A COMPARATIVE STUDY OF LIGHTWEIGHT CONCRETES

Thesis for the Degree of B. S.

MICHIGAN STATE COLLEGE

Arthur B. Hopperstead

1948

A Comparative Study of

Lightweight Concretes

A Thesis Submitted to

The Faculty of

MICHIGAN STATE COLLEGE

of

AGRICULTURE AND APPLIED SCIENCE

by

Arthur B. Hopperstead

Candidate for the Degree of

Bachelor of Science

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ACKNOWLEDGMENT

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INTRODUCTION

Conventional concrete made with sand and gravel has long been accepted as an excellent building material. Universal recognition has been accorded its qualities of permanence, adaptability, and strength. It weighs approximately 150 pounds per cubic foot, and when used structurally or with steel framing, the economical height to which a structure can be built is restricted. In dams, retaining walls, foundations, and bridge abutments, weight percubic foot is necessary and conventional concrete has no equal.

Sand and gravel, both as to gradation and physical properties, vary materially from deposit to deposit, and even within a deposit. When making concrete with them, continual investigation of their gradation, soundness, moisture content, etc. must be conducted to assure concrete that is economical, and uniform in strength and workability. Any change in source of aggregate for a particular job involves complete redetermination of mix design. In addition, gravel deposits are shallow and limited, presenting a problem of conservation.

The use of lightweight aggregates in concrete has several effects. In addition to reducing the weight per cubic foot by 20% to 75%, lightweight aggregates impart improvements to it. All of the lightweight aggregates contain amounts of dead air space within a cellular structure. All are chemically inert, and possess high fusing temperatures. These inherent properties also give lightweight concrete higher insulation, better accoustical value, and greater fire resistance than conventional concrete.

Another important feature is that lightweight aggregates, being an artificially processed material, can be carefully controlled during manufacture, resulting in a dependable product with known and uniform properties. Specifications can be written for a particular application, and the results will be dependable. The various raw materials from which lightweight aggregates are made are unlimited in quantity.

The future of lightweight concretes is bright. It can be expected that more extensive use will be made of this building material as designers and builders come to recognize the numerous applications and the advantages to the building industry, as well as to the owner.

TESTING

All of the different types of lightweight aggregate that were available, were used in making concrete for the various tests.

A standard mix,by volume, of one part cement to four parts aggregate was used, and sufficient water added to obtain a four inch slump.

The aggregates used were:-

(1) vermiculite concrete aggregate

(2) perlite concrete aggregate

(3) slag

(4) cinders with sand

(5) gravel with perlite fine aggregate

(6) sand and gravel, furnishing a comparative standard.

From each of these mixes, cylinders (6 x 12 inches) were made for compression tests, briquets for tension tests, and two inch cubes for testing moisture absorbtion and heat transfer.

The moisture absorbtion test consisted of lab curing the samples for seven days, air-drying for 24 hours, oven-drying for 24 hours, and immersion in water for 24 hours. The difference between the oven-dried weight and the moist weight after immersion was taken as the absorbed moisture, and the percentage expressed in terms of oven-dried weight.

The heat transfer test consisted of subjecting the cubes to a horizontal flame from a Mekker burner, and recording the heat rise on the opposite side at five minute intervals for thirty minutes.

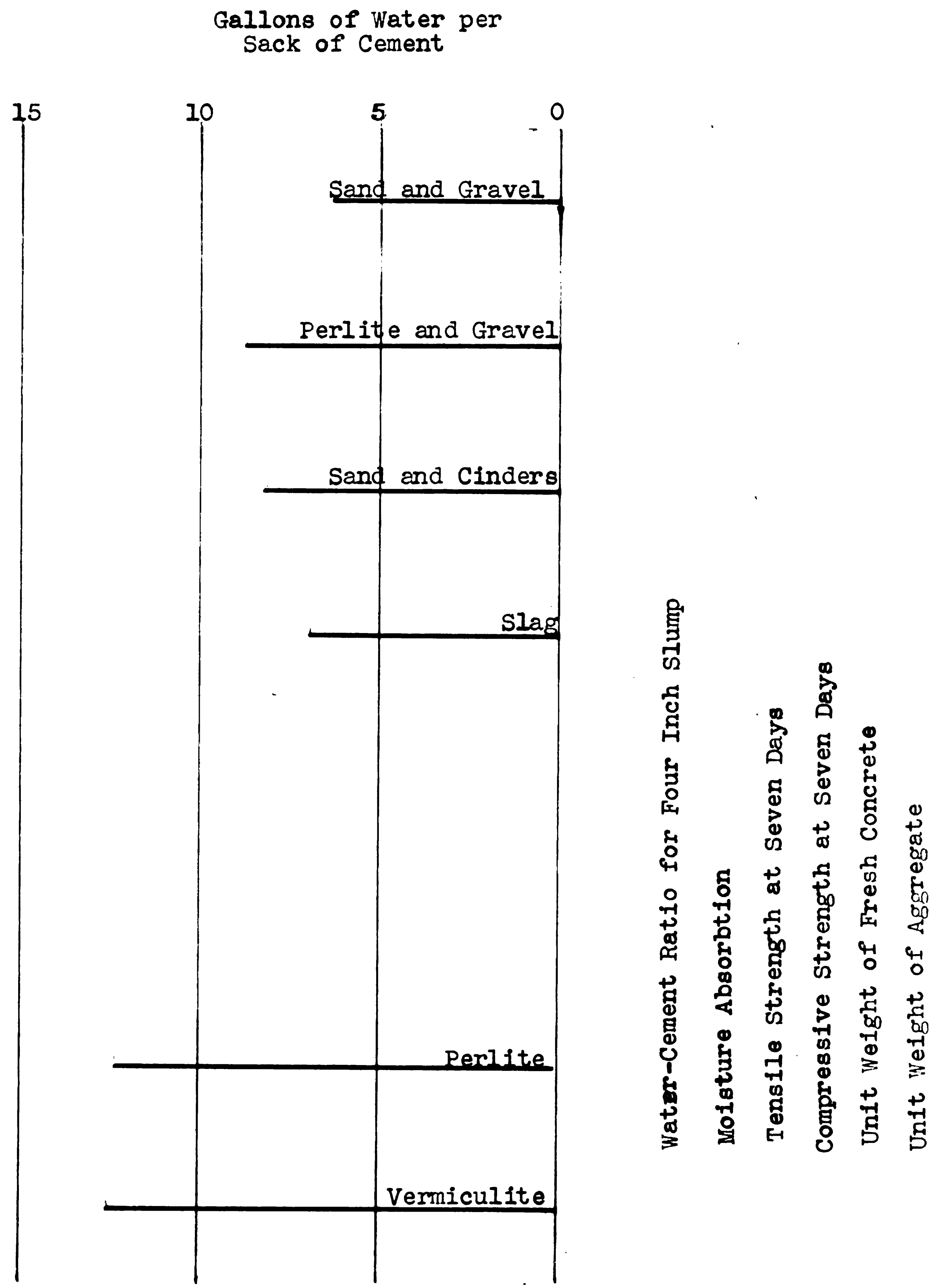
Neither of the two tests described above are standard, but were adopted for comparative purposes only.

The unit weight of each aggregate, and of concrete made from it, was found by filling a container of known volume in three increments, and rodding each increment 25 times.

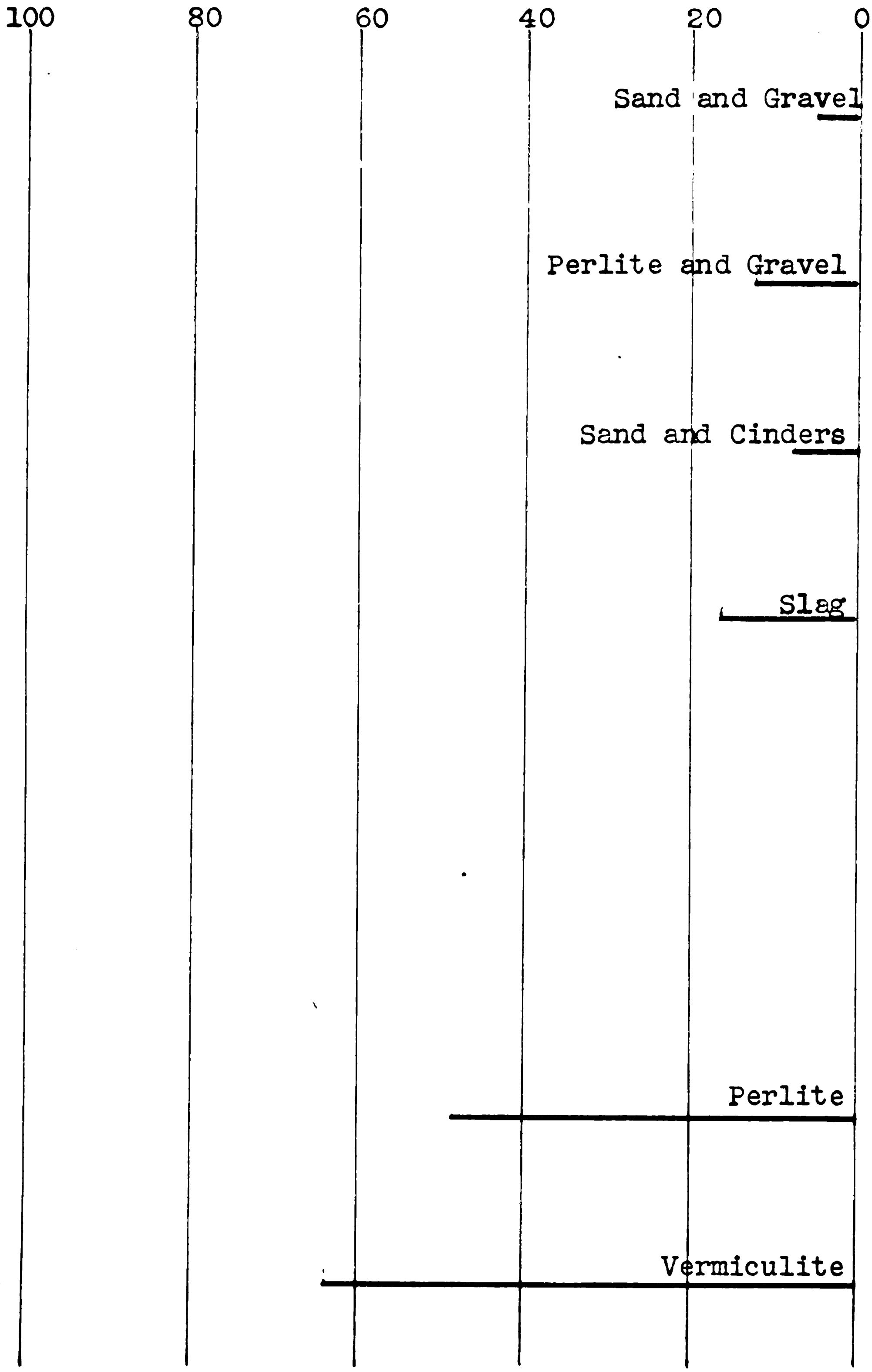
Results of the several tests were recorded in graphical form to illustrate more readily the comparative values.

