

(Paper No. 3549.)

“Some Experiments for Determining the Elastic and Ultimate Strength of Brickwork Piers and Pillars of Portland-Cement Concrete.”

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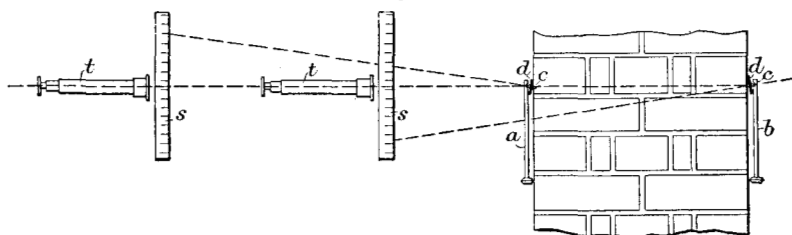
THE experiments described in this Paper formed part of a series of tests carried out by the Author and his students upon samples of brick, mortar, brickwork, concrete, and ferro-concrete. The experiments upon the larger specimens, including the brickwork piers and the specimens of concrete and ferro-concrete, were carried out in the vertical 750-ton compression testing-machine in the Materials Testing Laboratory at the Municipal School of Technology, Manchester. The elastic tests of the smaller specimens, such as individual bricks, and cubes of mortar and cement, were made in the 750-ton Wicksteed testing-machine in use in that laboratory.

Setting the Specimens in the Machines.—Some of the brickwork columns were built in position, ready for testing, on the lower platen of the testing-machine, whilst others were built outside the machine, on rigid square frames of timber, and were moved bodily into the machine after the proper interval of time had elapsed. Each specimen was first set vertically on the lower platen in a thin layer of neat cement. The upper surface, which had been left approximately true by the maker, was then covered with a thin layer of cement, and the upper platen brought down upon it with just sufficient force to render the top surface true. Before bringing down the table a thin sheet of greased millboard was interposed between the metal and the cement to prevent the latter from adhering to the platen, and at the same time to assist in equalizing the stress on the specimen. The specimens of concrete and mortar, as well as the bricks, were set in quick-setting plaster-of-Paris. Both these methods of

bedding were found to give fairly uniform distribution of the stress.

Measurement of the Compressive Strains.—In nearly all the tests recorded in this Paper, the compressions of the specimens due to the loads imposed were observed and measured by means of the Martens mirror-extensometer. The arrangement adopted for measuring the strains in a brick column by means of this instrument is shown in *Fig. 1*. Two rigid bars, *a* and *b*, are held in position, against the front and back of the column respectively, by means of light springs. Each of these bars carries at its lower end, and rigidly attached to it, a circular knife-edge, which is pressed against the material of the specimen by the spring. The upper end of each bar is provided with a groove, in which rests one edge of a short prism, *c*, of hardened steel, having a diamond-shaped section, and the other edge of this prism or double knife-edge is held by the pressure of the spring-clip against the surface of the

Fig. 1.



specimen. The measuring-bars, *a* and *b*, when adjusted in their proper positions, lie parallel to the axis of the specimen, and a plane containing the two edges of the rocking-prism, *c*, should be approximately normal to the axis of the specimen. At the end of an axial extension of the rocking-prism is carried a small plane mirror, *d*, which is capable of rotation about either of two axes at right angles, one of which is the axis of the prism. Two telescopes, one for each mirror, are carried on a tripod at *t*, and to each of these is attached a scale *s*. The diaphragm of each telescope is fitted with a horizontal cross-wire. When the instrument has been finally adjusted, each scale is observed through a telescope, its image being reflected from the face of the corresponding mirror; the cross-wire in the diaphragm of the telescope appears to lie across the scale, and the reading given by this cross-wire on the scale provides a measure of the compression of the specimen. As the load on the specimen increases, the distance between the two points of contact,

namely, the sharp edge of the disk at the lower end of the measuring-bar, and the edge of the rocking-prism which touches the surface of the material, diminishes, with the result that the prism, and consequently the mirror which it carries, becomes tilted through a small angle, and a different part of the scale is seen reflected from it on looking through the telescope. In this way the apparent movement of the hair-line along the image of the scale becomes a measure of any variation in the length of the measured portion of the specimen. In the particular case in question the arm of the optical lever, or the distance between the face of the mirror and the scale, is so chosen that the numbered divisions on the scale correspond to length-variations of thousandths of an inch. Each of these numbered divisions is actually 1 centimetre in length, and is divided into millimetres. These millimetre divisions thus correspond to ten-thousandths of an inch variation in the length of the specimen, and as it is possible to subdivide these into fifths with a fair degree of certainty, length-variations of the specimen can be read to within one fifty-thousandth of an inch. This instrument can be applied to almost any kind of test-specimen, as well as to parts of structures and machines in actual use; its readings are very clear and distinct, and at the same time a high degree of precision is attained. It is not suitable for rapid work, as the setting and adjustment take some little time to effect.

Method of Carrying out the Experiments.—In nearly every case the method of carrying out an experiment was as follows:—After the bedding had been completed, and before the commencement of the experiment, the Martens mirrors were fixed on the specimen and carefully adjusted. Loads were then imposed, by uniform increments, and readings were taken on the front and back mirrors after each increment of load. Before reaching the elastic limit of the material the load was removed and the permanent set, if any, was noted. This process was repeated until several sets of readings had been obtained. Then, for the final set of readings, the loadings were continued until the material began to crack, or until the cross-wire of the telescope got beyond the end of the scale. When this point had been reached the mirrors were removed and the specimen was tested to destruction by gradually increasing the load.

