MISSISSIPPI
STATE GEOLOGICAL SURVEY

WILLIAM CLIFFORD MORSE Ph.D.
Director

BULLETIN 61

LIGHT-WEIGHT AGGREGATE

GEOLOGY

by

WILLIAM CLIFFORD MORSE, Ph. D.
STATE GEOLOGIST

TESTS

by

THOMAS EDWIN McCUTCHEON, B. S., Cer. Engr.
BERNARD FRANK MANDLEBAUM, B. S. E.

UNIVERSITY, MISSISSIPPI
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MISSISSIPPI GEOLOGICAL SURVEY

COMMISSION

STAFF

LETTER OF TRANSMITTAL

Office of the Mississippi Geological Survey

University, Mississippi

November 24, 1945

To His Excellency,

Governor Thomas L. Bailey, Chairman, and

Members of the Geological Commission

Gentlemen:

Herewith is Bulletin 61, Light-weight aggregate, Geology by William Clifford Morse, State Geologist, and Tests by Thomas Edwin McCutcheon, Ceramic Engineer, and Bernard Frank Mandlebaum, Chemist. It is the fruits of months of field study and intensive laboratory experimental research.

This light-weight aggregate, produced not from a mixture of raw materials but from a single rock, gives promise of becoming an important concrete building material—a material when properly sized needs nothing more than water and cement.

Very sincerely yours,

William Clifford Morse
Director and State Geologist

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LIGHT-WEIGHT AGGREGATE

GEOLOGY

WILLIAM CLIFFORD MORSE

STATE GEOLOGIST

INTRODUCTION

THE PRODUCT

Never in the history of the United States has the Nation been in such dire need of building material—for, in the war effort, the forests have been seriously depleted of first class lumber. Anticipating this post-war need, the Mississippi State Geological Survey has, for some years, been conducting research experiments on the clays of the State for light-weight aggregate for concrete, not to mention limestone for mineral wool or rock wool for insulating purposes and stone for still other natural rock products.

With the coming of peace, or rather with the cessation of hostilities of World War II, the State Geological Survey is ready to announce the perfection of a product from one raw mineral that will, with no additions other than water and cement (5 volumes of aggregate to 1 volume of cement), make a concrete of approximately half the weight of gravel-sand concrete or stone-sand concrete—a concrete that has, in addition, insulating properties and moisture resisting properties.

USES

By the use of this light-weight aggregate, water, and cement, properly reinforced horizontally and vertically, between a single course outside brick wall and an inside form, a monolithic wall (mono = one, lithic = stone) can be had that is heat and cold resisting, moisture resisting, vermin proof, fire proof, earthquake proof, and even tornado proof—a wall of a brick house that will stand through the years.

By the use of this light-weight aggregate, water, and cement, properly reinforced horizontally and vertically, between a single course outside natural stone wall and an inside form, a monolithic wall can be had that is likewise heat and cold resisting, moisture resisting, vermin proof, fire proof, earthquake proof, and tornado proof—a wall of a stone house that will last through the years.

By the use of this light-weight aggregate, water, and cement, properly reinforced horizontally and vertically, between an outside form and an inside form, a monolithic wholly concrete wall can be had that is also likewise heat and cold resisting, moisture resisting, vermin proof, fire proof, earthquake proof, and tornado proof—a wall of a solid concrete house that will last through the years. Such a wall or such a house can be sprayed with rock stucco of any color that will likewise last through the years.

By the use of this light-weight aggregate, water, and cement, building blocks of the suggested design can be manufactured that can be laid and reinforced in a wall of a larger building that is also heat and cold resisting, moisture resisting, vermin proof, and fire proof.

By the use of this same light-weight aggregate, water, and cement in the hollows of the hollow tile, and by proper horizontal and vertical reinforcing, a monolithic concrete wall can be had without the use of either outside or inside forms—a wall or a house that can be sprayed with rock stucco of any color that will likewise last through the years.

By the use of this light-weight aggregate in connection with the present excellent brick and other permanent building material of the State, a building can be had of much longer durability and of much greater comfort than those now being constructed. And the buildings thus had add to the permanent wealth of the State.

THE SOURCES

This light-weight material can be produced wholly from the Porters Creek clay or wholly from the Basic City claystone or siltstone.

In a broad belt extending across the northeast quarter of Mississippi from the Tennessee line to the Alabama line is the Porters Creek clay, long known for its lightness in weight and its pronounced conchoidal fracture. It was conceived by the members of the Mississippi State Geological Survey that this clay, practically worthless in its natural state, might be set by firing it to a certain temperature and thereby made available as a light-weight aggregate for concrete. Months of research experiments have produced not only an aggregate of light-weight but one of many other excellent qualities.

In a broken belt through mid-Mississippi, also from the Tennessee line to the Alabama line, is the Basic City claystone or siltstone, likewise long known for its lightness in weight. Long weeks of research have shown that this siltstone can also be fired to a certain temperature and likewise be made available for light-weight aggregate for concrete.

PORTERS CREEK CLAY

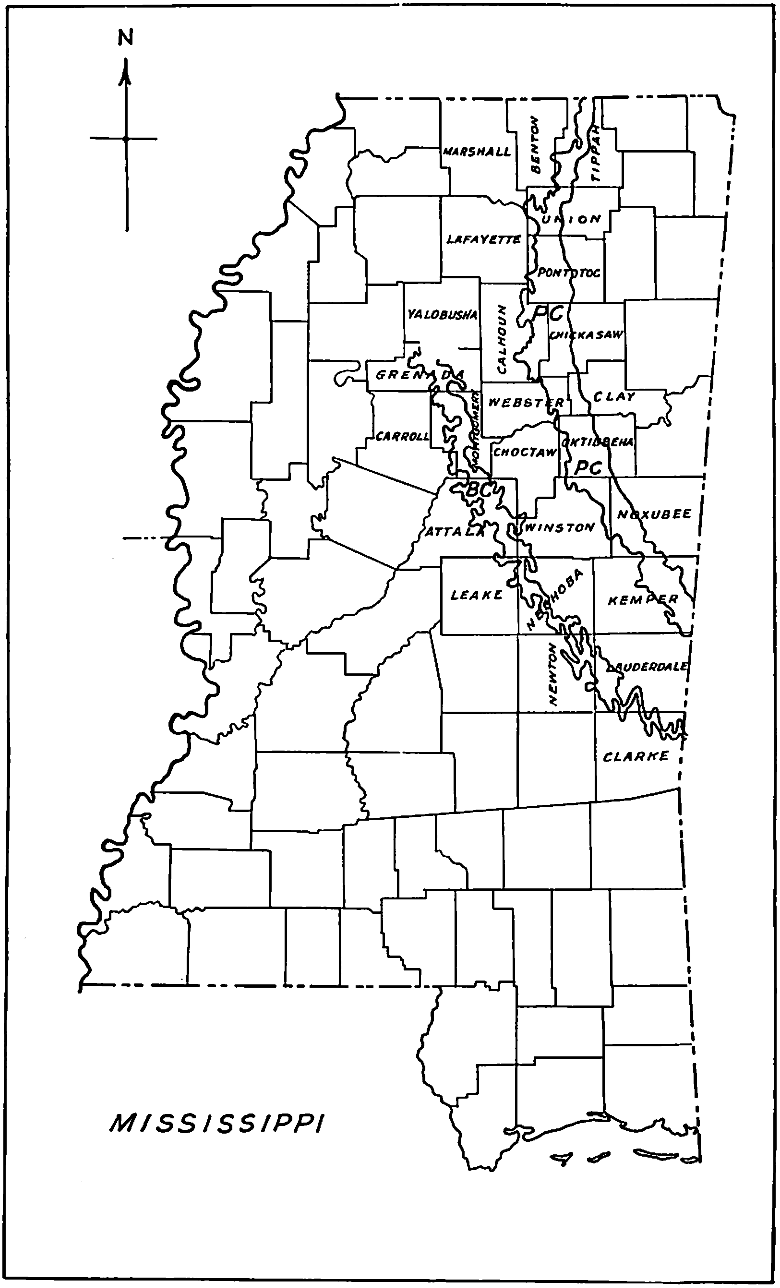
GENERAL DISCUSSION

Early known as the Flatwoods formation, because of the almost flat topography developed from it, the Porters Creek clay was later given its name from Porters Creek just west of Middleton, Tennessee, only a few miles from the Mississippi border. Here in the bluff of the creek it is exposed to a thickness of 22.0 feet, and back from the bluff to an additional thickness of 23.0 feet—and still farther it is partly exposed to an additional thickness of 17.0 to 21.0 feet.

SECTION OF THE EAST BANK OF PORTERS CREEK AT THE TYPE LOCALITY, 1.5 MILES WEST OF MIDDLETON, TENNESSEE. MEASURED JUNE 23, 1938.

	Feet	Feet
Porters Creek clay, total exposed		65.0
Clay, partly exposed, that extends 21.0 feet higher to the cabin at the south and 17.0 feet higher along the highway toward the east where the top is glauconitic. July 11 and 12, 1938	20.0	
Iron ore, hematite from siderite nodules	1.0	
Clay, broken up by weathering processes	22.0	
Top of bluff		
Clay or shale, very dark, which breaks by means of a conchoidal fracture and which is carbonaceous	22.0	
Water level of Porters Creek		

As previously stated, the Porters Creek clay extends across the northeast quarter of Mississippi from the Tennessee line to the Alabama line. Throughout that long belt much of the Porters Creek is a clay without distinct bedding but with a definite conchoidal fracture. Its presence is usually indicated by the nearly level topography developed from it—perhaps as much so by the well-nigh impassable wet weather roads native to the area.



Map 1. The Porters Creek (PC) belt and the Basic City (BC) belt in Mississippi.

Throughout that long belt, too, the Porters Creek clay, especially some parts of it, is characterized by its lightness in weight—low specific gravity—a quality perhaps due to tiny pores inherent in the clay. By firing the clay to a temperature below the fusion point these tiny pores are preserved and at one and the same time the raw clay is set—in short it is burned to a hardened condition just as the clay in a green brick is hardened on firing or burning.

Although the clay is light in weight throughout the whole belt, in some places it is lighter than at many others. One such place is in a high steep bluff along Tippah Creek in western Tippah County some 3 or 4 miles northwest of Ripley. Here on the Kate Davis place, Sec. 4, T. 4 S., R. 3 E., is one of the best natural exposures in the State. Here half ton and ton samples were obtained without excavating. Unfortunately, the exposure is some 4 miles from the nearest paved highway and railroad, the Gulf, Mobile, and Ohio.

SECTION OF THE EAST WALL OF TIPPAH CREEK, MEASURED OCTOBER 27, 1934.

	Feet	Feet
Porters Creek clay		50.0
Clay, bluish gray, having conspicuous conchoidal fracture and slightly developed bedding planes, to base pit, which is 2.0 or 3.0 feet above the flood plain	50.0	

The bluff pit, from which two car loads of clay were shipped for oil purification purposes by George L. Stephenson of Michigan City, has a nearly vertical working surface 50 feet high and 310 feet long. Hand Sample 9 of October 27, 1934. Ton Sample PC of November 11, 1943.

LOCAL DETAIL

In undescribed thinner outcrops, the Porters Creek clay is exposed along the Gulf, Mobile, & Ohio Railroad and State Highway 15 at numerous places north of Ripley and at a number of places farther north even to the Tennessee line. Between the railroad and the highway at the place where the old and the new highways join a mile north of Ripley an interval of 6.0 feet of the Porters Creek clay (Sample A) is exposed along the joint highways. At this place perhaps an interval of 8.0 feet of clay lies above drainage, and perhaps the overburden does not exceed 2.0 feet. Approximately 2.0 miles north of town and 0.5 mile west of the railroad, the clay is exposed in a ditch along an old road on the Sid Hall property. Here, Sample B was taken from 10 feet in the lower part without extending to the base of the exposure, and Sample C was taken from 15 feet in the upper part without extending to the top of the exposure. The exposed clay, by virtue of its position in a broad shallow col between a westward-flowing creek and an eastward-flowing creek, has only a foot or two of overburden.

Toward the south, the Porters Creek clay extends across Union, Pontotoc, Chickasaw, Clay, Webster, Oktibbeha, Winston, Noxubee, Kemper, and Lauderdale Counties, and even along the border of still other counties. Throughout this extent, the clay is light in weight, as tests of samples from a number of places reveal, but not necessarily so light as at some of the places previously mentioned.

