XXXVIII. *Experimental Researches on the Strength of Pillars of Cast Iron from various Parts of the Kingdom.*

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HAVING in the year 1840 offered to the Royal Society an extensive research upon this subject, which was honoured with the kindest notice of the Society, I felt grateful for the reception it had met with; and though in its preparation it had occupied my leisure time for some years, and contained the results of as many as 277 experiments, which I had made to prove the conclusions arrived at in it, I was still very anxious to improve and extend it. Indeed the importance of the subject would seem to justify every effort I could make for the purpose, when it is considered that a large portion of the houses, warehouses and shops in London, Manchester, Liverpool and throughout the country, depend for their principal supports upon iron pillars, which frequently appear very thin for the weight they have to bear, and being hollow do not allow us to judge from their appearance how small a quantity of metal they have in them, or in other words, whether the building is abundantly strong, or is ready to fall down and crush the persons within it, as has frequently happened to warehouses and other buildings dependent on iron supports. Some of the pillars are made to pass through more than one story, or even are based on the foundation, and support an intermediate floor and the roof.

The importance of the subject, in a practical point of view at least, rendered it desirable that a number of pillars of large size should be broken, to obtain data for the application of the principles established in the preceding research; but this was impracticable at that time, notwithstanding the liberality of Mr. FAIRBAIRN, who bore the expense of that inquiry. For by Mr. FAIRBAIRN's lever then used, more than 18 tons could not be safely applied, and the iron box or frame in which the pillars were broken did not admit pillars of greater length than $7\frac{1}{2}$ feet; but the laborious inquiry in which I was afterwards engaged by Mr. STEPHENSON, for investigating the properties of the Menai and Conway tubular bridges (that over the Conway in particular), required larger and more powerful apparatus than the preceding, and I can now apply more than three times the pressure formerly used, and break pillars of 10 feet long, and any shorter lengths, with even more accuracy than before.

A drawing of the former machine is given with the paper (Philosophical Transactions, 1840), and of the latter, with my experiments in the Report of the Commissioners appointed to inquire into the application of Iron to Railway Structures, 1849. The principle of both machines is the same; the present is a single lever, about 17 feet,

6 inches long, acting (usually) with a leverage of 8·4 upon the upper end of a strong bolt, which moves in a cylinder, just fitting it and keeping it always in the straight line of its pressure. The top of the bolt is rounded, so that the pressure may act through the axis, and the bottom is flat, and made horizontal, that it may press on the top of a vertical pillar, enclosed in a strong box, as before. See Plate XXXI.

The present experiments, and others in progress, were undertaken at the suggestion of Mr. ROBERT STEPHENSON, M.P., F.R.S., who knew that I had several experimental researches unfinished. He has generously contributed £200 towards the expense of the inquiry, and the Royal Society has added £200 *. By the kind permission of the Council of University College, London, my apparatus has been set up at the College, and the experiments made there.

I have in the present research broken only larger pillars than before, having had them cast 10 feet long, and from $2\frac{1}{2}$ to 4 inches in diameter, solid and hollow. The first series includes twenty pillars (twelve of 10 feet long, and eight shorter ones cut out of them); the whole of these were supplied by the proprietors of the Low Moor Iron-works, for which no charge has yet been made †. The iron of which these, with five exceptions, were made, was Low Moor iron, No. 2. The former research of 1840 was from Low Moor iron, No. 3; and the difference of the two is not very great, though the No. 2, as now used, is somewhat stronger than the other to bear a strain as a long pillar (p. 864), though softer than it and more easily crushed. The results of these experiments have been applied to the formulæ in my former research, which have undergone no change, except in the constants.

The former researches, and the formulæ to which they were reduced, had been applied to pillars of Low Moor iron only, with one exception; but though we could compute by them the strength for Low Moor iron, we had no evidence as to what were the relative strengths of pillars of the irons of the kingdom in general; and, at my request, Messrs. EASTON and AMOS have had cast for this purpose twenty-two solid pillars, each 10 feet long and $2\frac{1}{2}$ inches in diameter, of eleven kinds of iron, making thirteen kinds with two I have had from Low Moor. The comparison of the breaking weights of these pillars shows that the strengths of the irons vary at least as 2 to 3, and their crushing strengths as 5 to 9 nearly ‡.

In carrying out the experiments, in taking the dimensions, and applying the results to the formulæ in my research above mentioned, I have had the assistance of Mr. JOHN BRIDGE, M.A., of University College, my health and eyesight not being sufficient to enable me to bear the labour alone.

* Since finishing the experiments in the present research, except those contained in the short Appendix, another £100 has been contributed by the Royal Society, and £100 more by Mr. STEPHENSON, with which I am making experiments on pillars of timber, &c.

† A good balk of Memel timber was likewise sent gratuitously for experiment by the late Mr. THOMAS CUBITT, of Thames Bank, but his death prevented me having the power to thank him. His executors have liberally sent other timber for the purpose.

‡ The pillars were cast 12 feet long, to increase their soundness, and afterwards cut to 10 feet long.

1. Before referring to the experiments which form the basis of the present memoir, I will give some notice of the principal matters contained in the former, but not sufficiently dilated upon; especially as they have an important bearing upon what will follow, and will themselves receive further illustration, or perhaps be capable of demonstration.

The profound and beautiful researches of EULER on the strength of pillars * are entirely theoretical; they proceed on the supposition that the strength of a pillar is bounded by its power of resisting being bent out of a straight line, the resistance to incipient flexure being supposed to be the measure of its strength, which in long pillars, whose length is l and external and internal diameters d and d_1, is $\frac{d^4}{l^2}$ or $\frac{d^4-d_1^4}{l^2}$, according as they are solid or hollow†.

2. In commencing experiments, in my former research, on this subject, and keeping in view the theory of EULER, I sought with great care for the weight which would produce incipient flexure in columns, and more particularly in those of cast iron. In this metal flexure commenced with very small weights, much smaller than would be useful to load pillars with in practice; and I became convinced that no such point existed in cast iron, or at any rate none that would be useful to the engineer; and my subsequent experiments upon wrought-iron pillars have been attended with very little more success, in seeking for the weight producing incipient flexure. Having been unsuccessful in seeking for the weight which would first produce flexure in columns, and being convinced that if it were found it would be of little or no use in practice, I sought in future for the weights necessary to *break* the pillars tried, and in most instances for the deflection and decrement of length produced by the weights laid on.

3. The pillars broken were placed in a vertical position during the experiments, and their ends were pressed between two horizontal plates of hardened steel, which, from the nature of the machine, were kept perfectly parallel. It was found that in cylindrical pillars of cast iron, whose ends were turned perfectly flat, parallel and perpendicular to the axis, the breaking weight varied as the 3·55th power of the diameter nearly, and inversely as the 1·7th power of the length, or as $\frac{d^{3 \cdot 55}}{l^{1 \cdot 7}}$, instead of $\frac{d^4}{l^2}$, as in the theory of EULER. In hollow pillars it is as $\frac{d^{3 \cdot 55}-d_1^{3 \cdot 55}}{l^{1 \cdot 7}}$. The fractional indices above were found to apply to all solid pillars of cast iron, whose lengths varied from 120 times the diameter to as low as 30 times the diameter, or thereabouts. For pillars shorter than these it will be necessary to correct the results obtained, by considerations dependent on the crushing strength of the material. See pp. 403 to 406 of the former research‡.

4. The first experiments were made upon long uniform pillars, with their ends rounded in such a manner that the pressure applied to them would act in the direction of their axis, to meet the requirements of EULER's theory of the strength of pillars; but

* Berlin Memoirs, 1757.

† POISSON, Mécanique, 2nd edition.

‡ Philosophical Transactions, 1840, Part II.

it soon became evident that pillars of the same size with their ends flat, and well supported or bedded throughout, would require a much greater weight to break them than those with rounded ends; a large number of both kinds were made and broken by experiment to determine their relative strength to resist fracture, and it was found that so long as the pressure required had not been more than about one-fourth of that necessary to crush short specimens of the same material, the strength of a solid pillar with flat ends was a little more than three times that of one with rounded ends, the mean being 3·167, as shown in the abstract, page 387 of that research, but in other experiments it is still nearer to 3.

5. If the pressure necessary to break the pillar were much greater than about one-fourth of that which would crush short specimens of the same material, then the ratio 1 to 3 would become 1 to 2, or even less.

6. In the following abstract, pages 856 and 857, which includes experiments on hollow pillars with rounded and with flat ends, as above, and upon solid pillars of wrought iron and timber, the ratio of the strengths of the two kinds of pillars is nearly as 1 to 3, varying not widely from the former. From this abstract we see that pillars which have been loaded with more than about one-fourth of the crushing weight are in some degree injured, and the ratio in them differs from 1 : 3, becoming 1 : 2·6, 1 : 2·4, &c.

In the last column of the abstract, page 857, denominated $\frac{B}{C}$, it may be seen at a glance what portion of the crushing weight was required to break each pillar; and in those where it amounted to ·282, ·272, or above ·25*, they were generally injured by the pressure.

7. In the abstract, p. 393 of the former research, the relative strengths of pillars—with both ends rounded, one end rounded and one end flat, and both ends flat,—are determined in a great number of experiments, and found to be nearly as 1, 2, 3, from experiments on cast iron, wrought iron, steel and timber.

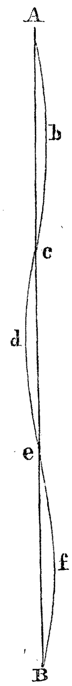
8. In the abstract, page 391 of the former research, pillars $60\frac{1}{2}$ inches long, with their ends turned flat, are compared, as to their strengths, with pillars of the same size with discs on their ends turned flat: the strengths of these two classes of pillars differed but little, but the pillars with discs on the ends are rather the stronger. In this abstract it was shown that pillars one-half the length of the preceding, and of the same diameter but with the ends rounded, were of the same strength as the preceding ones nearly, as shown by many experiments.

Attempt to account for the principal Results in the preceding description of the abstracts.

1. Of the general conclusion arrived at in the abstract last referred to, I would offer the following as an explanation. Suppose a long uniform bar of cast iron were bent by a pressure at its ends so as to take the form *AbcdefB*, where all the curves *Abc*, *cde*, *efB*, separated by the straight line *AceB*, would be equal, since the bar was supposed to

* The pillars of the "Second London Mixture," 6 feet 3 inches long, gave the same result when $\frac{B}{C}=\cdot 26$.

be uniform. The curve having taken this form, suppose it to be rendered immoveable at the points *b* and *f*, by some firm fixings at those points. This done, it is evident we may remove the parts near to A and B, without at all altering the curve *bcdef* of the part of the pillar between *b* and *f*, and consider only that part. The part *bf*, which alone we shall have to consider, will be equally bent at all the points *b*, *d*, *f*. The points *c* and *e* too are points of contrary flexure, consequently the pillar is not bent in them. These points are unconstrained except by the pressure which forces them together, and the pillar might be reduced to any degree in them, provided they were not crushed or detruded by the compressing force. These points may then be conceived as acting like the rounded ends of the pillars in Table I. in the former research, and the part *cde* of the pillar, with its ends *c* and *e* rounded, will be bearing the same weight as the whole pillar *bcdef* of double the length with its ends *b*, *f* firmly fixed.



2. That the strain at all the points *b*, *d*, *f* is nearly equal, is shown by subsequent experiments, in Tables V. and VI., upon pillars varying in length from 6 feet 3 inches to 5 feet and 2 feet 6 inches; that fracture in some cases took place at all three points at the same time, and in others at two of them, showing the fracture to have commenced on opposite sides of the middle and of the ends, as might be inferred from the foregoing figure, or the last in Plate XXXII.

3. That the strength of a pillar, with moveable or rounded ends, is equal to that of a pillar of the same diameter, and double the length, the ends being flat or firmly fixed, may be inferred from the reasoning above; but it is *proved* experimentally from various results in the abstract p. 391 of the former research, or as below.

4. The strengths of pillars of the same diameter, but of different lengths, vary inversely as the 1·7th or 1·6th power of the length, or in this case as $2^{1.7}$ or $2^{1.6}$ nearly, according to my experiments. Hence the strength of a pillar one-half the length of another is 3·249 or 3·031 times greater than it; or in other words, the strength of a pillar with flat ends is somewhat more than three times as great as that of one of the same length and diameter with rounded ends.

5. This is shown in the abstract, p. 387 of the former research, from numerous experiments on *solid* pillars, with both ends rounded and both ends flat, the mean ratio of their strengths being . . . . 1:3·167

In the abstract, pages 856 and 857 of the present research, the mean ratio from the comparison of the strengths of four *hollow* pillars, with rounded ends and of the like number with flat ends, was . . . . 1:3·077

In the same abstract, solid pillars of the two forms, of wrought iron and of timber, gave from several experiments a mean ratio of . . . . 1:3·076

} Mean ratio 1:3·107.

Abstract from Tables VIII., IX., XII., XIII., &c. of the former Research on the results obtained from two hollow

	Pillars with rounded ends.				Pillars
	Length of pillar.	Diameter of section.	Number of experiments deduced from.	Breaking weight.	Length of pillar.
Hollow columns of Low Moor iron, No. 3.	7 ft. 6¾ in., or 90¾ in.	External diameter 1·78 in. Internal diameter 1·21 in.	1	5585	7 ft. 4¾ in., or 88¾ in.
	90¾ in.	External diameter 1·74 in. Internal diameter 1·187 in.	1	5711	88¾ in.
	90¾ in.	External diameter 2·01 in. Internal diameter 1·415 in.	1	8357	88¾ in.
	90¾ in.	External diameter 2·23 in. Internal diameter 1·54 in.	1	12389	88¾ in.
Hollow columns of Low Moor iron, No. 2.	10 ft. 2 in., or 122 in., including caps on the ends.	External diameter 3·555 in. Internal diameter 2·693 in.	1	42331 lbs., or 43537 lbs. for 10 ft. or 120 in.	120 in.
	122 in., including caps on the ends.	External diameter 3·532 in. Internal diameter 2·659 in.	1	44683 lbs., or 45956 lbs. for 10 ft. or 120 in.	120 in.
Solid pillars. Wrought iron.	90¾ in.	Diameter 1·017 in.	2	1808	90¾ in.
	60½ in.	Diameter 1·015 in.	2	3938	60½ in.
Solid pillars. Timber.	60½ in.	Side of square 1·75 in.	2	3197 The second pillar was capped with iron at the ends, to prevent their being crushed.	60½ in.

Strength of Pillars of Low Moor Iron, No. 3, and of other Materials, with the pillars in the present research.

with flat ends, and sometimes with discs to give them a larger bearing at the ends.						Ratio of the strengths of pillars with both ends rounded and with both flat, the diameters being considered equal.		$\frac{B}{C}$.
Diameter of section.	Number of experiments deduced from.	Breaking weight (B).		Weight which would crush the specimen (C).				
				lbs.				
External diameter 1·78 in. Internal diameter 1·21 in. Area of section 1·339 sq. in.	1	17840 lbs., or 17177 lbs. for length $90\frac{3}{4}$ in.	Crushing weight per square inch of section 109801 lbs.=49·018 tons.	146975		1 : 3·075	Mean ratio 1 : 3·077	·1237
External diameter 1·74 in. Internal diameter 1·187 in. Area of section 1·2712 sq. in.	1	16705 lbs., or 16084 lbs. for length $90\frac{3}{4}$ in.		139584		1 : 2·816		·115
External diameter 2·01 in. Internal diameter 1·415 in. Area of section 1·6005 sq. in.	1	28353 lbs., or 27299 lbs. for length $90\frac{3}{4}$ in.		175742		1 : 3·266		·155
External diameter 2·23 in. Internal diameter 1·54 in. Area of section 2·0431 sq. in.	1	40569 lbs., or 39061 lbs. for length $90\frac{3}{4}$ in.		224330		1 : 3·153		·174
External diameter 3·555 in. Internal diameter 2·693 in. Area of section 4·230 sq. in.	1	114479 lbs. =51·11 tons.	Crushing weight per square inch 95928 lbs.=42·825 tons.	405774		1 : 2·629		·282
External diameter 3·532 in. Internal diameter 2·659 in. Area of section 4·245 sq. in. Weight of pillar 130 lbs.	1	110649 lbs. =49·39 tons.		407203		1 : 2·408		·272 This pillar had been split at one end in the first experiment, and was hooped.
Diameter 1·02	1	5280		....		1 : 2·920	Mean ratio 1 : 3·076	
Diameter 1·02	1	12990		....		1 : 3·298		
Side of square 1·75 in.	4	9625		....		1 : 3·011		

6. The great difference between the strength of a pillar with both ends rounded and both ends flat, is rendered obvious by their different modes of fracture, the former breaking in one place only, the middle; and the latter in three, at the middle and at each end.

7. In pillars with one end rounded and one end flat, fracture takes place at about one-third of the distance from the rounded end; and if the base of the pillar be enlarged with a disc, the distance of the place of fracture from the top of a pillar $30\frac{1}{4}$ inches long is but ·28 inch from one-third of the whole length from the top, deduced from a mean of two experiments, in which one pillar broke at 10·42 inches, and the other at 10·30 inches (mean, 10·36 inches) from the rounded end (see p. 439 of former research).

8. If the pillar had had both ends rounded, then the centre of fracture would have been at the middle, at *b* (first pillar, Plate XXXII.), or at half the height: in the cases before us, fracture took place at two-thirds of the height nearly, or at *b* (second pillar). Hence, comparing the distances A*b*, A*b* of the points of fracture from the rounded ends of two pillars of equal diameter and height, one with both ends rounded, and the other with one end rounded and one end flat, we have those distances as $\frac{1}{2}$ to $\frac{1}{3}$, or as 3 to 2 nearly.

9. The relative strengths of the two pillars should therefore be inversely as the 1·7th or 1·6th powers of their lengths, A*b*, A*b*, or as 3·249 : 6·473, or 3·031 : 5·8, differing not widely from 1 to 2, as is shown by various experiments in Tables I., II., V., XII., XIII. of the former research.

10. Moreover, it will appear that in the curve indicating the form of flexure to the third pillar, Plate XXXII., the distance A*bc* will apply to the first pillar, A*bcd* to the second pillar, and *bcdef* to the third pillar; these distances being inversely as 2, 3, 4, the 1·7th powers of which are 3·249, 6·473, 10·556, and the 1·6th powers 3·031, 5·8, 9·19, or as 1, 2, 3, nearly.

11. Hence, of three pillars of the same length and diameter, one with both ends rounded, one with one end rounded and one end flat, and the other with both ends flat, the strengths are as 1, 2, 3.

The following facts, from the subsequent experiments, illustrate the last of the preceding figures. See also forms of fracture, Plate XXXIII.

In pillars of "Second London Mixture," 2 feet 6 inches long and $1\frac{1}{2}$ inch diameter, fracture took place near to the middle and by breaking across near each end.

A pillar of Old Hill iron, 5 feet long and $2\frac{1}{2}$ inches diameter, broke in the middle, and broke across near each end.

In pillars 6 feet 3 inches long, fracture took place in the middle, and each end became split. This was the case in all these pillars.

In pillars 7 feet 6 inches long and $2\frac{1}{2}$ inches in diameter—that of Derwent iron broke in the middle and split off at each end; one of Old Park and one of London Mixture broke in three pieces, and split off at one end: there would appear to have been more points of contrary flexure in each of these two pillars than in the other cases.

General Remarks on the following Experiments.

The experiments forming the basis of this research are on the strength of cast-iron pillars in two series, the first being on Low Moor Iron, No. 2, each 10 feet long, varying in diameter from $2\frac{1}{2}$ to 4 inches, solid and hollow; of these there are fourteen, including two on Blaenavon iron, No. 3; the second series are on solid pillars of cast iron, 10 feet long and $2\frac{1}{2}$ inches diameter, from various parts of the kingdom, making twenty-four pillars, with two of a smaller diameter; other pillars cut out of the preceding ones, and made 7 feet 6 inches, 6 feet 3 inches, 5 feet, &c. long, amount with the former ones to seventy-two.

The experiments on these are distributed in Tables I. to VI. In two other Tables (VII. and VIII.) other experiments are given, to determine the transverse strengths of some of the irons, in order to compare these with their direct strength as pillars, besides numerous experiments to obtain the crushing strengths of the pillars, and the comparative hardness of the irons in different parts of their sections. The forms of the fractures of pillars in the first six Tables are given in Plate XXXIII.

It has been seen that the strength of long pillars of cast iron varies as a constant power n of the diameter nearly; the pillars being solid and uniform in texture, and nearly as the difference of the same powers of the external and internal diameters, when the pillars are hollow; or as d^n in solid pillars, and D^n-d^n in hollow ones, D and d being the external and internal diameters. This power n was found in my former researches* to be 3·55, from the mean result of many experiments on the strength of pillars flat at the ends. In the following experiments, which are on pillars of a larger kind than before, and the iron therefore somewhat softer than iron cast in smaller masses, the average value of n is much more near to 3·50 than to 3·55, the mean from nineteen comparisons being 3·513 (page 865). The strength of pillars, whose diameter is the same, varied inversely as the 1·7th power of the length nearly, according to the average result from pillars with rounded ends and with flat ends, in my former experiments. But in the present ones, on flat-ended pillars only, the power of the length from the results of twenty-five comparisons (page 866) is 1·63 nearly, instead of 1·7, as before found.

