(*Paper No. 2559.*)

“Building-Stones of Great Britain—their Crushing-Strength and other Properties.”

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VERY few systematic tests of the various properties of British building-stones have been published since the report of the Royal Commission of 1839 was issued. That commission was appointed to inquire into the question of “the selection of stone for building the new Houses of Parliament”; it issued a very valuable report on the stones then chiefly in use, and the results of the experiments they carried out have formed the standard of reference up to the present day. It is a well-known fact, however, that the qualities of the stone from any particular quarry are by no means constant, and a period of over fifty years having elapsed since the report appeared, the probability is great that the results then ascertained as to any stone may, by the present date, have become untrustworthy and almost useless, since entirely different parts of the quarry beds will now be worked. In view of this, and of the additional fact that many new quarries have since been opened up, it seemed to the Author that the time had come for a new series of experiments, and that the result of such an inquiry could not fail to be of service to both the engineering and the architectural professions.

He determined, at any rate for the present, to confine his work entirely to stones of Great Britain; and to carry out tests on the following properties:—Crushing-strength, density, absorptive power as a test of weathering, effects of low temperature, and lastly, an inquiry into the behaviour of stone under gradually increasing pressures with a view to determining the modulus or coefficient of elasticity.

The Author put himself in communication with a large number of quarry-owners throughout the country, with the object of obtaining specimens, and met with a very cordial response. He is much indebted to these gentlemen for the trouble taken in preparing specimens, and for much valuable information as to the

use of the stones, &c. Naturally, only a selection could be made of all the quarries now worked, but he endeavoured to obtain as representative a collection as possible. Three specimens of each stone were asked for, in the form of cubes $2\frac{1}{4}$ inches in the side. The Author was very anxious to have all the specimens of uniform size, and a $2\frac{1}{4}$ inch cube of the stronger granites was the maximum size which could be crushed in his testing-machine, the capacity of which is 100,000 lbs.

The building stones in ordinary use may be classed as granites, limestones, dolomites, and sandstones. As far as possible, specimens of each of these classes were obtained from each district where they occur. Appendix A gives a list of the quarries supplying stones, and the districts where they are situated, together with a few notes as to their use.

After the specimens were received they were allowed to remain for some time exposed to the dry warm air of the laboratory, till practically all the natural quarry water had been evaporated, and it was in this condition that all the measurements and experiments were made. The general plan adopted was to test one of the three specimens at once for crushing-strength; to use a second for density, absorption, &c., experiments and then to crush it; and to employ the third for elastic tests before crushing it.

It will probably be convenient to deal with each series of tests independently, and then to draw any conclusions as to their relation one to another.

Crushing-Tests.—These tests were carried out in the large Greenwood and Batley testing-machine belonging to the laboratory of University College, London; it is a horizontal machine of 100,000 lbs. capacity; in carrying out the experiments, the small force-pump was driven by a Crossley gas-engine. The testing-machine was described by Professor Kennedy, F.R.S., in his Paper on "Engineering Laboratories," read before the Institution in 1886;¹ it is not necessary, therefore, to again describe it. In all cases the load was applied gradually up to the maximum point.

The specimens were carefully prepared at the quarries, so as to insure parallelism of the two sides subjected to pressure; and in every case, except two (1202₂ and 1202₄), the specimens were placed in the machine in such a way that the pressure was applied on the bedfaces, *i.e.* the axis of pressure was perpendicular to the planes of the quarry-bedding.

In almost all cases, in building-work, care is taken, more espe-

¹ Minutes of Proceedings Inst. C.E., vol. lxxxviii. p. 1.

cially in the use of sandstones and other rocks which show very distinct planes of stratification, to place the stones in the walls, &c., in the position of natural bedding, because, if employed in any other way, they usually disintegrate much more rapidly under the weathering action of atmospheric influences; it did not, therefore, seem to the Author worth while to make any tests with the axis of pressure parallel to the planes of bedding. The two exceptions were at the special request of the quarry-owner supplying those stones.

The faces of the cube to which the pressure was applied (in addition to the careful quarry preparation) were strickled over in the laboratory with a thin layer of plaster of Paris; when this was dry, it was easily rubbed and pared to a smooth surface, and to perfect parallelism of the two pressure faces. The surfaces thus prepared were applied directly to the steel faces of the dies of the testing-machine, nothing whatever being interposed. This is a point of very considerable importance in the testing of stone and similar materials, and it appears to the Author that many of the very discrepant and anomalous results so often obtained in such tests may be easily explained by consideration of the methods adopted for holding the specimens in the testing-machine. It has been a common practice to interpose between the specimen and the dies of the machine sheets of lead or thin pieces of soft wood, with the idea that this would secure a perfectly uniform pressure all over the cube, in consequence of the softer lead or wood yielding and thus accommodating itself to inequalities in the pressure from want of parallelism or roughness in the two faces of the cube. It is, however, quite certain, whether the above result is obtained or not, that the introduction of the lead or wood very largely reduces the crushing-strength of the specimen, and the reason is not far to seek. The compressive forces produce lateral dilatation, and consequently a tension at right-angles to the line of pressure; now under the great pressure necessary the lead flows laterally, and the friction thus caused between it and the face of the cube sets up a very considerable tensile stress additional to the one mentioned above, the result being that the cube is torn asunder into a series of prisms parallel to the axis of pressure by this augmented lateral tensile stress, and the fracture is quite unlike the typical one of stone or such material when crushed in the form of cubes. The Author investigated this point, and determined the resultant loss of strength in using such interposed sheets of lead, &c., by a series of comparative tests, the results of which are given in the subjoined Table.

INFLUENCE OF INTERPOSED LEAD SHEETS ON THE STRENGTH OF STONE CUBES.

Name of Stone.	Method of Bedding.	Crushing Strength.	Loss of Strength by use of Lead between Cube and Dies.	
		Tons per Sq. Foot.	Tons per Sq. Foot.	Per Cent.
Binnie (1 cube). . .	Lead $\frac{1}{8}$ -inch thick.	253·4	154·1	37·8
„ (2 cubes) . . .	Plaster of Paris only.	407·5		
Hermard (1 cube) . .	Lead $\frac{1}{8}$ -inch thick.	253·4	139·7	35·5
„ (2 cubes) . . .	Plaster of Paris only.	393·1		
White Hailes (1 cube).	Lead $\frac{1}{8}$ -inch thick.	298·1	369·3	55·3
„ (2 cubes). . .	Plaster of Paris only.	667·4		
Arbroath (3 cubes). .	Lead $\frac{1}{8}$ -inch thick.	321·1	237·0	42·5
„ (3 „) . . .	Plaster of Paris only.	558·1		
Craigleith (3 cubes)	Lead $\frac{1}{8}$ -inch thick.	408·9	453·0	52·6
„ (3 „) . . .	Plaster of Paris only.	861·9		

Note.—For the first three stones the cubes were all cut from one block. This was not the case for Arbroath or Craigleith, the second sets being obtained at a later date.

The enormous reduction of strength, varying from 36 to 55 per cent., is very apparent, and the fact that the loss is greater the stronger the stone points very clearly to its origin, viz. the lateral flow of the lead under the great pressure to which it was subjected. The use of thin pieces of soft pine is still more destructive. Three specimens of Corncockle were tested; two with lead interposed had a mean strength of 195·1 tons per square foot, while one with pine carried only 145·4 tons before breaking up into a number of prisms.¹

The Author is therefore of opinion, that, for the sake of obtaining accurate and uniform results, stone cubes should always be prepared and tested in the way adopted in these experiments; in a few cases he interposed between the die and the plaster of Paris face millboard (which is practically incompressible at the pressures used), but it did no good, and if anything, harm. There is no necessity for anything, except the thin layer of plaster of Paris, which, to all intents and purposes, becomes part of the stone cube.

