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PHYSICAL PROPERTIES OF THE PRINCIPAL COMMERCIAL LIMESTONES USED FOR BUILDING CONSTRUCTION IN THE UNITED STATES

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By D. W. Kessler and W. H. Sligh

ABSTRACT

This paper is devoted mainly to the physical properties of the limestones used in this country for building purposes. Determinations of the strength of these materials in compression, flexure, and shear have been made, as well as a few measurements of tensile strength. In general, these properties were determined both perpendicular and parallel to the bedding. Compressive strengths have been determined also in the wet and dry conditions. Impact tests were made, since it is believed that the resistance to impact affords some information as to whether a material will be easily defaced in those parts of structures which are subjected to accidental blows. Elasticity measurements have been made on the materials in compression and in flexure, the latter determination being made mainly to compare the results obtained by the two methods. Permeability tests on some of the specimens in connection with absorption and porosity tests have afforded considerable information on the internal structure of the different materials. A series of continuous-load tests on specimens in compression and specimens in flexure have given some evidence that these materials are weakened to a slight extent under continual stress. A study of the expansion of limestone for various temperatures up to 300° C. indicates a low rate of expansion for the lower temperatures, but the rate increases as the temperatures increase. On lowering the temperature from 300 to 20° C. contraction is less than the expansion on heating; that is, the original length is not reached on cooling. The average coefficient of expansion for several specimens of oölitic limestone measured between 20 and 50° C. was found to be 0.000005 per degree C. A discussion of the probable effects on the stone facing of steel-frame buildings due to differential expansions is made. Considerable time has been devoted to the study of discolorations on limestone masonry and the relative staining qualities of different limestones. The nature, causes, and effects of efflorescence on limestone masonry has been given consideration. The disintegration effect, although manifesting itself in a different manner, has been found to be more serious in many cases than frost action. An extensive series of freezing tests has been made to determine the relative resistance of the various materials to frost action. In these tests an effort has been made to simulate more closely the actual conditions of frost action in buildings. A radical departure has been made in these tests from methods usually followed. Instead of determining the effect of a few freezings on the strength, the freezing and thawing process was continued to the point of destruction. Artificial weathering tests have been studied in this connection, but the results of such tests do not appear to be comparable with freezing tests or to afford a reliable indication of weathering qualities. Chemical effects of the elements have been studied mainly by observations on buildings. This action is so slight as to be inappreciable except where delicately carved limestone is freely exposed, in which case the figures may gradually lose their sharp lines. The limestones from the different quarry regions have been briefly described as to general characteristics in Chapters XXII to XXIX. These descriptions have been supplemented by lists of important structures in which the materials have been used.

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I. INTRODUCTION

This report is a part of a general investigation dealing mainly with the physical properties of building stone. The materials studied are those now in use, some of which have a wide distribution and others which are produced mainly for local demands.

The usual tests for strength, absorption, density, etc., have been supplemented with studies of a few problems of interest in connection with the use of stone. Information on elasticity, permeability, shearing strength, discoloration, and weathering qualities of limestone was obtained which has not heretofore been generally available. Considerable attention has been given to the last two mentioned subjects, since much interest has been recently manifested in these by many concerned in the use of limestone. An investigation of the behavior of limestone under continuous stress is in progress, and some of the available results have been included in this report. A study of efflorescence and its effects on limestone has been made in the laboratory, and several cases of efflorescence on buildings have received attention in this connection. Some information of interest concerning the thermal expansion of limestone has been developed which tends to indicate that for ordinary seasonal temperatures the coefficients usually given in text and handbooks are too high. Also, the unit weights of limestone often cited are found to be much too high for the greater portion of the material now on the market.

Physical data contained in Tables 2 to 14 were determined in the laboratories of the Bureau of Standards on samples submitted by the various producers of limestone. The greater portion of the chemical data and information relating to the quarry regions were obtained from State geological reports and other available sources. Range values cited for various physical properties on different types of natural stone were taken from the journals or wherever the information could be found, and many of these relate to materials from foreign countries. Lists of buildings exemplifying the use of the various limestones were supplied by the producers and supplemented as far as possible by references in the trade journals, State reports, etc.

A considerable amount of data on the shearing strength, elasticity, etc., of Indiana limestone was supplied by H. H. Dutton, research associate at the Bureau of Standards, for the Indiana Limestone Quarrymen's Association. Mr. Dutton also designed the apparatus for making punching, shear, and continuous load tests. For such chemical determinations on limestone as were made at this bureau credit is due to E. H. Berger and F. W. Smither. Thermal expansion measurements were made by W. H. Souder and Peter Hidnert. The authors wish to express their appreciation to G. F. Loughlin, of the United States Geological Survey, and Oliver Bowles, of the United States Bureau of Mines, for assistance in collecting test samples, and many useful suggestions in conducting the tests.

II. SAMPLES FOR TESTING

The selection of samples for testing was in most cases done by the producers. They were requested to select only materials that would be representative of their average product. In some cases where two or more types or grades were produced from the same quarry a sample of each was submitted. While this means of obtaining samples is not free from fault, it is, in fact, the only feasible way of securing them. Unfortunately, samples from several limestone deposits of interest could not be obtained, hence the report is not as complete as could be desired.

III. PREPARATION OF SPECIMENS

The samples each contained about 2 cubic feet of stone from which the specimens for the different tests were prepared by sawing, coring, and grinding. Figure 1 shows the saw used which is equipped with carborundum tooth insert wheels and carborundum rim wheels. The tooth wheel was used for cuts more than 6 inches deep and the rim wheel mainly for the lighter work.

The core drill used in preparing the cylindrical specimens for compression, absorption, and specific gravity tests is shown in Figure 2. It is a three-spindle drill press equipped with specially designed grit feeders. The core cutters are made of thin steel tubing mounted in a head which has a circular groove in the top and several small holes leading to the inside. The dry abrasive is fed into this groove and

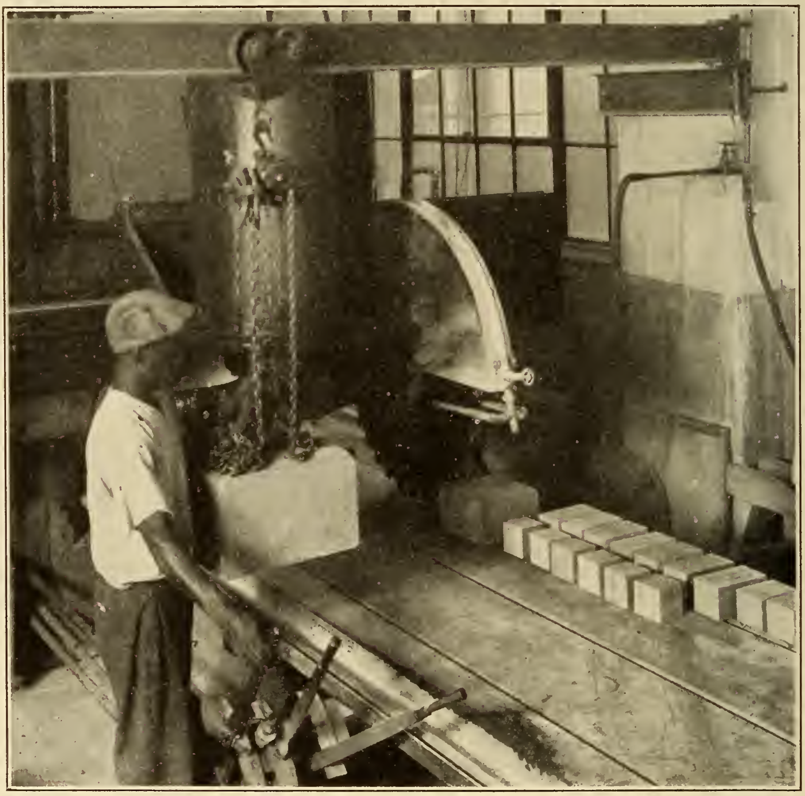

FIG. 1.—*Machine used for preparing test specimens*

carried down inside the tube by a small stream of water. A weighting device allows any desired pressure to be applied to the cutter, which when once started requires very little attention. This device has been found much more economical and more feasible for the purpose than diamond-core drills.

For the compressive tests it is necessary to dress the ends of the cores down to parallel surfaces. Two means were used for this purpose. One consisted of grinding each specimen separately by hand and determining the parallelism with calipers. A method later found to be more satisfactory consisted in mounting a group of specimens in a metal frame with plaster of Paris, as shown in Figure 3. Then the cast was finished on a surface grinder of the type which has an oscillating table to which the cast is attached and has a small emery wheel above. The table is shifted laterally a small amount after each cut until the entire surface is worked down to a plane. When both surfaces of the cast are planed in this way the specimens are broken loose from the plaster. It was found that a mixture of equal parts of hydrated lime and plaster of Paris was strong enough

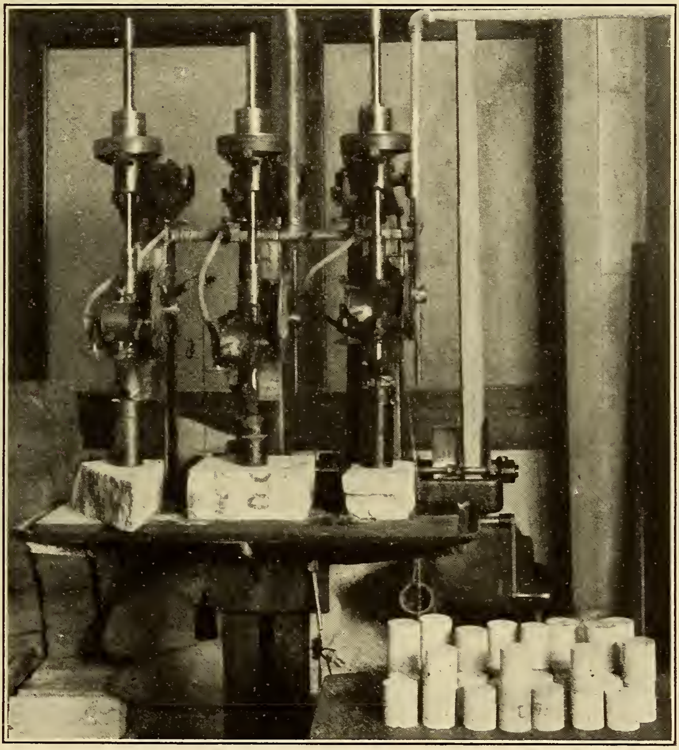

FIG. 2.—*Three spindle core drill for cutting cylindrical specimens*

to hold the specimens and permitted an easier separation when finished.

The prisms used for compressive elasticity tests and the slabs used for transverse tests were finished by hand grinding. When the slabs were broken in the transverse tests the ends were used for shear tests. Specimens for permeability tests were disks 3 inches in diameter and one-half inch thick. For these, slabs were cut to the proper thickness from which the disks were then cut with a core drill. Cubes 2¼ to 2½ inches in size were used in some of the tests instead of cores which were prepared by sawing and hand finishing.

In order to obtain the strength and elasticity both perpendicular and parallel to the stratification, it was necessary to prepare a separate set of specimens for each condition. Figure 25 illustrates the various conditions of loading with reference to the stratification in the compressive, transverse, tensile, and shear tests.

IV. COMPRESSIVE STRENGTH

Compressive strength tests were made on the various materials in both the dry and wet condition. The results given in Table 2 for the dry stone were obtained on specimens after 24 hours drying at 110° C. in the oven, while those given in Tables 2 and 3 were determined on specimens after two weeks soaking in water. In both the dry and wet conditions a part of the tests were made by applying the load perpendicular to the bedding and another part by applying the load parallel to the bedding. The greater part of the limestones are

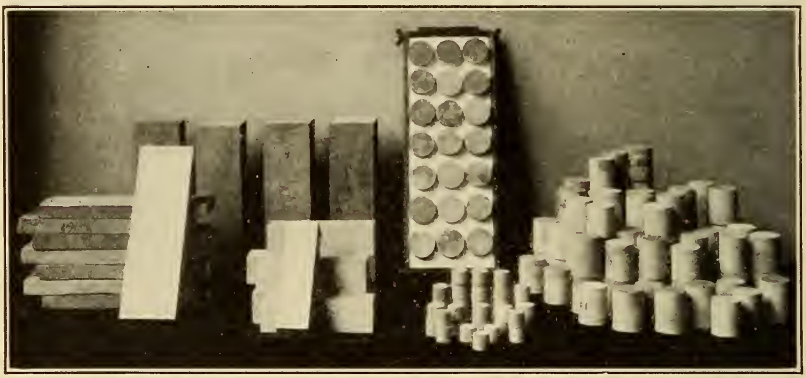

FIG. 3.—*Specimens ready for testing, and group of cylindrical specimens in the plaster cast at center*

somewhat weaker when loaded parallel to the bedding, and practically all are considerably weaker in the wet condition than the dry.

The usual practice in determining compressive strength of stone is to load small cubes until failure occurs. In this series of tests a part of the determinations were made on cubes approximately 2¼ inches in size, but it was found more feasible to prepare cylindrical specimens, and the later tests were made on this form. The cylindrical specimens were 2 inches in diameter and about 2¼ inches high. Comparative tests on the same material with the two shapes of specimens indicated that the unit strength is practically the same for each type.

Compressive strength is mainly of interest in comparing the qualities of different materials, although it is also of interest in a structural sense. It is frequently pointed out that practically all natural stone is strong enough for any structural requirement. However, there are many uncertainties as to the stress in masonry walls. It is not unusual to see broken stones in the walls of modern structures. Conditions which may cause breakage are numerous, but probably the most common are as follows: Unequal settlement, improperly bedded joints, unequal expansion of steel or concrete frames and the stone facing, and swaying of tall buildings due to earth tremors, wind storms, blasting, etc. Experience has taught that a large factor of safety is necessary to guard against cracking or spalling of the stone under such conditions. Probably the best illustration that can be offered in support of the above statement is that of the Washington Monument in Washington, D. C. In the highest stressed part of the masonry the factor of safety is nearly 20, yet the marble shows many cracks. Some of these are apparently due to unequal distribution of the load on certain blocks or a concentration of load on the pointing mortar, while others resemble compression failures.

High strength is always a desirable characteristic aside from its advantage in better resisting the usual stresses. In general, high strength denotes durability. A strong material is less apt to become defaced in those parts of the structure which are subject to accidental injury. All arrises that are within the reach of human hands are apt to become chipped, and thus badly marred in appearance. Weak stone is readily defaced in this way and often suffers defacement during construction. Delicate carvings in order to withstand accidental injury require considerable strength in the stone.

The strength of limestone from different localities varies greatly. The highest compressive strength recorded in this series of tests on the dry stone was 28,400 and the lowest 2,500 lbs./in.[2] For comparison with other types of stone the following range values are given:

	Lbs./in.[2]		Lbs./in.[2]
Basalt	28, 000–67, 000	Serpentine	11, 000–28, 000
Quartzite	16, 000–45, 000	Granite	10, 000–40, 000
Diorite	16, 000–35, 000	Marble	8, 000–27, 000
Syenite	14, 000–28, 000	Sandstone	5, 000–20, 000

V. TRANSVERSE STRENGTH

This test involves the determination of the strength of a material when submitted to bending stresses, as in a loaded beam. Since the resistance of stone to transverse stress is comparatively low, it is very important to give adequate dimensions to such structural members as lintels, and the determinations in this report are intended to be of value in this connection.

The tests on this property were made on small slabs usually 12 inches long and 4 by 1 inch in section. These were supported flatwise on adjustable knife-edges and loaded at the center through another knife-edge attached to the moving head of the testing machine. The strength is expressed in terms of the modulus of rupture, which is computed from the breaking load and dimensions of the test piece by means of the formula $M=\frac{3}{2}\frac{wl}{bd^2}$ in which $W=$ breaking load in pounds, $l=$ distance, center to center of the supporting knife-edges in inches, $b=$ breadth of specimen in inches, $d=$ thickness in inches. In order to calculate the load which a stone will bear when supported at the ends and loaded in the center where the modulus of rupture is known, this formula may be transposed to the form $W=\frac{2Mbd^2}{3l}$ and solved for W.

If the load is uniformly distributed over the length of the beam, as is more nearly the case in lintels, this formula becomes $W=\frac{4Mbd^2}{3l}$.

The curves shown in Figure 4 have been drawn to show the maximum uniformly distributed loads that stone beams of various dimensions, spans, and strengths will carry on each inch of width. This chart may be found of use in proportioning lintels.