The preceding results apply only to pillars whose length is thirty times the diameter or upwards; for pillars shorter than this, the formula for their strength would need correcting by the introduction of the crushing weight of the pillar†.

Tables of the powers above for pillars likely to occur in practice are as below.

* Philosophical Transactions, 1840.

† Ibid. Part II. pp. 404, 405.

TABLE I.—Powers of Diameters, or $d^{3\cdot 5}$.

$1\cdot 0^{3\cdot 5}$ = 1·0000	$3\cdot 7^{3\cdot 5}$ = 97·433	$5\cdot 7^{3\cdot 5}$ = 442·14	$7\cdot 7^{3\cdot 5}$ = 1266·83
$1\cdot 25^{3\cdot 5}$ = 2·1837	$3\cdot 75^{3\cdot 5}$ = 102·12	$5\cdot 75^{3\cdot 5}$ = 455·87	$7\cdot 75^{3\cdot 5}$ = 1295·85
$1\cdot 5^{3\cdot 5}$ = 4·1335	$3\cdot 8^{3\cdot 5}$ = 106·965	$5\cdot 8^{3\cdot 5}$ = 469·89	$7\cdot 8^{3\cdot 5}$ = 1325·35
$1\cdot 75^{3\cdot 5}$ = 7·0898	$3\cdot 9^{3\cdot 5}$ = 117·15	$5\cdot 9^{3\cdot 5}$ = 498·86	$7\cdot 9^{3\cdot 5}$ = 1385·78
$2\cdot 0^{3\cdot 5}$ = 11·314	$4\cdot 0^{3\cdot 5}$ = 128·00	$6\cdot 0^{3\cdot 5}$ = 529·09	$8\cdot 0^{3\cdot 5}$ = 1448·15
$2\cdot 1^{3\cdot 5}$ = 13·4205	$4\cdot 1^{3\cdot 5}$ = 139·55	$6\cdot 1^{3\cdot 5}$ = 560·60	$8\cdot 25^{3\cdot 5}$ = 1612·83
$2\cdot 2^{3\cdot 5}$ = 15·7935	$4\cdot 2^{3\cdot 5}$ = 151·835	$6\cdot 2^{3\cdot 5}$ = 593·43	$8\cdot 5^{3\cdot 5}$ = 1790·47
$2\cdot 25^{3\cdot 5}$ = 17·086	$4\cdot 25^{3\cdot 5}$ = 158·26	$6\cdot 25^{3\cdot 5}$ = 610·35	$8\cdot 75^{3\cdot 5}$ = 1981·66
$2\cdot 3^{3\cdot 5}$ = 18·452	$4\cdot 3^{3\cdot 5}$ = 164·87	$6\cdot 3^{3\cdot 5}$ = 627·61	$9\cdot 0^{3\cdot 5}$ = 2187·00
$2\cdot 4^{3\cdot 5}$ = 21·416	$4\cdot 4^{3\cdot 5}$ = 178·68	$6\cdot 4^{3\cdot 5}$ = 663·18	$9\cdot 25^{3\cdot 5}$ = 2407·11
$2\cdot 5^{3\cdot 5}$ = 24·705	$4\cdot 5^{3\cdot 5}$ = 193·305	$6\cdot 5^{3\cdot 5}$ = 700·16	$9\cdot 5^{3\cdot 5}$ = 2642·61
$2\cdot 6^{3\cdot 5}$ = 28·340	$4\cdot 6^{3\cdot 5}$ = 208·76	$6\cdot 6^{3\cdot 5}$ = 738·59	$9\cdot 75^{3\cdot 5}$ = 2894·12
$2\cdot 7^{3\cdot 5}$ = 32·3425	$4\cdot 7^{3\cdot 5}$ = 225·08	$6\cdot 7^{3\cdot 5}$ = 778·51	$10\cdot 0^{3\cdot 5}$ = 3162·28
$2\cdot 75^{3\cdot 5}$ = 34·488	$4\cdot 75^{3\cdot 5}$ = 233·58	$6\cdot 75^{3\cdot 5}$ = 799·03	$10\cdot 25^{3\cdot 5}$ = 3447·73
$2\cdot 8^{3\cdot 5}$ = 36·733	$4\cdot 8^{3\cdot 5}$ = 242·295	$6\cdot 8^{3\cdot 5}$ = 819·94	$10\cdot 5^{3\cdot 5}$ = 3751·13
$2\cdot 9^{3\cdot 5}$ = 41·533	$4\cdot 9^{3\cdot 5}$ = 260·43	$6\cdot 9^{3\cdot 5}$ = 862·92	$10\cdot 75^{3\cdot 5}$ = 4073·14
$3\cdot 0^{3\cdot 5}$ = 46·765	$5\cdot 0^{3\cdot 5}$ = 279·51	$7\cdot 0^{3\cdot 5}$ = 907·49	$11\cdot 0^{3\cdot 5}$ = 4414·43
$3\cdot 1^{3\cdot 5}$ = 52·4525	$5\cdot 1^{3\cdot 5}$ = 299·57	$7\cdot 1^{3\cdot 5}$ = 953·68	$11\cdot 25^{3\cdot 5}$ = 4775·66
$3\cdot 2^{3\cdot 5}$ = 58·617	$5\cdot 2^{3\cdot 5}$ = 320·635	$7\cdot 2^{3\cdot 5}$ = 1001·53	$11\cdot 5^{3\cdot 5}$ = 5157·54
$3\cdot 25^{3\cdot 5}$ = 61·886	$5\cdot 25^{3\cdot 5}$ = 331·56	$7\cdot 25^{3\cdot 5}$ = 1026·08	$11\cdot 75^{3\cdot 5}$ = 5560·74
$3\cdot 3^{3\cdot 5}$ = 65·283	$5\cdot 3^{3\cdot 5}$ = 342·74	$7\cdot 3^{3\cdot 5}$ = 1051·07	$12\cdot 0^{3\cdot 5}$ = 5985·96
$3\cdot 4^{3\cdot 5}$ = 72·473	$5\cdot 4^{3\cdot 5}$ = 365·91	$7\cdot 4^{3\cdot 5}$ = 1102·33	
$3\cdot 5^{3\cdot 5}$ = 80·212	$5\cdot 5^{3\cdot 5}$ = 390·18	$7\cdot 5^{3\cdot 5}$ = 1155·35	
$3\cdot 6^{3\cdot 5}$ = 88·5235	$5\cdot 6^{3\cdot 5}$ = 415·58	$7\cdot 6^{3\cdot 5}$ = 1210·17	

TABLE II.—Powers of Lengths, or $l^{1\cdot 63}$.

$1^{1\cdot 63}$ = 1·	$6\frac{1}{4}^{1\cdot 63}$ = 19·8282	$12^{1\cdot 63}$ = 57·4203	$19^{1\cdot 63}$ = 121·442
$2^{1\cdot 63}$ = 3·0951	$7^{1\cdot 63}$ = 23·8512	$13^{1\cdot 63}$ = 65·4226	$20^{1\cdot 63}$ = 132·032
$2\frac{1}{2}^{1\cdot 63}$ = 4·4529	$7\frac{1}{2}^{1\cdot 63}$ = 26·6901	$14^{1\cdot 63}$ = 73·8225	$21^{1\cdot 63}$ = 142·961
$3^{1\cdot 63}$ = 5·9939	$8^{1\cdot 63}$ = 29·6508	$15^{1\cdot 63}$ = 82·6093	$22^{1\cdot 63}$ = 154·223
$4^{1\cdot 63}$ = 9·5798	$9^{1\cdot 63}$ = 35·9265	$16^{1\cdot 63}$ = 91·7731	$23^{1\cdot 63}$ = 165·812
$5^{1\cdot 63}$ = 13·7823	$10^{1\cdot 63}$ = 42·6580	$17^{1\cdot 63}$ = 101·305	$24^{1\cdot 63}$ = 177·723
$6^{1\cdot 63}$ = 18·5518	$11^{1\cdot 63}$ = 49·8276	$18^{1\cdot 63}$ = 111·197	

Further Remarks on the Experiments on the Strength of Pillars (Tables I. and II.).

If the strength of a pillar be represented by $W=m\times\frac{D^n-d^n}{l^p}$, where D, d are the external and internal diameters in inches, l the length in feet, m, n, p constant quantities, the following experiments (1st Summary) will furnish us with the value of

$\frac{W}{D^n-d^n}=\frac{m}{l^p}$, of which expressions the first is represented by x, and is calculated on two suppositions for the value of n; the other depends on the value of p. From my former experiments, n was taken as 3·55, and p as 1·7; and from the experiments in the present research, we have $n=3·5$, and $p=1·63$, as mentioned before. To assist in computing the strength of pillars, according to this last supposition, the two Tables of powers of the diameters and lengths of pillars previously given (page 860) have been formed. The experiments give the mean value of x, or $\frac{W}{D^n-d^n}$ as 2085·2 or 2223·7 lbs. for the strength of a pillar 10 feet long and 1 inch diameter; but for a pillar of 1 foot long and 1 inch diameter it would be $x\times10^p$, where $10^p=50·119$, or 42·658.

First Summary of Results.

Results from the Experiments in Tables I. and II. upon pillars of Low Moor Iron, No. 2, and Blaenavon Iron, No. 3, the length of each being 10 feet, and the ends turned flat and perpendicular to the axis.

No. of experiment.		Value of x, or the breaking weight of a solid pillar 10 feet long and 1 inch diameter, flat at the ends, from the formula $x=\frac{W}{D^{3·55}-d^{3·55}}$.		Value of x from the formula $x=\frac{W}{D^{3·5}-d^{3·5}}$.		Error from using the mean from power 3·55, in terms of the value of x.	Error from using the mean from power 3·5, in terms of the value of x.
		lbs.		lbs.			
Hollow pillars, from $2\frac{1}{2}$ to 4 inches external diameter ...	1.	2201·1	Low Moor, No. 2. Mean 2085·2	2324·9	Mean 2223·7	$-\frac{1}{19·3}$	$-\frac{1}{23}$
	2.	2332·9		2463·7		$-\frac{1}{9·4}$	$-\frac{1}{10·3}$
	3.	2226·7		2374·2		$-\frac{1}{15·7}$	$-\frac{1}{15·8}$
	4.	2285·8		2471·3		$-\frac{1}{11·4}$	$-\frac{1}{10}$
	5.	1975·6		2121·7		$+\frac{1}{18·02}$	$+\frac{1}{20·8}$
	6.	2023·3		2173·9		$+\frac{1}{32·7}$	$+\frac{1}{43·7}$
	7.	1963·8		2127·6		$+\frac{1}{16·2}$	$+\frac{1}{22·1}$
	8.	1785·3		1928·8		$+\frac{1}{5·95}$	$+\frac{1}{6·54}$
Solid pillars, $2\frac{1}{2}$ inches in diameter.........	11.	2008·9		2105·2		$+\frac{1}{26·3}$	$+\frac{1}{17·8}$
	12.	2048·5		2146·1		$+\frac{1}{55·8}$	$+\frac{1}{27·7}$
	13.	2034·1	Blaenavon, No. 3. Mean 2065·4	2131·8	Mean 2164·4	$+\frac{1}{65}$	$+\frac{1}{65·4}$
	14.	2096·7		2197·0		$-\frac{1}{67}$	$-\frac{1}{67·4}$

In the first two experiments of the preceding summary, the results are perhaps somewhat too high, though great care was taken to avoid error. In the columns (Experiments 7 and 8) they are too low. These had been weakened by being turned on the outside to reduce their strength, as they had been cast stronger than it was supposed the

machinery would break without injury to it. The great reduction in strength produced by taking away the external crust, shows that to ornament a pillar it would not be prudent to plane it. It may, however, be mentioned that the eighth pillar had many flaws in it.

In experiments upon hollow pillars, it is frequently found that the metal on one side is much thinner than that on the other, but this does not produce so great a diminution in the strength as might be expected, for the thinner part of a casting is much harder than the thicker (Table VIII.), and this usually becomes the compressed side.

The strength of a solid pillar, 10 feet long and 1 inch diameter, being, from the first mean above, 2085·2 lbs., that of a solid pillar, 1 foot long and 1 inch diameter, will, since $10^{1·7}=50·119$, be $2085·2\times 50·119=104508$ lbs., or 46·65 tons; the strength being supposed to vary directly as the 3·55 power of the diameter, and inversely as the 1·7 power of the length, as obtained from the experiments in my former paper on this subject*.

The larger and more varied pillars in the present research, have, by experiments deduced from most of the irons in the kingdom, given more precise results for the constants on which the strength depends. They show that it varies directly as the 3·5 power of the diameter, much more nearly than as the 3·55 power, and inversely as the 1·63 power of the length, from a mean of many experiments in each case (see pages 865 and 866).

From the second mean value of x in the preceding summary, that depending on the 3·5 power of the diameter, the strength of a pillar 10 feet long and 1 inch diameter is 2223·7 lbs., and this multiplied by $10^{1·63}$ or 42·658 (see Table II. page 860), gives 94858·59 lbs.$=$42·347 tons, for the strength of a pillar 1 foot long and 1 inch diameter.

Whence w being the breaking weight in tons of a pillar whose length is l in feet, and external and internal diameters D and d in inches, the ends being flat and well-bedded, we have, in Low Moor iron, No. 2—

$$w=46·65\times\frac{D^{3·55}-d^{3·55}}{l^{1·7}},$$ from formulæ in Philosophical Transactions, 1840;

$$w=42·347\times\frac{D^{3·5}-d^{3·5}}{l^{1·63}},$$ from formulæ in the present paper.

The preceding chapter contains the results of experiments on the strength of pillars 10 feet long, solid as well as hollow, the hollow ones varying from 2½ to 4 inches external diameter, and the solid ones cast from models 2½ inches diameter. They are all of Low Moor iron, No. 2, except two, Nos. 13 and 14, of Blaenavon iron. In the previous research† the iron used was that of Low Moor, No. 3, and there appears to be very little difference in their strengths, though the No. 2 seems to be rather the stronger. The experiments in Table IX. of the previous paper are on hollow pillars 1·75 inch external diameter and upwards; and on solid pillars of the same diameter nearly, the

* Philosophical Transactions, 1840, Part II.

† Ibid.

length being 7 feet $6\frac{3}{4}$ inches. To compare the results of this latter series of pillars with those of a larger kind in the present research, we will select three hollow pillars, among the least objectionable in the series, and two solid ones, and reduce their results to what they would have been if the pillars had been 1 inch diameter and 10 feet long.

Pillars of Low Moor Iron, No. 3.

Length.		Diameter.	Breaking weight.	Value of x, or strength of a pillar 1 inch diameter and 10 feet long, from formula $x=\frac{W}{D^{3\cdot55}-d^{3\cdot55}}\times\frac{l^{1\cdot7}}{10^{1\cdot7}}$.		Value of x, or breaking weight of a pillar 1 inch diameter and 10 feet long, from formula $x=\frac{W}{D^{3\cdot5}-d^{3\cdot5}}\times\frac{l^{1\cdot63}}{10^{1\cdot63}}$.	
	in.		lbs.	lbs.		lbs.	
Hollow pillars...	$90\frac{3}{4}$	External diameter 1·75 in. Internal diameter 1·11 in.	20957	2230·7	Mean 2166·5	2352·8	Mean 2338·2
	$88\frac{3}{4}$	External diameter 2·04 in. Internal diameter 1·46 in.	32413	2222·6		2369·7	
	$90\frac{3}{4}$	External diameter 2·01 in. Internal diameter 1·368 in.	30789	2046·3		2292·2	
Solid pillars ...	$90\frac{3}{4}$	Diameter 1·76 in.	23179	1937·6	Mean 1966·2	2032·5	Mean 2061·4
	$90\frac{3}{4}$	Diameter 1·72 in.	21995	1994·9		2090·3	
The length l is taken in feet =7·5625 feet.							

Comparing the results of the pillars in the abstract above, which are on Low Moor iron, No. 3, with those in the first Summary, which are on the same iron, No. 2, and taking the value of x as a mean from the first six hollow pillars, we have as below:—

On the first supposition, that is, using the power 3·55 of the diameter, and 1·7 of the length,—

From the first summary, 2028·7 lbs. for solid, and 2174·2 for hollow pillars.
From the above abstract, 1966·2 lbs. for solid, and 2166·5 for hollow pillars.

On the second supposition, that is, using the power 3·5 of the diameter, and 1·63 of the length—

From the first summary, 2125·6 lbs. for solid, and 2321·6 for hollow pillars.
From the above abstract, 2061·4 lbs. for solid, and 2338·2 for hollow pillars.

These results are nearly in accordance with one another, and they show in both series of experiments, and according to both suppositions, that the hollow cylinders are somewhat stronger than the solid ones; which is attributable, no doubt, to the superior hard-

ness of the metal in the outer ring of the hollow castings: on this subject we shall see more further on (page 867).

According to the first supposition, the values of x for a hollow pillar and for a solid pillar are nearly as 22 to 20, and on the second supposition, nearly as 23 to 21. Of the two irons, the No. 2 seems to be somewhat the stronger, as appears also from the next article.

Relative Strengths of solid Pillars of Low Moor Iron, No. 3, and those of No. 2 of the same Iron.

From the experimental researches* we have for solid cylindrical pillars of Low Moor iron, No. 3, as a mean from ten experiments on small pillars, $w=98922\times\frac{d^{3\cdot55}}{l^{1\cdot7}}$, where w is the breaking weight in lbs., d the diameter in inches, l the length in feet, 3·55 the power of the diameter, and 1·7 the inverse power of the length on which the strength depends, nearly, and 98922 lbs. the strength of a pillar 1 foot long and 1 inch diameter. To make the comparison above, we shall adduce the results of the pillars in Table II. Exp. 11, 12, and Table IV. Exp. 11 of this research, from which we obtain, by the same method of computation, for the strength of a pillar 1 foot long and 1 inch diameter of Low Moor iron, No. 2,—

	lbs.
From Table II. Exp. 11	100684
From Table II. Exp. 12	102668
From Table IV. Exp. 11	100518
Mean	101290

Whence the strengths of Low Moor iron, No. 3 and No. 2, are as 98922 to 101290, or as 1 to 1·02394, by which the strengths of the pillars of Low Moor iron, No. 3, must be multiplied to obtain those of No. 2.

Two other small solid pillars in the preceding abstract, compared with the three in the present, give 98544 to 101290, or 1 to 1·02786.

Strength of Pillars dependent on their Lateral Dimensions.

In long pillars with their ends flat we have†, in cylinders $60\frac{1}{2}$ inches long, comparing the strength of that of

·77 inch diameter with that of	·997 inch diameter,	$n=3\cdot606$
·77 inch diameter with that of	1·29 inch diameter,	$n=3\cdot641$
·77 inch diameter with that of	1·56 inch diameter,	$n=3\cdot495$
·997 inch diameter with that of	1·29 inch diameter,	$n=3\cdot670$
·997 inch diameter with that of	1·56 inch diameter,	$n=3\cdot428$
	Mean . . .	$n=3\cdot568$

* Philosophical Transactions, 1840, Part II. p. 402.

† Ibid. p. 397.

In pillars of the same length with discs at the ends, comparing

·51 inch diameter with 1·00 inch diameter, $n=3{\cdot}922$
·51 inch diameter with 1·28 inch diameter, $n=3{\cdot}820$
·51 inch diameter with 1·53 inch diameter, $n=3{\cdot}775$
·775 inch diameter with 1·53 inch diameter, $n=3{\cdot}568$
·775 inch diameter with 1·28 inch diameter, $n=3{\cdot}578$
1·00 inch diameter with 1·53 inch diameter, $n=3{\cdot}412$

Mean . . . $n=3{\cdot}679$

In the larger pillars of the present research, each 10 feet long, and cast from models varying from $1\frac{1}{2}$ to $2\frac{1}{2}$ inches diameter, the iron being that termed "Second London Mixture" (see Table III. Exp. 21 to 24), comparing the strengths of pillars of the following diameters, with their ends turned flat, we have

1·530 inch diameter with 2·511 inches diameter, $n=3{\cdot}5016$
1·541 inch diameter with 2·511 inches diameter, $n=3{\cdot}6154$
1·530 inch diameter with 2·496 inches diameter, $n=3{\cdot}3708$
1·541 inch diameter with 2·496 inches diameter, $n=3{\cdot}4840$

Mean . . . $n=3{\cdot}4929$

In the same pillars rendered quite straight, and cut to be 6 feet 3 inches long, the ends being turned flat (see Table V. Exp. 5 to 9), we have, by comparing, as before,

1·530 inch diameter with 2·511 inches diameter, $n=3{\cdot}3068$
1·541 inch diameter with 2·511 inches diameter, $n=3{\cdot}2603$
1·530 inch diameter with 2·496 inches diameter, $n=3{\cdot}1670$
1·541 inch diameter with 2·496 inches diameter, $n=3{\cdot}1179$

Mean . . . $n=3{\cdot}2130$

Mean from all the above comparisons, nineteen in number, $=3{\cdot}513$.