Results of the Experiments.—The results of the experiments are numbered Nos. 1 to 24 inclusive. These numbers refer in most cases to individual experiments; in one or two instances groups of experiments are referred to.

Stress-strain curves have been plotted from the results of the

experiments, the stresses being given in tons per square foot and the strains in thousandths of an inch on 12 inches' length of the specimen. For purposes of comparison the same scale has been used throughout, as far as possible. In some cases curves have been plotted from all the sets of readings obtained, separate curves being plotted for the readings taken on the front and back faces of the specimen, and also for the means of the front and back readings. The readings taken on the front face are indicated by small open circles, whilst those taken on the back face are denoted by circular black spots, the mean curve being shown without any indication of the individual points. For the remaining experiments only the mean curves are given.

Limit of Proportionality.—For nearly all the materials experimented upon, the compressions were found to be sensibly proportional to the corresponding stresses during the earlier stages of the loading. This is clearly shown by the plotted diagrams. It will be seen that for a considerable period after the commencement of the loading the plotted points lie on a straight line. The point in the loading at which the line ceases to be straight and curvature begins may be taken as the "limit of proportionality." It will be observed that this limit is raised to a higher point after the first loading.

Modulus of Elasticity.—The value of the elastic modulus or coefficient has been calculated in the usual way, the stresses (S) taken being the differences between upper and lower limits of stress within the limit of proportionality, and as far apart as possible. The corresponding strains (X) were taken as the number of thousandths of an inch compression on a length of 12 inches. Where readings were taken on both front and back faces of the specimen, the mean reading was taken. In the actual experiments, measuring-bars of various lengths were used to suit the dimensions of the individual specimens, but for convenience in comparison the Author has reduced all the readings of compression to their equivalents for a uniform measured length of 12 inches.

Calculating from these stresses and strains, the elastic modulus becomes:—

$$E = \frac{12,000 S}{X} \text{ tons per square foot.}$$

The coefficient so obtained is the ordinary coefficient, or Young's modulus, E, as distinguished from what Professor Unwin calls E^t , which is calculated from strains after the permanent portion or "set" has been as far as possible eliminated. From some of the experiments described, several different values of the modulus have

been obtained, these values corresponding to the different successive loadings. It will be noticed that the permanent set is reduced with each successive loading—this reduction being most marked after the first loading—with the result that the modulus increases with each successive loading. This is not strictly true for every experiment in which several sets of readings have been taken, but it represents the general tendency. How far this reduction of set and increase of modulus might be carried by an indefinite number of successive loadings with relatively high stresses it is impossible to foretell, but the experiments appear to show that after two or three repetitions the strains become practically constant.

The Cracking-Stress.—On examining the curves it will be seen that with each successive loading the total strain corresponding to a given stress is reduced, this being probably due to a squeezing together and closing up of the interstices in the material. During the last loading previous to final destruction a point is always reached at which slight cracks begin to appear on the surface of the specimen. In most cases it was found that a warning of the approach of this point was given by slight creaking sounds being heard before any cracks could be actually seen. The load at which this cracking was first detected has been called the “cracking-load,” and from it is calculated the “cracking-stress.”

Usually very few strain measurements were possible after the cracking-load had been passed, the loads being gradually increased until a maximum was reached beyond which the load could no longer be supported by the specimen. This has been called the “crushing-load” and from it the “crushing-stress” has been calculated. A peculiarity of the plain concrete pillars tested is that they invariably failed completely at the cracking-load. In other words, the specimen collapsed on the first appearance of the minutest crack.

The following are the detailed results:—

No. 1:—

PIER OF COMMON WIRE-CUT BRICKS SET IN LIME-MORTAR.

(2 parts sand to 1 part lime.)

Tested 4 weeks after building.

Dimensions of pier:—1 foot 6 inches by 1 foot 6 inches, by 3 feet in height.

Results.

Began to crack with stress of	35·00	tons	per	square	foot.
Badly cracked	47·50	”	”	”	”
Crushed	53·00	”	”	”	”

With this specimen no attempt was made to take any measure-

ments of the elastic compressions, and the results yielded are simply those of a pier of the most ordinary soft bricks set in lime-mortar, and tested only 4 weeks after building.

No. 2 (*Fig. 2*):—

PIER OF COMMON WIRE-CUT BRICKS SET IN PORTLAND-CEMENT MORTAR.

(3 parts sand to 1 part cement.)

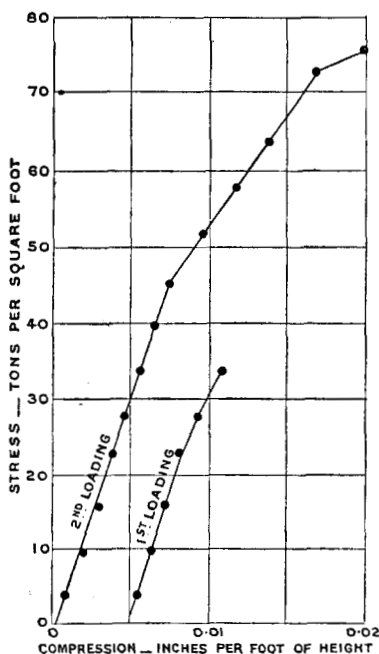
Tested 39 weeks after building.

Dimensions of pier:—1 foot $6\frac{1}{2}$ inches by 1 foot $6\frac{3}{8}$ inches, by 3 feet in height.

Martens mirrors set on back surface of pier. Measured length, 20 centimetres (7.88 inches).

Elastic modulus—	<i>Results.</i>	
	Lbs. per Square Inch.	Tons per Square Foot.
First loading, up to 40 tons per square foot	1,276,000	82,000
Second " " " " " "	1,400,000	90,000
First crack at 63.70 tons per square foot.		
Crushed " 84.30 " " " "		

Fig. 2.