Comments on the qualities of each mix will be found under the individual aggregate discussion, as well as suggestions for future work.

TEST RESULTS


Gallons of Water per Sack of Cement
15
10
5
0
Sand and Gravel
Perlite and Gravel
Sand and Cinders
Slag
Perlite
Vermiculite
Water-Cement Ratio for Four Inch Slump
Moisture Absorbtion
Tensile Strength at Seven Days
Compressive Strength at Seven Days
Unit Weight of Fresh Concrete
Unit Weight of Aggregate

Moisture Absorbtion in
Percent of Oven-Dried Weight



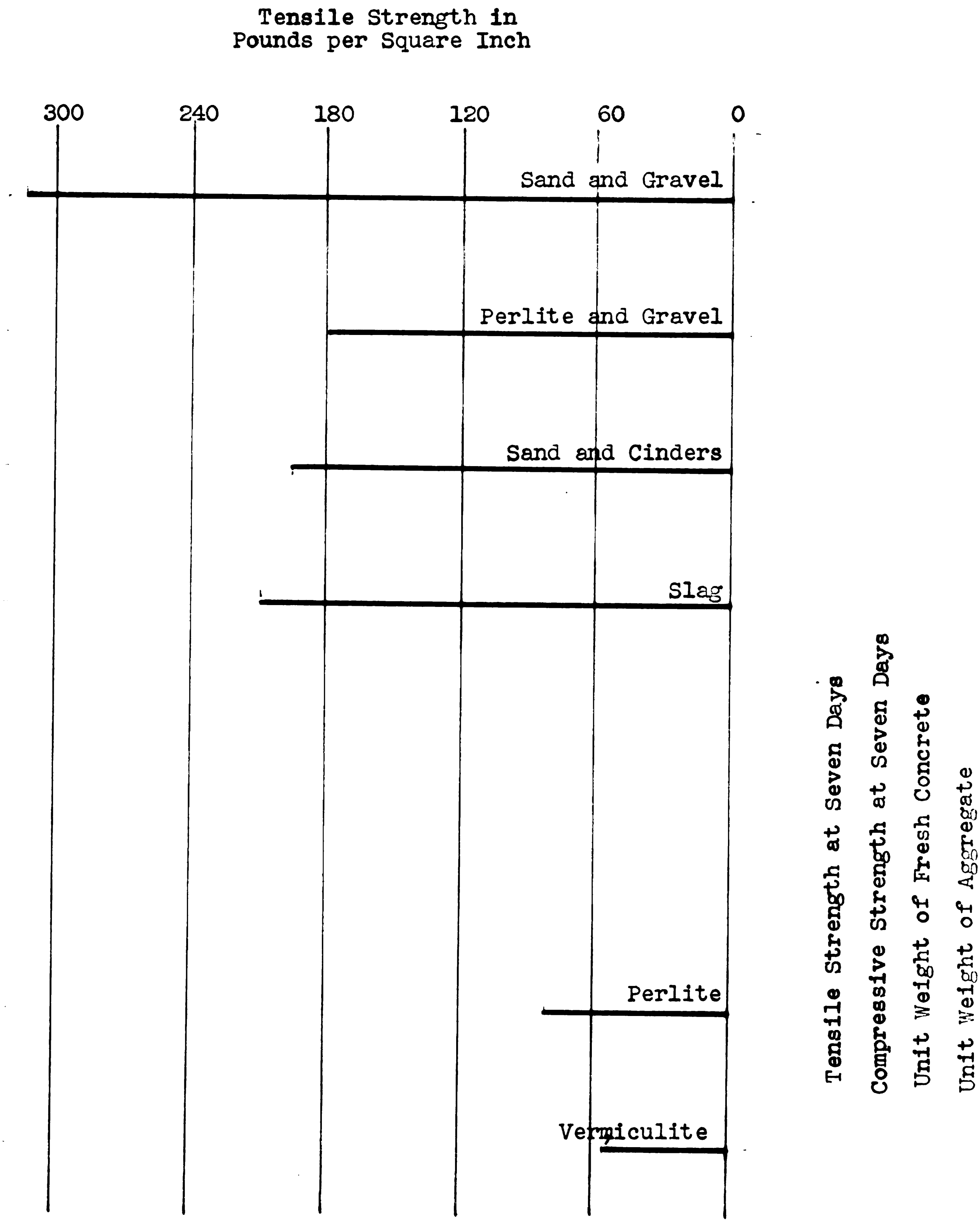
Moisture Absorbtion

Tensile Strength at Seven Days

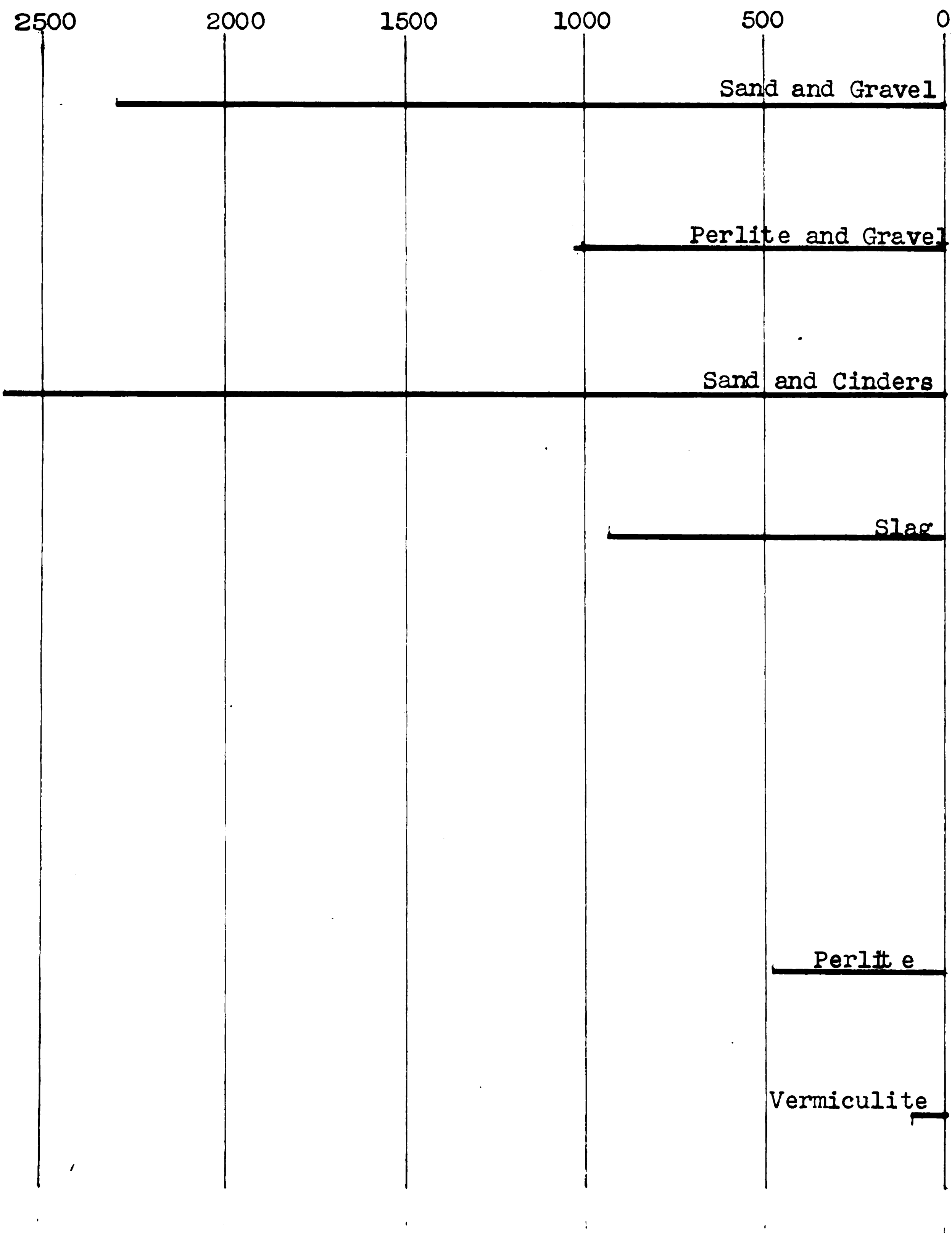
Compressive Strength at Seven Days

Unit Weight of Fresh Concrete

Unit Weight of Aggregate


Tensile Strength in
Pounds per Square Inch
300
240
180
120
60
0
Sand and Gravel
Perlite and Gravel
Sand and Cinders
Slag
Perlite
Vermiculite
Tensile Strength at Seven Days
Compressive Strength at Seven Days
Unit Weight of Fresh Concrete
Unit Weight of Aggregate