Methods given in textbooks for the design of lintels are based on the assumption that a triangular section of the masonry is supported by the lintel, the base of the triangle being the width of the wall opening and the height being two-thirds of this width. The computations involved in computing stresses by this method are rather long, so a method has been worked out which, by the use of curves in Figure 4, is much simpler. The first step in deriving this method is to determine the dimensions of a rectangular section of masonry which will produce the same bending moment as the theoretical triangular section. This is done by taking the base of the triangle and the length of the rectangle both equal to the width of opening, l, the height of triangle as $2/3\ l$, and the height of the corresponding rectangle as cl. The moments for the two conditions expressed in algebraic terms are then equated and solved for c, as follows:

In the case of the triangle, assuming a lintel width of one unit and a unit weight of masonry $=w$, the supported load will be

$$W=\left(\frac{l}{2}\times\frac{2l}{3}\right)w=\frac{l^2w}{3}$$

The end reaction neglecting the weight of the lintel will be

$$R=\frac{l^2w}{6}$$

The positive moment will be

$$M(+)=\frac{l^2w}{6}\times\frac{l}{2}=\frac{l^3w}{12}$$

and negative moment

$$M(-)=\frac{l^2w}{6}\times\frac{l}{6}=\frac{l^3w}{36}$$

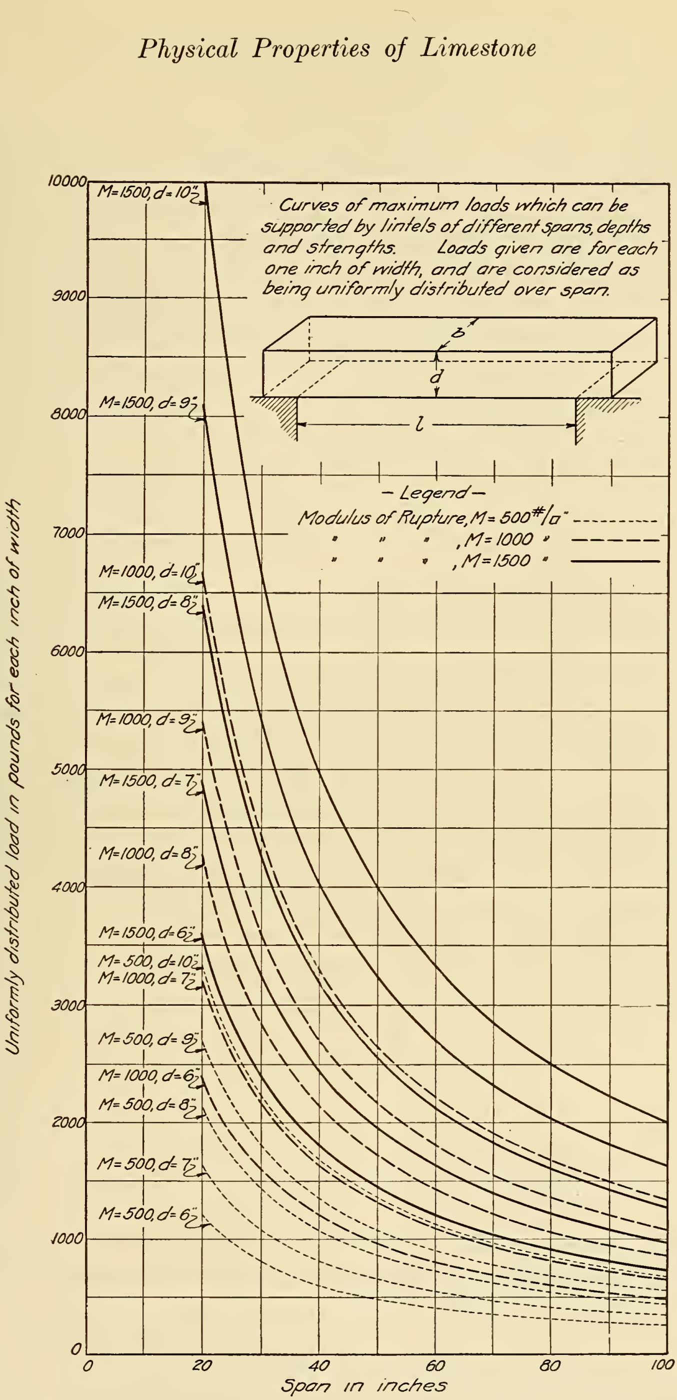

FIG. 4.—*Curves of maximum loads on stone beam of various spans*

The algebraic sum of these is

$$M(+)+M(-)=\frac{l^3w}{18}$$

In case of a rectangular section of masonry of length, l, and height, cl, the sum of the moments is

$$M(+)+M(-)=\frac{cl^3w}{8}$$

Equating these and solving for c

$$\frac{cl^3w}{8}=\frac{l^3w}{18} \qquad c=\frac{4}{9}$$

Hence the rectangular section will be $\frac{4l}{9}$ in height. As an approximation to avoid computing moments due to the weight of the lintel itself one may increase this to $\frac{5l}{9}$ and neglect the lintel weight.

In the theoretical design of lintels it is customary to consider the span as the width of opening plus one-half of the distance the ends project into the walls; that is, the distance between the centers of gravity of the two end bearings. However, if the ends project as much as 4 or 5 inches into the wall they become fixed and the lintel may act as a continuous beam, hence it is capable of supporting a larger load. It is proposed, for the sake of simplicity, to consider l in all cases as the width of opening plus 2 inches.

To assume a specific case, suppose it is desired to design a lintel for a window 4 feet wide, the building being of brick and a stone is to be used with a modulus of rupture of 1,000. The weight of brickwork may be taken as 125 lbs./ft.^{3} Since the curves are based on uniformly distributed loads per inch of width, the load computation would be

$$\frac{(48+2)\times\frac{5}{9}(48+2)\times 125}{1728}=\frac{50\times 5\times 50\times 125}{1728\times 9}=100 \text{ pounds.}$$

To find the thickness of lintel desired, follow up the 50-inch span line until it intersects the first curve for $M=1{,}000$, which intersection shows that a 6-inch depth would break under a load of 900 pounds. Hence, the factor of safety for this depth would be $900\div 100=9$. This is probably too low a safety factor, so one traces upward to the 7-inch thickness for this strength of stone and finds that this would break under a load of 1,300 pounds, giving a safety factor of 13. Probably a factor of 20 should be used, so by interpolating between the 8 and 9 inch curves one arrives at 8¾ inches as the proper thickness.

VI. TENSILE STRENGTH

Tensile-strength measurements are seldom made on stone, probably for the reason that the results are of no particular interest in a structural way. While it is true that stone is seldom, if ever, required to take direct tensile stresses from the structural conditions, it is, nevertheless, true that it may be so stressed by frost action. Freshly quarried blocks are frequently disrupted in winter because the stone does not have sufficient tensile strength to resist the expansive force of ice forming in the pores. It also seems evident that the resistance of stone to frost action in the general course of weathering is largely influenced by tensile strength. Hence, it appears that sufficient information would be obtained from this test on stone to justify its determination. Probably the most important determinations in this connection are the weakest direction with respect to bedding, planes of weakness, and conditions which effect a reduction of tensile strength.

A few samples of limestone were tested for tensile strength for this report by preparing briquette specimens similar in form to those used in cement testing. These were tested on the usual type of cement tensile testing apparatus. The results given in Table 5 indicate a range of tensile strength for the limestones of 280 to 890 lbs./in.^{2} However, the strongest and densest limestones were not tested for tensile strength, hence, a more complete set of tests would probably show a greater range of results than that stated above.

For comparison with other types of stone as to tensile strength the following values have been selected from the available data:

	Lbs./in.^{2}		Lbs./in.^{2}
Slate	3, 000–4, 300	Granite	600–1, 000
Marble	400–2, 300	Sandstone	280– 500
Serpentine	800–1, 600		

VII. SHEARING TESTS

The shearing strength of stone is of considerable importance in a structural way, but the available data on this property are not very complete. Various methods and various apparatus have been employed which renders the comparative value of the different determinations rather uncertain. One of the older methods employed a contrivance in which the shearing edges were displaced one-half inch from the supporting plates. The results obtained by this method are rather low, which indicates that the breaks are not true shearing breaks but are due to bending stresses. Other devices which appear to eliminate bending stresses are those of Johnson and Bauschinger. The former is a double shear apparatus and the latter shears a single surface. In both types of apparatus the metal parts which support the specimen are displaced only a very slight amount from the shearing edges.

The Johnson apparatus, which is illustrated in Figure 5, *A*, was used in making several tests on limestone but was found cumbersome to operate, and, furthermore, it was considerable trouble to prepare the required shapes of specimens. Hence, an apparatus was designed in which shearing tests could be made on the ends of the transverse test specimens. This is shown in Figure 5, *B*. It is a punching shear apparatus which punches a 2-inch disk from a slab of stone. The end of the punch is made adjustable similar to the spherical compression blocks in common use. A heavy coil spring supports the punch and its loading table at a small height above the specimen. The load required to compress this spring to the position of contact with the specimen is accurately determined and subtracted from the shearing load. This device was used with the same type of testing machine employed for making compression tests.

The shearing values obtained by the two methods are given in Tables 6 and 7. Tests were made on the stone by shearing in each

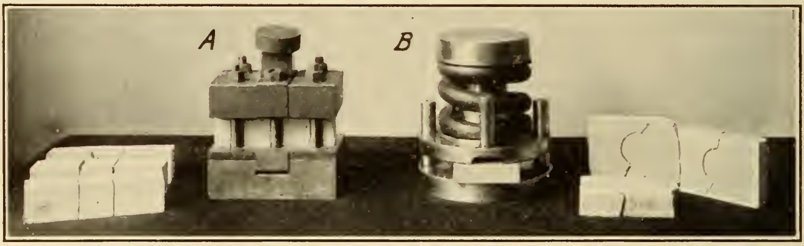

FIG. 5.—*Apparatus for making shear tests*

A, shears a section of a bar as shown at left.
B, punches a 2-inch disk from a slab.

direction of the bedding, but it should be noted that by the punching method the greatest difference in strength between the two directions is not indicated by these results. Tests made by shearing across the bedding planes evidently indicate the true shearing strength in this direction, but those in which the specimens were punched parallel to the bedding planes the values are probably somewhat higher than the actual shearing strength of the stone along the bedding. This is because only a small part of the sheared portion of the part punched out is really parallel to the bedding direction.

The values obtained by punching in the direction of bedding are generally somewhat lower than those obtained by punching perpendicular to the bedding. The lowest value obtained was 800 and the highest 4,580 lbs./in.^{2} The usual range of values for the typical limestones is from 1,200 to 3,000 lbs./in.^{2}, and the very dense materials indicate considerably higher values. The following ranges for other types of stone are indicated by the data on record:

	Lbs./in.^{2}		Lbs./in.^{2}
Marble	1, 300–6, 500	Serpentine	2, 600–5, 000
Granite	2, 000–4, 300	Sandstone	300–3, 000
Slate	2, 000–3, 600		

VIII. IMPACT TESTS

The impact results recorded in Table 8 were obtained with the Page apparatus shown in Figure 6. The specimen, which is a cylinder 1 inch in diameter by 1 inch high, is held on an anvil by means of a small clamp. A steel plunger, which rests on the specimen, weighs 1 kg and has its lower end rounded to a radius of 1 cm where it makes contact with the specimen. A 2-kilo weight is then dropped on the upper end of the plunger, first from a height of 1 cm and increased 1 cm for each succeeding drop until the specimen breaks. The height of the last drop is recorded as the toughness value of the stone.

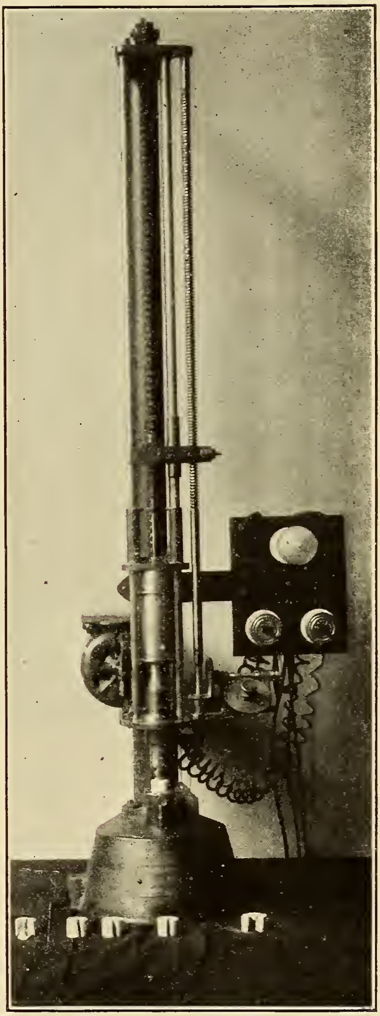

Fig. 6.—*Impact apparatus for determining the toughness of stone*

This test is applied mainly when materials are to be used for curbstones or similar purposes where subjected to impact. The limestones in this series of tests show a range in toughness values from 3 to 8, with an average of 4.4. Toughness values recorded for other limestones used mainly for road materials indicate values ranging from 4 to 21.

For comparison the following general range values for other stones is given:

Slate	10–56
Sandstone	3–47
Rhyolite	6–42
Diorite	12–36
Schist	6–34
Granite	7–31
Quartzite	14–30
Serpentine	6–17

IX. ELASTICITY

Modulus of elasticity determinations were made both in compression and flexure. It was found desirable to design special apparatus for the deformation measurements, since the usual types of compressometers and deflectometers are not well adapted for use on stone specimens. The compressometer constructed for this purpose is shown in Figure 7, *A*. This is of the averaging type; that is, the deformation on two opposite sides of the specimen is averaged and measured by a single dial. The lever magnification was 5 to 1 and the dial read to 0.001 inch, hence the probable accuracy per unit of length for a 10-inch gauge length was 0.00002 inch. The apparatus was made so it could be readily adjusted for various heights of specimen varying from 4 inches up to 12 inches. Another feature of the apparatus that is desirable is the arrangement to prevent harm to the delicate parts in case of an unexpected break.

In general, the specimens were 3½ by 3½ inches in section by 12 inches high which allowed a distance between points of deformation measurements of 11 inches. However, it was not always possible to get specimens of this height, and in some cases the distance

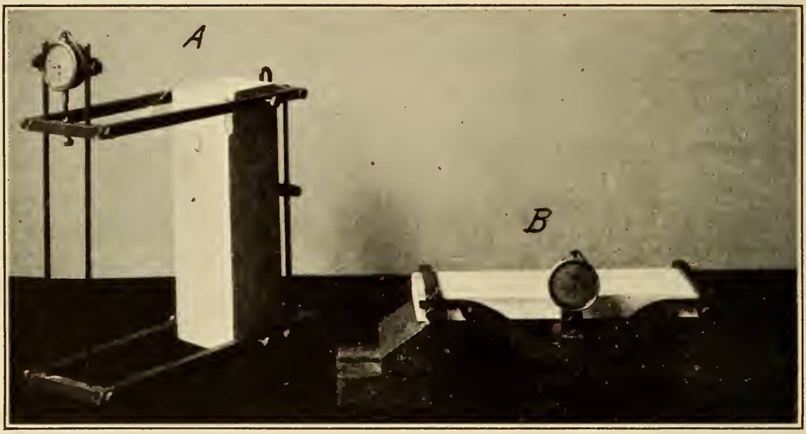

FIG. 7.—*Apparatus for determining the elasticity of stone*

A, for elasticity in compression.
B, for elasticity in transverse bending.

between points of measurement was as small as 5 inches. The procedure in making these tests was to set the dial to zero when the specimen was under an initial load of 500 pounds then recording the deformation for 5,000-pound increments of load. A slight variation from this procedure was found more satisfactory, which involved setting the counterpoise weight on the beam about 300 pounds short of the desired load, then running the load on until the beam raised. The point of equilibrium could then be quickly obtained by moving the counterpois weight at which point both the load and deformation were recorded. This effected a considerable saving in time in making the tests, since it requires several reversals of the load in order to balance the beam at any predetermined point. The slight variation in load increments in this procedure is taken care of in plotting the elastic curves. When the load on the specimen had reached about one-half of its breaking strength, it was decreased back to 500 pounds and the dial again read at the initial load. Usually it was found that the dial did not go entirely back to zero, especially in cases of the less compact materials. The gauge was then set to zero at the load of 500 pounds and the same operation repeated. Usually at the second return to the initial load the gauge would return almost to zero. In many cases three or four repetitions were made of the measurements as described and then the compressometer was reset on the other two faces of the specimen for a similar set of readings.

In Figure 8 is a typical set of curves showing the deformations plotted against the loads, using the vertical scale for loads and the horizontal for deformations. The heavy curves are drawn for the actual measurements, and the light line is drawn from zero point parallel to that part of the curve which indicates proportional deformations. In general, it will be noted that the curves are nearly straight lines except at the lower loads. In most cases the curves bend away from the vertical, but in a few cases the trend was in the opposite direction, as shown for serial No. 119. Usually in determining the modulus of elasticity of a material this variation for the lower loads is disregarded and attributed to the uncertainty of deformation measurements at this stage of the test. However, there is considerable evidence in these tests that these variations are due to some peculiarity in the structure of the material which influences its behavior under stress. Several repeat tests on each specimen with different settings of the compressometer invariably gave a recurrence of the same type of curve. Hence, there is some uncertainty as to whether one is justified in disregarding this part of the curve in computing modulus values. Such values based on stresses corresponding to actual working loads would in many cases differ materially from those based on the proportional part of the curve.

The modulus values given in Table 9 were computed from the slope of the straight line. Some of the material tested gave modulus of elasticity values as low as 1,500,000, while the highest recorded was 12,400,000. As a rule, the values obtained on the typical limestones ranged between 3,000,000 and 6,000,000, while the denser materials usually show values from 7,000,000 to 10,000,000.