Strength of Pillars dependent on their Length.

To find the inverse power of the length on which the strength of solid pillars of cast iron, cast from the same model, depends, the pillars being of various lengths and having their ends turned flat and perpendicular to the axis. From my former experiments* we have as below, x being the inverse power, and the lengths of the pillars varying from eighty to twenty times the diameter nearly.

Diameters considered equal.	Lengths of which the strengths are compared.	Value of x.	Mean value of x.
in. in.	ins. ins.		
·77 and ·77	60·5 and 30·25	1·843	
·77 and ·777	60·5 and 20·1666	1·682	
·77 and ·775	60·5 and 15·125	1·550	1·650
·997 and 1·01	60·5 and 30·25	1·691	
·997 and 1·022	60·5 and 20·1666	1·483	

* Philosophical Transactions, 1840, Part II. p. 399.

From the present experiments on pillars whose models were $2\frac{1}{2}$ inches diameter in most cases, Tables I. to VI.

Diameters of pillars compared.	Lengths of pillars compared.	Values of x.	Mean values of x.	Remarks.
in. in.	ft. ft.			
$2\frac{1}{2}$ and $2\frac{1}{2}$	10 $7\frac{1}{2}$	1·6303[a]	1·6303	[a] This result is a mean from ten comparisons on different kinds of iron. Tables II., III., IV.
$2\frac{1}{2}$ and $2\frac{1}{2}$	10 $6\frac{1}{4}$	1·8864 } [b]	1·6063	[b] From four kinds of iron, Level, London Mixture, Old Hill and Derwent. Tables III. and V.
$2\frac{1}{2}$ and $2\frac{1}{2}$	10 $6\frac{1}{4}$	1·5737		
$2\frac{1}{2}$ and $2\frac{1}{2}$	10 $6\frac{1}{4}$	1·5514		
$2\frac{1}{2}$ and $2\frac{1}{2}$	10 $6\frac{1}{4}$	1·4137		
$2\frac{1}{2}$ and $2\frac{1}{2}$	10 $6\frac{1}{4}$	1·482 } [c]	1·6724	[c] From the Second London Mixture. Tables III. and V.
$2\frac{1}{2}$ and $2\frac{1}{2}$	10 $6\frac{1}{4}$	1·4752		
$1\frac{1}{2}$ and $1\frac{1}{2}$	10 $6\frac{1}{4}$	1·8338		
$1\frac{1}{2}$ and $1\frac{1}{2}$	10 $6\frac{1}{4}$	1·8986		
$2\frac{1}{2}$ and $2\frac{1}{2}$	10 5	1·4523 } [d]	1·5232	[d] From Old Hill Iron. Tables III. and VI.
$2\frac{1}{2}$ and $2\frac{1}{2}$	10 5	1·5942		
Mean value of x from all the comparisons, twenty-five in number, 1·6285.				

In the former experimental paper, mentioned above, I assumed 1·7 as the inverse power which the strength of pillars of the same diameter and of different lengths followed nearly, this applying both to pillars with rounded ends and to those with flat ends; but it appears from above, that in flat-ended pillars, representing the great mass of those used in practice, the strength would be better represented by some number intermediate between 1·6 and 1·7: the results of the experiments here detailed give 1·63 as a mean nearly, and this number may be used for all pillars whose length is more than about thirty times the diameter. In pillars shorter than this the formula used for calculating their strength would require correcting, as previously mentioned in page 859.

Strength of Pillars, the Iron in the section of which is not uniform.

The iron of all the pillars in this research is assumed to be uniform and of equal resistance throughout the surface of fracture, but this is perhaps seldom or never the case in cast iron, except possibly in very large castings. My experiments on the crushing of cast iron, made for the British Association, to determine the relative values of hot and cold blast iron*, of which an abstract is given in my 'Experimental Researches on the Strength and other properties of Cast Iron, 1846†,' showed that small cylinders of cast iron, No. 2, from the Carron Iron-works, turned to the exact dimensions from castings made but little larger than the size intended, required to crush them 130163 lbs. per square inch when they were $\frac{1}{4}$ inch diameter, and 132319 lbs. per square inch when they were $\frac{3}{8}$ inch diameter, from means of several experiments. In cylinders and prisms cut out of larger masses, the crushing weight per square inch was reduced to 119730 lbs., 103012 lbs., 102884 lbs., 108315 lbs., 96764 lbs., &c. In the experiments made to determine the crushing strength of the iron in my former experiments on pillars‡, cylinders ·52 inch diameter and nearly of the size of the original casting, required 115910 lbs.

* Seventh Report, 1837. † WEALE, London.

‡ Philosophical Transactions, 1840, Part II. p. 419.

per square inch to crush them, and small rectangles cut out of masses 1 inch square required 103692 lbs. only.

In some experiments made by Captain (now Colonel) JAMES, as a Member of the Royal Commission for inquiring into the application of Iron to Railway Structures*, it was found that the central part of bars of iron planed was much weaker to bear a transverse strain than bars cast of the same size. He states that "it was found by planing out $\frac{3}{4}$-inch bars from the centre of 2-inch square and 3-inch square bars, that the central portion was little more than half the strength of that from an inch bar, the relation being as 7 to 12" (there may be some doubt whether the iron was sound at the centre). In page 111 of the same Report, I showed that rectangular bars of cast iron, cast 1, 2, and 3 inches square, laid upon supports $4\frac{1}{2}$ feet, 9 feet, and $13\frac{1}{2}$ feet asunder, were broken by weights of 447 lbs., 1394 lbs., and 3043 lbs. respectively. These weights, divided by the squares of the lengths, should give equal results; the quotients, however, were as 447, 349, and 338 respectively. I attributed this falling off and deviation from theory partly to the defect of elasticity, which I had always found in cast iron, but principally to the superior hardness of the smaller castings.

From the experiments on the resistance to a crushing force of the various kinds of iron used in this research, it was found that short cylinders, $\frac{3}{4}$ inch in diameter and $1\frac{1}{2}$ inch high, cut out of pieces cast $2\frac{1}{2}$ inches diameter, resisted with more force when cut out of the part near to the surface than when cut out of that near to the centre. To try this, many small cylinders, from four or five kinds of iron, were cut from the centre, and from the part intermediate between the centre and the circumference (Table VIII.), and it was found that the cylinders from the latter part were always stronger than those from the centre; thus, in cylinders from pillars of Old Park iron, No. 1, cast as above mentioned $2\frac{1}{2}$ inches diameter, the mean crushing force of the iron near to the circumference was 39·32 tons per square inch, and that from the centre 33·33 tons per square inch, the difference being 5·99 tons. Whence $\frac{5\cdot99}{39\cdot32}=\cdot1523$, the ratio of the falling off of the resistance of the central part to the resistance of the external part.

Cylinders from other irons used gave the results below (see Table VIII.).

Low Moor Iron, No. 2.—Crushing force per square inch.

Centre, 29·65 tons. Intermediate part, 34·59 tons.

External ring of a hollow pillar, 4 inches diameter, of which the outer crust had been removed, 39·06 tons.

External ring of a hollow pillar, about $3\frac{1}{2}$ inch. diameter, 51·78 tons. From another pillar, of about the same diameter, 49·20 tons; the iron of both of these being very thin.

Blaenavon Iron, No. 3.

Centre, 34·22 tons. Intermediate part, 37·28 tons.

* See Report, 1849, p. 250.

Second London Mixture.

Centre, 35·02 tons. Intermediate part, 42·56 tons.

Second London Mixture.—Specimens cut from pillars $1\frac{1}{2}$ inch diameter.

Centre, 46·46 tons. Intermediate part, 49·59 tons.

By comparing the results of the experiments on the resisting powers of the different irons in the kingdom to a crushing force, with those obtained from the direct strengths of pillars of the same irons, 10 feet long and $2\frac{1}{2}$ inches diameter, it appears that the crushing force varies rather widely from being as the direct strength of pillars from the same model. Though the ratio assumed is merely an approximation, it will afford means of approaching to the falling off in the strength of pillars, when the resistance of the different parts to a crushing force is known.

Taking the results from the breaking weights of three of the strongest iron pillars, each 10 feet long and $2\frac{1}{2}$ inches diameter, and the crushing weights of the irons from those pillars, we have from the strongest pillars—

Breaking weights of the pillars.		Crushing weights of the iron in their sections.	
66086		437350	
62794	Mean 63342 lbs.	485750	Mean 464070 lbs.
61147		469110	

and from those of the weakest irons—

52680		338450	
49387	Mean 48995 lbs.	346130	Mean 319345 lbs.
44918		273455	

Comparing the breaking weights of the pillars with the crushing weights of the irons, we have

$$48995 : 63342 :: 319345 : 412857.$$

The last number, 412857, ought to have been 464070 if the breaking weights had been as the crushing weights. But the breaking weight of pillars depends on the tensile and crushing weights conjointly, though principally upon the latter; the assumption of that proportion must be taken as an approximation only, as previously mentioned.

Let r, r' be the resistances to crushing per square inch of the parts near to the circumference and to the centre respectively; D, d the external diameter, and that which includes the softer part of the metal near to the centre. Then $r-r'=$ the falling off per square inch in the resistance of the softer part below that of the external part. Whence $\frac{r-r'}{r}=$ the defect of resistance of the central part, the resistance of the external part being represented by unity.

If then w be the breaking weight of a pillar; m, n constants, and as before assumed for solid pillars of uniform texture,

$$w=m\mathrm{D}^n, \quad \ldots \quad \text{(A.)}$$

the length being constant, then

$$w=m\left(D^n-\frac{r-r'}{r}d^n\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(B.)}$$

for pillars of variable texture, as above. If the pillar be hollow $r'=0$, and

$$w=m(D^n-d^n), \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(C.)}$$

as before found.

The falling off in the strength of solid pillars from that of hollow ones of the same external diameter, and of the same kind of iron, may be seen very evidently from the results of the experiments in Tables I. and II., and made the subject of further investigation, if the principles assumed be admitted.

Example 1. If in a hollow pillar, n, in equation C, be 3·5, and d be taken of different values as below, we shall have $w=m(D^{3\cdot5}-d^{3\cdot5})$; and

$$\text{if } d=\frac{D}{4},\ w=m(D^{3\cdot5}-\cdot0078\,D^{3\cdot5})=m\times\cdot9922\,D^{3\cdot5};$$

$$\text{if } d=\frac{D}{2},\ w=m(D^{3\cdot5}-\cdot0884\,D^{3\cdot5})=m\times\cdot9116\,D^{3\cdot5};$$

$$\text{if } d=\frac{2D}{3},\ w=m(D^{3\cdot5}-\cdot242\,D^{3\cdot5})=m\times\cdot758\,D^{3\cdot5};$$

$$\text{if } d=\frac{3}{4}D,\ w=m(D^{3\cdot5}-\cdot365\,D^{3\cdot5})=m\times\cdot635\,D^{3\cdot5};$$

$$\text{if } d=\frac{4}{5}D,\ w=m(D^{3\cdot5}-\cdot458\,D^{3\cdot5})=m\times\cdot542\,D^{3\cdot5};$$

$$\text{if } d=\frac{5}{6}D,\ w=m(D^{3\cdot5}-\cdot528\,D^{3\cdot5})=m\times\cdot472\,D^{3\cdot5}.$$

Example 2. In the formula (B.), for metals of variable texture, $w=m\left(D^n-\frac{r-r'}{r}d^n\right)$; and supposing, for example, as in Low Moor iron, $\frac{r-r'}{r}=\frac{39-29\frac{1}{2}}{39}=\frac{1}{4}$ nearly, or $w=m\left(D^{3\cdot5}-\frac{1}{4}d^{3\cdot5}\right)$,

$$\text{if } d=\frac{D}{4},\ w=m\left(D^{3\cdot5}-\frac{1}{4}\times\cdot00781\,D^{3\cdot5}\right)=m(D^{3\cdot5}-\cdot0019\,D^{3\cdot5})=m\times\cdot998\,D^{3\cdot5}=22\cdot954\,D^{3\cdot5};$$

$$\text{if } d=\frac{D}{2},\ w=m\left(D^{3\cdot5}-\frac{1}{4}\times\cdot0884\,D^{3\cdot5}\right)=m(D^{3\cdot5}-\cdot0221\,D^{3\cdot5})=m\times\cdot9779\,D^{3\cdot5}=22\cdot492\,D^{3\cdot5};$$

$$\text{if } d=\frac{2D}{3},\ w=m\left(D^{3\cdot5}-\frac{1}{4}\times\cdot242\,D^{3\cdot5}\right)=m(D^{3\cdot5}-\cdot0605\,D^{3\cdot5})=m\times\cdot9395\,D^{3\cdot5}=21\cdot608\,D^{3\cdot5};$$

$$\text{if } d=\frac{3D}{4},\ w=m\left(D^{3\cdot5}-\frac{1}{4}\times\cdot365\,D^{3\cdot5}\right)=m(D^{3\cdot5}-\cdot091\,D^{3\cdot5})=m\times\cdot909\,D^{3\cdot5}=20\cdot907\,D^{3\cdot5};$$

$$\text{if } d=\frac{4D}{5},\ w=m\left(D^{3\cdot5}-\frac{1}{4}\times\cdot458\,D^{3\cdot5}\right)=m(D^{3\cdot5}-\cdot1145\,D^{3\cdot5})=m\times\cdot8855\,D^{3\cdot5}=20\cdot366\,D^{3\cdot5};$$

(m being assumed as 23, as below.)

The mean value of x obtained from the first six pillars in the summary (page 861) is 2174 lbs., the power being 3·55; and for solid pillars it is 2029 lbs. (Exp. 11 and 12). These values for a power 3·5, as assumed in the problem above, are 2322 and 2126 lbs.

respectively, or as 23 to 21 nearly; if then m be assumed as 23, the falling off for different values of d will be, as in the example above, becoming successively 22·954, 22·492, 21·608, 20·907, 20·366; and the value of d, which gives 21, is about $\frac{3}{4}$D.

Example 3. Again, suppose $\frac{r-r'}{r}=\frac{1}{5}$, and the rest as before,

$$\left.\begin{array}{l} \text{if } d=\frac{2}{3}D,\ w=m\left(D^{3\cdot5}-\frac{1}{5}\times\cdot242\,D^{3\cdot5}\right)=m(D^{3\cdot5}-\cdot048\ D^{3\cdot5})=m\times\cdot952\ D^{3\cdot5}=21\cdot896\,D^{3\cdot5}; \\ \text{if } d=\frac{3}{4}D,\ w=m\left(D^{3\cdot5}-\frac{1}{5}\times\cdot365\,D^{3\cdot5}\right)=m(D^{3\cdot5}-\cdot073\ D^{3\cdot5})=m\times\cdot927\ D^{3\cdot5}=21\cdot321\,D^{3\cdot5}; \\ \text{if } d=\frac{4}{5}D,\ w=m\left(D^{3\cdot5}-\frac{1}{5}\times\cdot458\,D^{3\cdot5}\right)=m(D^{3\cdot5}-\cdot0916\,D^{3\cdot5})=m\times\cdot9084\,D^{3\cdot5}=20\cdot893\,D^{3\cdot5}; \end{array}\right\}\ \text{if } m \text{ be assumed as 23, as in the last example;}$$

and the value of d, which gives 21, is about $\frac{4}{5}$D.

The pillars in the following summary of results were all cast solid from models $2\frac{1}{2}$ inches diameter, and made 10 feet long, with their ends flat. Those of iron, denominated No. 1, were chosen for comparison from some of the leading irons in the kingdom. They vary in strength from 29·50 tons to 20·05 tons, or nearly as 3 to 2. Formulæ for the strength of pillars of all the irons tried, thirteen in number, are given, both on the supposition used in the former research, and also on that arrived at in the present. The weights which would crush short pillars of the same diameter are likewise given.

Second Summary.

Results of all the Experiments in Tables II. and III. on Solid Pillars of Cast Iron, 10 feet long, cast from models $2\frac{1}{2}$ inches diameter, and supplied from Low Moor, and from Messrs. EASTON and AMOS; with applications to the formulæ for their strength on different suppositions; and also the weights which would crush the pillars.

Description of Iron of which the pillar was formed.	Breaking weight of pillar.		Value of x from formula $x=\frac{W}{D^{3 \cdot 55}}$, where W is the breaking weight, D the diameter, and x the breaking weight of a pillar 1 inch diameter and 10 feet long.		Value of x from formula $x=\frac{W}{D^{3 \cdot 5}}$, where W is the breaking weight, D the diameter, and x the breaking weight of a pillar 1 inch diameter and 10 feet long.		Weight which would crush the pillar, calculated from Table VIII.	
	lbs.	Mean.	lbs.		lbs.		lbs.	
Old Park Iron, No. 1. Stourbridge. Cold blast.	66792 65381	66086	2571·5 2436·8	2504·1	2692·2 2552·3	2622·2	433350 441350	437350
Derwent Iron, No. 1. Durham. Hot blast.	57855 67733	62794	2147·2 2556·6	2351·9	2249·2 2677·4	2463·3	488060 483440	485750
Portland Iron, No. 1. Tovine, Scotland. Hot blast.	59736 62559	61147	2332·8 2328·3	2330·5	2441·8 2438·8	2440·3	462760 475460	469110
Calder Iron, No. 1. Lanarkshire. Hot blast.	60677 60677	60677	2379·7 2283·8	2331·7	2490·7 2391·8	2441·2	412200 421850	417025
London Mixture. One-half old plate iron and one-half Calder Iron.	54562 59266	56914	2013·7 2141·9	2077·8	2109·4 2244·4	2176·9	407790 412630	410210
Level Iron, No. 1. Staffordshire. Hot blast.	54091 56443	55267	2038·8 2179·2	2109·0	2135·2 2281·5	2208·3	339700 335130	337415
Coltness Iron, No. 1. Edinburgh. Hot blast.	56443 48917	52680	2133·5 1902·1	2017·8	2234·2 1991·1	2112·6	313460 308505	310980
Carron Iron, No. 1. County of Stirling. Hot blast.	52210 53151	52680	2001·6 2026·1	2013·8	2095·7 2121·6	2108·6	337910 338990	338450
Blaenavon Iron, No. 1. South Wales. Cold blast.	48917 49858	49387	1926·7 1930·5	1928·6	2016·5 2020·9	2018·7	344460 347800	346130
Old Hill Iron. No. 1. Staffordshire. Cold blast.	44683 45154	44918	1679·5 1690·0	1684·7	1759·0 1770·0	1764·5	273130 273780	273455
Second London Mixture. One-third No. 1 best Scotch pig iron, and two-thirds old metal.	63499 58325	60912	2417·2 2268·0	2342·6	2531·1 2374·1	2452·6	472120 466490	469305
Low Moor Iron, No. 2. Yorkshire. Cold blast.	55973 55973	55973	2008·9 2048·5	2028·7	2105·2 2146·1	2125·6	397590 393240	395415
Blaenavon Iron, No. 3. South Wales. Cold blast.	56914 57855	57384	2034·1 2096·7	2065·4	2131·8 2197·0	2164·4	428540 425190	426865

Formulæ for computing the Breaking Weights of Solid Pillars of the Irons in the preceding summary; where W is the breaking weight in lbs. or in tons, D the diameter in inches, and l the length in feet.

Description of Iron in the Pillar.	Strength of a pillar from formula $W=m.\frac{D^{3\cdot55}}{l^{1\cdot7}}$, where m is as below, according as the weight is in lbs or tons.	Strength of a pillar from formula $W=m.\frac{D^{3\cdot5}}{l^{1\cdot63}}$, where m is as below, according as the weight is in lbs. or tons.
	lbs. tons.	lbs. tons.
Old Park Iron, No. 1	125502=56·03	111858=49·94
Derwent Iron, No. 1	117872=52·62	105079=46·91
Portland Iron, No. 1	116802=52·14	104098=46·47
Calder Iron, No. 1	116862=52·17	104137=46·49
London Mixture	104137=46·49	92862=41·46
Level Iron, No. 1	105700=47·19	94202=42·05
Coltness Iron, No. 1	101130=45·15	90119=40·23
Carron Iron, No. 1	100929=45·06	89949=40·16
Blaenavon Iron, No. 1	96659=43·15	86114=38·44
Old Hill Iron, No. 1	84435=37·69	75270=33·60
Second London Mixture	117408=52·41	104623=46·21
Low Moor Iron, No. 2	101676=45·39	90674=40·48
Blaenavon Iron, No. 3	103515=46·21	92329=41·22

The numbers above represent the strength of a pillar 1 foot long and 1 inch diameter.