When readings are taken on one face only, as in this case, there arises a possibility of error in the calculation of the modulus. The compressions as given by readings taken on one face of the specimen may or may not be the average strains. In most cases there is at least some variation between the compressions on opposite faces. In the present instance it has been necessary to assume the compression to be uniform and equal to that at the back face. That this assumption is within certain limits justifiable is shown by an inspection of the pairs of curves plotted from the experiments in which both mirrors were used.

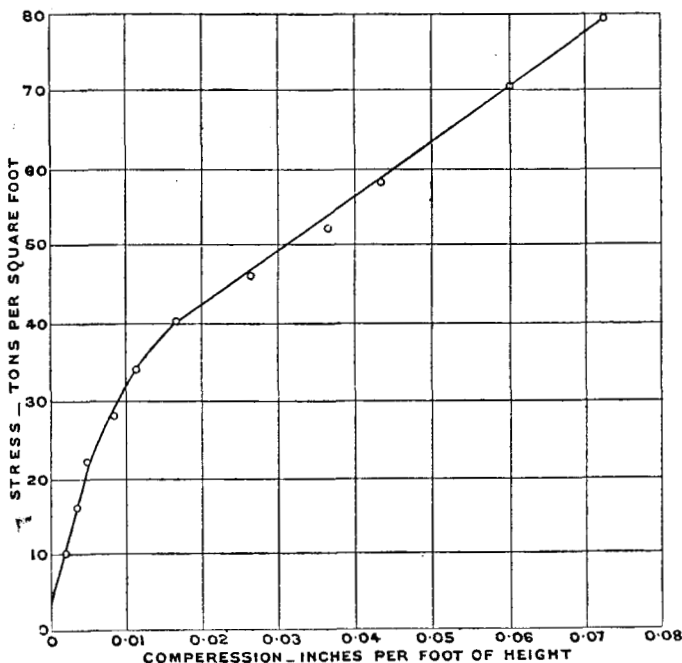
No. 3 (Fig. 3):—

PIER OF ACCRINGTON (HUNCOAT PLASTIC) BRICKS IN BLACK LIME-MORTAR.

Tested 4 weeks after building.

Dimensions :—1 foot 6½ inches by 1 foot 6½ inches, by 3 feet in height.

Fig. 3.



Results.

Elastic modulus—

[800,000] lbs. per square inch.

[51,400] tons per square foot.

Cracked at 78·30 tons per square foot.

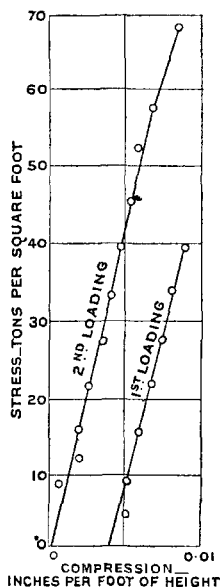
Crushed „ 95·50 „ „ „ „

The measurements of compressions were in this case taken on the whole length, and included the compression of the cement bedding at the ends. This measurement was effected by reading through a microscope attached to the lower platen on to a finely-divided steel scale attached to the upper platen of the testing-machine.

The elastic modulus arrived at is an illusory quantity, because the compressions measured are not those of the brickwork alone, but include the compressions of the packing- or setting-material

at the ends of the pier. The compression of this packing-material is relatively greater than that of the brickwork alone, with the result that the strains used in calculating the modulus are too great, and the modulus is too small.

Fig. 4.



No. 4 (Fig. 4).—

PIER OF BLUE STAFFORDSHIRE BRICKS SET IN
PORTLAND-CEMENT MORTAR.

(3 parts sand to 1 part cement.)

Tested 39 weeks after building.

Dimensions:—1 foot $6\frac{1}{2}$ inches by 1 foot $6\frac{1}{2}$ inches,
by 3 feet in height.

Martens mirrors set on front face of pier.

Length of measured portion, 20 centimetres (7.88
inches).

Results.

Elastic modulus—	Lbs. per Square Inch.	Tons per Square Foot.
First loading, up to 40 tons per square foot.	1,420,000	91,300
Second loading, up to 30 tons per square foot.	1,470,000	94,500
Second loading, 30 to 55 tons per square foot.	1,880,000	121,000

Cracked at 69.10 tons per square foot.

Crushed „ 97.70 „ „ „ „

No. 5 (Fig. 5).—

PIER OF BRINDLE-BRICKS SET IN BLACK LIME-MORTAR.

Tested 12 weeks after building.

Dimensions:—1 foot $6\frac{3}{4}$ inches by 1 foot $6\frac{1}{2}$ inches, by 2 feet 11 inches in
height.

Martens mirrors set on both front and back faces of pier.

Measured length, 20 centimetres (7.88 inches).

Results.

