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TESTS OF HOLLOW BUILDING TILES

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FIG. 1.—Tiles (from left to right) 4 by 5 by 12 inches, type 1; 3 by 12 by 12 inches, type 2; 4 by 12 by 12 inches, type 1; 4 by 12 by 12 inches, type 2; 6 by 12 by 12 inches, type 1; 6 by 12 by 12 inches, type 2; 6 by 12 by 12 inches, type 3; 8 by 12 by 12 inches, type 1; 8 by 12 by 12 inches, type 2; 8 by 12 by 12 inches, type 3.

FIG. 2.—Tiles (from left to right) 10 by 12 by 12 inches, type 1; 10 by 12 by 12 inches, type 2; 10 by 12 by 12 inches, type 3; 12 by 12 by 12 inches, type 1; 12 by 12 by 12 inches, type 2; 12 by 12 by 12 inches, type 3.

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By Bernard D. Hathcock and Edward Skillman

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I. INTRODUCTION

Hollow building tile has attained a place of considerable distinction as a structural material, and is used to-day for a variety of purposes, although it was comparatively unknown a few decades ago. Originally it was used mostly for its fire-resisting properties, but, as its other advantages have become more generally recognized, its range of usefulness has been broadened to a great extent. The following are some of its principal advantages: (1) It requires comparatively less labor in construction, as the space occupied by one tile is quite large; (2) it is relatively impervious to moisture; (3) it possesses good heat-insulating qualities; (4) it effects a saving in clay compared to solid brick because of the hollow cells of the tiles and a consequent reduction in the cost of transportation; (5) it possesses good fire-resisting properties; (6) it is a poor conductor of sound; and (7) it has sufficient strength to meet the needs of building practice under the limitations of adequate specifications. Of these several advantages this paper is limited to a discussion of the one pertaining to the strength of the tiles.

Tiles are made of red and buff-burning clays and sometimes fire clay possessing sufficient plasticity for molding into shapes and sizes according to their particular use. Sufficient water is added to the clay to insure a plastic state after kneading. Then it is

molded by being pressed through a die of the desired shape and size, dried by hot air in tunnel driers, and burned in some form of kiln, usually of the down-draft type. The temperature of the burning process is moderate, ordinarily between 1900 and 2300° F, which is well beyond the stage of initial vitrification of the clay but rarely high enough to complete vitrification. Tiles are made with several degrees of porosity which are produced by burning to different temperatures or sometimes by mixing sawdust with the clay before molding. The sawdust burns out during the firing process and leaves small cavities throughout the structure. Very porous tile is light in weight and a splendid fire resistant, and is used only where strength is of minor consideration. Dense or only slightly porous tile is much heavier and stronger, and is generally used for exterior walls where strength is the principal determining factor.

The properties of the clays used and the degree of burning introduce factors which greatly influence the strength and the possible absorption of the tiles. Different manufacturers and even the same manufacturer at various times use clays which are more or less different in their characteristics; consequently the product is correspondingly varied as would naturally be expected. In a down-draft kiln the upper courses of tiles are heated to a higher temperature than the lower ones. This gives the top tiles a higher degree of burning, those near mid height a medium degree, and those near the bottom a lower degree of burning. In general, it may be said that the high-burned tiles are dark in color, the medium-burned of medium shade, and the low-burned light. However, this is not true in every case, for the natural color of some clays or the presence of coloring matter will cause a variation. In the case of red-burning clays the color may vary from a light red to a chocolate color.

Many tests have been made upon hollow building tiles from time to time, and the results obtained are valuable, although they have been insufficient for definite conclusions, partly because so few of the tests were upon tiles of any one kind and partly because no relations were established between their properties; however, previous tests were especially useful as a guide for this series, as they indicated in a general way what was to be expected and also formed a basis for the method of procedure.

The strength and other properties determined from samples of individual tiles are not always indicative of the properties of a

finished structure; nevertheless safe design of tile construction requires a thorough knowledge of the average strength of the individual tiles and the possible variations in order that allowances may be made by applying the proper factor of safety. Besides the need of tests from a designer's viewpoint, they are of great importance if not absolutely imperative in the formulation of building codes which pertain to tile construction. Of necessity these codes should be based only upon sound knowledge, as they represent the interest of the builder, the owner, and the public in general.

The tests collated in this paper were executed with such care and discretion as is ordinarily warranted in laboratory work of this nature, and the results obtained are as consistent as can reasonably be expected if due allowance is made for the numerous factors introduced by the materials used and the processes of manufacture which would naturally tend to vary the physical properties of the tiles.

The tiles used in these tests were manufactured in the State of Ohio and generously supplied to the Pittsburgh branch of the Bureau of Standards by the National Fire Proofing Co.

II. SCOPE OF THE TESTS

The tests made upon a material are, as a rule, those which are closely related to its intended use, and with this in mind the tests described in this paper are limited to those of compression and absorption. The total number of tests performed is approximately 250, of which the majority were of tiles in compression. Stress-strain readings were taken upon 114 of these for moduli of elasticity determinations. To establish the relationship existing between the strength and porosity about 70 absorption tests were made upon samples taken from tiles previously tested in compression.

The various sizes and types of tiles tested, arranged according to their structure, are shown in Figs. 1 and 2 (frontispiece) in which all the tiles are lying on edge. Also the tiles were graded according to their color as dark, medium, or light, corresponding to the variations produced by burning as described in the introduction. The tiles tested were made with few exceptions from clay of the buff-burning variety, and the colors given above indicate variations in the buff color; that is, they correspond respectively to dark buff, medium buff, and light buff.

III. GENERAL PROCEDURE OF TESTS

1. MEASURING AND WEIGHING OF TILES

It was necessary that an accurate determination be made of the net sectional area of each tile as a basis for the computation of the increments of loading and the unit loads. This was done by measuring the walls and partitions of the tiles with calipers and computing the sectional area from these measurements. The product of the sectional area taken laterally with respect to the cells and the length gave the actual volume of material in a tile. The actual volume of material in a tile divided into its weight gave the weight per cubic unit of the constituent material.

2. COMPRESSION TESTS

Previous to the actual testing, the tiles were capped with plaster of Paris to insure a uniform bearing in the testing machine. Plugs were also set in the tiles for compressometer readings. The type of compressometer used was the 8-inch Berry strain gage, and readings were taken with it near the four corners of every tile upon which stress-strain relations were desired. The testing machines used were of the Olsen universal type.

