Transverse Strength of Brick Masonry.

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INTRODUCTION.

In spite of the fact that brick masonry is very generally used in engineering structures, comparatively few experiments have been made to determine its transverse strength. In fact, this strength has not usually been counted on in designing, as so little definite knowledge was to be had concerning it. For instance, when an opening for a door or window is cut in a brick wall, it is known that the masonry immediately above is subjected to transverse strains. Transverse strains also come in walls subjected to water or wind pressure and in tall chimneys. Brick arches, which theory shows would fall, considered simply as arches, do not fall, and it is undoubtedly the transverse strength of the masonry which prevents failure.

"Much surprise was expressed, at the time, at the comparatively enormous strength of some narrow strips of brick arches, 15 feet span, and only 4½ inches thick, tested by Mr. Fairbairn; but there were no just grounds for surprise."* The surprising strength of the arch was due to the transverse strength of the masonry.

The supports of masonry over doors and windows are sometimes considered as supporting the entire weight of the masonry above them. This involves the idea of fluid brick and is fallacious. When a wall is "green" it will have to be supported above openings, but if built up slowly the supports may be removed in many cases as soon as the lower courses have set. Knowing what modulus of rupture can be relied upon, the computation is simple.

PART I.

EXPERIMENTS BY OTHERS.

Investigation shows the literature on this subject to be exceedingly limited. The experiments made have been few and poorly performed. The following references bear more or less directly

Engineering, Vol. 14, p. 73.

upon the subject: *Engineer and Architect's Journal*, vol. 1, pp. 30, 45, 102, 135, (1837); vol. 11, p. 294, (1848); vol. 14, p. 510, (1851). *Engineering*, vol. 14, p. 1, (1872); *Indian Engineering*, Jan. 9, 1892, or *Railroad Gazette*, Feb. 26, 1892.

We will give a brief account of some of the most important experiments mentioned in these articles.

BRICK AND CEMENT BEAMS.*

Three experimental brick beams were built and broken by weights applied at the center. The beams were 10 feet long, 18 inches wide, and 12 inches deep. No. 1 was built of bricks with neat cement joints. No. 2 was the same, but had five pieces of hoop iron in the joints, one at center joint and two at each of the other joints. No. 3 was built with hoop iron and lime. One object in the experiment was to ascertain the additional strength given by the hoop iron. No. 1 broke with a load of 298 lbs. S=modulus of rupture =13.8 lbs. per sq. in. The bricks themselves were broken.

No. 2 broke with a load of 4 779 lbs. The hoop iron apparently increased the strength 16 times.

THE "NINE ELMS" BRICK BEAM.

This was a brick wall 24 feet 6 inches long. Distance btween supports 21 feet 4 inches. It supported about 11 tons for two years. There were seventeen pieces of hoop iron laid longitudinally in the beam. The mortar used was 1 part Roman cement to 1 part sand. The total breaking load was 68 326 lbs. The modulus of rupture given by *Eng'r and Arch't's Jour.* is "$S=\frac{lw}{4ad^2}=641$" lbs. per sq. in. *Engineering*, vol. 14, p. 45, gives S=290 lbs. per sq. in. We believe the latter to be the correct value. "There is no doubt that the iron supported by far the greater part of the weight." Some claimed that the hoop iron added practically nothing to the strength of the beam.

"Subsequent experiments have shown that the truth was to be found between these extremes, and that the hoop iron contributed just as much, and no more, additional strength as theory would indicate. In the case of the "Nine Elms" beam this would be a comparatively small amount, since the hoop iron was of no great section and the relative elasticities of the materials are such that in no case

Eng'r. and Arch't's Jour., vol. 1, p. 30.

could a large strain be imposed upon the iron in a compound beam until after the fracture of the brick work had occurred."

EXHIBITION BEAM OF 1851.†

A brick beam, very similar to the "Nine Elms" beam, was constructed of hollow and Portland cement mortar, 1 to 1.

Dimensions: Span, 21 feet 4 inches; depth, 4 feet 6 inches; width, 1 foot 6 inches. The beam cracked when the concentrated, load reached 41 600 lbs., and broke with a load of 62 800 lbs.

There were fourteen strips of hoop iron, 1¼ inches × 1-16 inch, reaching through the beam. Seven strips were broken and seven were drawn out. Modulus of rupture = 350 lbs. per sq. in. The strength was due largely to the iron, and the experiment gives no idea of what the beam might otherwise have held.

EXPERIMENTS ON CEMENT.‡

The following experiments, a summary of which is given on page 4, were made at Great Scotland Yard:

"1. Seventeen stock bricks were cemented together with Roman cement and projected from the face of a wall. They broke down with 7 lbs. placed on the end.