These interesting results emphasize also very clearly the effects of bad bedding in structures in reducing the strength of the stones used.

One cube, or in some cases two cubes, were, after drying in the laboratory, tested at once to destruction; these may be recognised

¹ This point is noticed in Silliman's "American Journal of Science and Arts," vol. xxii. pp. 30-38. Also in Unwin, "The Testing of the Materials of Construction."

in the appended Tables, in which all the results are given, by the absence of any figures in the columns for the other tests. As mentioned before, it was the Author's intention to use one cube of each set for absorption, &c., tests, before crushing. It so happened that the first stones tested were Bath and other oolitic limestones, and the Author found that there was apparently some reduction of strength caused by the immersion in water and subsequent re-drying; he, therefore, as far as this class of stones was concerned, abandoned this plan, and tested two samples of each set at once to destruction, reserving the third as before for elastic work. For the absorption tests two other cubes of each stone were obtained from the quarries and eventually crushed. No such effect was found in the case of the sandstones, dolomites, or granites,

Fig. 1.

CURVE A, CRUSHING-STRENGTHS. CURVE B, DITTO, AFTER IMMERSION IN WATER FOR SEVEN DAYS AND RE-DRYING. CURVE C, PERCENTAGE OF WATER ABSORBED.

and with them, therefore, the original plan was adhered to. Whether there really was a loss of strength is not quite certain; the curves in *Fig. 1* show diagrammatically the strengths of the two series of Bath stones, and it will be noticed that the curve indicating the crushing-loads for the immersed and redried cubes does show a distinct tendency to fall below the one for the series which was not placed in water; *Fig. 1* also shows by another curve the relative absorptions of the different stones.

In general, there was no preliminary cracking noticeable; where it did occur, the load at which it happened is given in the Table. Most of the stones gave way quite suddenly, and the type of fracture was that shown in *Figs. 2* and *3*, which are photo-zincographic

reproductions of fractured cubes. Let a cube or other solid be subjected to direct compressive forces, then on any plane section inclined to the axis of pressure, there will be on this plane a normal component and a tangential component of the axial pressure. The latter will tend to produce shearing strain on this plane, and were it the only internal force present it can easily be proved that it would reach its maximum value on planes inclined at 45° to the axis; but there can be no doubt that the normal component interferes with this by producing a resistance to the rubbing of the two surfaces over one another in the act of shearing. The plane at which shear does take place is therefore often not inclined at 45° to the axis; furthermore, the lateral dilatation before mentioned effects the result, causing the sides often to break off into prisms.

Were the maximum shear to occur on planes at 45° to the axis then the cube would tend to break up into six pyramids with their apices at the centre. Generally the two corresponding to the top and bottom faces (*i.e.* the ones in contact with the dies) remained intact, and could be removed from the machine; but the others usually crumbled into irregular pieces or dust. In several cases, however—notably the oolites—the side pyramids also remained unbroken, the fracture being quite perfect.

Tables are appended which give in columns the following data: (1) Laboratory test number; (2) Name of stone or quarry; (3) Crushing-load of each cube in tons per square foot; (4) Mean crushing-strength of each kind of stone; (5) Density; (6) Weight of one cube foot; (7) Absorption-power; (8, 9, and 10) Coefficients of elasticity. Remarks occur in the footnotes.

In the Tables, the stones are grouped under the four heads of sandstones, dolomites, limestones, and granites, and also largely in districts. It will be seen that the figures for crushing-loads are very closely concordant, and, as they speak for themselves, the Author does not consider it necessary to discuss them in detail. The means for each class may, however, be useful; they are as follows (crushing-strength per square foot):—Granites, 1112·2 tons, mean of thirteen varieties, forty-nine samples; oolites, 141·3¹ tons, mean of eighteen varieties, fifty-seven samples; sandstones, 489·8 tons, mean of twenty-five varieties, eighty-eight samples; dolomites, 500·5 tons, mean of four varieties, sixteen samples.

As a rule, the results are higher than those obtained in the older experiments, and more in agreement one with another. In

¹ This mean does not include limestones which are not oolitic, and does not include the immersed and redried oolites.

the case of Bath stones, two means have been given in the Tables; the one in brackets is for the cubes of each set, which were not immersed in water, while the other includes them all. Every test which was made is included in the Tables.

Density.—Each cube was for this purpose accurately measured to obtain its exact cubical contents, and was carefully weighed, then this weight was compared with the known weight of an equal volume of water at the standard temperature. The very close agreement of the results where two or more cubes of one kind of stone were tested is a sufficient proof of the carefulness and accuracy of these results. In the case of the granites, since the absorption of water is exceedingly small, the specific gravity or density was also determined by weighing the cube in air, and then in water; this method also gave very close results, and in strict agreement with those obtained by the other plan. The weight per cubic foot has been calculated from these density results, assuming 1 cubic foot of water to weigh 62.42 lbs.; the mean density is used for the calculation where there are several results. When the stone is removed from the quarry, it is practically saturated with quarry water; if it is desired to know the weight per cubic foot under these circumstances, it can easily be determined by increasing the figures given in column 6 by the amount of such water deduced from the proportional absorption given in column 7.

Absorption of Water.—For this test, the cube after it had been measured and weighed as above described, was lowered gradually into a vessel of water (earthenware crocks were used), and left there for a period of six or seven days. Saturation probably occurs within a very few hours, but it is safer to leave the cube under water for some days. At the end of this time, the stones were removed, wiped with a dry cloth to remove adherent water, and at once reweighed. The gain of weight compared with the figures for the dry stone is that due to the water absorbed. In column 7 of the Tables, the results are expressed as a percentage of the original weight, by dividing the gain by the dry weight. It may be mentioned that every care was taken to have the stones thoroughly dry before beginning these tests, and they were allowed to again dry before crushing them. The water used for a few of the earlier specimens—numbers 1059₂, 1061₁, 1062₁, 1063₁, 1064₁, 1065₂, 1077₂, 1082₂, 1087₂, 1088₂, 1089₂, 1090₂, 1091₂, 1092₂—was drawn from the College service-supply, obtained from the New River Company; but for all the others, pure distilled water was used.

That there was some dissolving action going on in the case of the oolites was shown by the condition of the water in the vessels after the stones were removed; it was slightly cloudy, and there was a distinct sediment. This is quite sufficient, probably, to account for any apparent loss of strength.

Of course, to be at all comparative, absorption tests must be made on cubes of the same size, so that the surfaces exposed to the water may bear the same relation to the volume of the cube. It is, therefore, not easy to compare one set of observations with another; in this case they are strictly comparable, as all the cubes were of the same size, and treated in precisely similar fashion. The relative amounts of absorbed water must be a very good guide to the relative weathering power of stones, since it shows to what extent deleterious agents in rain water and fogs will penetrate the stone, and furthermore, a freely absorbent stone must be very liable to the destructive action of frost. Summarising again, in order of absorption, oolites, on an average of twenty-seven samples, absorb 8.96¹ per cent. of their dry weight; dolomites, on an average of four samples, 5.43 per cent.; sandstones, on an average of twenty-six samples, 4.68 per cent.; granites, for fourteen samples, 0.27 per cent.