IV. DETAILS OF COMPRESSION TESTS

The sectional area and weight of each tile were determined as previously described. Then two small holes 8 inches from center to center were drilled with a small air-hammer drill near each corner of the tiles upon which stress-strain measurements were to be made. There were then placed in these holes, with plaster of Paris, small brass plugs three-sixteenths of an inch in diameter by three-eighths of an inch long, with appropriate holes for setting the gage.

The plaster of Paris caps were applied to each tile in the following manner: The surface of a smooth plate of steel was well coated with engine oil. Then a small quantity of a plastic mixture of plaster of Paris and water was spread on it in a space slightly larger than the end or face of the tile to be capped, and the tile was forced down into the mass. Care was taken that the axis of the tile remained vertical. The plaster mixture hardened in a short time, and the tile was slipped horizontally from the plate. The other end or opposite side was capped in the same manner. Special care was exercised to obtain caps of uniform thickness with smooth surfaces, and yet keep them as thin as possible.

In testing, each tile was placed in the machine on a hemispherical bearing block in such a manner that its vertical axis coincided with an imaginary vertical line passing through the center of the movable head. The tile and the upper part of the bearing block were rotated slowly as the movable head was brought in contact with the tile in order to secure the best bearing possible.

The speed of the moving head during a test was not less than 0.01 inch nor more than 0.05 inch per minute. The slowest speed was that of the 100 000-pound-capacity Olsen universal machine, and the fastest was that of the 600 000-pound-capacity Olsen universal machine.

No strain readings were taken in tests where the maximum height of the specimen was less than 10 inches, but where the specimen was 10 inches or more in height strain readings were taken with the 8-inch Berry gage, beginning with an initial load of 100 pounds per square inch of net sectional area and continued at increments of 500 pounds per square inch until failure was approached.

V. ABSORPTION TESTS

Three pieces were selected from each tile upon which the absorption determination was desired. Two of the three pieces were taken from opposite ends of the specimen and from different webs, and one from the middle portion. The pieces were approximately square and ranged from 12 to 20 square inches area of face and were free from cracks or fissures from the breaking in the compression test.

Preparatory to the absorption tests, all the specimens were first weighed and then dried over night in a gas oven at a temperature of about 120° C. After removal from the oven, the specimens were allowed to cool to room temperature and then were reweighed. As the second weighing closely checked the first in each case, they were immediately placed on a wire netting in a boiler, covered with distilled water, raised to the boiling point, and boiled for five hours. Then they were cooled in water to a final temperature of 10 to 15° C, removed from the water, and allowed to drain not more than one minute. The superficial water was removed with a towel, and the final weighing made at once.

The increase in weight of the piece after immersion times 100 divided by the dry weight gave the percentage of absorption.

VI. RESULTS AND DISCUSSION OF TESTS

1. WEIGHT PER CUBIC FOOT

The actual weights of the individual tiles tested ranged according to their sizes from about 9 pounds for the 4 by 5 by 12 inch to approximately 50 pounds for the 12 by 12 by 12 inch type 3. Weights of these and intermediate types are shown in Table 2, column 4. The average weight per cubic foot of the constituent material of the tiles tested was determined to be approximately 124 pounds by using the net sectional area, the length, and the weight as the basis for the computations. The maximum variations from this average were 116 and 135 pounds, or 6.5 and 8.9 per cent, respectively.

These variations from the average are not the extremes to be expected by any means, but actually represent the range in this particular lot. The variations in weight depend upon differences in the porosity caused by a nonuniformity in mixing the clay, by differences in burning temperatures, and by changes in the amount of pressure to which the clay is subjected while being molded, for the greater the pressure the more dense or compact it will be, and vice versa. Also different clays in their natural state are quite variable in their densities within certain limits; consequently corresponding variations are to be expected in the weight of tiles made from them regardless of the other factors. However, the greatest variation in weight is produced by mixing sawdust in different percentages as desired with the clay before burning. This is especially true in the case of porous and semiporous tile, but does not relate to the results obtained upon the dense wall tiles of this series of tests. Thus, for other lots of tiles, the average might be expected to deviate from that given above in accordance with the kinds of clays used, the pressure applied during the molding, and the degree of artificial porosity.

2. COMPRESSION TESTS

Table 1 gives the general results of the compression tests of the various sizes and types of tiles, including the position in which tested, the color, the net sectional area, the load at incipient failure, the maximum load sustained, and the modulus of elasticity. The average maximum compressive strengths and the range in compressive strengths of every size and type of tile tested are shown diagrammatically in Figs. 3, 4, and 5. The average moduli and range in moduli in millions of pounds per square inch of the same tiles are shown diagrammatically in Figs. 7 and 8.

FIG. 3.—Average and range of compressive strengths in pounds per square inch of net sectional area for tiles tested on end

FIG. 4.—Average and range of compressive strengths in pounds per square inch of net sectional area for tiles tested on edge

FIG. 5.—Average and range of compressive strength in pounds per square inch for net sectional area of tiles tested flat

Table 5 shows representative logs of compression tests upon tiles 10 by 12 by 12 inches, type 3, and 12 by 12 by 12 inches, type 1, respectively, and Fig. 6 shows the corresponding stress-strain curves. Columns 3, 4, 5, and 6 of Table 5 give the actual readings of the Berry strain gage at the four corners of the tiles, and columns 7, 8, 9, and 10 give the differences in the readings. The average of the differences, corrected for the constant of the gage, divided by the gage length in inches gave the strain which is recorded in column 13. These strains were used as abscissas in

FIG. 6.—Representative stress-strain curves of tiles. (See Table 5)

plotting the stress-strain curves of which the ordinates were the applied loads in pounds per square inch.

The behavior of the other specimens was very similar to those shown; that is, the strain was approximately a linear function of the applied load from the initial load to the point of incipient failure always and often to the maximum load.

The term incipient failure is used to designate the point in the loading at which the first noticeable failure of any kind commences. Usually it was cracking accompanied by sudden and sharp reports. The exact load at incipient failure could not be definitely determined every time, but the loads given in the tables are well within 500 pounds per square inch of the truth.