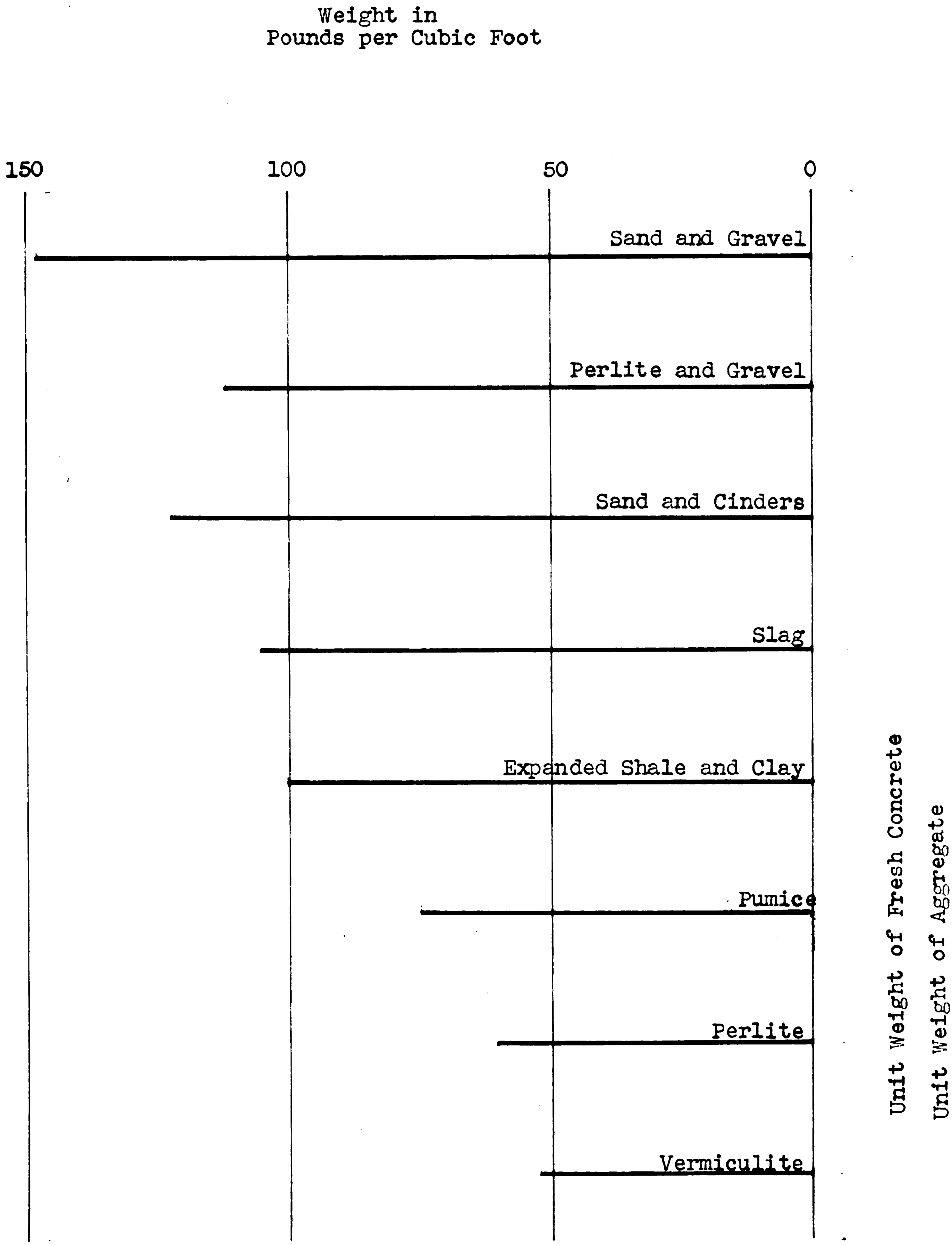
Compressive Strength in Pounds per Square Inch

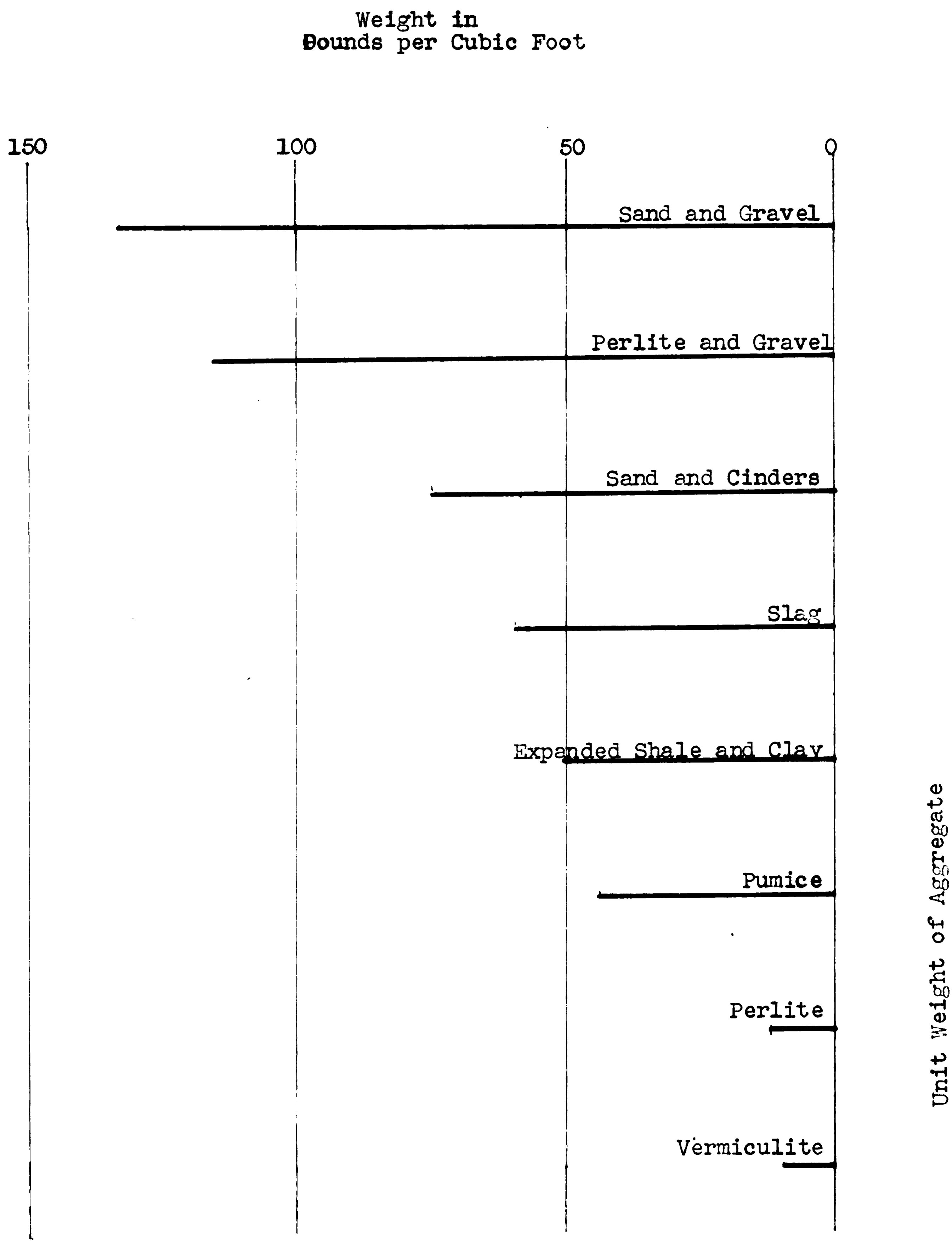


Compressive Strength at Seven Days

Unit Weight of Fresh Concrete

Unit Weight of Aggregate


Weight in
Pounds per Cubic Foot
150
100
50
0
Sand and Gravel
Perlite and Gravel
Sand and Cinders
Slag
Expanded Shale and Clay
Pumice
Perlite
Vermiculite
Unit Weight of Fresh Concrete
Unit Weight of Aggregate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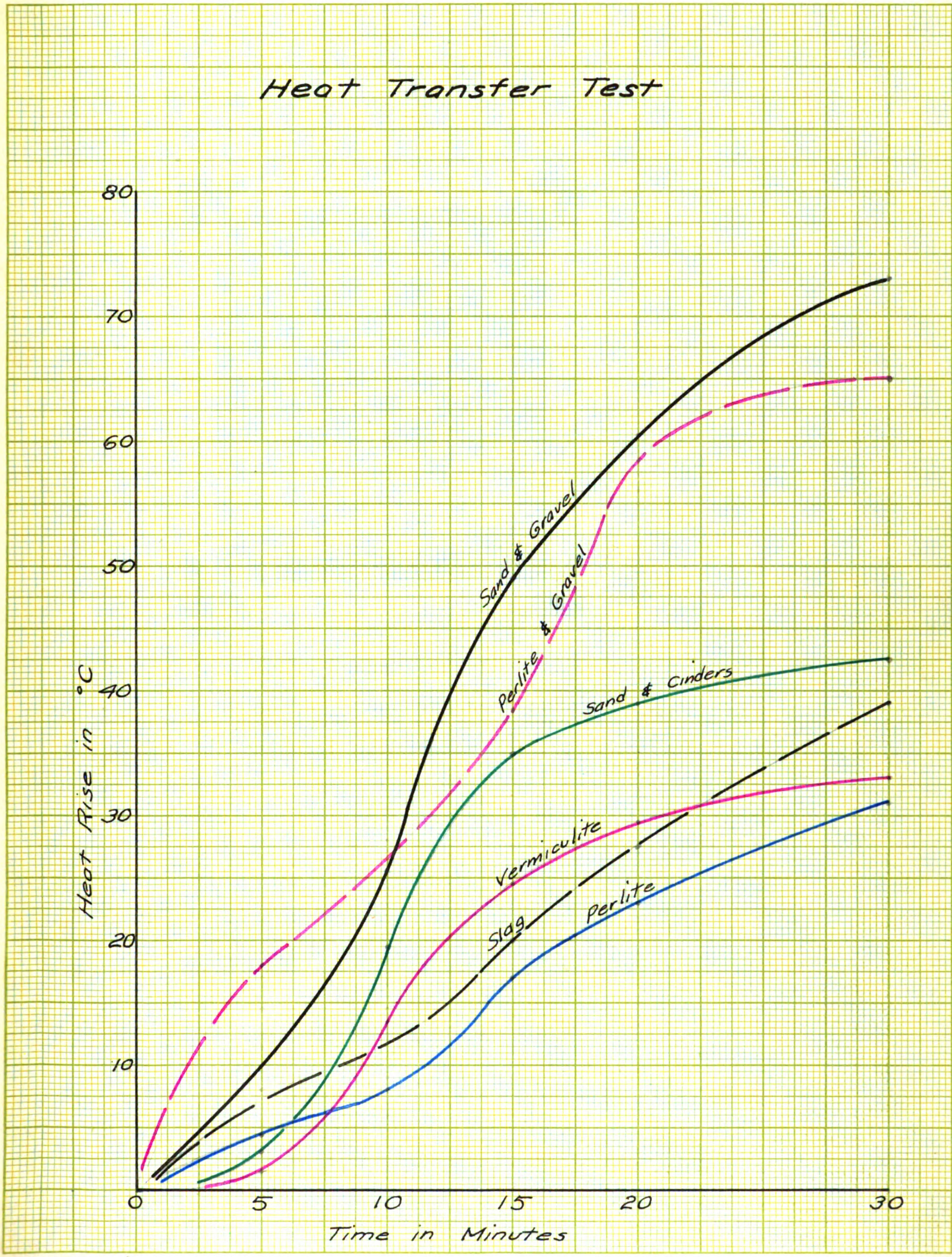
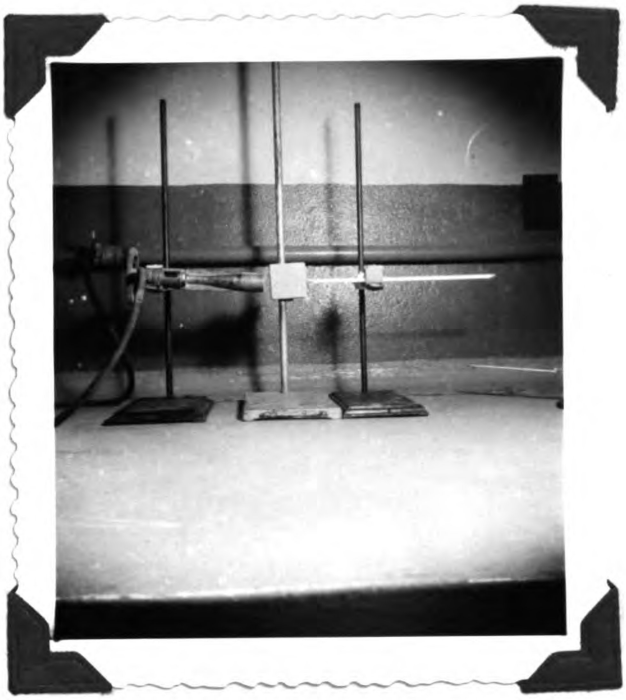


