country subject to earth quakes, such as California.

Actual cost comparisons of pumice aggregate and regular aggregate are rather difficult to make and are subject to local conditions and price trends. There is, however, some available data that will serve as an approximate comparison.

The average cost of pumice aggregate at the quarry in California in 1946 was $2.70 per yard as compared to $3.65 per yard in 1926.[22] The price of pumice aggregate delivered at the job site in Los Angeles from California mines in 1947 ranged from $3.75 to $4.50 per yard,[1] depending upon the kind of haulage and the presence or lack of terminal facilities. This was opposed to a cost of $2.40 for regular sand and gravel aggregates.

The Pumice Aggregate Sales Corporation quotes a price of $2.50 to $2.80 (depending on quantity) plus freight, with a 10% discount for payment within ten days of the invoice.[57]

It would appear, at first, that the additional cost of pumice aggregate would render it a luxury. Actually, however, the savings in steel and dead weight and the insulation and other properties that are afforded, make its use desirable in a great many cases.

In small buildings, especially in the precast panel construction type, the lighter weight cuts down the labor by providing greater ease of handling. This is also true of lightweight block units. Insulation is also saved, or a saving in fuel and comfort can be realized.

Pumice aggregate has been used on many large and small housing projects in the California and New Mexico areas. The Federal Government has built large housing facilities of pumice concrete at Imyoken, California (Naval Ordinance Test Station), and at Albuquerque, N.M.[1] A 100-acre subdivision 15 miles east of Los Angeles, known as Hugheston Meadows, is being built employing gunited pumice concrete.

However, it will be seen that these projects are confined to areas in the almost immediate vicinity of large pumice deposits, where the freight charges have no appreciable effect on the cost of the aggregate. For housing projects, the use of pumice will probably be confined to local or semi-local projects. Competition from other lightweight aggregates in other areas of the country becomes too strong as the freight charges increase. The advantages of little processing, ease in mining, and probably a little better quality, that pumice has over other

aggregates, becomes overbalanced by freight rates as a certain distance from the quarry is reached.

The advantages of using a lightweight aggregate increase with the height of a building, for, in addition to the advantages already mentioned for a small building, there are the added advantages of saving in steel, saving in form work (lighter forms) and greater earthquake resistance (increased strength to weight ratio) where this is important.

A great many large buildings are being built, or have been built in the last 3 or 4 years with proven cost savings in addition to other advantages.

The $377,000 Jackson County Memorial Hospital at Altus, Oklahoma was designed using pumice aggregate because it would afford an anticipated: (1) 50% reduction of frame dead load; (2) 45% reduction of reinforcing with the same live load capacity; (3) greater heat insulation value; (4) and the sound absorption qualities necessary in a hospital design.[1]

The $1,600,000 Telephone Company building in Los Angeles resulted in a net saving of $18,000 through the use of pumice concrete. This was in addition to advantages already mentioned for lightweight aggregate structures.[1]

The General Petroleum Building and the Prudential Life Insurance Building which are being constructed in Los Angeles at about $7,000,000 apiece, expect to save between 10 and 12% of the cost by using pumice concrete, vermiculite

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plaster, and general lightweight construction.[31]

The $6,000,000 Michelson Research Laboratory at Inyoken, California was built with pumice concrete with a great saving being realized.[1]

However, it is my opinion, that, although pumice is being shipped by the Aggregate Sales Company alone to over twenty states,[60] its use will eventually be confined to the West and Southwest almost entirely, as the new local aggregates now coming onto the market in larger quantities, begin to take over in their own local.

In the Southwest, pumice appears destined for greater usage, and cities such as Los Angeles may resort to the use of pumice almost entirely, with the exception of foundations and roads, which account for about 20% of the concrete used.[51]

Pumicite

Pumicite is chemically similar to pumice, but is different physically. It is also known as "volcanic ash" or "tuff."[51] It is a very fine sand, made of minute particles of glass which have been deposited either by wind or water. The particles have been defined as "atomized" by volcanic explosion. Particles are small and angular in shape and have an abrasive looking contour.

Due to the lightness of the fine particles, they are transported great distances from their volcanic origin. There are states, such as Kansas and Nebraska, where considerable pumicite is found and little if any pumice.[51]

Pumicite has for many years been used as an abrasive in the manufacture of abrasive soaps, household cleansers, and scouring powders.[51] It is rather soft and frail and has little use as an aggregate, except as a plaster aggregate, or in other uses where insulation and not strength govern.[12]

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Perlite

Perlite is a natural hard volcanic rock containing some internal water.[51] It is found near the volcanic core, is inert and has a specific gravity of 2.4. When crushed and heated to a high temperature, it exfoliates to about ten times its normal size and will weigh from 8 to 16 pcf.

It has been found advantageous to preheat the crude perlite, for too sudden a heating explodes the material and produces too many fines.[12] By preregulating the temperature in the preheater, an almost sized final product can be obtained.[8] The expanding heat range is from 1400-2500 F. Perlite has been expanded in horizontal, vertical, and inclined stationary and rotary type furnaces.[22]

Expanded perlite is light and rather frail; however, it has excellent insulation properties.[51] Table 5[18] gives the thermal conductivity factors of various perlite mixes.

Volume mix perlite-cement	Density (pcf)	Thermal Conductivity
8 - 1	25.4	.643
7 - 1	25.4	.657
6 - 1	27.1	.693
5 - 1	29.2	.726
expanded perlite aggregate	7.34 8.67	0.39 - 0.49
loose earth fill	----	10

Table 5.[18] Density and thermal conductivity of various perlite mixes.

Perlite is used in precast slabs, blocks, floor fill, fireproofing, and plaster. It makes a good insulation plaster with more plasticity than sand plaster. Perlite concrete has a strength as given in Table 6.[18]

Volume mix perlite-cement	Compressive strength (psi)
3 - 1	1730
5 - 1	918
7 - 1	560

Table 6.[18] Compressive strengths of various perlite mixes (typical)

Perlite concrete will weigh between 53-55 pcf. First attempts at expanding perlite in the United States date back to about 1940, although it was expanded and used in Germany prior to 1925.[22] There are now some thirty companies involved in developing perlite aggregate in California alone. Two of the largest perlite producers are the Continental Basic Materials Company of Chula Vista, California, and the Perlite Corporation of America.[9]

The Builders Supply Company of Phoenix has mixed red-black volcanic cinders with perlite resulting in a concrete block that is cheaper and stronger (not to mention heavier).[8]

It is much cheaper to ship perlite in its original state to kilns located in the vicinity where it is to be used, since the freight rates will be reduced. A good grade of crude perlite could be purchased at about $9.00 per ton at Los Angeles in 1947 (cost of expanding not included).[22] The cost of expanded perlite at this time ranged from about $4.00 to $13.50 per cubic yard.[22] It will be noted that, due to the processing necessary, and the fact that perlite deposits, so far, have been found in remote areas, that perlite is priced considerable higher than pumice.[11]

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Obsidian

Obsidian is a rock of volcanic origin which has essentially the same chemical analysis as other volcanic ores (see Pumice, table 1). Obsidian is very similar to perlite in many ways.[28]

When heated, a product weighing about 20 pcf is produced which is strong and possesses a thermal conductivity which is comparable to the best insulating materials on the market today.

The aggregate has been given the trade name of Continental Basic Material, or "CBM" as a trade mark. It is being produced by the Continental Basic Materials Corporation of Chula Vista, California, from two deposits both located at Beatty, Nevada.[24] Up to 1947, these were the only two deposits of this rock known to exist.

Concrete made with obsidian is claimed to have equal strength with that of conventional concrete and still weigh less than one half as much. It is further claimed, that it will give without cracking when subjected to overloads.[24]

The use of this material is still in the embryo stage as yet. It has proved very successful in its initial applications, and it does appear to have definite possibilities for future usage.[28]

Scoria

Scoria, or natural cinders, are dark colored, volcanic clinkers, a little tougher and somewhat harder than pumice. However, they are considerably heavier than most lightweight aggregates.[23]

According to F. Sommer Schmidt, Consulting Mining Engineer of California, who has done considerable research on the subject, "they do not have a field in which they excel, and they make no contribution to the science of lightweight aggregates."[51]

They are being used at present in the manufacture of cored floor slabs and blocks by Edgar D. Otto and Son, of Albuquerque, New Mexico.

Vermiculite

Vermiculite is a micaceous material which expands upon application of heat to as much as 30 times its original volume. The dried ground ore is subjected to about 1800° F. for 4 to 8 seconds, after which it weighs between 6 and 12 pcf. The minute mica layers expand like the pages of a book.

Vermiculite was first marketed from a Colorado deposit in 1915.[12] It is also mined in North Carolina. However, the principal and actually the only large scale production of vermiculite is near Libby, Montana.[12] The trade name of expanded vermiculite is Zonalite.

Until 1940, the chief use of this material was as a loose fill insulation. However, today it is being used in large quantities as an aggregate in concrete for fireproofing steel, and as an aggregate in concretes and plasters for insulative and acoustic purposes.[50]

Vermiculite concrete and plaster were used in the construction of the Mercantile National Bank Building of Dallas, Texas for fireproofing steel framework and ceilings, and as a fill for cellular steel floors.[12] Dead load was reduced by 15,634 tons, resulting in a saving of 1,880 tons of steel according to Walter W. Ahschlager, the architect.

The Alexite Engineering Division of the Alexander Film Co., Colorado Springs, Colorado, sells expanded vermiculite in bags u

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in bags under the trade name Per Alex, at an equivalent price of about $9.00 per yard F. O. B. Colorado Springs. This company also manufactures nailable lightweight bricks of vermiculite and perlite which sell locally for $50 per 1000 made with a 5-1 mix and meeting all local building code requisites.