The moduli of elasticity as given in Table 1 were obtained by calculation from the stress-strain data of the various tests. The modulus of elasticity is the ratio of the stress to the strain, or, in other words, the ratio of any ordinate of a stress-strain curve to the corresponding abscissa so long as the strain is a linear function of the stress. This condition held true in most of the tests to failure. The stress-strain curves of Fig. 6 are given as representative of the entire series, for those of the other tests were all similar to them.

By referring to these same curves of Fig. 6, it will be noticed that there is no well-defined proportional limit for tiles, when proportional limit is defined as the point where the ratio of the stress to the strain ceases to be a constant. This means that the increments of strain corresponding to equal increments of loading remain approximately the same throughout the entire range of the test. This indicates, in other words, that the flow of tile material under stress is governed by its constant modulus of elasticity almost to failure, which might be expected to occur without much warning in the way of a rapidly increasing strain such as is obtained in tests of steel and various other structural materials.

Table 4 gives a summary of the results of the compression tests, including the maximum negative percentage deviations of the loads at incipient failure, the maximum loads, and the modulus of elasticity from the respective average results for every size and type of tile tested. The maximum positive percentage deviations of the results are not given, for they are of little practical value, and at the same time they are from a builder's or designer's viewpoint on the side of safety. The maximum negative percentage deviations serve as a guide in the selection of the proper factor of safety, for it is essential from the standpoint of safety and economic design to know to what extent the properties of any one tile might possibly fall below the average of that particular type.

By referring to Table 1, columns 2 and 6, a comparison of the strengths of the tiles in the three positions may be made. From the size 4 by 5 by 12 inches to and including size 6 by 12 by 12 inches, type 1, the position of greatest strength was with the tiles flat, and from size 6 by 12 by 12 inches, type 2, to size 12 by 12 by 12 inches, type 3, it was with the tiles on end. But as the smaller size tiles are rarely used flat in practice, it may be said that they as well as the longer sizes develop a greater strength on end than in any other useful position. It is common practice to

FIG. 7.—Average and range of moduli of elasticity in units of million pounds per square inch of net sectional area for tiles tested on end

FIG. 8.—Average and range of moduli of elasticity in units of million pounds per square inch of net sectional area for tiles tested on edge and flat

lay tiles either on end or on edge in a building, but according to the results of this series of tests, excepting size 4 by 5 by 12 inches, it appears that an average of about 40 per cent more strength can be developed by laying the tiles on end rather than on edge; that is, by building all walls and other structures in such a manner that the load is applied to the tiles parallel to the flues or cells. The variations from this average are large and the strengths range from equality to a ratio of nearly three.

This increase in strength of the individual tiles by testing them on end was not due alone to a greater unit compressive strength in that position, but also to the fact that the load-bearing sectional area was greater in all the tiles tested with the exception of size 4 by 5 by 12 inches. The net sectional areas of all tiles tested are shown in column 4 of Table 1. Only in the case of the 12 by 12 by 12 inch tiles would it ever be feasible to consider laying tiles flat in a structure because of the enormous waste of material for smaller sizes, but, if the 12 by 12 by 12 inch tiles were laid flat, it would be uneconomical of strength, for twice the strength could be developed by laying them on end.

There was found to be no definite relation between the loads at the incipient failure and the maximum loads sustained by the tiles; however, it may be said that the fewer the partitions of a tile the more nearly the load at incipient failure approaches the maximum load, and vice versa. This is usually true because actual failure must be imminent in the case of tiles of few partitions when incipient failure occurs. And when failure begins, the maximum load is quickly reached, for the failure of one wall or partition decreases the resistance of the tile to a great extent and causes a proportional increase in the stress upon the other walls, which in turn increases the liability of their immediate failure. When a tile has a large number of partitions and its external walls are divided into numerous sections by intercepting partitions, the failure of one or two of them would not greatly influence the remaining sound sections of walls and partitions, and would not necessarily expedite the ultimate failure.

The actual tests indicate that, on the average, incipient failure occurs at approximately 76 per cent of the maximum load, but wide variations from this average were obtained. For instance, in one case the incipient failure occurred at only 19 per cent of the maximum load, and in several tests no incipient failure was perceived before the maximum load was reached.

By reference to the curves of Fig. 9, it will be noticed that there is a general relation between the modulus of elasticity and the maximum compressive strength of the tiles. Although there are wide variations, it appears that the higher the modulus the higher the maximum compressive strength will be also. This is true in about the same proportion for any position in which the tiles are tested, for it will be noticed that the curves of Fig. 9 are approximately parallel.

The relationship existing between the compressive strength of the tiles and their colors is not very definite, but the following table shows a summary of the results obtained in this series of tests:

Compressive Strength in Pounds per Square Inch

Color	Average	Range
Dark buff.....	7510	4650-10 700
Medium buff.....	7400	4500-12 360
Light buff.....	5530	4820- 7 500

This comparison is based upon results of only the tiles tested on end, because if the result of tests on edge and on flat were used they would introduce complicating factors, especially the variable heights of the test specimens. The results indicate that the dark and the medium-burned tiles are of nearly the same strength while the light-burned tiles are on the average 25 or 30 per cent lower.

The relation of the colors of the tiles to their moduli of elasticity is in about the same proportion as between their colors and compressive strengths. The following is a summary of the results:

Modulus of Elasticity

Color	Average	Range
Dark buff.....	4 519 000	2 830 000-6 160 000
Medium buff.....	4 352 000	3 190 000-5 260 000
Light buff.....	3 074 000	1 880 000-4 170 000

These results are also based only upon tests of tile on end. The light-burned tiles, it may be noticed, develop moduli of only about 60 per cent of those of the dark and medium burned.

3. ABSORPTION TESTS

Absorption tests were not made upon all the tile upon which compression tests were made, but some were made upon every size and type of the same lot. Those selected were tested in

FIG. 9.—Relation of moduli of elasticity in units of million pounds per square inch of net sectional area for tiles tested on edge (upper curve) and on end (lower curve) to the maximum compressive strengths

compression without taking strain readings, and samples were chosen from them and tested as previously described in the "General procedure of tests." The results of these tests are given in Table 2. Table 3 shows results of similar absorption tests, but the samples were not from the same lot of tiles as those of Table 2 and strain readings were taken during the compression tests. Fig. 10 shows the relation curve of percentage absorptions to the maximum compressive strengths of the tiles. This curve was plotted according to the results given in Tables 2 and 3, and shows the above relation only in a general way, for the results have such large percentage variations that a definite law can not be drawn. However, it may be said that there is a tendency for the maximum compressive strength to vary inversely with the percentage of absorption. This is because the absorption is a function of the porosity as is also the maximum compressive strength.