Heat Transfer Test
Heat Rise in °C
Time in Minutes
0
10
20
30
40
50
60
70
80
5
15
Sand & Gravel
Perlite & Gravel
Sand & Cinders
Vermiculite
Slag
Perlite
MADE IN U. S. A.

TYPICAL SET-UP FOR HEAT TRANSFER TEST



Left, Mekker burner

Center, Concrete test cube

Right, Thermometer

TYPICAL BREAKS IN COMPRESSION CYLINDERS

Vermiculite

Slag

Cinders and Sand

recording the heat rise on the opposite side at five minute intervals for thirty minutes.

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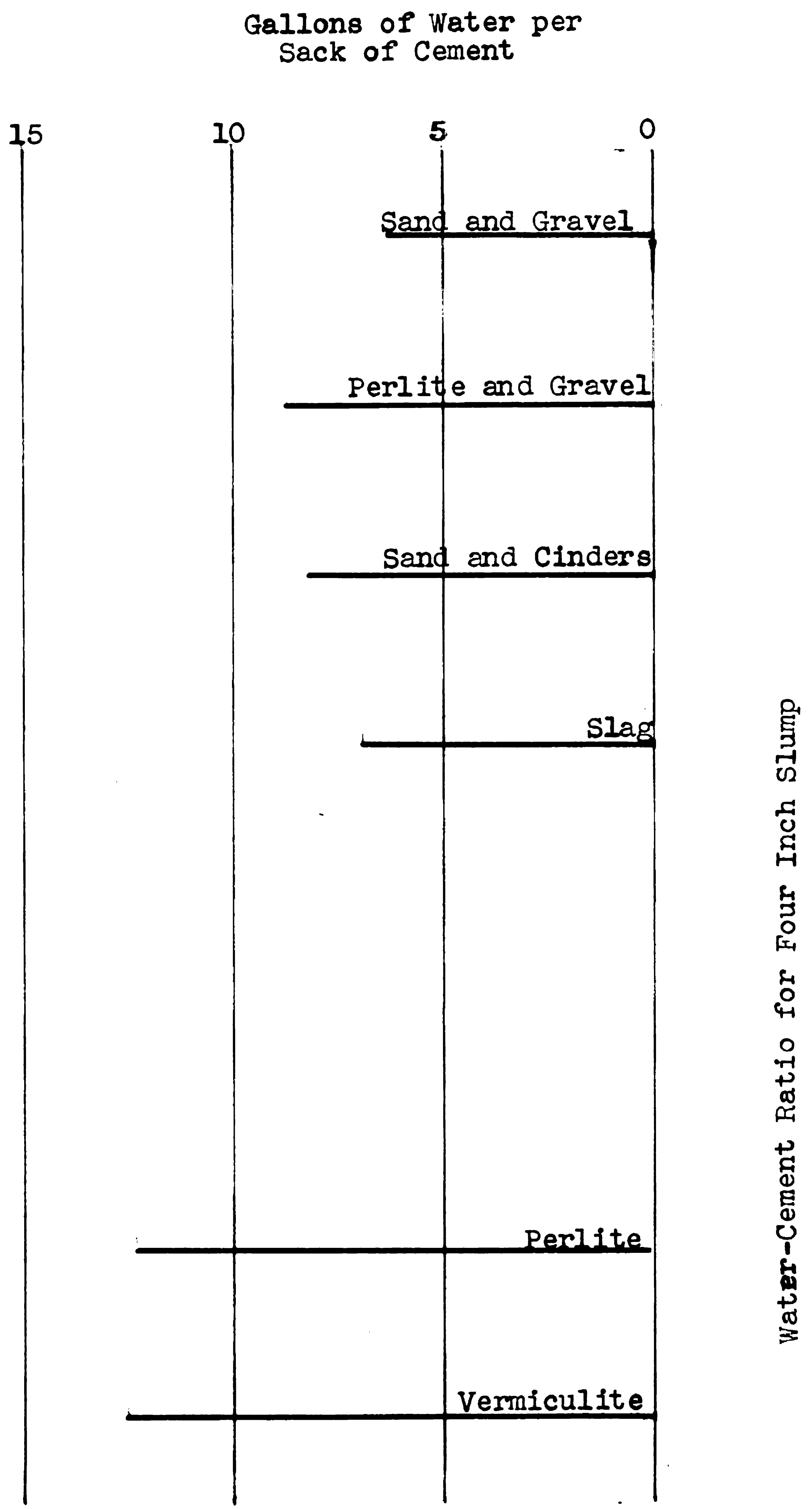
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Sand and Cinders
Slag
Perlite
Vermiculite
Water-Cement Ratio for Four Inch Slump