To compare the direct strength of long pillars of cast iron with their transverse strength.—If the pillars be cylindrical, and have their ends turned flat and perpendicular to their axes, the ultimate strength of a solid pillar will be represented by $w=m\frac{D^n}{l^p}$, where D is the diameter, l the length, and m, n, p constants. My former experiments* gave $n=3\cdot55$ and $p=1\cdot7$, but the present experiments on larger pillars give 3·5 and 1·63 for their values much more nearly.

The transverse strength of a cylinder, laid with its ends upon supports, and broken by a weight at its middle, is

$$w'=b.\frac{D^3}{l}.$$

Whence the ratio of the direct strength of a pillar to its transverse strength is

$$\frac{w}{w'}=\frac{m}{b}\cdot\frac{D^{n-3}}{l^{p-1}}.$$

If n be taken as 3·55 and p as 1·7, we shall have

$$\frac{w}{w'}=\frac{m}{b}\cdot\frac{D^{\cdot55}}{l^{\cdot7}};$$

and if n be taken as 3·5 and p as 1·63,

$$\frac{w}{w'}=\frac{m}{b}\cdot\frac{D^{\cdot5}}{l^{\cdot63}}.$$

* Philosophical Transactions, 1840.

Tables III., IV. and VII. give both the direct and transverse strength of the pillars to which the preceding remarks are applicable.

The following summary contains the results of the experiments in Tables II. to VI. upon solid pillars varying in length from 10 feet to 7 feet 6 inches, 6 feet 3 inches, and 5 feet, or as 8, 6, 5, 4, all from models $2\frac{1}{2}$ inches diameter; the results are from thirteen kinds of cast iron, as before, or from twenty-six pillars 10 feet long, eleven pillars 7 feet 6 inches long, six 6 feet 3 inches long, and three 5 feet long, forty-six pillars in all. This does not include pillars round at the ends, and others cast $1\frac{1}{2}$ inch diameter.

The mean crushing strength of short pillars of the irons, cast $2\frac{1}{2}$ inches diameter, is 175·7 tons. The other mean values are as below:—

Length.	Breaking weight.	Ultimate decrement of length.	Ultimate deflection.	Ratio of breaking weight to crushing weight.
	tons.	in.	in.	
10 ft.	23·27	·176	·75	·146
7 ft. 6 in.	40·57	·235	·66	·231
6 ft. 3 in.	51·77	·248	...	·294
5 ft.	57·69*	·296*	·57*	·472*

whence it appears that the ultimate decrement of length is inversely as the length nearly. Another object of these experiments, and of others on pillars of smaller diameter in Tables III. and V., was to determine the powers of the diameter and length on which the strength of pillars depends (see pp. 865 and 866).

* From two experiments only.

Third Summary.

Third Summary.—Comparison of the Crushing Weights, Breaking Weights, ultimate diameter, the lengths being different, and the

Description of Iron in the Pillar.	Weight which would crush a short pillar of the iron used, and of the same diameter, 2½ inches (from Table VIII.). (C.)	Pillars 10 feet long, from Tables II. and III.			
		Breaking weight. (B.)	$\frac{B}{C}$.	Ultimate decrement of length.	Ultimate deflection.
	lbs.	lbs. Mean.		in.	in.
Old Park Iron, No. 1. Cold blast	437350	65381, 66792 } 66086 lbs. =29·50 tons.	·151	·181, ·171 } ·176	·31, ·45 } ·38
Derwent Iron, No. 1. Hot blast	485750	57855, 67733 } 62794 lbs. =28·03 tons.	·129	·164, ·180 } ·172	·58, ·69 } ·63
Portland Iron, No. 1. Hot blast	469110	59736, 62559 } 61147 lbs. =27·30 tons.	·130	·175, ·179 } ·177	·84, ·92 } ·88
Calder Iron, No. 1. Hot blast	417025	60677, 60677 } 60677 lbs. =27·09 tons.	·145	·177, ·192 } ·184	·45, 1·13 } ·79
London Mixture. One-half old plate iron and one-half Calder Iron	410210	59266, 54562 } 56914 lbs. =25·41 tons.	·139	·190, ·188 } ·189	1·06, 1·10 } 1·08
Level Iron, No. 1. Hot blast	337415	54091, 56443 } 55267 lbs. =24·67 tons.	·164	·199, ·179 } ·189	1·14, ·91 } 1·03
Coltness Iron, No. 1. Hot blast	310980	56443, 48917 } 52680 lbs. =23·52 tons.	·169	·163, ·155 } ·159	·57, ·44 } ·51
Carron Iron, No. 1. Hot blast	338450	53151, 52210 } 52680 lbs. =23·52 tons.	·156	·166, ·173 } ·169	·38, ·45 } ·42
Blaenavon Iron, No. 1. Cold blast	346130	48917, 49858 } 49387 lbs. =22·05 tons.	·143	·169, ·159 } ·164	·83, ·65 } ·74
Old Hill Iron, No. 1. Cold blast	273455	44683, 45154 } 44918 lbs. =20·05 tons.	·164	·191, ·181 } ·186	·66, ·61 } ·64
Second London Mixture. One-third No. 1 best Scotch pig-iron, and two-thirds of old metal	469305	63499, 58325 } 60912 lbs. =27·19 tons.	·130	·189, ·159 } ·174	·66, ·70 } ·68
Low Moor Iron, No. 2. Cold blast	395415	55973, 55973 } 55973 lbs. =24·99 tons.	·141	....	1·23, ·79 } 1·01
Blaenavon Iron, No. 3. Cold blast	426865	56914, 57855 } 57384 lbs. =25·62 tons.	·134	....	1·00, ·90 } ·95
Means from all the results in each vertical column	393650 =175·74 tons.	52832 =23·27 tons.	·146	·176	·75

Deflections, and ultimate Decrements of Length of the Cast Iron Pillars, $2\frac{1}{2}$ inches ends turned flat and perpendicular to the axis.

Pillars 7 ft. 6 in. long, from Table IV.				Pillars 6 feet 3 inches long, from Table V.				Pillars 5 feet long, from Table VI.			
Breaking weight. (B.)	$\frac{B}{C}$.	Ultimate decrement of length.	Ultimate deflection.	Breaking weight. (B.)	$\frac{B}{C}$.	Ultimate decrement of length.	Ultimate deflection.	Breaking weight. (B.)	$\frac{B}{C}$.	Ultimate decrement of length.	Ultimate deflection.
		in.	in.			in.					
100191 lbs. =44·73 tons.	·229	·228	·56								
105365 lbs. =47·04 tons.	·217	·225	·51	112438 lbs.* =50·20 tons.	·231	·221					
102543 lbs. =45·78 tons.	·219	·245	·69								
93135 lbs. =41·58 tons.	·223	·231	·68								
93605 lbs. =41·79 tons.	·228	·234	·67	114320 lbs. =51·04 tons.	·279	·277					
98309 lbs. =43·89 tons.	·291	·244	·65	131275 lbs. =58·60 tons.	·389	·272					
87019 lbs. =38·85 tons.	·280	·254	·92								
72437 lbs. =32·34 tons.	·214	·235	·76								
71967 lbs. =32·13 tons.	·208	·222	·59	....	....	....	....	117612 lbs.† =52·51 tons.	·339	·253	
....	....	....	....	93622 lbs. =41·79 tons.	·342	·264	....	135592 } 122863 } Mean 129227 lbs. =57·69 tons.	·496 } ·449 } ·472	·285 } ·308 } ·296	·50 } ·64 } ·57
....	....	....	....	127432 } 116672 } Mean 122052 lbs. =54·49 tons.	·272 } ·249 } ·260	·244 } ·213 } ·228					
89371 lbs. =39·9 tons.	·226	....	·63								
85608 lbs. =38·22 tons.	·201	....	·59								
90868 lbs. =40·57 tons.	·231	·235	·66	115960 lbs. =51·77 tons.	·294	·248					

* This bar had probably been reduced in strength by straightening after a former experiment upon it.

† This result is probably less than it ought to be, as too large a weight was laid on at once.

The results hitherto given are principally deduced from the experiments in the eight following Tables.

Table I.—Experiments to obtain the Strength of Hollow Uniform Pillars of Low Moor Iron, No. 2, each pillar being 10 feet long, and having its ends turned flat and perpendicular to the axis.

No. of Experiment.	Description of Pillar. 10 feet long, and as above.	Deflection.	Weight producing the deflection.	Breaking weight, or that with which the pillar sank.	Value of x from formula $x=\frac{W}{D^{3\cdot55}-d^{3\cdot55}}$, where W is the breaking weight, D and d the external and internal diameters, the length of the pillar being 10 feet.	Value of x from formula $x=\frac{W}{D^{3\cdot5}-d^{3\cdot5}}$.	Remarks.
	inches.	inch.	lbs.	lbs.	lbs.	lbs.	
1.	Hollow uniform cylinder.	·35	20339				†It bore this nearly, but broke with 33197 lbs. laid on again.
	External diameter by various measurements ... 2·513	·40	22635				
		·46	24931				
	Internal diameter by various measurements ... 1·941	·54	27227				
		·68	29523				
	Weight of pillar 60¾ lbs.	·78	31819				
		1·00	34115	36411†, or 33197 Mean 34804 =15·54 tons.	2201·1	2324·9	For the form of fracture of this and the next pillar see Plate XXXIII.
2.	Hollow uniform cylinder.	·18	20339				
	External diameter by six measurements .... 2·520	·25	24931				
		·34	27227				
	Internal diameter by eight measurements .... 1·903	·39	29523				
		·48	31819				
	Weight of pillar 64½ lbs.	·61	34115				
		·75	36411				*The deflections marked thus in this and the following experiments were computed from the two preceding results.
		1·09	38707				
		1·16*	39166	39166 =17·48 tons.	2332·9	2463·7	
3.	Hollow uniform cylinder.	·04	20339				†With this weight it broke, after bearing it several minutes. The thickness of the ring of metal on the convex side was ·55 and on the concave ·17. The fracture took place nearly in the middle.
	External diameter from six measurements ...... 3·021	·06	24931				
		·08	29523				
	Internal diameter from ten measurements .... 2·354	·13	38707				
		·16	43299				
	Weight of pillar 89½ lbs.	·22	47891				
		·30	52483				
		·38	57075				
		·55	61667				
		·93	66259	66259† =29·58 tons.	2226·7	2374·2	
4.	Hollow uniform cylinder.	·06	20339				†It bore this nearly, but broke with 67636 lbs. laid on again.
	External diameter from nine measurements ... 3·035	·10	24931				The pillar broke nearly in the middle, and split at both ends; the metal differed in thickness on the opposite sides as 2 to 1 nearly, the thicker part being on the concave side and therefore compressed. See Plate XXXIII.
		·15	38707				
	Internal diameter from ten measurements .... 2·354	·17	43299				
		·23	47891				
	Weight of pillar 88 lbs.	·31	61667				
		·55	66259				
		·91	68555	72228†, or 67636 Mean 69932 =31·22 tons.	2285·8	2471·3	
5.	Hollow uniform cylinders.	·18	48917				With the weight 110649 this pillar sank down, but was not allowed to bend so as to break. It was preserved in order that an experiment might be made upon it in another way. When unloaded it became nearly straight, and was easily rendered so.
	External diameter from six measurements ...... 3·532	·22	58325				
		·32	77141				
	Internal diameter from eight measurements ... 2·646	·42	86549				
		·55	95957				
	Internal diameter from computation .... 2·673	·84	105365				
		1·00*	110649	110649 =49·39 tons.	1975·6	2121·7	
	Mean internal diameter ... 2·659						
	Weight of pillar 130 lbs.						
6.	Hollow uniform cylinder.	·11	58325				The remark in Experiment 5 applies also to the weight 114479 with which this pillar sank.
	External diameter from eight measurements ... 3·555	·15	67733				
		·19	77141				
	Internal diameter from eight measurements ... 2·664	·23	86549				
		·31	95957				
	By computation .... 2·722	·45	105365				
		·63	110069				
	Mean internal diameter ... 2·693	·80*	114479	114479 =51·11 tons.	2023·3	2173·9	
	Weight of pillar 128 lbs. 7 oz.						

TABLE I. (continued).

No. of Experiment.	Description of Pillar, 10 feet long, and as above.	Deflection.	Weight producing the deflection.	Breaking weight, or that with which the pillar sank.	Value of x from formula $x=\frac{W}{D^{3\cdot 55}-d^{3\cdot 55}}$, where W is the breaking weight, D and d the external and internal diameters, the length of the pillar being 10 feet.	Value of x from formula $x=\frac{W}{D^{3\cdot 5}-d^{3\cdot 5}}$	Remarks.
		inch.	lbs.		lbs.		
7.	Hollow uniform cylinder 9 ft. 9 in. long. External diameter from twelve measurements... } 3·804 inches. Internal diameter from eight measurements ... } 3·17 Weight of pillar 106 lbs. 10 oz.	·03 ·04 ·07 ·10 ·29 ·48*	20693 46271 74495 93311 102719 112127	112127, or 107403 lbs. =47·95 tons, if the pillar had been 10 feet long.	1963·8	2127·6	This and the following pillar were cast to be 4 inches external diameter, and were found so strong as to require weights which would injure the machinery. They were therefore turned outside to reduce their strength, and this, by taking away the hard external surface of the metal, seems to have produced that effect in a very great degree. They were cast 9 feet 9 inches long instead of 10 feet, so that they might be broken with rounded caps on the ends, which would only have required one-third of the weight required by pillars with flat ends. Ratio of thicknesses of metal on opposite sides in middle ·37 to ·25.
8.	Hollow uniform cylinder 9 ft. 9 in. long. External diameter from twelve measurements... } 3·819 Internal diameter at middle by eight measurements .... } 3·211 Weight of pillar 99 lbs. 14 oz.	·03 ·05 ·09 ·18 ·24	20693 39509 58325 77141 86549 99720	99720, or 95519 lbs. =42·64 tons, if the pillar had been 10 feet long.	1785·3	1928·8	Ratio of thicknesses of metal on opposite sides in middle ·21 to ·39, the thin side being the concave one. This pillar had many flaws in it.
9.	Pillars with rounded caps on the ends. { Hollow pillar, the same as in Experiment 5. Length, including caps on the ends, 10 ft. 2 in.	·12 ·18 ·26 ·30 ·36 ·42 ·55 ·68 1·16 to 1·37	20693 25397 30101 32453 34805 37157 39509 41861 44213	44683, or 45956 lbs. =20·51 tons, the breaking weight of the pillar if 10 feet long.			
10.	Hollow pillar, the same as in Experiment 6. Length, including caps on the ends, 10 ft. 2 in.	·14 ·21 ·31 ·47 ·63 ·85 1·40	20693 25397 30101 34805 37157 39509 41861	42331 lbs., or 43537 lbs. =19·44 tons, if the pillar had been 10 feet long.			

The hollow pillars in Experiments 5 and 6 had been prevented from being broken by a prop, which was made to act on their middle immediately after they had been bent *beyond* their utmost power of resisting. They were then unloaded and reserved for another experiment, as below; after being rendered straight and turned afresh at the ends, rounded caps were affixed to the ends, to enable the straining force to be applied

in the direction of the axis, as in Experiments 9 and 10. The strength in these cases should have been only one-third of what it was in the former ones, according to the results in pages 855 to 857; but it is greater than that, in the ratio of 20 to 17 nearly, arising in a great measure from crushing of the plates and the ends of the pillars, through the weight.

Table II. (Table I. continued).—Experiments to obtain the Strength of Solid Uniform Pillars of Low Moor Iron, No. 2, and of Blaenavon Iron, No. 3, the pillars being 10 feet long and $2\frac{1}{2}$ inches diameter nearly, with the ends turned flat and perpendicular to the axis.

No. of Experiment.	Description of Pillar, 10 feet long, and as above.	Deflection.	Weight producing the deflection.	Breaking weight, or weight with which the pillar sank.	Value of x from formula $x=\frac{W}{D^{3\cdot55}}$, where W is the breaking weight and D the diameter, the length of the pillar being 10 feet.	Value of x from formula $x=\frac{W}{D^{3\cdot5}}$.	Remarks.
	inches.	inch.	lbs.		lbs.		
11.	Solid uniform cylinder of	·10	20693				
	Low Moor Iron, No. 2.	·15	25397				
	Diameter from eighteen measurements .... } 2·553	·20	34805				
		·25	37157				
	Weight of pillar 159 lbs. 9 oz.	·29	39509				
		·33	41861				
		·38	44213				
		·43	46565				
		·51	48917				
		·61	51269				
		·78	53621				
		1·23	55973	55973 =24·99 tons.	2008·9	2105·2	
12.	Solid uniform cylinder of	·10	20693				
	Low Moor Iron, No. 2.	·13	25397				
	Diameter from eighteen measurements .... } 2·539	·16	30101				
		·19	34805				* See note to Experiment 2, which applies to the cases below marked with an asterisk.
	Weight of pillar 158 lbs. 15 oz.	·22	37157				† After bearing the weight 55973 lbs. for half a minute or more, it sank.
		·25	39509				
		·28	41861				
		·35	44213				
		·39	46565				
		·45	48917				
		·55	51269				
		·67	53621				
		·79*	55973	55973† =24·99 tons.	2048·5	2146·1	
13.	Solid uniform cylinder of	·10	20693				
	Blaenavon Iron, No. 3.	·13	25397				
	Diameter from eighteen measurements .... } 2·556	·16	30101				
		·20	34805				
	Weight of pillar 160 lbs. 3 oz.	·25	39509				
		·34	44213				
		·42	48917				
		·55	51269				
		·66	53621				
		·90	55973				
		1·00*	56914	56914 =25·41 tons.	2034·1	2131·8	
14.	Solid uniform cylinder of	·07	20693				
	Blaenavon Iron, No. 3.	·11	25397				
	Diameter from eighteen measurements .... } 2·546	·14	30101				
		·17	34805				
	Weight of pillar 159 lbs. 6 oz.	·21	39509				
		·28	44213				
		·37	48917				
		·43	51269				
		·54	53621				
		·74	55973				
		·90*	57855	57855 =24·83 tons.	2096·7	2197·0	

Table III.—Experiments to determine the Strength of Solid Uniform Pillars, 10 feet long and 2½ inches diameter nearly, from various parts of the kingdom. The pillars were all cast erect and in dry sand, from the same iron model, nearly 12 feet long; they were afterwards cut to 10 feet long, and their ends turned flat and perpendicular to the axis. Two pillars were cast from each kind of iron. The irons are arranged in the order of their strength.

No. of Experiment.	Description of Pillar; each being cast solid, 2½ inches diameter nearly, and turned, 10 feet long, and flat at the ends.	Weights laid on.	Decrement of length.	Deflection of middle.	Breaking weight, or that with which the pillar sank.	Value of x from formula $x=\frac{W}{D^{3\cdot55}}$, where W is the breaking weight, D the diameter, and x the strength of a pillar 1 inch diameter and 10 ft. long.	Value of x from formula $x=\frac{W}{D^{3\cdot5}}$.	Remarks.
	inches.	lbs.	inch.	inch.	lbs.	lbs.	lbs.	
1.	Old Park Iron, No. 1.	20693	·065	·04				
	Stourbridge. Cold blast.	25397	·076					
	Mean diameter from nine measurements .... } 2·503	30101	·087	·06				
		34805	·097					
	Weight of pillar 151½ lbs.	39509	·106	·08				
		44213	·116					
		48917	·127	·10				
		53621	·138					
		58325	·149	·18				
		63029	·161	·33				
		66792	·171*	·45*	66792	2571·5	2692·2	
2.	Old Park Iron, No. 1.	20693	·072					
	Stourbridge. Cold blast.	25397	·084					
	Mean diameter from eight measurements .... } 2·526	30101	·095					
		34805	·105					
	Weight of pillar 154 lbs.	39509	·116					
		44213	·127					
		48917	·139					
		53621	·150	·07				
		58325	·161	·14				
		63029	·174	·27				
		65381	·181*	·31*	65381	2436·8	2552·3	
3.	Derwent Iron, No. 1.	20693	·066	·08				
	Durham. Hot Blast.	25397	·077					
	Mean diameter from eight measurements .... } 2·529	30101	·089	·10				
		34805	·100					
	Weight of pillar 152 lbs.	39509	·112	·16				
		44213	·123	·20				
		48917	·137	·27				
		53621	·151	·43				
		57855	·164*	·58*	57855	2147·2	2249·2	
4.	Derwent Iron, No. 1.	20693	·060	·02				
	Durham. Hot blast.	25397	·071					
	Mean diameter from eight measurements .... } 2·517	30101	·081					
		34805	·091					
	Weight of pillar 151¼ lbs.	39509	·102					
		44213	·113					
		48917	·124					
		53621	·135	·06				
		58325	·147	·13				
		60677	·153	·19				
		63029	·159	·23				
		65381	·166	·35				
		66733	·180	·69	66733	2556·6	2677·4	
5.	Portland Iron, No. 1.	20693	·068	·09				
	Tovine, Scotland. Hot blast.	25397	·079					
	Mean diameter from eight measurements .... } 2·493	30101	·090	·11				
		34805	·101					
	Weight of pillar 150¼ lbs.	39509	·112	·15				
		44213	·124	·19				
		48917	·136	·24				
		53621	·150	·37				
		55973		·46				
		58325	·169	·68 to ·73				
		59736	·175*	·84*	59736	2332·8	2441·8	

* The quantities marked with an asterisk were computed in each case from the two preceding results, as before.