The modulus of elasticity values on other materials obtained from an examination of the available data indicate the following ranges:

Slate	9, 000, 000–15, 000, 000	Granite	5, 700, 000–8, 200, 000
Marble	7, 200, 000–14, 500, 000	Sandstone	1, 900, 000–7, 700, 000
Serpentine	4, 800, 000– 9, 600, 000		

Elasticity measurements were also made on the different materials by the flexure test, which consisted of subjecting small slabs to bending stresses and measuring the deflection for various loads. The specimens used were usually 12 by 4 by 1 inches. These were supported flatwise on knife-edges of the usual type and loaded in the

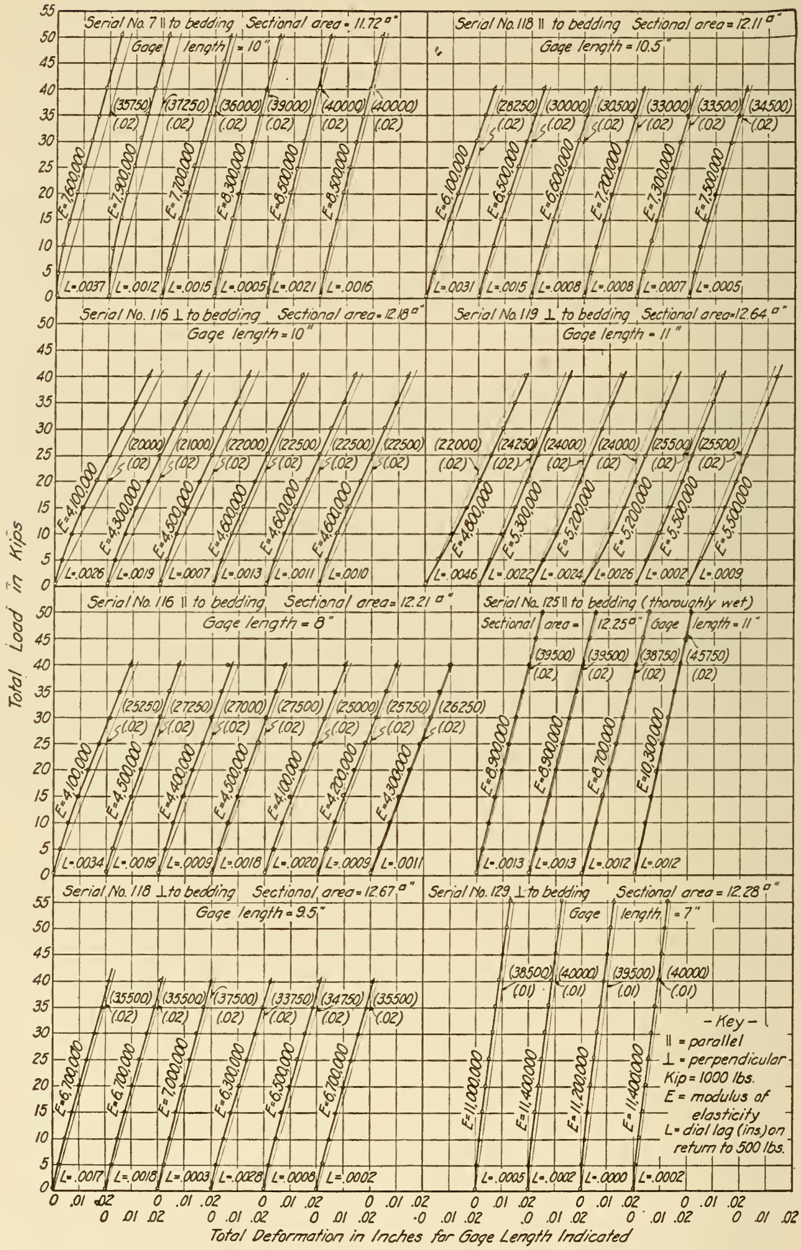

FIG. 8.—*Elastic deformation curves obtained for eight specimens of limestone, showing repetition tests*

middle through another knife-edge at the middle. The supporting knife-edges were of the rocker type, which provided a uniform bearing. The apparatus found most satisfactory for these tests is shown in Figures 7, *B*, and 9. This is a hand-operated loading device mounted over a platform scale of 600 pounds capacity. By this means a higher accuracy was obtained than with the regular testing machines available, since these are constructed for heavier work and are less sensitive. With this device the load measurements could be obtained to an accuracy of 1 ounce.

The deflectometer used was constructed for the purpose and consisted of a metal frame carrying an Ames dial, which could be suspended on the neutral axis of the specimen. The dial was actuated

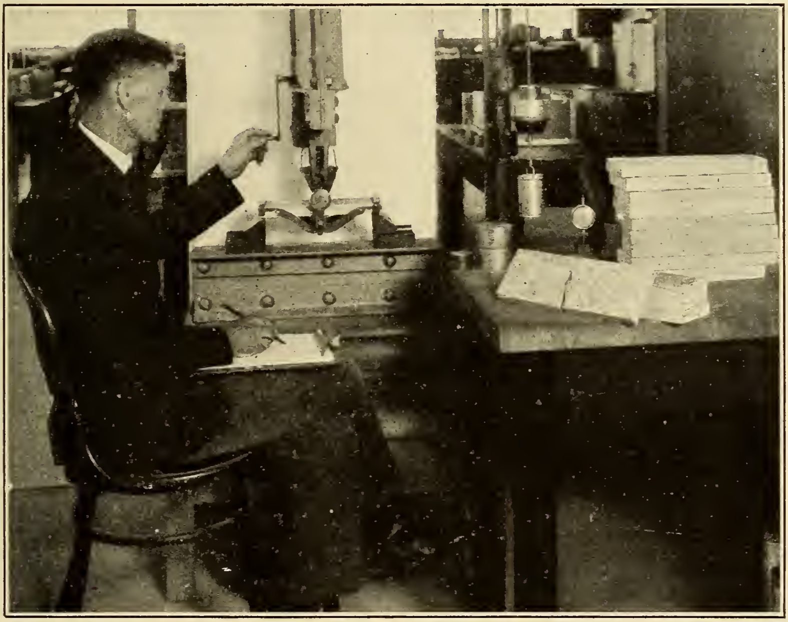

FIG. 9.—*Apparatus for making transverse strength and elasticity tests*

by means of a small lever pivoted in the middle, one end having an adjusting screw which could be brought in contact with the lower side of the specimen while the other end made contact with the plunger of the dial. In this test the loads were applied in increments of 10 pounds, and deformation readings were made for each 50 pounds of load. The dial readings were recorded to the nearest 0.0001 inch.

The deformations were plotted against the loads, and a straight line was drawn parallel to the proportional part of the curve from the zero point. The modulus of elasticity value was then computed from some convenient point on this line by the formula $E=\frac{wl^3}{4\triangle bd^3}$ in which w = the load ordinate of a chosen point on the slope line, $\triangle$ = deformation ordinate of this point, l = distance between supporting knife-edges in inches, b and d = the breadth and thickness of the specimens, respectively, in inches.

A comparison of the elasticity values obtained on identical materials as recorded in Tables 9 and 10 shows in many cases a very appreciable lack of agreement. As a rule, the compression moduli are higher. Nineteen samples taken at random gave an average modulus in compression of 5,100,000, and the same materials in flexure gave an average of 3,300,000. This difference is probably due to the low and uncertain strength of limestone in flexure. It will be noted that several of the typical limestones gave very low values in flexure while the compression moduli for the same were near the average. While it is doubtful if the flexural elasticity determination on limestone is of particular interest in a structural way, it has sometimes been assumed that the results of such tests are comparable with compression elasticity values. The determinations made in this series of tests were mainly for the purpose of drawing a comparison between the values obtained by the two methods. More care and accuracy were practiced in this case than is usual for such tests, hence it is believed that considerable evidence has been developed that the flexural elasticity determination for stone is not comparable with the compression elasticity.

X. ABSORPTION TEST

Absorption tests for this report were made on the same sizes and shapes of specimens used in the compression tests. The dry weights were obtained after a drying period of at least 24 hours in an electric oven at 110° C. The absorption period was two weeks, during which time the specimens were entirely immersed in water at room temperatures. At the end of the absorption period the specimens were removed from the water one at a time, surface dried with a towel, and immediately weighed. In all cases the weights were determined to the nearest one-hundredth of a gram. Following the established custom the percentage of absorption was obtained by dividing the weight of absorbed water times 100 by the dry weight of the specimen. This value is termed the "absorption by weight." Since stones of different mineral composition are not of equal bulk density, it is evident that by this computation the values obtained are not strictly comparable. For this reason it is more logical to compute absorption results on the volume bases; that is, by dividing the volume of absorbed water by the volume of the specimen. Such results are entirely comparable for all types of stone. In Table 11 the absorption "by weight" and "by volume" are both given. The latter is obtained by multiplying the absorption by weight value by the apparent specific gravity of the specimen.

A considerable range in the absorption of limestones from different localities is indicated by the results, the lowest "by volume" value being 0.04 per cent and the highest 24.8 per cent. Some of these materials are very dense and approximate the texture of marble. In this class may be placed the Onondaga limestone, those materials from southwestern Missouri and the Illinois limestones. Considering the more typical building limestones, as those from Indiana, Kentucky, Alabama, Texas, and Minnesota, the absorption values usually range between 6 and 15 per cent by volume. The usual ranges for other types of stone computed on the same basis are as follows:

	Per cent
Sandstone	6–18
Slate	0. 3–2. 0
Granite	. 4–1. 8
Marble	. 1– . 4

XI. APPARENT SPECIFIC GRAVITY

Apparent specific gravity is the ratio of the dry weight of a material to the weight of an equal volume of water. The only difficulty involved in this determination is that of obtaining accurately the volume of the specimen. The simplest way of doing this is to weigh the specimen dry and then weigh it suspended in water. The difference between the two weights in grams is equal to the volume of the specimen in cubic centimeters. However, in making this test on porous materials like most limestones one has to prevent the specimen from absorbing while weighing it suspended in water. This is best accomplished by determining the volume of the specimens after saturation with water; that is, after they have soaked several days. This involves three weight determinations instead of two; namely, the dry weight in air, the saturated weight in air, and the weight of the saturated specimen in water. The apparent specific gravity is then computed by means of the formula $G=\frac{W_1}{W_2-W_3}$, in which $W_1=$ dry weight, $W_2=$ wet weight, and $W_3=$ weight suspended in water. By making this test in conjunction with the absorption test only one more weighing is necessary; that is, the weight suspended in water.

The apparent specific gravity is of value in determining the actual unit weight of the stone and for computing the porosity. To determine the weight in pounds per cubic foot of the dry stone one multiplies the apparent specific gravity by 62.5. The determination of the actual amount of pore space in a stone involves the use of the "true specific gravity," which will be defined in the following section. For stones of fairly definite composition the apparent specific gravity value alone affords considerable information in regard to porosity. Most limestones are fairly pure calcium carbonate, and the actual or "true specific gravity" may be assumed to be 2.72. The apparent specific gravity value of such limestones will be lower than 2.72, because of the pores or void spaces; hence the difference is a valuable index to porosity.

The apparent specific gravity values of the limestones tested for this report varied from 1.87 to 2.69. The lowest value corresponds to a porosity of 31 per cent, while the highest indicates a porosity of slightly more than 1 per cent.

Several of the limestones are dolomitic—that is, they contain a considerable amount of magnesium carbonate—and in such cases the true specific gravity may vary from 2.72 for a pure calcite to 2.86 for a true dolomite. Unless one knows approximately the percentage of magnesium carbonate present in a magnesium limestone the apparent specific gravity determination alone affords little information concerning the porosity.

The following range values for apparent specific gravity are given for comparison with other types of stone:

Basalt	2. 9–3. 2	Slate	2. 6–2. 8
Soapstone	2. 8–3. 0	Serpentine	2. 5–2. 84
Gneiss	2. 7–3. 0	Granite	2. 6–2. 7
Marble	2. 7–2. 86	Sandstone	2. 2–2. 7

XII. TRUE SPECIFIC GRAVITY

This may be defined as the unit weight of the mineral constituents of the stone. It may be considered as the weight in grams of 1 cubic centimeter of stone which has the pores entirely filled with the same mineral substance as the original. The accurate determination of this property is more difficult than that of the apparent specific gravity.

Determinations for this report were made by grinding the stone to a fine powder and making the measurements on the part passing a 200-mesh sieve. This is assumed to practically eliminate the pores, so the task remaining is to accurately determine the volume of a known weight of the powdered material. This was done by means of a Le Chatelier flask, which is a long-neck bottle with volumetric graduations on the neck. This is filled with gasoline or other suitable liquid to the lowest graduation, then a carefully weighed portion of the dry powder is poured in. The rise in level of the liquid is approximately the volume of the particles. There are sources of error in this measurement which have to be eliminated as far as possible. Considerable air is carried into the liquid with the powder, which should be removed before the volume reading is made. This is done by thoroughly agitating the powder in the liquid by swinging the flash around in a circle. Another source of error is that of temperature changes in the liquid between the times when the first and second volume readings are made. A difference of 1 or 2° between these readings causes a large error, since the volume change of the entire liquid is included in that which is supposed to be only the volume of the powder. This is practically eliminated by setting the flash in a tank of water of constant temperature for several minutes before each volume reading. When the volume of a known weight of the powdered material is determined, the true specific gravity value is computed by dividing this weight by the volume. The weight of powder used in these tests was 55 g. Check tests on the same material indicated a maximum variation of 0.03, and the usual range was 0.01.

The true specific gravity values are used with the apparent specific gravity in computing the actual pore space. This is also of some value in the absence of a chemical analysis in classifying a limestone.

The composition of the building limestones usually varies from fairly pure calcium carbonate to various combinations of a calcium carbonate with magnesium carbonate up to the true dolomite $CaMg(CO_3)_2$. Since the true specific gravity of calcium carbonate is 2.72 and that of dolomite is 2.86, the determination of this value for any particular limestone affords considerable information as to the composition.

XIII. POROSITY

The amount of pore space can be calculated when the apparent and true specific gravity values are known. This is usually expressed as a percentage by volume and is calculated by the formula $P=\frac{100}{t}(t-a)$, in which t = the true specific gravity and a = the apparent specific gravity.

The porosity of a stone is of interest in considering the probable weathering qualities. It represents the limit of absorption. A stone in the usual laboratory tests seldom absorbs an amount of water equal in volume to the total pore space. The following table gives the results of a series of tests on a typical limestone to determine the saturation obtained during six months' complete immersion in water:

Long-period absorption tests on limestone

[Limestone Serial No. 90. Porosity = 13.67. Apparent specific gravity = 2.35]

Size of cubes in inches	Cube No.	Percentage of absorption by weight in—					Per cent by volume, 6 months	Saturation at 6 months
		1 hour	2 hours	5 hours	24 hours	6 months		
1½	1	3.16	3.20	3.23	3.40	5.18		
	2	3.22	3.28	3.33	3.50	5.36		
	3	3.07	3.23	3.39	3.43	5.29		
Average		3.13	3.24	3.32	3.44	5.28	12.40	0.91
2	1	3.19	3.22	3.28	3.41	4.87		
	2	3.25	3.28	3.30	3.42	4.84		
	3	3.26	3.28	3.32	3.74	4.91		
Average		3.23	3.26	3.30	3.52	4.87	11.48	.84
2½	1	3.43	3.46	3.50	3.62	5.04		
	2	3.43	3.46	3.50	3.58	4.95		
	3	3.43	3.49	3.54	3.66	5.14		
Average		3.43	3.47	3.51	3.62	5.04	11.83	.87
3	1	3.52	3.47	3.57	3.62	4.75		
	2	3.23	3.23	3.23	3.46	4.57		
	3	3.23	3.23	3.27	3.37	4.58		
Average		3.33	3.31	3.36	3.48	4.63	11.87	.87

Cubes of five sizes were prepared ranging in size from 1½ inches up to 4 inches. For convenience the absorption values were determined by weight and reduced to the volume basis for the six months' period. By dividing the values in the next to the last column by the porosity value of this material—namely, 13.62—the saturation is obtained. These values indicate that the pore space was about nine-tenths filled during this period of immersion. It has been assumed by some authorities that if a stone is frozen when more than nine-tenths saturated it will be disrupted. This conclusion is based on the fact that water expands one-tenth of its volume in freezing, and hence if there is not sufficient free space to accommodate this expansion the stone will be stressed to a higher point than the cohesive strength can resist. When stone is fresh from the quarry it is probably entirely saturated and many quarry operations have to be discontinued in winter else the stone will be ruptured by frost. Whether a stone will rupture in this way depends mainly on the amount of pore space and the cohesive strength. Evidently there are other factors which play some part in determining the resistance of stone to freezing, such as elasticity, permeability, and pore structure. By disregarding the effect of these properties a simple formula may be derived which shows approximately the relation between porosity and stress caused by freezing stone in the saturated condition. Ice in forming exerts a pressure of about 2,000 lbs./in.[2] Consider any section of area A through a block of stone which has a porosity p and tensile strength t. The area of the pores at this section will be Ap and that of the solid stone will be $A—Ap$. The equation of equilibrium between the stressed stone and ice in the case where the pores are entirely filled will be

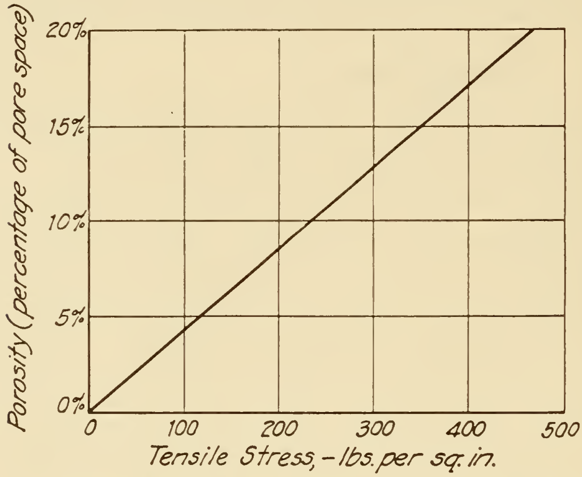

Fig. 10.—*Tensile stress caused in stones of different porosities when frozen in a water-saturated condition*

$$2{,}000\ Ap = (A—Ap)t$$

from which

$$t = \frac{2{,}000\ p}{1—p}$$

The elasticity and permeability of the stone would evidently tend to diminish the stress below that indicated by the formula. In Figure 10 this relation is shown graphically. The curve shows that a stone of 15 per cent porosity may be subjected to a disrupting force of about 350 lbs./in.^{2}, and that stones of less than 1 per cent porosity are not stressed appreciably.