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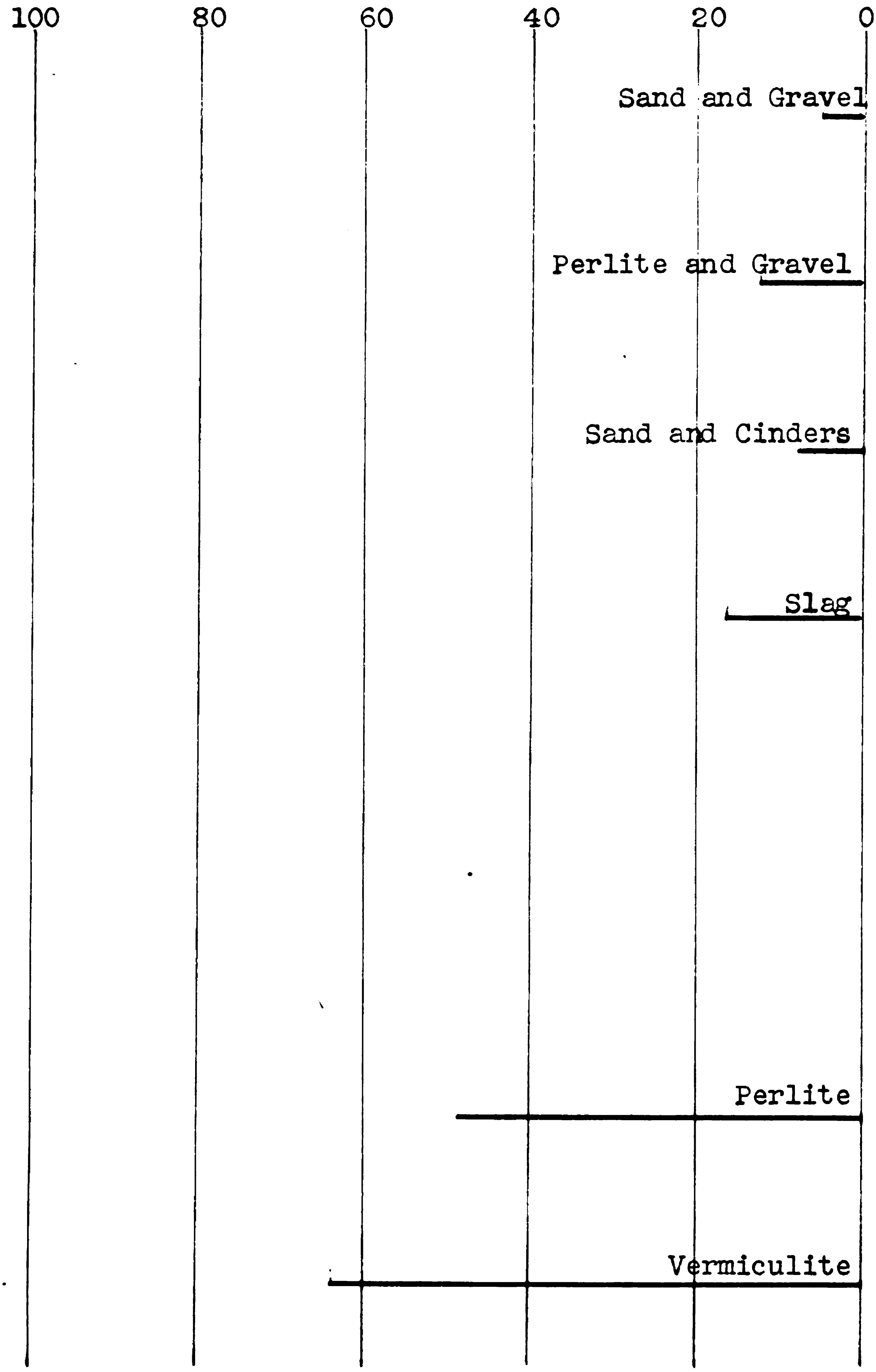
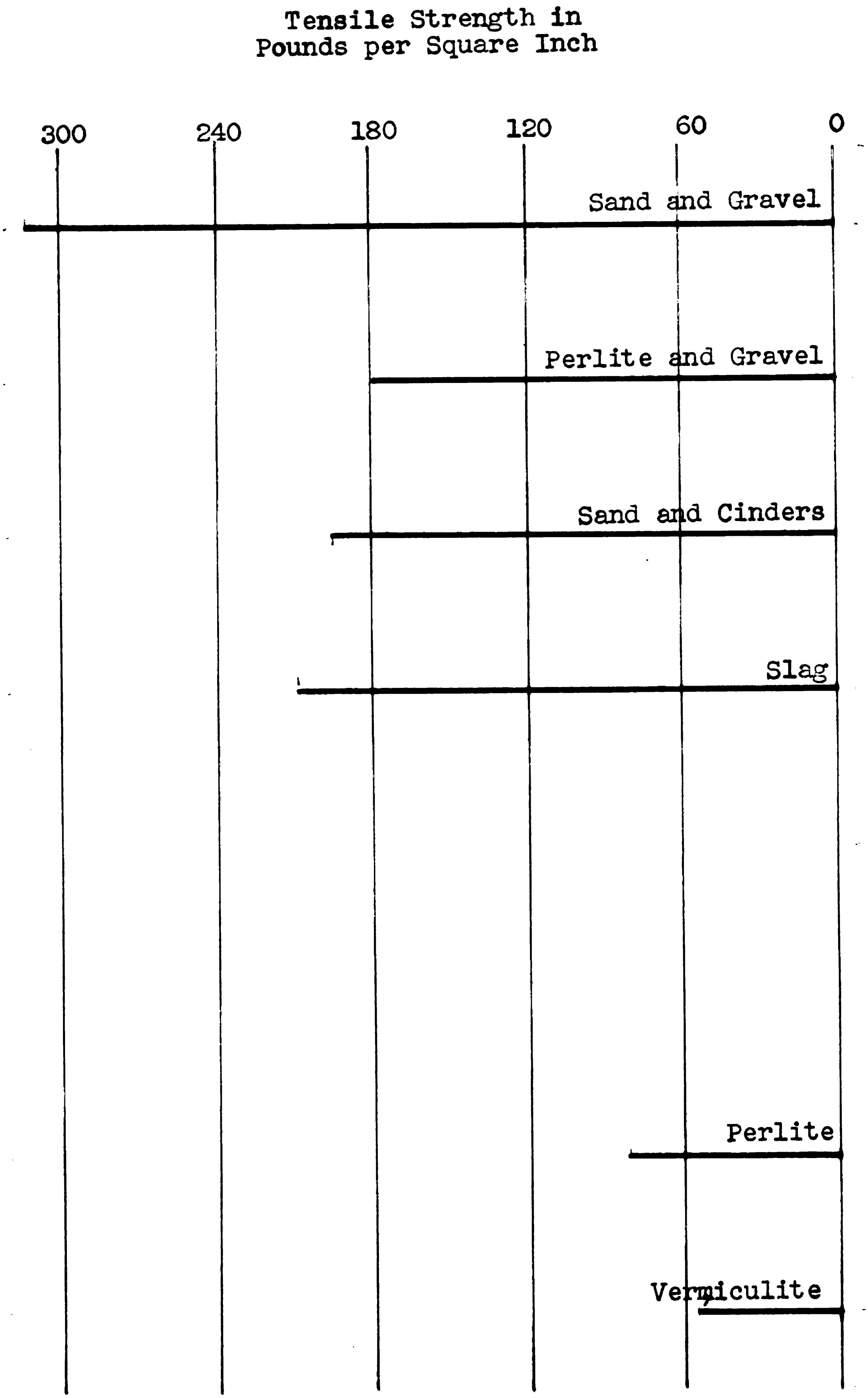
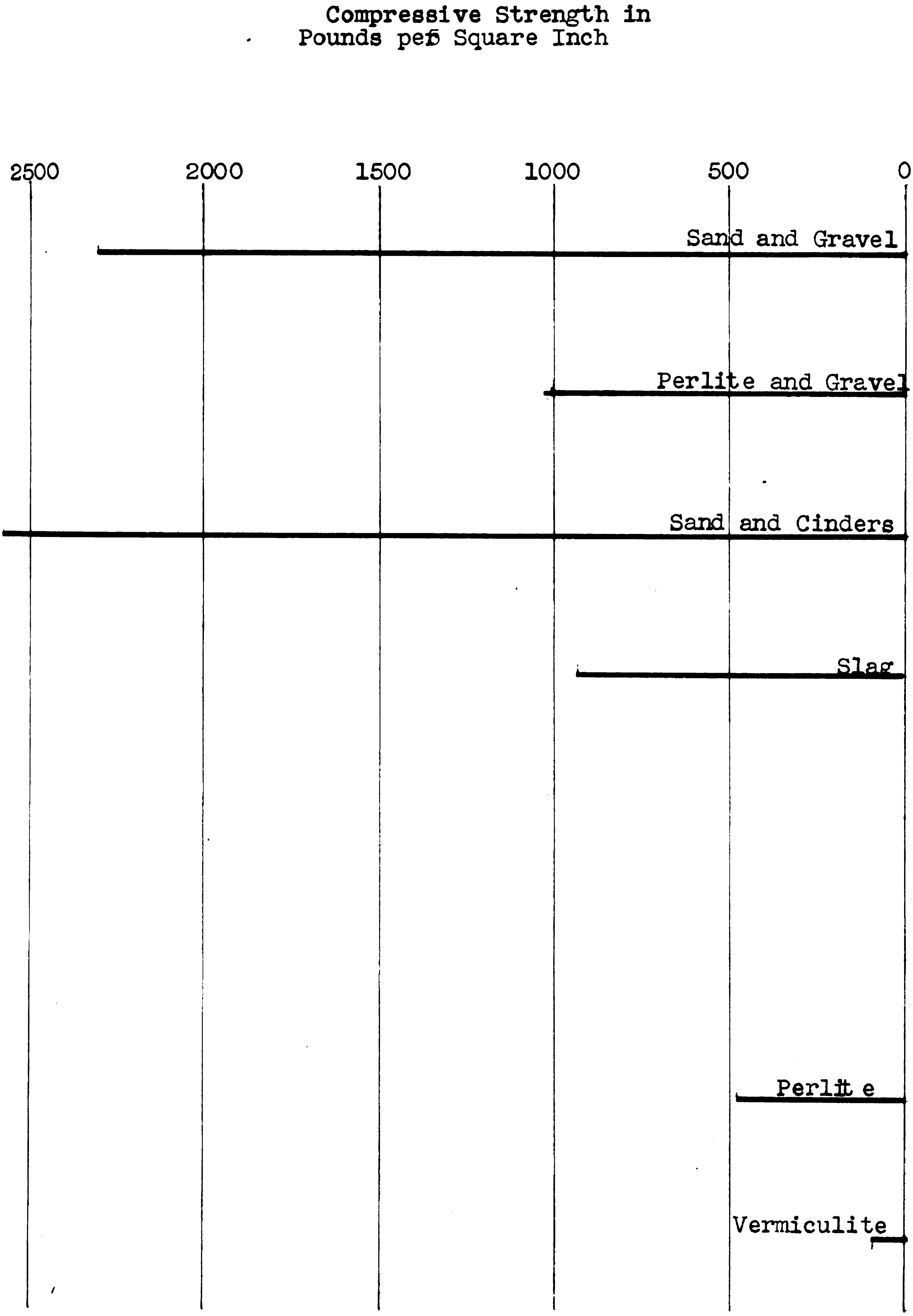
Percent of Oven-Dried Weight