Table III. (continued).

No. of Experiment.	Description of Pillar: each being cast solid, 2½ inches diameter nearly, and turned, 10 feet long, and flat at the ends.	Weights laid on.	Decrement of length.	Deflection of middle.	Breaking weight, or that with which the pillar sank.	Value of x from formula $x=\frac{W}{D^{3.55}}$, where W is the breaking weight, D the diameter, and x the strength of a pillar 1 inch diameter and 10 ft. long.	Value of x from formula $x=\frac{W}{D^{3.5}}$.	Remarks.
	inches.	lbs.	inch.	inch.	lbs.	lbs.	lbs.	
6.	Portland Iron, No. 1.	20693	·065	·09				
	Tovine, Scotland. Hot blast.	25397	·075					
	Mean diameter from eight measurements .... 2·527	30101	·086	·11				
	Weight of pillar 156½ lbs.	34805	·097					
		39509	·107	·17				
		44213	·118					
		48917	·130	·27				
		53621	·145	·41				
		58325	·159	·58				
		60677	·170	·77				
		62559	·179*	·92*	62559	2328·3	2438·8	
7.	Calder Iron, No. 1.	20693	·069	·04				
	Lanarkshire. Hot blast.	25397	·081					
	Mean diameter from eight measurements .... 2·490	30101	·093	·05				
	Weight of pillar 149 lbs. 10 oz.	34805	·105					
		39509	·116	·08				
		44213	·128					
		48917	·140	·15				
		53621	·153	·25				
		58325	·169	·38				
		60677	·177*	·45*	60677	2379·7	2490·7	
8.	Calder Iron, No. 1.	20693	·069	·06				
	Lanarkshire. Hot blast.	25397	·081					
	Mean diameter from eight measurements .... 2·519	30101	·092	·08				
	Weight of pillar 151¾ lbs.	34805	·104					
		39509	·115	·14				
		44213	·127					
		48917	·140	·28				
		53621	·154	·43				
		58325	·179	·83				
		60677	·192*	1·13	60677	2283·8	2391·8	
9.	London Mixture.	20693	·069	·04				
	One-half old plate iron and one-half Calder iron.	25397	·082					
	Mean diameter from eight measurements .... 2·533	30101	·095	·06				
	Weight of pillar 152½ lbs.	34805	·107					
		39509	·121	·14				
		44213	·134	·20				
		48917	·149	·35				
		53621	·183	·94				
		54562	·190*	1·06*	54562	2013·7	2109·4	
10.	London Mixture.	20693	·067	·09				
	One-half old plate iron, and one-half Calder iron.	25397	·079					
	Mean diameter from eight measurements .... 2·548	30101	·091	·12				
	Weight of pillar 156 lbs. 14 oz.	34805	·103					
		39509	·114	·20				
		44213	·126	·23				
		48917	·139	·33				
		53621	·153	·48				
		58325	·180 to ·182	·91 to 1·00 in 2 minutes.				
		59266	·188*	1·10*	59266	2141·9	2244·4	
11.	Level Iron, No. 1.	20693	·070	·08				
	Staffordshire. Hot blast.	25397	·082					
	Mean diameter from eight measurements .... 2·518	30101	·094	·13				
	Weight of pillar 151 lbs. 2 oz.	34805	·107					
		39509	·122	·23				
		44213	·137	·34				
		48917	·155	·53				
		53621	·195	1·08				
		54091	·199*	1·14*	54091	2038·8	2135·2	
12.	Level Iron, No. 1.	20693	·069	·08				
	Staffordshire. Hot blast.	25397	·082					
	Mean diameter from eight measurements .... 2·501	30101	·094	·13				
	Weight of pillar 150¼ lbs.	34805	·107					
		39509	·121	·24				
		44213	·132	·31				
		48917	·147	·45				
		53621	·167	·74				
		56443	·179*	·91*	56443	2179·2	2281·5	

Table III. (continued).

No. of Experiment.	Description of Pillar; each being cast solid, 2½ inches diameter nearly, and turned, 10 ft. long, and flat at the ends.	Weights laid on.	Decrement of length.	Deflection of middle.	Breaking weight, or that with which the pillar sank.	Value of x from formula $x=\frac{W}{D^{3\cdot55}}$, where W is the breaking weight, D the diameter, and x the strength of a pillar 1 inch diameter and 10 ft. long.	Value of x from formula $x=\frac{W}{D^{3\cdot5}}$.	Remarks.
	inches.	lbs.	inch.	inch.	lbs.	lbs.	lbs.	
13.	Coltness Iron, No. 1.	20693	·065	·05				
	Edinburgh, Hot blast.	25397	·077					
	Mean diameter from eight	30101	·089	·06				
	measurements .... } 2·516	34805	·100					
	Weight of pillar 151¼ lbs.	39509	·112	·10				
		44213	·125	·15				
		48917	·139	·23				
		53621	·154	·44				
		56443	·163*	·57*	56443	2133·5	2234·2	
14.	Coltness Iron, No. 1.	20693	·068	·04				
	Edinburgh. Hot blast.	25397	·081					
	Mean diameter from eight	30101	·094	·06				
	measurements .... } 2·496	34805	·108					
	Weight of pillar 149 lbs. 10 oz.	39509	·123	·16				
		44213	·139	·30				
		48917	·155*	·44*	48917	1902·1	1991·1	
15.	Carron Iron, No. 1.	20693	·070	·03				
	County of Stirling. Hot blast.	25397	·083					
	Mean diameter from eight	30101	·097	·04				
	measurements .... } 2·506	34805	·110					
	Weight of pillar 149¾ lbs.	39509	·124	·06				
		44213	·137	·12				
		48917	·154	·27				
		52210	·166	·38*	52210	2001·6	2095·7	
16.	Carron Iron, No. 1.	20693	·076	·04				
	County of Stirling. Hot blast.	25397	·091					
	Mean diameter from eight	30101	·104	·06				
	measurements .... } 2·510	34805	·116					
	Weight of pillar 149¼ lbs.	39509	·130	·11				
		44213	·144	·18				
		48917	·159	·32				
		53151	·173*	·45*	53151	2026·1	2121·6	
17.	Blaenavon Iron, No. 1.	20693	·070					
	South Wales. Cold blast.	25397	·082	·08				
	Mean diameter from eight	30101	·096	·10				
	measurements .... } 2·487	34805	·109					
	Weight of pillar 150 lbs. 14 oz.	39509	·122	·21				
		44213	·137					
		48917	·169	·83	48917	1926·7	2016·5	
18.	Blaenavon Iron, No. 1.	20693	·064	·03				
	South Wales. Cold blast.	25397	·076	·05				
	Mean diameter from eight	30101	·088	·07				
	measurements .... } 2·499	34805	·100					
	Weight of pillar 151¾ lbs.	39509	·117	·16				
		44213	·130					
		48917	·154	·60				
		49858	·159*	·65*	49858	1930·5	2020·9	
19.	Old Hill Iron, No. 1.	20693	·088	·07				
	Staffordshire. Cold blast.	25397	·106					
	Mean diameter from eight	30101	·123	·09				
	measurements .... } 2·520	34805	·140					
	Weight of pillar 151¾ lbs.	39509	·159	·13				
		44213	·188	·61				
		44683	·191*	·66*	44683	1679·5	1759·0	
20.	Old Hill Iron, No. 1.	20693	·079	·04				
	Staffordshire. Cold blast.	25397	·094					
	Mean diameter from eight	30101	·111	·08				
	measurements .... } 2·523	34805	·126					
	Weight of pillar 151 lbs. 10 oz.	39509	·144	·30				
		44213	·175	·56				
		45154	·181*	·61*	45154	1690·0	1770·0	

TABLE III. (continued).

No. of Experiment.	Description of Pillar; each being cast solid, 2½ inches diameter nearly, and turned, 10 feet long, and flat at the ends.	Weights laid on.	Decrement of length.	Deflection of middle.	Breaking weight, or that with which the pillar sank.	Value of x from formula $x=\frac{W}{D^{3\cdot55}}$, where W is the breaking weight, D the diameter, and x the strength of a pillar 1 inch diameter and 10 ft. long.	Value of x from formula $x=\frac{W}{D^{3\cdot5}}$.	Remarks.
	inches.	lbs.	inch.	inch.	lbs.	lbs.	lbs.	
21.	Second London Mixture.	20693	·061					
	Two-thirds of old metal and	25397	·071					
	one-third of No. 1 best	30101	·081					
	Scotch pig-iron.	34805	·092					
	Mean diameter from eight measurements .... } 2·511	39509	·103	·05				
		44213	·113	·08				
	Weight of pillar 153 lbs.	48917	·128	·16				
		53621	·141	·29				
		58325	·156	·46				
		63029	·186					
		63499	·189*	·66*	63499	2417·2	2531·1	
22.	Second London Mixture.	20693	·060					
	Two-thirds of old metal and	25397	·071					
	one-third of No. 1 best	30101	·081	·05				
	Scotch pig-iron.	34805	·091					
	Mean diameter from eight measurements .... } 2·496	39509	·102	·10				
		44213	·114	·18				
	Weight of pillar 151½ lbs.	48917	·127	·30				
		53621	·143	·53				
		58325	·159*	·70*	58325	2268·0	2374·1	
23.	Second London Mixture.	7284	......	·02				
	Two-thirds of old metal and	9521	......	·13				
	one-third of No. 1 best	10980	......	·70	11204			
	Scotch pig-iron.							
	Mean diameter from eight measurements .... } 1·530							
	Weight of pillar 56 lbs. 2 oz.							
24.	Second London Mixture.	7284	......	·12				
	Two-thirds of old metal and	9524	......	·22				
	one-third of No. 1 best	9972	......	·30				
	Scotch pig-iron.	10420	......	·42				
	Mean diameter from eight measurements .... } 1·541	10532	......	·48	10868			
	Weight of pillar 56 lbs. 2 oz.							

Table IV.—Solid Pillars cut out of the 10 feet pillars, 2½ inches diameter, previously experimented upon, and now made 7 feet 6 inches long, quite straight, and with their ends turned flat and perpendicular to the axis, the iron being obtained from various parts of the United Kingdom (Tables III. and II.).

No. of Experiment.	Description of Pillar, 7 feet 6 inches long, and as above.	Weights laid on.	Decrement.	Deflection.	Breaking weight, or that with which the pillar sank.	Remarks.
		lbs.	inch.	inch.		
1.	Old Park Iron, No. 1. Stourbridge. Cold blast. Cut out of the pillar in Table III. Exp. 2. Diameter 2·526 inches.	20693	·058			Broke into four pieces.
		30101	·078			
		39509	·098			
		48917	·118			
		58325	·138			
		67733	·157	·10		
		77141	·176	·17		
		86549	·196	·25		
		91253	·207	·32		
		95957	·221	·44		
		100191	·234*	·55*	100191 lbs. = 44·73 tons.	
2.	Old Park Iron, No. 1. From Exp. 1, Table III. Diameter 2·503 inches.	20693	·059	·02		The low result of the breaking weight in this experiment renders it probable that the pillar had sustained some injury by straightening after the former experiment. This pillar broke in three pieces of nearly equal length, splitting at one end. See Plate XXXIII.
		30101	·078			
		39509	·096	·05		
		48917	·113	·08		
		58325	·132	·12		
		67733	·151	·15		
		77141	·171	·23		
		86549	·195	·36		
		91253	·209	·47		
		95487	·222*	·57*	95487 lbs. = 42·63 tons.	
3.	Derwent Iron, No. 1. Durham. Hot blast. From Exp. 4, Table III. Diameter 2·517 inches.	20693	·059			
		30101	·076			
		39509	·094	·02		
		48917	·112			
		58325	·129	·04		
		67733	·146	·06		
		77141	·165	·10		
		86549	·182	·15		
		95957	·205	·29		
		100661	·215	·40		
		105365	·225*	·51*	105365 lbs. = 47·04 tons.	
4.	Portland Iron, No. 1. Tovine, Scotland. Hot blast. From Exp 6 Table III. Diameter 2·527 inches.	20693	·059			
		30101	·077			
		39509	·095			
		48917	·112	·06		
		58325	·131	·08		
		67733	·149	·10		
		77141	·168	·14		
		86549	·188	·19		
		95957	·210	·33		
		100661	·235	·45 to ·59		
		102543	·245*	·69*	102543 lbs. = 45·78 tons.	
5.	Calder Iron, No. 1. Lanarkshire. Hot blast. From Exp. 7, Table III. Diameter 2·490 inches.	20693	·063			
		30101	·082			
		39509	·102			
		48917	·121	·05		
		58325	·143	·08		
		67733	·164	·13		
		72437	·175	·17		
		77141	·187	·22		
		81845	·200	·31		
		86549	·213	·40		
		91253		·60		
		93135	·231*	·68	93135 lbs. = 41·58 tons.	
6.	London Mixture. One-half old plate iron and one-half Calder Iron. From Exp. 10, Table III. Diameter 2·548 inches.	20693	·057	·02		This pillar broke in three pieces of nearly equal length, splitting at one end. It would appear that in this pillar, and in that of Exp. 2, there were more points of contrary flexure than in others. Plate XXXIII.
		30101	·077			
		39509	·097	·06		
		48917	·116	·08		
		58325	·137	·10		
		67733	·157	·16		
		77141	·179	·24		
		81845	·191	·29		
		86549	·205	·41		
		91253	·224	·58		
		93605	·234*	·67*	93605 lbs. = 41·79 tons.	

Table IV. (continued).

No. of Experiment.	Description of Pillar, 7 feet 6 inches long, and as above.	Weights laid on.	Decrement.	Deflection.	Breaking weight, or that with which the pillar sank.	Remarks.
		lbs.	inch.	inch.		
7.	Level Iron, No. 1.	20693	·061			
	Staffordshire. Hot blast.	30101	·082			
	From Experiment 12, Table III.	39509	·102			
	Diameter 2·501 inches.	48917	·124			
		58325	·144			
		67733	·165			
		77141	·185	·08		
		81845	·196	·17		
		86549	·207	·22		
		91253	·218	·32		
		95957	·235	·54		
		98309	·244*	·65*	98309 lbs. = 43·89 tons.	
8.	Coltness Iron, No. 1.	20693	·068			
	Edinburgh. Hot blast.	30101	·088			
	From Experiment 13, Table III.	39509	·110	·08		
	Diameter 2·516 inches.	48917	·132	·10		
		58325	·153	·14		
		67733	·177	·23		
		72437	·189	·29		
		77141	·201	·35		
		79493	·209	·48		
		81845	·218			
		86549	·251	·72 to ·81		
		87019	·254*	·92*	87019 lbs. = 38·85 tons.	
9.	Carron Iron, No. 1.	20693	·078	·10		Comparing the result from this pillar with that from the preceding one on Coltness Iron, the strengths of which should have been equal, as shown by the 10-feet pillars of these irons, I conceive this experiment to be in some degree defective, the pillar having probably been injured by the former experiment upon it.
	County of Stirling. Hot blast.	30101	·101	·12		
	From Experiment 15, Table III.	39509	·124	·16		
	Diameter 2·506 inches.	48917	·149	·22		
		58325	·175	·32		
		67733	·209	·56		
		70085	·222	·66		
		72437	·235*	·76*	72437 lbs. = 32·34 tons.	
10.	Blaenavon Iron, No. 1.	20693	·083	·07		
	South Wales. Cold blast.	30101	·106	·11		
	From Experiment 17 or 18, Table III.	39509	·128	·13		
	Diameter 2·5 inches nearly.	48917	·152	·17		
		58325	·176	·27		
		67733	·208	·49		
		71967	·222*	·59*	71967 lbs. = 32·13 tons.	
11.	Low Moor Iron, No. 2.	20693	......	·04		
	Cut from the pillar in Experiment 12, Table II.	48917	......	·07		
	Diameter 2·539 inches.	67733	......	·14		
		72437	......	·16		
		77141	......	·21		
		81845	......	·28		
		86549	......	·50		
		89371	......	·63*	89371 lbs. = 39·90 tons.	
12.	Blaenavon Iron, No. 3.	48917	......	·08		
	Cut out of the pillar in Experiment 13, Table II.	53621	......	·10		
	Diameter 2·556 inches.	58325	......	·13		
		63029	......	·17		
		67733	......	·22		
		72437	......	·27		
		77141	......	·36		
		81845	......	·49		
		85608	......	·59*	85608 lbs. = 38·22 tons.	
13.	Low Moor Iron, No. 2.	20693	......	·09		The strength was probably reduced by being experimented upon before, and afterwards rendered straight; the breaking weight would otherwise have been 63871 lbs. nearly, according to the inverse 1·7th power of the length. Ratio of the thicknesses of the sides ·20 to ·35, the thin side being compressed.——For form of fracture see Plate XXXIII.
	This pillar differs from the preceding ones in being *hollow*; it was cut out of the pillar in Experiment 2, Table I.	25397	......	·13		
	Length 7 feet 6 inches.	30101	......	·18		
	External diameter 2·520 inches.	34805	......	·21		
	Internal diameter 1·903 inch.	39509	......	·26		
	Ends flat.	44213	......	·29		
		48917	......	·36		
		51269	......	·40		
		53621	......	·55		
		55973	......	·70*	55973 lbs. = 24·99 tons.	

Table V.—Solid Pillars cut out of the 10-feet pillars, $2\frac{1}{2}$ inches diameter, previously experimented on, and now made 6 feet 3 inches long, quite straight, and with their ends turned flat and perpendicular to the axis, the irons being obtained from various parts of the United Kingdom (Table III.).

No. of Experiment.	Description of Pillar, 6 feet 3 inches long, and as above.	Weights laid on.	Decrement.	Deflection.	Breaking weight, or that with which the pillar sank.	Remarks.
		lbs.	inch.	inch.		
1.	Derwent Iron, No. 1. Durham. Hot blast. From Exp. 3, Table III. Diameter 2·529 inches.	20693	·024			The pillar broke where it had been beaten with a hammer to straighten it after the former experiment, by which its strength was probably reduced. The situation of the neutral line in this and the following experiment is strongly marked. The pillar broke at the middle, and was cracked at each end. See Plate XXXIII.
		30101	·043			
		39509	·062			
		48917	·082	·02		
		58325	·100			
		67733	·119			
		77141	·137	·10		
		86549	·158			
		95957	·177			
		105365	·202	·32		
		112438	·221*	......	112438 lbs. = 50·20 tons.	
2.	London Mixture. One-half old plate iron, and one-half Calder iron. From Exp. 9, Table III. Diameter 2·533 inches.	33881	·085			The pillar cracked at both ends, and broke in the middle. For form of fracture see Plate XXXIII.
		43289	·105			
		52697	·124	·10		
		62105	·142			
		71513	·161			
		80921	·181	·12		
		90329	·200			
		99737	·218	·18		
		104441	·232	·27		
		109145	·247	·32		
		113849	·274	·52		
		114320	·277*	......	114320 lbs. = 51·04 tons.	
3.	Level Iron, No. 1. Staffordshire. Hot blast. From Exp. 11, Table III. Diameter 2·518 inches.	33881	·085			It broke into a number of pieces. See figure, Plate as above.
		43289	·103			
		52697	·123			
		62105	·142			
		71513	·161			
		80921	·179			
		90329	·186			
		99737	·213			
		109145	·232			
		118553	·252			
		129137	·269			
		131275	·272*	......	131275 lbs. = 58·60 tons.	
4.	Old Hill Iron, No. 1. Staffordshire. Cold blast. From Exp. 20, Table III. Diameter 2·523 inches.	20693	·065			The pillar broke across in the middle, and cracked at both ends. See form of fracture, Plate as above.
		33881	·103			
		43289	·122	·03		
		52697	·146			
		62105	·164			
		71513	·188			
		80921	·214	·22		
		85625	·230	·28		
		90329	·250	·41		
		93622	·264*	......	93622 lbs. = 41·79 tons.	
5.	Second London Mixture. About two-thirds of old metal, and one-third of best Scotch pig-iron. From Exp. 21, Table III. Diameter 2·511 inches.	33881	·068			Broke by splitting in the middle and at the ends, one being broken off. See Plate as above.
		43289	·086			
		52697	·102			
		62105	·117			
		71513	·133			
		80921	·149			
		90329	·164			
		99737	·181			
		109145	·197	·04		
		118553	·218	·14		
		123601	·233	·26		
		127432	·244*	......	127432 lbs. = 56·89 tons.	