There is also the threat of a foreign vermiculite source giving competition to the local product.[25] The total output of a vermiculite mine in northern Transvaal, Africa, has been contracted for by an American company. This company stated that the ore was of a much higher grade, and in addition, labor costs in African mines are about 1/20 of the American labor costs.

The 1947 output of this African mine was expected to reach about 25,000 tons; and after American machinery had been installed, the production was expected to jump to about 180,000 tons. The total American production in 1946 was 75,000 tons. It is not known exactly how closely these figures were fulfilled.

Haydite

Haydite is a lightweight, burned shale or clay aggregate.[56] It is ground to a maximum size of about 1½ inches, and heated slowly reaching a temperature of about 2000° F., at which the carbon content oxidizes forming gases, which result in the aggregate taking a light cellular structure. It is then crushed and screened to size.

Haydite concrete will develop strengths of 4000 to 5000 psi, and weighs between 100 and 110 pcf.[51] Due to its cellular nature, it should be presaturated before use.

Haydite has been used rather extensively for about 25 years with proven advantages.[56] Tests on haydite have been conducted by practically every engineering society and university in the country. It is one of the oldest lightweight aggregates on the market today. Haydite was used extensively during World War II in the building of concrete ships.[56]

In 1930, there were two licensed manufacturers of Haydite aggregate; today there are eight,[19] located in: Kansas City, Missouri; St. Louis, Missouri; South Park, Ohio; Daneville, Illinois; Buffalo, New York; San Rafael, California; Toronto, Canada; and Bothell, Washington.

The Carter-Waters Corporation of Kansas City, Missouri, has set up a new plant on a 65-acre tract, and are mining and processing a 75-100 foot seam of shale.[19] Operations include: stripping the overburden, blasting, loading, crushing, storage, burning, cooling, crushing and screen grading.

Burning is done in oil-fired rotary kilns 6 x 60 feet, with a 40-minute travel time for the shale through the kiln. The material emerges as a clinker at 2,150° F. and cools for 10 days before being crushed and graded.

An 8 x 8 x 16 block of Haydite weighs 25#, and has a minimum compressive strength of 1000 psi with good sound absorption, and heat insulating properties.

The Carter-Waters Corporation is now experimenting with Haydite in precast units. Other companies are already producing these units successfully.

Rocklite

Rocklite is a product manufactured at Ventura, California[28] from a shale having a water content both chemically and physically combined. When heated to 2500° F., the expansion of the water puffs the material and control of temperature gives a more or less continuous surface coating to the particles.

Rocklite is crushed before heating, and the different sizes heated separately, thus preserving the skin coating. This is a particular advantage and the result is an aggregate that will require less cement and provide greater strength than an aggregate which is crushed after expansion.[51]

Rocklite is capable of developing a concrete of over 6000 psi and has low absorption qualities.[28] It is somewhat heavier than pumice and is more expensive due to the heat treatment and increased crushing expense over that of pumice. It is a very desirable lightweight aggregate where high strength is required and insulation and cost are secondary.[51]

Sinterlite

The Stearns Manufacturing Company, Incorporated, of Adrian, Michigan, have developed a lightweight aggregate from fly-ash.[20] Fly-ash is a coal ash still containing some unburned coal, which, when mixed with clay, shale, earth, or slag, can be burned to produce a very satisfactory lightweight aggregate, which they have called Sinterlite.

The burning takes place in a specially designed machine. The basic unit of this Sinterlite machine consists of an automatic continuously rotating pan.[27] The raw materials, mixed with a small amount of fuel, are fed to this pan and sintered.

Airox

Airox is made of diatomaceous earth which is subjected to two heat treatments to provide a silica coating on spongy structural fragments with a hard interior. Good strength is obtained up to 6000 psi with a weight of 113 pcf.[51] The process, however, has not been able to compete in the general building program because of its high production cost.[51] It was first prepared for and sponsored by the Maritime Commission for ship building purposes during World War II.[51]

The Air-Ox Company, of Los Angeles, producers of Airox have now developed a cheeper product using an oil impregnated diatomaceous earth.[20] The material is calcinated, expanded, and is atomized with an exterior clay-like coating. It is again burned giving a strong, synthetic coated aggregate weighing 88 pcf, with strengths up to 4000 psi in a standard mix.

Lite Rock

The Empire Building Material Company, of Portland, Oregon, is manufacturing a lightweight aggregate block under the trade name Lite Rock.[21]

Lite-Rock is an expanded shale product. The shale is blasted from a shale mine near Portland, crushed to 2½ inch maximum size, expanded, and pulverized. Expansion takes place in an oil-fired rotary kiln 6 x 60 feet.

Lite-Rock aggregate weighs 9 pcf after expansion, and an 8 x 8 x 16 block made of this material weighs 23#.

Empire claims that their product is of greater strength than pumice block, and still retains all of the advantages of insulation, nailability, etc., present in a pumice block .

The price of Lite-Rock block is slightly above that of pumice block.

Celocrete

Celocrete is a lightweight aggregate produced by the Celotex Corporation of Chicago.[54] Celocrete was marketed under the name Pottsco for a number of years by the Celotex Corporation.

Celocrete is an expanded blast furnace slag. By a patented process, molten slag is converted into a hard, tough, cellular, annealed mass, which, when crushed and graded, can be mixed with cement and water, and will form a chemically inert concrete.

Celocrete is sold to various manufacturers of building units throughout the country. Celocrete blocks, 8 x 8 x 16, weigh between 26# and 29# and have the usual advantages of lightweight units.

Celocrete blocks are sold very extensively and have a pleasing, attractive surface appearance. However, the availability of celocrete aggregate is now limited by the fact that its production is far behind demand.

Concrete Plank

The Concrete Plank Company, Incorporated, of Jersey City, New Jersey, has, for several years, turned out a concrete plank consisting of hard coal cinders, and crushed blast furnace slag, as an aggregate, and portland cement as the cementing ingredient.[52]

The planks weigh the equivalent of about 75 pcf, and come in 2-inch and 2 3/4-inch thicknesses of varying lengths and widths. They are reinforced both top and bottom with a mesh of welded steel rods.

The actual compressive strength of the material is 850 psi with an increase due to the reinforcing rods present.

The planks are not considered as fireproof, but can come under the fireproof codes in many cities, if used in conjunction with vermiculite plaster.

The planks have several advantages including: good insulation and sound properties, rot-proof, form work can be saved, planks can be nailed,cut and sawed, and a reduction in dead load can be realized.

Vegetable Fibers

The University of Michigan has made over 8,000 tests on 225 different lightweight materials that may be suitable for building purposes, when mixed with portland cement and small quantities of certain inexpensive chemicals.[51]

The light, strong fibers bind the concrete and also contribute lightness, bulk, and insulative properties. The chemicals are added to lessen the amount of cement, prevent shrinking, and increase strength. For fiber materials, peanut hulls, cotton stalks, rice and wheat straw, cornstalks, flax shives, and sawdust can be used.[32] Among the best fibers are materials obtained from northern jack pine and winter-cut popple or aspin.[32] Processing these woods consists of a single grinding operation. The tests have shown that these fibrous concretes are exceedingly practical for farm structures, where the raw materials are readily available.

One of the disadvantages is that many fibers require special preparation to remove harmful juices.[32] The juices in ordinary farm wastes, such as straw, and cornstalks, usually contain substances that are harmful to the set of the cement. It is not difficult to remove these substances, but the special treatment requires a certain amount of time. The mixers on the market at the present time are not entirely satisfactory either, for mixing these fibrous substances.

Slabs made of fibrous concrete weighed from 1/3 to 1/2 that of regular gravel-sand concrete.[32] Two inch boards of the new material showed, in the tests, almost as great an insulation value as two layers of Celotex between plywood facings, and having a thickness of slightly over two inches.

Slabs of insulative concrete will not burn, but will char when exposed to intense heat.[32] In use, the new material will probably be cast into slabs, and fastened over the building frame. It is claimed that these slabs, properly made, will be non-rotting, and termite proof.

Durisol

Durisol is a lightweight, precast slab employing a mineralized organic aggregate. Chemically mineralized wood shavings are combined with portland cement, and moulded into modular slabs, blocks, and tiles, to meet a variety of uses in building construction.[53]

Durisol units weigh about 50 pcf, are fire resistant, insulating, sound absorbing, and inert. These units are not subject to attack by mould, fungi, rats, or termites, and are unaffected by moisture.

Durisol, Incorporated, is a very new company and is completing the first of nine proposed plants at Beakon, New York, at a cost of $500,000.[33] Durisol originated in this country a short time ago in a small plant at Aberdeen, Maryland.[35] However, Durisol has been used successfully for many years in Switzerland and other European countries "for all types of construction."

Durisol units sell for from $.30 - $.40 per square ft. for the plain type, and from $.80 - $.90 for reinforced units, coated with ½ inch of white cement. These rates are F.O.B. Beakon, New York, or Aberdeen, Maryland.[53]

Coral Concrete

Good quality concrete was successfully made during World War II with coral and sea water.[34] This was done on Bermuda, where fresh water was not available, and where there is none of the ordinary rock usually employed in concrete making.

The National Bureau of Standards and the cement industry had conducted research on the use of sea water for mixing concrete. It had been found, that sodium and other chlorides would not induce corrosion, that sulfides might, but that these were present in very small quantities only.

The engineers in Bermuda obtained a considerable reduction in water-cement ratio by using a pozzolanic (volcanic ash) compound in the mixture. Chemically, the compound used was calcium lignosulfate. Its use reduced water requirements by about 17% and resulted in a concrete that tested over 4,000 $\#/in^2$.

Wood-Wool Blocks in Norway

The use of concrete blocks made with lightweight aggregate seems to be gaining in favor in Norway.[17] A recent development is the use of "wood-wool" with a cement binder for wall construction, placed within reinforced concrete frames.