The following summary of results shows the relationship of the percentages of absorption to the colors of the tiles:

Per Cent Absorption

Color	Average	Range
Dark buff.....	5.3	3.8- 6.7
Medium buff.....	7.3	5.1- 8.7
Light buff.....	9.3	7.2-10.9

Although there is overlapping in the percentages of absorption from one color to another, it may be said that, in general, judging by these results, the darker the tiles the lower the percentages of absorption are likely to be. However, as previously stated, this is not always true, because either the material or the artificial color of the tiles may often be deceptive in this respect, and it should be remembered that the tiles tested in this series were made of buff-burning clay.

VII. GENERAL SUMMARY OF TESTS

The following conclusions, drawn from the tests collated in this paper, are based directly upon the results obtained, and their applicability to other tiles must, of necessity, be dependent upon similar conditions. In drawing independent conclusions and making applications it should be borne in mind that conditions in practice are quite different from those of the laboratory, that there are many grades and varieties of tiles, and that wide variations in

FIG. 10.—Relation of percentages of absorption of tiles to their maximum compressive strengths. (See Tables 2 and 3)

the strength properties are possessed by tiles which are apparently similar.

1. The weight of the tiles per cubic unit varies greatly with the porosity of the constituent material.

2. The porosity of the constituent material of tiles is dependent upon the clays used, the percentage of sawdust mixed with the clay before burning, the pressure to which it is subjected during molding, and the degree of burning.

3. The color of the same tile material is subject to change during the burning process, and the resulting tiles may vary in color from very light to very dark shades, depending upon the temperature reached and the time of burning.

4. The strain produced by loading a tile is approximately a linear function of the applied load until failure is reached, or, in other words, the modulus of elasticity of a tile is nearly constant until failure.

5. There is no definite elastic limit for tile; that is, the proportional limit is usually coincident with failure.

6. An incipient failure is not always indicative that the ultimate failure is being approached, as it often occurs early in a test.

7. In general a tile develops greatest compressive strength when laid on end.

8. The tile having the highest modulus of elasticity may not have the greatest strength, but, in general, if the modulus is high, it is to be expected that the compressive strength will also be relatively high.

9. The dark and medium buff tiles have approximately the same relative compressive strengths and moduli of elasticity. The average compressive strength of tiles of these colors tested on end is about 7500 pounds per square inch, with a possible range from 4500 to 12 000 pounds per square inch, and the average modulus of elasticity is about 4 430 000 pounds per square inch, with a possible range from 2 800 000 to 6 200 000 pounds per square inch. The same properties of light-burned tiles are on an average about 30 per cent lower.

10. The maximum compressive strength of tiles varies approximately inversely with the percentage of absorption.

11. The percentages of absorption of tiles vary with the color. In general, the darker the tiles the lower the percentage of absorption is likely to be.

TABLE 1.—Compression Tests of Hollow Building Tile

Size of tile	How tested	Color	Net section area, in square inches	Load at incipient failure, in pounds per square inch	Maximum load		Modulus of elasticity, in pounds per square inch
					Pounds	Pounds per square inch	
Type 1:							
4 by 5 by 12 inches....	End.....	Light.....	10.11	5500	75 825	7500	4 170 000
	Do.....	Dark.....	9.98	6500	74 850	7500	4 370 000
	Do.....	do.....	9.77	6000	68 390	7000	4 410 000
Average.....				6000	73 020	7330	4 317 000
	Edge.....	Medium..	15.37	2000	69 000	4490	
	Do.....	do.....	15.37	2500	76 700	4990	
	Do.....	do.....	15.25		91 500	6000	
Average.....				2250	79 070	5160	
	Flat.....	Medium..	14.16	7000	102 350	7230	
	Do.....	do.....	14.00	7000	104 800	7490	
	Do.....	do.....	14.04		125 640	8950	
Average.....				7000	110 930	7890	
5 by 8 by 12 inches....	End.....	Medium..	16.79	4500	123 420	7350	4 020 000
	Do.....	do.....	16.79	5500	100 740	6000	3 580 000
	Do.....	do.....	16.79	5000	104 380	6220	3 300 000
Average.....				5000	109 510	6520	3 633 000
	Edge.....	Medium..	13.55	2500	65 400	4826	
	Do.....	Dark.....	14.52	2400	85 850	5910	
	Do.....	Medium..	13.55	1640	79 800	5890	
Average.....				2180	77 020	5540	
	Flat.....	Medium..	23.08		135 000	5850	
	Do.....	do.....	22.25		128 000	5780	
	Do.....	Dark.....	23.30		143 350	6150	
Average.....					135 450	5930	
3 by 12 by 12 inches..	End.....	Light.....	16.02	3000	80 580	5030	4 090 000
	Do.....	Dark.....	16.24	2500	74 000	4560	2 830 000
	Do.....	Light.....	14.99	3500	74 950	5000	4 000 000
Average.....				3000	76 510	4860	3 640 000
	Edge.....	Medium..	10.32	3000	65 500	6350	
	Do.....	do.....	10.32	2420	64 050	6210	
	Do.....	do.....	11.16	2150	41 500	3720	
Average.....				2520	57 020	5430	
	Flat.....	Medium..	21.53		137 400	6880	
	Do.....	do.....	21.99		152 100	6920	
	Do.....	do.....	21.09		128 300	6080	
Average.....					139 270	6460	
Type 2: 3 by 12 by 12 inches	End.....	Dark.....	17.42	3500	95 370	5470	4 180 000
	Do.....	Medium..	17.23	3500	77 535	4500	3 760 000
	Do.....	Dark.....	16.89	3500	89 680	5310	3 570 000
	Average.....				3500	87 530	5100	3 837 000
	Edge.....	Light.....	10.71	3540	58 000	5420	
	Do.....	Medium..	11.13	3140	49 450	4440	
	Do.....	Dark.....	10.85	3480	37 800	3480	
Average.....				3390	48 420	4450	
	Flat.....	Light.....	21.60		141 550	6550	
	Do.....	Medium..	21.72		154 300	7100	
	Do.....	Dark.....	21.03		210 000	9990	
Average.....					168 620	7550	