TABLE V. (continued).

No. of Experiment.	Description of Pillar, 6 feet 3 inches long, and as above.	Weights laid on.	Decrement.	Deflection.	Breaking weight, or that with which the pillar sank.	Remarks.
		lbs.	inch.	inch.		
6.	Second London Mixture. About two-thirds of old metal, and one-third of best Scotch pig-iron. From Exp. 22, Table III. Diameter 2·496 inches.	33881	·060			Broke in the middle and at the ends. See Plate XXXIII.
		43289	·077			
		52697	·094			
		62105	·110			
		71513	·126			
		80921	·143			
		90329	·160			
		99737	·177			
		109145	·197			
		116672	·213*	....	116672 lbs. = 52·09 tons.	
7.	Second London Mixture. Mean diameter from eight measurements 1·530 in.	7358	·014			For the form of fracture in this and the two following pillars, see Plate as above.
		9710	·024			
		12062	·032			
		14414	·040			
		16766	·048			
		19118	·057			
		21470	·066			
		23822	·075			
		26174	·091			
		26527	·093*	....	26527 lbs.	
8.	Second London Mixture. From Exp. 23, Table III. Diameter 1·530 inch.	7358	·027			
		9710	·036			
		12062	·044			
		14414	·051	·06		
		16766	·059			
		19118	·068	·12		
		21470	·077	·28		
		23822	·090	·38		
		24763	·095*	....	24763 lbs.	
9.	Second London Mixture. From Exp. 24, Table III. Diameter 1·541 inch.	7358	·027			
		9710	·034			
		12062	·043			
		14414	·051			
		16766	·060			
		19118	·068	·07		
		21470	·077			
		23822	·088	·19		
		25939	·098*	....	25939 lbs.	

Additions to the preceding experiments in Table V., the pillars being cut from the $1\frac{1}{2}$ inch bars used in Experiments 7, 8 and 9, their lengths being as below, and their ends turned flat.

No. of Exp.	Description of Pillar.	Breaking weight.	Remarks.
		lbs.	
10.	Length 3 feet. Diameter 1·528 inch. From Experiment 7.	57384	
11.	Length 3 feet. Diameter 1·544 inch. From Experiment 8.	70555	
12.	Length 3 feet. Diameter 1·527 inch. From Experiment 9.	57856	
13.	Length 2 feet 6 inches. Diameter 1·531 inch. From Experiment 8.	85138	These pillars broke in the middle, and broke off at each end. For form of fracture see figures in Plate XXXIII.
14.	Length 2 feet 6 inches. Diameter 1·530 inch. From Experiment 9.	72907	
15.	Length 2 feet 6 inches. Diameter 1·515 inch. From Experiment 7.	70555	

Table VI.—Solid Pillars cut out of the 10-feet pillars, $2\frac{1}{2}$ in. diameter, from various parts of the kingdom, the pillars being now rendered straight and cut to 5 feet long nearly, and of which the first three have their ends turned flat and perpendicular to the axis, and the others have their ends rounded, so that the force is applied along the axis of the pillar.

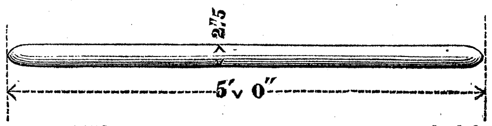
No. of Experiment.	Description of Pillar, 5 feet long nearly, and as above.	Weights laid on.	Decrement of length.	Deflection of middle.	Breaking weight, or that with which the pillar sank.	Remarks.
		lbs.	inch.	inch.		
1.	Old Hill Iron, No. 1.	20693	·038			Supposing that the strength of pillars of the same diameter varies inversely as the 1·7th power of the length, the breaking weight of this, if 5 feet long, would be 135592 lbs., and of the following pillar 122863 lbs.; mean 129227 lbs.=57·69 tons. For form of fracture see figure in Plate XXXIII.
	Staffordshire. Cold blast.	38644	·074			
	From the pillar in Exp. 19,	48052	·090			
	Table III.	57460	·109			
	Length 59·9 inches.	66868	·128			
		76276	·146			
		85684	·165			
		95092	·184	·09		
		104500	·202			
		113908	·223	·16		
		117612	·234	·20		
		123212	·247	·27		
		128812	·264	·37		
		135977	·285*	·50*	135977 lbs.=60·70 tons.	
2.	Old Hill Iron, No. 1.	38644	·097	·05		One of these two pillars broke across in the middle, and near to each end.
	From the same pillar as the	48052	·118			
	preceding experiment,	57460	·137	·07		
	Table III., Exp. 19.	66868	·157			
	Length 59·9 inches.	76276	·178	·10		
		85684	·198	·13		
		95092	·220	·17		
		104500	·243	·21		
		113908	·270	·34		
		117612	·285	·46		
		123212	·308*	·64*	123212 lbs.=55·01 tons.	
3.	Blaenavon Iron, No. 1.	20693	·052			
	From the pillar in Exp. 17	38644	·080			
	or 18, Table III.	48052	·096			
	Length 5 feet.	57460	·111			
		66868	·127			
		76276	·145			
		85684	·161			
		95092	·179			
		104500	·202			
		113908	·239			
		117612	·253*	......	117612 lbs.=52·51 tons.	
4.	Pillars with their ends rounded (see figure). Low Moor Iron, No. 2.	48917	......	·04		
	From the pillar in	53621	......	·07		
	Exp. 11, Table II.	58325	......	·12		
	Length 59·5 inches.	63029	......	·26		
	Diameter 2·553 ins.	65381	......	·60	65381 lbs., or 64458 lbs. for a length of 5 feet.	The ends of the pillar were crushed by the pressure, the diameter of the crushed part being ·73 inch, and the crushing had been perceptible, and apparently one-third to half an inch when two-thirds of the breaking weight was laid on. There were several cracks at the ends of the pillar through the pressure. The strength had probably been much increased by the flattening of the ends. See Plate XXXIII. for the forms of fracture in this and the two following pillars.
5.	Blaenavon Iron, No. 3.	53621	......	·05		With a pressure of three-fourths of the breaking weight, the diameter of the compressed circle at the ends was about ·6 inch, and the diameter after fracture was ·72 inch nearly.
	From the pillar in	58325	......	·07		
	Exp. 14, Table II.	63029	......	·10		
	Length 59·5 inches.	65381	......	·13		
	Diameter 2·546 ins.	67733	......	·18		
		70085	......	·26	71967 lbs., or 70950 lbs. if the length had been 5 feet.	

TABLE VI. (continued).

No. of Experiment.	Description of Pillar, 5 feet long nearly, and as above.	Weights laid on.	Decrement of length.	Deflection of middle.	Breaking weight, or that with which the pillar sank.	Remarks.
		lbs.	inch.			
6.	Blaenavon Iron, No. 3. From the pillar in Exp. 14, Table II., same as last. Length 59·5 inches. Diameter 2·546 inches.	58325 67733 72437	....	·14 ·22 ·30	73378 lbs., or 72342 lbs. for a length of 5 feet.	Diameter of crushed end of pillar ·63 with weight 30101 lbs., and after fracture ·79. Many small cracks in the end.

The strength of the three last pillars had probably been much increased by the flattening at the ends. If the ends of the pillar had been small and not crushed, the strength would have been about one-third of that of a pillar of the same diameter and length, with its ends turned flat and well-bedded.

The crushing at the ends was not only shown in the pillar, but in the hard steel plates against which it was pressed. The case is analogous to that of a wheel sinking into a hard surface upon which it should roll.

TABLE VII.—Transverse strength of the 10-feet Pillars, cast $2\frac{1}{2}$ inches diameter, and now cut to 5 feet long, laid on supports 4 feet 6 inches asunder, and broken by weights laid on in the middle.

Portland Iron, No. 1. Diameter 2·493 inches. Distance between the supports 4 feet 6 inches.

First half of bar.		Second half of bar.		
Weights laid on.	Deflections.	Weights laid on.	Deflections.	
lbs.	inch.	lbs.	inch.	
560	·06	560	·063	
1120	·145	1120	·113	
1680	·22	1680	·215	Breaking weight of first bar .... 4324 lbs. } Mean 4632 lbs.; whence
2240	·31	2240	·31	Breaking weight of second bar ...... 4940 lbs. }
2800	·40	2800	·40	Breaking weight for 10-ft. bar = 2084
3360	·51	3360	·50	Breaking weight for 7-ft. 6-in. bar = 2779
3920	·66	3920	·63	
4324	·75*	4480	·77	
broke.	ult. defl.	4940	·87*	
		broke.	ult. defl.	

Calder Iron, No. 1. Diameter 2·519 inches. Distance between the supports 4 feet 6 inches.

560	·05	560	·06	
1120	·14	1120	·14	
1680	·22	1680	·21	
2240	·30	2240	·30	Breaking weight of first bar .... 4324 lbs. } Mean 3904 lbs.; whence
2800	·38	2800	·395	Breaking weight of second bar ...... 3484 lbs. }
3360	·49	3360	·49	Breaking weight for 10-ft. bar = 1757
3640	·55	3484	·51*	Breaking weight for 7-ft. 6-in. bar = 2342
3920	·59	broke.	ult. defl.	
4324	·64*			
broke.	ult. defl.			

Coltness Iron, No. 1. Diameter 2·496 inches. Distance between the supports 4 feet 6 inches.

1120	·18	560	·09	
1680	·295	1120	·19	Breaking weight of first bar .... 4044 lbs. } Mean 3848 lbs.; whence
2240	·41	1680	·31	Breaking weight of second bar ...... 3652 lbs. }
2800	·56	2240	·43	Breaking weight for 10-ft. bar = 1732
3360	·75	2800	·59	Breaking weight for 7-ft. 6-in. bar = 2309
4044	·96*	3360	·77	
broke.	ult. defl.	3652	·84*	
		broke.	ult. defl.	

TABLE VII. (continued).

Carron Iron, No. 1. Diameter 2·510 inches. Distance between the supports 4 feet 6 inches.

First half of bar.		Second half of bar.		
Weights laid on.	Deflections.	Weights laid on.	Deflections.	
lbs.	inch.	lbs.	inch.	
560	·07	560	·08	Breaking weight of first bar .... 3428 lbs. } Mean 3428 lbs.; whence
1120	·155	1120	·16	Breaking weight of second bar ...... 3428 }
1680	·25	1680	·26	Breaking weight for 10-ft. bar = 1543
2240	·35	2240	·37	Breaking weight for 7-ft. 6-in. bar = 2057
2800	·46	2800	·48	
3080	·54	3080	·55	
3428	·62*	3428	·63*	
broke.	ult. defl.	broke.	ult. defl.	

TABLE VIII.—Crushing weights of short cylinders of different kinds of Cast Iron, cut from the bars, $2\frac{1}{2}$ inches diameter previously used, and now turned to be $\frac{3}{4}$ inch diameter nearly, and $1\frac{1}{2}$ inch high. The results are means from three or four experiments on each kind of iron. The specimens were usually cut out of the iron between the centre and the circumference of the bar, denominated the medium part. In several cases they were cut out of the centre of the bar, and sometimes out of the circumference.

Description of Iron.	Diameter of specimen.	Crushing weight of specimen.	Crushing weight per square inch of section.	
	inch.	lbs.	lbs.	
Old Park Iron, No. 1. Medium.	·747 ·747	38333 38862	87466 88674	88070 lbs. = 39·32 tons.
Old Park Iron, No. 1. Centre.	·747 ·747 ·747 ·747	32923 32453 32923 32571	75122 74050 75122 74319	74653 lbs. = 33·33 tons.
Derwent Iron, No. 1. Medium.	·747 ·747 ·747 ·747	43096 42684 42684 41861	98334 97394 97394 95517	97160 lbs. = 43·37 tons.
Coltness Iron, No. 1. Medium.	·747 ·747 ·747 ·747	27749 27925 27455 27396	63316 63718 62646 62511	63048 lbs. = 28·14 tons.
Blaenavon Iron, No. 1. Medium.	·748 ·748 ·748	31336 31395 30748	71310 71444 69972	70909 lbs. = 31·66 tons.
Level Iron, No. 1. Medium.	·749 ·748 ·750 ·749	30277 30101 30101 29748	68716 68500 68135 67516	68217 lbs. = 30·45 tons.
Carron Iron, No. 1. Medium.	·750 ·750 ·751 ·751	31747 29278 30101 30101	71860 66272 67953 67953	68509 lbs. = 30·58 tons.
London Mixture. Medium.	·749 ·750 ·749	36157 35452 35452	82061 80247 80461	80923 lbs. = 36·08 tons.
Calder Iron, No. 1. Medium.	·750 ·749 ·750 ·749	38039 35040 38980 37333	86103 79526 88233 84730	84648 lbs. = 37·79 tons.

TABLE VIII. (continued).

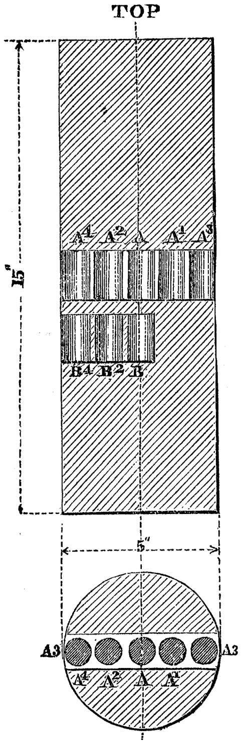
Description of Iron.	Diameter of specimen.	Crushing weight of specimen.	Crushing weight per square inch of section.	
	inch.	lbs.	lbs.	
Portland Iron, No. 1.	·747	41567	94846	94802 lbs. = 42·32 tons.
Medium.	·748	41273	93923	
	·750	42743	96750	
	·750	41391	93690	
Old Hill Iron, No. 1.	·749	24255	55049	54761 lbs. = 24·45 tons.
Medium.	·747	24221	55266	
	·750	23843	53969	
Low Moor Iron, No. 2.	·748	34570	78669	77489 lbs. = 34·59 tons.
Medium.	·748	33511	76260	
	·747	33982	77539	
Low Moor Iron, No. 2.	·742	29631	68525	66407 lbs. = 29·65 tons.
Centre.	·741	27749	64346	
	·742	28690	66349	
Blaenavon Iron, No. 3.	·737	35511	83241	83517 lbs. = 37·28 tons.
Medium.	·737	35746	83792	
	·737	35629	83517	
Blaenavon Iron, No. 3.	·747	38568	88003	76643 lbs. = 34·22 tons.
Centre.	·747	34805	79416	
	·747	27396	62511	
Second London Mixture.	·747	41626	94980	95338 lbs. = 42·56 tons.
Medium. From 2½-inch. pillar, as	·747	41861	95517	
all above have been.	·747	41861	95517	
Second London Mixture.	·747	34805	79411	78451 lbs. = 35·02 tons.
Centre. From 2½-inch. pillar, as	·747	34099	77806	
all above have been.	·748	34335	78135	
Second London Mixture.	·750	49858	112855	111080 lbs. = 49·59 tons.
Medium. From 1½-inch pillar.	·750	48917	110725	
	·750	48447	109661	
Second London Mixture.	·750	41861	94754	104071 lbs. = 46·46 tons.
Centre. From 1½-inch pillar.	·750	48094	108863	
	·750	47976	108595	
Low Moor Iron, No. 2.	·420	12415	89610	87502 lbs. = 39·06 tons.
From a hollow pillar 4 inches diameter and ½ inch thick.	·422	11944	85395	
The height of the first two of these was ·72 inch, and of the last 1·502 inch.	·421	11592	83273	
Low Moor Iron, No. 2.	·298	8010	114845	115993 lbs. = 51·78 tons.
From the thin ring of a hollow pillar about 3½ inches diameter.	·300	8255	116785	
Height of specimens ·53 inch.	·298	8115	116350	
Low Moor Iron, No. 2.	·297	7905	114105	110212 lbs. = 49·20 tons.
From the thin ring of a hollow pillar about 3½ inches diameter.	·296	7555	109790	
Height of specimens ·53 inch.	·296	7345	106740	

Of the different irons tried in the preceding experiments on pillars, whether solid or hollow, the external part of the casting was always harder than that near to the centre, and the iron of the external ring of a hollow casting was very hard, the hardness increasing with the thinness. Thus, in solid pillars 2½ inches diameter of Low Moor iron, No. 2, the crushing force per square inch of the central part was 29·65 tons, and that of the intermediate part near to the surface was 34·59 tons, whilst the external

ring, $\frac{1}{2}$ inch thick, of a hollow cylinder 4 inches diameter, of which the outer crust had been removed, was crushed with 39·06 tons per square inch; and external rings of the same iron thinner than half an inch, required from 49·2 to 51·78 tons per square inch to crush them. These facts show the great superiority of hollow pillars over solid ones of the same weight and length.

TABLE VIII. (continued).—Casting of larger dimensions than before used.

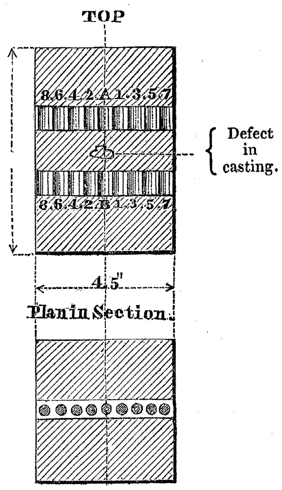
To ascertain whether the internal strength of larger pillars varied in the same manner as that of smaller ones, a cylindrical casting was made 5 inches diameter and 15 inches long. It was cast vertically, from Blaenavon iron. Through the axis of this cylinder, a slab, 15 inches long, 5 inches broad, and about 1 inch thick, was taken. Across the middle of this slab five cylinders, $1\frac{1}{2}$ inch long and $\frac{3}{4}$ inch diameter, were obtained at equal distances from each other, the middle one being in the centre, and the outer ones as near as possible to the sides. Three other small cylinders of the same size were also obtained, the positions of which were as in the figure.



Mark on Cylinder.	Diameter of Cylinder.	Crushing weight of Cylinder.	Crushing weight per square inch.	
	inch.	lbs.	lbs.	Mean.
A4	·749	27749	62979	65739
B4	·748	30101	68500	
A2	·750	27749	62811	62444
B2	·748	27279	62078	
A	·748	27749	63147	64218
B	·748	28690	65289	
A1	·748	28690	65289	
A3	·748	29160	66358	

Comparing the results of the experiments above, it appears that the external part of the casting was somewhat stronger than the internal. But the variation was only from 62 to 66, and therefore much less than was obtained from the smaller masses.

To obtain some additional information as to the distribution of the metal in a large casting, one was formed 9 inches square and 12 inches long, or upwards. It was cast erect from Derwent iron, No. 1, and was then placed upon a slotting machine, and cut directly across in the middle. It was found, however, that there was a hole in the centre, about $\frac{3}{4}$ inch or 1 inch in diameter; transverse slices were therefore cut, one from above and one from below the central defective piece; these two slices, each 9 inches square and 1 inch thick nearly, were divided from one side to the other, passing through the centre of each, into nine equal parts, and from each part cylinders were cut, all of the same diameter, $\frac{3}{4}$ inch, and length $1\frac{1}{2}$ inch, four on each side of the central one. See figure annexed.



Upper Slice of Mass.

Mark on Cylinder.	Diameter of Ditto.	Crushing weight of Ditto.
	inch.	lbs.
8	·748	31512
6	·747	32923
4	·748	31042
2	·747	37157
A	·748	37627
1	·748	39980
3	·748	39039
5	·748	35275
7	·748	31983

Lower Slice of Mass.

Mark on Cylinder.	Diameter of Ditto.	Crushing weight of Ditto.
	inch.	lbs.
8	·748	30571
6	·748	31512
4	·749	32924
2	·748	30571
B	·748	29160
1	·748	30101
3	·748	32924
5	·749	32924
7	·749	33394

The iron in this mass seems to have been extremely irregular, particularly in the upper part of the casting. In the part marked B, which was cast under the greater head of metal, the iron from three divisions near the centre, or one-third of the distance across, was crushed with somewhat less weight than that from the external part, the greatest difference being from 29160 at the centre, to 33394 at the side. The mean resistance of the three central cylinders in this slice is 29944 lbs., and of the six external ones 32375 lbs., the difference being much less than in the iron of the smaller castings tried.

The iron in the upper part, marked A in the figure, being cast under a less head of metal than the former, and floating at the top of the softer metal below, was considerably stronger than the other. The central portion of this was, contrary to all our previous experience, much harder than the rest, and varied from 31512 and 31983 at the sides, to 37627, 39039 and 39980 near to the middle. To explain this strange anomaly in the absence of other knowledge, it seems not improbable that some additional heavier metal had been poured into the top part of the mould, when that in the lower part had in some degree solidified.

From the experiments upon the two last castings, which are on a larger scale than those which precede them, it appears that the difference of hardness between the external and internal parts of a large casting is much less than in a small one, and may frequently be neglected.

APPENDIX.