"2. Eleven stock bricks, cemented together with 1 part sand and 1 part Roman cement, broke down with 7 lbs. placed on the end.

"3. Thirty-eight bricks, cemented with neat Portland cement broke down with 14 lbs. placed on the end.

"4. Thirty bricks, cemented with 1 part Portland cement and 1 part sand, broke down with 15 lbs. at the end.

"6. Twenty-five bricks, with 1 part Portland cement and 4 parts sand, broke down with 56 lbs. at the end.

"7. Twenty-six bricks, with 1 part Portland cement and 5 parts sand, broke down with 74 lbs.

"8. Sixteen bricks, with 1 part Portland cement and 1 part sand, supported at both ends, broke down with 1500 lbs. at the center."

The unreliability of these experiments is shown by a comparison of 4 and 9 with 5, 6, or 7; and by comparing 6 and 7 in the following table:

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†*Eng'r and Arch't's Jour.*, vol. 14, p. 510.
‡*Eng'r and Arch't's Jour.*, Vol. 14, p. 510.

TABLE I. TESTS OF CANTILEVER BRICK-BEAMS.*

NO. OF BEAM	NO. OF BRICKS.	CHARACTER OF MORTAR.		BREAKING LOAD.	MODULUS OF RUPTURE.
1	17	Roman Cement,	Neat.	7 lbs. at end.	13 lbs. per sq. in.
2	11	" "	1 to 1.	7 " " "	9 " " "
3	38	Portland "	Neat.	14 " " "	330 " " "
4	30	" "	1 to 1.	15 " " "	210 " " "
5	22	" "	1 to 2.	168 " " "	310 " " "
6	25	" "	1 to 4.	56 " " "	210 " " "
7	26	" "	1 to 5.	74 " " "	247 " " "
8	16	" "	1 to 1.	3000 " at center.	234 " " "

**Eng'r and Arch't's Jour.*, Vol. II.

INDIAN BEAMS‡

Thirty beams were tested. All were about 30 inches square and were broken with a span of 10 feet. They were made in Dec., 1888. One half were tested in Feb., 1889 and half in Nov., 1889. The joints were ¼ inch thick. The article does not give the character of the mortar.

Three kinds of brick were used: (A) Almost wholly of bats or new half bricks with three whole bricks in the header course every 30 inches, to insure a slight bond. (B) Whole bricks once used, called demolition bricks. (C) New whole bricks.

The beams were loaded with steel rails, laid on sleepers 4 inches by 8 inches and 16 feet long placed across the beam near the center.

In computing S the equivalent uniform load was used and the weight of the beam was included. The formula for S is

$$S = \frac{3\,Wl}{2bh^2}$$

TABLE II. STRENGTH OF INDIAN BRICK BEAMS.

PERIOD OF SETTING.		MODULUS OF RUPTURE, IN POUNDS PER SQUARE INCH.		
		CLASS A.	CLASS B.	CLASS C.
		Nos. 1 to 7 Inclusive.	Nos. 1 to 5 Inclusive.	Nos. 1 to 5 Inclusive.
70 to 76 Days.	Maximum	87.78	108.86	112.67
	Minimum.	75.74	98.86	94.00
	Average	79.78	102.86	103.34
		Nos. 8 to 10.	Nos. 6 to 10.	Nos. 6 to 10.
260 to 270 Days.	Maximum	94.00	145.51	150.00
	Minimum.	78.45	112.19	109.56
	Average	87.78	126.19	133.20

‡*Indian Engineering*, Jan. 9, 1892.

PART II.

EXPERIMENTS BY THE AUTHORS.

The following experiments were performed by the writers in the testing laboratory of the University of Illinois, and represent as nearly as may be the conditions of actual practice.

MORTAR USED.

The mortar for the first beam and first pier was made thus: One part by weight of Louisville cement to two parts of sand, *i. e.*, 1 volume of cement to 1.35 volumes of sand. The mortar for the remainder of the beams consisted of 1 volume of cement to 2 volumes of sand.

In making these experiments the mortar was never frozen although nearly reaching that temperature some of the time.

The mortar was laid within 15 or 20 minutes after water was added to the cement.

The bricks were moistened before laying and the mortar made of about the same consistency as ordinary lime mortar.

TESTS OF CEMENT.

Fineness. 93.3 % passed sieve No. 50 (2 500 meshes per square inch); 86.3 % passed sieve No. 80; 83.8 % passed sieve No. 100. This was on the basis of 100 % of original cement placed on each sieve.

