III.—*On the Comparative Value of various kinds of Stone, as Exhibited by their Powers of Resisting Compression.*

By W. Fairbairn, F.R.S., &c.

[*Read April 1st*, 1856.]

Our knowledge of the properties of stone, viewed as a building material, is very imperfect, and our architects and stonemasons have yet much to learn concerning the difference between one kind of stone and another, both as regards their chemical constitution, their durability, and their powers of resisting compression. On this subject we have the experiments of Gauthey, Rondelet and Rennie, which to some extent supply the deficiency and furnish data for the resistance to a crushing force of a considerable variety of stone. These are, however, to some extent inapplicable to the purposes for which such data are required, and not finding them in exact accordance with the results of some experiments recently made, I have endeavoured to inquire into the causes of the discrepancy, and to account for the difference.

Stone is found in various forms and conditions, embedded in and stratified under the earth's surface. That portion of it which is used for building purposes, is a dense coherent brittle substance, sometimes of a granulated, at others, of a laminated structure. These qualities varying according to its chemical constitution and the mode in which it has been deposited. Sometimes the laminated and granular rocks alternate with each other; at others, a rock of a mixed form prevails, partaking of the characteristics of both structures. Independent of these properties is its power of resistance to compression, which depends chiefly upon its chemical combinations and the pressure to which it has been subjected whilst under the earth's surface from the weight of superincumbent materials. The granite also, and other igneous rocks, owe their hardness to their having crystallized more or less rapidly from a fused mass.

In attempting to ascertain the ultimate powers of resistance of rocks which have been deposited by the action of water, it is necessary to observe the direction in which the pressure is applied, whether in the line of cleavage, or at right angles to it. In nearly all of the following experiments this precaution was attended to, and it will be seen that the strength is far greater when the force is exerted perpendicularly to the laminated surface, than when it is applied in the direction of the cleavage. In building with such stone, it is also important that it should be laid in the same position as that in which it is found in the quarry, as the action of rain and frost rapidly splits off the laminæ of the stone when it is placed otherwise. The strength of the igneous, or crystalline rocks, is the same in every direction, owing to the arrangement of the particles of which they are composed.

It might have been advantageous to have ascertained, by analysis, the chemical composition of the substances experimented on; but as this varies in almost every locality, and that in accordance with the superincumbent and surrounding strata, this is of less consequence in practice than a knowledge of absolute facts in connexion with the properties of the material. Deductions from direct experiment are of no small importance to the architect and builder, as he should not only be acquainted with the strengths and other properties of the material on which he works, but also with the changes of those qualities under the varied forms of stratified, metamorphic, and igneous rocks.

On the durability of the specimens, I have made no further inquiry than in regard to their power of resistance to strain. Any addition would require a separate investigation into the chemical constituents of the different specimens, and into those changes to which stone of almost every description is subjected when exposed to the action of the atmosphere. In omitting this branch of the investigation I have not forgotten its importance, but have very properly left its development to abler hands.

Before giving the results of the inquiry, I may observe that a portion of the experiments were undertaken at the request of Mr. E. W. Shaw, the surveyor of the borough of Bradford, in Yorkshire, in order to ascertain the best and strongest qualities of stone for paving the streets of that town. The following tables give the result of the experiments on fifteen specimens of Yorkshire sandstone, and on some specimens from Wales and other places, as follow.

Experiments to determine the force necessary to fracture, and subsequently to crush, 2in. cubes of sandstone from the Shipley quarries, Bradford. The pressure applied in the direction of the cleavage.

No. of Expt	Weights laid on in lbs.	Remarks.	No. of Expt	Weights laid on in lbs.	Remarks.	No. of Expt	Weights laid on in lbs.	Remarks.
Specimen No. 1. Shipley.			Specimen No. 2. Heaton.			Specimen No. 3. Heaton Park.		
12	31732		11	31732		8	26356	
13	33524	fractured	12	33524	fractured	9	28148	
...	......	......	...	......	.....	10	29940	fractured
16	38900	crushed	16	40692	crushed	11	31732	crushed
Specimen No. 4.			Specimen No. 9. Old Whatley.			Specimen No. 10. Manningham-lane.		
This specimen was defective and crushed as the first weight, 28148 lbs., was laid on.			11	31732		8	26356	
			12	33524		9	28148	fractured
			13	35316 & crushed	fractured suddenly.	...	......	......
						14	37108	crushed

The results of the experiments 1, 2, 3, 9, 10, fractured and crushed in the line of cleavage, are given in the following table.