Sweden's Ytong

Sweden is now producing a celular lightweight concrete called Ytong.[30] A finely ground mixture of burnt lime and burnt shale and aluminum powder constitute the raw materials. The processed materials are then cured in an autoclave.

Concrete having a unit weight of 44 pcf will develop over 800 psi with a K factor of 1.06. At a density of 28 pcf Ytong has a compressive strength of 300 psi with a K factor of .68.

German By-Product Aggregate

Germany has been using a lightweight aggregate consisting of a molten blast furnace slag treated with steam and highly controlled, for many years.[12] This aggregate is used for precast blocks, cast-in-place walls of houses and for panel filling of steel frame buildings.

Nodulized Fuller's Earth

A process was recently developed in Florida whereby Fuller's earth is nodulized with water and processed in rotery kilns.[28] The principle objective is to produce a lightweight aggregate that will require no crushing after manufacture.

Nodulized Diatomaceous Shale

A recent California development, based on the pre-sizing of aggregate, is the nodulizing of an oil impregnated diatomaceous shale.[28] A fine powder of high fusion is used to coat the particles and prevent their sticking together.

Mul-Kra "Wonder Block"

The Marketing Association of Saginaw, Michigan has produced a building block made of wood fiber, special mastics, and cement.[28] The blocks are said to have ten times the insulation value of common concrete blocks and are claimed to be sawable and nailable. Blocks subjected to a 900 F. degree flame for two hours did not burn.

Porète Concrete Units

The Portte Manufacturing Company of North Arlington, New Jersey manufactures a number of lightweight precast units for floors and roofs.[55] They have employed mineralized wood fibers and air in different proportions to obtain units for various purposes.

PRESTRESSED CONCRETE

Introduction to Prestressed Concrete

Prestressed concrete will some day be commonplace in this country because of the many advantages that it affords. It was mentioned not long ago at an A. C. I. Convention that prestressed concrete was the "big future" of the reinforced concrete design field.[78] To date, little has been done with prestressed concrete in this country, with the exception of its use in the construction of prestressed pipes and tanks. This has been mainly due to the fact that prestressing requires a multitude of small manual operations involving great attention and close supervision.[78] With labor costs as they are in this country today, many engineers have been frightened away from the use of prestressing in their designs. However, the United States has on no previous occasion refused to recognize an improvement merely because of an apparent obstacle. Prestressed concrete is destined for great things in this country, as engineers begin to successfully devise labor saving devices for its economical employment.

What is prestressed concrete? Briefly, it consists of subjecting high strength rods or wires to initial stresses before the concrete has been poured about them. When the concrete has been poured, and has set, the stressing devices are released, and the concrete is subjected to a precalculated compressive stress by the tension in the prestressing rods or wires.

When a load is applied to the prestressed concrete, the compressive forces in the concrete are merely reduced. The design is usually such that, for any design loading, the concrete will never be taken out of compression.

The design principle is based on the following facts: that small rods and particularly steel wires and cables can be designed for very high tensile strengths; that in normal reinforced concrete design, a large part of the compressive strength of the concrete is never utilized. The advantages of prestressed concrete are, therefore, rather obvious, and can be outlined as below:

(1) In a normal reinforced concrete design, the thickness of a slab is determined by the shear and bending moment for which it is designed. In a prestressed slab design, the bending moment and shear are resisted by the initial tension in the prestressed steel, and the initial compression in the concrete; and the slab thickness has little part in the design at all. Thus, a slab must only be designed thick enough to withstand the initial compressive stress imposed by the prestressing steel, provide a suitable bond for the prestressing wires, and provide an impervious waterproof thickness. Concrete is therefore reduced in quantity, with a subsequent reduction in useless dead load.

(2) Since the steel wires or cables used can be made with very high tensile strengths, and since no steel is

required to withstand tension, as no tension exists, a reduction in steel is therefore realized.

(3) Since the concrete is always in compression, cracks due to shrinkage, temperature changes, etc., cannot develop, and a waterproof slab can be insured.

(4) Since slabs can be made thinner with the same live load capacity, more headroom will be available in a prestressed design.

(5) With no fear of cracks developing, and less dead weight present, longer spans can be designed safely.

(6) The factor of safety can be reduced in a slab design, for even if an unpredictable overload should be sufficient to induce tension in the concrete of a slab and cause cracks to develop, with the removal of the load, the cracks will close tightly and an impregnable surface will again be present.

From these tremendous advantages that prestressing offers, we may well say that prestressed concrete is the ultimate in reinforced concrete design (if it can be classified as such). Therefore, how can it fail to become an integral part of this country's future in construction design.

Historical Sketch

Prestressed concrete originated in Europe and its development has practically been confined to Europe up to the present time.[78]

The Germans employed prestressed tie rods in arches as early as 1928. In 1936, a river separation structure of 220 feet was built by German engineers, a radical step in the right direction. During the war, the Germans designed and built many structures employing prestressing principles including the covering of their submarine pens.

Two other countries have been instrumental in the prestressed concrete field, namely: France, under the guidance of Eugene Freyssinet, and Belguim, under the direction of George Magnel.

In France, the famous Plougastil Bridge, with three spans of 660 feet, a combined highway and railway bridge of prestressed concrete, was handed over to traffic in 1931. The success of this and other projects were inspiration enough for Freyssinet, and he has since designed many such bridges and structures. In France, about three years ago, Freyssinet completed a highway girder bridge with a span of 180 feet, and the phenomenally shallow depth of 4' 2" at the center. It spans the Marne River in the neighborhood of Chateau Thierry. Five other such bridges on the same system are in the process of erection or just recently completed.

Professor George Magnel has designed numerous prestressed railway and highway bridges with spans up to 66 feet in the vicinity of Brussels. In 1944, Magnel designed several structures for carrying pipelines over long spans.

The Swiss have employed prestressed concrete for a number of short-span highway and railway bridges, and for galleries as a protection from avalanches.

Many airport hangars with spans of 150 feet or more were built shortly before, and during the war in several European countries, as well as in India.

Prestressed concrete has been used in this country for about ten years in the construction of large pipes and tanks. Also, in the early 30's, the 230 foot arches of the Rogue River Bridge in Oregon were built employing one phase of prestressing. Jacks were used at the crown to induce compression in the ribs.

Prestressed beams have been tested in our labs, but their actual use has never come about, with the exception of a warehouse recently built in Cicero, Illinois, which will be discussed later.

Philadelphia is planning to build a prestressed concrete girder bridge employing high tension wires and using modern prestressing methods,[82] which have been employed in Europe for some time. It will be the first of its kind in this country and could provide the necessary force for

the construction of similar projects in the near future.

At the September, 1948, meeting of the Congress of the International Association of Bridge and Structural Engineers held at Liege, Belgium, more than 500 delegates, representing 28 countries attended.[84] It was the first such meeting since the Berlin meeting of 1936.

A prefabricated, prestressed concrete factory building, covering 350,000 square feet, was one of several remarkable developments reviewed and discussed.[84] The building, located in Ghent, has 70 foot spans of prefabricated, prestressed concrete, and only half a dozen forms were used in the entire building.

About 20 engineers and contractors representing 10 countries of this group, laid the groundwork for the formation of an International Association for Prestressed Concrete.[83]

Prestressed Concrete Pipe

--The Largest Prestressed Concrete Pipe on Record--

Prestressed concrete pipe has been manufactured in the United States in fairly large numbers for the last decade by several companies. This pipe has ranged in sizes from 20 inches up to as large as 50 inches, usually accompanied by an inner steel liner.

However, recently Montreal, Canada, let bids on the manufacture of concrete pressure pipe for an intended new and larger water supply intake from the St. Lawrence River.[71] On the strength of reports of the successful use of prestressed pipe in Europe and Australia, notably those built by Freyssinet in France and Roda patents in Australia, the Montreal Water Board tendered alternate designs--the conventional type, and the prestressed type.[70] Bids on the conventional design were 50% higher than the one accepted employing the prestressed design.

The contract was awarded jointly to the Preload Company of Canada, Ltd., and the Atlas Construction Company, Ltd., both of Montreal. It consisted of the construction (not installation) of approximately 9500 feet of 84 inch pipe. Using the prestress design, a saving of 800 tons of steel and 10% of the cement was realized over the conventional design. Each pipe section weighs about 16 tons, is 18 feet long and 84 inches inside diameter, with walls 5½ inches thick.

The plant for making the pipe was completed in May, 1946, and the first pipe length was made in December, 1946. Difficulty in obtaining materials and equipment delayed operations until April 1947, when the scheduled production of 3 pipes per day got underway.

The pipes are stressed with longitudinal and circumferential steel. Longitudinal steel consists of 12 pairs of wires each .44 inches in diameter equally spaced around the perimeter and located in the center of the core wall. These wires were given an initial stress of 70,000 psi, which induced 188 psi in the concrete. This would leave a calculated residual stress of 49,700 psi in the steel and 103 psi in the concrete after loss due to elastic deformation, plastic flow, shrinkage, and bending induced when supported by a sling at the mid-girth.

Circumferential reinforcing consisted of a continuous spiral of #8 gage wire having an ultimate strength of 220,000 psi and wound on the concrete core. It was spaced at .31 inches on the flanges and .63 inches on the barrel, and was applied under an initial stress of 725 psi in the concrete. This would leave a calculated 108 psi in the concrete, and 114,120 psi in the steel under full 50 psi hydrostatic pressure, and after the losses of elastic deformation, plastic flow, and shrinkage had been subtracted.

The actual plant layout and the pouring methods employed are too lengthy to describe at this time. The longitudinal wires were threaded at the top and the prestressing was accomplished by elongating the wires to a precalculated length (about ½ inch) with a pneumatic wrench.

The concrete used averaged well over 4500 psi, had practically a zero slump, and was vibrated into place.