The following experiments were made after the others had been offered to the Royal Society, or during the months of October and November 1857, and as the former solid pillars were from various parts of the kingdom, and usually of the iron termed No. 1, I was desirous of adding the results from a few solid pillars of the quality No. 2. These latter pillars were mostly cast circular, and were made 10 feet long and $2\frac{1}{2}$ inches diameter, with their ends turned flat as before. To these were added pillars of nearly the same weight, of a square and a triangular form of section, to ascertain the comparative strength of pillars whose sections were circular, square, and triangular.

The cylindrical pillars, in the experiments of which an abstract is given below, though of different irons, were all cast from the same model; and the square and the triangular pillars were of the same kind of iron as two of the circular ones (the Calder, No. 2), and were intended to be of the same weights as these. All the pillars were made uniform throughout their lengths, 10 feet long each, and turned flat at the ends.

As the weights of the different pillars did not differ widely from 150 lbs. each, the breaking weight of each is reduced to what it would have been if the weight had been 150 lbs.

The reduced results are as below.

Pillars broken.	Second quality of iron, or that of No. 2.	Assumed weight of Pillars.	Breaking weights and forms of section.
		lbs.	lbs.
1st pillar........	Coltness Iron, No. 2	150	○ 50328
2nd pillar	Old Park Iron, No. 2	150	○ 54736
3rd pillar	Blaenavon Iron, No. 2	150	○ 55611
4th pillar	Calder Iron, No. 2	150	55658 } ○ Mean. 55299 lbs.
5th pillar	Calder Iron, second specimen	150	54940 }
6th pillar	Calder Iron, No. 2	150	49185 } □ 51537 lbs.
7th pillar	Calder Iron, second specimen	150	53890 }
8th pillar	Calder Iron, No. 2	150	57332 } △ 61056 lbs.
9th pillar	Calder Iron, second specimen	150	64780 }

From the three last mean results it appears that the strengths of circular, square, and triangular solid pillars of the same quality, weight and length, vary as 55299, 51537, and 61056, the last being the strongest. This last conclusion, respecting the strength of triangular solid pillars, may not be considered void of importance. See Notes to experiments 8 and 9, Table IX. following.

Whence it appears that solid triangular pillars with flat ends are stronger than those with either circular or square sections; but this seems not to be the case in pillars with rounded ends, for from my former experiments*, a pillar, whose section is +, as in the connecting rod of a steam-engine, the ends being moveable, is very weak to bear a strain

* Philosophical Transactions, 1840, pages 413 and 455.

as a pillar; and indeed less than half the strength of a hollow cylindrical pillar of the same weight and length, rounded at the ends.

Comparing the results of the cylindrical pillars tried, it appears that those of the second quality, or No. 2, are usually weaker than those of No. 1 of the same iron. In the irons below we have the breaking weights of pillars, 10 feet long and $2\frac{1}{2}$ inches diameter, of the first and second quality, as follow:—

	lbs.		lbs.
Old Park Iron, No. 1 . .	66086	No. 2, or second quality . .	55032
Calder Iron, No. 1	60677	No. 2, or second quality . .	55032
Coltness Iron, No. 1 . .	52680	No. 2, or second quality . .	50328

The properties of the irons of the second quality are deduced from the following Table of experiments; those of irons termed No. 1 may be obtained from the second summary of results, page 871.

Table IX.

Cast-iron pillars of the quality No. 2, supplied by Messrs. Easton and Amos, October and November 1857. The pillars were cast to be $2\frac{1}{2}$ inches diameter, and each was cut 10 feet long, the ends being turned flat and parallel.

Experiment 1.

Cylindrical Pillar, Coltness Iron, No. 2.
Mean diameter from eight admeasurements 2·494 inches.
Weight of Pillar 150 lbs.

Weights laid on. lbs.	Deflections. inch.	Decrements of length. inch.
20693	·17	·057
25397	·20	·078
30101	·24	·091
34805	·31	·105
39509	·42	·120
44213	·62	·135
48917	·98	·163
50328	Broke with this in two places near the middle.	

As the weights of the following pillars differed generally but little from that above, and a leading object being to compare the results together, the breaking weight has been reduced, as before mentioned, in each case, to what it would have been for a pillar weighing exactly 150 lbs.

Experiment 2.

Cylindrical Pillar, Old Park Iron, No. 2.
Mean diameter from eight admeasurements 2·503 inches.
Weight of Pillar 150 lbs. 13 oz.=150·812 lbs.

Weights laid on. lbs.	Deflections. inch.	Decrements of length. inch.
20693	—	·084
25397	·07	·098
30101	—	·111
34805	·09	·124
39509	·12	·138
44213	·18	·152
48917	·30	·166
53621	·78	·194
55032 broke it.	It broke exactly in the middle.	—

Whence 150·812 lbs. : 150 lbs. :: 55032 lbs. : 54736 lbs.=reduced breaking weight.

Experiment 3.

Cylindrical Pillar, Blaenavon Iron, No. 2.
Mean diameter from eight admeasurements 2·486 inches.
Weight of Pillar 148 lbs. 7 oz.=148·437 lbs.

Weights laid on. lbs.	Deflections. inch.	Decrements of length. inch.
20693	—	·046
25397	—	·059
30101	—	·073
34805	·02	·086
39509	·09	·098
44213	·15	·112
48917	·30	·128
53621	·72	·156
55032 sank. Not broken.	—	—

Whence 148·437 lbs. : 150 lbs. :: 55032 lbs. : 55611 lbs.=reduced breaking weight.

Experiment 4.

Cylindrical Pillar, Calder Iron, No. 2.

Mean diameter from eight admeasurements 2·469 inches.

Weight of Pillar 148 lbs. 5 oz.=148·3125 lbs.

Weights laid on.	Deflections.	Decrements of length.
lbs.	inch.	inch.
20693	·11	·070
25397	·13	·084
30101	·16	·097
34805	·19	·110
39509	·24	·122
44213	·30	·130
48917	·45	·147
53621	·72	·165
55032 broke it.	Broke $4\frac{1}{2}$ inches from the middle.	—

Whence 148·312 lbs. : 150 lbs. : : 55032 lbs. : 55658 lbs.=reduced breaking weight.

Experiment 5.

Cylindrical Pillar, Calder Iron, No. 2.

Mean diameter from six admeasurements 2·497 inches.

Weight of Pillar 150·25 lbs.

Weights laid on.	Deflections.	Decrements of length.
lbs.	inch.	inch.
20693	·17	·077
25397	·21	·089
30101	·25	·102
34805	·29	·117
39509	·34	·131
44213	·38	·144
48917	·55	·158
53621	·94	·182
55032 Sank without fracture.		—

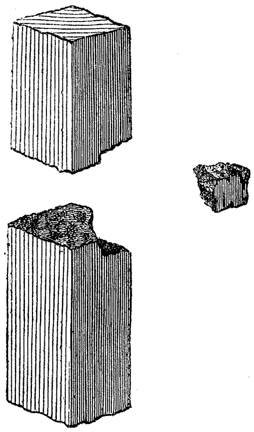
Whence 150·25 lbs. : 150 lbs. : : 55032 lbs. : 54940 lbs.=reduced breaking weight.

$$\therefore \quad \frac{55658+54940}{2}=55299 \text{ lbs.},$$

the mean strength of a cylindrical pillar of Calder Iron, No. 2, 10 feet long and $2\frac{1}{2}$ inches diameter nearly.

Experiment 6.—Square Pillar, Calder Iron, No. 2.
Side of square from eight admeasurements 2·194 inches.
Weight of Pillar 146 lbs. 5 oz.=146·312 lbs.

Weights laid on. lbs.		Deflections. inch.	Decrements of length. inch.
20693		·19	·068
25397		·23	·081
30101		·27	·094
34805		·35	·108
39509		·47	·122
44213		·69	·142
47976	Broke.	—	—



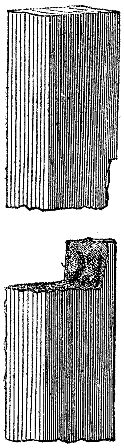
Broke about 5 inches from the middle by bending in the diagonal.

Whence 146·312 lbs. : 150 lbs. :: 47976 lbs. : 49185 lbs.=reduced breaking weight.

The figures standing over each other represent the pillar, at the place of fracture, near the middle; and the small additional piece, that of the part broken out from one corner by compression.

Experiment 7.—Square Pillar, Calder Iron, No. 2.
Side of square from eight admeasurements 2·221 inches.
Weight of Pillar 149·25 lbs.

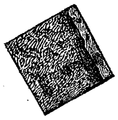
Weights laid on. lbs.	Deflections. inch.	Decrements of length. inch.
20693	·14	·077
25397	·17	·090
30101	·21	·103
34805	·27	·115
39509	·34	·128
44213	·45	·143
48917	·64	·160
53621	1·14	·195



Broke in about a minute with this weight, bending in the direction of the side.

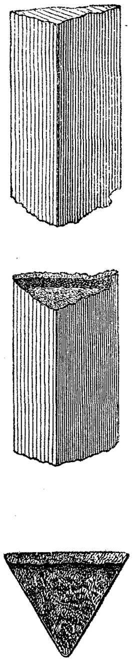
Whence 149·25 lbs. : 150 lbs. :: 53621 lbs. : 53890 lbs.=reduced breaking weight.

$$\therefore \quad \frac{53890+49185}{2}=51537 \text{ lbs.},$$



the mean strength of a square pillar 150 lbs. in weight, its length being 10 feet.

The vertical figures represent the pillar at the place of fracture, which in this case was different in form from the preceding one, and along the side; these and the smaller figure, representing the transverse section, show the small size of the compressed part.



Experiment 8.—Triangular Pillar, Calder Iron, No. 2.

Mean from six admeasurements of sides of triangle near the middle 3·545 inches.

Weight of Pillar 158·75 lbs.

Weights laid on.	Deflections.	Decrements of length.
lbs.	inch.	inch.
20693	·23	·080
25397	·27	·092
30101	·33	·107
34805	·39	·121
39509	·46	·134
44213	·53	·147
48917	·64	·161
53621	·79	·177
58325	1·06	·203
60677	Broke, having bent parallel to one side.	—

Whence 158·75 lbs. : 150 lbs. :: 60677 lbs. : 57332 lbs. = reduced breaking weight.

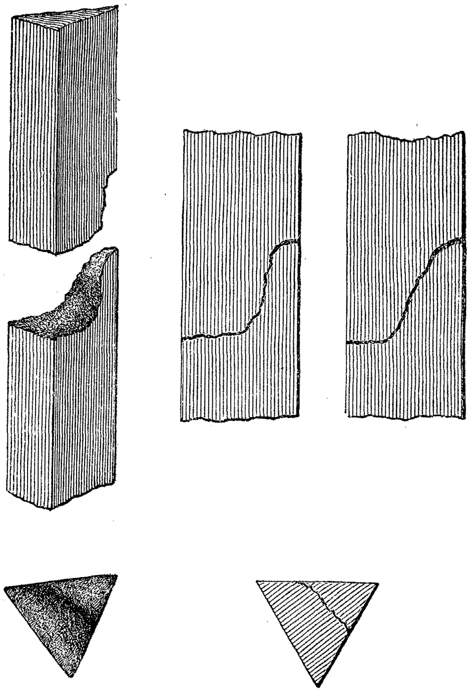
This triangular pillar differed but little, in the form of its fracture, from the preceding rectangular one, as shown by the figure of the compressed part along its side; its strength, however, is greater than that of any other yet tried.

Experiment 9.—Triangular Pillar, Calder Iron, No. 2.

Mean breadth of the sides from nine admeasurements, in three parts, near to the middle 3·47 inches.

Weight of Pillar 155·75 lbs.

Weights laid on.	Deflections.	Decrements of length.
lbs.	inch.	inch.
20693	·08	·070
25397	·09	·082
30101	·11	·093
34805	·14	·105
39509	·18	·117
44213	·22	·130
48917	·27	·141
53621	·36	·154
58325	·48	·169
63029	·69	·185
67263 Broke.	See form of fracture.	—



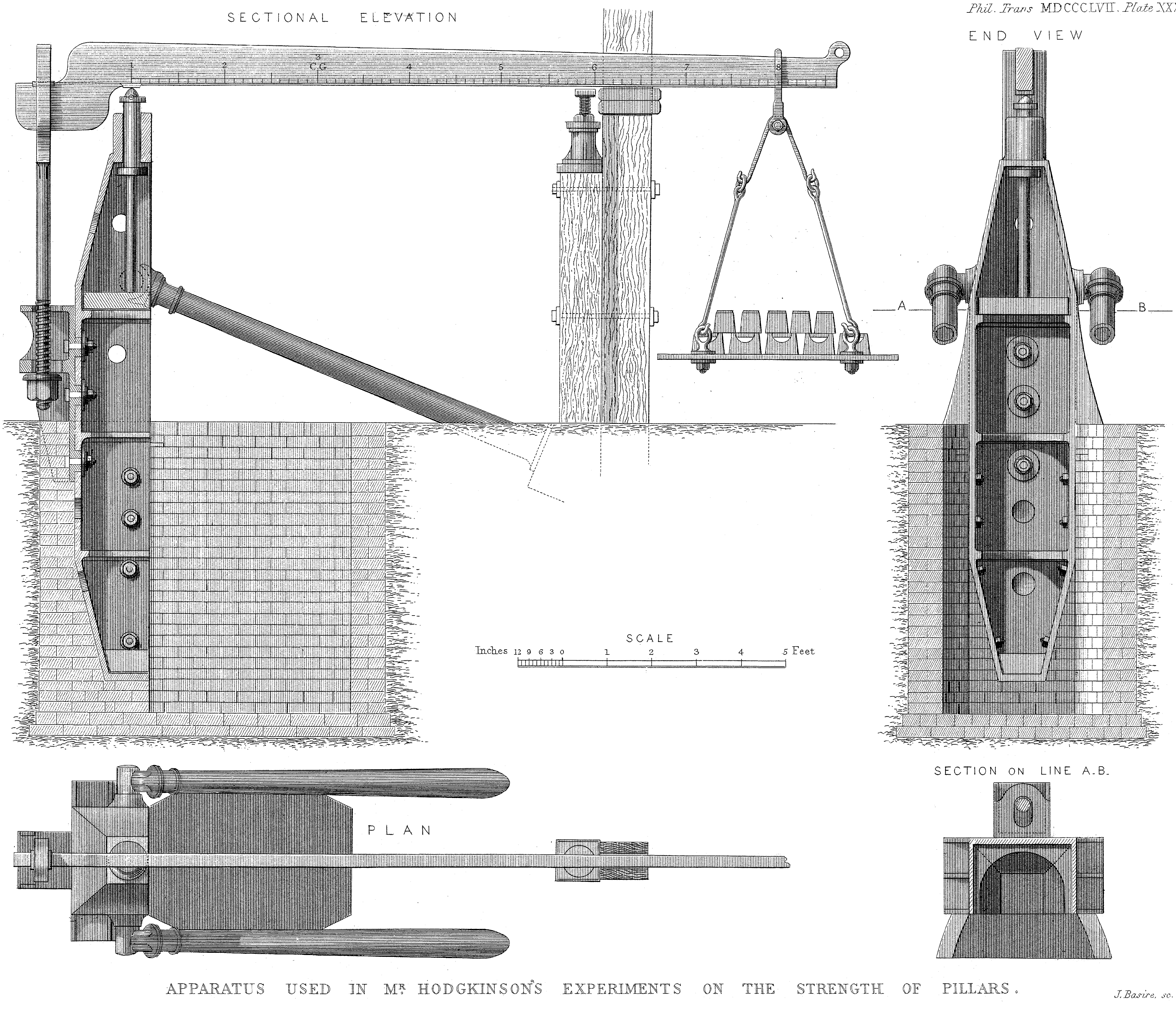
Whence 155·75 lbs. : 150 lbs. :: 67263 lbs. : 64780 lbs. = reduced breaking weight.

$$\therefore \frac{57332+64780}{2} = 61056 \text{ lbs.},$$

the mean strength of a triangular pillar, 10 feet long, if its weight were 150 lbs.

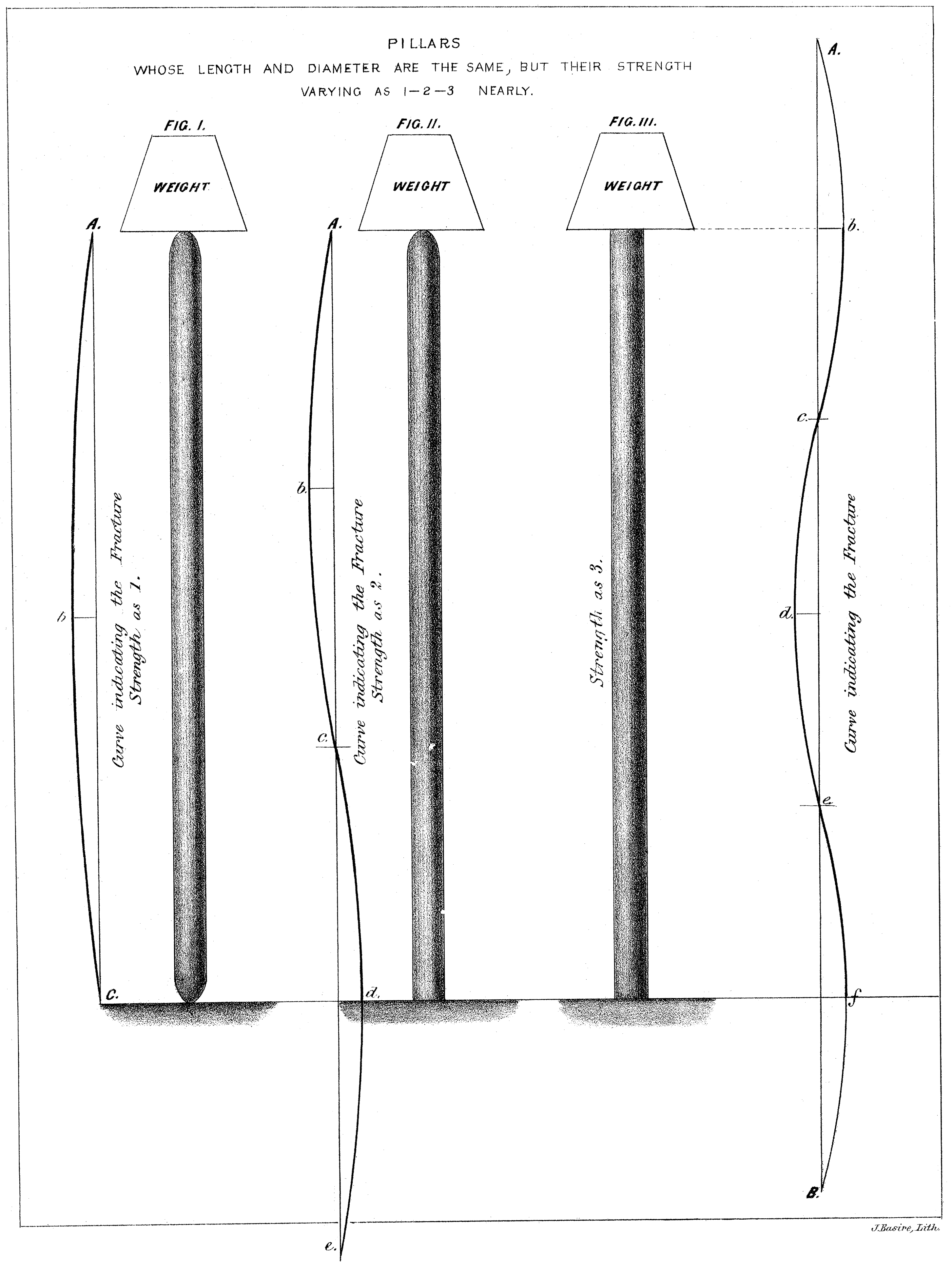
This pillar broke, different from the last, by compression of the edge, showing great additional strength.

Note. The last pillar broke by the compression of one of the edges, and the iron in these, being harder than that in the thicker parts, would offer greater resistance to crushing than in them; and hence the strength of the pillar would be increased (see the experiments in Table VIII.). The part subjected to crushing would in this pillar be at a greater distance from the centre of the section than in the others; and from my numerous experiments on the resistances to crushing and to tearing asunder in cast iron, it appears that the former is, on the average, about six times as great as the latter. See my experiments in the Report of the Commissioners on the Application of Iron to Railway Structures, page 15. From these and other causes the greater strength of a solid triangular pillar of cast iron, above one of a circular or square section, may be inferred; a conclusion not without importance in some applications of the metal.