No. of Specimen	Locality.	Size.	Weight at which it fractured.	Weight at which it crushed.
1	Shipley, Bradford.	2in. cube	33524	38900
2	Heaton............	,,	33524	40692
3	Heaton Park.......	,,	29940	31732
9	Old Whatley.......	,,	35316	35316
10	Manningham-lane..	,,	28148	37108
	Mean.		32090	36749

Experiments to determine the force required to fracture, and subsequently to crush, 2in. cubes of sandstone from the Shipley and other quarries, near Bradford. Pressure being applied at right angles to the cleavage.

No. of Expt	Weights laid on in lbs.	Remarks.	No. of Expt	Weights laid on in lbs.	Remarks.
Specimen No. 5. Idle Quarry.			Specimen No. 6. Jegrum's-lane.		
15	38900		18	44276	
16	40692		19	45172	fractured.
17	42484	fractured.	...	......	....
18	43380	crushed.	22	47860	crushed.
Specimen No. 7. Spinkwell.			Specimen No. 8. Coppy Quarry.		
10	29940		14	37108	first fracture..
11	31732	fractured.	...	.... .	....
...	......	....	16	39796	second fracture.
14	37108	crushed.	...	......	....
			18	41588	crushed.
Specimen No. 11 failed.					

Results of experiments on specimens 5, 6, 7, 8, fractured and crushed at right angles to the cleavage.

No. of Specimen	Locality.	Size.	Weight at which it fractured.	Weight with which it crushed.
5	Idle Quarry, Bradford................	2in. cube.	42484	43380
6	Jegrum's-lane......	"	45172	47860
7	Spinkwell...........	"	31732	37108
8	Coppy Quarry......	"	37108	41588
	Mean.		39124	42484

By the foregoing experiment it will be observed that the resisting powers of stone to compression, are greatest when the pressure is applied perpendicularly upon the bed or laminated surface, and that in the ratio of 100 : 82 in the force required to fracture, and 100 : 86 in the force required to crush this description of stone. Hence, as already observed, the powers of resistance of every description of laminated stone, are most effective when the beds are placed horizontally or perpendicularly to the direction of the pressure, and this position is the more important when the stone is exposed to the atmosphere, as it partially prevents the absorption of moisture, which in winter tends to destroy the material by the contraction of the stone and the expansion of the water at low temperatures.

Experiments to determine the force required to fracture and crush 1*in.*, 1½*in.*, *and* 2*in. cubes of stones from Scotland, Wales, and other places.*

No. of Expt	Weight laid on in lbs.	Remarks.	No. of Expt	Weight laid on in lbs.	Remarks.
Specimen No. 12. Grauwacke. Penmaenmawr, Wales. 2in. cube.			Specimen No. 14. Granite. Mount Sorrel. 2in. cube.		
16	40692	slight fracture.	19	46068	
...	....	....	20	47860	
29	63988	second fracture.	21	49652	
30	65780		22	51444	fractured, and after a slight rest crushed.
31	67572	crushed.			