In Chickasaw County, in State Highway 15 cut, 0.4 mile east of Woodland and 0.4 mile south of town, fresh and weathered clays are exposed.

SECTION OF HIGHWAY 15 CUT AT WOODLAND, MEASURED MAY 3, 1945

	Feet	Feet
Porters Creek clay, total exposed		23.5
Clay, weathered dark, having a conchoidal fracture	4.5	
Clay, fresh dark, having typical Porters Creek conchoidal fracture. Sample 5	9.0	
Clay, weathered, extending down to the valley level	10.0	

In Clay County, in the Montpelier-Mantee State Highway 46 cut at the road forks 5.0 miles east of Mantee, the Porters Creek clay is exposed along the road ditch.

SECTION OF STATE HIGHWAY 46 CUT, 5.0 MILES EAST OF MANTEE. MEASURED AUGUST 31, 1945.

	Feet	Feet
Porters Creek		8.0
Clay, thickness undetermined		
Clay, dark. having a conchoidal fracture. Sample 9	8.0	
Clay, thickness undetermined		

In Webster County, in the cut along the Gulf, Mobile, & Ohio Railroad at Pole 264, 1.5 to 2.0 miles north of Cumberland, the Porters Creek Clay is exposed along the tracks.

SECTION OF RAILROAD CUT NEAR CUMBERLAND. MEASURED MAY 3, 1945.

	Feet	Feet
Porters Creek clay		15.0
Clay, weathered	6.5	
Clay, dark, somewhat stratified and somewhat conchoidal. Sample 6	8.5	

In Oktibbeha County, along old State Highway 82 at the east wall of Trim Cane Creek, the Porters Creek clay is exposed in the road ditch.

SECTION ALONG OLD STATE HIGHWAY 82 AT TRIM CANE VALLEY. MEASURED AUGUST 30, 1945.

	Feet	Feet
Recent		2.0
Overburden	2.0	
Porters Creek clay		6.0
Clay, having a conchoidal fracture and containing a white precipitate along vertical joints. Sample 7. To the base of the poor exposure, but not to the valley level	6.0	

Also in Oktibbeha County, in State Highway 12 cut, parallel with the Illinois Central Railroad, at Bradley, the Porters Creek clay is excellently exposed.

SECTION OF STATE HIGHWAY 12 CUT AT BRADLEY. MEASURED MAY 4, 1945.

	Feet	Feet
Overburden		7.0
Massive material	7.0	
Porters Creek clay		18.0
Clay, dark shaly	4.0	
Clay, dark, having a conchoidal fracture. Sample 4	9.0	
Clay, dark, extending farther down toward the valley flat	5.0	

In Noxubee County, in a shallow cut in State Highway 14 at the Winston County line, the Porters Creek clay is poorly exposed.

SECTION OF HIGHWAY 14 CUT. MEASURED MAY 5, 1945.

	Feet	Feet
Porters Creek clay		9.5
Clay, black, weathered	4.0	
Clay, black, having a conchoidal fracture—all rather badly weathered. Sample 1	5.5	

In Kemper County, in a highway ditch parallel with the DeKalb & Western Railroad at the Gulf, Mobile, & Ohio Railroad Station at Sucarnochee, the weathered Porters Creek is exposed for some distance.

SECTION OF THE HIGHWAY DITCH AT SUCARNOCHEE. MEASURED MAY 5, 1945.

	Feet	Feet
Porters Creek clay		22.0
Clay, weathered	5.5	
Clay, black, having a conchoidal fracture and containing iron concretions. Sample 2	16.5	

Also in Kemper County, in U. S. Highway 45 cut 1.5 miles south of the Highway over-pass over the Gulf, Mobile, & Ohio Railroad at Sucarnochee, the Porters Creek clay is well exposed.

SECTION OF U. S. HIGHWAY 45 CUT. MEASURED MAY 5, 1945.

	Feet	Feet
Porters Creek clay		14.5
Clay, weathered	5.5	
Clay, dark, having a conchoidal fracture. Sample 3	9.0	
To the base of the exposure but not of the clay.		

The Porters Creek clay Sample 8 was taken from the same place about four months later.

PHYSICAL PROPERTIES

As previously stated, one of the most characteristic features of the Porters Creek clay throughout its outcrop belt from Tennessee to Alabama is its low specific gravity, its lightness in weight, its most valuable property. Whereas limestone, one of the common coarse aggregates for concrete, weighs about 165 pounds to the cubic foot, the calcined (1800°F.) Porters Creek clay weighs as little as 67.4 pounds to the cubic foot. At only three places does it attain 100.0 pounds or slightly more. At these places of greater weight, the increase is probably due to fusion and shrinking of the impure clay. Although the clay is lightest in northern Mississippi, especially in Tippah County, there seems to be no logical reason why places in the middle and southern parts of the belt may not be found where the clay is as light as at any place thus far studied.

TABLE 1

PORTERS CREEK CLAY PHYSICAL PROPERTIES AFTER FIRING TO 1,800°F.

County, Location, and Sample No.		Bulk Specific Gravity	Weight Cu. Ft.
Tippah, Tippah Creek	PC	1.10	68.5
Highway 15	A	1.08	67.4
Col	B	1.12	70.0
Col	C	1.08	67.4
Chickasaw, Woodland	5	1.537	95.2
Clay, Montpelier	9	1.44	90.0
Webster, Cumberland	6	1.517	94.5
Oktibbeha, Trim Cane	7	2.05	128.0
Bradley	4	1.440	90.0
Noxubee, Line	1	1.483	92.5
Kemper, Sucarnochee	2	1.720	106.6
Highway 45	3	1.607	100.0
" "	8	1.39	86.6

BASIC CITY CLAYSTONE OR SILTSTONE

GENERAL AND LOCAL DETAIL

In a broken belt through mid-Mississippi, early known to extend from the Tennessee line to the Alabama line (though later erroneously restricted to the part of the belt from the Mississippi River Bluffs to the Alabama line by some members of the U. S. Geological Survey and the State Geological Survey), is the Basic City claystone or siltstone (Tallahatta), long known for its lightness in weight.

The Basic City claystone or siltstone derives its name from the village of Basic (rhymes with classic), where, in one of the arcs about Meridian, it has its greatest development. Here in a cut of both the Southern and the Gulf, Mobile, & Ohio Railroads one-half mile north of Basic Station, it has long been exposed and frequently studied.

SECTION OF THE RAILROAD CUT AT BASIC. MEASURED NOVEMBER 29, 1924

	Feet	Feet
Basic City claystone or siltstone		42.0
Quartzite, largely pure sand south to a joint plane, beyond which is typical claystone, slightly sandy. There seems to be a change in sedimentation as well as in cementation for some unknown reason	15.0	
Claystone, shaly to thin bedded, in alternate hard layers and soft beds, the hard ones slightly sandy	18.5	
Claystone, nodular layer of indurated	1.5	
Claystone, partly indurated to shaly; fossiliferous	2.9	
Claystone, indurated sandy	2.5	
Claystone, sandy, to railroad ditch	1.6	

Above the section, blocks of quartzite extend up the hill 5.0 feet, and blocks of slightly sandy claystone 10.0 feet. It is this Basic City quartzite that was erroneously correlated with the Kosciusko quartzite at Kosciusko and farther north.

The more recent, nearby cuts along U. S. 11 Highway have laid open the Basic City siltstone to a greater thickness—revealing a total of 70.0 feet or more. Here, as in the Railroad Cut, the claystone or siltstone is light in weight.

Northwest along the line of outcrop, the Basic City claystone or siltstone is not so typically developed. In Grenada County the claystone is interstratified with chocolate shales and sands and loses much of its typical character, so much so in fact that the whole section is grouped together as undifferentiated Tallahatta.

Still farther north in western Lafayette County the Basic City siltstone or claystone is either more fully developed or more fully preserved—and more nearly typical. Here a thick interval of some 30 feet of it has been laid open in the Monolithic Paving Company quarries (Sec. 16, T. 9 S., R. 4 W.) where it was produced for road metal under the trade name of "Monolithic." Here, too, it is most accessible in quantity and freshness for laboratory research experiments.

SECTION OF THE MONOLITHIC PAVING COMPANY QUARRY

	Feet	Feet
Recent		5.0
Covered	5.0	
Winona		5.0
Sand, reddish brown	5.0	
Contour 460 feet.		
Basic City		64.0
Siltstone, light-weight, light color, partly mottled with iron stain. Quarry stone. Uneven base	32.0	
Sand, brown	22.0	
Siltstone shale, light-weight, light color, "paper shales"	10.0	
Undetermined		6.0
Interval covered to valley bottom	6.0	

This same Basic City claystone or siltstone has been laid open in an extension quarry across the small valley from the original quarry. Although the siltstone and claystone is variable from place to place, the extension quarry exposes a similar section. Here a representative sample, BC, was taken from the whole face, although the laboratory tests later showed that some of the material differed from the typical stone.

PHYSICAL PROPERTIES AND USES

As previously stated, one of the most characteristic features of the Basic City claystone or siltstone is its lightness in weight wherever it is typically developed, as, for example, at different places from Lafayette County to the Alabama line. Typical siltstone or claystone from the readily accessible Monolithic Paving Company quarries when calcined (fired to 1800°F.) has a bulk specific gravity of 1.12 and a cubic foot weight of 70.0 pounds. When calcined, therefore, the siltstone or claystone has practically the same light weight as the calcined Porters Creek clay and has other similar physical properties.

The siltstone or claystone in Lafayette County is, therefore, a valuable light-weight aggregate for concrete—and perhaps it is likewise valuable in other counties.

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LIGHT-WEIGHT AGGREGATE

TESTS

THOMAS EDWIN McCUTCHEON

BERNARD FRANK MANDLEBAUM

INTRODUCTION

The first study of light-weight aggregate made from the Porters Creek clay was begun in 1939 during the regular mineral survey of Tippah County. The results of this preliminary investigation were published in 1940 in Bulletin 42. The Tippah County survey revealed the existence of large deposits of light-weight clay in the Porters Creek formation that, when burned and crushed into aggregate, would make a unique light-weight concrete.

The present investigation is a more extensive study of the Porters Creek clay as a burned light-weight aggregate and its application in insulating concrete, concrete block, mortar, and plaster. Special attention has been given to the strength and insulating properties of the new products and comparisons have been made with sand and gravel concrete and concrete made from Birmingham bloated slag. A new design for concrete block is suggested which will permit semi-monolithic construction with individual units and without wood or metal forms.

A parallel study of the Basic City claystone as a light-weight insulating aggregate is included in this report.

The new products proposed are not suggested as a substitute for existing building materials of well known qualities and applications but as new materials giving permanence as well as comfort to homes and other buildings. Each common building material has its application and limitation in the building industry. Insulating concrete and allied products seem destined to take their place along side the better known products. They, too, have their limitations which have been considered as well as their most effective application.

RAW MATERIALS

PORTERS CREEK CLAY

PROPERTIES AND CHARACTERISTICS

The light-weight clay is gray buff to dark gray in color. There are no bedding or lamination planes in lumps of the clay, the distinguishing feature between the light-weight clay and the heavier laminated clays of the silty and bentonitic phases of the Porters Creek clay. It is further characterized by its conchoidal fracture, semi-concentric cleavage, and occasional thin localized micaceous silt laminae, and, when dry, its levity. The clay is hard and tough when dry and is a network of sub-microscopic pores which are not appreciably altered on burning. The freshly mined clay contains up to 40 percent water. On air drying at normal room temperatures over a period of several months, the clay still contains 10.75 percent moisture, which is lost at 110°C. An additional 4.89 percent moisture and water of hydration is lost on burning. The loss of such water on drying and burning with the ordinary variety of clay is accompanied by volume shrinkage of the mass which is to some extent proportional to the volume of water lost. The unique characteristic of the Porters Creek clay is that its loss of water on drying and burning is not accompanied by a corresponding volume shrinkage. As a result, a unit volume of heavy wet clay after drying and burning is lighter in weight by virtue of loss in weight (moisture). On drying and burning the space occupied by water in the clay becomes open pores which accounts for the levity and insulating property of the aggregate.

The Porters Creek clay used in this investigation consisted of approximately a ton sample (PC) delivered to the laboratory by W. C. Morse. The chemical analysis of the clay is as follows:

Ignition loss	4.89	Iron, Fe_2O_3	4.45	Magnesia, MgO	2.16
Silica, SiO_2	76.64	Titania, TiO_2	0.53	Alkalies, Na_2O, K_2O	0.11
Alumina, Al_2O_3	10.42	Lime, CaO	0.48	Manganese, MnO_2	Trace

The bulk specific gravity of the clay when dried at 110°C. is 1.125.