TABLE 1.—Compression Tests of Hollow Building Tile—Continued

Size of tile	How tested	Color	Net section area, in square inches	Load at incipient failure, in pounds per square inch	Maximum load		Modulus of elasticity, in pounds per square inch
					Pounds	Pounds per square inch	
Type 1: 4 by 12 by 12 inches	End.....	Dark.....	19.44	.....	106 920	5500	3 780 000
	Do.....	do.....	18.79	3500	135 260	7200	4 840 000
	Do.....	do.....	20.70	3000	154 700	7470	4 360 000
	Average.....	.....	.....	3250	132 290	6720	4 327 000
	Edge.....	Light.....	12.47	1120	47 000	3770	.....
	Do.....	do.....	12.24	1230	67 530	5520	.....
	Do.....	Dark.....	12.47	1450	61 650	4940	.....
	Average.....	.....	.....	1270	58 730	4740	.....
	Flat.....	Medium.....	21.84	.....	170 130	7790	.....
	Do.....	do.....	23.06	.....	112 030	4860	.....
	Do.....	Light.....	23.26	.....	146 020	6280	.....
	Average.....	.....	.....	.....	142 730	6310	.....
Type 2: 4 by 12 by 12 inches	End.....	Medium.....	20.63	5000	134 095	6500	4 640 000
	Do.....	do.....	20.58	3000	133 770	6500	4 970 000
	Do.....	Dark.....	20.27	4000	132 000	6510	4 750 000
	Average.....	.....	.....	4000	133 280	6500	4 787 000
	Edge.....	Light.....	13.26	.....	49 000	3700	.....
	Do.....	do.....	12.55	5500	105 880	8440	.....
	Do.....	Dark.....	12.72	3300	85 650	6730	.....
	Average.....	.....	.....	4400	80 180	6290	.....
	Flat.....	Medium.....	25.74	.....	185 070	7190	.....
	Do.....	do.....	25.58	.....	202 000	7900	.....
	Do.....	Dark.....	25.80	.....	192 120	7450	.....
	Average.....	.....	.....	.....	193 060	7510	.....
Type 1: 6 by 12 by 12 inches	End.....	Dark.....	22.80	6000	181 080	7940	3 760 000
	Do.....	do.....	24.90	5000	170 000	6830	4 720 000
	Do.....	Medium.....	25.56	6000	166 140	6500	3 910 000
	Average.....	.....	.....	5670	172 410	7090	4 130 000
	Edge.....	Medium.....	13.56	4000	66 770	4920	3 180 000
	Do.....	do.....	12.12	.....	66 680	5500	3 510 000
	Do.....	do.....	13.06	3830	55 040	4210	3 430 000
	Average.....	.....	.....	3920	62 830	4880	3 373 000
	Flat.....	Medium.....	23.86	.....	181 340	7600	.....
	Do.....	do.....	23.96	.....	218 650	9130	.....
	Do.....	do.....	24.62	.....	185 300	7530	.....
	Average.....	.....	.....	.....	195 100	8090	.....
Type 2: 6 by 12 by 12 inches	End.....	Dark.....	29.63	6500	305 180	10 300	5 960 000
	Do.....	do.....	31.32	8800	291 340	9300	4 700 000
	Do.....	do.....	30.03	9500	321 860	10 700	5 370 000
	Average.....	.....	.....	8270	306 130	10 100	5 343 000
	Edge.....	Light.....	19.34	3500	115 530	5970	3 970 000
	Do.....	Dark.....	18.75	3500	120 300	6420	5 540 000
	Do.....	do.....	19.06	3000	130 860	6860	5 330 000
	Average.....	.....	.....	3330	122 230	6420	4 947 000
	Flat.....	Medium.....	25.38	3300	201 820	7950	.....
	Do.....	do.....	26.11	2300	170 080	6510	.....
	Do.....	do.....	25.85	2320	158 660	6130	.....
	Average.....	.....	.....	2640	176 850	6860	.....

TABLE 1.—Compression Tests of Hollow Building Tile—Continued

Size of tile	How tested	Color	Net section area, in square inches	Load at incipient failure, in pounds per square inch	Maximum load		Modulus of elasticity, in pounds per square inch
					Pounds	Pounds per square inch	
Type 3: 6 by 12 by 12 inches	End.....	Medium..	33.78	5500	310 300	9190	6 260 000
	Do.....	do.....	33.46	6000	413 540	12 360	5 430 000
	Do.....	Dark.....	33.55	6500	319 100	9510	5 380 000
	Average.....			6000	347 650	10 350	5 690 000
	Edge.....	Dark.....	22.13	3000	142 900	6460	4 700 000
	Do.....	Medium..	22.32	3500	145 860	6540	4 550 000
	Do.....	Dark.....	21.69	1500	128 780	5930	5 700 000
	Average.....			2670	139 150	6310	4 983 000
	Flat.....	Medium..	29.87	1030	180 320	6040	.....
	Do.....	Dark.....	29.09	920	151 180	5200	.....
Type 1: 8 by 12 by 12 inches	Do.....	do.....	30.45	975	147 500	4840	.....
	Average.....			975	156 330	5360	.....
	End.....	Dark.....	26.92	3500	241 400	8970	4 540 000
	Do.....	Medium..	27.46	6500	211 920	7720	4 070 000
	Do.....	do.....	27.61	5000	208 200	7540	4 700 000
	Average.....			5000	220 510	8080	4 437 000
	Edge.....	Medium..	12.19	3940	56 180	4610	3 240 000
	Do.....	Dark.....	11.26	4170	64 300	5710	4 810 000
	Do.....	Medium..	12.00	2000	48 410	4030	2 930 000
	Average.....			3370	56 300	4780	3 660 000
Type 2: 8 by 12 by 12 inches	Flat.....	Medium..	23.66	192 200	201 340	8510	.....
	Do.....	Dark.....	22.93	217 500	192 200	8382	.....
	Do.....	do.....	23.34	203 680	217 500	9320	.....
	Average.....			203 680	.....	8740	.....
	End.....	Dark.....	37.49	2000	272 920	7280	4 540 000
	Do.....	Medium..	39.54	4000	251 340	6360	4 070 000
	Do.....	Light.....	44.52	3000	240 240	5400	2 140 000
	Average.....			3000	254 830	6350	3 583 000
	Edge.....	Dark.....	20.73	2000	112 540	5430	6 160 000
	Do.....	Medium..	20.27	1500	85 250	4210	4 070 000
Type 3: 8 by 12 by 12 inches	Do.....	Light.....	19.74	1750	99 360	5030	2 460 000
	Average.....			1750	99 050	4890	4 230 000
	Flat.....	Dark.....	27.76	3050	177 000	6378	.....
	Do.....	Medium..	27.56	3050	173 800	6310	.....
	Do.....	do.....	28.41	3050	147 640	5200	.....
	Average.....			3050	166 150	5960	.....
	End.....	Light.....	40.22	3250	211 390	5260	2 660 000
	Do.....	Medium..	42.08	270 860	270 860	6440	3 190 000
	Do.....	Light.....	41.82	201 700	201 700	4820	1 880 000
	Average.....			3250	227 980	5510	2 573 000
Type 3: 8 by 12 by 12 inches	Edge.....	Light.....	20.99	123 380	123 380	5880	3 240 000
	Do.....	do.....	21.59	86 360	86 360	4000	1 910 000
	Do.....	do.....	21.16	108 790	108 790	5140	2 660 000
	Average.....			106 180	.....	5010	2 603 000
	Flat.....	Medium..	31.03	2000	143 850	4635	.....
	Do.....	do.....	30.20	1860	124 940	4137	.....
	Do.....	Light.....	30.39	3900	157 520	5183	.....
	Average.....			2590	142 100	4650	.....