After steam curing, the core passed to a turntable where the circumferential wire was applied. The turntable was geared to the prestressing mechanism, which ran on tracks parallel to the length of the core. As the table revolved, the prestressing mechanism fed the wire through a tension die, and at the same time moved up the vertical tracks in synchronism with the rotation of the turntable. A second gear was employed for winding the flange.

The unit stress in the wire was checked by a calibrated torque wrench connected to the tension die, and also by micrometer reading of the wire diameter.

After the wire had been wound, it was gunited with 3/4 inches of concrete with a mix proportion of 4 parts sand, one part cement, and 8% by weight of hydrated lime. The gunite coat was then cured and the pipe removed from plant by crane to a storage yard, or the testing bed.

One pipe of every twenty was subjected to a hydrostatic test of 50 psi for 15 minutes. Not a single pipe showed any sign of leakage or failure.

The first pipe produced was subjected to various tests designed to approximate field and handling conditions. After the pipe had withstood all normal tests without

measurable deflection, it was allowed to drop on a knife edge at its midlength from various heights up to 24 inches. The only damage noted was a local scoring of the surface of the covercoat. The wire was not cut, and there was no sign of failure of bond between the gunite and the concrete core. This is quite remarkable as the pipe weighed 16 tons.

A 4½ foot section of the same pipe was then cut out and subjected to the A.S.T.M. bearing crushing strength tests with excellent results. Failure occured at a load of 15,600 pounds/foot by clean breaks at the four quarter points. The bond of the gunite cover coat remained excellent, there was no spalling, and no flying of wire.

All of these tests had been performed on a pipe section employing only 800 pounds of steel as compared with about 3800 pounds in a conventional design; truly, an impressive material economy.

Prestressed Tanks

The Preload Corporation, the Canadian branch of which has already been mentioned in connection with the Montreal prestressed pipe project, has also designed some 550 tanks for water, sewage, oils, chemicals, and other liquids within approximately the last eight years.[90] To my knowledge, it is the only company to date in North America, which has the equipment and facilities to undertake this task (other companies have done such work using Preload methods and equipment) and I am sure that it is the largest such company if others exist. The Preload Company has offices in about fifteen major cities in the United States and Canada.[90]

The average size of these tanks have been those with a capacity of 80-100 feet.[74] Prestressed wire is wound around the circumference of the tank with a patented wire winding machine, which is suspended from a vehicle which travels on tracks located on the top of the tank walls. The mechanism travels at about 3 miles per hour and the wire is stressed (by being drawn through a die) to 140,000 psi.

The largest of these tanks is located in Rockford, Illinois and several large tanks are now being built for the city of Los Angeles. These projects will be discussed individually in some detail.

The World's Largest Covered Prestressed Tank

Recently completed at Rockford, Illinois, by the Preload Corporation was the world's largest prestressed covered tank.[73] The tank measures 167 feet outside diameter, and has a capacity of 5,000,000 gallons.

Subcontractor on the job was the Jack Construction Company of Kansas City, a slipform specialist. Employing 5 foot high steel slipforms, the entire wall was poured continuously in 75 hours. The slipform principle consists of jacking special forms gradually up the wall as soon as the concrete below has set up. One inch jack rods spaced 20 feet apart were employed for this purpose.

The wall was prestressed with both vertical and circumferential steel. The vertical prestressing was accomplished by placing .31 inch rods in slots left in the poured wall at two foot centers and applying the required stress using special turn buckles.

The horizontal prestressing was accomplished by applying 180 miles of #8 piano wire using the Preload prestressing mechanism already mentioned. The wire had an initial diameter of .162 inches and after being drawn through the prestressing die, the wire was reduced to a diameter of .142 inches. One layer of wire was applied to the entire 30 foot height of wall, a second layer covered the bottom two thirds of the wall and a final layer was placed on the lower third of the wall. A gunite coat was applied after each layer. The initial concrete wall has a thickness of 15 inches which was increased to 18 inches after guniting.

The top two feet of the wall was wound with five layers of prestressing wire. It is interesting to note that this prestressing was sufficient to raise this ½ acre, 4 inch concrete dome cover 2 inches off of the dome forms.

The foundation for the wall had been trowel finished and coated with emulsified asphalt to permit free lateral movement of the wall after the prestressing wire had been applied. The joint was then caulked and filled with a permanently pliable mastic.

The cost of the project, excluding excavation and backfill amounted to $2.75 per gallon of storage capacity.

Prestressed Digestion Tanks for Los Angeles

The Pacific Bridge Company is presently engaged in perhaps its largest contract employing the Preload method. The contract calls for the construction of 18 prestressed concrete digestion tanks having a capacity of 2,500,000 gallons each.[76] The tanks are part of an activated sludge plant being built for the city of Los Angeles, and located near Segundo, California.

The tanks are 110 feet, 11 inches inside diameter and have a wall thickness of 20½ inches and a height of 34 feet. Each tank is equiped with a concrete roof dome of 5 inches thickness. The prestressing is carried out in the same manner as that already described for the Rockford project.

Work was started on these tanks April 12, 1948, and is expected to be completed in March, 1949.

England's First Prestressed

Cast-in-Place Highway Bridge

Work was recently completed on England's first prestressed cast-in-place highway bridge over Hob Hole drain at Fishtoft, near Boston, Lincolnshire.[80] The bridge has a span of 74 feet with an 8 inch roadway slab incorporated on 43 inch concrete deck girder beams. Five girders spaced at 4½ feet carry the prestressing cables.

The cables consisted of a one inch diameter bobbined core and twelve .2 inch high tensile steel wires. A total prestress of 26 tons was induced in each cable imparting 138,000 psi to the prestressing wires. The prestressing was sufficient to induce an estimated 2000 psi compression in the bottom of the girders, and 100 psi in the top flange of the girders. This will be sufficient to just counteract the full design moving and stationary live load.

The prestressing produced a 5/8 inch camber in the bridge besides the 4 inch dead load camber which had been allowed.

The work followed the Freyssinet methods and employed Freyssinet prestressing equipment as well. England has constructed structures of minor importance of prestressed concrete for a number of years; however, like the United States, they have not kept pace with the radical designs of France or other European nations.

Orly Field Runway Near Paris

Prestressed Concrete-designed by Freyssinet

One of Eugene Freyssinet's most recent projects was the construction of an airstrip at Orly Field near Paris.[81] The runway is 1400 feet by 200 feet and is incorporated alongside of regular conventional strips where a comparison can be made. The runway is 6 3/8" thick and can stand a load 15 times greater than a conventional reinforced concrete strip of the same thickness or is equivalent to the strength of a conventional strip at least two feet thick.

The entire runway is made up of one meter square precast blocks using a 1:2.2:2.6 concrete mix with a water cement ratio of 3½ gallons per bag of cement.

The slabs are laid on a 14 inch deep consolidated foundation with a maximum bearing of 100 psi. The 14 inch foundation is covered with 2 inches of fine sand and is topped with asphalt paper.

The interesting part of the design, is that the entire strip is laid out with diagonal joints, in order to give prestressing in two directions using uni-directional prestressing cables. The diagonal joints are separated with roller bearings to insure as nearly full stress transfer as possible.

The transverse cables were laid between the one meter blocks. They consist of thirty parallel ¼ inch diameter steel wires with an average ultimate tensile strength of

220,000 psi. The cables were dipped in asphalt and wrapped with heavy building paper. At the edge of the strip, the 30-wire cables were separated into three strands and anchored by pinching them between Freyssinet patented interlocking cones.

The cables were tightened in steps up to 128,000 psi imparting a stress of 4,750 psi to the concrete.

In order to withstand the pressure in the longitudinal direction which would be imparted when the cables were released, and butresses 6 feet wide running the full width of the runway were constructed.

Freyssinet claims that his 6 3/8 inch runway will carry several times the weight of the largest plane yet built. Because of its thinness, temperature stresses are reduced to a minimum. Under very heavy loads, cracks may develop, and, in fact, are desirable, since the cracks will increase the flexibility of the concrete, enabling full use of the foundation support, without large bending moments. The tension in the cables automatically close the cracks completely when the load is removed.

America's First Prestressed Floor

About two years ago in Cicero, Illinois, America's first prestressed project was completed.[79] It was in the form of a floor for a warehouse owned by J. A. Roebling Sons.

After 18 months of service, the floor has shown no signs of cracking, when under microscopic examination, even though subjected to loads estimated at 1000 psi (seven times the contact load of the largest airplane.) The load is in the form of large rolls of cable resting on wooden rollers.

The floor is 96 x 144 feet in size, and is built without joints. It consists of a 3-inch prestressed slab placed on a 9-inch reinforced concrete base. The base is topped with a patented surface material to obtain a smooth finish. In addition, a 1/32-inch film of paraffin was applied and a layer of copper coated building paper was placed face down on this paraffin surface. This was designed to keep the coefficient of friction between .30 and .38 and allow free movement of the prestressed slab over the base.

The slab is prestressed in two directions. The breadth of the slab is prestressed with seven wire strands of galvanized wire, having an ultimate strength of 45,000# each or 181,000 psi. These strands are placed midway in the slab and wrapped with paraffin paper tubes to prevent bonding with the concrete. The length of the slab is

prestressed with two layers of No. 6 bridge wire placed 4½ inches on centers horizontally, also wrapped to prevent bond.

After the concrete had been poured and had set sufficiently, the stranded wires across the breadth of the slab, which had been fabricated in two pieces, were pulled together by special jacks at openings which had been left at the center of the slab. The outer ends of these wires were bonded in the concrete. When the concrete had been stressed to about 650 psi, the wires were clamped together and the jacks removed.

The wires running the length of the slab were anchored in the concrete at one end and jacked against steel plates at the other end. When the concrete had been stressed to about 700 psi, the nuts were placed on the threaded ends of the wires and drawn up against bearing plates. The jacks were then removed.