BASIC CITY CLAYSTONE

PROPERTIES AND CHARACTERISTICS

The claystone is light gray to pink and tan in color. It breaks with a conchoidal fracture and has to some extent semi-concentric cleavage planes, but they are not so pronounced as in the Porters Creek clay. The material contains some clay but is principally crypto-crystaline silica. It is non-slaking, and selected lumps of it have been subjected to 12 cycles of freezing and thawing tests under saturated conditions without effect.

Freshly mined claystone contained 24.1 percent water when dried at 110°C. An additional 4.37 percent moisture and water of hydration is lost on burning. The light-weight quality of the claystone, like that of the Porters Creek clay, is attributed to its porous structure which is not appreciably affected by drying and burning.

The claystone used in this investigation was collected by the authors from the pit of the Monolithic Paving Company in Lafayette County. An effort was made to obtain an average sample, but in so doing the better quality of claystone was mixed with some which on burning had a chalk-like structure. The soft material was easily disintegrated during the soundness tests and is believed to have caused the generally lower crushing strength values than might have been obtained from selected claystone.

The chemical analysis of the average sample is as follows:

Ignition loss	4.37	Iron, Fe_2O_3	3.13	Magnesia, MgO	1.20
Silica, SiO_2	79.69	Titania, TiO_2	0.64	Alkalies, Na_2O, K_2O	0.20
Alumina, Al_2O_3	10.12	Lime, CaO	0.28	Manganese, MnO_2	None

The average sample has a bulk specific gravity of 1.23.

AGGREGATES

PREPARATION AND PROPERTIES

DRYING AND BURNING

The moist clays in lumps were dried and burned in one operation by placing the materials in a ventilated muffle kiln and heating slowly for the first few hours and then rapidly to the final temperature of 1800°F. The operation required about 10 hours for firing which included holding the temperature at 1800°F. for an hour. This method of drying and burning was dictated by the available equipment, is expensive, and is not to be compared with commercial procedures. The optimum temperature of burning was determined by a series of preliminary tests on material burned at 1400°F., 1600°F., 1800°F., 2000°F., and 2200°F. At 1800°F. there was good development of color, hardness, and strength. The improvement at higher temperatures was not sufficient to justify the cost of higher temperature burning in commercial operations. The alteration in porosity between 1800°F. and 2200°F. was less than 2 percent.

The Porters Creek clay burned in the muffle kiln under oxidizing conditions was salmon-pink in color and is the material used in the concrete specimens on which most of the data in this report were obtained. A second sample was burned in an open kiln under slightly reducing conditions which produced a buff color. Comparison tests were made on the buff material.

CRUSHING AND SCREENING

The burned clays were crushed in a No. 2 jaw crusher which on the first setting produced aggregate having a maximum size of 3/4-inch. The aggregate from the crusher was passed over a 3/8-inch screen. The material remaining on the screen was recrushed in the jaw crusher at a closer setting to pass the 3/8-inch screen. A portion of the—3/4, + 3/8 aggregate was reserved for use as large aggregate. The material passing the 3/8-inch screen was passed over a 16-mesh screen. The residue retained on the screen was reserved for medium aggregate and the portion passing the 16-mesh screen was reserved as fine aggregate. Some of the fine aggregate (—16 mesh) was further screened on a 60-mesh screen to remove dust and this fine aggregate was reserved as fine-dustless. The remaining —60- mesh material was reserved for use in mortar, plaster, and some of the concrete tests.

A crushing and screening test of 400 pounds of material produced 58.84 percent that passed a 3/8-inch screen and was retained on a 16-mesh and 42.16 percent that passed a 16-mesh screen.

A screen analysis of the aggregates combined in the proportions produced is as follows:

Screen	Percent
On 3/8	0.00
Through 3/8 on 1/4	11.60
Through 1/4 on 10	29.60
Through 10 on 30	33.83
Through 30 on 80	14.00
Through 80 on 200	4.45
Through 200	6.78

The system of crushing and screening employed was designed to produce as little of the dust size material as possible. In so doing a deficiency of sand size (—30 + 80-mesh) particles resulted. In one series of concrete tests a higher proportion of sand size aggregate was used. This was produced by grinding the medium size aggregate in a burr mill and screening on 60-mesh to remove the dust. More dust than fine aggregate was produced. The method was not considered a practical solution. This is one of the problems in producing a commercial aggregate in the best proportion of sizes for the production of a sound concrete. It is believed that a series of roll crushers, screens, and an oversize return conveyor to crushers would be the best system to produce sufficient fine aggregate with a minimum of dust. Having in mind that some dust would be produced regardless of the system of crushing and screening employed, a series of concrete tests was made using a substantial proportion of —60-mesh material. The dust was also used in plaster and mortar tests. It is believed that all of the dust produced in a commercial operation could be profitably utilized.

PHYSICAL TESTS

The properties of the aggregates listed in the tables below were determined from a number of large pieces (1″ x 2″ x 2″) before crushing. The results are the average of several determinations from representative samples.

	Apparent Sp. Gr.	Bulk Sp. Gr.	Absorption in Percent	Porosity in Percent
Porters Creek clay	2.42	1.075	51.02	55.30
Basic City claystone	2.15	1.12	42.75	47.55

The materials on which the physical tests were made were subjected to 12 cycles of freezing and thawing tests under saturated conditions. The first few cycles produced no apparent disintegration except to break some of the larger pieces where they were fire-cracked. At the end of the 8th cycle some of the Basic claystone specimens had broken into smaller pieces and were not further affected at the end of 12 cycles. Most of the Porters Creek specimens began scaling after the first few cycles and increased up to the 8th cycle after which the scaling was less noticeable. At the end of the 12th cycle a few of the Porters Creek specimens had disintegrated beyond recognition, the more resistant specimens had lost approximately 10 percent of their volume by scaling. The scales did not seem to disintegrate further after breaking loose. This test, designed to show the limitations of the material under saturated conditions where the specimens are submerged during freezing and thawing, is extremely severe and is not comparable to weathering conditions in building construction except where the aggregate might be misused in concrete foundation work, outside steps, or walks.

The aggregates in the proportion and range of sizes used in the concrete specimens were subjected to the regular sodium sulfate soundness test commonly employed in testing rock aggregates. The test is designed to disintegrate porous aggregate, and as a test for soundness or weathering is not considered literally applicable to porous light-weight aggregate inasmuch as concrete made from such aggregate is not intended for use in place of impervious sand and gravel concrete where the latter is better suited. The results of the test are given here to show the relative soundness of aggregates made from the Porters Creek clay and the Basic claystone. The test was made according to Standard Method T75 of the American Association of State Highway Officials. The results are for five cycles:

	Loss in Percent
Porters Creek clay, Pink	29.24
Porters Creek clay, Buff	11.35
Basic claystone	68.13

Burning under reducing conditions materially improves the Porters Creek clay aggregate insofar as this test showed. The large loss of the Basic claystone is due to the inclusion of chalk-like material in the sample.

PARTICLE SIZE PROPORTIONS

THEORETICAL AND PRACTICAL CONSIDERATIONS

Particles of aggregate are of different sizes and shapes. When compounded into concrete by the addition of cement and water, they are bonded together at their points of contact by the cement matrix. The space between particles of aggregate where there is no direct contact is known as void space. If the proportion of particle sizes is such that a large percent of void space is produced, a higher ratio of cement to aggregate will be required to produce a strong sound concrete. It is of economic importance that the void space between aggregate particles be reduced to the practical minimum by proportioning the aggregate sizes whereby there will be enough small particles to fill the void space between larger particles, thus increasing the number of cementation contacts and reducing the quantity of cement matrix which might otherwise be wasted in filling void space.

Rounded particles in the optimum proportion of sizes will pack to a greater density than plate-like particles. Aggregate particles crushed from lumps of burned clay are both rounded and flat. They are predominantly flat and angular after the first crushing operation and become rounded by further processing for reduction in size. Perfectly spherical particles of the same diameter may be theoretically packed into five geometric patterns*, having void space ranging from 25.95 percent to 47.64 percent. By the addition of spheres of four successively smaller diameters the void space may be reduced to 14.9 percent and by a further addition of fine powder the void space may be theoretically reduced to 3.9 percent. Under practical conditions it is not possible to predetermine the geometric pattern to which particles will pack. The usual arrangement of uniform-sized particles is a combination of the several systems and even with the addition of the theoretical number and sizes of filler particles it is not possible to attain theoretical density. However, a study of theoretical considerations leads to practical methods of determining the optimum sizes and proportions of the aggregate at hand that will produce a concrete with minimum void space and maximum strength when using an economical ratio of cement to aggregate.

DETERMINATION AND APPLICATION OF PARTICLE SIZES

The apparatus and method employed in determining the density and void space of various combinations of aggregate sizes are described in the appendix of this report. Dozens of tests were run, but the results of only a few determinations will be given here.

TABLE 2

SHOWING APPLICATION OF PARTICLE PACKING FOR THREE SIZES OF AGGREGATE

Porters Creek Aggregate		Bulk Specific Gravity	Void Space in Percent	
Screen Size	Percent		Amount	Reduction
—¾ + 4	100	0.686	46.6	
—4 + 16	100	0.728	43.5	
—16 + 80	100	0.759	41.1	
—¾ + 4 —4 + 16	60 40	0.794	38.2	18.0
—¾ + 4 —4 + 16 —16 + 80	36 24 40	0.90	30.2	35.2

*1937, White-Walton.

TABLE 3

SHOWING APPLICATION OF PARTICLE PACKING FOR FIVE SIZES OF AGGREGATE

Porters Creek Aggregate		Bulk Specific Gravity	Void Space in Percent	
Screen Size	Percent		Amount	Reduction
—½ + ⅜	100	0.688	47.0	
—⅜ + 10	100	0.691	46.2	
—10 + 20	100	0.710	44.8	
—20 + 60	100	0.663	48.4	
—60	100	0.825	35.6	
—½ + ⅜ —⅜ + 10	60 40	0.753	42.0	10.6
—½ + ⅜ —⅜ + 10 —10 + 20	36.0 24.0 40.0	0.784	39.0	17.0
—½ + ⅜ —⅜ + 10 —10 + 20 —20 + 60	28.6 19.4 32.0 20.0	0.804	37.6	20.0
—½ + ⅜ —⅜ + 10 —10 + 20 —20 + 60 —60	20.5 13.5 22.0 14.0 30.0	0.91	29.4	37.4

The data in the two preceding tables serve to illustrate the practical applications and the limitations of particle size proportions applied to aggregates. The limiting factor in obtaining maximum density is governed by 1) the maximum size of aggregate to be used and 2) the maximum permissible amount of very fine aggregate. It is to be noted that it was possible to obtain an aggregate density of 0.90 when using large aggregate and no dust size particles, and a density of only 0.91 when using pea size aggregate and 30 percent dust size particles (—60-mesh material).

The application of particle size proportions to concrete mixtures is further limited by the type of concrete and the available proportion of aggregate sizes. Three-quarter inch to one inch aggregate is permissible in plastic concrete mixes for use in 6-inch monolithic construction. For thin walls and concrete blocks 3/8-inch aggregate is about the maximum size. Dust size particles can be used in only limited amounts as an excess tends to weaken the cement matrix. It was found that approximately 10 percent of —80-mesh material including dust, gave higher compressive strength in concrete than the same mixture of aggregate washed free of dust. (See concrete mixes).

Some commercial light-weight concrete products derive part of their levity and insulating quality from a high percent void space resulting from the use of an aggregate of limited size range. Such products are less water resistant and have less strength than denser products made from a wider range of aggregate sizes.

One factor which has retarded the more general use of light-weight concrete and products has been their deficiency in strength compared to sand and gravel concretes and masonry made from stone and burned clay products. It is believed that a thorough study of particle size proportions applied to various commercial light-weight aggregates would improve the quality of the products and encourage a more general use of the material. Inasmuch as the aggregate made from the Porters Creek clay and the Basic City claystone are naturally light in weight, it has not been necessary to depend on artificial void space for insulation and levity. The clay aggregates when packed to maximum density in concrete mixtures compare favorably in weight and insulation value to less compact commercial products and have strengths approaching that of sand and gravel concrete when using comparable amounts of cement.