Tensile Strength. The tensile strength was determined by breaking American standard briquettes on a Riehle testing machine.

TABLE III. TENSILE STRENGTH.

POUNDS PER SQUARE INCH.					
AGE—7 DAYS.			AGE—24 DAYS.		
NEAT.	1 TO 2 BY WEIGHT.	1 TO 2 BY VOLUME.	NEAT.	1 TO 2 BY WEIGHT.	1 TO 2 BY VOLUME.
79	28	19	118	38	28
61	24	16	116	35	31
74	26	19	114	35	21
81	26	14	130	39	35
74	26	17	125	40	34
74	26	17	121	37	30

TEST OF SAND.

Fineness. The sand used had all passed a No. 12 sieve (144 meshes per square inch), 98.3 % passed a No. 20 sieve; 78.3 % passed a No. 30 sieve. Coarser sand was not available.

BRICKS USED.

The bricks measured 7 inches by $3\frac{1}{2}$ to $3\frac{3}{4}$ inches by $2\frac{1}{8}$ to $2\frac{1}{4}$ inches. They were ordinary sand-molded building brick. Average weight=4.45 lbs.

Transverse Strength. Ten bricks were broken as simple beams and the following values of the modulus of rupture obtained: 606, 1 348, 606, 808, 1 313, 1 666, 1 010, 1 010, 1 010 and 960 lbs. per square inch. Mean value, 1 034 lbs. per square inch.

DESCRIPTION OF THE BEAMS.

To obtain values of the modulus of rupture of brick masonry eight beams and two piers were built and broken. The beams were broken as simple beams with concentrated load at center. The piers were first broken as cantilever beams and afterwards as simple beams.

Beam No. 1—Distance between supports=43.75 ins. Age when broken = 28 days.

The beam failed at the center, about as much from lack of cohesion in the mortar as from mortar separating from the brick. This statement will apply to all the beams. One brick was broken by tension.

Since the weight of the beam (350 lbs) acts as a uniform load, its effect is the same as 175 lbs. at the center. Hence the breaking load =1652+175=1827 lbs. Therefore,

$$\text{modulus of rupture} = \frac{6M}{d^2b} = \frac{6\times1827\times43.5}{4\times7.75\times217.56}$$

Pier No. 1. Pulled over as a cantilever beam. Age=28 days. Failed by mortar separating from brick. Weight of pier=295 lbs. Force to break=205 lbs. applied 42.5 ins. from joint of rupture. Maximum tension per sq. in.

$$=\frac{Ml}{2I}-\frac{W}{S}=\frac{205\times42.5\times11\frac{1}{2}}{2\times\frac{1}{12}\times7\frac{1}{2}\times(11\frac{1}{2})^3}-\frac{295}{7\frac{1}{2}\times11\frac{1}{2}}=49.3 \text{ lbs.}$$

Beam No. 2 consisted of pier No. 1 broken as a simple beam. Length between supports, 43 ins.; depth=$7\frac{1}{2}$ ins.; width=$11\frac{1}{2}$ ins.

Weight 295 pounds. Load to break: concentrated, 160 lbs.; weight of beam considered at center, 148 lbs.

$$S=\frac{6M}{b\,d^2}=\frac{6\times 308\times 43}{4\times 11\frac{1}{2}\times (7\frac{1}{2})^2}=30.7 \text{ lbs. per sq. in.}$$

In this case, and also in the pier, the unit stress is necessarily small since there is no interlocking action of the brick as in an ordinary beam.

Beam No. 3. Built essentially the same as No. 1. Age=56 days. Length=4 feet; depth=$4\frac{3}{4}$ inches; width=$7\frac{3}{4}$ inches; distance between supports=43 inches. Weight=350 pounds. Concentrated load=3 273 pounds. The beam did not fail, thus showing a strength of at least $=\frac{6M}{b\,d^2}=\frac{6\times 3\,448\times 43}{4\times(04\frac{3}{4})^2\times 7\frac{3}{4}}=117.2$ lbs. per sq. in.

It was then turned on the flat side and broken with a concentrated load of 1 507 lbs. $S=\frac{6\times 1\,682\times 43}{4\times(14\frac{3}{4})\times(7\frac{3}{4})^2}=122.4$ lbs. per sq. in.

Beam No. 4. Age=49 days; depth and width consisted of the same number of courses as No. 1; depth=15 inches; distance between centers=122 inches; width=$7\frac{3}{4}$ inches; weight=1 000 lbs.

Five bricks broke when the beam failed. When this beam was broken deflections were taken at the center by means of a level and rod. These are given in Table IV.

TABLE IV. Deflections.