Fig. 1 shows diagrammatically for Bath stones the relation between absorption and strength to resist crushing, and also the apparent resultant loss of strength. There are two sets of cubes of Westwood Ground, one set having been treated by Mr. Kessler's process for hardening and preserving calcareous stones; the effect of its application seems to be a slight reduction in strength, with also a slight lowering in the quantity of water absorbed. The process is largely used in France, and seems to be very successful in reducing and checking decay of oolitic and other limestones.

Freezing.—The Author had intended making a complete set of tests on this point during the severe frosts of last winter; but before he was able to carry out this idea, except to a very limited extent, the frost broke up, and the idea was for the time abandoned. A few specimens were subjected to the test; they were soaked in water all day, and then at night placed outside on the ground, or on a ledge about 7 feet above the ground, and thus exposed to a temperature varying from about 20° to 32° Fahrenheit; in the morning they were brought inside and thawed by gently warming. This process was repeated some ten or twelve times, and then the cubes were left exposed to the atmosphere and rain

¹ This omits 1059₂ and 1184₂ the Doulting Chelyuch Bed Stones.

for some two or three weeks after the thaw set in. The stones used were white and red Mansfield, Magnesian limestone, Ancaster freestone, Brown Weather bed, and the granites Corrennie, Cove, Kemnay. The loss of weight of the granites was not perceptible, and in the case of the others did not exceed 0.002 lb. (the cubes all weighing about a pound), that is practically there was none. Similarly compared with their fellow cubes, there was no loss of strength. These few results are perhaps inconclusive, but they seem to point to very small loss of strength due to freezing; it is, however, the Author's intention to pursue the question further.

Coefficients of Elasticity.—It is a matter of extreme difficulty to obtain these coefficients for stone. The specimens operated on are necessarily small, and the quantities to be measured very minute. It is a difficult enough matter to obtain thoroughly trustworthy results when dealing with iron and steel, the specimens of which can be made in lengths of 10 inches and upwards; when dealing with only $2\frac{1}{4}$ -inch cubes, it becomes impossible to use any ordinary strain-measuring apparatus. The Author, therefore, requested his assistant, Mr. A. G. Ashcroft, Assoc. M. Inst. C.E., to undertake the devising of a new measuring gear, for use with these small cubes, capable of magnifying about 2,500 times. The essentials were, the gear must be very sensitive and free from all inertia and resultant backlash. After several trials, the apparatus shown in Plate 8 was elaborated, and was finally used in all these tests.

Plate 8 gives three views of the instrument. Fig. 1 is a side elevation, Fig. 3 a plan, and Fig. 2 an end elevation. The principle on which the gear is arranged is to obtain the needful magnification by a system of levers, that is by mechanical exaggeration, and not by optical means. A brass frame *a* embraces the cube, and is attached to it at the top and bottom by two pairs of set screws; the centres of these pairs are exactly $1\frac{1}{2}$ inch apart; this forms the length on which the compressions are measured. The brass frame *a* is made in two pieces, each piece being a square frame with two uprights at opposite ends of one diagonal, thus the two pieces when placed together form a hollow prismatic frame; the two parts are secured together and united, with freedom to move relatively to one another, by eight spring pieces, *b*. One of the two sides of *a*, supports on one side an arm *c*, and on the other a long arm *d*, with a scale attached to it; the arm *c* carries at its end at right-angles to itself a small piece of steel *e*, the attachment being a spring one; on the end of *e* is a centre dot. Surrounding the frame *a* is a cross frame *f*, which is made double for balancing purposes; this cross frame is attached

by spring pieces of the "Emery" type (which take the place of knife-edges) g to each of the two halves of a ; on the end of this cross-frame, close to the piece e , is another centre dot. Any compression of the stone cube will cause the cross frame to move relatively to the arm c , and the distance apart of the two "Emery" springs being 0.3 inch, while the horizontal length of c is 7 inches, there is a resultant exaggeration of the cube's compression, at the centre dots, of about twenty-three fold. Resting by means of needles in the two centre dots is a pointer h , whose length is one hundred times the distance between the two needles; the end of the pointer as it moves over the scale has, therefore, a motion one hundred times as great as that of the centre dots relatively to one another, or magnifies between 2,300 and 2,400 times the compression of the cube. By the system of springs used throughout in the construction, and the lightness of all the parts the Author believes that all backlash has been eliminated, and the gear is extremely sensitive; it also accommodates itself to any inequalities in the pressure. The actual magnification was determined by testing it against the laboratory standard gear on a piece of cast-iron prepared for the purpose. It proved to be 2,358 times. This calibration gave also an opportunity of testing its delicacy and accuracy before using it with the stone cubes.

The method of carrying out the tests was as follows: a load was applied sufficient to keep the specimen with the gear attached in its position in the machine between the dies, and the corresponding scale reading was taken as zero; this load varied from 250 lbs. to 1000 lbs. per square inch. This plan was adopted to prevent any possibility of derangements of the gear by shocks, in putting on and off the load, such as might occur if the pressure had been entirely removed, and it was easy to let back the load to these amounts when taking sets. The loads were then increased gradually by 250 lbs., 500 lbs., or 1,000 lbs. per square inch at a time according to the strength of the stone, and each time readings of the position of the pointer on the scale taken, till the highest load it was desired to apply was reached; the load was then let back to the starting load, and the permanent set measured. A fresh set of observations was then made with this new zero, the same method of procedure being followed. In a few cases still further series of readings were made; but as, in most cases, the additional permanent set produced by the second application of the load was extremely small, these additional series were not made unless something anomalous had occurred.

The results are given in columns 8, 9, and 10. The coefficient

of elasticity was calculated for both series of readings from the definition that the coefficient = $\frac{\text{stress}}{\text{proportional strain}}$. Column 8 gives the result in all cases for the first set of readings, that is, when the compression for each increase of load consisted of two parts, an elastic and a permanent compression, the latter often forming a very considerable proportion of the observed strain; the coefficients are, therefore, those of the stone in its natural condition. Column 9 gives the result of the other set of readings, after the stone had been reduced, so to speak, to a state of ease; practically nearly all the strain for each increase of load being elastic, the coefficients are therefore for the state of ease. The tenth column gives the range of loading within which the specimens were tested, and, therefore, within which the coefficients apply, all the results being given in tons per square foot to correspond with the units used for the crushing-tests.

The stress-strain curves for some typical sandstones are given in *Figs. 4, 5, and 6*. For the first application of the load, the additional strain for each increment of load diminishes as stress increases, the curve is distinctly convex upwards, and on removal of load there is a large permanent set; on reloading, the curve still in general retains its upward convexity but much diminished, and in some cases the stone becomes almost perfectly elastic, stress and strain being strictly proportional. The figures given below as an example are the scale readings for 1198₃ Darley Top stone.

Stress.	Scale Readings and Sets.			
	First Loading. Differences.		Second Loading. Differences.	
Lbs. per Square Inch.				
500	0·0		0·0	
1,000	0·94	0·94	0·64	0·64
1,500	1·87	0·93	1·31	0·67
2,000	2·68	0·81	1·90	0·59
2,500	3·40	0·72	2·48	0·58
3,000	3·96	0·56	2·98	0·50
	Set 0·93		Set 0·0	
	Elastic 3·03		Elastic 2·98	

Note.—Unity = 0·0005 inch.