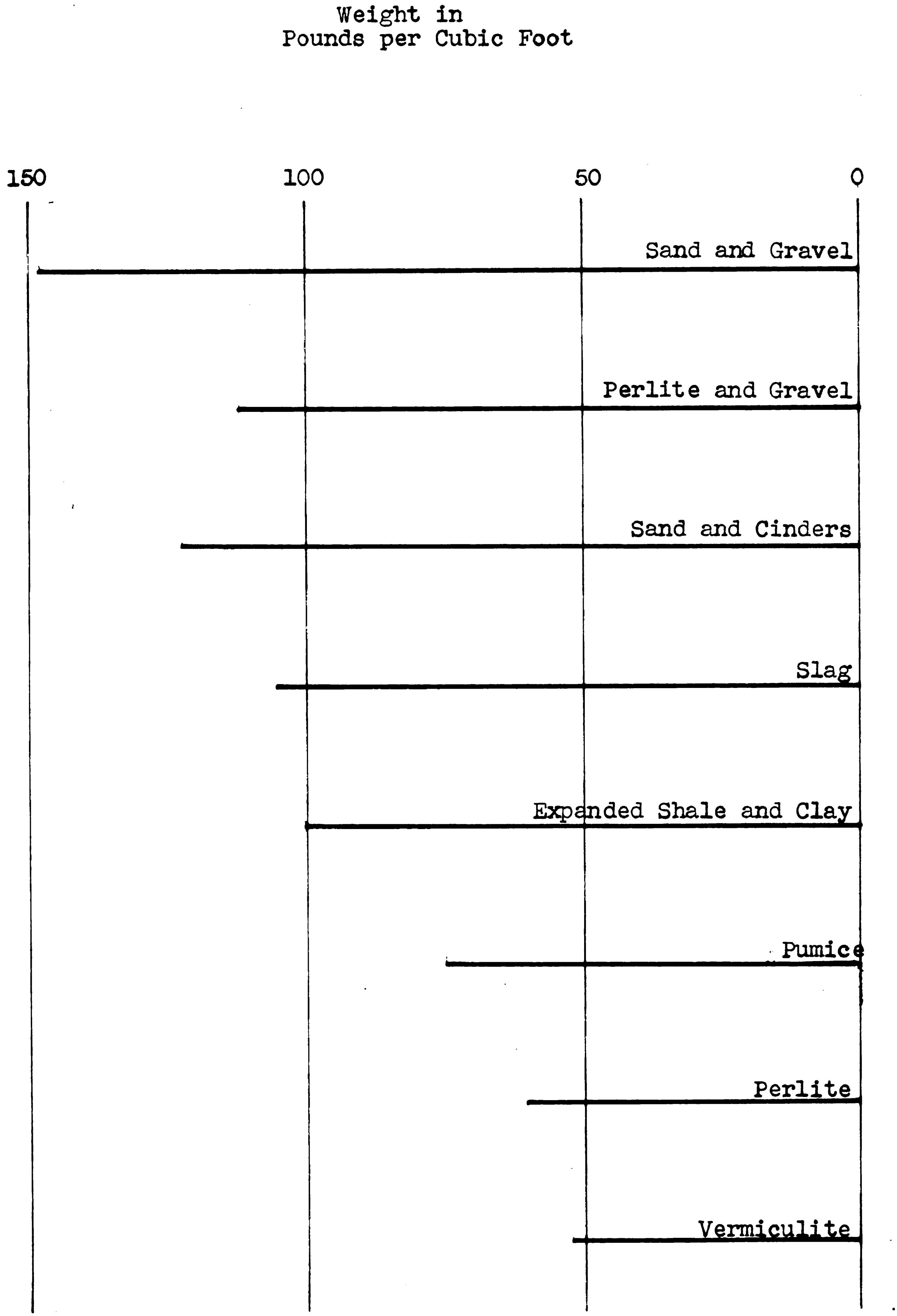
Moisture Absorbtion



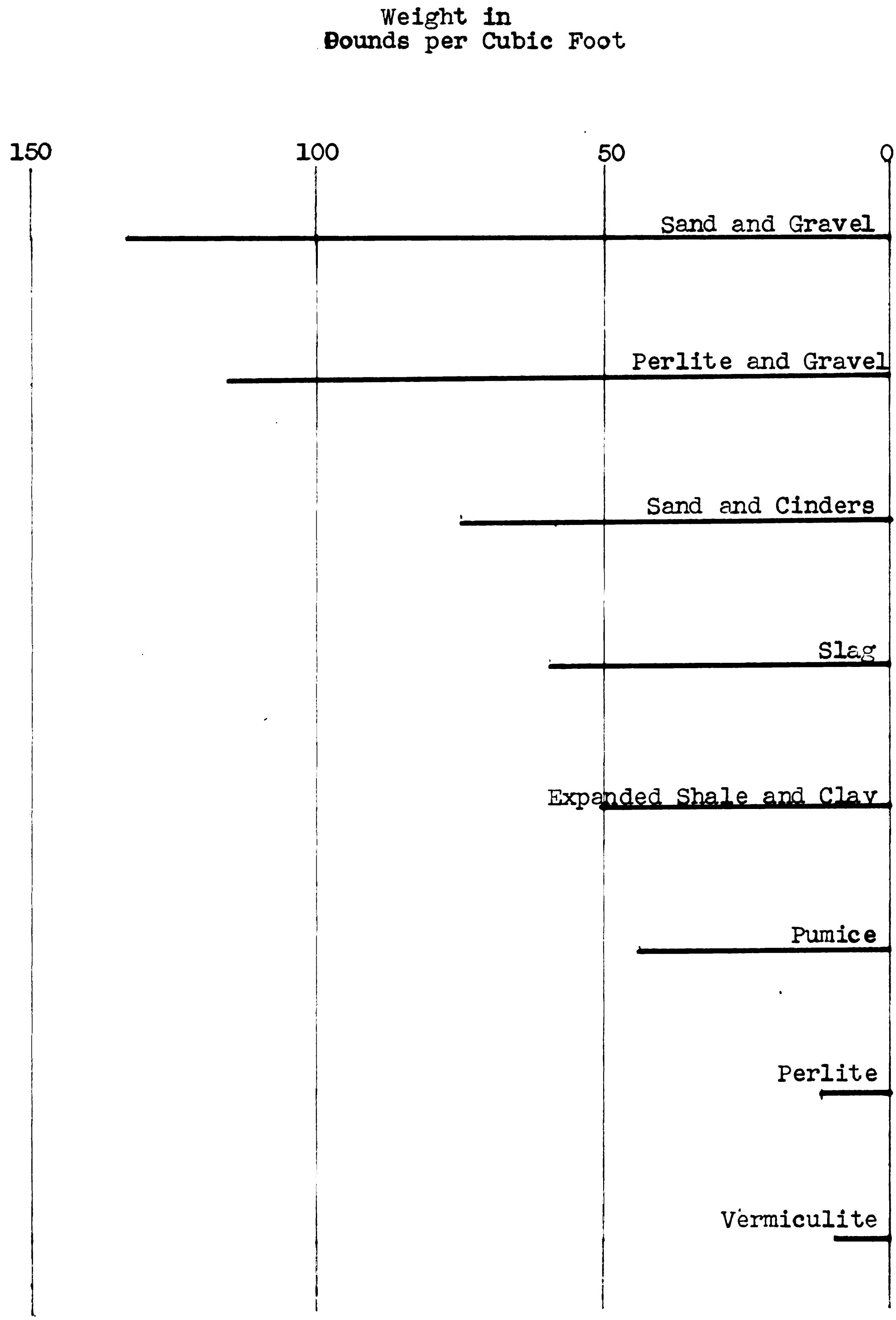
Tensile Strength at Seven Days



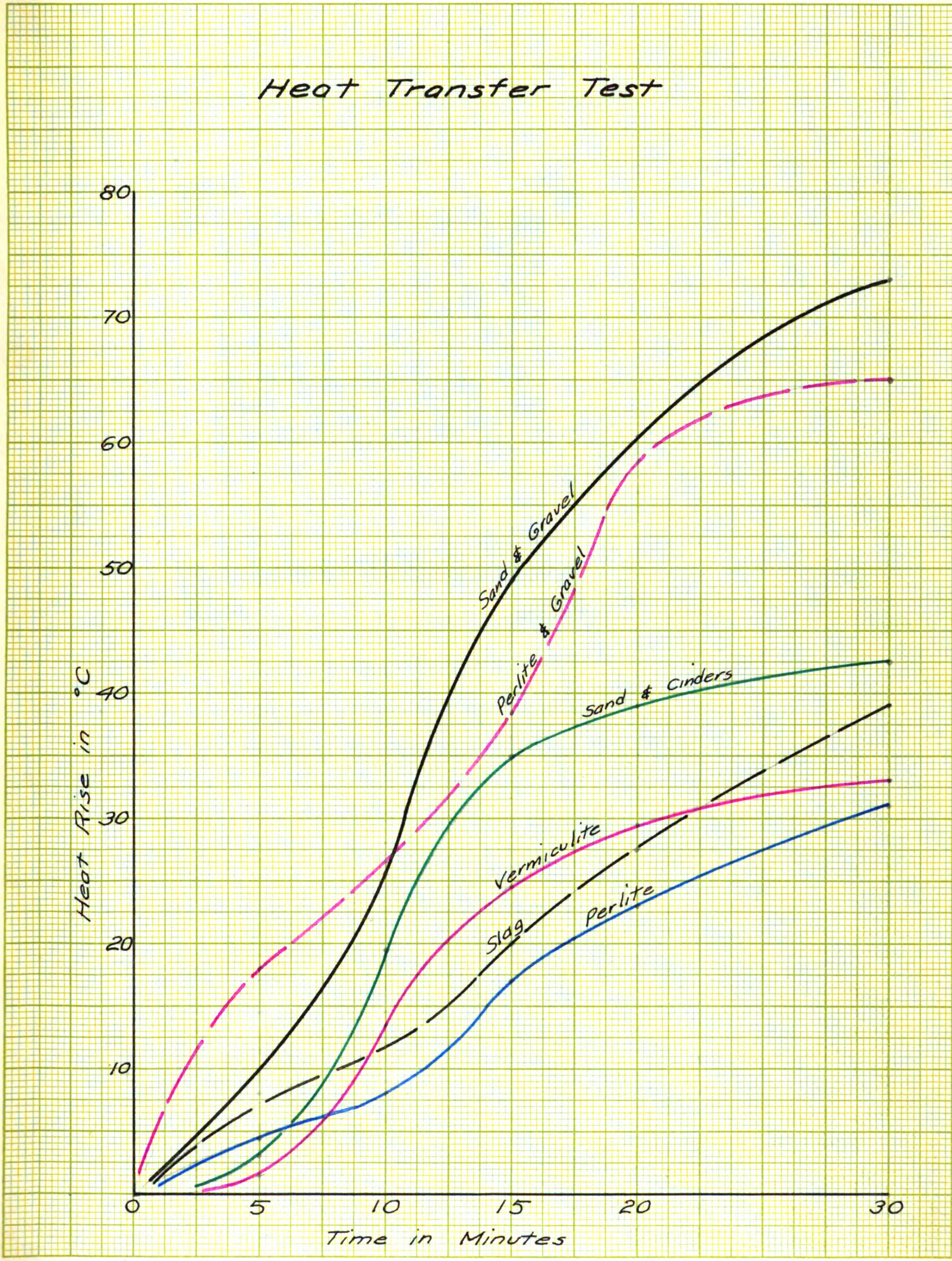
Compressive Strength at Seven Days



Unit Weight of Fresh Concrete



Unit Weight of Aggregate


Heat Transfer Test
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Time in Minutes
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Sand & Gravel
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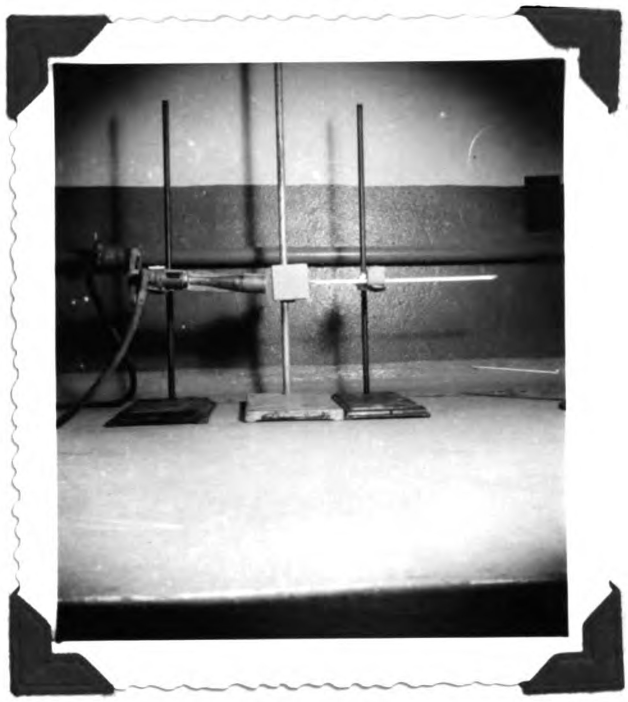
Slag
Perlite