Elastic modulus—	Lbs. per Square Inch.	Tons per Square Foot.
First loading, up to 22 tons per square foot,	1,360,000	87,400
Second „ „ 34 „ „ „ „	1,350,000	86,800
Third „ „ 22 „ „ „ „	1,350,000	86,800
Fourth „ „ 28 „ „ „ „	1,520,000	97,700

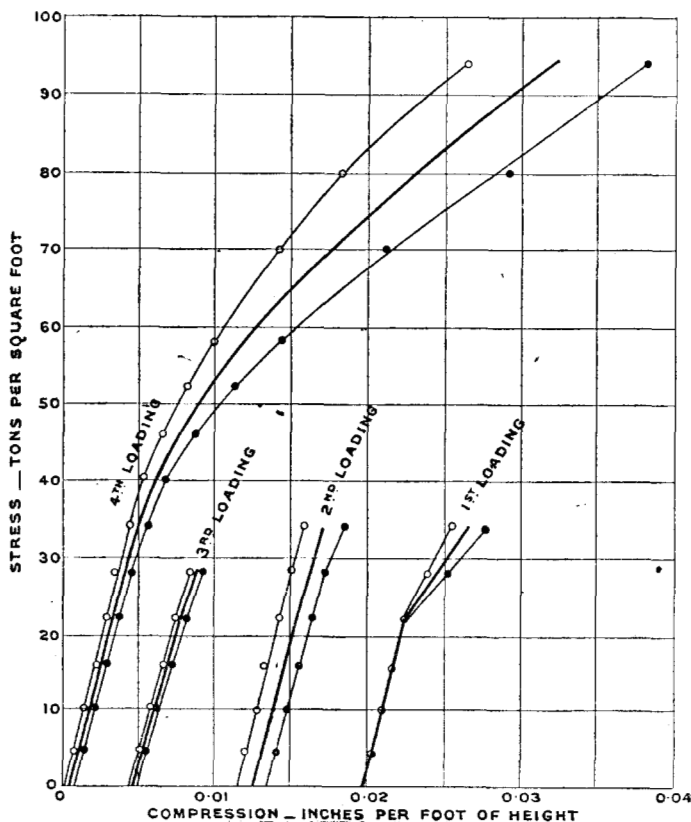
Cracked at 100.00 tons per square foot.

Crushed „ 164.60 „ „ „ „

This was the first of a set of six piers, built in pairs, of the same
kind of bricks but with three different kinds of mortar. The three

kinds of mortar used were black lime-mortar, composed of lime, sand, and ground cinder; Portland-cement mortar, made with 3 parts of sand to 1 part of cement; and Lias-lime mortar, composed of Lias-lime and sand. The piers were tested in two sets of three piers each, made with the three mortars, at intervals of approximately 3 months and 6 months after building. All four piers

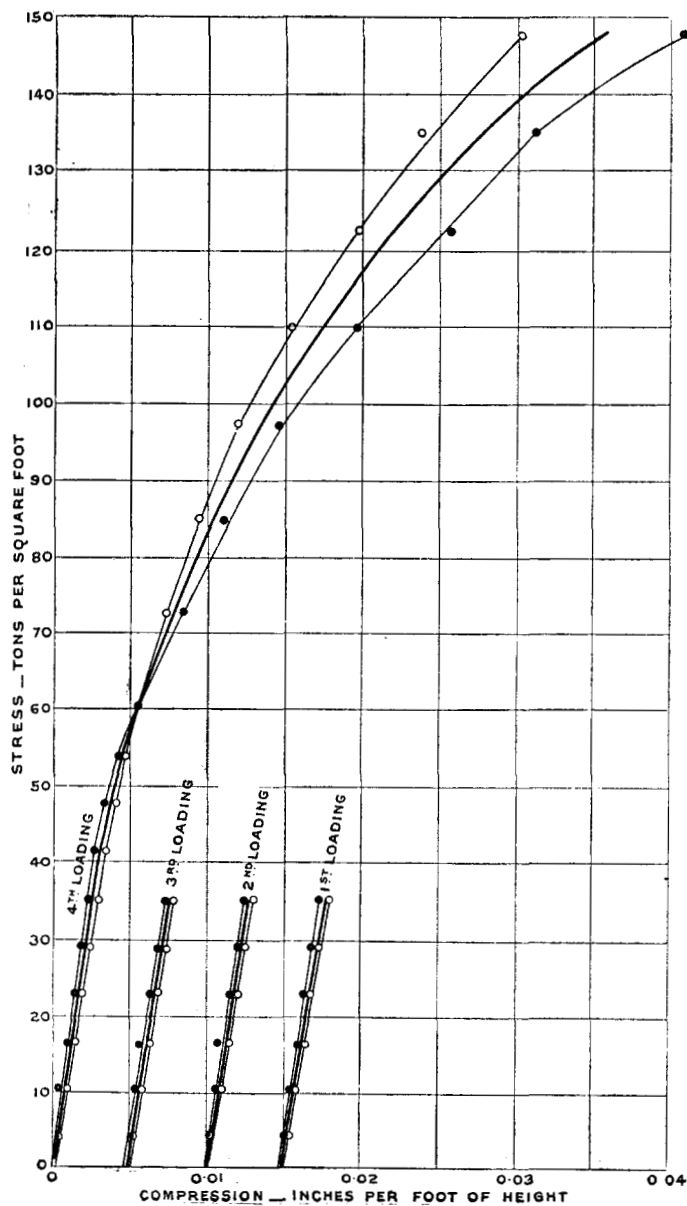
Fig. 5.



built with lime-mortar and cement-mortar gave excellent results, but those built with Lias-lime mortar were less satisfactory; this is probably accounted for by the bricklayer having mixed the mortar too long before it was to be used, with the result that it must have been partially set before it was laid on the bricks. Nos. 6, 7, 8, 9 and 10 form the remaining piers of the same series.

No. 6 (Fig. 6):—

Fig. 6.



BRINDLE-BRICK PIER SET IN BLACK LIME-MORTAR.

Tested 25½ weeks after building.

Dimensions:—1 foot 6 inches by 1 foot 5½ inches, by 2 feet 11 inches in height.

Martens mirrors set on both faces of the pillar.

Measured length 20 centimetres (7·88 inches).