By Table 12 it will be noted that many of the limestones have porosity values of 15 per cent or higher. Such tensile strength determinations as have been made indicate that as a rule limestone is strong enough to resist stresses of 300 to 600 lbs./in.^{2} However, the strength of stone is not always uniform, and there are usually planes of weakness along which blocks may be easily ruptured.

It will be seen by Table 12 that the porosity values for limestone vary greatly for different deposits, the lowest found being slightly more than 1 per cent and the highest 31 per cent. For comparison with other types of natural stone the following range values are of interest:

	Per cent		Per cent
Diabase	0. 2–1. 2	Quartzite	1. 5– 2. 9
Granite	. 3–2. 6	Sandstone	1. 9–22. 0
Marble	. 4–1. 8		

XIV. PERMEABILITY

The permeability of stone and similar materials is usually measured by the rate at which water will flow through the pores. The flow rate apparently should be proportional to the porosity, but the meager amount of test data on this property seems to indicate that this is not necessarily the case. Certain materials of low porosity show relative high permeability values, and vice versa.

An apparatus for such determinations on stone has been described in Bureau of Standards Technologic Paper No. 305. This apparatus can be used to measure the flow rate at any desired water pressure up to 300 lbs./in.^{2} Experiments indicate that the flow is proportional to the pressure within certain limits. During the first hour or more the flow under a constant pressure may increase slightly, probably due to the very fine pores requiring some time to become filled. After a period of a few hours at this pressure the flow usually decreased somewhat. This is believed to be caused by the finer pores becoming partly filled with loose particles.

Results of tests on various types of stone under 100 lbs./in.^{2} pressure indicated a flow rate in cubic inches of water per hour through 1 square foot of stone one-half inch thick, as follows:

Granite	0. 08–0. 28	Limestone	0. 95–1, 500+
Slate	. 11	Sandstone	220–4, 200+
Marble	. 90–28. 0		

Permeability measurements indicate characteristics of the pores which are not determined by absorption or porosity tests. For instance, two stones of nearly equal porosity values may differ in permeability by several hundred per cent. The following examples will serve to illustrate this point:

Serial No.	Per cent absorption by volume	Per cent porosity	Permeability [1]	Serial No.	Per cent absorption by volume	Per cent porosity	Permeability [1]
2	11.0	13.2	16.2	113	12.2	17.0	16.0
7	6.5	7.6	.95	114	8.3	9.5	109.0
48	9.0	14.0	1,500	115	12.2	13.5	8.6

[1] Permeability is here referred to as the rate at which water will flow through 1 square foot of stone, one-half inch thick in cubic inches per hour under a pressure of 100 lbs./in.[2]

A comparison of serial numbers 7 and 114 will show that these two stones differ only a small amount in porosity while the permeability values differ a hundredfold. Likewise Nos. 2, 113, and 115 have porosity values of the same order as No. 48, but the permeability of the last-named stone is many times that of the others. There is some evidence that an open texture—that is, one which permits an easy flow of water—will prove more resistant to frost action. However, there are evidently many factors which affect this quality of stone, and it would not be logical to judge any material from a permeability test alone.

XV. CONTINUOUS LOAD TESTS

Occasionally sound blocks of stone are broken in the walls of buildings where the load is evidently far below the breaking load. This has led some to assume that stone fatigues and finally yields under less stress than that indicated by laboratory tests. In order to obtain some information as to how limestone resists continued stress, a series of stone beams were prepared and loaded to 63 per cent of their tested strength. This series of tests is shown in Figure 11. The beams were 1½ by 4 inches in section and 30 inches long. These were supported on adjustable steel knife-edges 1 inch from the ends and loaded by suspending weights at the center. The beams were left under the stress of 63 per cent of the maximum load for two and one-half years and no breaks occurred. Deflection measurements were made at intervals to determine if the specimens continued bending under the loads. These measurements indicated a maximum sag of 0.005 inch above the initial bending and an average of 0.002 inch.

At the end of two and one-half years the loads were increased to approximately 80 per cent of the breaking load. Under these loads 2 specimens broke within 1 hour, 2 more after 4 hours, and 4 more within 24 hours. Another broke after 5 weeks, while 6 have not broken after 9 months.

An apparatus was also constructed for a continuous compression test which is shown in Figure 12. This apparatus applies the load to a single specimen. One test produced a break after 28 days when the load was 80 per cent of the ultimate strength while another test on a similar material loaded the same amount has held for a year without breaking.

Fatigue tests made by any means are apt to be misleading, due to the fact that one can not determine accurately the strength of the particular specimens upon which fatigue tests are made. The means of arriving at this strength employed in the tests described above was

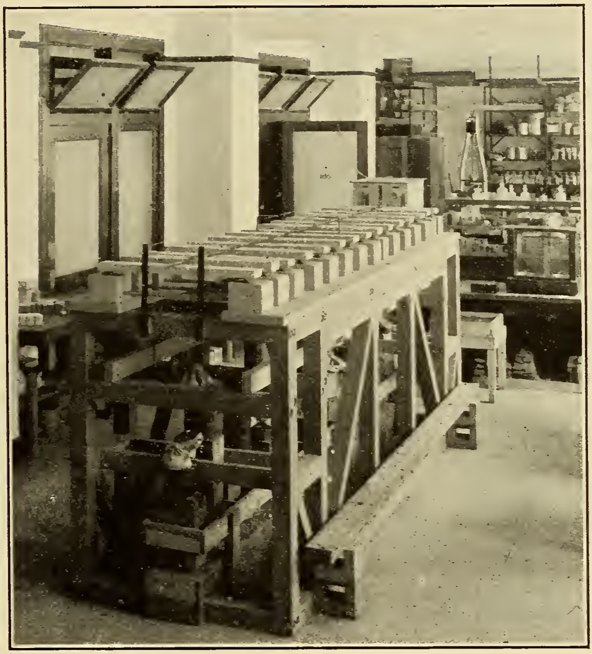

Fig. 11.—*Continuous load tests on stone beams to determine fatigue effects*

to cut several specimens from adjacent parts of a block of stone, selecting the middle specimen for fatigue tests and making strength determinations on all the others. The average strength obtained in this way was assumed as that of the specimen used for fatigue tests. Due to the variation in strength of any material from one point to another it is found that any particular test may easily vary as much as 10 per cent from the means of a series of tests. Hence this variation must be taken into account in analyzing the results of such tests. In the beam tests 60 per cent of the specimens broke within a short period of time when loaded to 80 per cent of the ultimate strength. It may be safely assumed that some of these were loaded to more than 80 per cent of their ultimate strength, and probably those not broken were stressed less than 80 per cent. However, the tests afford very good evidence that limestone does fatigue and yield under a continuous load, which is less than what the ordinary laboratory tests indicate. The loads used were much nearer the breaking strength than would ordinarily occur in structures. High loads were required in order to determine the fatiguing effects within a reasonable period of time. A series of tests sufficient in scope to determine the rate of fatigue or the law governing the fatigue of stone would be of considerable value. This series of tests, however, does not seem to indicate that one is justified in assuming that fractures in the masonry of comparatively new buildings are the result of fatigue.

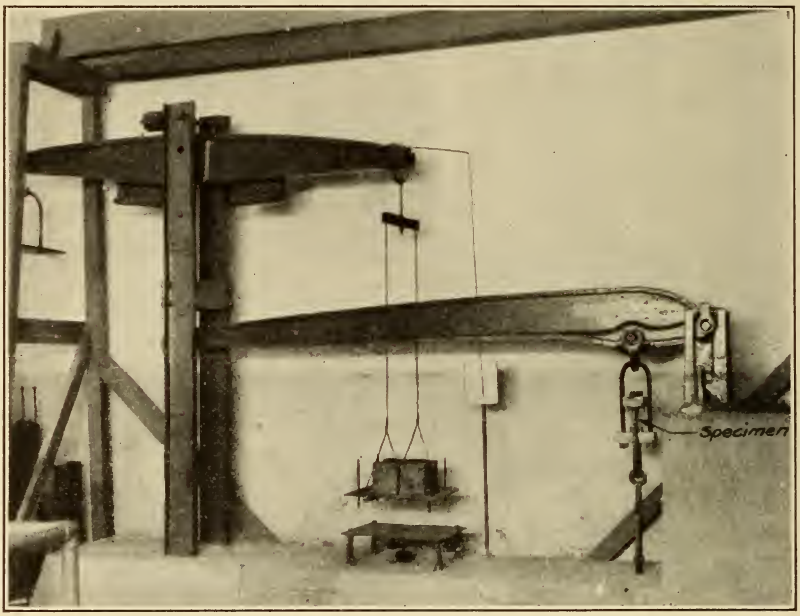

FIG. 12.—*Continuous load apparatus for determining fatigue effects in compression*

XVI. THERMAL EXPANSION

The thermal expansion of limestone is of considerable importance in a structural way, especially when limestone is used in connection with materials which expand at an appreciably different rate. Limestone does not expand at a constant rate for different temperature ranges. At ordinary diurnal temperatures the coefficient of expansion is much less than at high temperatures. This is illustrated by Figure 13, taken from Bureau of Standards Scientific Paper No. 352. Features of particular interest in this set of measurements are the increase in rate of expansion as the temperature increases and the permanent increase in length due to heating. Many of the coefficient of expansion values for stone found in various test and handbooks are based on measurements at temperatures considerably above the usual climatic temperatures, hence they are too high for use in calculating ordinary structural movements. Seasonal temperature ranges of 40 to 50° C. are not uncommon, and coefficient measurements for this temperature range are of most interest. A few measurements have been made on samples of Indiana limestone for this report over the range of 20 to 50° C., which indicate an average linear coefficient of 0.000005 for this material. While this indicates a comparative low expansion, it is sufficient to produce appreciable movements or stresses in a structure. Thus, the movement in 100 feet of limestone masonry for a temperature rise of 50° C. can be computed as follows:

$$100 \times 12 \times 50 \times 0.000005 = 0.3 \text{ inch}$$

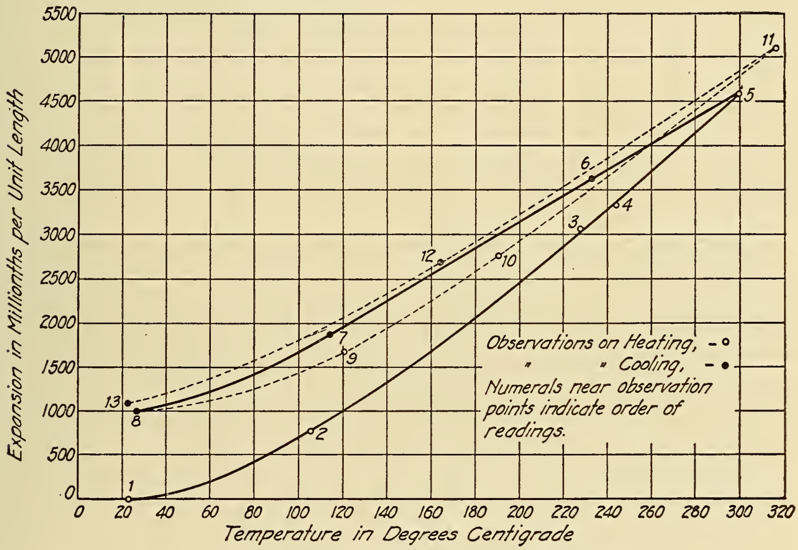

FIG. 13.—*Thermal expansion curves for limestone*

Probably the most important consideration in connection with structural movements due to temperature changes is what happens when two materials are used which have different coefficients of expansion. Suppose a steel frame building faced with limestone is erected in summer when the temperatures are 80° F. or 26.5° C. In winter the temperature may drop to −20° F., or the equivalent of a change of 55° C. The contraction of the limestone per 100 feet will be

$$100 \times 12 \times 55 \times 0.000005 = 0.33 \text{ inch}$$

and that of the steel frame

$$100 \times 12 \times 55 \times 0.00001 = 0.66 \text{ inch}$$

The difference of 0.33 inch per 100 feet would cause both the steel and limestone to be stressed, the limestone being compressed and the frame subject to tension; but for the elasticity of the materials one or the other would be ruptured. The amount of stress caused in either material will depend on the relative amounts of the two materials at any section and the modulus of elasticity values. One may compute the maximum stress possible in either material due to this temperature drop by assuming the other to be entirely rigid. To compute the highest possible compressive stress in the limestone due to this condition, it may be assumed that it is compressed 0.33 inch per 100 feet. The modulus of elasticity of limestone may be taken as 5,000,000. The expression $E=\frac{Wl}{Ae}$ gives the relation between the factors under consideration; that is, E = modulus of elasticity, W = load in pounds, A = stressed area in square inches, e = total change in dimension over the length l. As it is assumed that each 100 feet of stonework is compressed 0.33 inch, $e=0.33$ inch and $l=100\times 12=$ 1,200 inches. To obtain the compressive stress in pounds per square inch, let $A=1$ and substituting the values for A, E, e, and l, one obtains

$$5{,}000{,}000=\frac{1{,}200\ W}{0.33}$$

from which $W=1{,}250$ lbs./in.^{2} [a]

This stress is considerably above that caused by dead loads in the tallest structures, but is still well below the usual strength of limestone. Hence, it may be safely assumed that the limestone could take all of the compression under such conditions without failure, providing the loads were not concentrated on certain blocks of stone or parts of blocks. However, it is doubtful if such stresses are ever uniformly distributed, and some parts of the masonry are apt to be stressed above this amount. Spalling may occur where the vertical joints are not well filled with mortar, because such a condition would concentrate the stresses along the edges of the blocks.

The Industrial Building of the Bureau of Standards may be cited as an instance where spalling of limestone has occurred which appears to be due to differential temperature movements. The frame is of reinforced concrete, and the building has limestone coping, cornice, and trim. Figure 14 is from a photograph of a portion of the parapet wall. The position of the coping block at an offset in the wall shows unmistakable signs of such movements. The coping block joining the two principal walls instead of being in its proper position is lying **Z** shape with these. A prominent crack in the brickwork below the coping as shown affords further evidence of such movements.

[a] In general, the stress in the limestone caused by such conditions would be less than this due to the fact that the steel frame is not rigid and would, hence, compensate for part of the movement. Furthermore, the steel being inclosed it is not apt to reach as low a temperature as the stonework.

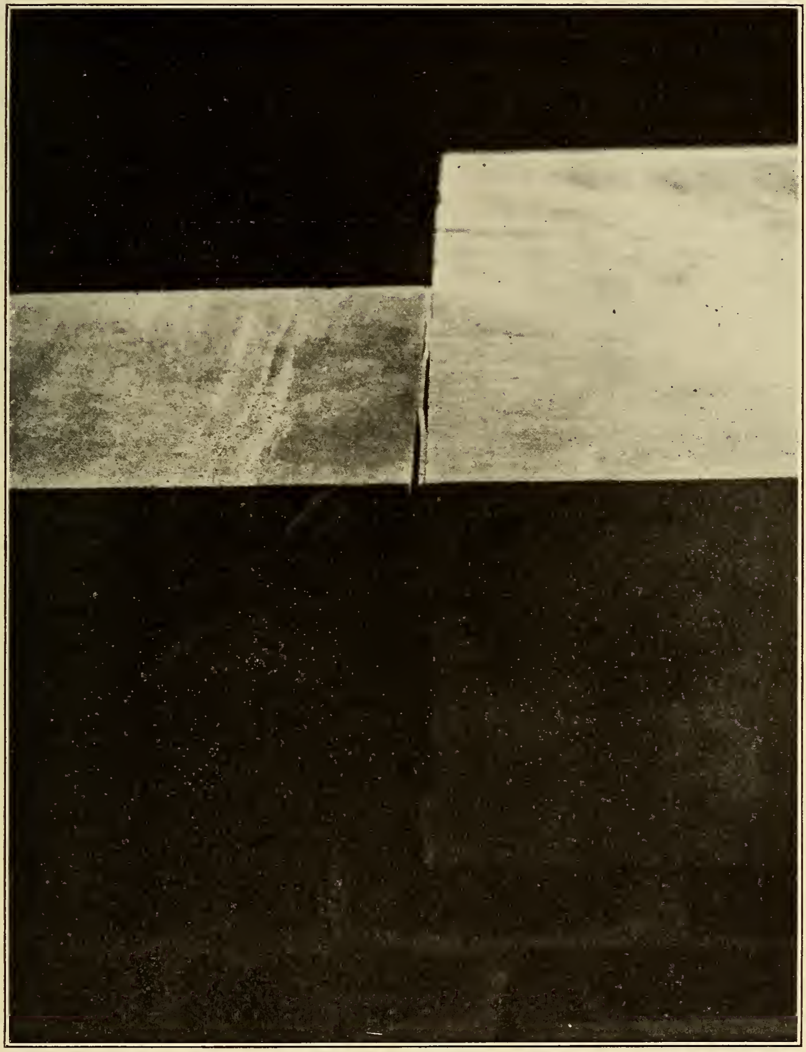

Fig. 14.—*Photograph of offset in parapet wall illustrating the effects of differential expansion between limestone and reinforced concrete*

Evidently such differential movements are minimized due to the stone being on the outside, and, hence, subjected to greater temperature ranges than the framework.

