REPORT ON THE COMPRESSIVE STRENGTH, SPECIFIC GRAVITY, AND RATIO OF ABSORPTION OF THE BUILDING STONES IN THE UNITED STATES

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Trieste

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COMPRESSIVE STRENGTH, SPECIFIC GRAVITY,

AND

RATIO OF ABSORPTION

OF THE

BUILDING STONES

IN THE UNITED STATES,

BY

Q. A. GILLMORE,

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OFFICIAL REPORT TO THE CHIEF OF ENGINEERS, U. S. ARMY.

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1876.

UNITED STATES ENGINEER OFFICE,
New York, August 10, 1875.

GENERAL: I have the honor to state that my tests to determine the compressive strength, specific gravity, and ratio of absorption of the building-stones in the United States in most general use have been considerably extended since my report of July 30, 1874. The methods pursued and the results obtained, inclusive of those first reported, are embodied, and to some extent discussed, in the paper herewith submitted.

My assistant, Mr. Louis Nickerson, had immediate charge of all the experiments and tests made during the past year, and I am indebted to him for valuable suggestions and zealous co-operation during the progress of the work.

Very respectfully, your obedient servant,

Q. A. GILLMORE,
Lieut. Col. of Engineers, Bvt. Maj. Gen., U. S. A.

Brig. Gen. A. A. HUMPHREYS,
Chief of Engineers, U. S. A.

REPORT.

FORM OF SPECIMENS AND METHOD OF TESTING.

Many of the specimens were delivered from the quarries in the form of cubes, measuring 2 inches each way, but the greater part have been wrought into form at Fort Tompkins. The desire has been to get average specimens, rather than to have the quarries picked for fine pieces, and it is thought that the attempt has been in general successful. Each cube was placed between two cushion-blocks of soft pine wood, 2 inches by 2 inches square, and slightly* more than $\frac{1}{4}$ inch in thickness, one on the top and the other under the bottom; the grain of the wood being parallel in each to the other—though no difference was observed when this was changed, as regards amount of record. This arrangement caused the pressure to come more gradually upon the stone, and the cushions, becoming much indurated by the effects of pressure, to some extent took the place of the mortar used in actual building.

For iron and wood, Hodgkinson has shown that trial specimens should be at least one and one-half times as high as the width of bed; but stone, except when used as columns, is usually laid of less height than bed, and the cubical form of specimens adopted for the experiment affords sufficient security for the angular breakage which he proved to be necessary for a true result. This latter fact is corroborated by subsequent experiments.

The cubes recorded in the general tables were brought to a true, smooth, and regular, but not a polished, surface. The granites and marbles, however, embraced in the tables under the head of "Sundry special experiments," were carefully rubbed down to the border of a polish, because in these great homogeneity and fineness, especially of bed-surface, was rather desired than the true building-strength of the stone. This latter plan undoubtedly increased the resistance. It is not, however a *high* valuation that we want for the general table, but a safe one; and, moreover, we desire to arrive at some knowledge of the resistance which the rock will have when applied in the usual manner in a wall. The mode used would seem to yield the truest answer to the experimental inquiry. Sandstones, of course, having no polish, give no difference of result from this cause. It must also be remembered that the general tables seek as nearly as possible to give the average strength of the average stone from any particular quarry, while the "Sundry special experiments," having been made with carefully picked stones, will give higher results from that cause. There may be some exception to the last remark in the East Chester marble, but, if so, that is believed to be the only one.

Each specimen of all the kinds was carefully prepared by an expert stone-cutter, and the bed-side marked. These were then placed upon a table near the hydrostatic-press, used in such a manner as to mix them completely, and so prevent any inadvertent choice being made when they were picked up. They were there examined, squared, measured, and calipered, and then tested on bed or edge, under steel, wood, lead, or leather, as the routine prescribed. When placed in the press, each specimen was carefully centered to the axial line of pressure, and the power applied neither fast nor slow, but steadily. The records were not attempted to be made exact within 500 pounds—equal to 125 pounds per square inch on 2-inch beds and over. On smaller specimens than 1-inch cubes 100 pounds was made the limit of error.

The weight of the movable parts of the press, with its attendant friction and the pump-stroke—about 800 pounds in all—is to be subtracted from the records in the general tables, or 200 pounds per square inch. The subject of friction is discussed under the head of "Testing the press and gauges."

GAUGES.

The press is supplied with two gauges, one indicating the pressure up to 100,000 pounds; the other to only 5,000 pounds. Both are connected by pipes with the lower end of the cylinder of the ram. Both gauges may be used simultaneously until the capacity of the 5,000-pound gauge is exhausted, when its connection with the cylinder is shut off by a little valve worked by a hand-wheel. Generally, in testing stones, the lighter gauge is not used.