Elastic modulus—

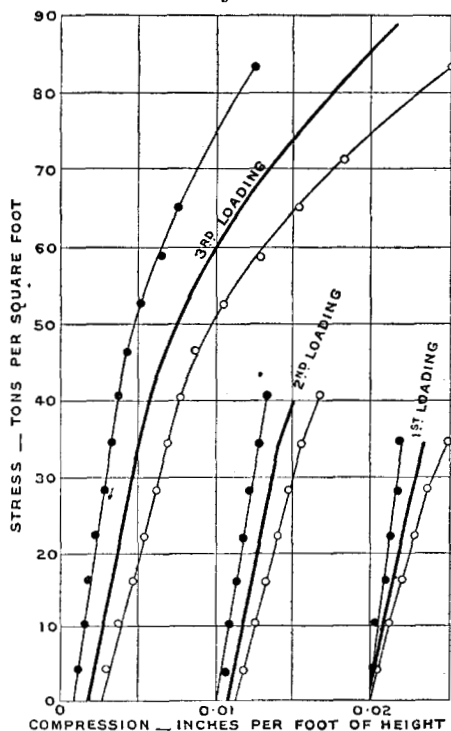
<i>Results.</i>					Lbs. per Square Inch.	Tons per Square Foot.
First loading, up to 28·97 tons per square foot					2,605,000	167,500
Second	"	"	"	"	2,508,000	161,200
Third	"	"	"	"	2,520,000	162,000
Fourth	"	"	"	"	2,330,000	149,800

Slight crack heard at 109·70 tons per square foot.

Cracked throughout, 147·20 " " "

Crushed at 185·00 tons per square foot.

Fig. 7.



No. 7 (Fig. 7):—

BRINDLE-BRICK PIER SET IN PORTLAND-CEMENT MORTAR (3 to 1).

Tested 12 weeks after building.

Dimensions:—1 foot 6½ inches by 1½ foot 6 inches, by 2 feet 11 inches in height.

Martens mirrors set on both front and back faces.

Measured length, 20 centimetres (7·88 inches).

Elastic modulus—

<i>Results.</i>					Lbs. per Square Inch.	Tons per Square Foot.
First loading, up to 16·26 tons per square foot					1,940,000	125,000
Second	"	"	"	"	1,930,000	124,000
Third	"	"	"	"	1,880,000	121,000

Cracked at 132·00 tons per square foot.

Crushed, 169·00 " " "

No. 8 (*Fig. 8*):—

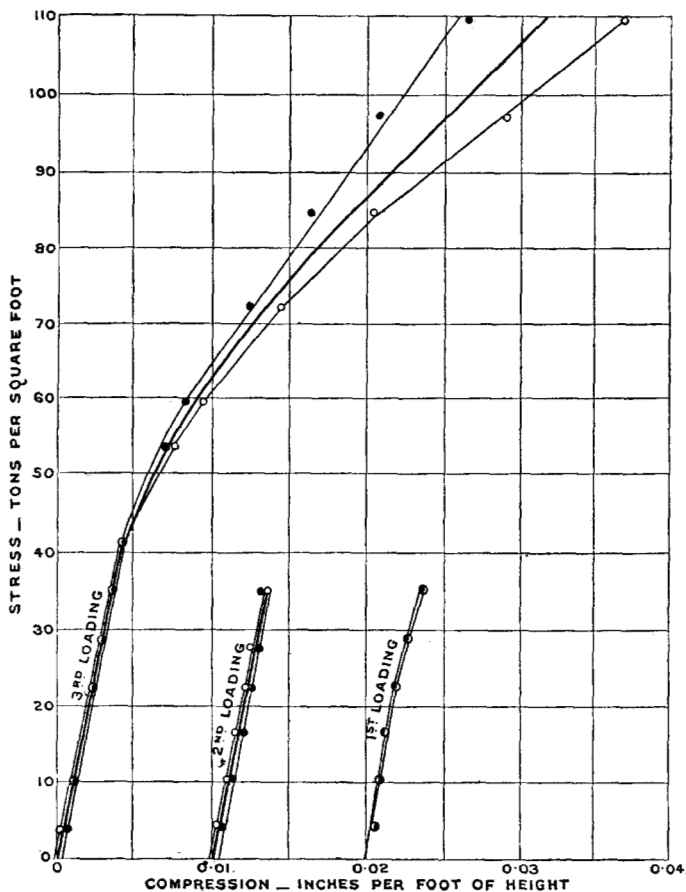
BRINDLE-BRICK PIER SET IN PORTLAND-CEMENT MORTAR.

Tested 26 weeks after building.

Dimensions:—1 foot 6 inches by 1 foot 6 inches, by 2 feet 11 inches in height.

Martens mirrors set on both front and back faces of the pier.

Measured length, 20 centimetres (7·88 inches).

Fig. 8.

Elastic modulus—

{ *Results.*Lbs. per Square
Inch.Tons per
Square Inch.

First loading, up to 28·81 tons per square foot	1,980,000	127,000
Second " " 28·81 " " " "	2,050,000	132,000
Third " " 41·25 " " " "	1,895,000	122,000

Began to crack at 90·20 tons per square foot.

Crushed at 161·30 tons per square foot.

No. 9 (Fig. 9):—

BRINDLE-BRICK PIER SET IN LIAS-LIME MORTAR.

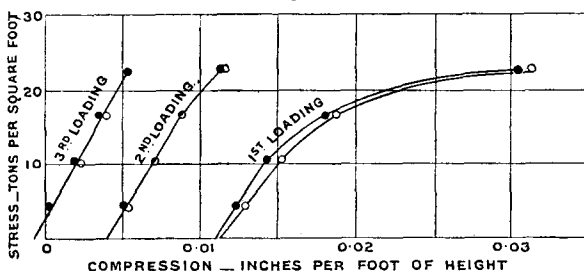
Tested 12 weeks after building.