The coefficient of expansion values indicated by the test of Indiana limestone shown in Figure 13 for different temperature ranges are as follows:

Derived from the heating curve:	
From 25 to 100°	0.000009
From 100 to 200°	.000017
From 200 to 300°	.000022
Derived from the cooling curve:	
From 300 to 200°	.000015
From 200 to 100°	.000014
From 100 to 25°	.000010

An examination of the available date on the thermal expansion of various types of stone shows the following ranges:

Limestone (20 to 100° C.)	4.2 to 22×10^{-6}
Marble (20 to 100° C.)	3.6 to 16×10^{-6}
Quartzite (20 to 100° C.)	16.0×10^{-6}
Sandstone (20 to 100° C)	5.0 to $12 \times 10 \times^{-6}$
Slate (0 to 100° C.)	9.4 to 12×10^{-6}
Granite (20 to 100° C.)	6.3 to 9×10^{-6}

XVII. DISCOLORATION OF LIMESTONE

In the discussion of this subject the term "discoloration" is considered as any change from the natural color other than that caused by surface deposits of soot or grime which are apt to collect on any building. The kinds of discoloration which may mar the appearance are as follows: First, local stains caused by the absorption of extraneous matter from other parts of the building or carried into the stone by ground water; second, alteration of certain mineral ingredients of the stone where exposed to the weather; third, impurities in the stone leached to the surface by percolating waters.

Limestone in general is apt to be discolored from the first-named cause, while only certain deposits appear to be appreciably affected from the second and third. Usually those limestones containing minerals which are altered at the surface change color rather uniformly, and the change is often desirable rather than unsightly. Several limestone deposits contain a sufficient amount of organic matter in the form of oil or bituminous matter which comes to the surface as the stone seasons, producing undesirable discolorations. In many cases such discolorations are temporary and are soon carried away by rain. Occasionally, under certain conditions in the structure a large amount of this discoloring matter is leached from the stone, producing ugly brown or almost black spots which do not disappear of their own accord and are very difficult to remove by cleaning processes. These discolorations are a great source of annoyance, and the fact that any particular deposit is subject to such is apt to detract from its otherwise desirable qualities. Such discolorations are sometimes erroneously called iron stains because of their resemblance to iron rust.

A few years ago an investigation was undertaken at this bureau to determine if stains are less apt to occur with certain types of setting mortars than others. It has long been the opinion of builders that when cements of low iron content and lime mortars are used that stains are not so apt to occur. So-called nonstaining cements have been placed on the market which are almost white and nearly free from iron impurities. These have been widely used in setting limestone. In the first series of tests of discoloration effects 12 limestone-faced panels were constructed on the coping of a building using various combinations of mortar and a few types of waterproofing. These panels were made of common brick faced with 4 inches of limestone, the whole capped with limestone. The following table shows the construction of the various panels.

Construction of limestone test panels

[Discoloration tests]

Panel No.	Setting mortar		Waterproofing
	Limestone	Brickwork	
1	1 normal Portland, 2 white sand.	1 normal Portland, 2 white sand.	All faces of limestone except front and exposed ends painted with bituminous waterproofing material to ½ inch of front face.
2	do	do	None.
3	1 slag cement plus 10 per cent lime, 2 white sand.	do	Do.
4	do	1 slag cement plus 10 per cent lime, 2 white sand.	Do.
5	do	1 normal Portland, 2 white sand.	Paint back of limestone with bituminous waterproofing.
6	1 natural cement, 2 white sand.	do	Do.
7	do	1 natural cement, 2 white sand.	None.
8	1 white Portland, 2 white sand.	1 normal Portland, 2 white sand.	Do.
9	1 white Portland, 2 Potomac sand.	1 white Portland, 2 Potomac sand.	Do.
10	Lime mortar	Lime mortar	Do.
11	Duplicate of No. 1 with C grade limestone.		
12	Duplicate of No. 3 with C grade limestone		

These panels were closely observed for several months for discoloration effects. While some results of interest were obtained from these panels, it was soon found that more severe conditions were necessary for conclusive results. A series of tests was then resorted to in which water was leached through blocks of limestone for an extended period of time. Figure 15 shows a group of blocks that were leached for six months with water passing through the stone alone; that is, no mortar was used. This was for the purpose of determining if stains could be produced without mortar. It will be noted that all of these tests developed more or less efflorescence, and that brown discolorations occurred on blocks Nos. 1 and 2. A few incon-

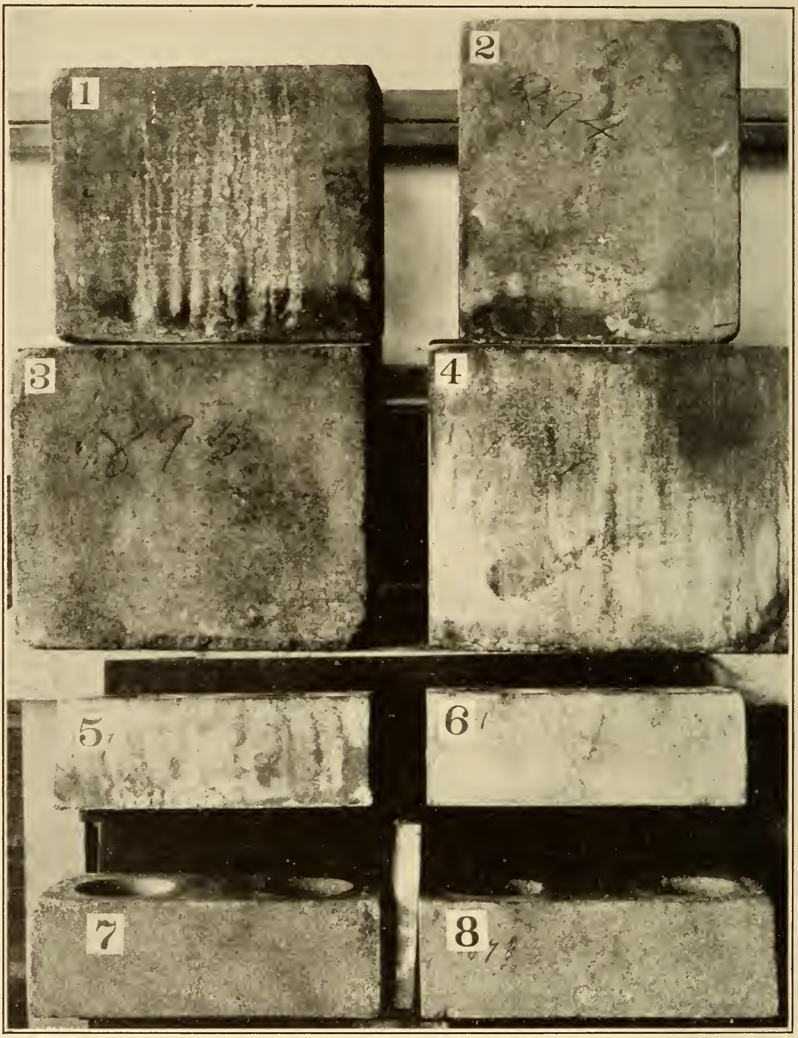

Fig. 15.—*Tests showing effects of leaching limestone with pure water*

spicuous spots of brown discoloration occurred on other blocks, but not of sufficient intensity to merit attention. This group of tests indicates that water alone may, after prolonged leaching, cause staining.

Another group of tests consisted of leaching water first through mortar and then through the limestone. In a part of these tests distilled water was used and in the others ordinary tap water was used. In each case the results were identical, which fact seems to eliminate the suspicion that staining may come from impure water. In Figure 16 is shown a group of these tests after a few weeks of leaching. All tests were with mortars and limestone except the left end of block No. 2, which was with a solution of sodium hydroxide instead of mortar. On the right half of block No. 4 a Portland cement mortar was used which contained an abnormally high amount of iron, while on the left side of the same block a mortar was used which consisted of a normal Portland cement. These two tests, side by side, afford very good evidence that the iron content of the cement has nothing to do with staining, since the cement containing a large amount of iron produced no appreciable staining while the other produced a heavy stain. The test with sodium hydroxide seems to indicate that the alkaline condition is mainly responsible for the appearance of such discolorations. While it is well known that all mortars are somewhat alkaline, a careful study of the difference in alkalinity for the mortars used indicated that this did not account for the different results obtained in these tests.

Further tests of this nature have indicated that any particular kind of mortar may produce variable results when used on several blocks of limestone from the same quarry. This fact seems to show that the organic impurity in the stone varies from one point to another or occurs in segregated masses. The same conclusion may often be drawn from observation of the way limestone discolors buildings. A particular block in the wall sometimes discolors badly while adjacent blocks are not appreciably changed.

In order to identify the composition of the staining matter, it was necessary to obtain a larger sample than can ordinarily be scraped from the surface of limestone. It was found that when limestone is dissolved in hydrochloric acid the organic impurity remains as a residue, so a rather large sample was obtained in this way. E. H. Berger, formerly of this bureau, conducted a series of tests on this material, and the report follows:

The sample consisted of a very finely divided sandy substance containing a brownish-black waxy material. It weighed 18 g and was obtained as a residue on dissolving 2,000 g of Indiana limestone in chemically pure hydrochloric acid and amounts to about 0.9 per cent of the limestone. On analysis this residue was found to consist chiefly of clay with about 10 per cent of a substance of an organic nature. The residue, both before and after drying, was treated with carbon bisulphide, carbon tetrachloride, chloroform, ether, benzol, mineral spirits, aqueous sodium hydroxide (specific gravity 1.2), and pyridine. It was found to be insoluble in all of these substances except pyridine, in which solvent a sufficient amount was dissolved to impart a dark-brown color. On destructive distillation the residue yielded greenish yellow gases and a few drops of a tarry substance similar to that obtained in the destructive distillation of bituminous coal.

About 1 g of the residue was tested for manganese by the sodium bismuthate method, and a slight trace was found. It, however, was no stronger than that obtained on the original stone.

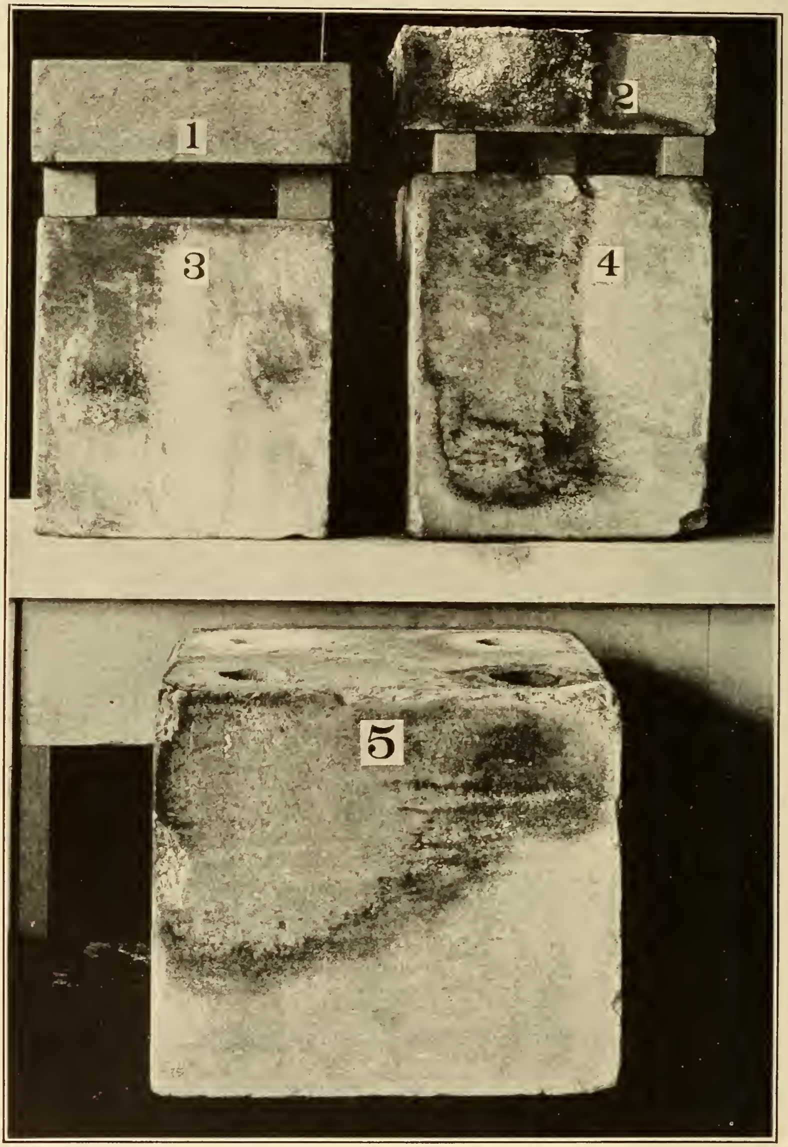

FIG. 16.—*Tests showing effects of leaching water through mortar and various limestones*

Samples of the badly stained layer were taken from several pieces of stone and tested for manganese by the sodium bismuthate method. Slight traces were found which were no stronger than that obtained on the original stone.

A piece of the stone was ground to pass a 200-mesh sieve and boiled for 20 minutes with sodium hydroxide solution (specific gravity 1.2). No coloration of the solution or the stone was observed.

The above tests all indicate that the stain which is developed on Indiana limestone on exposure to the air and to water containing alkali from mortar is of an organic nature. The organic substance present in a very small amount (about 0.1 per cent) in this stone is related to bituminous coal.

Probably the discoloring matter is altered after exposure to air because old stains of this kind on buildings are very difficult to remove. However, when freshly leached from limestone with a solution of sodium carbonate it is easily dissolved in water. The following study of a sample obtained by leaching a block of limestone for five days with a 5 per cent sodium carbonate and washing off the discoloration with water, was made by T. P. Sager, of this bureau:

	Per cent
Organic matter in solution	0. 37
Total organic matter in sample	. 38

The analysis indicates that the greater part of the organic matter was dissolved by the water used to wash the surface deposit from the stone.

The most plausible explanation of such discolorations on limestone is that water in leaching through the masonry becomes somewhat alkaline in passing through the mortar, and thus acts as a solvent on a part of the organic impurity in the stone. This solvent action of caustic solutions on organic matter is frequently made use of in detecting the presence of organic impurities in sand. A similar series of tests were made on various limestones by leaching out the organic matter with an alkaline solution. In these experiments it was found that a 5 per cent solution of sodium carbonate was more effective in bringing out the organic impurity than sodium hydroxide, hence the comparative tests were made with the carbonate solution. Specimens of the same type used for absorption tests—namely, 2-inch cylinders 2¼ inches high—were placed in beakers which were then partly filled with the Na_2CO_3 solution, so that the stone was about one-half above the liquid. These were let stand for seven days, which operation resulted in bringing to the surface of the stone an appreciable amount of the impurity when present. From two such tests on each stone the discoloration was collected and made up to 200 cc with water. In this way a measure of the relative amounts of impurities were indicated by the intensity of color shown from the various tests. By this means it was found that a considerable number of the limestones did not indicate any appreciable amount of discoloring impurity. These, designated by their serial numbers as given in the first column of Table 1, page 560, are as follows: 6, 7, 102, 110, 115, 118, 119, 120, 121, 125, 126, 127, 128, 129, 131, and 132. Another group showed the presence of a very slight amount of impurity; namely, 11, 51, 66, 67, 75, 86, 111, 112, 113, 114, 116, 117, and 130. The third group, which indicated an appreciable amount of organic impurity, were compared in the following manner

A considerable amount of a solution of somewhat deeper brown color was made up for a standard. Two graduated cylinders of the same size placed side by side were filled to the 50 cc mark—one with the standard solution and the other with the particular sample in question. Then, the standard solution was diluted with water until the color of the two appeared the same. The ratio of the two volumes was then computed and considered as an index of the relative amounts of organic matter leached from the two samples. Thus, if the standard had to be diluted with 50 cc of water to bring it to the same color as a particular sample the ratio would be 50:100, that is, the sample contained one-half as much organic matter as the standard. The results of tests on those limestones showing an appreciable amount of organic matter are listed below in order of increasing amounts.