To check the working of the 100,000-pound gauge next to the press, another gauge of similar capacity was employed as a test-gauge. It is attached to the connecting-pipe, near to the pump. These gauges were manufactured in the city of New York, on a modified arrangement of Bourdon's principle.

THE BREAKAGE OF STONE.

The diagram accompanying this report shows sketches of eight samples of stone. The first one, named homogeneous stone, is imaginary, and represents the general form of breakage of many sandstones and saccharine marbles. The separate pieces shown are such as are usually picked up after breakage, although with other varieties of stone they are generally more angular. The other sketches of stone represent samples actually tested and broken. The numbers given with each ot them correspond with those in the tables. The position of the cube when tested is also stated, whether it was placed on "bed" or on "edge."

Considering the infinitely-varied composition and character of all kinds of rock, it may be said that no material is less calculated to permit the establishment of special laws by a general form of breakage. It may be safely assumed, however, that more numerous and extended experiments, carefully and patiently conducted, will ultimately lead to the development of certain general laws relating to the behavior of stones under pressure, a knowledge of which will be most useful to the engineer and builder.

Homogeneous stones seem, in most cases, to break in the following manner, (see Plate I:) The forms of fragments *a* and *b* are approximately either conical or pyramidal, according as the stone is friable and of obviously granular structure, like sandstone and a few kinds of marble and granite, or compact, such as the true limestones and most marbles and granites. The more or less disk-shaped pieces *c* and *d* are detached from the sides of the cube with a sort of explosion, flying off in a more or less intact condition. In *e* and *f*, the stone is generally found crushed and ground to powder by the attrition of the larger fragments. Of course, this general result is modified by the nature and quality of the grain in the stone, and those other causes of irregularity which leave no two cubes of the same strength and condition, although they may have been cut directly apart from each other.

This form of breakage occurs also in non-homogeneous stones broken on bed; but it must be remembered that here the modification must be taken into account which "grain" produces as against homogeneity, rendering the object liable to split in rectangular fragments. This frequently lengthens the cone or pyramid in stones on bed, and causes those set on edge to actually split in rectangular disks; the style of splitting being, of course, irregularly modified for different specimens. Sand-cracks, &c., in stones have also their influence in directing the pressure; even the difficulty of determining the bed in some stones, after being cut, may be a source of errors.

SPECIFIC GRAVITY.

The stones whose resistance to crushing-pressure had been tested were also experimented upon in relation to their specific gravity. In the course of these investigations, it was sometimes necessary to be content with rather small fragments of stone, of not more than 15 to 18 pennyweight; but generally they weighed from one to two ounces.

On commencing this part of the work, some doubt was felt in regard to the best means of obtaining the correct displacement of porous stones; and all stones are more or less porous. It appeared evident that in weighing the stone first in air and then in water an error would be committed by saturation. The first idea, to give the stone a coating of thin varnish, was abandoned, because, although the pellicle would be thin, yet no means could be taken to know precisely what its thickness was, or what it amounted to in its effects. The second idea, to soak the stone in very fluid resin, the pellicle to be washed from the surface before dry, was given up, because it was desirable to preserve the specimens intact for experiments on freezing and other tests.

The plan finally adopted was, first, to remove from the stone all loose particles, and round off all sharp corners and edges, bringing it, in fact, practically to that condition commonly known as water-worn. It was then carefully weighed in air, immersed in water, and allowed to remain there until all bubbling had ceased, and its weight taken. It was then taken out of the water and weighed again, in its saturated condition, with the precaution of previously denuding the stone of superabundant water, by being compressed lightly in bibulous paper. The specific gravity is now found by dividing the weight of the stone, when perfectly dry, by its weight in the air after having been saturated, *minus* its weight in water.

This may also be expressed by the formula—

$$\text{Specific gravity} = \frac{W}{W_{\prime\prime} - W_{\prime}}$$

W representing weight of dry stone in air; $W_{\prime\prime}$ representing weight of saturated stone in air; $W_{\prime}$ representing weight of stone immersed in water.

In determining the specific gravity of stone, the weight of water was assumed to be 62½ pounds per cubic foot.

RATIO OF ABSORPTION.

The term "ratio of absorption" simply expresses the weight of water absorbed by the stone as compared with the weight of the dry stone; that is, if the stone when dry weighs 300 units, and the column of "ratio of absorption" shows the fraction $\frac{1}{300}$, it means that, by immersion in water, the stone will absorb 1 unit of it, weighing 301 units immediately after its removal from the water.