DEFLECTION IN INCHES.	DIFFERENCES.	WEIGHTS APPLIED.
0.00	0.00	0.00
0.05	0.05	WT. OF BEAM
0.06	0.01	" + 200 lbs.
0.07	0.01	" + 400
0.11	0.04	" + 600
0.17	0.06	" + 800
0.23	0.06	" +1000
Beam Broke		" +1224

At the vertical joints the mortar separated from brick; at the horizontal joints the mortar failed in cohesion. $S=\frac{6\,M}{b\,d^2}=\frac{6\times 1\,724\times 122}{4\times(15)^2\times 7\frac{3}{4}}$ $=181$ lbs. per sq. in.

Beam No. 5. Depth=15 inches; width=$7\frac{3}{4}$ inches; distance between supports=55 inches; weight=500 pounds; age=61 days; breaking load applied at center=1 678 lbs. $S=\frac{6\,M}{b\,d^2}=\frac{6\times 1\,928\times 55}{4\times 7\frac{3}{4}\times(15)^2}$ $=91.2$ lbs. per sq. in.

Beam No. 6. Width and depth same as No. 5; distance between supports=55 inches; age=62 days; load to break =2 070 lbs; weight of beam=500 lbs. $S=\frac{6\times 2\,320\times 55}{4\times 7\frac{3}{4}\times (15)^2}$=115.5 lbs. per sq. in.

Beam No. 7. Age=62 days; distance between supports=44 inches; depth=$7\frac{1}{4}$ inches; width=$3\frac{1}{2}$ inches; center load=378 lbs; weight of beam=80 lbs. Beam was not broken.

S= at least $\frac{6\ M}{bd^2}$= at least $\frac{6\times 418\times 44}{4\times (7\frac{1}{4})^2\times 3\frac{1}{2}}$=at least 153.8 lbs. per sq. in.

Beam No. 8. Two courses high and two courses wide. Depth =$4\frac{1}{2}$ inches; width=$7\frac{1}{2}$ inches; distance between supports=45 inches; weight of beam=125 pounds; breaking load=200 pounds; age=62 days; $S=\frac{6\times 45+262}{4\times 7\frac{1}{2}\times (4\frac{1}{2})^2}$=112.7 lbs. per sq. in.

Beam No. 9. Same section as beam No. 2. Built as a pier. Distance between supports=37 inches; width=$7\frac{1}{2}$ inches; depth=$11\frac{1}{2}$ inches; age=62 days; weight of beam=270 lbs.; center load=970 lbs. $S=\frac{6\times 970\times 37}{4\times 7\frac{1}{2}\times (11\frac{1}{2})^2}$= 54.3 lbs. per square inch.

Beam No. 10. Age=35 days. Distance between supports=6 feet; depth=14 inches; width=8 inches; center load=1 000 lbs.; weight of beam=670 lbs. $S=\frac{6\times 1\,435\times 72}{4\times 5\times 196}$=99 lbs. per square inch.

TABLE V. Summary of Results.

No. of Beam.	Age in Days.	Probable Tensile Strength of Mortar at that Age in Lbs. per Sq. In.	Modulus of Rupture of Beam in Lbs. per Sq. In.	Remarks.
3	56	50	117.2.......122.4	Broken Sideways.
4	49	48	181.	Mortar 1 to 2 by Volume.
5	61	52	91.2	"
6	62	52	115.5	"
7	62	52	153.8	"
8	62	52	112.7	"
10	35	45	99.0	"
9	62	52	54.3	" Built as a Pier.
2	28	40	30.7	Mortar 1 to 2 by Weight.
1	28	40	71 1	" " " "
PIER	28	40	49.3	" " " "

CONCLUSION.

The table shows, roughly, that the beams built as regular masonry have a modulus of rupture of about twice the tensile strength of the mortar used. With the best construction we believe it may be even three times the tensile strength of the mortar, as shown by beams No. 4 and 7. When built as piers, with no interlocking action, the modulus of rupture is about the same as the tensile strength of the mortar used.

The experiments on deflections with beam No. 4 while not enough to draw any certain conclusion from, would seem to show that brick masonry is elastic and that up to a certain point the deformation is proportional to the stress applied.

The result of experiments in the past, while showing a certain transverse strength, have not been definite or uniform enough to furnish reliable conclusions. We believe we have shown that this strength can be counted upon in designing.

While the nature of this subject does not permit of its being carried in an experimental way as far as might be desired, without considerable expense, we would suggest that much can yet be done towards finding the strength actually obtained in brick buildings. The tearing down or failure of such buildings affords an excellent opportunity for this and it is to be hoped that experiment and observation will be turned in this direction.