Serial No. of stone	Ratio	Serial No. of stone	Ratio	Serial No. of stone	Ratio
2	0.06	20	0.33	32	0.50
133	.07	47	.33	43	.50
51	.08	88	.33	89	.50
59	.08	23	.40	90	.50
4	.17	25	.40	13	.67
31	.25	10	.50		

These tests show that some limestones contain practically no organic matter that can be easily leached out, while a large group contain a considerable amount. All of the third group would probably be subject to staining in a structure by the organic matter contained in the stone, while the first and second groups would not be at all likely to stain from this cause.

While the tests last referred to were limited to a few samples and are not intended to be a complete study of the subject, the results indicate that such means would prove valuable in determining whether any particular limestone contains an appreciable amount of organic impurity. Usually the amount of such organic impurity is so small that a quantitative analysis does not give much information. Furthermore, if organic matter is found by a chemical analysis it does not prove that the impurity is in a form which can easily be leached out or cause stains. As an indicator of such impurities this test can easily be applied anywhere, since no special apparatus is necessary, and the only chemical required can be purchased at any drug store. An irregular shaped piece of stone partly submerged in a weak solution of sodium corbonate should indicate within a few days if an appreciable amount of discoloring matter can be leached out. This, in a positive test, comes to the surface of the stone above the liquid with an efflorescence caused by the recrystallization of the sodium carbonate where the solution evaporates. If the efflorescence is entirely white, the test may be interpreted as negative; that is, no appreciable amount of organic impurity is present. In a positive test the crystals will be discolored, usually brown or dark.

Some limestones contain an appreciable amount of oil which comes to the surface as the stone seasons. This causes a rather uniform murky appearance until the oil has evaporated, after which the stone assumes its natural color. This type of impurity in limestone does not readily respond to the test with sodium carbonate, but it may be determined by soaking a handful of the stone fragments a few days in a bottle of benzol. The oily matter is diffused through the benzol, giving a brown color.

The question of how to prevent discoloration on limestone is frequently asked. Probably the best recommendation that can be made in this connection is to prevent excessive percolation of water through the masonry. Observations usually show that a common condition which causes discoloration is that of starting the limestone work below grade. Limestone being a rather porous material, it allows a great deal of moisture to rise by capillarity through its pores when in contact with moist soil. Under such conditions a large percentage of limestone buildings develop discolorations on the first two or three courses above the ground level. To prevent this, a grade waterproofing may be used, in which case one should be selected that is known to be durable. Doubtless the best means to prevent discoloration on the lower courses of limestone is to use a granite foundation or one course of granite extending through the wall at or somewhat above grade. A thin course of slate has been employed to some extent and appears to be an excellent material for the purpose. Other parts of buildings subject to excessive staining are those immediately below projecting courses, as the cornice and water table. Frequently the roof drainage system becomes faulty, allowing the walls to become saturated at various points, which condition is apt to produce discoloration. Obviously, the remedy in the last case is to repair the drainage system. Discolorations below projecting ledges may be largely overcome by sealing the vertical joints with a good mastic cement and waterproofing the top face of such courses with a colorless waterproofing. The type of waterproofing that has shown the best results consists of paraffin dissolved in a suitable solvent. Such a material may be made by dissolving about three-fourths of a pound of 45° C. melting point paraffin to the gallon of benzol. This should be applied like paint when the stone is entirely dry. Usually two coats are desirable, the second to be applied 24 hours or more after the first. Due to the fact that this waterproofing changes the appearance of light-colored stones somewhat, one should be careful in its use on ledges not to let it run down over the vertical faces.

While there is some evidence that when certain types of mortar are used discolorations are less apt to occur, it is practically certain that stains will occur with any mortar where excessive amounts of water percolate through the masonry. Since the composition of any cement or lime is apt to vary considerably from year to year due to changes in composition of raw materials employed, it is doubtful if a recommendation for the use of any particular brand of cement is justified. Probably the worst cases of discoloration occur while buildings are being erected due to rains on the open walls. Many builders cover the tops of the walls with waterproof canvas or similar material during rains, which practice is believed to be very commendable and should be generally followed.

XVIII. WEATHERING QUALITIES OF LIMESTONE

In studying the weathering qualities of stone in the laboratory the usual procedure is to determine the effect of freezing and thawing on the compressive strength. Six or eight specimens of the sample in question are prepared; half of them are tested for compressive strength in the original state and the other half for the same property after 25 freezings. The principal objection to this procedure is that the original strength of the specimens which are frozen is not known and can be only approximated. In this procedure it frequently happens that the strength tests on the frozen specimens are higher than that obtained on those in the original condition. If one applies the same reasoning in such cases as when the frozen specimens give lower strengths, the conclusion would be that the material was improved by frost action.

In the weathering tests made for this report the specimens were frozen and thawed until disintegration occurred, and the number of freezings required to produce a certain state of decay was used as an index of durability. This in many cases was a long, tedious procedure and would not be at all feasible for a routine test. In a series of tests of this kind it is believed to be justified, first, by the fact that the information gained will be of value as long as the tested deposits of stone are worked, and, second, because it is desirable to find some reliable means of recognizing good or bad weathering qualities by means of simpler tests. In order to study the latter phase of the problem, one must first gain some reliable information in regard to the weathering qualities of the materials. Another departure from the usual procedure in these tests was that of freezing the specimens in a partly saturated condition, the degree probably being more nearly comparable with that which occurs in masonry walls. The specimens were after each freezing immersed in water at about 20° C. for 30 minutes, which effected complete thawing and approximated the saturation that an exposed stone would receive in an ordinary rain. Even this period of soaking probably caused the stone to be frozen in a higher state of saturation than ordinarily occurs in buildings, because under service conditions the stone usually has a considerable time to dry after rains before freezing temperatures are reached. Probably the worst condition in buildings occurs when snow is lying on the coping, cornice, etc., and this thaws slightly in the middle of the day, which keeps those parts of the masonry fairly well soaked until freezing temperatures are again reached. Also, the lower courses of masonry are kept in a damp condition due to moisture rising through the stone by capillarity. Other parts of buildings are less subject to soaking, and while the condition of saturation in the tests may be comparable with that of the more exposed part of the masonry it would probably be overdrawn for other parts. However, tests can never entirely reproduce actual conditions, and the best that can be done is to establish such conditions as are practical and keep them constant for all the tests. In this way the results on one material becomes comparable with those on other materials.

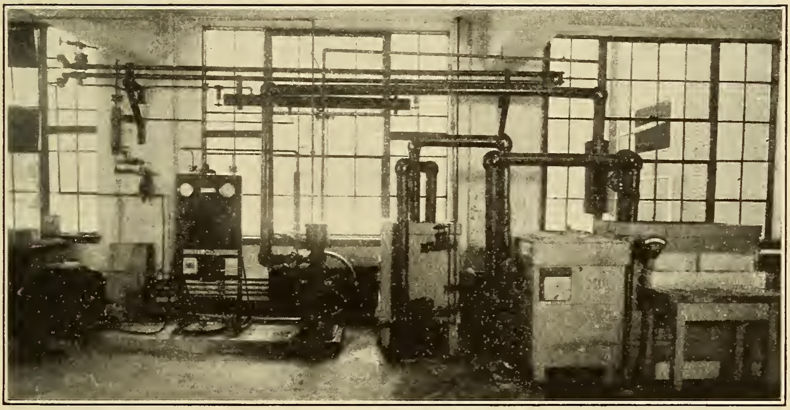

Fig. 17.—*Apparatus used in making frost-action tests*

The apparatus used in the freezing tests shown in Figure 17 consisted of a 1-ton-capacity ice machine which cooled the low-temperature chambers where the specimens were frozen. One chamber was equipped with an automatic thawing device which permitted three or more freezings to be made each day, depending on the size of the charge. The other chamber was operated by hand; that is, the specimens were removed when frozen and placed in water for 30 minutes. With this only two freezings could be made in a day.

The temperature of the brine surrounding the freezing chambers was maintained at −14° C. Thawing was done in tap water the temperature of which varied from 15 to 20° C.

The specimens were frequently examined and graded by an arbitrary system in which eight stages were recognized. The first of these was called the "a" condition, which showed no effects of frost action, and the last the "h" condition, at which the specimen was practically destroyed. The intervening steps were approximated as equal stages of decay between "a" and "h." The eight specimens in Figure 18 are intended to represent the various stages as indicated. However, the manner of disintegration may be very different for different materials, and no photograph could properly illustrate the various stages of decay in all cases. A group of disintegrated specimens showing the manner in which frost attacks different limestones is illustrated in Figure 19. In Table 14 are given the results of tests

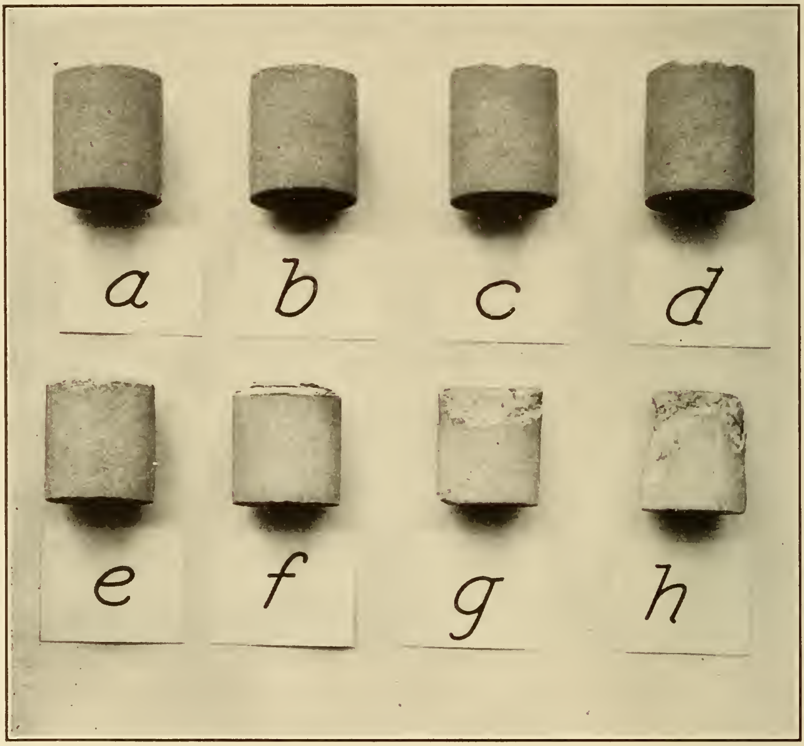

FIG. 18.—*Specimens from freezing test illustrating various stages of decay, which are designated a, b, c, etc.*

as far as they are completed. Where the final stage has not been reached some idea may be gained of the resistance to frost action by noting the progress during the stages passed. It will be seen that some of the materials disintegrated in less than 100 freezings while other have passed 2,900. These results afford some evidence of the relative durability of the different limestones when used under similar climatic conditions and where frost action is the chief cause of deterioration. It should be understood, however, that frost action is not the only element that may take part in the destruction of stone. Other considerations will be discussed in the following chapters.

Having gained some information as to the relative durability of different deposits, it becomes a matter of interest to estimate the number of years' service that may be expected from these various materials. This would involve the determination of a relation between the number of freezings required to produce disintegration and the number of years' service to which this is equivalent. Evidently any estimate of this kind can not be more than an intelligent guess. Some information may be gained by the study of climatic conditions.

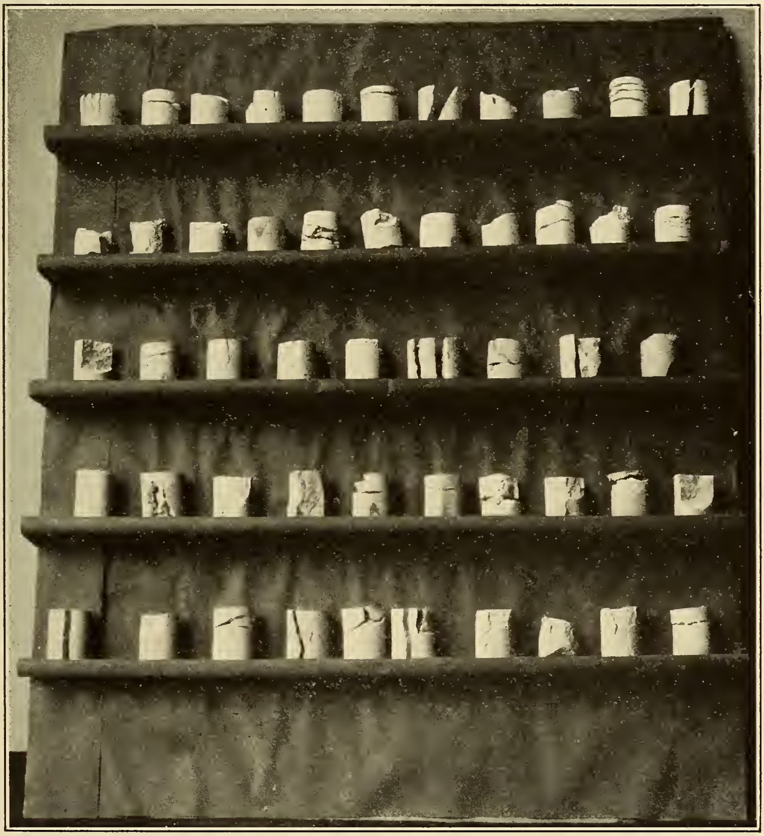

FIG. 19.—*Results of freezing tests on various limestones*

The temperature and precipitation records for three winters at Washington were examined. It was assumed that temperatures 2° below the freezing point or lower would congeal the moisture in the stone. The number of times the temperature fell below this point after thawing weather were counted. Unless precipitation had occurred within 24 hours previous to such temperature drops they were not counted, since it is probable that the stone would be too dry to be injured. The average number of freezing spells so counted for the three winters was 16. This may be near enough to the average climatic condition for estimating purposes. If each freezing were as severe as the test conditions, one could estimate with some degree of accuracy how long the various materials would last in this climate, but evidently stone in a building has more time to dry before freezing occurs than the test specimens have. It would probably be fair to assume that one-fourth of this number are severe; that is, one year of actual weathering is equivalent to four freezings under the test conditions. On such basis the least resistant materials, which were disintegrated in 100 freezings, would give 25 years' service, and those that withstood 1,000 freezings would be good for 250 years.

A more logical course in drawing a relation between the freezing test and number of years' service is to make tests on materials which have been in use for a long period of years and show approximately how many years' service can be expected from them. This procedure in this country is hardly possible because our stone buildings are not old enough to show advanced stages of decay.

About 50 years ago Professor Julien made a rather extensive study of stone weathering on buildings in New York City. In his report he concluded that the durability of limestone in that city varied from 20 to 40 years. In the light of present observations this limit appears to be much too low, and it seems probable that his studies were based on inferior materials. However, under certain severe conditions which sometimes arise, almost any kind of masonry may disintegrate within a few years. In estimating the weathering qualities one should discriminate between such local conditions and those which are general in their action.

Sixty-five samples of limestone were included in the freezing tests which were chosen as well as possible to represent the various producing districts. Usually three specimens of each sample were so tested, but in some cases a larger number was used. It frequently happened that specimens from the same sample showed a large difference in resistance to frost action, or in some cases one part of a specimen would disintegrate readily, the remaining part holding out in a sound condition for several hundred freezings. In computing the following summary of results the average number of freezings required to disintegrate all the specimens of a certain sample to the "h" condition was considered as the "resistance number" of that sample:

1.6 per cent of samples failed in less than 100 freezings.
11.0 per cent of samples failed in less than 200 freezings.
19.0 per cent of samples failed in less than 300 freezings.
25.0 per cent of samples failed in less than 400 freezings.
30.0 per cent of samples failed in less than 500 freezings.
33.0 per cent of samples failed in less than 600 freezings.
35.0 per cent of samples failed in less than 700 freezings.
41.0 per cent of samples failed in less than 800 freezings.
44.0 per cent of samples failed in less than 900 freezings.

The number of samples which required more than 1,000 freezings to produce the "h" condition was found to be 38 per cent of the total.

Since it is a matter of considerable interest to determine how far the simple tests, such as compression, absorption, and porosity, can be depended upon in judging weathering qualities, the curves in Figure 20 have been plotted to indicate the various relations. In this figure the vertical lines *l*, *m*, *n*, etc., represent different groups of specimens, as follows: *l* that group which failed in less than 100 freezings, *m* that which failed between 100 and 200 freezings, *n* that which failed between 200 and 300, etc. The average values of com-

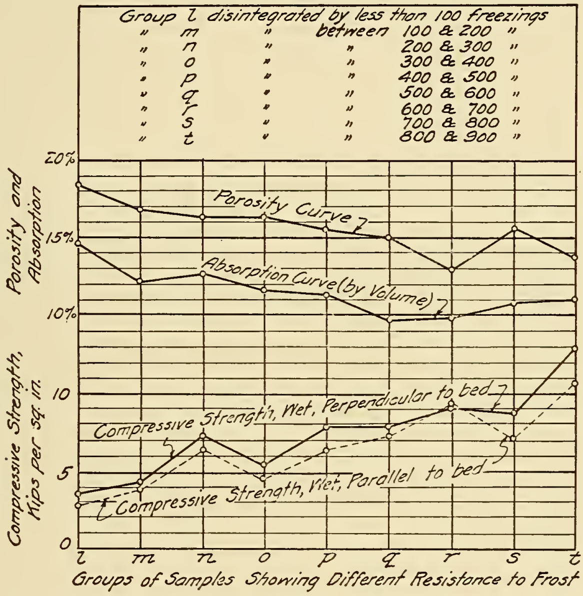

FIG. 20.—*Relation of porosity and strength to frost resistance*

pressive strength, absorption, and porosity were plotted on the respective lines as indicated by the vertical scales. The strength values used were those obtained by testing the materials in the wet condition. The curves indicate in a general way that the higher strengths and lower porosity or lower absorption values are favorable to frost resistance. However, one can choose several individual samples from this series of tests which have low strengths and high porosity values but have shown good resistance to frost. Hence it seems quite likely that there are other properties than strength and porosity which influence weathering qualities. As pointed out in Bureau of Standards Technologic Paper No. 305, there appears to be some significance to the permeability of stone in this respect. Apparently a stone of low strength and high porosity may show good resistance to frost if it has an open texture; that is, if the stone offers little resistance to the flow of water through the pores.