CONCRETES

PREPARATION AND TESTS

INTRODUCTION

Light-weight aggregate concretes differ in many respects from sand and gravel concretes. A study of the more common characteristics has been made to acquaint concrete workers and engineers with the new light-weight aggregate to enable them to obtain proper workability and maximum efficiency with the minimum use of Portland cement. A series of concrete mixtures has been made and tested for the purpose of showing the quality of the concretes when using several proportions of cement, various water contents (producing plastic, semi-plastic, and moist working quantities), several variations in aggregate sizes, and different degrees of compacting the concretes in forming. The method of compacting the mixture and the testing procedure are given in the appendix of this report. The explanation here, and that which follows, is intended for use in comparing the properties of the concrete compositions given in the accompanying tables.

AGGREGATE

The light-weight aggregate being less than half as dense as sand and gravel occupies over twice the volume of sand and gravel per unit weight. The concrete mixtures were made on a volume basis using the aggregates in the several sizes compacted to maximum density. It was found that the volume of concrete produced after adding cement and water was never less than the original volume ot aggregate, and, for practical purposes, the ratio of cement to aggregate on a dry basis is equivalent to the composition of the finished concrete. The job practice of mixing several volumes of gravel with the required volume of sand results in a decrease in the volume of concrete produced from the volumes of aggregate used by virtue of shrinkage caused by the sand filling voids within the mass of gravel. When cement is added to such a mixture on a volume basis the concentration of cement in the finished concrete may be one-fourth to one-third greater than on a dry basis.

A 1-6 mixture, using 1 volume of cement to 3 volumes of gravel and 3 volumes of sand, may be equivalent to a 1-4 or 1-5 ratio in the finished concrete.

CEMENT

Atlas Portland cement was used in making the concrete mixtures. The amount per batch was weighed using the manufacturers weight of 94 lbs. per cubic foot for the equivalent volume basis of measurement.

WATER

The amount of water used in the light-weight aggregate concretes is apparently abnormally high when compared to that required for sand and gravel concrete; however, the greater part of the water is absorbed by the aggregate, and it is only the excess over absorption that affects the workability and strength of the concrete. It was impractical to determine the amount of water used over that absorbed by the aggregate. The total amount used was determined by the working quality of the concrete which may or may not have been the same in all cases for what was considered a moist, semi-plastic or plastic mix.

WORKABILITY AND COMPACTION

In all cases the light-weight aggregate was first saturated in a known amount of water and allowed to soak from 30 minutes to one hour. The cement was then added and the mass thoroughly mixed adding enough additional water to obtain the proper degree of workability. The moist mixtures were those which would not show an excess of water under heavy tamping. The semi-plastic mixes would not show an excess of water under light tamping. The plastic mixes could not be heavily tamped as the consistency was that of a semi-liquid. They were rodded in the usual manner but could not be compacted because of a tendency of the mass to float. The resistance of the plastic light-weight concrete toward being compacted is the principal difference in the working quality when compared to plastic sand and gravel concretes. The heavy stone concretes will settle to a compact mass under little or no tamping and float off the excess water. In the light-weight concretes the excess water remains in the concrete producing artificial void space when the concrete has set. This characteristic may be avoided by using less water as in the semi-plastic mixes but would require more labor for tamping what would ordinarily be a poured concrete. Should the plastic light-weight concretes have sufficient strength for the purpose, it would be lighter in weight than the moist or semi-plastic mixtures and have a better insulating value.

CRUSHING STRENGTH

The crushing strength in pounds per square inch (psi) was determined by means of a 50-ton Olson machine through the courtesy of the School of Engineering, University of Mississippi. The specimen tested were 6 inches in diameter and 12 inches in height and were made in standard metal cylinders designed for the purpose. Two specimens were made for each mixture and the crushing strength is reported for each specimen when there was a difference in the degree of compaction or as the average value when the compaction was equal.

SUMMARY OF DATA

Concrete mixes 1, 2, and 3 were made from aggregate as produced by crushing large lumps to pass the 3/8-inch screen. All dust produced in crushing was used. The screen analysis is given under "Aggregates." The three mixes contained the same amount of aggregate and water; the cement content was 1-4, 1-5, and 1-6. It is to be noted from the table that the maximum strength increased over 1000 psi by an increase in cement concentration from 1-6 to 1-4, and that the minimum increase was approximately 400 psi. The maximum and minimum strength for a single mixture is attributed to the degree of compacting the concrete specimens and is reflected in the density and porosity of the finished concrete.

Concrete mixes 4, 5, and 6 are similar in every respect to mixes 1, 2, and 3 except that fine aggregate and dust smaller than 60-mesh were removed and the difference was made up with —16 +60 aggregate. The removal of the fines created a lighter weight concrete by increasing the void space and resulted in generally weaker concretes. An examination of the fractured concrete specimens revealed numerous small voids which probably could have been filled by having a higher proportion of sand size aggregate in the mixture.

Concrete mixes 7, 8, and 9 are comparable to mixes 1, 2, and 3 except in this case the water content was increased to produce a plastic concrete. The decrease in strength and density and the increase in porosity is apparent when compared to the dryer mixes 1, 2, and 3. Mix 10 is the same as mix 8 except that hydrated lime was added. The increased strength of approximately 200 psi is interesting but not conclusive without taking into consideration the added cost of lime.

Concrete mixes 11 and 12, using 3/4-inch aggregate, contained the same volume of cement and a variation in water content to produce a plastic and a semi-plastic mix. The mixtures were designed for thick monolithic construction. Mix 12 containing less water averages 200 psi stronger than the more plastic mix 11.

Mix 13 was designed to obtain a better working consistency than mixes 11 and 12. The fine aggregate was increased at the expense of the coarse. The strength of the mix is approximately 100 psi higher than mix 11 and is much lower than mix 12.

TABLE 4

COMPOSITION AND PHYSICAL PROPERTIES OF CONCRETE MIXTURES

PORTERS CREEK AGGREGATE—PINK

Concrete No.	Aggregate: Size screen	Aggregate: Percent	Aggregate: Lbs. per cu. ft. compacted	Volume Ratio: Cement to aggregate	Volume Ratio: Water to aggregate	Weight Ratio: Cement to aggregate	Weight Ratio: Water to aggregate	Concrete: Crushing strength Psi. 28D	Concrete: Lbs. per cu. ft.	Concrete: Workability and Compaction	Concrete: Porosity in percent
1	—⅜+16	60	53.41	1–4	1–1.87	1–2.28	1–1.60	2690	78.0	Moist Heavy	45.8
	—16	40						1900	73.6	Light	50.8
2	—⅜+16	60	53.41	1–5	1–1.87	1–2.84	1–1.60	1950	74.3	Moist Heavy	50.7
	—16	40						1940	73.0	Light	50.9
3	—⅜+16	60	53.41	1–6	1–1.87	1–3.40	1–1.60	1625	72.4	Semi-plastic Heavy	51.0
	—16	40						1490	70.9	Light	53.1
4	—⅜+16	60	50.23	1–4	1–1.99	1–2.13	1–1.60	2480	75.5	Moist Heavy	50.4
	—16+60	40						1540	73.7	Light	50.1
5	—⅜+16	60	50.23	1–5	1–1.99	1–2.66	1–1.60	1560	74.0	Moist Heavy	51.7
	—16+60	40						1310	72.1	Light	52.7
6	—⅜+16	60	50.23	1–6	1–1.99	1–3.07	1–1.60	1150	71.8	Semi-plastic Heavy	53.5
	—16+60	40						1120	71.2	Heavy	54.3
7	—⅜+16	60	53.41	1–4	1–1.64	1–2.26	1–1.40	2200	75.6	Plastic Light	51.5
	—16	40						2054	74.3	Light	52.6
8	—⅜+16	60	53.41	1–5	1–1.55	1–2.84	1–1.37	1623	71.5	Plastic Light	53.6
	—16	40						1613	70.6	Light	53.6
9	—⅜+16	60	53.41	1–6	1–1.72	1–3.37	1–1.47	1127	70.6	Plastic Light	53.9
	—16	40						1120	70.6	Light	54.2
10	—⅜+16	60	53.41	1–5	1–1.55	1–2.84 (Lime 1–15.50)	1–1.37	1840 Ave.	70.2	Plastic Light	53.9 Ave.
	—16	40									
11	—¾+⅜	25	56.35	1–5	1–1.63	1–3.01	1–1.47	1344	71.1	Plastic Light	53.4
	—⅜+16	38									
	—16+60	15						1243	71.5	Light	54.1
	—16	22									
12	—¾+⅜	25	56.35	1–5	1–1.77	1–3.01	1–1.60	1540	71.7	Semi-plastic Heavy	53.8
	—⅜+16	38									
	—16+60	15						1415	71.1	Light	54.7
	—16	22									
13	—¾+⅜	20	56.16	1–5	1–1.71	1–3.06	1–1.55	1456	73.6	Semi-plastic Heavy	54.6
	—⅜+16	30									
	—16+60	25						1349	70.8	Light	54.5
	—16	25									
14	—¾+⅜	20	56.16	1–4.7	1–1.77	1–2.80	1–1.60	2130	73.0	Moist Heavy	52.2
	—⅜+16	30									
	—16+60	25						1790	73.0	Light	52.8
	—16	25									

PORTERS CREEK AGGREGATE—BUFF

	Aggregate			Volume Ratio		Weight Ratio		Concrete			
Concrete No.	Size screen	Percent	Lbs. per cu. ft. compacted	Cement to aggregate	Water to aggregate	Cement to aggregate	Water to aggregate	Crushing strength Psi. 28D	Lbs. per cu. ft.	Workability and Compaction	Porosity in percent
15	—⅜+16 —16	60 40	53.41	1-5	1-1.78	1-2.80	1-1.52	1315 Ave.	73.6 Ave.	Plastic Light	53.1 Ave.
16	—⅜+16 —16	60 40	53.41	1-5	1-2.00	1-2.80	1-1.71	2295 Ave.	76.8 Ave.	Moist Heavy	50.8 Ave.
17	—⅜+16 —16	50 50	53.41	1-5	1-1.75	1-2.80	1-1.50	1423 Ave	73.3 Ave.	Plastic Light	52.7 Ave.
				BASIC CITY (TALLAHATTA) CLAYSTONE							
18	—⅜+16 —16	60 40	51.79	1-5	1-1.86	1-2.74	1-1.55	1540 1415	76.8 73.5	Semi-plastic Heavy Light	48.5 51.6
				BIRMINGHAM BLOATED SLAG							
19	—¼	100	49.92	1-5	1-2.57	1-2.65	1-2.06	878 Ave	75.0 Ave.	Plastic Light	48.1 Ave.
20	—¼	100	49.92	1-5	1-3.33	1-2.65	1-2.66	1550 Ave.	79.8 Ave.	Moist Heavy	44.8 Ave.
				SAND AND GRAVEL							
21	—¾+½ —½+⅜ —⅜+10 —16	20 20 20 40	121.06	1-5	1-3.90	1-6.43	1-7.56	2207 Ave.	133 Ave.	Plastic Heavy	19.9 Ave.

Mix 14 was intended to be the same as mix 13 but with lower water content. Through error the cement to aggregate volume ratio was made 1-4.7 instead of 1-5 giving a slightly higher concentration of cement. The large increase in strength over mix 13 is attributed to better compaction afforded by the lower water content and the higher cement concentration.

Concrete mixes 15, 16, and 17 were made from the buff Porters Creek aggregate produced by burning under reducing conditions. The ratio of cement to aggregate is the same for the three mixes.

The variation in composition is in water content, aggregate size proportion, and degree of compaction. Mixes 15 and 16 are comparable except for water content and the degree of compaction. The increase of strength by 980 psi of mix 16 over mix 15 is attributed to the lower water content and the greater compaction afforded by the dryer mix.

Mix 17 is comparable to mix 15 in the quantity of cement and water used. A higher proportion of fine aggregate was used in mix 17 to improve plastic working quality and further resulted in an average increase in strength of 108 psi.

Mix 18 represents a semi-plastic concrete made from the Basic City claystone. The physical properties of this concrete are similar to comparable mixtures made from the pink Porters Creek aggregate.

Concrete mixes 19 and 20 were made from Birmingham bloated slag, a material which has been extensively used in the south for monolithic construction and block making. The physical properties are in general similar to the Porters Creek clay and the Basic City claystone aggregate concretes except that the strengths of the slag concretes are decidedly less when using the same proportions of cement and the same degree of compaction.