No. of Expt	Weight laid on in lbs.	Remarks.	No. of Expt	Weight laid on in lbs.	Remarks.
Specimen No. 15. Grauwacke. Ingleton. 2in. cube.			Specimen No. 16. Granite. Aberdeen. 2in. cube.		
13	35316	first fracture.	8	26356	
...	....	....	9	27546	fractured.
20	47860	second fracture.	10	28148	
...	....	....	11	28340	not crushed.
25	53236	not crushed.			
Specimen No. 17. Syenite. Mount Sorrel. 2in. cube.			Specimen No. 18. Granite. Bonaw. 1½in. cube.		
17	42484		2	15604	
18	44276		3	17396	fractur'd in 2 nearly eq. pts.
19	46068		...	....	
20	47284	crushed.	7	24564	crushed.
Specimen No. 19. Furnace Granite. Inverary. 1½in. cube.			Specimen No. 20. Granite. A. 1½in. cube.		
4	19188		4	19188	
5	20980		5	20980	
6	22772		6	22772	fractured.
7	24564	crushed.	7	24564	crushed.
Specimen No. 21. Limestone. B. 1½in. cube.			Specimen No. 22. Limestone. C. 1½in. cube.		
1	13812		2	15604	
2	15604		3	17396	
3	17396	fractured.	4	18292	fractured.
4	19188	crushed.	5	19188	crushed.
Specimen No. 23. Magnesian Limestone. Anston. 1in. cube.			Specimen No. 24. Magnesian Limestone. Worksop. 1in. cube.		
1	1258		13	3834	
2	2154	fractured.	14	3946	fractured.
...	......	....	...	......	....
10	3050	crushed.	38	7098	crushed.
Specimen No. 25. Sandstone. 1in. cube.			Specimen No. 26. Sandstone. 2in. cube.		
8	2938		11	9770	
9	3050	fractured.	12	10218	fractured.
...	......	....	...	......	....
13	3498	crushed.	20	12228	crushed.

Results of experiments on stone from North Wales and other places. Specimens Nos. 12, 14, 17, 18, 19, 20, 21, 22, 23, 24, 25, and 26.

No. of Speci-men.	Description of Stone.	Locality.	Size.	Weight with which it fractured, in lbs.	Weight with which it crushed, in lbs.	Pressure required to crush a 2in. cube, in lbs.
12	Grauwacke.	Penmaenmawr ...	2in. cube.	40692	67572	67572
14	Granite.....	Mount Sorrel......	,,	51444	51444	51444
17	Syenite.....	,, ,, ...	,,	47284	47284	47284
18	Granite.....	Bonaw, Inverary..	1½in.cube	17396	24564	43669
19	,,	Furnace, ,,	,,	24564	24564	43669
20	,,	(A)	,,	22772	24564	43669
21	Limestone..	(B)	,,	17396	19188	34112
22	,,	(C)	,,	18292	19188	34112
23	,,	Anston........	1in. cube.	2154	3050	12200
24	,,	Worksop............	,,	3946	7098	28392
25	Sandstone..	... ...	,,	3050	3498	13992
26	,,	... ...	2in. cube.	10218	12228	12228

The Welsh specimen of grauwacke, from Penmaenmawr, exhibits great powers of resistance, nearly double that of some of the Yorkshire sandstones, and about one-third in excess of the granites, excepting only the granite from Mount Sorrel, which is to the Welsh grauwacke, as ·757 : 1. Some others, such as the Ingleton grauwacke, supported more than the granites, but are deficient when compared with that from Penmaenmawr. The specimen No. 23 is the stone of which the Houses of Parliament are built. Specimens Nos. 25 and 26 were broken to show experimentally the ratio of the powers of resistance as the size is changed. The results are sufficiently near to prove that the crushing weights are as the areas of the surface subjected to pressure.

The specific gravity and porosity of the different kinds of rock vary greatly, and Mr. Shaw, in his desire to obtain the best quality of Yorkshire paving stone, had those from the neighbourhood of Bradford carefully tested in regard to their powers of absorption; the experiments, which were conducted with great precision, gave the following results.

Experiments to ascertain the amount of water absorbed by various kinds of stone.