Some of the specimens have at first strain-increments gradually increasing up to a maximum, and then diminishing with further

Fig. 4.

Fig. 5.

Fig. 6.

12023 Lightcliffe Bed { A. First test.
B. Second test.
Plane of pressure parallel to bedding.
12024 Lightcliffe Bed { A. First test.
B. Second test.
Plane of pressure perpendicular to bedding.
Compressions measured on a length of $1\frac{1}{4}$ inch.

SANDSTONE. STRESS-STRAIN CURVES.

11983 Darley Top { A. First test.
B. Second test.
12003 Bramley Fall { A. First test.
B. Second test.
12053 Aspatria { A. First test.
B. Second test.

Compression measured on a length of $1\frac{1}{4}$ inch.

SANDSTONE. STRESS-STRAIN CURVES.

10873 Prudham { A. First test.
B. Second test.
11343 White Plean { A. First test.
B. Second test.
11403 Dean Forest { A. First test.
B. Second test.

Compression measured on a length of $1\frac{1}{4}$ inch.

SANDSTONE. STRESS-STRAIN CURVES.

Fig. 7.

10612 White Mansfield {A. First test.
(C. Third test.
10622 Red Mansfield {A. First test.
(F. Sixth test.
10652 Brown Weather- {A. First test.
Bed. {C. Third test.
11182 Yellow Magnesian Limestone {A. First test.

DOLOMITES, &c. STRESS-STRAIN CURVES.

Fig. 8.

10683 Doulting Fine Bed {A. First test.
(B. Second test.
10693 Doulting Chelvyndy {B. Second test.
Bed. {C. Third test.
10603 Ham Hill {A. First test.
(B. Second test.
10642 Ancaster Freestone A. First test.

LIMESTONES. STRESS-STRAIN CURVES.

Fig. 9.

10751 Monks Park {A. First test.
(B. Second test.
10781 Curgriff {A. First test.
(B. Second test.
10811 Westwood Ground {A. First test.
(B. Second test.

BATH-STONES. STRESS-STRAIN CURVES.

increase of loading, so that the curve is at first convex downwards, and then convex upwards; this is seen in some of the curves given in the figures. *Fig. 6* illustrates the different behaviour of two specimens of the same stone when tested in the one case with the plane of pressure parallel to, and in the other case at, right angles to bedding; the compression in the latter case is distinctly smaller, there being a marked difference of the two coefficients. The mean value of the coefficient for all the sandstones¹ is for the first test 108,040 tons per square foot, and for the second test 132,280 tons; expressed in lbs. per square inch, these figures are 1,680,600 and 2,057,700 respectively—that is, the stone is from fifteen to twenty times as compressible as steel.

Fig. 10.

GRANITE. STRESS-STRAIN CURVES.

Fig. 7 gives the curves for the magnesian limestones; they are of the same general character. Number 1061_{2c} shows very clearly the change of curvature at a load of 2,000 lbs. per square inch. The mean coefficients² are 254,500 and 321,000 tons per square foot respectively, showing the much denser character of these crystalline rocks. *Figs. 8 and 9* are the curves for typical oolites, again of the same general character. The marked difference between the softer Doulting bed and the harder Chelynch one, shown in *Fig. 8*,

¹ Except No. 1202, Lightcliffe.

² Including Ancaster Brown Weather Bed.

again illustrates the effect of the more compact arrangement due to the natural crystalline character. The mean values for the limestones (omitting 1059) are 133,530 and 150,750 tons per square foot; they are thus for the first test of nearly the same value as those for the sandstones in the state of ease.

The granites are illustrated by *Fig. 10*. The range of stress is of course much greater, but they also exhibit the above characteristics. Much less set was produced by the first loading; this is seen by the closer approximation of the two values of the coefficient of elasticity. The value of the coefficient is for the first test 479,000, and for the other test 522,100 tons per square foot, or in lbs. per square inch, 7,450,000 and 8,121,000 respectively, about a quarter of the corresponding values for steel.

The Author believes these figures will be of considerable interest and importance when the design of structures is being dealt with, where great weights have to be carried on foundations or by piers and columns, and as also affording data for calculating the stresses thrown upon masses of masonry by expansion and contraction due to changes of temperature. It had originally been intended to also deal with these constants by means of transverse tests, and to extend the inquiry into the transverse strength of some of the leading stones. Pressure of work has necessitated the postponement of this and a few other points, but it is proposed to undertake the inquiry very shortly. Enough has been done to show the value, necessity, and importance of systematic tests of stone when being used in large works. Engineers, who would never dream of employing iron and steel without careful tests, accept large quantities of stone without any form of test, trusting merely to a casual examination. Although stone is not subject to the imperfections and carelessness of manufacturing processes, still, like all natural substances, it varies greatly in quality, and hence the need of tests is just as great as in the case of manufactured articles.

The communication is accompanied by a series of diagrams, from which Plate 8 and the Figs. in the text have been compiled.

APPENDIXES.

APPENDIX A.—LIST OF QUARRIES, ETC.

Name of Stone.	Locality of Quarry.	Remarks.	Owner of Quarry.
Sandstones.			
Prudham . . .	{Fourstones, Hexham, Northumberland}	{Fine yellow stone, used in Heriot Watt College, The University, Edinburgh, &c.}	W. Benson and Co.
Corncockle . . .	{Lockerbie, Dumfriesshire}	{Fine red sandstone, slightly marked with black}	"
Gunnerton . . .	{Barrasford, Hexham, Northumberland}	{Second class, yellow rock}	Steel and Turner.
Cragg	{Woodburn, Bellingham, Northumberland}	{Very hard, fine grain, yellow rock}	"
Corsehill . . .	{Annan, Dumfriesshire}	{Fine red sandstone, very largely used}	{Corsehill Quarry Company.
Polmaise . . .	{Bannockburn, Stirlingshire}	{Very fine rock, white}	{Baird and Stevenson.
White Plean . . .	"	{Specimens were from hard beds, fine white rock}	Macmartin and Gowans.
Arbroath . . .	{Carmyllie Quarries, Arbroath, Forfarshire}	{Pavement rock, fine greenish rock}	Duncan, Falconer and Co.
Auchinlea . . .	{Cleland, Motherwell, Lanarkshire}	{Poor stone, easily wrought, coarse white}	T. Gibb and Sons.
Craigleith . . .	Edinburgh	{Very hard, grey white, extensively exported}	J. Pennycook and Son.
White Hailes . .	Slateford, Edinburgh	{White, dark bands, strong rubble stone for foundations, &c.}	R. Young, agent for proprietor.
Dean Forest . .	{Drybrook, Gloucestershire}	{Pavement beds fine yellowish green.}	T. Williams.
Gatelawbridge .	{Thornhill, Dumfriesshire}	{Fine red stone}	{W. Thomson and Sons.
Blue Hailes . . .	Slateford, Edinburgh	{Good for inside work, grey, with dark, clayey bands}	R. Young, agent for proprietor.
Binnie	{Binnie Quarry, Linlithgowshire}	{Formerly much used in Edinburgh, Scott monument, &c. Fine reddish grey}	M. Knight.