Mix 21 is a sand and gravel concrete made from locally available aggregate. The amount of water used in this concrete is higher than that recommended for maximum strength; however, the amount was determined by the working quality of the plastic mass which was comparable to other plastic concretes tested and to concrete used in local building construction. The sand and gravel concrete does not represent the strongest concrete that can be made from the same materials but is comparable to the average mixture that is generally used.

HEAT CONDUCTIVITY

In residential construction, the most important advantage of light-weight concrete is its insulation value over sand and gravel concrete, stone, and brick. The importance of insulation in home construction is generally recognized. Most any type of structure can be insulated either during or after construction by means of rock wool in the case of frame buildings or by means of furring strips and insulation board in the case of heavy masonry construction. To incorporate insulation within the structure itself is the unique advantage of using light-weight concrete not only in the wall but also in the ceilings and floors. Homes, insulated after construction, are usually only partly insulated on account of the expense. Such insulation is usually applied on the ceiling from the attic, less often in or on the walls and rarely to the floor. While some insulation is better than none at all, few enjoy the advantages of complete insulation which may be obtained in post-war homes from the use of light-weight aggregate in concrete and allied products.

The resistance of a material to the passage or flow of heat is a measure of its insulation value. Materials of high insulation value resist or retard the flow of heat. The amount of heat that will flow through a material is dependent on its heat conductivity (K), which is the reciprocal of the resistance of the material to the passage of heat, its thickness, the temperature difference between the hot and cold faces, the area of the faces, and the time element involved. The quantity of heat is measured here in British thermal units (Btu) which is the amount of heat necessary to raise the temperature of one pound of water one degree Fahrenheit. On a unit basis the heat conductivity (K) of a material is the amount of heat (Btu) that will flow through a unit area (1 square foot) of unit thickness (1 inch) in a unit time (1 hour) when the temperature difference between the hot and cold surfaces is 1°F. Values for K are useful in comparing the relative insulation value of different materials. The exact value for K is difficult to obtain as many other factors enter into the determination. The values for K reported here were determined as described in the appendix. They are considered to be accurate relative values but not necessarily absolute values for the different concretes tested.

TABLE 5

INSULATION VALUES OF CONCRETES

CONCRETE MIX NO.	AGGREGATE USED	HEAT CONDUCTIVITY K
12	Porters Creek	3.171
18	Basic City claystone	3.255
20	Bloated slag	2.167
21	Sand and gravel	11.438

K = Btu/sq.ft./1 in. thick/hr./1°F.

Since the heat conductivity (K) is the reciprocal of the resistance of the materials to the flow of heat, it follows that the smaller the value for K the greater the insulation property. It is to be noted that the Porters Creek clay and Basic City claystone concretes have over three and one half times the insulation value of an equal thickness of sand and gravel concretes.

WEATHER RESISTANCE

Claims of the weather resistant quality of any new product should be conservative until such qualities have been proved over a period of time through exposure to severe weathering conditions. Laboratory tests at best should not be taken as being conclusive but an indication of common sense precautions. Any kind of porous concrete should not be expected to remain dry under saturated conditions. Neither will any porous concrete resist indefinitely the action of freezing and thawing under saturated conditions.

Even though the light-weight concretes are very porous they exhibit an unusual resistance to the capillary action of water. Block and cylindrical specimens partly submerged in water for several days were not wet above one and one half inches of the water level. A slab, made from mixture No. 12, 2 3/4 inches thick, was subjected to a flowing stream of water over one face. At the end of 48 hours the opposite face of the slab was dry and at the end of 72 hours there was no visible water on the back of the slab, but approximately 80 percent of the back surface felt damp. The test indicates that there would be little likelihood of moisture from blowing rain permeating a wall of the light-weight concrete, but that a stream of water as might be encountered from a leaky gutter or downspout could soak through the wall during a long rainy season.

Part of a light-weight concrete block made from mix 12 was subjected to freezing and thawing tests under saturated conditions. At the end of 7 cycles there was no apparent disintegration of the concrete. At the end of 10 cycles some of the aggregate had broken loose at the edges where there was poor cementation. At the end of 13 cycles the main body of the specimen was sound. The resistance of the concrete to freezing and thawing is considered good in view of its high porosity and low cement content. The test indicates that the light-weight concrete should not be used in contact with the ground or in walks and foundation work but should last indefinitely when protected from water conditions that would permit complete saturation.

CONCRETE BLOCK

TYPES AND USES

Concrete building block and tile are manufactured extensively throughout the country from locally available sand and stone aggregate, from slag, and from several varieties of light-weight aggregate. The product is probably the least expensive masonry unit available to the building trade. A wider use of the product is limited by the expense of transporting aggregate and finished block. Light-weight aggregate and light-weight block could obviously be transported longer distances for wider distribution. Although many sizes and shapes of block and tile are made for special uses the most common product is the four cell 8 x 8 x 16 inch unit.

Advocates of concrete block stress the uniformity of the product, permanence, and the speed and economy of construction. However, there are two problems which face the industry; they are an improvement in the aesthetic quality and an improvement in the strength of the finished walls. The drab cement color of the usual variety of block is unattractive. This has been improved to a certain extent by introducing mineral pigments into the concrete mixture and by painting the exposed surfaces. These treatments while effective add expense which would be unnecessary with block made of the Porters Creek aggregate in attractive shades of pink and buff.

The problem of obtaining greater strength in concrete block walls is more difficult due to the inherent weakness of cement mortar bond. Concrete workers recognize the difficulty of bonding concrete products with cement mortar. The mortar will not adhere to concrete as strongly as to stone or brick masonry. Failure of concrete block walls under severe stress, as from wind pressure, is due to the mortar bond weakness rather than the ultimate strength of the individual unit. In storm areas, as in the vicinity of Miami, Florida, the block walls are encased in a frame of reinforced concrete which adds adequate strength to the walls to withstand the strongest wind pressure encountered.

A new design in concrete block is suggested for use where great strength in walls is needed. It is called the "H" block for the 8 x 8 x 8 inch unit and the double H block for the 8 x 8 x 16 inch unit. The new design is shown in Figures 1 to 7 inclusive. It differs from the conventional block by providing a smaller number of open end cell spaces having larger volumes. The sides of the cells are corrugated to give a mechanical grip on the concrete used to fill the cell space. When the blocks are laid in the conventional manner, the large cells form continuous hollow shafts which may be completely filled to form a semi-monolithic wall or alternately filled to form a reinforced hollow block wall. A provision is also made for reinforcing steel if needed.

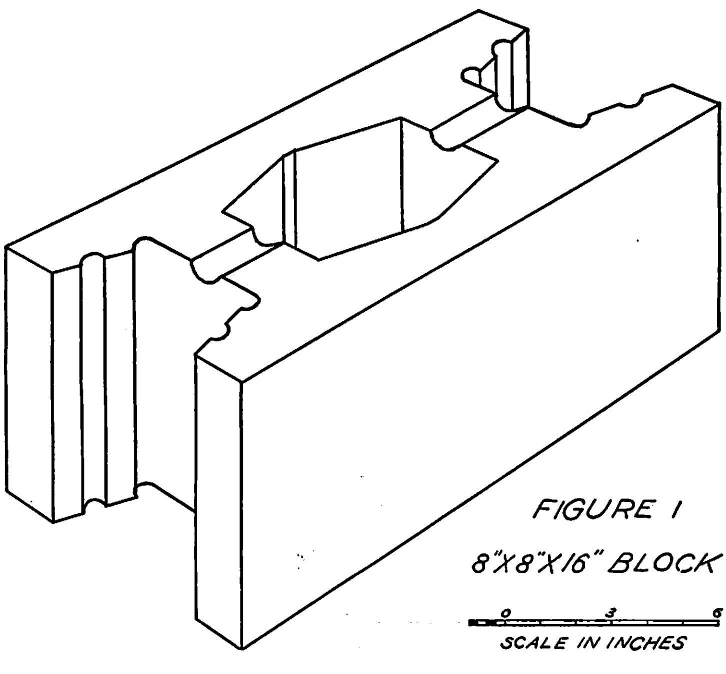

Figure 1. Double H block, perspective.

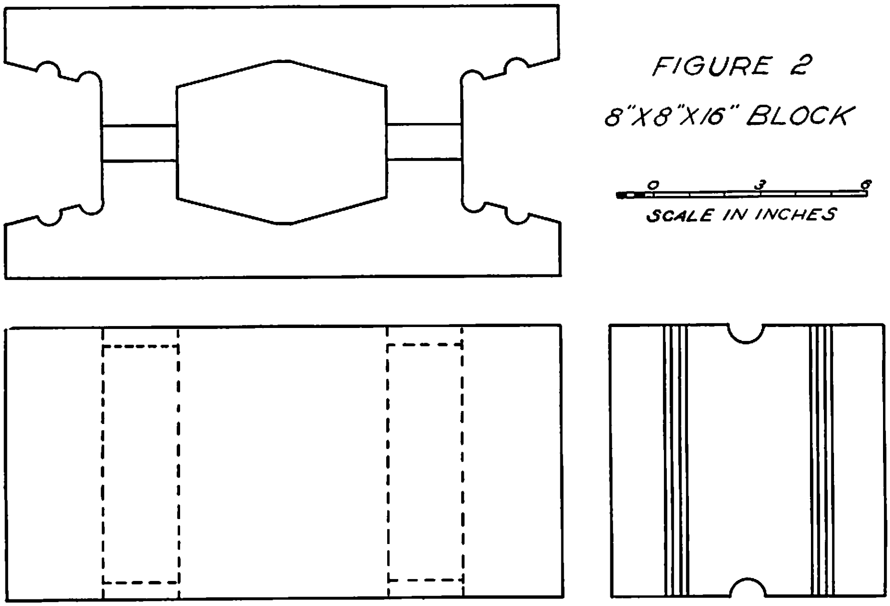

Figure 2. Double H block, detail.

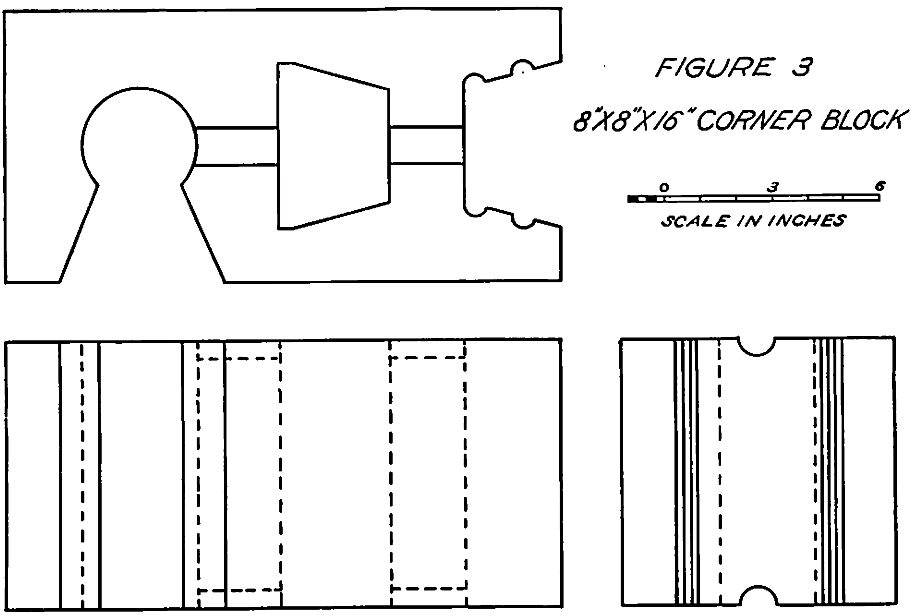

Figure 3. Double H corner block, detail

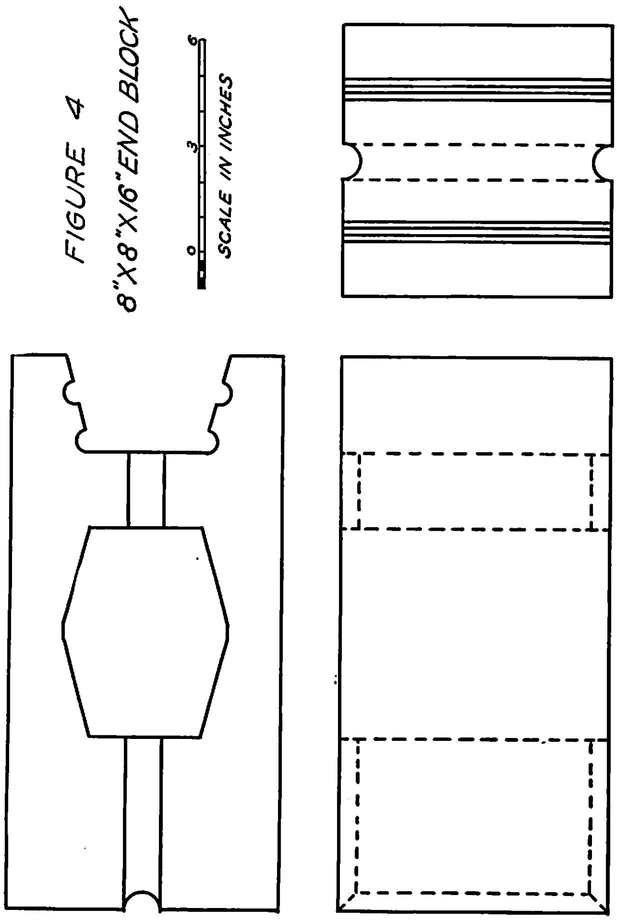

Figure 4. Double H end block, detail.