No. of Specimen.	Description of Stone.	Locality.	Weight before immersion.	Weight after immersion for 48 hours.	Diff'rence of Weight.	Proportion absorbed.
			lbs.			
1	Sandstone..	Shipley	5.4687	5.5546	.0859	1 in 63.6
2	"	Heaton...........	5.2578	5.3632	.1054	1 in 49.8
3	"	Heaton Park.	5.1718	5.2896	.1171	1 in 44.1
4	"	Spinkwell	5.2968	5.4726	.1758	1 in 30.1
5	"	Idle Quarry.	5.7178	5.8203	.1016	1 in 56.3
6	"	Jegrum's-lane	5.5976	5.7187	.1211	1 in 46.2
7	"	Spinkwell	5.6757	5.7851	.1094	1 in 53.8
8	"	Coppy Quarry......	5 5703	5.6914	.1211	1 in 46.0
9	"	Old Whatley.	5.4726	5.6132	.1406	1 in 38.9
10	"	Manningham-lane.	5.4882	5.6093	.1211	1 in 46.3
11	"	" "	5.6289	5.7539	.1250	1 in 45.0
12	Grauwacke.	Wales	6.4101	6.4140	.0039	1 in 1641.0
13	Granite.....	Mount Sorrel	5.6875	5.6992	.0117	1 in 485.0
14	"	" "	5.8007	5.8124	.0117	1 in 495.0
15	Grauwacke.	Ingleton.	5.7500	5.7539	.0039	1 in 1962.6

From the above table it will be observed that specimen No. 15, the Ingleton grauwacke, is the least absorbent, and No. 12, the Welsh grauwacke, absorbs almost as little, while Nos. 9 and 14 of the sandstones absorb most. The granites, though closely granulated, take up much more water than the grauwackes, but less than the sandstones. The resistance of the grauwacke specimens to the admission of water is four times that of the granite, and thirty-six times that of sandstone, such as is found in the Yorkshire quarries.

No. of Specimen	Description of Stone.	Locality.	Size.	Specific gravity.	Pressure to fracture specimen.	Pressure to crush specimen.	Pressure per square inch to crush specimen.	Cubic feet in a ton.	Ratios of powers of absorption.
			cube		lbs.	lbs.	lbs.		1 in
1	Sandstone.	Shipley*........	2in.	2.452	33524	38900	9725	14.616	63.6
2	,,	Heaton*........	,,	2.420	33524	40692	10173	14.809	49.8
3	,,	Heaton Park* ..	,,	2.385	29940	31732	7933	15.027	44.1
4	,,	Spinkwell	,,	2.329	defec	tive.	....	15.388	30.1
5	,,	Idle Quarry†....	,,	2.464	42484	43380	10845	14.545	56.3
6	,,	Jegrum's-lane†..	,,	2.400	45172	47860	11965	14.933	46.2
7	,,	Spinkwell†	,,	2.456	31732	37108	9277	14.592	53.8
8	,,	Coppy Quarry† ..	,,	2.408	37108	41588	10397	14.833	46.0
9	,,	Old Whatley*...	,,	2.415	35316	35316	8829	14.840	38.9
10	,,	Manning'm-lane*	,,	2.401	28148	37108	9277	14.927	46.3
11	,,	,, ,,	,,	2.421	fai	led.	....	14.804	45.0
12	Grauwacke	Penmaenmawr ..	,,	2.748	40692	67572	16893	13.042	1641.0
13	Granite ..	Mount Sorrel ...	,,	2.657	....	....	....	13.489	485.3
14	,,	,, ,, ...	,,	2.675	51444	51444	12861	13.398	495.0
15	Grauwacke	Ingleton........	,,	2.787	35316	(53236)	not crd	12.866	1962.6
16	Granite ..	Aberdeen	,,	—	27546	(28340)	not crd	—	—
17	Syenite ..	Mount Sorrell...	,,	—	47284	47284	11821	—	—
18	Granite ..	Bonaw..........	1½in	—	17396	24564	10917	—	—
19	,,	Furnace	,,	—	24564	24564	10917	—	—
20	,,	A	,,	—	22772	24564	10917	—	—
21	Limestone.	B	,,	—	17396	19188	8528	—	—
22	,,	C	,,	—	18292	19188	8528	—	—
23	,,	Anston..........	1in.	—	2154	3050	3050	—	—
24	,,	Worksop........	,,	—	3946	7098	7098	—	—
25	Sandstone.	D	,,	—	3050	3498	3498	—	—
26	,,	E	2in.	—	10218	12228	3057	—	—

On comparing the results of the experiments on the Yorkshire sandstones, it will be seen that the difference of resistance to pressure does not arise so much from the variable character of the stone in different quarries, as from the position in which it is placed as regards its laminated surface, the difference being as 10:8 in favour of the stone being crushed upon its bed to the same when crushed in the line of cleavage; the same may be said of the limestones.