APPENDIX A.—LIST OF QUARRIES, ETC.—*continued.*

Name of Stone.	Locality of Quarry.	Remarks.	Owner of Quarry.
Sandstones—<i>continued.</i>			
Hermard . .	{ West Calder, Mid- lothian . . . }	{ Hard grey rock, much used in Edinburgh Museum, Calton Prison, &c. }	A. Colville.
Howley Park .	Morley, Leeds . .	{ Used for staircases, copings, &c., fine reddish grey . . }	Howley Park Quarry Com- pany.
Grinshill . .	{ Grinshill, Shrews- bury . . . }	{ Easy to work, fine grey white . . . }	{ Bridge and Cureton Quarry Com- pany.
Darley Top .	{ Dacre Banks, York- shire . . . }	{ Much used in Leeds, coarse red grey . . }	John Trickett and Co.
Hercules Ridge.	"	{ Bridge work, &c., coarse red brown . . . }	"
Bramley Fall.	"	{ Manchester ship canal works, &c., very coarse white . . }	"
Ackworth . .	{ Pontefract, York- shire . . . }	{ Much used for sills and coping work, light grey, fine grains }	J. Smith.
Robin Hood .	Wakefield, Yorkshire	{ Steps and landings, fine reddish brown . }	G. Armitage and Sons.
Aspatria . .	Cumberland . . .	Fine red sandstone .	H. Graves.
Lightcliffe .	{ Lightcliffe, Halifax, Yorkshire . . }	{ Paving, landings, steps, &c., very fine pale green . . . }	W. H. Bentley.
Dolomites, &c.			
White Mans- field . . .	{ Lindley Quarries, Mansfield, Not- tingham . . . }	{ Fine white siliceous dolomite . . . }	F. D. Lindley.
Red Mansfield	"	Fine light red . . .	"
Yellow Mag- nesian Lime- stone . . .	{ Mansfield Wood- house Quarry . . }	{ Fine, crystalline, yel- low, true dolomite . }	"
Anston . .	{ Kiveton Park, Shef- field . . . }	{ Stone used for Houses of Parliament, fine light yellow . . . }	James Turner and Son.
Limestones.			
Ancaster Brown Weather Bed Ragstone .	{ Ancaster Quarries, Grantham, Lin- colnshire . . . }	{ Coarse, crystalline, red brown . . . }	F. D. Lindley.

APPENDIX A.—LIST OF QUARRIES, ETC.—*continued*.

Name of Stone.	Locality of Quarry.	Remarks.	Owner of Quarry.
Limestones—<i>continued</i>.			
Ketton . . .	{ Stamford, Rutland- shire . . . }	White oolitic . . .	G. Hibbins.
Limestone . .	{ Banchory, Aber- deenshire . . . }	Causeway work; crys- talline.	
Portland . . .	Isle of Portland . .	White oolitic . . .	F. J. Barnes.
Corsham Down	Somersetshire . .	{ Oolitic rocks, white, verging towards cream . . . }	Bath Stone Firms, Limi- ted, Bath.
Farleigh Down			
Monks' Park .			
Box Ground .			
Coombe Down			
Corngrit . . .			
Stoke Ground			
Winsley Ground . . .			
Westwood Ground . . .			
Doulting . . .	{ Doulting Quarries, Shepton Mallet, Somersetshire . . }	White, oolitic, and semi-crystalline . .	Charles Trask and Sons.
Ham Hill . . .	{ Norton, Stoke- under-Ham, Som- erset . . . }	Reddish brown . . .	{ Ham Hill Stone Com- pany.
Ancaster Free- stone . . .	{ Ancaster Quarries, Grantham, Lin- colnshire . . . }	Cream	F. D. Lindley.
Granites.			
Penryn . . .	Penryn, Cornwall . .	Grey	{ West of Eng- land Granite Company.
Cornish Grey.	Cornwall	„ coarsish . . .	{ Whitehead and Sons.
Corrennie . .	Aberdeenshire . . .	Close-grained pink . .	{ John Fyfe, Aberdeen.
Cove	„	{ Pavement work; fine dark grey . . . }	
Kemnay . . .	„	{ Forth Bridge; fine whitish grey . . }	
Craigton . . .	{ Banchory, Aber- deenshire . . . }	Red, coarse	{ J. Littlejohn, agent for Sir R. Burnett.
Peterhead . .	Aberdeenshire . . .	„ „	{ Whitehead and Sons.
Dyce	„	Fine dark grey . . .	„
Hill of Fare .	„	Red, fairly coarse . .	„
Sclattie . . .	„	Fine grey-white . . .	„
Persley . . .	„	„ „	„
Rubislaw . . .	{ Aberdeen, Aber- deenshire . . . }	London Bridge; fine dark grey	{ Rubislaw Granite Com- pany.
Ben Cruachan	Argyleshire	Coarsish dark grey . .	{ Whitehead and Sons.

APPENDIX B.—TABLE GIVING CRUSHING STRENGTHS, ABSORPTION, DENSITY, COEFFICIENTS OF ELASTICITY, &c., OF BUILDING-STONES.

University College Laboratory Test Number.	Name of Stone or Quarry.	Crushing Load per Square Foot in Tons.		Density.	Weight of 1 Cubic Foot Lbs.	Absorption of Water.	Coefficient of Elasticity for Pressure.			
		Actual.	Mean.			PerCent. of dry Weight Ab- sorbed.	First Time Load Applied.	Re- applica- tion of Load.	Range of Stress.	
Sandstones.										
1,087 ₁	Prudham. Four- stones Quarry.	473·8		2·27	..	4·00	78,200	125,300	32·1 to 128·6	
1,087 ₂		393·8	..	2·30	..	..				
1,087 ₃		517·3	..	..	..	..				
1,122 ₁		454·2	..	..	142·5	4·32	91,960	109,200	32·1 to 192·8	
1,122 ₂		454·2	..	..						
1,146 ₁		408·5	..	2·31	..	..				
1,146 ₂		472·4	..	2·25	..	..				
1,146 ₃		468·2	455·3	..	..	..				
1,090 ₁	Corncockle	264·7 (a)	..	2·13	132·6	4·57	138,700	156,300	32·1 to 192·8	
1,090 ₂		399·4	..	2·12						..
1,090 ₃		487·3 (b)	383·8	..						..
1,091 ₁	Gunnerton	460·0	..	2·10	130·8	5·16	109,400	111,950	32·1 to 192·8	
1,091 ₂		315·8 (c)	..	2·09						..
1,091 ₃		288·0	354·6	..						..
1,092 ₁	Cragg .	388·7 (d)	..	2·19	136·1	4·13	124,800	153,300	32·1 to 192·8	
1,092 ₂		710·5	..	2·17						..
1,092 ₃		622·2	573·8	..						..
1,115 ₁	Corsehill .	417·5	..	2·24	130·4	7·94	101,600	121,000	32·1 to 192·8	
1,115 ₂		341·6 (e)	..	..						..
1,115 ₃		579·6	..	..						..
1,123 ₁		552·3	..	2·02	..					
1,123 ₂		454·2 (f)	..	2·01	..					
1,142 ₁		402·5	..	..	..					
1,142 ₂		388·0	..	..	..					
1,142 ₃		423·9 (g)	444·9	..	..					
1,121 ₁	Polmaise .	572·8	..	2·28	141·7	4·58	119,600	138,100	32·1 to 192·8	
1,121 ₂		571·9	..	2·26						..
1,138 ₁		517·2 (h)	..	..						..
1,138 ₂		526·3	..	..						..
1,138 ₃		569·5	551·5	..						..