XIX. EFFECTS OF EFFLORESCENCE

The disintegrating effect of efflorescence on masonry has often been pointed out by various authorities, but its importance has probably never been fully appreciated. Efflorescence is more often regarded as merely a disfiguring deposit of salts on the surface. However, an examination of the surface where such deposits occur will sometimes show an appreciable amount of decay if not a deep spalling or crumbling of the masonry.

Efflorescence is a growth of crystals on the surface and in the pores of the masonry where a salt solution evaporates. The solvent carrying the salt is probably always water. The source of the salt may be varied, but in most cases it is leached from the masonry walls by water as it slowly percolates through the pores. No building material is entirely free from water-soluble salts, and the small amounts of such which usually appear in chemical analyses as a few tenths of 1 per cent are sufficient when leached out and concentrated at some point on the surface to cause efflorescence. It may also be caused by salts carried by ground waters, and the efflorescence frequently seen on the lower courses of buildings is more apt to be due to this cause. Soot which collects on roofs and horizontal parts of masonry always contains a small amount of water-soluble material which may be leached into the masonry by rains. Buildings near the seashore are often affected in this way by sea salts which are carried through the air by the spray. Severe cases of efflorescence have been known to occur due to building contractors using common salt to thaw ice out of the Lewis holes before hoisting blocks into place. The use of common salt to thaw ice from stone steps is frequently practiced and part of the salt is carried into the stone which reappears on the surface when the stone dries. Efflorescence is not confined to the outside of masonry but sometimes occurs on the interior, particularly on the inside of basement walls.

The composition of the salts causing efflorescence may be as varied as their source. Any salt that is soluble in water even to a very slight degree may be finally dissolved and leached to the surface under continued damp conditions. Even a part of the calcium carbonate of limestone is sometimes dissolved when water trickles down between the stone facing and masonry backing. When the solution finds its way to the surface and evaporates, a crust or stalactite may be formed on the exposed surface. Such formations are frequently found on the soffits of masonry arches. Chemical examination of three samples of this hard incrustation from stone structures gave the following compositions:

	No. 1	No. 2	No. 3
SiO_2	3.40	0.40	
Fe_2O_3 and Al_2O_3	2.80	1.20	Trace.
CaO	50.60	52.45	50.00
MgO	Trace.	Trace.	
SO_3	Trace.	Trace.	
CO_2	34.60	35.70	3.92
Ignition loss	43.00	45.76	38.58

These analyses indicate that the composition is mainly calcium carbonate.

Samples of efflorescence collected from limestone masonry accompanied by disintegration gave the following composition:

	No. 5	No. 6		No. 5	No. 6
SiO_2	0.28	2.20	SO_3	42.32	5.40
Fe_2O_3 and Al_2O_3	.10	3.00	SO_2		3.25
CaO	31.30	46.90	Ignition loss	25.03	34.60
MgO	1.33	Trace.			

The composition of these seem to be mainly water-soluble sulphates.

Two samples of efflorescence collected from sandstone masonry where disintegration had occurred were analyzed and the results follow:

	No. 8	No. 9		No. 8	No. 9
SiO_2	0.00	0.01	Cl	0.03	0.04
A_2O_3 and Fe_2O_3	.02	.03	SO_3	2.97	10.77
CaO	.41	.26	CO_2	.07	.14
MgO	.82	4.34	Ignition loss	.64	1.57
Na_2O	.50	2.27			

These analyses indicate that the materials consist chiefly of calcium magnesium and sodium sulphates.

In general, it may be said that any soluble salt that is present in the masonry may under damp conditions cause efflorescence. The more common salts found in masonry and their solubilities expressed as the number of grams that can be dissolved in 1 liter of water at 20° C. are as follows:

	Solubility grams per liter
Sodium sulphate ($Na_2SO_4,10H_2O$)	194
Magnesium sulphate ($MgSO_4,7H_2O$)	356
Calcuim sulphate ($CaSO_4$)	2

Other salts which may occasionally be present in the masonry or find admittance from external sources are:

	Solubility grams per liter
Sodium carbonate (Na_2CO_3)	214
Potassium sulphate (K_2SO_4)	111
Sodium chloride (NaCl)	358
Potassium chloride (KCl)	343
Calcium chloride ($CaCl_2$)	745

Limestone itself evidently contributes an appreciable amount of soluble matter in the formation of efflorescence. The efflorescence shown in Figure 21, *LL*, was leached from the blocks of stone with pure water. Three grams of this material were scraped from one block and found to contain the following:

SiO	0.28	MgO	1.33
Al_2O_3 and Fe_2O_3	.10	SO_3	42.32
CaO	31.30	Ignition loss	25.03

This is shown to be mainly calcium and magnesium sulphates.

As a rule, natural stone may be lower in water-soluble matter than artificial products, although one is probably never justified in saying that any one material is entirely responsible for the formation of efflorescence. Other materials shown in Figure 21 are brick (*B*), natural cement mortar (*M*), and sandstone (*S*). All of these developed considerable efflouresence after being leached with pure water.

The disintegration action of efflorescence is similar to that of frost. When the solution of salts evaporates, the salts are left behind and form crystals. Some of the crystals develop in the pores of the stone and in their growth exert a wedging action which gradually pries loose small fragments from the surface. This action is far more severe and shows its effects more rapidly than frost, although it manifests itself in a different way. A stone when frozen in a water-saturated condition may be subjected to stress all the way through and it may be disrupted along a seam of weakness, although this seldom occurs except with freshly quarried blocks. In the case of efflorescence the wedging action is only near the surface, since crystals can not form except where evaporation occurs. Under continual dampness on the walls efflorescence may occur, but all the crystals will necessarily be on the surface and no decay will ensue. For this reason one frequently finds that the masonry near the ground level is in good condition while at a certain height above the ground a zone of decay is noted. This is evidently due to moisture rising from the ground which keeps the lower part continually damp, but where the damp condition ceases the crystals of dissolved matter form in the pores.

The rapidity of decay from severe cases of efflorescence is proven by the fact that noticeable disintegration sometimes occurs within a year after the structure is completed. Even the densest and strongest materials are not immune to such action, although such materials are usually more resistant to this condition than the weak and porous ones. The effect of this action on any porous material may be demonstrated by placing a small column of the material upright in a shallow basin and keeping a salt solution in the basin. The solution will be drawn up through the pores and form an efflorescence on the surface above the solution. Usually disintegration will occur under such conditions within a few weeks.

Figure 21 shows efflorescence on specimens of stone, brick, and mortar formed by leaching water through the materials in a manner similar to that described above. A noticeable amount of decay was produced on some of these tests. It will be noted that some stone specimens effloresced near the middle while others effloresced only at the top. This is due to the difference in density of the stones. Those of greater density do not become damp to as great a height as the more porous ones and, as previously pointed out, the crystals are deposited at the top of the damp part.

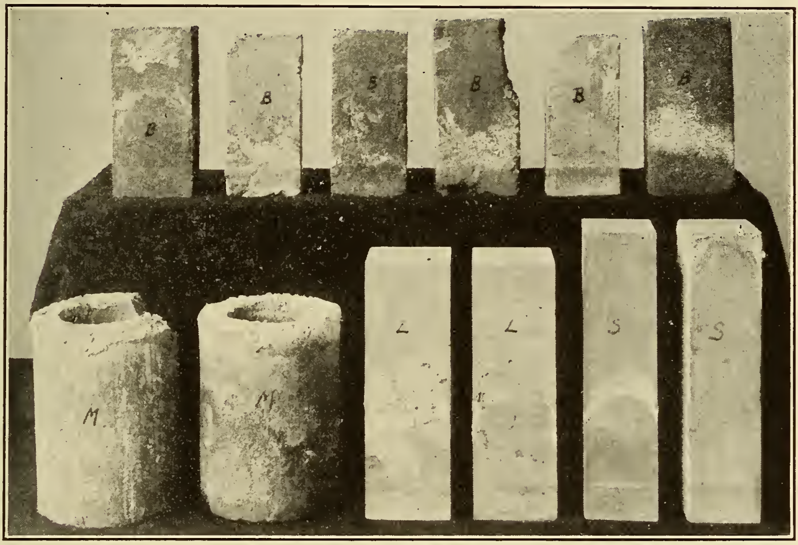

FIG. 21.—*Efflorescence on brick, mortar, limestone, and sandstone due to leaching with pure water*

XX. ARTIFICIAL WEATHERING TESTS

A method, which consists in crystallizing a salt in the pores, is sometimes used for simulating the effects of frost action. This is done by soaking the stone in a salt solution and then drying it to cause the salt to crystallize. The crystals in forming cause internal stresses in the stone somewhat like that of frost. The salt which has been mostly used for this purpose is sodium sulphate. The information available on the action of this salt indicates that it causes a very severe action, and that many materials are disintegrated by a few repetitions of the operation. While the test is assumed to produce only a physical action, there is evidence that in some cases there is a chemical action as well. Due to the fact that this salt crystallizes in three common forms—namely, Na_2SO_4, $Na_2SO_4,7H_2O$ and

$Na_2SO_4,10H_2O$—it appears that the conditions of the test must be carefully controlled in order to insure the formation of a particular type of crystal, since a variation from one to another may cause variable results.

Since a test of this kind is very desirable in some respects, a rather extensive series of tests was made to determine if sodium chloride would prove more satisfactory than sodium sulphate. This crystallizes in only one form and appears to be free from chemical action on such materials as limestone. Tests were made with a 15 per cent

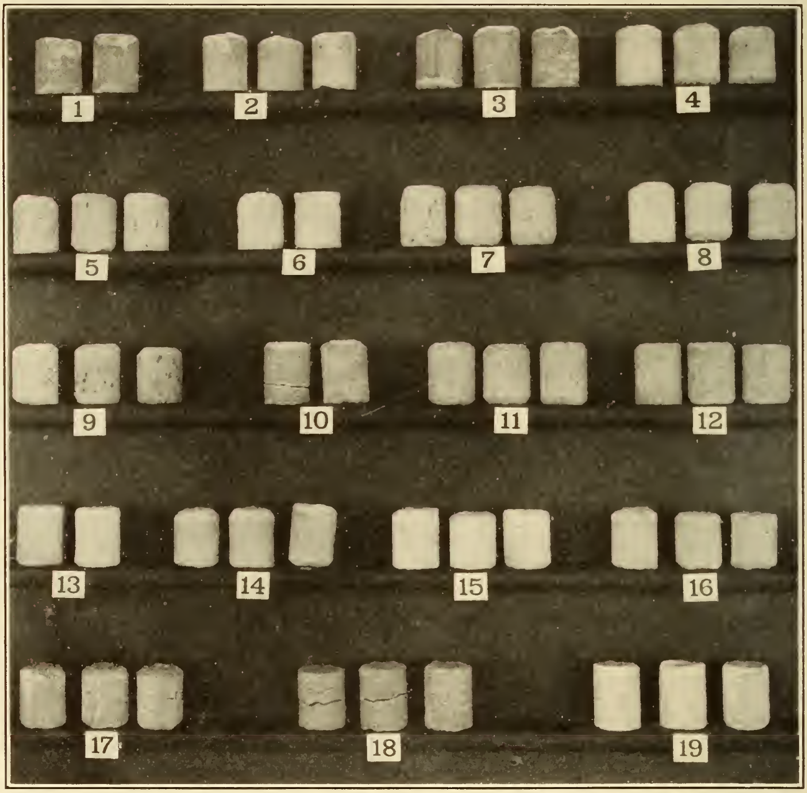

FIG. 22.—*Effects of artificial weathering tests with a 15 per cent solution of sodium chloride*

solution of this salt by soaking the specimens in the solution for 17 hours and drying them in an oven at 110° C. for 7 hours. It was found that certain limestones which were disintegrated by 30 repetitions of this process would require from 210 to 300 freezings to produce the same amount of decay. Certain other limestones indicated a greater resistance to the crystallization test than to frost action. This lack of agreement with the freezing test indicates that the results are not reliable for judging weathering effects. It may, however, afford some information in regard to how a material would resist the disintegration effects of efflorescence.

Figure 22 shows a set of specimens which were subjected to the sodium chloride crystallization test. It will be noted that in most cases the decay manifests itself as a gradual crumbling of the surface, while the freezing test more frequently produces spalls, or often splits the specimen. This is evidently due to the fact that as the salt solution is drawn to the surface in drying practically all of the crystals form on or slightly under the surface. Hence, the interior is not stressed in this case, but when a stone is saturated with water and frozen ice, will form wherever water is present. This difference in the action of the two tests indicates that the crystallization method may not be a reliable means of determining weathering qualities.

XXI. CHEMICAL EFFECTS OF THE ELEMENTS

Most limestones, being composed mainly of calcium carbonate, are readily attacked by acids. Rain water, being slightly acidic, has a slow solvent action on the parts of limestone masonry exposed to the rain. The surface solution goes on at such a slow rate that it is not usually noticeable except on delicately carved parts which are freely exposed. In general, this action is advantageous, since it tends to keep the surface fresh and clean. Sometimes it will be noted that limestone buildings appear cleaner than many other kinds of masonry.

Those limestones of a dolomitic nature are not so readily dissolved by acids, and hence do not weather from this cause at the same rate as those which are mainly calcium carbonate.

XXII. RELATION OF VARIOUS TESTS

In a series of tests of this kind it becomes a matter of interest to determine if any definite relations exist between various tests. In Figure 23 the ratios of certain values have been plotted for the tests of different samples. The serial numbers of the samples are denoted by the horizontal scale, and the vertical scale is used for ratios. The lower curve gives the ratios of tensile strength to compressive strength. All the strengths used were those obtained by testing the material perpendicular to the bedding. It will be noted that the tensile strengths obtained were all less than one-tenth of the compressive strength, while some were as low as 0.03 of the compressive strength. The average ratio so obtained is approximately 0.05.

The second curve from the bottom gives the relation of transverse strength to the compressive strength. It will be seen that most of the ratios fall between 0.1 and 0.3, but a few fall below 0.1. The average ratio obtained for tests on 103 samples or by approximately 200 individual tests was 0.166.

The third curve from the bottom gives the ratios of shearing strength to compressive strength. Thirty-six samples were considered in determining these ratios, or approximately 100 individual tests. The average ratio so obtained was 0.20.

Another curve is plotted from the volume absorption values divided by the total pore space. The absorption values were those obtained by soaking the specimens totally immersed for two weeks in water at ordinary room temperatures. It will be seen from this curve that the degree of saturation obtained on different materials

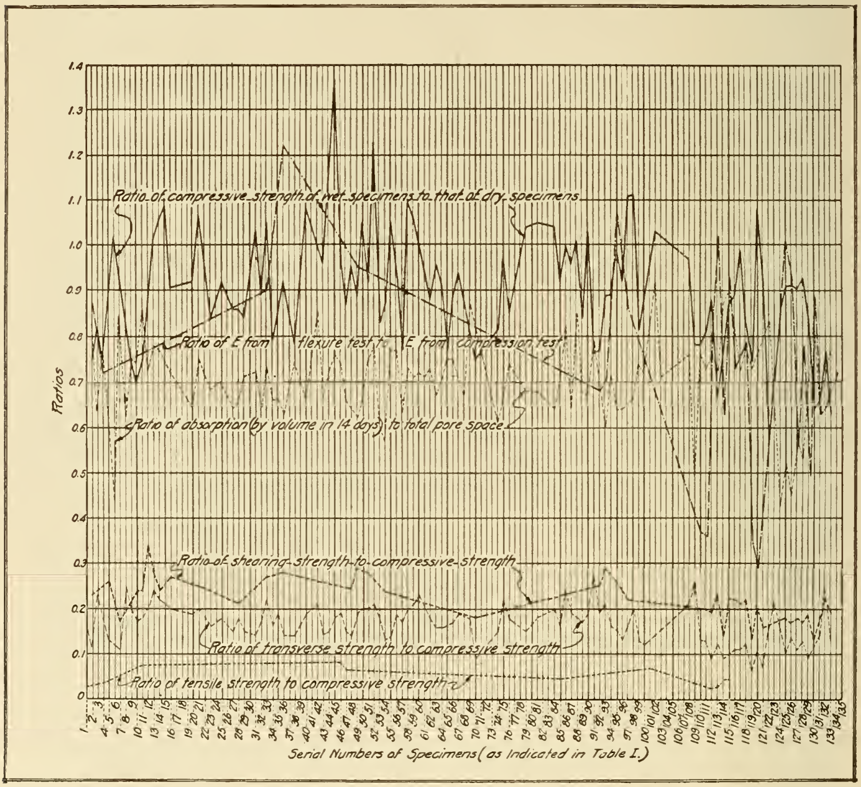

FIG. 23.—*Ratios of various tests*

during this period of immersion varied considerably, the lowest shown being 0.43 and the highest 0.91. The average saturation for all the tests was 0.70.