Comparing the strengths indicated by the above experiments, I find a very close approximation in the granites, but considerable difference in the Yorkshire sandstones. Mr. Rennie obtained his specimens from the same district, the valley of the Aire; but the force required to crush the Brom-

* Pressure applied in the direction of the cleavage.

† Pressure applied perpendicularly on the bed of the stone.

ley Fall stone was much less than that required to fracture similar specimens from the Shipley quarries. The following table gives some useful results for comparison.

Description of Material.	Crushing force in lbs. per square inch.	Authority.
Porphyry	40416	Gauthey.
Granite, Aberdeen	11209	Rennie.
„ mean of 3 varieties	11564	Experiments 14, 18, 19.
Sandstone, Yorkshire	6127	Rennie.
„ „ mean of 9...	9824	Experiments 1 to 9.
Brick, hard..	1888	Rennie.
„ red	805	Rennie.

From the above it is evident that there is a considerable difference between the results of Mr. Rennie's experiments and those in the preceding tables. This may, perhaps, be due to the different methods pursued in the experiments, or from taking the first appearance of fracture as the ultimate power of resistance. Whereas, there is in some cases a difference of nearly a third between the weight required to produce the first crack, and that required subsequently to crush the specimen. This is the more remarkable as all the specimens did not appear to follow the same law, as in some the weight which fractured the specimen by a continuation of the process ultimately crushed it. Experiments of this kind require close observation, and the reason just given may probably account for the difference between Mr. Rennie's and my own results.

All information respecting the strength of materials must be derived from direct experiment, which is always the safest and best guide; and fully aware of the importance of this fact, I have deemed it expedient to append the following list of the bearing powers of some other materials employed in building, and to which reference may be made in any case where the load is excessive, or where the material is subjected to severe strain.

The necessity of these experiments was the more apparent some years since, in the construction of the Britannia and

Conway tubular bridges, when fears were entertained of the security of the masonry to support, upon the given area, the immense weight of the tubes, upwards of 1,500 tons, resting on one side of the tower. To ascertain how far the material (Anglesea limestone) was calculated to sustain this load, the following experiments were instituted by Mr. Latimer Clarke.

"*Results of experiments made with actual weight on the materials used in the Britannia bridge, January,* 1848.

Brickwork.

	lbs. per square inch.
No. 1.—9in. cube of cemented brickwork (Nowell and Co.), No. 1 (or best quality) weighing 54 lbs., set between deal boards. Crushed with 19 tons 18 cwt. 2 qrs. 22 lbs.	= 551.3
No. 2.—9in. cube of brickwork, No. 1 weighing 53 lbs., set in cement. Crushed with 22 tons 3 cwt. 0 qr. 17 lbs..................................	= 612.7
No. 3.—9in. cube of brickwork, No. 3 weighing 52 lbs., set in cement. Crushed with 16 tons 8 cwt. 2 qrs. 8 lbs.	= 454.3
No. 4.—$9\frac{1}{4}$in. brickwork, No. 4 weighing $55\frac{1}{2}$ lbs., set in cement. Crushed with 21 tons 14 cwt. 1 qr. 17 lbs.	= 568.5
No. 5.—9in. brickwork, No. 4 weighing $54\frac{1}{4}$ lbs., set between boards. Crushed with 15 tons 2 cwt. 0 qr. 12 lbs.	= 417.
Mean	521.

Note.—The last three cubes of common brick continued to support the weight, although cracked in all directions; they fell to pieces when the load was removed. All the brickwork began to show irregular cracks a considerable time before it gave way.

The average weight supported by these bricks was 33.5

tons per square foot, equal to a column 583.69 feet high, of such brickwork.