(a) Cracked at 227 tons per square foot.

(b) From flag end of quarry.

(c) Cracked and then gave way.

(d) Mill-board used on one side only.

(e) Cracked at 288 tons per square foot.

(f) Cracked at 388 tons per square foot.

(g) Cracked at 380 tons per square foot.

(h) Cracked at 454 tons per square foot.

APPENDIX B.—TABLE GIVING CRUSHING STRENGTHS, ABSORPTION, DENSITY, COEFFICIENTS OF ELASTICITY, &c., OF BUILDING-STONES—*continued*.

University College Laboratory Test Number.	Name of Stone or Quarry.	Crushing Load per Square Foot in Tons.		Density.	Weight of 1 Cubic Foot Lbs.	Absorption of Water. PerCent. of dry Weight Ab- sorbed.	Coefficient of Elasticity for Pressure.		
		Actual.	Mean.				First Time Load Applied.	Re- ap- lica- tion of Load.	Range of Stress.
Sandstones— <i>contd.</i>									
1,134 ₁ 1,134 ₂ 1,134 ₃	W h i t e Plean .	631·0 (a)	..	2·21	138·2	{ 4·25	146,600	157,400	32·1 to 192·8
		569·5	..	2·22					
		637·9	..	2·22					
		612·8							
1,135 ₁ 1,135 ₂ 1,135 ₃	Arbroath .	512·5	..	2·44	151·0	{ 2·32	134,600	164,800	32·1 to 192·8
		628·3	..	2·40					
		533·6	..	2·40					
		558·1							
1,136 ₁ 1,136 ₂ 1,136 ₃	Auchinlee	189·8	..	2·09	128·9	{ 6·90	62,900	84,080	32·1 to 128·4
		190·6	..	2·04					
		230·5	..	2·04					
		203·6							
1,137 ₁ 1,137 ₂ 1,137 ₃	Craigleith	870·0 (b)	..	2·23	138·6	{ 3·61			
		900·8	..	2·21					
		815·0 (c)	..	2·21					
		861·9							
1,139 ₁ 1,139 ₂ 1,139 ₃	W h i t e Hailes .	621·6	..	2·32	143·8	{ 3·71	78,780	105,100	32·1 to 192·8
		682·5	..	2·29					
		682·0	..	2·29					
		662·0							
1,140 ₁ 1,140 ₂ 1,140 ₃	D e a n Forest .	475·4	..	2·43	151·4	{ 2·71	113,600	172,000	32·1 to 192·8
		520·4	..	2·42					
		594·1	..	2·42					
		530·0							
1,141 ₁ 1,141 ₂ 1,141 ₃	Gatellaw- bridge .	497·5	..	2·09	129·5	{ 5·84	143,600	168,100	32·1 to 192·8
		519·7	..	2·06					
		469·9	..	2·06					
		495·7							
1,143 ₁ 1,143 ₂ 1,143 ₃	BlueHailes	428·3	..	2·31	143·2	{ 4·70	54,290	86,960	32·1 to 128·4
		480·5	..	2·28					
		470·2	..	2·28					
		459·7							
1,144 ₁ 1,144 ₂ 1,144 ₃	Binnie. .	605·7	..	2·19	135·1	{ 5·22	124,200	152,300	32·1 to 192·8
		531·6	..	2·14					
		570·0	..	2·14					
		569·1							

(a) Cracked at 558 tons per square foot. Specimens are from hard beds.

(b) Carried this load for a few seconds.

(c) Cracked at 710 tons per square foot.

APPENDIX B.—TABLE GIVING CRUSHING STRENGTHS, ABSORPTION, DENSITY, COEFFICIENTS OF ELASTICITY, &c., OF BUILDING-STONES—*continued*.

University College Laboratory Test Number.	Name of Stone or Quarry.	Crushing Load per Square Foot in Tons.		Density.	Weight of 1 Cubic Foot Lbs.	Absorp- tion of Water. PerCent. of dry Weight Ab- sorbed.	Coefficient of Elasticity for Pressure.		
		Actual.	Mean.				First Time Load Applied.	Re- applica- tion of Load.	Range of Stress.
Sandstones—contd.									
1,145 ₁ 1,145 ₂ 1,145 ₃	Hermard .	496·8 445·0 430·5		2·30 2·27	142·6	{ 4·70 ..	150,100	191,900	32·1 to 128·4
		457·4							
1,196 ₁ 1,196 ₂ 1,196 ₃		Howley Park .	451·3 467·3 481·6						
	466·7								
1,197 ₁ 1,197 ₂ 1,197 ₃	White Grinshill		171·5 210·5 245·9		1·96 1·96 1·97	122·5	{ 7·80 ..	101,000	115,500
		209·3							
1,198 ₁ 1,198 ₂ 1,198 ₃		Darley Top	549·2 536·0 465·0		2·23 2·24 2·21				
	516·7								
1,199 ₁ 1,199 ₂ 1,199 ₃	Hercules Ridge .		323·5 397·1 286·6		2·22 2·24 2·17	138·0	{ 3·60 ..	154,200	171,200
		335·7							
1,200 ₁ 1,200 ₂ 1,200 ₃		Bramley Fall. .	218·9 246·6 249·6		2·11 2·11 2·13				
	238·4								
1,203 ₁ 1,203 ₂ 1,203 ₃	Ackworth		392·5 380·5 394·4		2·25 2·25 2·26	140·7	{ 5·00 ..	61,960	90,960
		389·1							
1,204 ₁ 1,204 ₂ 1,204 ₃		Robin Hood .	574·3 571·6 576·0		2·32 2·32 2·31				
	574·0								
1,205 ₁ 1,205 ₂ 1,205 ₃	Aspatia .		223·0 203·6 275·0		1·97 1·98 1·97	123·2	{ 8·50 ..	64,990	80,100
		233·9							

APPENDIX B.—TABLE GIVING CRUSHING STRENGTHS, ABSORPTION, DENSITY, COEFFICIENTS OF ELASTICITY, &c., OF BUILDING-STONES—*continued*.

University College Laboratory Test Number.	Name of Stone or Quarry.	Crushing Load per Square Foot in Tons.		Density.	Weight of 1 Cubic Foot Lbs.	Absorption of Water. PerCent. of dry Weight Ab- sorbed.	Coefficient of Elasticity for Pressure.												
		Actual.	Mean.				First Time Load Applied.	Re- applica- tion of Load.	Range of Stress.										
Sandstones— <i>contd.</i>																			
1,202 ₁ 1,202 ₂	Lightcliffe. Bed 3 .	1,090.0 960.2 (a)		2.39 2.39	149.6	2.30	Tons per Square Foot.	Tons per Square Foot.	Tons per Square Foot.										
1,202 ₃ 1,202 ₄		996.8 (b) 1,035.0 (c)		2.40 2.41							127,800 191,600	32.14 to 192.8 32.14 to 192.8							
Dolomites.																			
1,061 ₁ 1,061 ₂ 1,061 ₃ 1,116	W h i t e Mansfield	395.5 471.9 433.3 546.0		2.25 .. 2.24	140.1	5.01	209,800	235,600 (d)	32.1 to 256.8										
1,062 ₁ 1,062 ₂ 1,062 ₃ 1,117		537.8 642.8 573.5 (f) 613.6		2.30 .. 2.29						143.2	4.58	137,100	198,700 (e)	32.1 to 192.8					
1,063 ₁ 1,063 ₂ 1,063 ₃ 1,118 ₁ 1,118 ₂		383.7 570.2 557.7 (g) 671.8 703.8		 2.33 2.33											145.4	4.62	406,100	..	32.1 to 192.8
1,195 ₁ 1,195 ₂ 1,195 ₃		327.1 296.9 281.7		2.12 2.11 2.12															
1,065 ₁ 1,065 ₂ 1,065 ₃ 1,120	Ancaster Brown Weather Bed . .	626.4 510.1 492.8 581.3		2.50 2.51	156.3	2.42	289,700	499,800	32.1 to 192.8										
Limestones.																			