After 1½ years of service, the longitudinal wires were tested and were found to have lost 7½% of their initial stress, the transverse wires had lost 9½%. Tests were made by placing concentrated loads up to 36,000# on an area of 63 square inches directly over a construction joint of the base slab. A deflection of .05 inches was noted. When the load was removed, no permanent deformation had taken place.

The cost of this initial prestressing project was more than that of a conventional design. However, the greater durability and low maintainance cost were held to justify the extra first cost. It was built as a trial adaption of prestressed concrete to highways and airplane runways.

Prestress Bond

It might be wondered as to the capability of the bond between the stretched steel wires and the concrete being sufficient to maintain the initial stress in the wire. This is probably one of the things that would give the most concern to the novelist in the prestressing field.

It has been proved conclusively in hundreds and thousands of tests that sufficient bond can be obtained without a great deal of trouble. Sweden has found in its ten years of rather extensive use of "piano wire concrete" that the quality of the bond is dependent upon the following factors:[75]

(1) quality of the concrete

(2) working of the concrete in the form

(3) strength of concrete at release of wire

(4) type of curing before and after release

(5) prestress of the concrete

(6) diameter and surface properties of the wires

(7) distribution of the wires in the concrete

The breaking of a wire of a prestressed tank, for example, is said to only effect a few inches in the immediate area of the break. It may be better explained by realizing that a break in the wire will release its tension at that point, and the length will begin to decrease with a corresponding increase in diameter. It is this increase in diameter of the wire that, it is felt, is responsible for plugging the hole and preventing further slip of the broken strand.[74] It is apparent that this phenomenon is a very fortunate one indeed.

PRECAST CONCRETE

Precast Concrete

Precast concrete units have been manufactured for many years in this country and have found a rather sizable market. The wartime construction program was a big selling point for these units, for they provide a much quicker means of building erection than actual on-the-job monolithic concrete structures. The postwar boom in the building industry also has provided a ready market for precast units again principally on the strength of their time saving advantage.

There were many companies producing precast units before the war and the number has been many times multiplied in recent years. It would be more than a big job in itself to attempt to give a thoroughly comprehensive picture of the precast industry today. I shall therefore not even attempt to mention the many types of units now being produced nor the companies producing these products. I have rather chosen to give a few illustrative examples of a few of these precast unit developments, perhaps cover two or three of the more recent and more formidable contributions, and make some general statements concerning these contributions, which in most cases will be purely my own opinions to be taken merely as speculative comments by a very green speculator.

I have already mentioned that precast units are time savers. This is generally true. To say that precast

structures are generally more or less expensive than monolithic structures would be impossible. In some cases, precast units have proved to be many times cheaper and in other cases, the opposite is true. The economy factor is controlled by such things as: type of unit, type of structure, time value of erection, availability of suitable monolithic aggregates, height of structure, labor costs and efficiency, number of structures to be built, etc. It will be seen that economy is controlled in general by local, and specific conditions, and that on no two projects will this factor be the same, or very often nearly the same.

The Large Structural Units of the
Cementstone Corporation
of Pittsburgh

Perhaps the greatest contribution to the precast type of construction has been made by the Cementstone Corporation of Pittsburgh. This company manufactures precast units for the complete framing of buildings up to four stories in height.[108] These units include columns, girders, beams, roof, floors, and walls.

The number of shapes have been standardized and simplified to cut down on cost and increase the design simplicity. However, these standard shapes are being made over a large range of sizes to cover a multitude of uses. Special design tables have been devised to further simplify the designers problems.

The precast units are cast in adjustable steel forms to fulfill the size requirements. The reinforcement is welded into a rigid cage before the form is poured, and all steel ends which may appear at the surface of the concrete are coated with Monel metal to prevent rust. The concrete used is very rich--8½ sacks of cement per cubic yard--and is placed with a slump of 2 inches and vibrated both internally and externally. The units are steam cured for three days and develop a strength of 5000 psi during this time. The 28-day strength of these units is 7000 psi.

The units are hauled to the job site by truck and erected by crane. Connections are made by patented dowel and pipe sleeve connections, or with bolts. Precast concrete brackets are bolted to the columns for supporting the girders; and precast "U" shaped brackets are bolted to the girders for supporting the floor joists.[100]

All units are designed for handling as well as for their structural function.[101] Precast girders, joists, and slabs are designed as simply supported beams using a working stress of 2250 psi for concrete and 20,000 psi for steel.

In addition to standard buildings, Cementstone shapes have been applied to standard precast grandstands, small bridges, airport hangars, and other projects.[99]

It is claimed that Cementstone buildings can be erected as cheaply as structural steel unprotected, and for at least 20% less than steel fireproofed, or poured-in-place concrete. The winter time saving is even greater. The company estimates the practical economic distance from the factory for Cementstone structures at 200 miles, although Cementstone units have been shipped by rail for considerably longer distances on a competitive cost basis.

The erection time of Cementstone units is very short. The frame of a two story building in Pittsburgh with a floor size of 110 x 120 feet was erected by a crew of six men and a crawler crane in 13 working days.[98]

* * * * * * * * * *

Venturing a little commentary at this time---it does seem that these units could be an up and coming design feature, that could be expanded to other municipalities.

It is apparent to anyone who has had occasion to observe labor in the field in the last few years, that the tradesman is not doing the efficient and productive job that has been expected of him in the past. This existing condition is the result of two facts: first, that the building trades have not kept their training or apprentice systems in stride with the increased construction programs, fearing that, by expanding their trades, their own positions would be weakened, especially in the event of an economic collapse; second, that plentiful jobs have made the tradesman less concerned about the security of his job, since the fear of his being "fired" for inefficiency has been very greatly reduced. Therefore, by cutting down our labor to the very minimum, eliminating all the elaborate form work which a monolithic structure entails, we are subsequently increasing our efficiency and also accuracy.

It is also true that concrete poured in the field is affected by many variable conditions such as: weather, poor form work (resulting from poor lumber, awkward location, or labor inefficiencies and inaccuracies), over or under mixing, variable slump, improper vibration, haphazard reinforcement location, and often improper curing conditions. By confining the pouring operation to the ideal settings of a precasting plant, it seems reasonable to expect that the resulting concrete units are much more liable to be up to design specifications. Realizing this, the safety factor could be reduced by assuming larger working stresses, with the units still remaining on the safe side. It does seem in the light of these arguments, that the precast system does have definite economic and structural advantages.

It might also be quite practical to incorporate a lightweight aggregate into certain of the precast units, such as the floor, wall, and roof panels, with a saving in transportation and design dead loading with increased insulation value. Prestressing might also be made applicable to these precast units, with a saving in steel, dead load, and handling costs, if the extra labor can ever be justified.

I definitely feel that the precast unit has a promising future, although I am sure there are those who are of just the opposite opinion. It is true that the time saving element may not continue to be as large a selling point as it has been when things settle down; but, the economy factor seems to be gaining, and this is always a sure sales promoting item.

Large Precast Slabs

Normac Incorporated, a Los Angeles building concern, is constructing a large number of buildings employing large precast slabs.[95] These slabs, which are often large enough to form one side of a room, are cast with aluminum window and door casings embedded in the concrete.

The slabs consist of a lightweight perlite concrete poured between layers of standard concrete reinforced with wire mesh. The perlite is obtained from a plant operated by the Great Lakes Carbon Company and located at Torrance, California.

The Normac plant is located at Puente, and had a capacity of 4 complete houses per day in 1947 with each house requiring about 36 slabs. This included all interior and exterior walls and roof. Houses were available in a variety of different designs.

In 1947 each house, having a floor area from 600 to 1140 square feet, was erected complete with all plumbing, lights, etc., and a two car garage for from $5200 to $9200. This price applied for medium to large housing projects.

Lightweight Precast Panels

A west coast firm, Buttress and McClellan Incorporated of Los Angeles has developed a process in which wall panels and other precast units, such as roof slabs, beams and rigid frames are poured horizontally using low curb-like forms.[97] These units are poured at the job site, often using pumice as an aggregate, and erected with a crane. Panels are troweled or broomed for the desired finish.

Steel plates are incorporated on the edge of the wall slabs for welding to steel columns or to each other, and dowels are left protruding from the edges of the panels if concrete columns are to be used. All joints are grouted after erection.

Using this precast method for standard buildings, wall costs are estimated at $.75/sq. ft. as compared to $1.10/sq. ft. for brick or $1.35 - $1.50 for poured concrete.

On a standard warehouse building of about 10,000 sq. ft. and of truck height with average lighting, plumbing, painting and a wood roof, the quotation is $3.75/sq. ft., which can be reduced to $2.80 sq. ft. on jobs of 40,000 to 50,000 feet; with a concrete roof, quotations are $4.50 to $3.00.

Concrete - Gypsum Precast Units

In the construction of a new nylon plant at Chattanooga, Tennessee, the du Pont Company used a precast - gypsum concrete unit for the wall construction at a cost comparable with that of brick.[96] The wall consisted of a 4" core of gypsum block between concrete facings, and strengthened with a light perimeter bar mesh.

The inside walls were poured on Kraft-paper laid on concrete. The concrete was poured with zero slump and the steel mesh vibrated into place. The pre-wetted gypsum tile was next laid on this slab and the outside of the slab poured. A finish coat of grout ¼ inch thick was hard steel troweled in place, the edges tooled, and the surface textured with a hair pushbroom. The panels were then cured for 7 days under wet blankets. The finished panels weighed 65 psf and averaged 80 square feet in area. Under ideal conditions, one crew placed 2700 square feet in one day.

The finished building has a very pleasing appearance with very good insulating qualities.

WHOLE HOUSE CASTING

Pouring Concrete Houses in A Big Way

The need for large scale housing units in the war and post-war eras started a lot of wheels turning in the heads of a lot of engineers; the outcome--a lot of ideas, some good, some not so good.