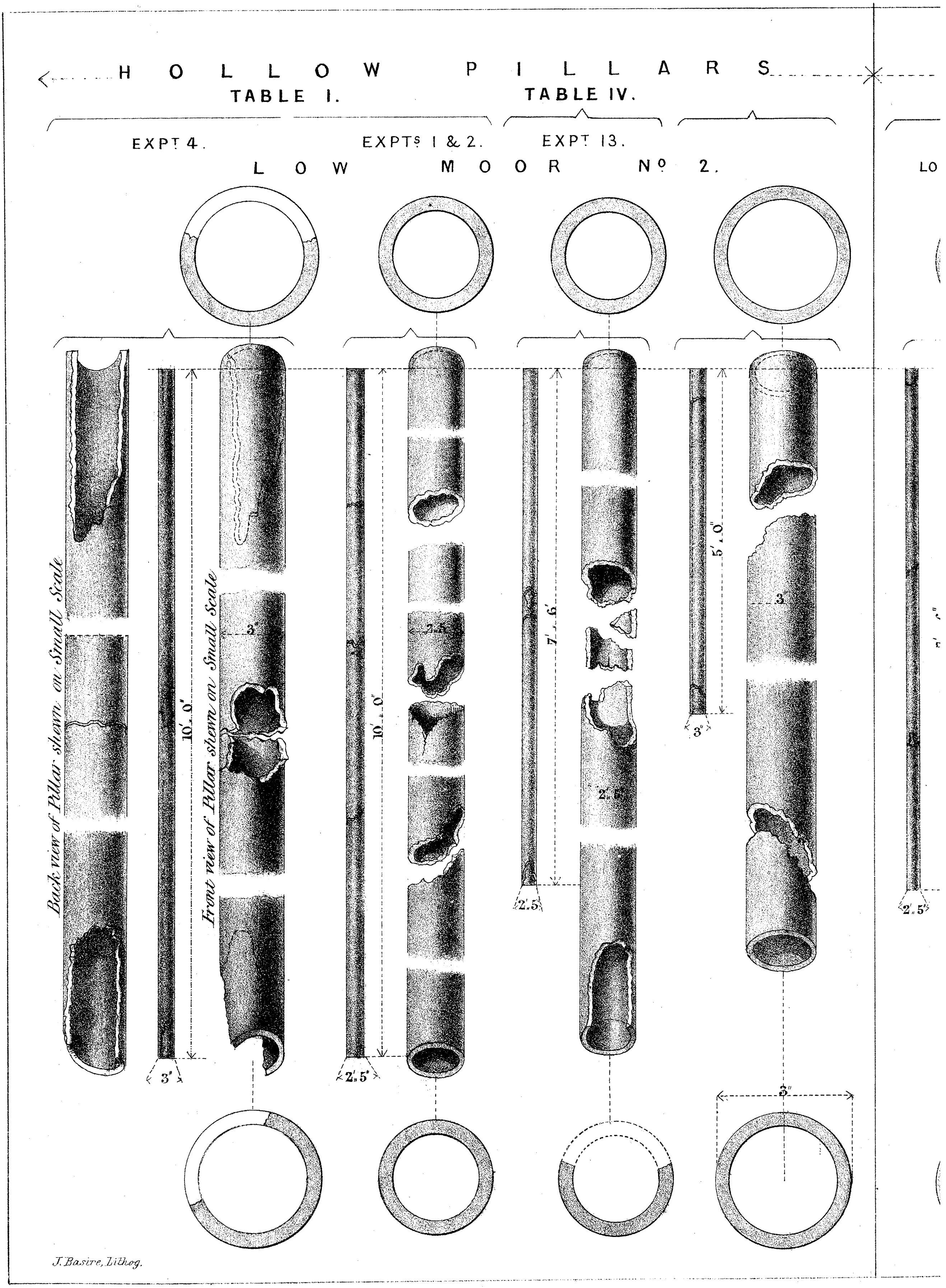


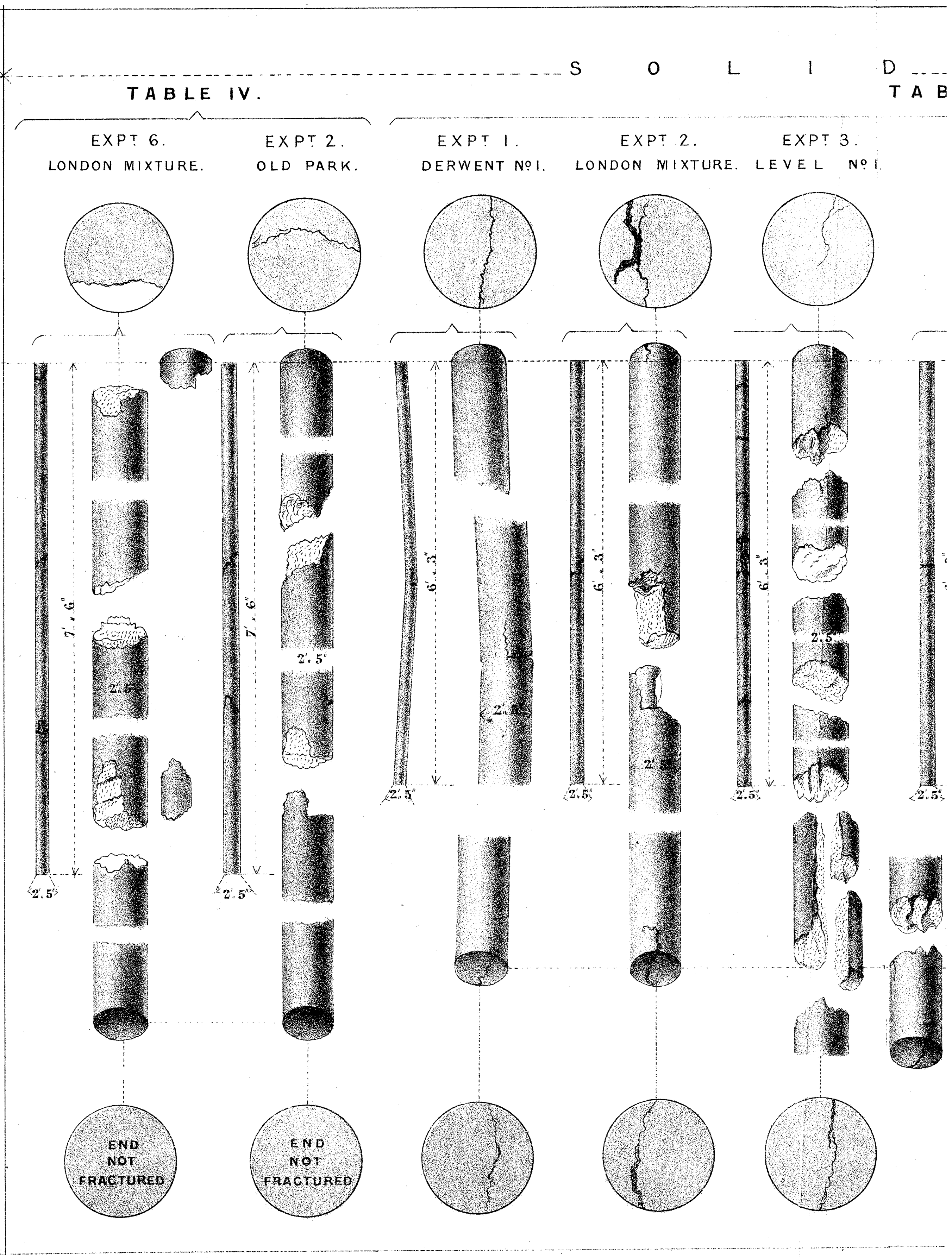
APPARATUS USED IN Mr. HODGKINSON'S EXPERIMENTS ON THE STRENGTH OF PILLARS.

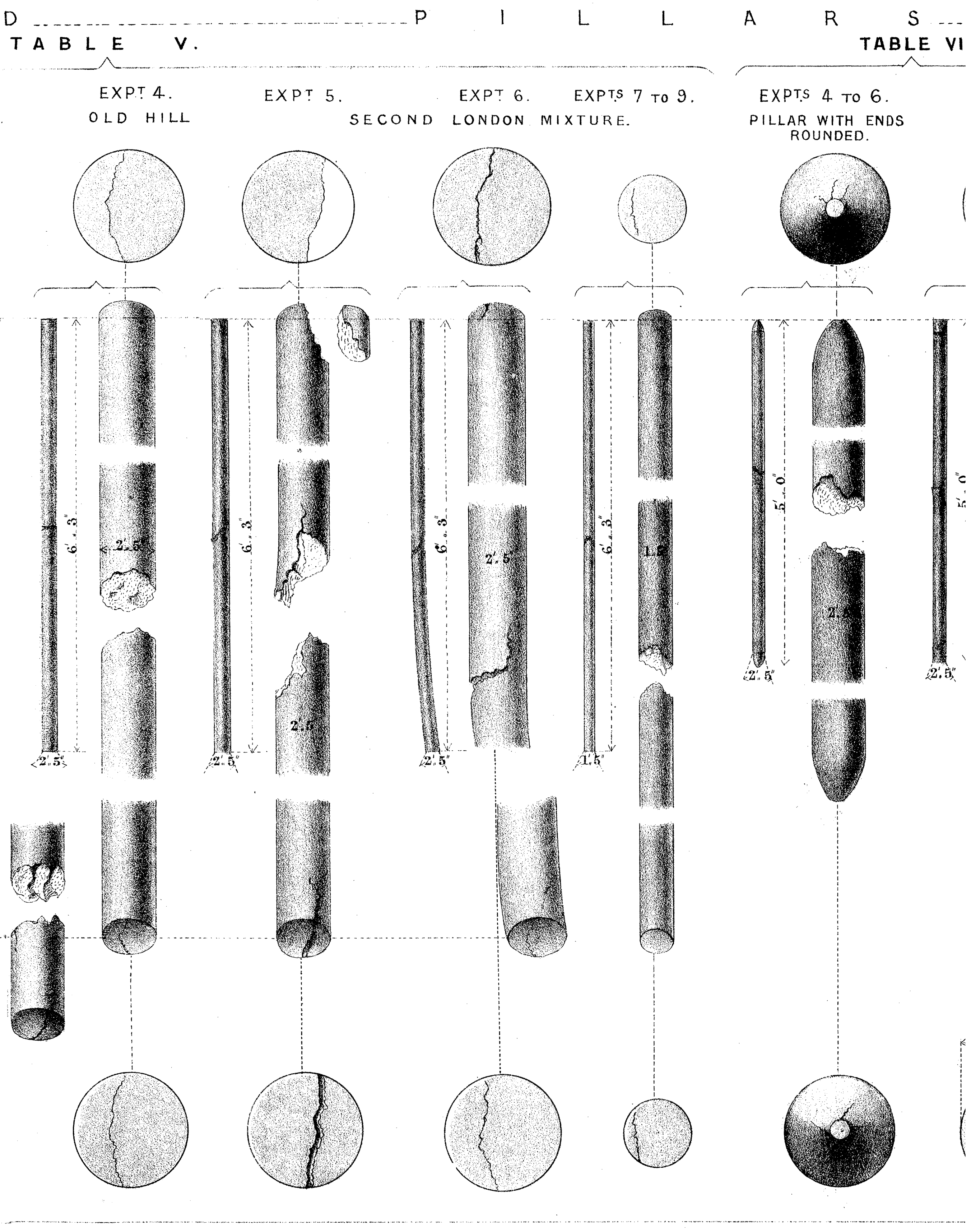
J. Basire, sc.



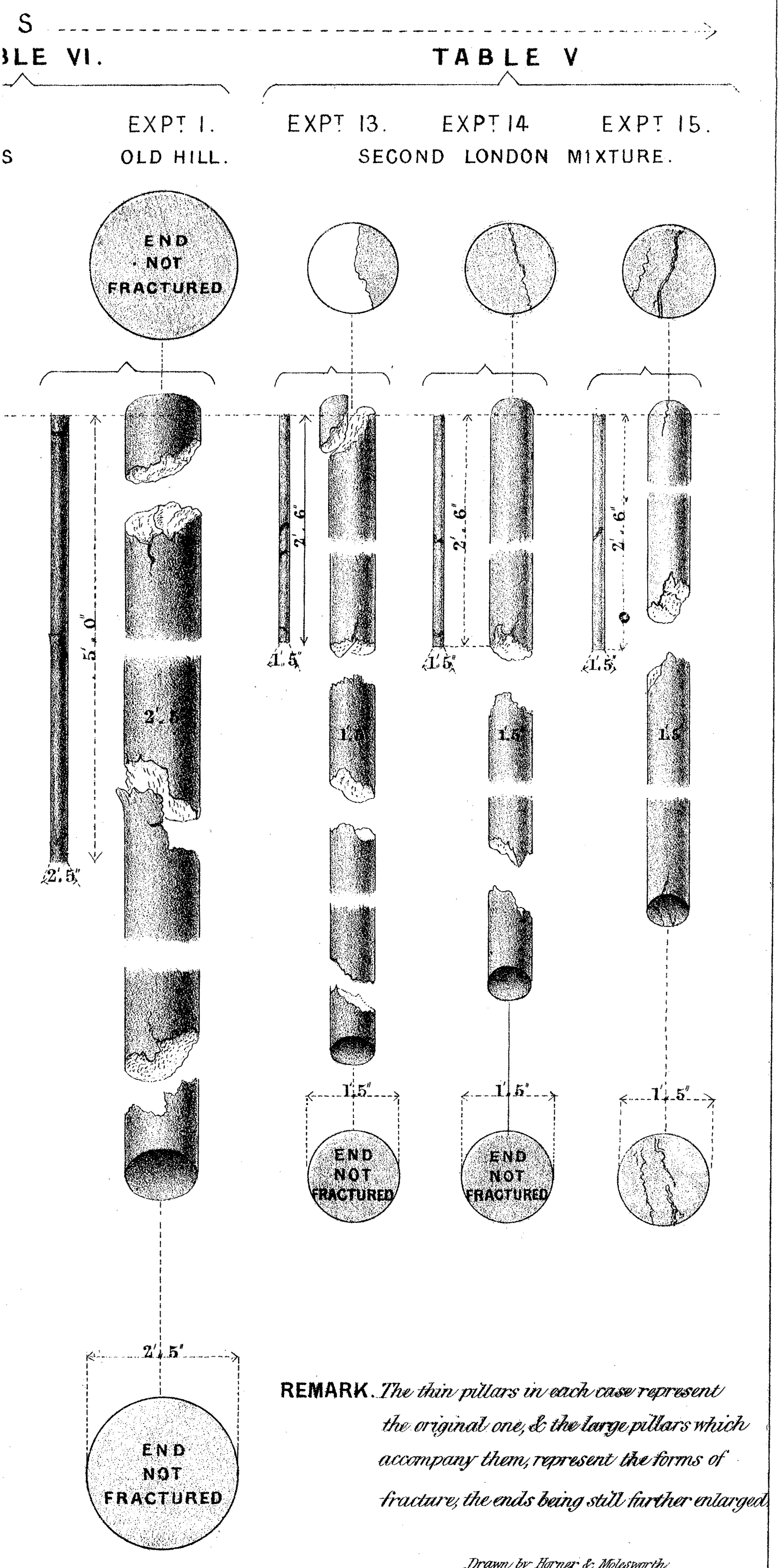
J. Basire, Lith.

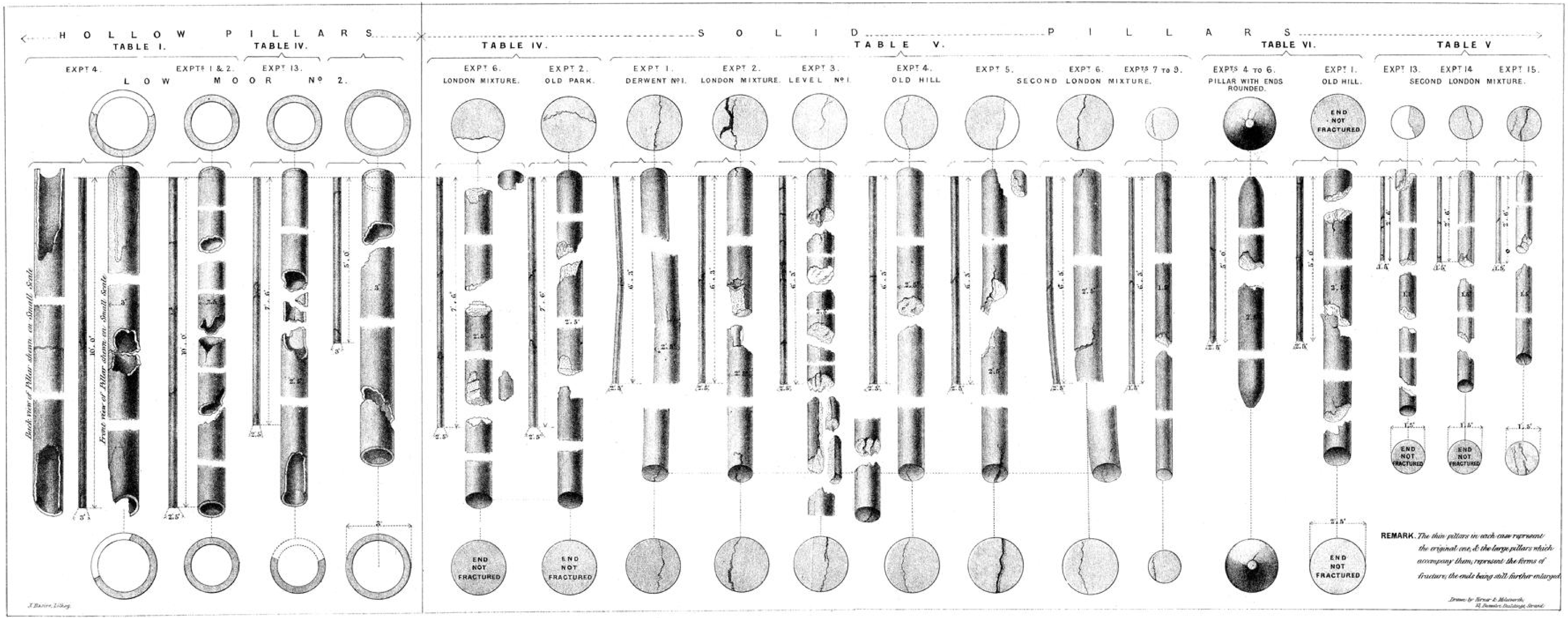

HOLLOW PILLARS
TABLE I.
TABLE IV.
EXPT 4.
EXPTS 1 & 2.
EXPT 13.
LOW MOOR No 2.
LO
Back view of Pillar shewn on Small Scale
Front view of Pillar shewn on Small Scale
10'. 0"
3"
3'
10'. 0"
2". 5'
3.5
7'. 6'
2'. 5
2". 5"
5'. 0"
3"
3"
2'. 5'
J. Basire, Lithog.


S O L I D
TABLE IV.
TAB
EXPT 6.
LONDON MIXTURE.
EXPT 2.
OLD PARK.
EXPT 1.
DERWENT Nº 1.
EXPT 2.
LONDON MIXTURE.
EXPT 3.
LEVEL Nº 1.
7' " 6"
6' " 3"
2' " 5"
END NOT FRACTURED



D P I L L A R S
TABLE V.
TABLE VI
EXPT 4.
OLD HILL
EXPT 5.
EXPT 6.
EXPTS 7 TO 9.
SECOND LONDON MIXTURE.
EXPTS 4 TO 6.
PILLAR WITH ENDS ROUNDED.
6' 3"
2'.5"
6' 3"
2'.5"
6' 3"
2'.5"
2'.5"
6' 3"
1'.5"
5' 0"
2'.5"


S
ꟷLE VI.
TABLE V
EXPT 1.
OLD HILL.
EXPT 13.
EXPT 14
EXPT 15.
SECOND LONDON MIXTURE.
END NOT FRACTURED
5'.0"
2'.5"
2'.6"
1'.5"
END NOT FRACTURED
END NOT FRACTURED
END NOT FRACTURED
REMARK. The thin pillars in each case represent the original one, & the large pillars which accompany them, represent the forms of fracture, the ends being still further enlarged.
Drawn by Horner & Molesworth, 13, Beaufort Buildings, Strand.


HOLLOW PILLARS
SOLID PILLARS
TABLE I.
TABLE IV.
TABLE V.
TABLE VI.
EXPT 4.
EXPTS 1 & 2.
EXPT 13.
LOW MOOR No 2.
Back view of Pillar shewn on Small Scale
Front view of Pillar shewn on Small Scale
EXPT 6. LONDON MIXTURE.
EXPT 2. OLD PARK.
EXPT 1. DERWENT No 1.
EXPT 2. LONDON MIXTURE.
EXPT 3. LEVEL No 1.
EXPT 4. OLD HILL
EXPT 5.
EXPT 6.
EXPTS 7 TO 9.
SECOND LONDON MIXTURE.
EXPTS 4 TO 6. PILLAR WITH ENDS ROUNDED.
EXPT 1. OLD HILL.
EXPT 13.
EXPT 14
EXPT 15.
SECOND LONDON MIXTURE.
END NOT FRACTURED
REMARK. The thin pillars in each case represent the original one, & the large pillars which accompany them, represent the forms of fracture, the ends being still further enlarged.