(a) Carried this load for a few seconds.

(b) Cracked at 942 tons per square foot.

(c) Cracked at 910 tons per square foot.

(d) Third application of load.

(e) Sixth application of load.

(f) Cracked at 531 tons per square foot, millboard interposed.

(g) Cracked at 508 tons per square foot.

(h) Third application of load.

APPENDIX B.—TABLE GIVING CRUSHING STRENGTHS, ABSORPTION, DENSITY, COEFFICIENTS OF ELASTICITY, &c., OF BUILDING-STONES—*continued*.

University College Laboratory Test Number.	Name of Stone or Quarry.	Crushing Load per Square Foot in Tons.		Density.	Weight of 1 Cubic Foot Lbs.	Absorption of Water. PerCent. of dry Weight Ab- sorbed.	Coefficient of Elasticity for Pressure.					
		Actual.	Mean.				First Time Load Applied.	Re- applica- tion of Load.	Range of Stress.			
							Tons per Square Foot.	Tons per Square Foot.	Tons per Square Foot.			
				Limestones— <i>contd.</i>								
1,180 ₁	{ Portland Base Bed. P. Quarry. }	296.0		2.21 2.20	137.6	{ 6.84 ..						
1,180 ₂		240.6	..									
1,180 ₃		324.4	287.0									
1,181 ₁	{ Portland Base Bed. R. Quarry. }	133.4		2.02 1.97	124.5	{ 11.10 ..						
1,181 ₂		147.6	..									
1,181 ₃		159.5	146.8									
1,182 ₁	{ Portland White Bed. . }	173.5		2.14 2.10	132.3	{ 7.51 ..	236,900	..	16.07 to 64.28			
1,182 ₂		211.6	..									
1,182 ₃		229.0	204.7									
1,201 ₁	{ Ketton . }	70.5	..	1.97 2.14 2.04	127.9	{ 8.10 ..	141,300	156,900	16.07 to 64.28			
1,201 ₂		128.4	..									
1,201 ₃		106.1	101.7									
1,206 ₁	{ Limestone (crystal- line) . }	888.2	..	2.81 2.81 2.78	174.7	..	61,980	116,000	16.07 to 64.28			
1,206 ₂		1,075.5	..									
1,206 ₃		905.0	956.2									
1,073 ₁	{ Corsham Down . }	128.6	..	2.11 2.05 2.04	..	..	72,460	..	16.07 to 64.28			
1,073 ₂		106.3	..							129.0		
1,073 ₃		93.5	(109.5)									
1,185 ₁		70.1	..			11.18						
1,185 ₂		74.2	94.5			11.06						
1,074 ₁	{ Farleigh Down . }	69.3	..	1.92 1.95 1.92	..	12.64 13.13	147,000	166,100	16.07 to 96.42			
1,074 ₂		63.9	..							120.5		
1,074 ₃		61.3 (a)	(64.8)									
1,186 ₁		58.1	..								8.31	
1,186 ₂		60.1	62.5							7.74		
1,075 ₁	{ Monk Park . }	172.0	..	2.18 2.17 2.22	..	8.31 7.74	147,000	166,100	16.07 to 96.42			
1,075 ₂		112.8	..							136.7		
1,075 ₃		150.5	(145.1)									
1,187 ₁		118.3	..									
1,187 ₂		144.4	139.6									

(a) Cracked and then gave way.

APPENDIX B.—TABLE GIVING CRUSHING STRENGTHS, ABSORPTION, DENSITY, COEFFICIENTS OF ELASTICITY, &C., OF BUILDING STONES—*continued*.

University College Laboratory Test Number.	Name of Stone or Quarry.	Crushing Load per Square Foot in Tons.		Density.	Weight of 1 Cubic Foot Lbs.	Absorp- tion of Water.	Coefficient of Elasticity for Pressure.		
		Actual.	Mean.			PerCent. of dry Weight Ab- sorbed.	First Time Load Applied.	Re- applica- tion of Load.	Range of Stress.
Limestones—contd.									
1,076 ₁	B o x Ground.	88·4	..	1·99	..	..	138,700	129,200	16·07 to 64·28
1,076 ₂		95·9	..	..	127·9	7·49 8·10			
1,076 ₃		81·9 (a)	(88·7)	..					
1,188 ₁		126·1	..	2·11					
1,188 ₂		95·1	..	2·05					
			97·5						
1,077 ₁	C o o m b e Down .	151·2	..	..	128·6	{ .. 5·80 6·19			
1,077 ₃		141·5 (a)	(128·7)	..					
1,189 ₁		93·3	..	..					
1,077 ₂		94·9	..	2·06	..				
1,189 ₂		107·5	..	..	..				
			117·7						
1,078 ₁	Corngrit .	172·4	..	2·10	..	..	243,700	243,700	16·07 to 96·42
1,078 ₂		136·0	..	..	133·6	8·72 9·04			
1,078 ₃		112·8 (a)	(140·4)	..					
1,190 ₁		144·0	..	2·18					
1,190 ₂		107·3	..	2·14	..				
			134·5						
1,079 ₁	S t o k e Ground.	96·4	..	2·02	..	..	109,300	..	32·14 to 80·35
1,079 ₂		93·4	..	..	126·3	11·14 10·55			
1,079 ₃		106·7 (b)	(98·8)	..					
1,191 ₁		83·1	..	2·00					
1,191 ₂		70·4	..	2·05	..				
			90·0						
1,080 ₁	Winsley Ground.	114·9	..	2·11	..	..	164,000	..	16·07 to 96·42
1,080 ₂		104·9	..	..	132·9	{ 7·74 7·74			
1,080 ₃		100·7 (a)	(106·8)	..					
1,192 ₁		85·2	..	2·13					
1,192 ₂		98·0	..	2·15	..				
			100·7						
1,081 ₁	Westwood Ground.	118·5	..	2·08	..	..	62,300	128,900	16·07 to 64·28
1,081 ₃		140·4	..	..	130·3	8·59 9·12			
1,081 ₂		109·5	(122·8)	..					
1,193 ₁		89·7	..	2·10					
1,193 ₂		93·0	..	2·08	..				
			110·2						

(a) Cracked and then gave way.

(b) Cracked at 100 tons per square foot.

APPENDIX B.—TABLE GIVING CRUSHING STRENGTHS, ABSORPTION, DENSITY, COEFFICIENTS OF ELASTICITY, &c., OF BUILDING STONES—*continued*.