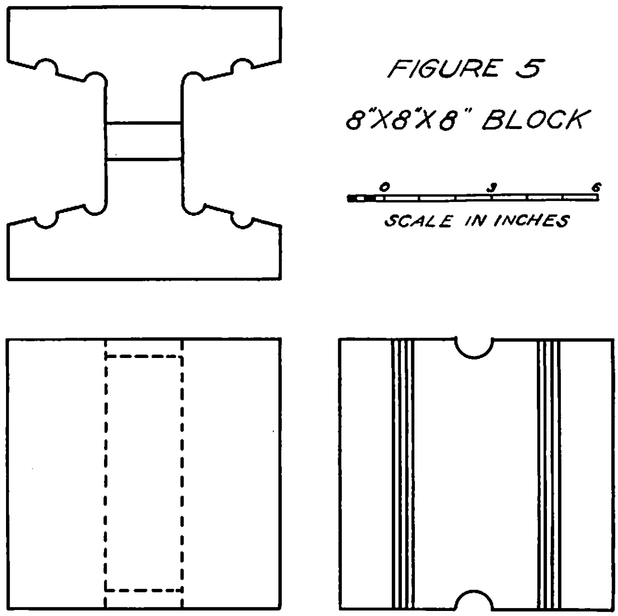

Figure 5. H block, detail.

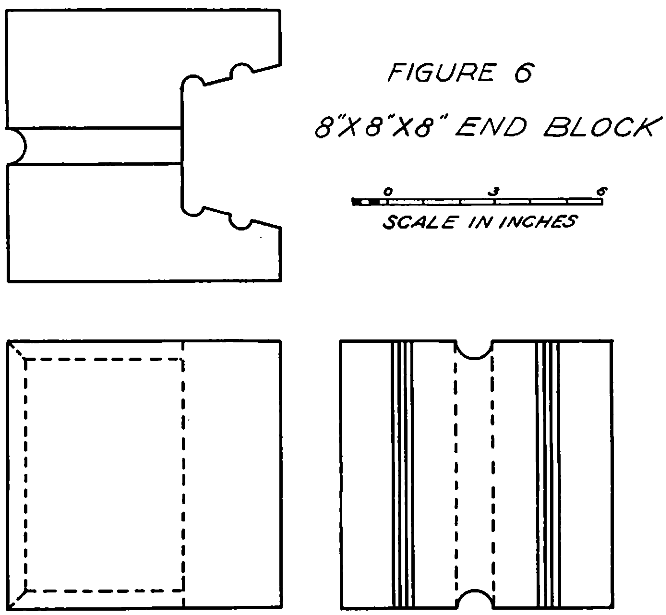

Figure 6. H end block, detail.

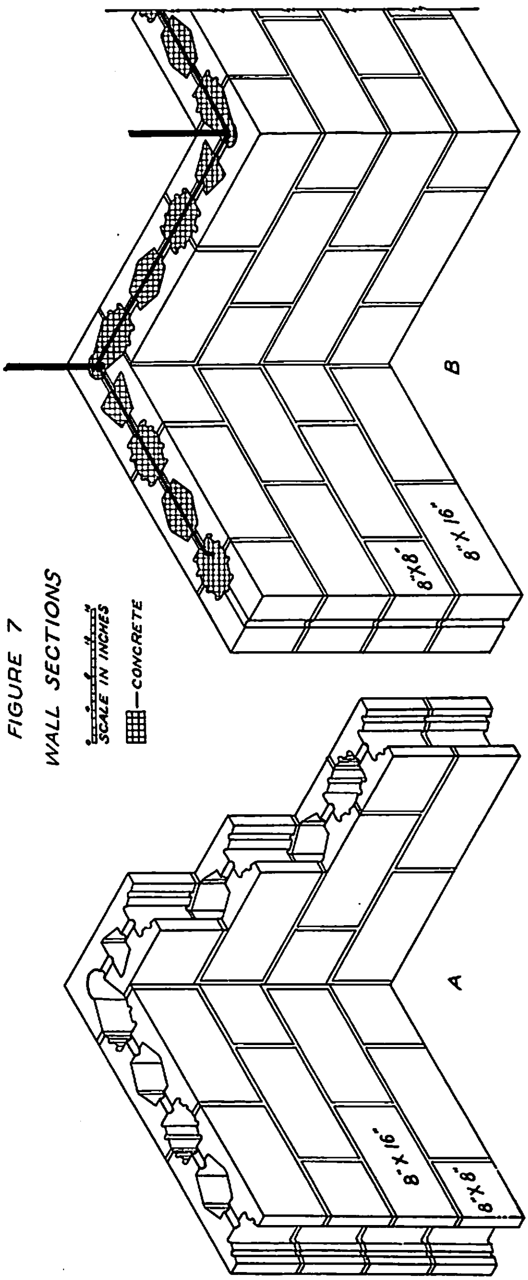

Figure 7. Wall sections, perspective.

PHYSICAL TESTS

The increase in joint strength by filling the cell spaces with concrete of the same composition as the block is shown in Figure 8 (Details of the tests are given in the appendix). Drawing A, Figure 8, illustrates the applications of side stress to the vertical joint. The conventional mortar joint failed under a load of 230 pounds, while the same type of joint after filling with concrete failed at 5,570 pounds. The increase in strength is over 24 times that of the unfilled joint.

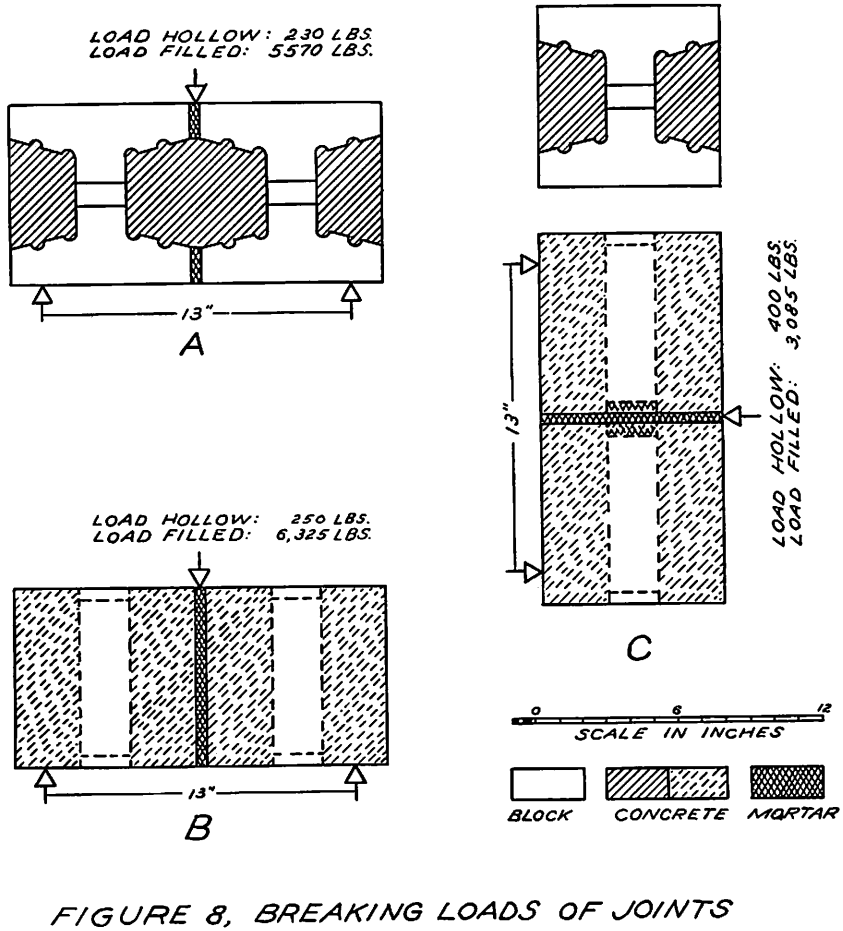

Figure 8. Joint strength of block, filled and hollow.

Drawing B, Figure 8, shows the application of vertical stress to the vertical joint. The increase in strength of the filled joint over the conventional mortar joint is over 25 times.

Drawing C, Figure 8, shows the application of side stress to the bedding joint. Here the increase in strength is over 7.5 times the unfilled joint. The increase might have been greater if it were practical to test one full cell filling instead of two half cell fillings.

Two 8 x 8 x 8 inch H blocks were tested for crushing strength with the following results:

Total Load	Gross Area	Bearing Area	Psi gross	Psi bearing
55,250 Lbs	56.25 sq. in.	33.71 sq. in.	982	1639

The concrete mixture was the same as No. 8 which was a plastic mix of pink Porters Creek aggregate of 1-5 cement ratio. The gross strength of 982 psi surpasses the minimum requirement of 700 psi. The strength of blocks made under commercial conditions where the water content is low and the compaction heavy would likely exceed 1200 psi for the gross bearing area.

PLASTER

TYPES AND USES

Plaster, in a general sense, is a composition of fine-aggregate, a cementing material, and enough water to form a semi-fluid mixture. The aggregate is usually sand and the cementing material may be Portland cement, lime, gypsum, or a combination of them plus fiber or hair. For a water-proof plaster, the usual combination is Portland cement and sand; and for stucco, lime is added. For interior use, gypsum is the most common binder. Interior plaster is usually built up of two or more layers known in the trade as the scratch coat, the brown coat, and the finish coat. The scratch coat is rich in cement and is used to obtain a bond on relatively smooth surfaces, but is unnecessary on wood and metal lath, rough concrete, and masonry, unless needed for waterproofing. The brown coat comprises, by far, the greater bulk of the plaster, because of the greater thickness needed to smooth and level rough walls and ceilings. The thickness may vary from 1/4 inch to 2 inches. The usual application is 1/2 inch to 1 inch in thickness. The brown coat consists of a mixture of gypsum and sand in the proportion of 1 to 3 parts by volume. The brown coat may serve as the finish coat, but more commonly it is covered by a thin finish coat of gypsum and lime plaster, and troweled smooth.

The primary function of interior plaster is to provide a smooth interior finish. Although it is strong enough to support its own weight for common ceiling heights, it adds little if any strength to the structure, and its dead weight must be provided for by other parts of the structure. Plaster made from sand aggregate has about the same heat insulation value and sound deadening quality as ordinary masonry of equivalent thickness.

The possibility of using fine aggregate made from the Porters Creek clay and the Basic City claystone in plaster (brown coat) offers three useful purposes other than providing an interior finish. These are: 1, an insulating material, 2, a reduction in dead load on structural parts of the building, and 3, a sound deadening material. Further, the manufacturer of light-weight aggregate for use in concrete is provided with a profitable means of disposing of surplus fine aggregate and dust produced in crushing the burned clays.

PHYSICAL TESTS

Local quartz building sand and —16-mesh Porters Creek aggregate were used to make the plasters listed in the table of physical properties. A commercial brand of fibered gypsum was used as the binder. The mixtures were in the proportion of 1 part of gypsum to 3 parts of aggregate by volume. Water was added in amounts to give the proper working consistency. Heat conductivity test slabs were formed to make insulation comparison tests and Figure 8 test pieces were made for tensile strength tests. The plasters were allowed to cure for ten days at room temperature and were then dried at a temperature of 60°C. for two days. Heat conductivity tests were conducted as described in the appendix. Tensile strength tests were made on a Fairbanks testing machine. Specific gravity determinations were made by means of a mercury volumeter. Screen analyses of the sand and the —16-mesh Porters Creek aggregate are given under "Concretes."