The method adopted for ascertaining the specific weight of stone furnished at the same time the means to determine the "ratio of absorption." The weight of the saturated stone minus the weight of the dry stone gives, as a result, the amount of water absorbed. This might, perhaps, more correctly be called the "avidity of absorption," since it was limited to the period of bubbling. Some few stones, having been kept immersed in water for several consecutive days, showed a slight increase in weight.

Since the capacity of a stone to absorb water has much influence on its durability, even during the warm season, and far more so in cold weather, the addition to the tables of this column was deemed advisable.

TESTING THE PRESS AND GAUGES.

It was deemed essential that the accuracy of the gauge records should be verified, and that the law under which friction was developed under varying pressure should be ascertained for the instruments actually used in testing the several kinds of stone, viz, Hoe's hydrostatic press, and Willing & Co.'s gauges.

Two gauges were used. One of them, of 500 pounds capacity, was extremely sensitive; so much so that besides other useful results, it accurately indicated the power used in lifting and working the unloaded ram, leaving only the efficient power and friction to be accounted for or measured. The other and larger gauge has a capacity of 100,000 pounds.

From careful experiments made by Mr. J. Hicks, civil engineer, of Bolton, England, on rams of 4-inch and 8-inch diameter, it appears that the friction of a 4½-inch ram—the one used in these trials—is about nine-tenths of 1 per cent. of the total pressure.

Assuming the law of the increase of friction to have been definitely ascertained by these experiments for hydraulic presses generally, it was thought best to make some special trials with the one in use. These were several times repeated with approximately corresponding results.

They were conducted in the following manner: It had been repeatedly noticed that small cubes of Michigan pine, when placed in the press and crushed against the grain, gave very uniform results. One-inch cubes, for instance, cut from the same piece side by side, crushed suddenly at from 5,800 to 6,000 pounds pressure. An average obtained with 1-inch cubes of pine crushed separately was thus established.

It was further ascertained by trials that sets of 2, 3, 5, 10, 15, 16, or 18 1-inch cubes of the same material, placed in the press in succession, the cubes in each case being set side by side, though not within lateral supporting-distance of each other, gave proportional results—that is, the aggregate crushing pressure divided by the number of cubes, gave the average crushing strength obtained with the single cube, within a reasonable limiting error of, say, 500 pounds for large numbers. All the cubes in each set crushed suddenly and together. Several repetitions of this experiment gave similar results. It was also tried with 2-inch and with 3-inch cubes, the aggregate crushing resistance—friction, of course, included—being always proportional to the number of cubes simultaneously crushed. The results of the more exact experiments of Mr. Hicks were therefore corroborated, that the resistance from friction must have been a constant percentage of the power employed, and not, as has been sometimes supposed, a differential increase. Indeed, this last-named hypothesis could not possibly obtain under the known laws of friction unless abrasion should set in between the lubricated leather packing and the copper lining at between 1 pound and 6,000 pounds pressure per square inch. These were examined after a year's time, during which the entire power of the ram up to 100,000 pounds—equal to 6.290 pounds per square inch—had been repeatedly used. The leather was found to be natural and the copper glazed. Abrasion therefore had not taken place.

There appears to be a singular and unfounded prejudice against the use of gauges for recording pressures, due apparently to the fact that several having proved incorrect, when properly tested, the results have been more or less widely advertised; while the true instruments, constituting a very large majority of those in actual use, have remained unnoticed. It is unnecessary to say the same rule would banish the yard-stick and the pound-weight from existence, the first being often too short, and the latter too light.

The three principal kinds of gauges are the *spiral-spring* gauge, the *diaphragm-spring* gauge, and the one used in all the experiments and tests herein recorded, known as the *tubular-spring* gauge. Its essential and characteristic feature is the tubular spring made of fine cast-steel, carefully bored, bent, tempered, and tested. The bending of course changes its original circular section to an elliptical one. As the fluid is forced into this, the greater pressure in the direction of the minor axis tends to change its sectional form toward the circle, as the figure of greatest capacity, which of course it can never reach until it becomes straight as at first, but which it approaches as the pressure increases, growing straighter at the same time. It is this straightening of the spring which works the gearing and revolves the index-hands.

The fact that this simple instrument can be made to register correctly upon a graduated dial, is full proof of the great delicacy of which it is capable. It has certain advantages over the beam-scale for large pressures in this, that while the beam may be very correctly graduated for any ratio, say 1 to 100, and be very perfect for comparatively low pressures, yet it depends upon knife-edges, which, when we have raised our power, say