TABLE 1.—Compression Tests of Hollow Building Tile—Continued

Size of tile	How tested	Color	Net section area, in square inches	Load at incipient failure, in pounds per square inch	Maximum load		Modulus of elasticity, in pounds per square inch
					Pounds	Pounds per square inch	
Type 1: 10 by 12 by 12 inches.	End.....	Light.....	39.00	-----	193 600	4960	2 190 000
	Do.....	Dark.....	37.36	-----	281 630	7540	4 130 000
	Do.....	Medium..	37.82	3500	287 800	7610	3 970 000
Average.....				3500	254 340	6700	3 430 000
	Edge.....	Medium..	20.76	-----	108 100	5210	4 020 000
	Do.....	do.....	20.47	3950	98 340	4800	3 240 000
	Do.....	do.....	20.57	3000	129 780	6310	3 480 000
Average.....				3480	112 410	5440	3 580 000
	Flat.....	Medium..	21.55	-----	92 310	4280	3 450 000
	Do.....	do.....	21.53	2500	88 860	4130	3 720 000
	Do.....	do.....	21.20	-----	74 450	3510	2 720 000
Average.....				2500	85 210	3970	2 963 000
Type 2: 10 by 12 by 12 inches.	End.....	Medium..	41.98	3500	279 140	6650	4 810 000
	Do.....	do.....	43.00	4500	379 500	8830	3 660 000
	Do.....	Dark.....	42.76	3500	389 840	9120	6 160 000
Average.....				3830	349 490	8200	4 877 000
	Edge.....	Dark.....	20.69	3000	178 820	8640	5 430 000
	Do.....	do.....	20.57	1500	159 480	7750	4 180 000
	Do.....	Medium..	20.79	5000	148 700	7150	3 710 000
Average.....				3170	162 330	7850	4 440 000
	Flat.....	Light.....	23.48	4500	131 450	4620	2 140 000
	Do.....	Dark.....	25.69	7200	186 400	7260	4 700 000
	Do.....	do.....	26.00	2500	141 200	5430	5 750 000
Average.....				4730	153 020	5770	4 237 000
Type 3: 10 by 12 by 12 inches.	End.....	Medium..	46.38	4500	407 860	8792	4 230 000
	Do.....	do.....	48.60	6500	407 440	8382	3 930 000
	Do.....	do.....	48.17	-----	419 040	8706	3 550 000
Average.....				5500	411 450	8630	3 903 000
	Edge.....	Medium..	22.87	-----	128 440	5614	3 400 000
	Do.....	Dark.....	22.81	3500	127 920	5607	3 866 000
	Do.....	Medium..	23.58	-----	127 240	5394	2 720 000
Average.....				3500	127 870	5540	3 327 000
	Flat.....	Medium..	30.96	2000	133 900	4330	3 760 000
	Do.....	do.....	30.19	2000	144 420	4780	4 490 000
	Do.....	Dark.....	30.23	1500	131 060	4340	6 060 000
Average.....				1830	136 460	4480	4 770 000
Type 1: 12 by 12 by 12 inches.	End.....	Dark.....	45.10	5000	277 520	6153	4 030 000
	Do.....	Medium..	47.38	6000	348 000	7350	4 070 000
	Do.....	do.....	42.52	5200	303 200	7130	5 540 000
Average.....				5400	309 570	6880	4 547 000
	Edge.....	Medium..	22.26	2500	115 800	5202	3 970 000
	Do.....	do.....	22.68	3500	122 580	5402	4 180 000
	Do.....	do.....	22.59	1500	105 020	4649	2 980 000
Average.....				2500	114 470	5080	3 710 000
	Flat ^a						

^a Same as on edge.

TABLE 1.—Compression Tests of Hollow Building Tile—Continued

Size of tile	How tested	Color	Net section area, in square inches	Load at incipient failure, in pounds per square inch	Maximum load		Modulus of elasticity, in pounds per square inch.
					Pounds	Pounds per square inch	
Type 2: 12 by 12 by 12 inches.	End.....	Medium..	47.91	5500	334 440	6980	4 180 000
	Do.....	..do.....	47.25	3500	316 450	6740	3 970 000
	Do.....	..do.....	45.78	4500	329 960	7206	4 650 000
Average.....				4500	327 620	6980	4 267 000
	Edge.....	Medium..	21.69	2500	106 950	4932	3 820 000
	Do.....	..do.....	22.09	1500	96 660	4376	2 820 000
	Do.....	..do.....	22.03		100 000	4540	2 690 000
Average.....				2000	101 200	4620	3 110 000
	Flat.....	Medium..	28.44		126 300	4442	2 590 000
	Do.....	..do.....	27.96	2500	99 690	3565	2 140 000
	Do.....	..do.....	27.64		133 980	4848	3 710 000
Average.....				2500	119 990	4290	2 813 000
Type 3: 12 by 12 by 12 inches.	End.....	Light.....	55.69	5500	353 220	6342	2 870 000
	Do.....	..do.....	55.30	2000	312 500	5650	3 240 000
	Do.....	..do.....	55.64	3500	296 200	5324	3 500 000
Average.....				3670	320 640	5770	3 203 000
	Edge.....	Light.....	30.91	3400	119 620	3870	2 090 000
	Do.....	..do.....	30.27	2400	135 700	4483	2 770 000
	Do.....	Medium..	28.18	2000	146 190	5188	3 970 000
Average.....				2600	133 840	4510	2 943 000
	Flat.....	Medium..	28.30	4000	126 550	4472	3 600 000
	Do.....	Light.....	29.97	1670	104 315	3481	2 090 000
	Do.....	Medium..	29.37	2200	146 500	4988	3 240 000
Average.....				2620	125 790	4310	2 977 000