Dimensions:—1 foot $6\frac{1}{2}$ inches by 1 foot $5\frac{1}{2}$ inches, by 2 feet 11 inches in height.

Martens mirrors set on both front and back faces of the pier.

Measured length, 20 centimetres (7·88 inches).

Fig. 9.



Results.

Elastic modulus—

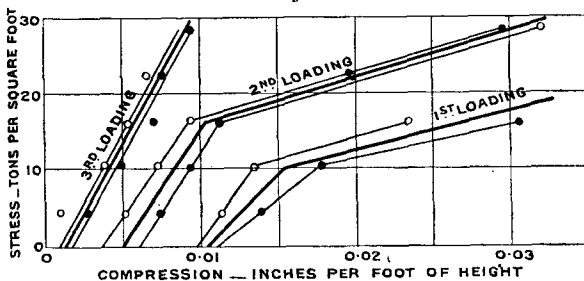
		Lbs. per Square Inch.	Tons per Square Foot.
First loading, up to 10·25 tons per square foot		543,000	34,900
Second " " 16·48 " " "		624,000	40,100
Third " " 23·60 " " "		688,000	44,200

Began to crack at 38·10 tons per square foot.

Crushed at 118·70 tons per square foot.

No. 10 (Fig. 10):—

Fig. 10.



BRINDLE-BRICK PIER SET IN LIAS-LIME MORTAR.

Tested 26 weeks after building.

Dimensions:—1 foot 6 inches by 1 foot $6\frac{1}{2}$ inches, by 2 feet 11 inches in height.

Martens mirrors set on both front and back faces of the pier.

Measured length, 20 centimetres (7·88 inches).

Elastic modulus—				Results.	Lbs. per Square Inch.	Tons per Square Foot.
First loading, up to 10·15 tons per square foot					396,000	25,500
Second " " 16·25 " " " "					598,000	38,500
Third " " 28·50 " " " "					638,000	41,000
Cracked at 40·70 tons per square foot.						
Crushed „ 101·70 " " " "						

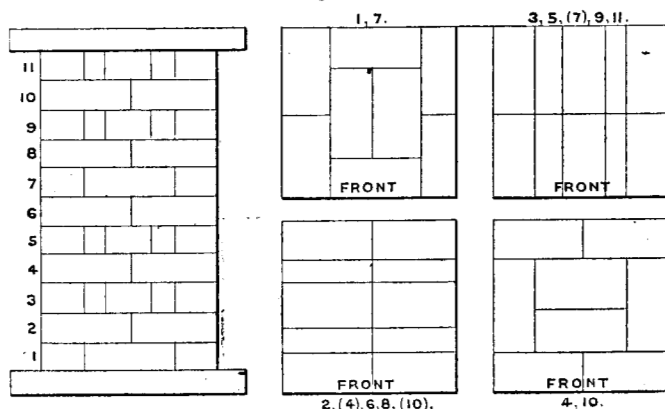
All the brickwork piers experimented upon in the foregoing tests (Nos. 1 to 10) were built by working bricklayers, who freely used their own discretion as to the bond and other details of construction. This was done so that the work might be as nearly as possible the kind of brickwork usually met with in ordinary engineering practice. The actual bond used was in the main that shown in *Figs. 11*.

The results of the tests of brickwork piers are summarized in the following Table:—

No.	Kind of Bricks.	Kind of Mortar.	Weeks after Building.	Approximate Limit of Proportionality.	Cracking Stress.	Crushing Stress.	Elastic Modulus.	
				Tons per Sq. Foot.			Tons per Sq. Foot.	Lbs. per Sq. Inch.
1	Common wire-cut	Lime	4	..	35	53
2	Common wire-cut	Portland-cement	39	25	64	84	82,000	1,276,000
3	Accrington	Black lime	4	24	78	96	90,000	1,400,000
4	Blue Staffordshire	Portland-cement	39	55	69	98	51,400	[800,000]
							91,300	1,420,000
							94,500	1,470,000
							121,000	1,880,000
							87,400	1,360,000
5	Brindle	Black lime	12	22	100	165	86,800	1,350,000
							86,800	1,350,000
							97,700	1,520,000
							167,500	2,605,000
6	"	" "	25½	40	110	185	161,200	2,508,000
							162,000	2,520,000
							149,800	2,320,000
7	"	Portland-cement	12	35	132	169	125,000	1,940,000
							124,000	1,930,000
							121,000	1,880,000
							127,000	1,980,000
8	"	" "	26	30	90	161	132,000	2,050,000
							122,000	1,895,000
							34,900	543,000
9	"	Lias-lime	12	10	38	119	40,100	624,000
							44,200	688,000
							25,500	396,000
10	"	" "	26	10	41	102	38,500	598,000
							41,000	638,000

Nos. 11, 12, 13 and 14 (*Fig. 12*). Single bricks, similar to those used in the construction of the piers.—The elastic tests were made with the bricks placed on end, with the Martens mirrors attached.

Figs. 11.