TABLE 6

PHYSICAL PROPERTIES OF PLASTERS.

PLASTER (BROWN COAT)	BULK DENSITY	LBS./SQ. FT. 1IN. THICK	TENSILE STR. LBS./SQ. IN.	RELATIVE HEAT CONDUCTIVITY*
Porters Creek	0.952	4.95	84.8	2.201
Sand	1.742	9.06	94.0	6.678

*Btu per sq. ft. per inch in thickness, per hour, per degree F. difference in temperature of opposite faces.

POSSIBILITIES

The Porters Creek plaster having nearly half the weight and three times the insulating value of sand plaster offers many possibilities. The decrease in strength from sand plaster is of little consequence in view of the large reduction in dead weight. As an insulating material it will retard the flow of heat through building walls and ceilings, three times as effectively as sand plaster. It would be especially effective in preventing "sweating" of solid concrete and masonry walls and would eliminate the necessity of furring strips and lath in plastering such walls where usually needed to obtain insulation and prevent the condensation of moisture. In hollow masonry and frame construction it would add to the insulating value of such walls when compared to sand plaster. In the same manner it would be desirable to use on walls and ceilings made from light-weight concrete or blocks.

As a sound deadening material the Porters Creek plaster would be particularly useful in public eating places, churches, hospitals, theatres, school rooms, and auditoriums. In office buildings, apartment buildings, and hotels, the plaster on partition walls would add to the privacy and mental comfort of tenant and guests. In the private home, it would aid in restricting bath room noises and radio reception to the immediate vicinity.

The reduction in dead weight from the use of the light-weight plaster is not very important in one-story construction but does become increasingly important in multiple story buildings by allowing lighter construction throughout. The possibility of using the plaster in pre-fabricated homes is a field of unknown potentiality but offers promise. As a filler in gypsum wall board is another possibility .

The attractive salmon-pink color of the plaster for many uses would require no further finishing or decorating.

Although tests have not been made on plaster produced from the Basic City claystone, it is believed that this material offers equal possibilities.

MORTAR

TYPES AND USES

Mortar, like plaster, consists of a fine aggregate, a cementing material, and water. The cementing material may be Portland cement, lime, or a combination of both. Natural cement is used where available. Mineral pigments may be added for coloring effects, and ground plastic clay is added to improve workability .

Mortar is used to bond masonry units in forming walls, floors, foundations, and chimneys, from rock materials as stone, brick, tile, etc. It is used as a surface coating on rough concrete floors.

Mortar, rich in Portland cement, is used where great strength is required, where waterproofing is needed, and in finishing floors. The usual masonry mortar contains a considerable amount of lime which lightens the color and improves the workability. Mortar made from aggregate and lime serves as a cheap bond but is slow in developing strength.

PHYSICAL TESTS

Typical mortar mixtures were made consisting of 6 parts of fine aggregate, 1 part of Portland cement, and 1 part of hydrated lime by volume, plus enough water to develop a workable mass. The aggregates used were —16-mesh local masonry sand and —16-mesh burned Porters Creek clay. Screen analyses of the aggregates are given under "Concretes." Figure 8 test pieces were made and allowed to cure for 28 days in a moist atmosphere. The average tensile strength determinations are as follow:

Porters Creek	206 lbs. per sq. in.
Sand	160 lbs. per sq. in.

It was surprising that the mortar made from sand was the weaker. This may be due to the fairly uniform size gradations in the natural sand, a condition which will vary according to the source of available building sand.

POSSIBILITIES

Mortars, made from the burned Porters Creek clay and Basic City claystone, are not recommended for water proofing, or to resist abrasion, or for general purpose building. However, they would be particularly useful when used for bonding building blocks and tile made from the light-weight aggregate by maintaining in the mortar the insulating quality of the block, the color of the block, and a similar porosity needed to obtain a uniform coating of plaster or stucco.

APPENDIX

PACKING OF AGGREGATES

The packing of aggregates was done to determine the best proportion of the several sizes to be used, that is, the combination of sizes that would give the least void space when the aggregate was made into concrete with cement and water, and also to determine the specific gravity for use in calculations in determining the volume ratios between aggregate, cement, and water.

This packing of aggregates was done in a vibrating device which consisted of a brass pipe, 8 inches long and 2 inches inside diameter, and closed with a solid bottom. This cylinder was mounted on a metal shaft, which moved in a vertical reciprocating motion, and held in place by a bearing. The free end of the shaft was in contact with a revolving eccentric which transmitted the vibrating motion to the brass cylinder containing the aggregates.

At each downstroke, the cylinder fell by gravity force to an abrupt stop. The rate of vibration was 600 strokes per minute. The rotary motion of the eccentric was actuated by a small electric motor.

The aggregate mixture was weighed out and placed in the brass cylinder, then a heavy round iron piston that exactly fitted the inside of the brass cylinder was placed on top of the aggregate. After vibrating exactly 20 minutes, the piston was removed, and the annular space above the aggregate measured. Knowing the total volume of the cylinder and the total depth, the volume occupied by the known weight of the aggregates was measured, and the specific gravity and the percent void space was calculated.

PREPARATION AND TESTING OF CONCRETE SPECIMENS

Because concrete is usually mixed in volume proportions of aggregate, cement, and water, the specimens for this work were calculated by volume, but they were made up by weighing each component material. This was done by using the specific gravities of the aggregate and the cement to calculate the weight proportions to be used.

The specific gravity of the aggregate was obtained from the packing data for each combination of sizes. The specific gravity of the cement, which was Atlas Portland Cement, was obtained from the manufacturers figures of 94 pounds per cubic foot. As discussed in the text, the water used for each concrete mix was varied to obtain the desired workability.

In the preparation of cylindrical specimens for crushing strength tests, the aggregate was weighed out, and a weighed amount of water added and mixed well with the aggregate. This was allowed to set for a half an hour while the aggregate absorbed some or most of the water.

The cement, weighed, but in volume proportion of 1 to 5, etc. to the aggregate, was mixed in, and finally, what more water was needed for workability was added and the whole mixed well. This concrete was then rodded into standard cylindrical forms, 6 inches in diameter and 12 inches deep, filling about 1/10 of the mold at a time, and rodding it well with a 3/4-inch rod. The concrete was allowed to set 24 hours, and then the mold removed and the specimen placed in a damp box for curing.

After 28 days of curing, the specimens were removed from the damp box, and plaster of Paris applied to each end. On the same day, these specimens were crushed on an Olson 50-ton testing machine.

Two samples were broken from each crushed specimen, one from the middle and one from the outside. The samples, weighing 75 to 100 grams, were boiled in water, and after cooling, were weighed wet. They were then dried at 110°C. and the dry weight obtained, and the volume of each was determined in a mercury volumeter. From the wet weight, dry weight, and dry volume, the porosity and specific gravity values were calculated.

Pieces from each of the crushing test specimens were also examined minutely as to their structure, distribution of aggregates, cement, etc.

The method in preparing the concrete blocks in this testing was the same as the method for preparing the crushing strength specimens except in removal from the form or mold. Shortly after the blocks were made, the center core was removed by pulling it out, and after the block set 24 hours, the sides of the mold were removed and the block placed in the damp box for curing.

The blocks for joint breaking were cured in the damp box for two weeks, and then mortared together in pairs. The mortar was made of one part cement, one part lime, and six parts sand by volume. The pairs of blocks to be filled were filled, the day after the mortar was applied, with a concrete of the same proportions as that of the blocks themselves, and packed by rodding. After the filling and mortar had cured 28 days in the damp box, plaster of Paris was applied to assure a smooth uniform bearing surface. The joint breaking strength was tested on the Olson testing machine. At the points of contact with the testing machine 1 1/2-inch half round lenghts of iron, 9 inches long, were used so that the breaking load was directed at the points desired, as shown in Figure 8.

HEAT CONDUCTIVITY APPARATUS

DESCRIPTION OF FIGURE 9

Figure 9 is a cutaway drawing of the heat conductivity apparatus, showing side and end views. The apparatus consisted essentially of five parts:

1. The cold box, or bottom part, in which a constant temperature of 4 to 5 degrees Centigrade was maintained.

2. The test slab, which fitted over the cold box and rested in a frame.

3. The wooden frame, which held the slab and rested on the cold box, giving space for insulation to be packed around the slab; thereby minimizing the loss of heat around the ends of the slab.

4. The heat box, which fitted over the slab and in which a constant heat was maintained.

5. The adiabatic box, which was an outer shell surrounding the heat box and resting on the wooden frame.

No wiring from the apparatus to electrical measurement devices or to electric current sources is shown on Figure 9.

The apparatus was constructed for the purpose of determining the heat conductivity constant of the various concretes and plasters tested in this report. The heat conductivity constant is usually called

K and is in terms of Btu per inch thickness, per square foot area, per degree Fahrenheit temperature change per hour.

The apparatus was not meant to be a standard for such a test, and the results may not be comparable with data from other methods of testing. The results, however, are comparable with each other—the apparatus being, as it was constructed, a comparison conductivity apparatus.

To understand limitations and use of the apparatus, it is best to discuss its several parts separately.

THE COLD BOX

The cold box was a refrigerating box, with cooling coils in the bottom fed by a motor and compressor of the usual electric refrigerator type, and insulated with cork. A masonite shelf was set in the cold box, with an electric fan (F_s) inserted in the shelf. The fan circulated air down around the cooling coils and up around the ends and sides of the shelf across the bottom face of the test slab.

A heating coil (Hc) was attached just below the fan in order that the air might be heated slightly to maintain equilibrium in the cold box, and the refrigerator was kept running constantly after equilibrium was reached and a run was being made. A thermostat (Tr) controlled this heating unit.

Three thermometers (Tc) inserted in the box were used to read the temperature of the circulating air.

THE TEST SLAB

The test slabs were all made 38 inches x 20 1/2 inches in size, which gave a workable conduction area of 37 inches x 19 1/2 inches or 5 square feet when placed in the apparatus. The two plaster slabs were one inch thick each, and all others were 2 3/4 inches thick. Five holes were bored in the test slab and fifteen thermocouples (Ts), arranged in series, passing through these holes, which were then plugged and insulated with cotton and Duco cement. The thermocouple series was of Copper and Ideal wire, having a calibrated rating of 0.570 millivolts for the series and leads. The thermocouples were spaced so that each was affected by 1/15 of the area of the test slab, or 1/3 of a square foot of test slab area. They were attached to the face of the test slab by Duco cement, which helped insulate them from the air temperature.

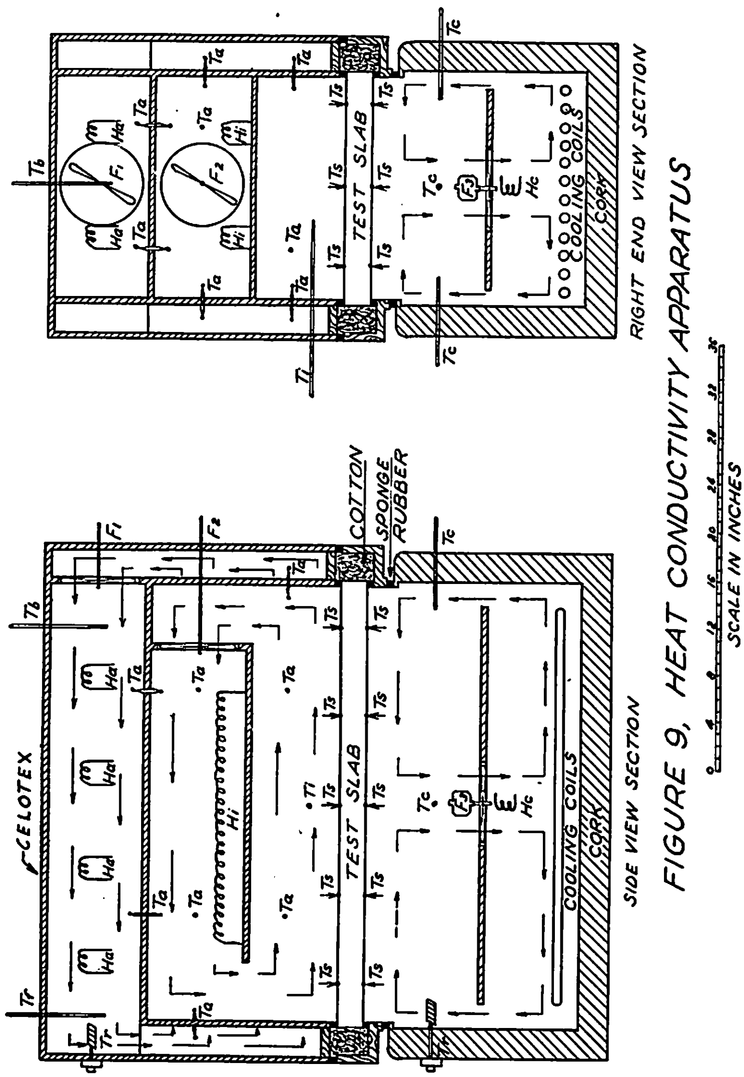

Figure 9. Sections of heat conductivity apparatus.