What was actually needed was a quick, cheap, efficient method of furnishing substantial, adequate housing facilities; and fulfilling these requisites on a competitive basis. Of course, for some time there were almost enough of these jobs to go around, so the competition wasn't too keen. However, a smart contractor is always looking toward the next job, and usually from a competitive angle. Besides, there is always present the incentive to cut down on costs of a job already under contract, that is, insofar as specifications will allow.

As lumber began to get scarser and poorer, many sections of the country turned to the use of masonry units for cheaper and faster house erection. Concrete blocks came into use rather extensively until the block plants got behind, and bricklayers became scarser. Monolithic house pouring then appeared, employing the use of various sized panel forms that could be moved from house to house. However, the erecting and stripping of these forms still required considerable time and labor. Precast units were the next phase of economy, although considerable labor was still involved in their production, transportation, and erection.

The engineers of R. G. Le Tourneau Inc., a large contracting firm of large construction equipment, came up recently with a rather large idea for the erection of housing units on a large scale. A similar idea was introduced by the Callan Builders, Inc., a contracting firm of Port Washington, Long Island. These two ideas appear to be the ultimate in the large scale mass production of housing units. A discussion of each of these methods follows.

The Le Tourneau House

The Le Tourneau method of house building has been employed for several years. The method consists of pouring a housing unit into large steel forms located at the batching plant directly under a concrete shute, and transporting the entire finished unit in one piece to the proposed building site. A specially designed vehicle has been built to carry these units, and is called the Tournalayer.

To the inner form are attached all of the necessary fixtures that are to become an integral part of the walls; this includes door and window frames as well as plumbing, and electrical appurtenances. Steel reinforcing mats are next fixed in place, and the Tournalayer then deposits the outer form over that of the inner form. The units are poured in about one hour, depending on the size. After about 16 hours, the Tournalayer picks the completed structure and the outside form up over the inside form, and carries it to the building site. Here the building is properly positioned, and the outside form picked up over the structure and returned to be placed over the inner form again for another pour. The batching plant is usually centrally located on the project, and the inner forms remain directly under the batching bin until the last house is completed, without ever being moved.

Le Tourneau forms come in various sizes for both single and double family dwellings. A typical double family dwelling consists of a 32 x 24 foot unit and an 18 x 24 foot unit, which are poured separately and connected with a corridor.

Pumice aggregate is generally used for weight saving and insulation purposes.

The Le Tourneau equipment for these projects is leased by the company on a lease-royalty basis.[110] The economic advantages are said to cover projects of 50 or more units. The Tournalayer has been used on many projects in the Southwest including the Murdoc Air Force Base,[111] Lake Murdoc, California; Los Angeles; and Corpus Christi, Texas.

The Callan House

On a 150-house project at Port Washington, Long Island, New York, the Callan Builders Incorporated of Manhasset, New York are employing large size elaborate forms for pouring complete housing units. A total of 23 forms is required to form all exterior and interior rooms, and roof gables, and chimney for a 900 square foot dwelling with a 220 square foot garage attached. The walls consist of three inch layers of concrete on either side of a one inch thickness of insulation board. The novel feature is that all windows and door frames, trim, and mouldings are actually poured of concrete in one initial monolithic unit. The forms are given a high polish and thoroughly oiled between each pouring, so that the walls can be painted or papered directly without any plaster coat required.

The inner forms are first placed on a six inch insulated, and radiantly heated floor, and anchored together. A 6 x 6 inch mesh of #6 welded wire is placed on either side of the insulation board in the wall forms. Door and window frames are additionally reinforced with ½-inch rods. Finally, the outside forms are erected and bolted to the cores through window and door openings.

The forms are then poured with ready mix concrete of a 1-2-3 mix, 5 gallons per sack, and with ½-inch maximum size aggregate. The cores are collapsible and are easily removed. Of course, the size of the units makes the use of a crane in the placing and removal of the forms imperative.

A concrete shell is built in two 8-hour days by ten men.[112] It takes four men another week to complete a home ready for occupancy. Like the Le Tourneau system, this type of house can only be built economically in large numbers. However, it was undoubtedly designed to more than pay for itself in a single project. The cost on the Port Washington project was claimed to be 30% less than for comparable houses built in the conventional manner.[113]

AIR ENTRAINMENT AND CEMENT DISPERSION

Air Entrainment

Air entrainment of concrete has been recognized and accepted for the past eight or nine years. However, the principle of air entrainment has actually been employed for about twenty years unknowingly, through the use of Portland-natural cement blends.[137] It was discovered that a blending of a natural cement with Portland cement produced a more durable pavement surface, and the mixture was adopted by the highway departments of several states. It is not known exactly what causes this greater durability in these mixtures, although it is now generally accepted that air entrainment is one of the principle factors. It has also been proposed that the surface characteristics of a natural cement are such as to favor a greater water retentivity, and hence increase the fattiness of the mix.

Other materials were subsequently found to produce air entrainment including resin, beef tallow, Orvus (sodium lauryl sulphate), stearates and other soaps, greases, and foam forming materials. As investigations became more numerous and thorough, many of these air entraining agents were dropped for the use of better and more economical substitutes.

Vinsol resin, a by-product in the naval stores industry, was probably the greatest awakener of interest in air entrainment.[137] It was discovered that small quantities added to the cement clinker to facilitate grinding caused the cement to entrain a considerable amount of air, and to be more cohesive and fatty. Vinsol resin is still used extensively today together with such other accepted air entraining agents as Orvus, and Darex (a triethanolamine salt of sulphonated hydro-carbon).

There are actually three methods of introducing air into concrete.[137] One method is the use of such substances as aluminum or hydrogen peroxide, which form gases due to a reaction with the constituents of the cement. This method has been used very little because it has not proved as effective, or economical as some other methods. A second method, is the use of a dispersing agent. Actually, a dispersing agent is capable of absorbing a comparatively small amount of air, its principle function being to disperse the cement particles. The dispersing agent will be discussed later. The third method is the use of those substances already mentioned--rosin, beef tallow, stearates, Vinsol resin, Orvus, and Darex. These substances, in general, are wetting agents or foaming agents. They absorb air by decreasing the surface tension of water, and form stable foams. It is these substances that are generally referred to when the term air entraining agent is employed, and it is these substances which will be now discussed.

For many years the advantages of air entraining agents were confined to their use in preventing scaling and deterioration of highway pavements. It is just within the past four or five years that they have become generally accepted as invaluable for use in any concrete structure. The use of air entrained concrete is probably in its most rapid stages of increase at the present time. Much progress is also being made in the further development of air entraining agents and their applications.

It is generally recognized that the durability of a concrete road surface is governed by its ability to resist not only the load and the friction of traffic, but in particular the stresses introduced by changes in temperature, with freezing and thawing being of special importance. All conventional concrete has a tendency to segregate and bleed to varying degrees depending on several variable factors, chiefly: consistency, water-cement aggregates, the degree of mixing, and method and care in placing. It is this segregation, and bleeding that is indirectly responsible for the failure of a pavement surface to withstand freezing and thawing cycles and traffic frictional wear. When bleeding occurs in a plastic concrete, minute channels are left in the interior of the hardened concrete, and provide an entrance for water at the surface. Upon freezing, the water exerts a detrimental stress on the surface of the concrete that can be further enlarged by traffic friction. The result is a deteriorated pavement.

The action of an air entraining agent on a concrete mix is to cause the mix to absorb air which becomes a part of the mass in the form of millions of tiny, even microscopic air cells distributed throughout the mix. These tiny air cells, because of their greater surface area, immobilize the free water in the plastic concrete thereby greatly decreasing bleeding and the resulting channels. The combination of fewer channels and the disconnected air cells in the hardened concrete, minimizes the opportunity for water to move into the surface. Furthermore, if some water does get into the air cells, there is space enough for ice crystals to expand, which greatly decreases the dangers from temperature change.[121]

Air entrained concrete also has greater resistance to attack by chemicals. This is again principally due to the fact that bleeding is reduced, for if the resistance of a pavement to water absorption is increased, the harmful chemicals cannot be carried by the water into the concrete pores.

An air entrained concrete has considerably greater workability and plasticity. It is thought that the air particles act somewhat like water in making the mix mobile. A reduction in the amount of water required of from ½ to 1 3/4 gallons per sack can be realized.[123]

In its application to other than its use for highway pavements, the advantages of its greater increased workability make it highly desirable. In addition, it gives a very pleasing appearence free from the streakedness and surface irregularities often inherent in a conventional non-air entrained mix. Vibration can also be cut down to a minimum.

The amount of air which is desirable to be entrained in a concrete is generally specified as from 3 to 5 percent by volume. A concrete with an air content less than this amount, begins to lose its effective properties, while a concrete containing over the specified percentage of air will begin to lose its strength with little advantageous gain in workability.

It has been found that the air entraining ability is governed by many factors other than the amount of air entraining agent present. Commenting on air entrained concrete, John Chambers, a Chicago city engineer recently stated,[126] "The advantages of air entrained concrete for scale prevention on steel paving subject to de-icing chemicals has been proved conclusively on city streets. As with other street and highway departments, however, Chicago's department of streets has experienced difficulty in controlling the air content in concrete-----." For this reason, with the air entraining agents on the market to date, it is generally considered better to add the agent at the mixer rather than purchase the cement which has had the agent already added, where the size of the job warrants the extra expense. This has been accented by the fact that different brands of air entrained cement often give different percentages of entrained air. Chicago has successfully used Darex purchased in 55 gallon drums ready to use, for air entraining purposes.[126]

It has been found that the grading of the fine aggregate has a considerable effect upon the amount of entrained air. In general, fine aggregate entrains more air than coarse aggregate.[131] However, the finer sands, particularly those passing a #100 mesh sieve, tend to serve as air entraining depressants.[126] The amount of sand in the #30 and #50 mesh class seems to have the greatest control over the actual amount of air entrained.[122] There is some conflict as to the actual effect of the grading of the aggregate on the amount of air entrained. The majority agree however, that this effect is slight if not negligible.