TYPICAL SET-UP FOR HEAT TRANSFER TEST



Left, Mekker burner

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TYPICAL BREAKS IN COMPRESSION CYLINDERS

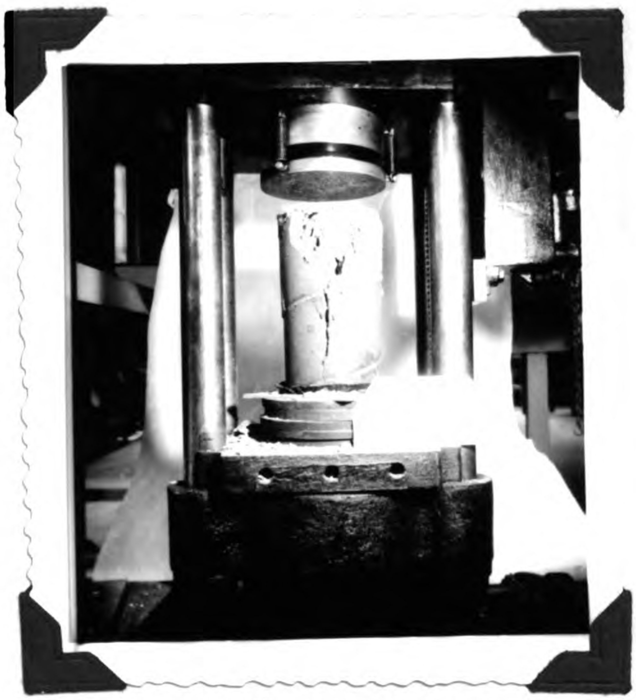
Vermiculite

Slag

Cinders and Sand

TYPICAL BREAKS IN COMPRESSION CYLINDERS

Sand and Gravel



Perlite and Gravel

THE LIGHTWEIGHT AGGREGATES

VERMICULITE

Vermiculite is a micaceous mineral mined chiefly in Colorado, Montana, North Carolina, and South Carolina. It occurs in nature as a result of the action of heat and water on phlogopite mica and biotite.

Vermiculite aggregate is produced by exposing the raw ore to heat of plus 1800° F. The water between the laminations changes to steam and expands the flakes to about fifteen times their original size.

Due to the bulkiness of expanded vermiculite in proportion to its weight, it is more feasible to ship the raw ore to strategically located plants, where the ore is processed and the commercial product distributed. The price of expanded vermiculite generally reflects its proximity to the producing plant. To compete with the other lightweight aggregates in a given location, the expanding plant must be contingent to that area.

Concrete made with expanded vermiculite weighs as low as twenty pounds per cubic foot, and is used in place of concrete made with sand and gravel primarily for its extremely light weight, its insulation qualities, its accoustical value, and where strength is not required.

Because of the millions of entrapped air cells caused by the expansion process, vermiculite concrete has a high insulation value. This quality lends itself for use as insulating concrete in such installations as roof decks, radiant heating floors, interior walls of cold storage buildings, precast blocks and slabs, boiler insulation, and many other applications demanding low heat conductivity.

These same air cells provide the accoustical value of vermiculite concrete. It is used in hospitals, churches, theatres, and other places where low values of sound transmission are desired.

Vermiculite concrete has a low compressive strength, flexural strength, and modulus of elasticity, and cannot be used for load bearing members. The low strengths exibited can be partly attributed to the high w/c ratio required to obtain a workable mix, but is primarily due to the nature of the aggregate, which is spongy and easily crushed.

Vermiculite used in the tests was obtained from the Universal Zonolite Insulation Company, and is manufactured under the trade name Zonolite. The work done with Zonolite brought out several facts. The unit weight of this aggregate varies according to the method of consolidation, i.e. vibrated or tamped. It is suggested that a mix determined by weight be used rather than one by volume.

The testing also indicated that the extremely light weight of this concrete causes a problem of consolidation which is not solved by rodding or interior vibration. It is suggested that exterior vibration might prove more feasible.

Evidence of shrinkage was noticed in the test cylinders, probably due largely to the quantity of entrained air bubbles occuring in the mix. It was impossible to determine the amount of entrained air, because the aggregate contains an undetermined amount and floats on water.

The mix was very workable when sufficient water was added, and its consistency can be described as slushy, not at all harsh or gritty.

Further work with vermiculite concrete should include experiments to determine:-

(1) bond strength

(2) control of shrinkage

(3) its utility as a structural member when used with other aggregates, observing:-

(a) compressive strength

(b) flexural strength

(c) accoustical and insulating properties

(d) the most economical combination for a particular application.

PERLITE

Perlite is a natural voncanic glass formed when the lava cools in the fissures radiating from the core of a volcano. It is a hard, black rock appearing to be very solid, but actually permeated with minute gas pockets. Perlite deposits are found in the Rocky Mountain region of the Western and Southwestern States.

The action of perlite when exposed to heat of plus 2000° F. depends on the source of the ore. Some types explode and other foam when heated. Exposure to this heat causes most types to expand and bleach to colors from pure white to light tan, each particle containing innumerable air bubbles with thin outer walls.

Most of the present producing plants are located at or near the perlite deposits. The greatest use of perlite concrete is found in the surrounding areas. The high transportation charge for the processed perlite limits its economical shipping range, and other lightweight aggregates have found greater application in the states to the east. Facilities for processing perlite ore are presently being developed in other areas, and a much wider use of perlite concrete can be expected in the future.

The vitrified air cells in processed perlite give concrete made with this aggregate its high values as insulation, as accoustical concrete, and as a lightweight building material. It is a relatively strong aggregate, and in the correct proportions with cement and water passes building code requirements. It has been used effectively as a monolithic pour over existing roofs for insulation and fireproofing, as building units, for refractory bricks, and in prefabricated roof slabs. Where sound-deadening is required, it is highly effective.

Experiments show however, that the cement content of concrete made with perlite aggregate is much higher than that made with sand and gravel for the same strengths. This means an expensive concrete, but it is quite often justified by the saving in weight, and the gain of fire-proofing, insulation, and sound-deadening.

The perlite used in these experiments came from two sources. Dantore fine aggregate came from the Gregg Lumber Company, Grand Rapids, Michigan, their ore coming from Oregon. PerAleX concrete aggregate and fine aggregate was obtained from the Alexander Film Company, Colorado Springs, Colorado.

Both types of perlite showed distinct bleeding when enough water was added to get the desired slump. Normal portland cement was used and no dispersion agent added. The use of air-entraining cement or an agent to create dispersion would help reduce the water-gain and bleeding. It is also suggested that the addition of fine sand be checked as a possible remedy for this condition.

Suggestions as to further experimentation with perlite aggregates include:-

(1) methods to control water-gain and bleeding

(2) determination of bond strength

(3) determination of the required proportions of cement and aggregate to obtain given compressive and flexural strengths.

PUMICE

Pumice is a siliceous mineral of volcanic origin. It is a white or gray porous, glassy froth, containing numerous elongated, parallel cells.

Because it is volcanic in origin, the only sources of pumice in the United States are in the Western region where volcanoes were once active.

Pumice is mined from open pits and then screened for use as aggregate. Only a small fraction mined is oversize and requires crushing. The pumice obtained from acceptable deposits is quite uniform in composition and strength.

Widest use of pumice aggregate for concrete is found in the West where the deposits are readily available and the transportation charges are not excessive. The distant location of the mines has made it difficult for pumice to economically compete with other lightweight aggregates in the East and Middle West.

Pumice concrete is more expensive than conventional concrete, but possesses the advantages of being lighter in weight, sound deadening, having a low thermal conductivity, being nailable, and easily handled. Pumice concrete has a lower modulus of elasticity than sand and gravel concrete, giving it reduced brittleness- a distinct virtue in earthquake areas.

Because it is strong as well as light in weight, pumice concrete is used for additional stories on existing buildings, and for structures where foundation loads are limited. Its insulation qualities make it desirable for application where fireproofing or low thermal conductivity is required. As accoustical concrete, it is used in walls of theatres and auditoriums, and is aspecially effective when given a rough finish. Its ability to be nailed and sawn makes it easier to install windows, doors, or partitions.

As evidence of the increased use of pumice as a lightweight concrete aggregate, the producers of pumice are presently organizing to secure uniform standards for the material, and to exchange existing technical information.

EXPANDED SLAG

Expanded slag aggregate is made by treating molten blast furnace slag with controlled amounts of water. This process causes the slag to expand and become cellular in structure. The expanded material is then crushed and graded in sizes from 3/8 inch to dust.

Production of slag aggregate is dependent upon the steel industry for blast furnace slag. Extensive use of this aggregate is found in the East and Middle West where the steel industry centers.

The cellular structure of expanded slag and its accompanying dead air spaces provide its value as a sound and heat insulator, and as a fire resistant material. Used in concrete, it is strong and durable, and is used extensively as a monolithic pour and in masonry units.