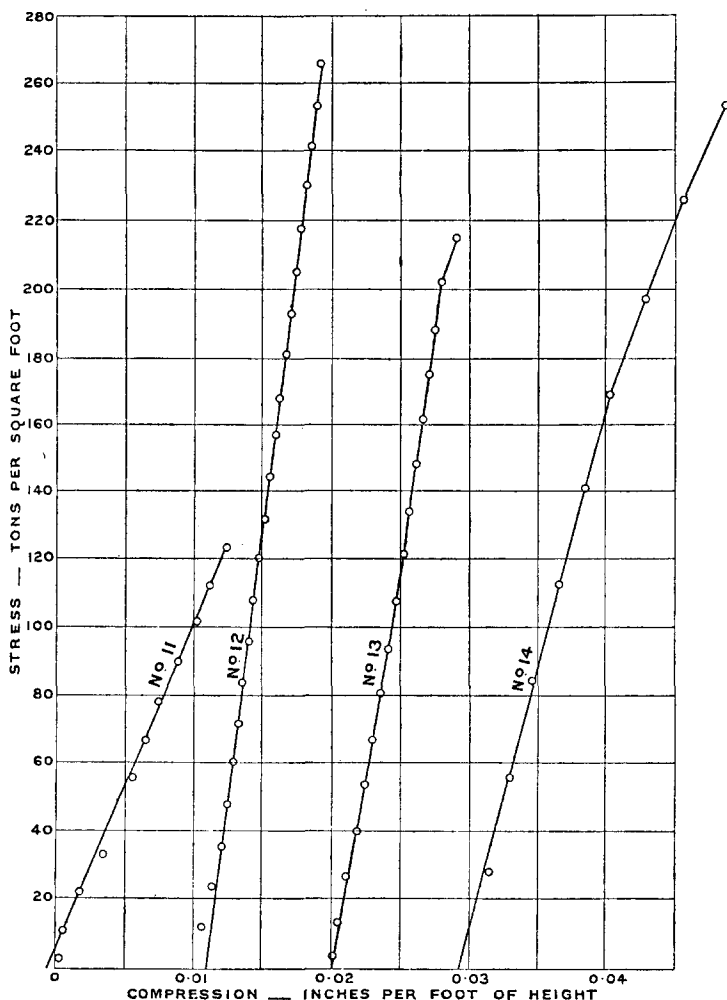
The crushing-tests were made with the bricks set on their proper beds in plaster-of-Paris.

The curves plotted in *Fig. 12* refer to the four kinds of bricks tested. The principal results obtained from these tests are given together in the following Table :—

No.	Kind of Brick.	Dimensions.	Elastic Modulus.	Cracking Stress.	Crushing Stress.
		Inches.	Lbs. per Square Inch.	Tons per Sq. Foot.	Tons per Sq. Foot.
11	Common wire-cut (Manchester).	$8\frac{3}{4} \times 4\frac{3}{8} \times 3$	1,760,000	87	264
12	Accrington (Huncoat Plastic).	$8\frac{3}{4} \times 4\frac{3}{8} \times 3$	3,160,000 (up to 36 tons per sq. foot). 5,920,000 (from 36 tons to 200 tons per sq. foot). 4,430,000 (0 to 100)	118	250 (mean of three tests)
13	Blue Staffordshire.	$9 \times 4\frac{1}{2} \times 3$	5,280,000 (100 to 200) 2,830,000 (up to 160 tons per sq. foot)	82	356
14	Blue Brindle (Staffordshire).	$8\frac{7}{8} \times 4\frac{1}{4} \times 3$	2,830,000 (up to 160 tons per sq. foot)	204 (mean of nine tests)	485 (mean of nine tests)

Nos. 15 and 16 (Fig. 13). Cubes made from the lime-mortar and cement-mortar used in building the piers.—These experiments are not satisfactory, as the results of tests of cubes of a mortar are not

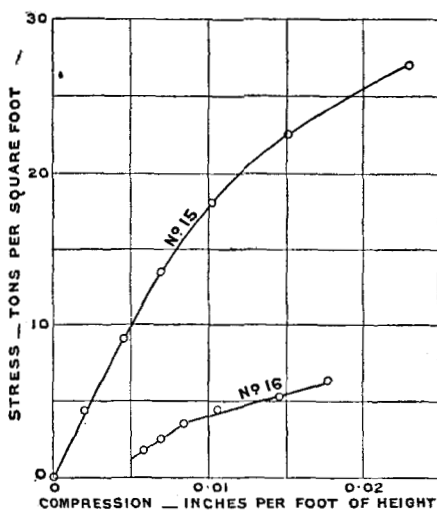
Fig. 12.



comparable with the results of loading the same material when used to form the joints of brickwork, except perhaps as regards the elastic modulus. This is not only by reason of the difference

in dimensions, but also because the material resulting from setting in the form of a relatively large cube under no pressure is not the same as that obtained from the setting which takes place in thin layers between bricks under some small pressure.

Fig. 13.



The curves obtained from these experiments are shown in Fig. 13, and the results are summarized in the following Table:—

No.	Composition.	Dimensions.	Elastic Modulus.	Cracking Stress.	Crushing Stress.
15	Black lime-mortar (lime, sand, and ground cinder), 28 weeks old	Inches. 4 × 4 × 4	Lbs. per Square Inch. 352,000	Tons per Sq. Foot. 31.8	Tons per Sq. Foot. 31.8
16	Portland-cement mortar (3 sand, 1 cement) 24 weeks old	4 × 4 × 4	131,500	10.0	10.0