Temperature has a very definite effect on the ability of concrete to absorb air. A high temperature will cause a decrease in the air absorbed by as much as 2 or 3% over a range of 35 to 50 degrees F.

In the use of air entrained concrete on the building of a bridge over the Chesapeake Ship Canal, built with PCA assistance, it was discovered that the percentage of air entrained was directly affected by the temperature of the mix, type of mixer and time of mixing, porosity of the constituents, and the consistency of the mix.[128] Factors such as time of mixing in transit trucks, and type of transit-truck had no effect on the entrained air within normal time limits. It was also discovered that, using air entrained cement, in which the air entraining agent had been interground with the cement at the factory, that the control of air content was most easily accomplished by careful control of the mix consistency. For slumps of 1½ to 2 inches, the air content could be kept within allowable limits. For a 3-inch slump, the air entrainment ran as high as 2 percent over the maximum allowable. A 1½ to 2 inch slump was found to be still quite workable. Authorities of this project concluded that addition of the air entraining agent at the batching plant would have been more advisable.

The air entrained in a concrete mix causes bulking and an increased volume. This volume change makes it necessary to compensate the mix to maintain the desired cement content. Because the entrained air greatly improves the workability and increases slump, the mix is usually adjusted by reducing the sand and water contents.[121]

With the mix so adjusted, the concrete made with air entraining cement generally has a higher strength in lean concrete where a considerable reduction in sand and water can be made, and slightly lower strength in rich concrete.

At a recent ACI convention, it was stated that the approved air entraining agents reduce the strength of an average design mix by about 200 psi for each one percent of air content. A new agent was also discussed which had been tested and required only half as much water in the mix as with approved agents, with no loss in strength resulting. It was reported to be of an expansive type and being considered for approval. It was also mentioned that Vinsol resin and Darex would not corrode steel, and that these agents cannot be premixed with calcium chloride or hard waters, even though such combinations can be successfully carried out in the mixer.[129]

The decrease in the strength of an air entrained concrete is accompanied by a decrease in bond and flexural strength of the mix. These decreases are, within a reasonable degree of accuracy, about of the same percentage as the loss in compressive strength.[127]

About three years ago, an air meter was devised by W. K. Klein, a former cement company official, and Stanton Walker, director of engineering of the National Ready Mixed Concrete Association.[132] This meter has been a great aid in the determination of the percent of air entrained in a mix. It is a great improvement over the former method of computing the air content from the specific gravity of the mix ingredients and the quantity of ingredients in the mix; and a later method known as the Hook method which consisted of determining the amount of water required to displace the air in the mix.

The Klein-Walker method utilizes Boyle's Law which states that the pressure at a constant temperature varies as the volume occupied by the gas. In a concrete mix, the aggregate, cement, and water are relatively incompressible; however, the air entrapped in the concrete will be compressed according to Bayle's Law. A container of fixed volume is filled with concrete in three layers with 25 roddings of each layer. The surface is then struck off. A reservoir is clamped to the top of the bucket and filled with water to a certain height. Air is pumped into the portion of the reservoir above the water until a fixed pressure is established. The change in height of the water column indicates the compression of the air in the concrete and is read directly in percent of air meters now being produced similar to the Klein-Walker type.

It is felt that the air entrainment principle will eventually be used almost universally, to some greater or lesser degree. The air entraining agent that will finally become recognized as having the better qualities is possibly still undiscovered.

Cement Dispersion

In a mixture of Portland cement and water, the individual particles tend to group together and form flocs. This is due to a certain amount of adhesive quality possessed by the particles of which there is present no counteractive repellent force. However, if a suitable dispersing agent is introduced into the mix, the flocs will acquire like negative charges and will be repelled from each other, resulting in a well dispersed medium. This action is essentially what takes place when a dispersing agent is added to concrete.[132] In addition, a certain amount of air is absorbed at the surface of the mix; although this amount of air is generally below 3% by volume, or below the range of what are generally considered as acceptable air entraining agents.[137]

The action of dispersing agents has been known and used in other industries for many years.[132] In the tire industry for example, the dispersion of carbon black in the rubber is a very valuable action indeed, increasing the wearability of a tire many times. The dispersion principle has also been used in ceramics, dyes, paints, and other products.

It was about 19 years ago when a suitable dispersing agent for concrete was discovered.[132] This material is calcium lignosulphate, a derivative of lignin, the substance found in the cells of wood. About 500 pounds of lignin are found in every ton of wood waste.

The principle dispersing agent now being produced and used extensively throughout this and other countries, is Pozzolith, a product of the Master Builders Company of Cleveland (also Buffalo and Toronto). Pozzolith has been manufactured since 1933 and has calcium lignosulphate as a base.

Dispersion of a cement increases the effectiveness of the cement by increasing its surface area, and releases the water that is normally trapped in the colloidal groups.[137] The workability is also increased by this action, in addition to the action of the air which is entrained in the process. A reduction in the mixing water can therefore be realized. Also, due to the greater effectiveness of the cement, the strength of the mix is increased, as compared to a decrease with an air entrained concrete.

It is claimed that the percentage of entrained air in a Pozzolith mix remains fairly constant regardless of the variable conditions which normally effect an air entrained concrete.[132] Of course, a change would be less noticeable with the smaller amount of entrained air present.

It is difficult if not impossible to compare the merits of an air entraining agent, and a dispersing agent. Both are to be desired in controlled amounts, and an agent which

which would act in a dual capacity would seem to be the most desirable. The manufacturers of Pozzolith claim that their product acts in such a capacity. There are possibly other materials which are more effective, or will be when they become recognized.

Pozzolith has been mentioned in connection with its use in pumice concrete to improve the workability, and decrease bleeding in connection with the Prudential Insurance Company building in Los Angeles. Pozzolith has been used on thousands of structures[137] such as: the Matilija Dam in Ojai, California (40,000 cubic yards of concrete); the Foley Bros. Building, Houston, Texas (50,000 cubic yards of concrete); the concrete used in constructin the largest bull ring in Latin America at Sports City, Mexico; the General Motors Office, Havana, Cuba; Sears Roebuck Store, Washington, D. C.; Shamrock Hotel, Houston, Texas; etc.

Pozzolith sells for about $.15 per pound (.6 pounds being normally used to a bag of cement) or contributes about six percent to the cost of a concrete mix.

GUNITE

Gunite

Gunite is the material which is applied with the cement gun. It consists of cement and a fine aggregate (usually sand) intimately mixed with water under pressure, and applied from a nozzle under pressure.

The cement gun is a machine manufactured by the Cement Gun Company of Allentown, Pa. It consists of a hopper-like machine into which the dry mixed aggregate and cement raw materials are fed, a rubber hose through which the mixed material is forced under pneumatic pressure, and a mixing and application nozzle, where the hydration of the material takes place. The hydration is accomplished by water being forced by high pressure jets to the center of the nozzle, and the dry material passing through these streams of water.[149] The amount of mixing water is controlled at the nozzle, and can be determined by the appearance of the surface to which the gunite has been applied.[150]

The cement gun was manufactured by Carl Ackely, the African explorer, as a means of filling the inside of the framework over which his animal skins had been stretched.[151]

The cement gun was first used commercially by a few railroads in 1911 and has been employed in increasing quantities since this date. It has lately found several new uses to which it can be adapted.

A sand-cement gunite mix is usually specified in the

3:1 to $4\frac{1}{2}$:1 proportional mix class. When applied by a skillful operator, within a normal pressure range, and with the proper consistency, a 28-day strength of 6000 psi can be obtained. Gunite is generally applied in conjunction with a wire reinforcing mesh. 1940 Joint Committee Specifications have recommended practice relative to proportioning, consistency, and reinforcement design for pneumatically applied mortar mixes.

One of the principle advantages of the cement gun process is that coatings can be applied to surfaces without the necessity of form work. This advantage becomes greatly accented when the surface has an irregular shape such that a very elaborate system of form work would be otherwise required. Being applied under pressure, gunite can have a much dryer consistency, and a greater penetration ability than a conventional concrete mix. The pressure application has a tendency to produce a more dense and quite waterproof mortar, with a greater fireproofing quality than concrete of the same thickness.

The chief drawback to a gunite application is that there is a considerable loss of the material due to rebound which introduces an extra cost factor.

Gunite has been used extensively in the repair, reclamation and renovation of old concrete and masonry buildings, stacks, tanks, canals, tunnels, etc. It has also found usage in the fireproofing, insulating and waterproofing of various structures. The application of gunite directly to the soil for canals, irrigation ditches and swimming pools has proved adequate and economical.

Among the new uses to which gunite has been applied, is its use in connection with prestressed wire for concrete tanks and pipes,[90] which has already been discussed. A discussion of gunite in connection with steel panel house construction, and in dry block masonry walls will follow.

The economy of using gunite cannot be discussed in general terms. For many applications it is the only practical answer, especially in its use in connection with the repair of deteriorated stacks, dams, tunnels and other structures; in the encasement of steel; and as a coating over prestressing wires for tanks and pipes. The use of lightweight aggregate instead of sand mixed with cement may give gunite a new field of usefulness.

There are at present approximately a dozen companies which specialize in gunite work exclusively and on a large scale.[151] Two of the larger of these firms are the National Gunite Contracting Company, and the Gunite Concrete and Construction Company. Both of these companies have several branch offices throughout the country.