TABLE 2.—Absorption Tests

Size of original tile	Color	Net section area, in square inches	Weight, in pounds	Load at incipient failure, in pounds per square inch	Maximum load		Absorption (per cent)
					Pounds	Pounds per square inch	
Type 2:							
4 by 5 by 12 inches.....	Dark.....	10.9	9.25	4130	58 950	5420	6.7
	Medium..	10.6	9.12	5750	68 000	6420	8.6
Average.....		10.8	9.19	4940	63 475	5920	7.7
4 by 12 by 12 inches.....	Dark.....	20.8	19.40	6540	166 000	7980	6.1
	Do.....	22.8	19.60	6280	177 300	7780	6.0
	Medium..	22.3	19.38	5160	158 450	7100	6.2
Average.....		22.0	19.46	8990	167 250	7620	6.1
Type 3:							
6 by 12 by 12 inches.....	Dark.....	37.6	32.70	7030	376 000	10 000	3.8
	Medium..	38.8	31.65	6700	284 000	8400	5.1
	Dark.....	37.6	31.70	7580	335 000	8920	3.8
Average.....		38.0	32.02	7100	331 670	9110	4.2
8 by 12 by 12 inches.....	Light.....	44.7	36.80	6260	284 000	6350	10.4
	Medium..	42.7	37.20	8630	374 200	8770	8.7
	Light.....	42.7	35.65	5330	227 600	5330	10.9
Average.....		43.4	36.55	6740	295 270	6820	10.0
Type 1: 12 by 12 by 12 inches..	Medium..	44.2	39.50	5750	396 300	8980	6.3
	Dark.....	46.6	40.15	4200	362 700	7780	6.3
	Medium..	45.5	39.90	6070	352 500	7750	7.8
Average.....		45.4	39.85	5340	370 500	8170	6.8
Type 3: 12 by 12 by 12 inches..	Medium..	56.6	49.30	4240	341 800	6040	8.7

TABLE 3.—Absorption Tests

Size of original tile	Color	Net section area, in square inches	Load at incipient failure, in pounds per square inch	Maximum load		Modulus of elasticity, in pounds per square inch	Absorption (per cent)
				Pounds	Pounds per square inch		
Type 3:							
6 by 12 by 12 inches.....	Dark.....	33.8	7000	334 900	9910	5 130 000	4.9
	Do.....	34.1	5000	279 300	8180	4 580 000	4.6
	Medium..	33.7	4000	252 300	7480	2 700 000	4.4
Average.....		33.9	5330	288 830	8520	4 136 700	4.6
8 by 12 by 12 inches.....	Medium..	42.7	3000	217 800	5100	3 450 000	6.3
	Do.....	43.9	4940	216 550	4940	3 180 000	9.0
	Do.....	46.5	4980	232 000	4980	2 700 000	9.9
Average.....		43.7	4310	222 120	5010	3 110 000	8.4
12 by 12 by 12 inches.....	Light.....	58.1	5000	426 200	7340	3 400 000	7.2
	Do.....	63.8	5000	379 200	5940	3 570 000	8.8
	Medium..	56.9	5500	427 440	7520	3 850 000	6.3
Average.....		59.6	5170	410 950	6930	3 606 700	7.4