Concrete made from expanded slag has found application in such structures as commercial and institutional buildings, industrial plants, apartment houses, and residences. Its lighter weight means greater ease of handling. It is an excellent insulator against heat and sound, has great fire resistance, and is easily nailed, cut, or channeled.

Expanded slag aggregate used in the concrete for testing was obtained from the Atlas Brick and Block Company, East Lansing, Michigan.

The concrete made from this aggregate was very harsh, and considerable bleeding and water-gain was noticed. Slag aggregate is by nature very abrasive. The lack of sufficient fine material and dust was evident. Experiments by others have shown that the addition of fine, silicious sand materially reduces both the harshness and the bleeding. It has also been found that admixtures are not as effective as sand in controlling this condition.

Further experiments with slag concrete should include:-

(1) attempts to reduces the harshness and bleeding, using-

(a) fine, silicious sand

(b) admixtures

(2) the determination of the properties such as:-

(a) compressive strength

(b) flexural strength

(c) accoustical and insulation values.

CINDERS

Cinders are a vitrified waste product obtained from industrial furnaces burning bituminous coal. After crushing, cinders are graded for use in concrete.

Cinders are generally available in any locality depending on coal for heat,light, and power. Although they were once to be had for the hauling cost, the popularity of masonry units using cinders has helped to raise their price.

A lightweight, strong, and porous aggregate, cinders are chiefly used to make masonry units, popularly called "cinder blocks". They make an attractive and relatively inexpensive unit, being as strong as concrete made from sand and gravel, considerably lighter, and possessing better qualities of insulation and sound-deadening.

Cinder blocks can be used nearly any place where concrete blocks are adaptable. Many examples of buildings using these units can be found in areas where cinders are economically available.

Cinders used for testing were obtained from Standard Block and Supply, Lansing, Michigan. The standard practice of adding sufficient sand to fill the voids was followed.

Used alone in concrete, cinders make a very harsh mix. The addition of sand materially reduces the harshness, and controls bleeding to a great extent, but adds to the unit weight of the concrete.

The most economical combination of sand and cinders must be determined by trial mixes, because of the variation of gradation of the aggregates depending on their source.

Further work with cinder concrete should include experiments to determine:-

(1) bond strength

(2) the effect on bleeding and harshness using various combinations of sand and cinders

(3) its utility as structural member, observing:-

(a) compressive strength

(b) flexural strength

(c) insulation and accoustical properties.

EXPANDED SHALE AND CLAY

Expanded shale and clay aggregates are generally made by heating the previously crushed raw material in a rotary kiln to temperatures of plus 2000 F. The escaping gases are trapped, forming expanded cellular structures. After cooling, the aggregate is crushed and graded to various sizes.

This aggregate is commonly called Haydite, the name under which this expansion process was first patented.

Production of expanded clay aggregates is carried on throughout the country, and producing plants are generally located near acceptable deposits of shale of clay raw material.

The development of aggregates of this type is assuming extreme importance, because it means that a raw material found in many parts of the country can be used to make an aggregate which is very often superior to sand and gravel for use in concrete. Extensive investigation of other methods of expansion are presently being carried on to make more available and less expensive aggregates from shale and clay.

Expanded clay aggregate concrete approximates the strength of concrete made with sand and gravel with the same cement factor. In addition, it weighs one-third less, and is superior to conventional concrete in fireproofing, insulation against sound and heat, and durability under extreme conditions.

Concrete made with this material has found its ideal use throughout the country in all types of structures where lightness in weight is desirable or necessary. It is more expensive than conventional concrete, but because it possesses the advantages of lightness, excellent strength, fireproofness, and insulation, it very often effects economy in the long run.

Its popularity and universal use is attested to by a statement made by the Haydite producers that " nearly every city over 200,000 population in the United States and southern Canada has some Haydite concrete construction."

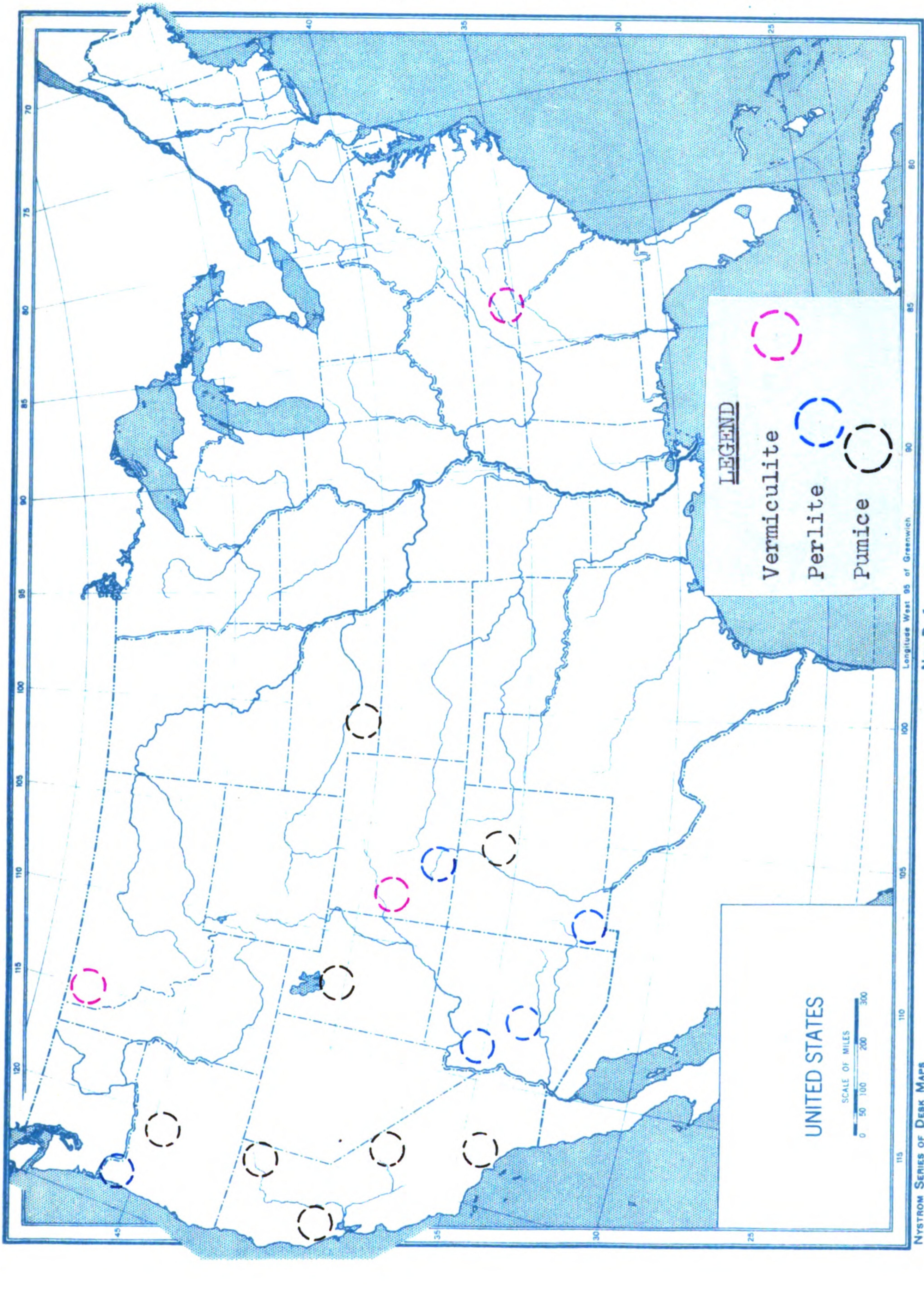
Being one of the first of the lightweight aggregates to be used in modern concrete construction, expanded shale and clay hasbeen extensively tested in monolithic concrete and in precast masonry units.

DISTRIBUTION OF LIGHTWEIGHT AGGREGATE DEPOSITS AND PRODUCERS IN THE UNITED STATES

The following map depicting the areas containing deposits of lightweight aggregate ares, and the overlay showing the location of lightweight aggregate producers, were reproduced from information obtained from the Office of the Housing Expediter, Washington 25, D.C.

LOCATION OF PRODUCERS OF LIGHTWEIGHT AGGREGATES

LOCATIONS OF DEPOSITS OF LIGHTWEIGHT AGGREGATE ORE



CONCLUSION

Each of the lightweight aggregates used in concrete has its own peculiar adaptations and limitations. Economical distribution of any lightweight material in the expanded form is limited because of high shipping costs. It is necessary to determine where each aggregate has its application.

Vermiculite concrete is best used where insulation is primary and strength is not required. Aggregate production is largely centered in the Middle West and Chicago area. The development of processing plants in other areas is necessary for more general application as a building material.

Perlite concrete possesses some strength in addition to its value as insulation. To obtain sufficient strength as a load bearing member, a high cement factor is required, making it an expensive mix. Centers of perlite aggregate production lie in the West near the perlite deposits. Wider use of perlite concrete depends on extension of producing plants into areas where this aggregate is not now available.

Pumice concrete has proven to be a valuable, all around building material. Mined in the West, pumice is used as aggregate with no expansion process required. This restricts its use to the region contingent to deposits. The Western states have used this material extensively, and it continues to be largely a localized building material.

Expanded slag aggregate concrete is strong enough for structural use and is used in masonry units. Production of slag aggregate necessarily depends upon steel production. Its demand near steel centers makes this aggregate unavailable in other parts of the country.

Cinders were first used in concrete as a cheap aggregate. Their use in masonry units continues to increase. The gradation of the cinders determines the amount of sand required, and the insulation value of cinder concrete varies inversly as the sand content.

Expanded shale and clay aggregates used in concrete have been universally accepted for structural use, being just as strong and durable as convention concrete. The producers are presently spread thinly over the country. The expansion process is controlled by patents, but extensive investigation of cheaper methods of production are in progress. The development of additional production facilities would add materially to its use for concrete by making it available.

It is evident that lightweight concrete possesses advantages over conventional concrete. It is important, too, that the limitations of the individual lightweight concretes be realized. General use of this advantageous building material will increase as it becomes more available and its qualities become known.

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ZONOLITE CONCRETE, Universal Zonolite Insulation Company

HAYDITE MANUAL,

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Much of the information was supplied by the companies in the form of correspondence, and miscellaneous brochures and booklets too numerous to list.