Steel Panel Gunited Houses

The Steel Building Units Corporation of California has developed a hydraulic loom which weaves pencil steel into structural panels for use in house erection.[142] The panels consist of two layers of steel in the form of mats consisting of 3/8-inch rods running vertically at 16-inch centers, and ½-inch rods running horizontally at the same spacing. Each mat is further stiffened with diagonals from every other joint and the two mats are welded apart with 3/8-inch spreaders at each joint. The hydraulic loom provides initial tension in the steel so that all connections are tight. An 8 x 20 foot unit can be produced every thirty minutes.[141]

The entire house is assembled using these panels, including the interior walls and the roof. The exterior wall panels are supported by pouring a 14-inch foundation wall around them, and the remaining panels are tied to these wall panels. Next, the door and window openings are cut out and the frames and the conduits are layed in place. Plywood forms are buttoned to the inside of the wall panels for a portion of the house and gunite is sprayed against these panels in three or four coats to a thickness of 5 inches. Meanwhile, the forms can be moved to another section of the house. A lightweight aggregate is used in the gunite mixture on these California projects.

The use of this type of structure has been so far limited to a few California projects, including a 100-acre subdivision east of Los Angeles known as Hugheston Meadows. However, the Steel Building Units Corporation is planning to expand their idea to other parts of the country.

This type of construction is said to cut the building time in half over conventional methods.

Gunited Dry Block Wall

A recent experiment at Dallas, Texas, may prove of a national interest.[140] The experiment was conducted by the Pittsburgh Testing Laboratories and the Southwestern Laboratories. A wall of block was laid up dry and coated with a .51-inch layer of gunite on one side and .92 inches on the other. One side of the wall was reinforced with steel mesh. Another wall was laid up with mortared joints in the conventional manner.

These walls were subjected to various test loadings. With each wall resting on two supports 42 inches apart, they were loaded with concentric loads at the top center. The plastered dry-block wall failed at 11,500#; the conventional wall at 4,400#. Each wall was also subjected to a loading in the flat position. The conventional wall failed at 2,080#; the dry laid gunite wall at 6,770#.

The tests were so successful that the city of Dallas indicated that it would approve the method, and the local F.H.A. Agency made application to its Washington office for approval. There was no economy factor mentioned, although it is assumed that the gunite method would provide a substantial decrease in cost where the size of the job warranted the use of the equipment required. The method would certainly reduce the work of the bricklayer, if not eliminate his need altogether. This could be considered an important factor considering the great shortage of bricklayers in the country today.

MISCELLANEOUS

Building Economics

Arthur J. Boase, manager of the structural and railways bureau of the PCA, Chicago, has recently presented several recommendations that will tend to yield a better concrete at a lower cost.[181] His recommendations are these:

(1) the use of air entrained concrete

(2) the use of a controlled high strength concrete

(3) proper vibration

(4) the use of mechanical floats

(5) the use of cranes

(6) the employing of skeleton framing for buildings over two stories (rather than bearing walls)

(7) the use of precast units

The World's Longest Reinforced Concrete Arch Spans

Further indicating that this country is still a follower when it comes to concrete design, is the interesting fact that there are 15 reinforced concrete arch spans in the world that are longer than the longest which the United States can exhibit.[182] The longest of these spans is the Sandoe Bridge located in Sweden. This bridge has a span of 866 feet. The longest such span in the United States is the George Westinghouse Bridge located in Pittsburgh and having a span of only 418 feet or less than one half that of Sweden's giant.

New Jobsite Concrete Testing Method

The city of Fort Wayne, Indiana uses a rather novel means of testing concrete sampled at the jobsite.[183] A sample of 500 to 3000 grams is obtained from each pour on the job and is sealed and taken to the city laboratory. The sample is tested for moisture content, and then broken down and subjected to a screen analysis. The city claims that they can obtain the 28 day strength of the concrete within 200 psi, and the water content within ½ gal/cu. yd.

The city performs these tests for all of its projects and at a fixed fee for private individuals desiring the information.

Comfort Concrete

A new concrete mix has been introduced recently to improve the softness or resiliency of concrete floors.[184] The concrete consists of an ordinary mix with some asphaltic emulsion added, and is called "comfort concrete."

Along this line, the American Bitumuls Company of San Francisco has recently introduced a colloidal asphalt concrete admix product which they have named Hydropel.[185] Hydropel is added to regular concrete in the quantity of 1½ gallons per sack.

The company claims that their product has these advantages:

(1) improved cement dispersion

(2) reduced water absorption

(3) increased shock ability or resiliency

(4) complete protection from alkaline, salt or destructive gas attack

The company claims Hydropel can be used advantageously for pavements, sewage plant structures subject to sulfide or gas corrosion, and floors of all kinds. A steel ball is said to bounce 2½ times as high on plain concrete as on Hydropel concrete, indicating its resiliency or softness.

Concrete Floors Poured in Reverse Order

A Mexican civil engineer has succeeded in developing a system for pouring concrete floors from the top down.[179] Manuel Gonzales Flores of Mexico City came up with the idea and in a practical application of his principle, a considerable degree of success was achieved.

The system was devised for pouring concrete floors for a steel frame building. The steel framework is first erected in the usual manner. Assuming a flat concrete roof, the roof forms are suspended from vertical rods which are connected in some adjustable manner to the steel framework above. After the concrete has been poured and has sufficiently set, the vertical rods are loosened and the building is lowered by enough of the rods to keep the form together. Since the rods must pass through the floor which has already been poured, wooden spools are set in the form around the rods. These spools are later removed and the holes grouted. After the form has been lowered to the position of the top floor, the rods are again secured in place, and the floor poured. The remaining floors are poured in the same manner from the top down.

The advantages of such a system are rather obvious. The same forms can be used for every floor without the necessity of tearing them down and reassembling them again. This not only saves time but it also saves on material, for the continual stripping and reassembling of forms is hard on them. Another advantage is that after the first pouring the building has been provided with a roof protecting the workmen from inclement weather. This is a particularly advantageous feature for localities that have a great deal of rain certain times of the year. The economic advantages would, of course, be limited to multi-story buildings having certain types of framing.

Reinforcing Steel in Bundles

In most ordinary reinforced concrete beam or girder designs, there is ample room in the beam to space the reinforcing steel, at the specificational separating distances required for proper bonding with the concrete, without the necessity of enlarging the size of the beam to carry this spaced steel. However, it is quite often the case, that a beam is loaded in such a manner that this enlargement becomes apparently necessary. It is in these instances that it may often be economical to locate the bars in bundles and thereby reduce the size of the beam in width and depth.[177] It is, of course, necessary to anchor each bar of these bundles firmly to compensate for the loss in bond. This extra anchorage is not always practically possible but in many cases it can be done without difficulty.

A small bridge in Whatcom County, Washington, employed bundle reinforcing and made possible the use of beams 7½ inches thick, where 11½ inches would have been required with normal spacing; a similar but smaller saving was also realized in the depth of the beam. The beam span was 60 feet.

The large scale use of bundle bars was employed in the design of the Quitandinha Hotel in Petropolis, Brazil. Reinforcing bundles were used in rigid frames of 100 foot span, over an ice skating rink incorporated with the hotel, with a considerable saving.

Heat Control of Large Concrete Masses using Ice

In 1939, in the building of seven dams for a hydro-electric plant in the Harz Mountains of Germany, it was decided to use crushed ice to counteract the heat generated during the early stages of setting. This was believed to be the first use made of ice for such a purpose.[172] The success of this project is not known.

Since the time of this early experiment, it has been definitely established that, except in an exceptionally large mass of concrete, precooling the mix with ice will keep the concrete within safe temperature limits during the setting period, and prevent shrinkage cracks.[172]

Ice is now being employed in the construction of the Davis Dam, on the Colorado River;[170] and the Fort Gibson flood control and hydroelectric dam on the Grand River near Muskogee, Oklahoma.

The Fort Gibson Dam is a $32,800,000 project and will require about 500,000 cubic yards of iced concrete. An ice making plant has been set up and consists of three machines each with a 48-inch diameter freezing unit. These units have a total daily capacity of 180 tons and furnish 135 tons of ice (2" x ½" cylindrical pieces) and the remaining tonnage of cold water for use in mixing concrete for the dam. It has been found that 162½# of ice added to each cubic yard of concrete will lower the temperature of the mix from 95 °F. to 53 °F.[171]

The refrigeration plant at the Davis Dam consists of three machines each with a 34-inch diameter freezer unit, supplying 60 tons of crushed ice per day. The ice is conveyed on belts to the adjacent batching plant and weighed for proper proportioning.

As much as 400# of ice is added to each four yard batch to keep the temperature of the concrete within limits---- 80° F when placed.[170] With the air often reaching 110° F in this part of the country, the concrete often reaches 170° F. It might be pointed out, that the ice has, of course, melted by the end of the mixing period, so that no actual ice goes into the dam as such (the effects that this would have are apparent).

These iced mixes eliminate the use of cooling pipes running through the dam, and prove cheaper and more effective.

Expanding Concrete

A French engineer, H. Lassier, claims that he has developed a cement capable of producing a controlled expansion.[175] He has published a series of articles explaining his cement in the French Journal, "Genie Civil."

The expanding cement consists of a portland cement base, sulfo-aluminate cement, and a powdered blast furnace slag. The sulfo-aluminate cement is the expanding agent, and the blast furnace slag is the stabilizing or controlling agent. Expansion takes fifteen days and requires moist curing for this period.

The effect of the expanding agent on the reinforced concrete is to place the reinforcement in tension and the concrete in compression, or sort of a self induced pre-stressing effect. This action decreases the diagonal tension considerably and increases the strength of the slab to as much as 1000 psi in 60 days in actual tests made.

The expansion is caused by the growth of the sulfo-aluminate crystals, which are usually needle shaped. It remains to be proved that this reaction can be adequately controlled to prevent continued expansion on extensive weathering, which would have disastrous effects on the strength of the concrete. However, it is definitely a thought worth mentioning.

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