TABLE 4.—Summary of Results of Compression Tests

Size of tile	How tested	Average load at incipient failure, in pounds per square inch	Maximum negative deviation from the average (per cent)	Average maximum load, in pounds per square inch	Maximum negative deviation from the average (per cent)	Average modulus of elasticity, in pounds per square inch	Maximum negative deviation from the average (per cent)
Type 1:							
4 by 5 by 12 inches.....	End.....	5580	26.0	6770	19.9	4 317 000	3.4
	Edge.....	2250	11.1	5160	13.0		
	Flat.....	7000	0.0	7890	8.4		
5 by 12 by 12 inches.....	End.....	5000	10.0	6520	8.0	3 633 000	9.2
	Edge.....	2180	24.8	5540	12.8		
	Flat.....			5930	1.3		
3 by 12 by 12 inches.....	End.....	3000	16.7	4860	6.2	3 640 000	22.2
	Edge.....	2520	14.7	5430	31.5		
	Flat.....			6460	5.9		
Type 2: 3 by 12 by 12 inches..	End.....	3500	0.0	5100	11.8	3 837 000	7.0
	Edge.....	3390	6.3	4450	21.8		
	Flat.....			7550	13.3		
Type 1: 4 by 12 by 12 inches..	End.....	3250	8.3	6720	18.2	4 327 000	12.6
	Edge.....	1270	11.8	4740	20.4		
	Flat.....			6310	23.0		
Type 2: 4 by 12 by 12 inches..	End.....	6495	53.8	7060	7.9	4 787 000	3.1
	Edge.....	4400	25.0	6290	4.1		
	Flat.....			7510	4.3		
Type 1: 6 by 12 by 12 inches..	End.....	5670	13.4	7090	8.3	4 130 000	9.0
	Edge.....	3920	2.3	4880	13.7	3 373 000	5.1
	Flat.....			8090	6.9		
Type 2: 6 by 12 by 12 inches..	End.....	8270	21.4	10 100	7.9	5 343 000	12.0
	Edge.....	3330	10.0	6420	7.0	4 947 000	19.8
	Flat.....	2640	12.9	6860	10.6		
Type 3: 6 by 12 by 12 inches..	End.....	6140	34.8	9330	19.8	4 913 000	45.0
	Edge.....	2670	43.8	6310	6.0	4 983 000	8.7
	Flat.....	975	5.6	5360	9.7		
Type 1: 8 by 12 by 12 inches..	End.....	5000	30.0	8080	6.4	4 437 000	8.3
	Edge.....	3370	40.7	4780	15.7	3 660 000	19.9
	Flat.....			8740	4.1		
Type 2: 8 by 12 by 12 inches..	End.....	3000	33.3	6350	15.0	3 583 000	40.3
	Edge.....	1750	14.3	4890	13.6	4 230 000	41.8
	Flat.....	3050		5960	12.7		
Type 3: 8 by 12 by 12 inches..	End.....	4770	37.2	5750	16.2	2 841 500	33.8
	Edge.....			5010	20.2	2 603 000	26.6
	Flat.....	2590	28.2	4650	11.1		
Type 1: 10 by 12 by 12 inches..	End.....	3500		6700	26.0	3 430 000	36.2
	Edge.....	3480	13.8	5440	11.8	3 580 000	8.9
	Flat.....	2500		3970	11.6	2 963 000	8.2
Type 2: 10 by 12 by 12 inches..	End.....	3830	8.6	8200	18.9	4 877 000	25.0
	Edge.....	3170	52.6	7850	8.9	4 440 000	16.4
	Flat.....	4730	4.7	5770	20.0	4 237 000	49.5
Type 3: 10 by 12 by 12 inches..	End.....	5500	18.2	8630	28.8	3 903 000	9.0
	Edge.....			5540	2.6	3 327 000	18.2
	Flat.....	1830	18.0	4480	3.3	4 770 000	21.2
Type 1: 12 by 12 by 12 inches..	End.....	5370	21.8	7530	18.3	4 547 000	11.4
	Edge.....	2500	40.0	5080	8.5	3 710 000	19.7
	Flat.....	2500	40.0	5080	8.5	3 710 000	19.7
Type 2: 12 by 12 by 12 inches..	End.....	4500	22.2	6980	3.4	4 267 000	7.0
	Edge.....	2000	25.0	4620	5.3	3 110 000	13.5
	Flat.....			4290	16.9	2 813 000	24.0
Type 3: 12 by 12 by 12 inches..	End.....	4390	54.5	6310	15.6	3 404 900	15.7
	Edge.....	2600	23.1	4510	14.2	2 943 000	29.0
	Flat.....	2620	36.2	4310	19.2	2 977 000	29.8

TABLE 5.—Representative Tests of Tile

10 BY 12 BY 12 INCHES, TYPE 3^a

Total load, in pounds	Berry Gage readings				Differences				Average of the differences	Average of the differences, corrected	Strain, in inches per inch
	A	B	C	D	A	B	C	D			
4 638	0.0306	0.0302	0.0317	0.0311	0.0000	0.0000	0.0000	0.0000	0.00000	0.00000	0.00000
23 190	.0310	.0304	.0330	.0324	.0004	.0002	.0013	.0013	.00080	.00076	.00010
46 380	.0316	.0311	.0343	.0337	.0010	.0009	.0026	.0013	.00177	.00168	.00021
69 570	.0320	.0319	.0351	.0349	.0004	.0017	.0034	.0038	.00267	.00254	.00032
92 760	.0322	.0329	.0361	.0362	.0026	.0027	.0044	.0051	.00370	.00352	.00044
115 950	.0342	.0341	.0368	.0373	.0036	.0039	.0062	.0072	.00470	.00446	.00056
139 140	.0351	.0353	.0376	.0383	.0045	.0051	.0059	.0072	.00567	.00538	.00067
162 330	.0361	.0366	.0382	.0393	.0055	.0064	.0065	.0082	.00665	.00632	.00079
185 520	.0372	.0377	.0388	.0403	.0066	.0075	.0071	.0092	.00760	.00722	.00090
208 710	.0384	.0386	.0397	.0413	.0078	.0084	.0080	.0102	.00860	.00817	.00102
231 900	.0400	.0395	.0408	.0423	.0094	.0093	.0091	.0112	.00975	.00925	.00116
255 090	.0414	.0401	.0415	.0435	.0108	.0099	.0098	.0124	.01072	.01020	.00128
278 280	.0430	.0409	.0426	.0448	.0124	.0107	.0109	.0137	.01192	.01132	.00142
301 470	.0446	.0412	.0436	.0458	.0140	.0110	.0119	.0147	.01290	.01225	.00153
407 860	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

12 BY 12 BY 12 INCHES, TYPE 1^c

Total load, in pounds	Berry Gage readings				Differences				Average of the differences	Average of the differences, corrected	Strain, in inches per inch
	A	B	C	D	A	B	C	D			
4 738	0.0290	0.0295	0.0300	0.0296	0.0000	0.0000	0.0000	0.0000	0.00000	0.00000	0.00000
23 690	.0293	.0302	.0318	.0313	.0003	.0007	.0018	.0017	.00112	.00106	.00013
47 380	.0299	.0315	.0333	.0327	.0009	.0020	.0033	.0031	.00232	.00220	.00028
71 070	.0306	.0323	.0341	.0338	.0016	.0028	.0041	.0042	.00317	.00301	.00038
94 760	.0315	.0331	.0352	.0348	.0025	.0036	.0052	.0052	.00412	.00392	.00049
118 450	.0325	.0340	.0363	.0355	.0035	.0045	.0063	.0059	.00505	.00480	.00060
142 140	.0332	.0347	.0376	.0366	.0042	.0052	.0076	.0069	.00597	.00567	.00071
165 830	.0337	.0356	.0392	.0376	.0047	.0061	.0092	.0080	.00700	.00665	.00083
189 520	.0342	.0369	.0408	.0390	.0052	.0074	.0108	.0094	.00820	.00779	.00097
213 210	.0344	.0380	.0421	.0403	.0054	.0085	.0121	.0107	.00917	.00872	.00109
236 900	.0350	.0393	.0436	.0417	.0060	.0098	.0136	.0121	.01037	.00985	.00123
260 590	.0353	.0405	.0451	.0430	.0063	.0110	.0151	.0134	.01145	.01088	.00136
284 280	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
348 000	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

^a Tested with cells vertical.^b Cracking.^c Shearing.^d Maximum load.^e Cracked with load report.^f Maximum load.

WASHINGTON, September 18, 1918.