By arranging the thermocouples in series, with alternate couples on opposite faces of the test slab, one couple acted as the cold junction and the next as the hot junction, thereby giving the current in millivolts generated by the temperature difference between the faces of the slab, but not the temperature of either face.

The lead wires of the thermocouples extended under the rubber insulation of the test slab to a millivoltmeter which could be read accurately to 0.05 millivolts.

THE WOODEN FRAME

A rectangular wooden frame, about 3 1/2 inches larger than the test slab, rested on the cold box and held the test slab and the wall of the adiabatic box, both being insulated by a strip of sponge rubber. The spaces between the edges of the test slab and the frame were filled with cotton for insulation.

The joints of the frame were sealed with scotch tape as a further precaution against heat leakage.

THE HEAT BOX

The heat box was made of celotex, put together around a wooden frame. It was the same size as the test slab, 39 inches x 20 1/2 inches, and was 15 inches deep, and rested on the slab, separated from the slab by a strip of sponge rubber. The joints of the box were sealed with scotch tape and the inside painted with shellac and aluminum paint for precaution against heat loss.

A masonite shelf was placed across the box, as shown, to hold both the heating coils (Hi) and the fan (F2) and to serve as a baffle to guide the circulating air. The air was drawn by the fan, across the heating coils, down across the face of the slab, then back up at the opposite end and into the fan.

The heating coils were heated by a 110-volt circuit, which was controlled, before entering the apparatus, by a coil rheostat, and measured by a voltmeter. Constant power was maintained throughout each determination at 50, 75, or 100 watts. The holes through the celotex for wires were plugged with cotton and sealed with Duco cement to prevent flow of air through them.

THE ADIABATIC BOX

The adiabatic box was designed to prevent heat flow from the heat box to the outside room. All heat flowing out of the heat box was assumed to pass through the test slab.

The adiabatic box was made of celotex, put together around a wooden frame, which surrounded the heat box, leaving a space of 3 1/2 inches around all four sides, and a 10-inch space at the top between the walls of the heat box and the wall of the adiabatic box.

Heat was supplied by eight heating coils (Hc), six controlled by a rheostat on the outside, and two activated by a thermostat (Tr) to adjust small temperature differences. A fan (F1) drove the air across the heating coils and down around the sides of the heat box, then back up and through the fan. The air current was guided by baffles of celotex (Figure 9).

Sixteen Copper-Ideal thermocouples (Ts) were placed in series, with alternating hot and cold junctions placed in the heat box and adiabatic box. Each thermocouple covered 1/16 of the total area of the heat box. The lead wires of this thermocouple series connected, outside of the apparatus, to a tapping key and a galvanometer. As long as there was no deflection on the galvanometer, no heat was flowing from the hot box to the adiabatic box or vice versa; and all measured heat in the heat box was assumed to be flowing through the test slab. Around the area of the heating coils, there was probably heat flow into the heat box, and conversely, at points furthest from the heating coils, there was probably heat flow into the adiabatic box, but when there was no galvanometer deflection, this heat flow was assumed to be equalized.

This method of controlling heat loss seemed better than any insulation that could have been placed around the heat box, especially for this type of apparatus. It is nearly impossible to insulate with insulating material a box such as the heat box, without loss of heat through the insulation, but by use of an adiabatic box, better insulation of the heat box was obtained.

Two thermometers (Tf and Tb) gave readings on the air temperature, both before and after the air crossed the heating coils. The temperature reading (Ta average) given in the data was the average of these thermometers.

OPERATION

The apparatus was all put in place, care being taken that the cotton and sponge rubber insulation was packed evenly and in the correct places; and all lead wires to or from the apparatus were checked for breaks.

The cold box, heat box, and adiabatic box were all plugged into the electric circuit and the fans started. By means of the coil rheostat, the power to the heat box was regulated at the desired wattage. And the equivalent number of heating units in the adiabatic box were plugged in, roughly 2 units at 50 watts, 4 at 75 watts, and 6 at 100 watts input in the heat box.

It took from 18 to 24 hours for the apparatus to come to equilibrium, the last 2 or 3 hours being used for fine control of the heating units Ha and Hc, controlled by the thermostats Tr in the cold box and adiabatic box. When the thermometers Ti and Tc were constant and there was no heat flow from the heat box and adiabatic box, as recorded by the deflection galvanometer, a run was started.

During the run, the millivoltumeter was read every three minutes, as were all thermometers, the wattmeter, and the deflection galvanometer. The average of 21 readings, one every three minutes for an hour, was reported.

DATA AND CALCULATIONS

Table 7 gives the data obtained in a typical determination for the heat conductivity constant. Table 8 is a summary of the data obtained and reported for the various specimens on which heat conductivity determinations were made.

TABLE 7

DATA SHEET OF PORTERS CREEK

CONCRETE SPECIMEN HEAT CONDUCTIVITY DETERMINATION

Time in minutes	Galvanometer deflection	Watts	Millivolts	Tc °C	Tb °C	Tf °C	TA Average (Tb + Tf)/2 °C	Ti °C
0	None	100	18.50	41.6	62.8	72.5	67.65	64.50
3	None	100	18.25	42.4	62.8	72.2	67.50	64.60
6	None	100	18.45	41.6	62.8	72.2	67.55	64.55
9	None	100	18.55	40.8	62.9	72.3	67.60	64.55
12	None	100	18.40	42.0	62.9	72.3	67.60	64.55
15	None	100	18.45	42.0	62.9	72.3	67.60	64.55
18	None	100	18.55	40.2	62.9	72.4	67.65	64.60
21	None	100	18.30	42.4	62.9	72.3	67.60	64.60
24	None	100	18.50	42.0	62.9	72.3	67.60	64.60
27	None	100	18.45	42.0	62.9	72.2	67.55	64.65
30	None	100	18.50	41.6	62.8	72.3	67.55	64.65
33	None	100	18.55	41.0	62.9	72.3	67.60	64.75
36	None	100	18.45	42.0	62.9	72.3	67.60	64.70
39	None	100	18.50	41.4	62.9	72.2	67.55	64.80
42	None	100	18.50	41.4	62.9	72.3	67.60	64.75
45	None	100	18.55	41.4	62.9	72.3	67.60	64.80
48	None	100	18.45	41.4	62.9	72.3	67.60	64.80
51	None	100	18.55	41.0	63.3	72.4	67.85	64.75
54	None	100	18.45	41.6	62.9	72.4	67.65	64.70
57	None	100	18.55	41.0	62.9	72.4	67.65	64.65
60	None	100	18.50	42.0	63.0	72.4	67.70	64.70
Average		100	18.471	5.31°C			67.61°C	64.66°C
Centigrade to Fahrenheit conversion				41.56°F			153.70°F	146.39°F

Calculated K = 3.218 Calculated ΔT = 32.41°C Calculated ΔT = 58.34°F

TABLE 8

SUMMARY OF RESULTS OF HEAT CONDUCTIVITY DETERMINATIONS

Specimen	Watts	Milli volts	Tc °C	(Tb + Tf)/2 TA Ave. °C	Ti °C	ΔT °C	K	Average K
Porters Creek	40	7.543	5.11	31.06	30.39	13.08	3.153	
Porters Creek	50	9.588	4.14	36.39	35.76	16.80	3.100	
Porters Creek	75	13.869	4.58	51.06	49.61	24.33	3.214	
Porters Creek	100	18.471	5.31	67.61	64.66	32.41	3.218	3.171
Basic City claystone	50	10.705	2.77	41.16	39.89	18.78	2.776	
Basic City claystone	75	12.964	5.15	51.66	50.60	22.74	3.439	
Basic City claystone	100	16.738	4.44	63.38	61.88	29.36	3.551	3.255
Bloated slag	50	14.481	4.70	44.55	44.20	25.41	2.052	
Bloated slag	75	20.567	4.68	60.89	59.31	36.08	2.168	
Bloated slag	100	26.043	4.44	75.60	72.85	45.68	2.282	2.167
Sand-Gravel concrete	50	2.543	4.55	33.49	32.18	4.46	11.687	
Sand Gravel concrete	75	4.183	3.06	39.17	37.60	7.34	10.657	
Sand-Gravel concrete	100	4.967	2.15	45.10	43.26	8.71	11.969	11.438
Porters Creek plaster	75	7.390	5.29	39.90	39.00	12.95	2.194	
Porters Creek plaster	100	9.790	5.67	50.36	49.67	17.18	2.208	2.201
Sand plaster	75	2.457	10.14	35.46	34.53	4.31	6.600	
Sand plaster	100	3.200	12.40	43.80	43.34	5.61	6.756	6.678
Thermocouple	50	19.200	4.95		37.80			
Thermocouple	75	22.250	5.55		45.40			
Thermocouple	100	27.500	5.40		53.90			

The headings for each column in these tables refer to the readings of the instruments in the apparatus. The galvanometer deflection is the reading of the galvanometer controlled by the thermocouple series, Ta. The readings of the wattmeter and millivoltmeter are given in the column headed watts and millivolts. For the various thermometer readings, the column Tc is the temperature reading of the cold box; Tb and Tf being the temperature of the two thermometers in the adiabatic box, and their average temperature is shown in the column Ta average. The column headed Ti is the temperature readings of the thermometer in the heat box. The column ΔT is the calculated temperature from the readings of the millivoltmeter, that is, the temperature difference between the hot and cold faces of the slab.

Whatever thermometers were on hand, with the appropriate ranges, were used, some reading in Centigrade and some in Fahrenheit. Therefore the averages of the typical determinations were given in both temperature scales, to facilitate calculations.

During a determination, or run, several superfluous readings were made that did not entei into calculation of the conductivity constant, K; such as the thermometers in the cold box, Tc, the heat box, Ti, and the adiabatic box, Tf and Tb. These thermometers readings were taken merely for the purpose of keeping track of the possible temperature changes of the circulating air during a run.

For the purpose of control and equilibrium, the deflection of the galvanometer connected with the thermocouples, Ta, was read at the same time as the other instruments, every 3 minutes.

The only two instruments that affected the K calculations were the wattmeter, which was kept constant at the same power input during a run, and the millivoltmeter which was connected with the slab thermocouples, Ts.

The series of 15 thermocouples, Ts, and lead wires to the millivoltmeter, as used on the test slab, was callibrated to determine the total millivolts generated per degree difference in temperature of the hot and cold junctions. This calibration was done by suspending the junctions in the circulating air of the heat box and cold box and measuring the temperature of the hot and cold air. As shown under thermocouples in the resume of determinations in Table 8 the constant of millivolts per degree Fahrenheit temperature difference for the thermocouple series, average of three determinations, is 0.57 as calculated from $\frac{\text{Millivolts}}{\text{Ti} - \text{Tc}} \times \frac{9}{5}$. For the three determinations, this equalled 0.5845, 0.5583, and 0.5670; an average of 0.57.

The mathematical formula for the heat conductivity constant K is:

$$K = \frac{\text{British thermal units x slab thickness in inches}}{\text{Slab area in sq.ft. x temperature difference in F. degrees x hour}}.$$

Since Btu was measured in watts, Btu $= \frac{\text{watts}}{0.293}$ and temperature difference measured in millivolts, $\Delta T = \frac{\text{Millivolts}}{0.57} \times \frac{9}{5}$ and calculated to degrees F. And for a slab 2.75 inches thick, with an area of 5 square feet,

$$K = \frac{\frac{\text{watts}}{0.293} \times 2.75}{5 \times \frac{\text{millivolts}}{0.57} \times \frac{9}{5}} = \frac{9.385 \times \text{watts}}{15.789 \times \text{millivolts}} = 0.5944 \times \frac{\text{watts}}{\text{millivolts}}$$