Sandstone.

	lbs. per square inch.
No. 6.—3in. cube red sandstone, weighing 1 lb. $14\frac{5}{8}$ oz., set between boards (made quite dry by being kept in an inhabited room). Crushed with 8 tons 4 cwt. 0 qr. 19 lbs.	= 2043.
No. 7.—3in. cube sandstone, weighing 1 lb. 14 ozs., set in cement (moderately damp). Crushed with 5 tons 3 cwt. 1 qr. 1 lb.	= 1285.
No. 8.—3in. sandstone, weighing 1 lb. $15\frac{1}{2}$ ozs., set in cement (made very wet). Crushed with 4 tons 7 cwt. 0 qr. 21 lbs.	= 1085.
No. 9.—6in. cube sandstone, weighing 18 lbs., set in cement. Crushed with 63 tons 1 cwt. 2 qrs. 6 lbs.	= 3924.8
No. 10.—$9\frac{1}{4}$in. cube sandstone, weighing $58\frac{1}{2}$ lbs., set in cement ($77\frac{1}{2}$ tons were placed upon this without effect, = 2042 lbs. per square inch, which was as much as the machine would carry)	
Mean	2185.

All the sandstones gave way *suddenly*, and without any previous cracking or warning. The 3in. cubes appeared of ordinary description; the 6in. was fine grained, and appeared tough and of superior quality. After fracture the upper part generally retained the form of an inverted square pyramid about $2\frac{1}{2}$in. high and very symmetrical, the sides bulging away in pieces all round. The average weight of this material was 130 lbs. 10 ozs. per cube foot, or 17 feet per ton.

The average weight required to crush this sandstone is 134 tons per square foot, equal to a column 2351 feet high of such sandstone.

LIMESTONE.

	lbs. per square inch.
No. 11.—3in. cube Anglesea limestone, weighing 2 lbs. 10 ozs., set between boards. Crushed with 26 tons 11 cwt. 3 qrs. 9 lbs.	= 6618.
This stone formed numerous cracks and splinters all round, and was considered crushed; but on removing the weight about two-thirds of its area were found uninjured.	
No. 12.—3in. limestone, weighing 2 lbs. 9 ozs., set between deal boards. Crushed with 32 tons 6 cwt. 0 qr. 1 lb................................	= 8039.
This stone also began to splinter externally with 25 tons (or 6220 lbs. per square inch), but ultimately bore as above.	
No. 13.—3in. limestone, weighing 2 lbs. 9 ozs., set in deal boards. Crushed with 30 tons 18 cwt. 3 qrs. 24 lbs.	= 7702.6
No. 14.—Three separate 1in. cubes limestone, weighing 2 lbs. 9 ozs., set in deal boards. Crushed with 9 tons 7 cwt. 1 qr. 14 lbs.	= 6995.3
All crushed simultaneously.	
Mean..............................	7579.

All the limestones formed *perpendicular* cracks and splinters a long time before they crushed.

Weight of the material from above = 165 lbs. 5 ozs. per cubic foot, or 13½ feet per ton.

The weight required to crush this limestone is 471.15 tons per square foot, equal to a column 6433 feet high of such material."

Previously to the experiments just recorded, it was deemed advisable not to trust to the resisting powers of the material of which the towers of either bridge were composed; and, to make security doubly sure, it was ultimately arranged to rest the tubes upon horizontal and transverse beams of great strength, and by increasing the area subject to compression, the splitting or crushing of the masonry might be prevented. This was done with great care, and the result is the present stability of those important structures.

In conclusion, I have now to submit to the consideration of the society and the practical builder the following general summary of results, obtained from various materials, showing their respective powers of resistance to forces tending to crush them.

GENERAL SUMMARY OF RESULTS ON COMPRESSION.

	Description of Material.	Crushing force in lbs. per square inch.	Authority.
Iron and Steel.	Cast steel		Fairbairn's Experiments on the Mechanical Properties of Metals.—Transactions of the British Association, 1854.
	Blister steel		
	Cast iron (white, derived from 14 meltings)	214816	
	Ditto (from 12 meltings)	163744	
	Ditto (from ordinary castings)	89600	
Stone.	Porphyry	40416	Gauthey.
	Grauwacke, Penmaenmawr	16893	Exprmts. No. 12.
	Granite, mean of 3	11565	Do. Nos. 14, 18, 19.
	Sandstone, Yorkshire	6127	Rennie.
	Ditto, mean of 9 exprts.	9824	Exprmts. 1 to 10.
	Ditto, Runcorn	2185	Clark.
	Limestone	8528	Exprmts. 21, 22.
	Ditto, Anglesey	7579	Clark.
	Ditto, Magnesian—mean	5074	Exprmts. 23, 24.
	Brick, hard	1888	Rennie.
	Ditto, red	805	"
	Ditto, mean of 4 exprts.	1424	Clark.
Timber.	Box	9771	Hodgkinson.
	English Oak (dried)	9509	
	Ash (ditto)	9363	
	Plumtree (ditto)	8241	
	Beech	6402	
	Red Deal	5748	
	Cedar	5674	
	Yellow Pine	5375	