University College Laboratory Test Number.	Name of Stone or Quarry.	Crushing Load per Square Foot in Tons.		Density.	Weight of 1 Cubic Foot Lbs.	Absorption of Water. Per Cent. of dry Weight Ab- sorbed.	Coefficient of Elasticity for Pressure.																					
		Actual.	Mean.				First Time Load Applied.	Re- ap- plication of Load.	Range of Stress.																			
Limestones-- <i>contd.</i>																												
1,082 ₁ 1,082 ₂ 1,194 ₁ 1,082 ₂ 1,194 ₂	Westwood Ground (fluated)	124.8 106.6 (a) 103.1 82.1 118.2	(111.5) 106.9	 2.12 ..	132.3	8.46 7.61																						
1,058 ₁ 1,058 ₂ 1,053 ₃ 1,183 ₁ 1,183 ₂		Doulting Fine Beds								117.4 101.7 115.7 103.5 81.3	(111.6) 103.9	2.04 1.98 1.99	125.0 10.70 11.05	97,580	121,000	32.14 to 80.35												
1,059 ₁ 1,059 ₂ 1,059 ₃ 1,184 ₁ 1,184 ₂										Doulting Chelynoch Bed							134.9 157.4 209.3 211.6 190.7	2.42 2.40 180.8	150.4 3.30	357,600 (e)	379,000	32.14 to 112.49						
1,060 ₁ 1,060 ₂ 1,060 ₃																	Ham Hill						133.8 (b) 157.7 (c) 207.5 (d)	2.18 166.3	136.0 6.27	140,600	164,500	32.14 to 112.49
1,064 ₁ 1,064 ₂ 1,064 ₃ 1,119																							Ancaster Freestone					
Granites.																												
1,088 ₁ 1,088 ₂ 1,089 ₁ 1,089 ₂ 1,089 ₃	West of England. Penrhyn	1,285.9 808.7 (g) 1,010.9 1,087.2 1,108.3	 1,060.2	 2.65 165.4	0.12 0.12																							
1,112 ₁ 1,112 ₂ 1,112 ₃		Cornish Grey							911.6 928.2 1,028.0	2.59 161.7 ..	463,500	538,300	64.3 to 514.3															

(a) Cracked at 99.8 tons per square foot.

(b) Yellow Bed.

(c) White Bed.

(d) White Bed.

(e) Second application of load.

(f) Millboard used.

(g) Cracked at 713 tons per square foot, not well bedded.

APPENDIX B.—TABLE GIVING CRUSHING STRENGTHS, ABSORPTION, DENSITY, COEFFICIENTS OF ELASTICITY, &C., OF BUILDING-STONES—*continued*.

University College Laboratory Test Number.	Name of Stone or Quarry.	Crushing Load per Square Foot in Tons.		Density.	Weight of 1 Cubic Foot Lbs.	Absorp- tion of Water.	Coefficient of Elasticity for Pressure.					
		Actual.	Mean.			Per Cent. of dry Weight Ab- sorbed.	First Time Load Applied.	Re- applica- tion of Load.	Range of Stress.			
Granites—contd.							Tons per Square Foot.	Tons per Square Foot.	Tons per Square foot.			
1,097 ₁ 1,097 ₂	Aberdeen- shire. Corennie	1,224.9 (a)	..	2.61	162.9	0.38	523,600	540,700	64.3 to 514.3			
		1,243.6 (b)	..									
		1,234.3										
1,108 ₁ 1,108 ₂ 1,108 ₃		1,098.0	..	2.55	159.1	0.42						
	1,440.0 (c)	..										
	1,417.0 (d)	..										
	1,318.3											
1,098 ₁ 1,098 ₂ 1,098 ₃	Aberdeen- shire. Cove	1,024.4	..	2.71	169.1	0.55						
		1,023.0	..									
		914.0	..									
		987.1										
1,099 ₁ 1,099 ₂ 1,099 ₃	Aberdeen- shire. Kemnay	961.9 (e)	..	2.63	164.1	0.42						
		1,017.8	..									
		1,285.8 (c)	..									
		1,088.5										
1,104 ₁ 1,104 ₂ 1,104 ₃		1,183.0	..	2.58	161.0	0.21						
		1,173.3 (f)	..									
		1,277.0	..									
		1,211.1										
1,101 ₁ 1,101 ₂ 1,101 ₃	Aberdeen- shire. Craigton	1,182.0	..									
		1,348.0	..									
		1,316.0	..									
		1,282.0										
1,102 ₁ 1,102 ₂ 1,102 ₃	Aberdeen- shire. Peterhead	973.0	..	2.54	158.5	0.29	644,000	657,000	64.3 to 514.3			
		1,345.0	..									
		1,305.0	..									
		1,207.7										
1,103 ₁ 1,103 ₂ 1,103 ₃	Aberdeen- shire. Dyce	908.4	..	2.65	165.4	0.19				587,600	621,400	64.3 to 514.3
		1,156.0	..									
		1,253.0	..									
		1,105.8										

(a) Removed from machine unbroken, but cracked.

(b) Removed from machine unbroken, but badly cracked,
put in again and crushed up.

(c) Carried load for a few seconds, and then crushed.

(d) Cracked at this load,
and one side broke off only.

(e) Millboard interposed on one side.

(f) Cracked slowly and then gave way.

APPENDIX B.—TABLE GIVING CRUSHING STRENGTHS, ABSORPTION, DENSITY, COEFFICIENTS OF ELASTICITY, &c., OF BUILDING-STONES—*continued*.

University College Laboratory Test Number.	Name of Stone or Quarry.	Crushing Load per Square Foot in Tons.		Density.	Weight of 1 Cubic Foot Lbs.	Absorption of Water.	Coefficient of Elasticity for Pressure.		
		Actual.	Mean.			Per Cent. of dry Weight Ab- sorbed.	First Time Load Applied.	Re- application of Load.	Range of Stress.
Granites—contd.							Tons per Square Foot.	Tons per Square Foot.	Tons per Square Foot.
1,106 ₁	{ Aberdeen- shire. Hill of Fare }	1,278.0	..	2.57	160.4	0.40	381,000	460,400	64.3 to 385.7
1,106 ₂		1,402.9 (a)							
1,106 ₃		1,400.0 (b)							
			1,360.3						
1,109 ₁	{ Aberdeen- shire. Sclattie }	651.2	..	2.58	161.0	0.10	266,000	321,700	64.3 to 257.1
1,109 ₂		978.0							
1,109 ₃		922.2							
			850.5						
1,111 ₁	{ Aberdeen- shire. Pers- ley grey }	826.6	..	2.60	162.3	0.19	522,300	..	64.3 to 514.3
1,111 ₂		1,027.4							
1,111 ₃		974.4							
			942.8						
1,113 ₁	{ Aberdeen- shire. Rubislaw }	1,148.0	..	2.64	163.7	0.09	445,000	525,200	64.3 to 385.7
1,113 ₂		915.0							
1,113 ₃		1,233.5							
			1,098.8						
(c) 1,207 ₁	{ Rubislaw }	1,303.0	..	2.62	163.7	..	445,000	525,200	64.3 to 385.7
1,207 ₂		1,334.0							
1,207 ₃		1,232.0							
			1,289.7	2.62					
1,105 ₁	{ Ben Cruachan }	1,008.0	..	2.75	171.6	0.29			
1,105 ₂		855.8							
1,105 ₃		766.8							
			876.9						

(a) Removed from machine unbroken. (b) Carried this for a few seconds, and then crushed.

(c) Obtained from rock 177 feet beneath the surface.

Fig : 1.

SIDE ELEVATION.

Fig : 2 .

END ELEVATION.

Fig : 3.

P L A N .

Scales; 1/2 of Full Size.