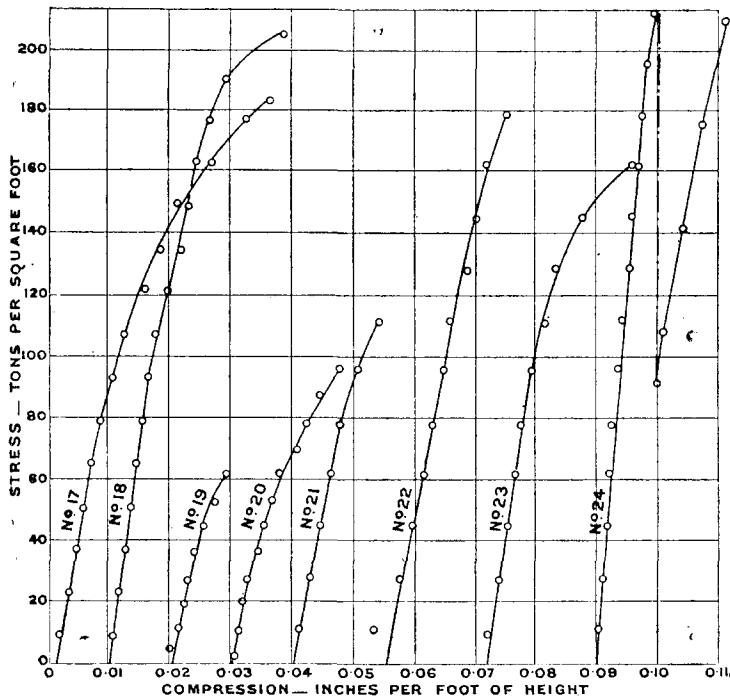
Nos. 17 to 24 (Fig. 14). Cubes and columns of Portland-cement concrete, and pillars of reinforced concrete.—The curves obtained are shown in Fig. 14, and the principal results are given in the following Table:—

No.	Material.	Age. Weeks.	Approximate Limit of Proportionality.	Cracking Stress.	Crushing Stress.	Elastic Modulus.	
						Tons per Sq. Foot.	Lbs. per Square Inch.
17	Concrete cube, dock gravel and finely - ground cement (5 to 1).	13	65	183	211	105,000	1,633,000
18	Concrete cube; dock gravel and ordinary cement (5 to 1). . . .	34	95	196	225	164,000	2,550,000
19	Concrete column; dock gravel and ordinary cement (5 to 1)	15	40	70	70	113,000	1,750,000
20	Ditto. . . .	27	40	101	101	118,000	1,830,000
21	Concrete column; broken sandstone and Portland cement (5 to 1) .	53	75	141	141	{ 99,000 120,000	{ 1,540,000 1,860,000
22	Reinforced concrete column; dock gravel and ordinary cement (5 to 1)	15	140	120	210	{ 113,000 142,000	{ 1,760,000 2,210,000
23	Ditto. . . .	27	109	211	236	169,000	2,630,000
24	Concrete same as No. 21. Transverse links twisted. . . .	53	190	211	343	{ 307,000 (mean of five tests)	{ 4,780,000 (mean of five tests)

Of these, *Nos. 17, 18, 19, 20, 22 and 23* are experiments taken from a series carried out by the Author in connection with the construction of the new transit-sheds for the most recently-constructed of the docks for the Manchester Ship-Canal Company. The sheds are constructed on the Hennebique reinforced-concrete system. *Nos. 21 and 24* are respectively a plain concrete and a ferro-concrete column formed of the material used in the construction of a highway-bridge in Rochdale, on the Hennebique system. The material of these specimens of concrete and ferro-concrete varies in respect of both the kind of ballast used and the make of the cement. In all cases the ballast was sufficiently small to pass through a $\frac{5}{8}$ -inch or $\frac{3}{4}$ -inch mesh, and was in some cases pebbly gravel and sand obtained in excavation for the dock, while in others it consisted of broken stone and sand. The cubes were 1 foot in length of side; the columns were all 12 inches by

10 inches in cross-section, and 3 feet in height. The ferro-concrete columns were of the standard Hennebique construction, having four bars of steel $1\frac{3}{4}$ inch in diameter placed near the corners of the pillar and running from top to bottom. At the commencement of the experiments the load was equally distributed on steel and concrete alike, but, owing to the greater compression of the concrete as compared with that of the steel, as the test proceeded

Fig. 14.



the steel carried more and more of the load until the specimen began to fail from the buckling of the bars. This buckling is partly prevented by the lateral tying together of the bars with wrappings of thin round steel placed at frequent intervals. The better results in the case of No. 24 as compared with those of Nos. 22 and 23 are in great measure due to closer spacing of the bindings and more secure fastening to prevent them being pulled open by the buckling of the bars. Where several values are given for

the elastic modulus, they refer to the values as calculated from the readings taken during the successive loadings. The curves plotted in *Fig. 14* represent the means of the back and front readings taken from the last loading.

Conclusions.—The results of the experiments upon the brickwork appear to lead to the following conclusions:—

(1) Up to loads considerably in excess of those used in actual practice the strains are sensibly proportional to the stresses.

(2) Each of the materials experimented upon possesses a fairly definite elastic modulus, under ordinary loads.

(3) With repetition of the load the strain is found to diminish, until, after three or four repetitions, it becomes sensibly constant, possibly owing to the squeezing together of the particles and the closing up of the interstices. This diminution of the strain causes a small increase in the modulus.

(4) At loads considerably in excess of working-loads, proportionality of strain to stress gradually ceases. The point at which this occurs may reasonably be called the “limit of proportionality.”

(5) The elastic properties of brickwork, as well as its ultimate strength, appear to depend less upon the bricks than upon the quality of the cementing material.

(6) In all cases the best results are obtained where the mortar employed not only provides a highly elastic bed for the bricks, but has the property of adhering to the bricks in their vertical joints, thus knitting the whole into a homogeneous material.

(7) It is reasonable to suppose—although the experiments upon this point were hardly complete enough to warrant a hasty generalization—that the more nearly the elastic coefficient of the mortar approaches that of the bricks, and the more uniform the thickness of the joints, the more uniform will be the stress upon the bricks, and consequently the stronger the brickwork.

(8) The diagrams show that with the method employed for setting the specimens in the machine a very uniform distribution of the stress is obtained.

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The Paper is accompanied by fourteen drawings, from which the Figures in the text have been prepared.