It is observed by Professor Hodgkinson, in his experiments on timber, that great discrepancies occurred when the woods were in different degrees of dryness; wet timber, though felled for a considerable time, bearing in some instances less than one-half what it bore when dry.

Professor Hodgkinson has also experimented on round and square columns of sandstone from Ped Delph, Littleborough, Lancashire, a much harder stone than that found on the banks of the Aire. With regard to these experiments, it appears "that there is a falling off in strength in all columns from the shortest to the longest, but that the diminution is so small, when the height of the column is not greater than about twelve times the side of its square, that the strength may be considered uniform, the mean being 10,000 lbs. per square inch or upwards.

"From the experiments on the columns 1in. square, it appears that when the height is fifteen times the side of the square, the strength is slightly reduced; when the height is twenty-four times the height of the base, the falling off is from 138 to 96 nearly; when it is thirty times the base, the strength is reduced from 138 to 75; and when it is forty times the base, the strength is reduced to 52, or to little more than one-third. These numbers will be modified to some extent by experiments now in progress.

"As long columns always give way first at the ends, showing that part to be weakest, we might economize the material by making the areas of the ends greater than that of the middle, increasing the strength from the middle both ways towards the ends. If the areas of the ends be to the area of the middle, as the strength of a short column is to that of a long one, we should have for a column, whose height was twenty-four times the breadth, the areas of the ends and middle as 13766 to 9595 nearly. This, however, would make the ends somewhat too strong, since the weakness of the long columns arises from their flexure.

"Another mode of increasing the strength would be that of preventing flexure, by increasing the dimensions of the middle.

"From the experiments it would appear that the Grecian columns, which seldom had their length more than about ten times the diameter, were nearly of the form capable of bearing the greatest weight when their shafts were uniform, and that columns tapering from the bottom to the top were only capable of bearing weights due to the smallest part of their section, though the larger end might serve to prevent lateral thrusts. This latter remark applies, too, to the Egyptian columns, the strength of the column being only that of the smallest part of the section.

"From the two series of experiments, it appeared that the strength of a short column was nearly in proportion to the area of the section, though the strength of a larger one is somewhat less than in that proportion."

I give these extracts from Mr. Hodgkinson's paper, to show the advantages to be derived from proper attention to the construction of columns, not only as regards their resistance to a crushing force, but as to the propriety of enlarging the ends to increase their powers of resistance.

Experimental data cannot always be applied in architectural constructions; but it is, nevertheless, essential that the architect and builder should be cognizant of the facts, in order that they may prepare their plans, as far as possible, in accordance with them, and effect the greatest amount of work with the least waste of material.

The accompanying plate exhibits the appearance of some of the fractured specimens; in all, it will be observed, that there is a tendency to give way by one or more wedges forcing out from the sides in all directions.

The plate shows the fractured appearance of,

Specimen No.	1.	Sandstone,	Shipley, Bradford.
,,	2.	,,	Heaton, Bradford.
,,	3.	,,	Heaton Park, Bradford.
,,	5.	,,	Idle Quarry.
,,	7.	,,	Spinkwell.
,,	12.	Grauwacke,	Penmaenmawr, Wales.
,,	14.	Granite,	Mount Sorrel.
,,	20.	,,	A.
,,	21.	Limestone,	B.
,,	22.	,,	C.
,,	23.	,,	Anston.
,,	25.	Sandstone,	D.
,,	26.	,,	E.

The other specimens operated upon were not sufficiently defined in the line of fracture to admit of their form being sketched; most of them having been crushed almost to powder.