A curve near the top shows the relation of compressive strength wet to compressive strength dry. While this curve shows a considerable number of points above the 1.0 line, which indicates that certain materials are stronger in the wet condition than the dry, the average for all was found to be 0.90.

The ratio of the modulus of elasticity obtained from the flexure test to that obtained from the compression test is seen to be a rather uncertain quantity. As shown by the curve, the lowest ratio was 0.29 and the highest was 1.22. In plotting this curve the flexural values of E obtained in the tests "perpendicular" were divided by those obtained from the compression tests "parallel." The reason for this is that in both tests the strain is measured in the same direction of the stratification. It appears that the values of E determined in the flexure test "parallel" could also be compared to those obtained in compression "perpendicular," since these two tests strain the stone perpendicular to the stratification. However, the values obtained in the flexture tests "parallel" are quite variable and occasionally very low, probably for the reason that the strength of limestone is rather uncertain along the bedding planes when submitted to tension. The average ratio of E in flexure to E in compression obtained from

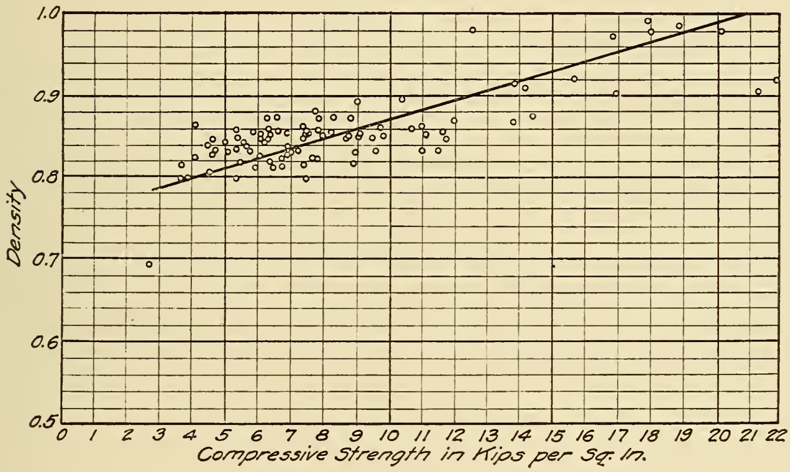

Fig. 24.—*Ratio of compressive strength of density*

the values used for the curve is 0.75. This average is obtained from tests on 29 samples, the number of individual tests being 211. By computing the ratio from the E values obtained in the flexture test "parallel" and those obtained in the compression test "perpendicular" the value was found to be 0.57. However, by discarding 3 samples, which appeared to give erratic results in the flexure test, the average ratio for the remaining 20 samples was found to be 0.76.

Figure 24 shows the results of compressive strength determinations plotted against densities. The strength values used were those obtained by testing the dry stone perpendicular to the bedding. The densities were obtained by subtracting the porosity values from unity. An average curve drawn for these points shows in a general way that compressive strength increases with the denisty. However, it is readily seen from this figure that stones of the same density often vary in strength by several thousand pounds per square inch. Evidently there are other factors than density which take part in determining the strength of limestone, as the amount and character of cementing material, amount of crystallized carbonates present, etc.

XXIII. ALABAMA LIMESTONE

Six samples of limestone from this State were tested, four of which were from Rockwood and two from Waco. Both materials are from a subcarboniferous deposit in the Tennessee Valley. This is a light-colored oölitic limestone that occurs in a formation of considerable thickness and extent. The samples received from Waco were somewhat lighter in color than those from Rockwood. An analysis at the Bureau of Standards of a sample from Rockwood gave the following composition:

	Per cent		Per cent
SiO_2	0.20	Na_2O	0.21
Fe_2O_3	.32	SO_3	.05
Al_2O_3	.28	Total S	.11
CaO	54.70	CO_2	43.13
MgO	.72	Loss on ignition	43.46

According to the State reports this material was first quarried in 1885 and has been used extensively in public buildings in Alabama and adjoining States. It is stated that the material has given very favorable results as a building material in comparison with other limestones of this type. The compression tests indicated values ranging from 5,000 to 14,600 lbs./in.^{2} for the dry stone and a reduction of from 20 to 25 per cent for the wet material. Absorption values ranged from 3.7 to 5.5 per cent by weight. Modulus of elasticity values were slightly above the average for this type of limestone. Permeability measurements indicate a rather close texture. Freezing tests on some of the samples indicated a rather unsatisfactory resistance to frost action, some of the specimens being destroyed by less than 100 freezings. Samples from a later development of this quarry showed a more satisfactory resistance to frost action. All tests indicated a tendency for the material to split in thin layers parallel to the bedding.

The following list of structures illustrating the use of this limestone was supplied by the Rockwood Alabama Stone Co. quarry, Russellville, Ala.

Structure	Location	Year built
Alabama Power Co. Building	Birmingham, Ala	1925
Southern Railway System Building	do	1924
Cumberland Lodge No. 8	Nashville, Tenn	1910
Fourth and First Bank Building	do	1917
Vendome Building	do	1923
Nashville Trust Building	do	1925
Life and Casualty Building	do	1925

SUPPLEMENT TO BUREAU OF STANDARDS TECHNOLOGIC PAPER No. 349[1]

[March 4, 1929]

(Insert at page 548)

Since the original issue of this report it has been noted that certain statements concerning the frost resistance of Alabama limestone have been frequently misconstrued. While laboratory determinations indicate that this deposit of stone has a resistance to frost action which is somewhat below the average for this class of materials it should not be assumed that the stone is unfit for use. The results of freezing tests given in Table 14 on page 585 when considered in acccordance with the plan for estimating durability as outlined on pages 537 and 538 indicate that this limestone should prove satisfactory for use in most types of buildings.

A recent study of a number of the buildings in which Alabama limestone has been used shows no evidence of decay. Some of these buildings are over 40 years old. Several old gravestones in the Alabama quarry region dated between 1813 and 1848 were examined, and no evidence of decay from frost action was noted.

This stone has a high degree of resistance to the disintegrating effect of efflorescence which, as explained in Section XIX of this report, is far more destructive than frost. Tests show that mortar stains may form on this limestone but they appear to be of a temporary nature.

XXIV. ILLINOIS LIMESTONE

Two samples of limestone from Illinois were tested for this report—one from Joliet and one from Quincy. At this time these materials were quarried intermittently to supply the local demands. The Quincy limestone belongs to the Burlington series and is worked mainly in the bluffs along the Mississippi River. The upper beds, being thin and cherty, are not used. According to the State reports the composition of this limestone varies considerably, as shown by the following limiting values:

	Per cent
$CaCO_3$	71. 00–94. 68
$MgCO_3$	4. 31–24. 00
Fe_2O_3 and Al_2O_3	. 64– 4. 00
SiO_2	. 37

The sample of this material received for testing was a bluish-gray stone which was very hard and showed a tendency to fracture in various directions.

The sample of Joliet limestone was from the Swan, Medin & Co. quarry, which is one-fourth mile southeast of the city. This is a very fine grained light gray dolomitic limestone from the Niagaran series, which is sometimes called the "Athens marble." The State report on this material gives several analyses which indicate that it varies between the following limits:

	Per cent
$CaCO_3$	47. 76–54. 67
$MgCO_3$	39. 00–42. 9
Al_2O_3 and Fe_2O_3	. 12–20. 3
SiO_2	3. 08– 9. 46

This limestone has been used locally to a considerable extent in the past. It contains minute particules of pyrite which causes it to weather to a buff color. Due to its hardness and uniform texture it is sometimes used for floor tile and pavements.

XXV. INDIANA LIMESTONE

Ninety samples of this limestone were secured for testing purposes which were selected from various quarries so well distributed over the district as to be thoroughly representative of the present-day product. This material has been variously designated as "Bedford stone," "Bedford oölite," "Salem limestone," and "Indiana oölitic limestone." It occurs in the lower carboniferous strata and outcrops in a zone of variable width from Putnam County southward to the Ohio River. The principal quarry districts are in Lawrence and Monroe Counties. It consists mainly of somewhat rounded shell fragments cemented together by calcite. Textures vary from fine to coarse, and the colors are designated as buff and gray. That part of the strata above the ground-water level contains the buff-colored stone, while that below is bluish gray when first quarried.

Several grades or types are recognized by the trade which are distinguished by texture and color. Passing from the fine textures to coarse these grades for the buff stone are designated as "statuary," "select buff," "standard buff," and "rustic." For the gray stone and mixtures of buff and gray the stock is designated as "select gray," "standard gray," and "variegated."

The following table gives the results of chemical analyses made at the Bureau of Standards on various samples. The serial numbers used at the head of the columns to designate all the materials in this table except the last two are described in the following table. Sample A was a composite formed by mixing together specimens of the buff stone from 19 quarries and B was a composite formed by mixing samples of gray stone from eight quarries.

Chemical analyses of Indiana limestone

[Alice W. Epperson, analyst]

	Serial Nos.						Composite A	Composite B
	8	63	64	46	85	93		
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
SiO_2	0.24	0.70	0.40	0.24	0.94	0.30	0.69	0.80
Fe_2O_3	.05	.08	.08	.05	.10	.05	.18	.12
Al_2O_3	.55	.68	.52	.75	.62	.61	.44	.68
CaO	54.80	54.54	54.70	54.60	54.50	54.80	54.58	54.40
MgO	.72	.59	.60	.68	.78	.38	.60	.56
K_2O	.00	.00	.00	.00	.00	.00	.00	.00
Na_2O	.005	.16	.16	.12	.21	.21		
SO_3	.07	.06	.05	.05	.22	.05		
Total S	.26	.25	.27	.85	.34	.63	Trace.	
Loss	43.53	43.31	43.00	43.57	42.56	43.60	43.58	43.45
CO_2	43.30	42.90	41.70	43.10	42.50	43.10		43.24
Organic matter	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	

An examination of all the available analyses on this limestone indicates the following range in composition:

	Highest	Lowest		Highest	Lowest
	Per cent	*Per cent*		*Per cent*	*Per cent*
Silica	1.75	0.15	Calcium carbonate	98.27	89.40
Iron oxides	3.00	.05	Magnesium carbonate	4.22	.11
Alumina	2.20	.06	Alkalis	.83	.005

The extreme values found in the physical data without regard to direction of bedding in strength tests are as follows:

	Highest	Lowest
Compressive strength, pounds per square inch	17,700	2,720
Modulus of rupture, do	2,020	540
Modulus of elasticity	5,450,000	3,310,000
Absorption by weight, per cent	6.68	2.41
Porosity, do	20.37	8.09
Weight per cubic foot, pounds	156	136

This material is so well known in all parts of the country that a list of structures seems almost unnecessary, but the following more prominent examples may be found of interest:

Post office, Birmingham, Ala.
Union Station, Little Rock, Ark.
City Hall, San Francisco, Calif.
St. John's Cathedral, Denver, Colo.
Music Building, Yale University, New Haven, Conn.
Interior Department Building, Washington, D. C.
Union Station, Jacksonville, Fla.
State Capitol Building, Atlanta, Ga.
Auditorium Hotel, Chicago, Ill.
Public Library, Chicago, Ill.
State Capitol Building, Springfield, Ill.
State Capitol Building, Indianapolis, Ind.
Post Office Building, Des Moines, Iowa.
State Capitol Building, Topeka, Kans.
Customhouse and Post Office, Louisville, Ky.
Post Office Building, New Orleans, La.
Courthouse, Portland, Me.
Baltimore & Ohio Railroad Co. Office, Baltimore, Md.
Massachusetts Institute of Technology, Boston, Mass.
Municipal Building and City Hall, Springfield, Mass.
General Motors Building, Detroit, Mich.
Union Station, St. Paul, Minn.
State Capitol Building, Jackson, Miss.
Union Station, St. Louis, Mo.
Post Office Building, Billings, Mont.
High School Building, Omaha, Nebr.
City Hall, Jersey City, N. J.
Metropolitan Museum of Art, New York, N. Y.
Courthouse, Syracuse, N. Y.
State Capitol Building, Raleigh, N. C.
Trinity Cathedral, Cleveland, Ohio.
State Capitol Building, Oklahoma City, Okla.
Library Building, Portland, Oreg.
State Library Building, Harrisburg, Pa.
State Capitol Building, Pierre, S. Dak.
Union Station Building, Memphis, Tenn.
City Hall, Dallas, Tex.
Cathedral High School, Burlington, Vt.
Union Station Building, Norfolk, Va.
Baltimore & Ohio Station, Wheeling, W. Va.
State Historical Library, Madison, Wis.
City and County Building, Cheyenne, Wyo.

While about 100 samples of this limestone were tested for various physical properties, only 35 samples were included in the freezing tests. These were chosen to represent, as well as possible, the various grades and types of this material. A considerable range was found in the resistance of this product to frost action as indicated by the following summary of the results:

2.8 per cent of samples failed in less than 100 freezings.
14.0 per cent of samples failed in less than 200 freezings.
23.0 per cent of samples failed in less than 300 freezings.
34.0 per cent of samples failed in less than 400 freezings.
40.0 per cent of samples failed in less than 500 freezings.
45.0 per cent of samples failed in less than 600 freezings.
48.0 per cent of samples failed in less than 700 freezings.
54.0 per cent of samples failed in less than 800 freezings.

The number of samples which were not destroyed by 1,000 freezings was 38 per cent of the total number tested.

XXVI. KENTUCKY LIMESTONE

The only limestone from Kentucky that was tested for this report was from the vicinity of Bowling Green, Warren County. This is an oölitic limestone similar in many respects to that from Indiana. The beds vary in thickness from 10 to 22 feet without seams. It varies in color from light gray to dark gray. The freshly quarried stone contains an appreciable amount of oil which imparts a rather murky appearance. On exposure this gradually evaporates, leaving a light-gray or nearly white stone. This limestone has been in use locally for more than 100 years, and the oldest buildings, according to the State report, indicate good weathering qualities.

Compressive strength tests indicate a range for the dry stone from 2,700 to 7,400 lbs./in.^{2} Absorption tests gave values ranging from 3.7 to 5.8 per cent by weight. The elastic properties are about normal for this type of stone. Freezing tests indicate a satisfactory degree of resistance to frost action, only one specimen out of 17 being destroyed by less than 900 freezings, while the greater number have shown slight change after 1,200 freezings. The specimen that failed did so by splitting parallel to the bedding, indicating that if the material is set on edge in the wall it would not prove as durable as when placed on its natural bed.

The following list of structures illustrating the use of Bowling Green limestone was supplied by the Bowling Green Quarries Co. quarry, Bowling Green, Ky.

Structure	Location	Year
John J. Raskob residence	Claymont, Del	1916
St. John's Cathedral	Jacksonville, Fla	1908
Chamber of Commerce	Atlanta, Ga	
Irving Park Boulevard Cemetery, entrance and office	Chicago, Ill	1920
Capital State Savings Bank	39 North Clark Street, Chicago, Ill.	1922
Lincoln Trust and Savings Bank	Chicago, Ill	1925
Bennet Building	Peoria, Ill	
Alfred E. Erskine residence	South Bend, Ind	1920
Louisville & Nashville R. R. Co. passenger station	Bowling Green, Ky	1925
Governor's Mansion	Frankfort, Ky	1912
United States Government Building	Lexington, Ky	
The Presbyterian Theological Seminary	First Street and Broadway, Louisville, Ky.	1906
First Christian Church	Louisville, Ky	1910
Speed Memorial Art Museum, University of Louisville	do	1925
Christian Science Temple	do	1919
Baptist Hospital	do	1923
St. Mary's Industrial Buildings	Baltimore, Md	1910–1922
Title Guarantee and Trust Building	do	1912
All Saints Parochial School	do	1924
Loyola College Gymnasium Building	do	1925
Immaculate Conception School Building	Towson, Md	1920
United States Government Building	Gulfport, Miss	1910
Hall of Records	Brooklyn, N. Y	
St. Thomas Cathedral	Fifth Avenue, New York, N. Y.	
Bryn Athyns Church	Bryn Athyn, Pa	
Miseri Cordia Hospital	Fifty-fourth and Cedar Avenue, Philadelphia, Pa.	1916
St. Vincent's Home, Drexel Hill	Philadelphia, Pa	1919
Girard Life Insurance Co	Fifth and Chestnut Streets, Philadelphia, Pa.	1918
Alfred E. Burke residence	Broad Street near Oxford, Philadelphia, Pa.	1910
Church of Our Lady of Victory	Philadelphia, Pa	
Gailox Memorial Cathedral	Memphis, Tenn	1923
Tennessee Trust Co	do	
United States Customhouse	Nashville, Tenn	1923
Peabody College Buildings	do	1912–1923
Sacred Heart Church	Washington, D. C	1921
Daughters of the American Revolution Annex	do	1922
Trinity Chapel, Catholic University	do	1922
E. H. Everett residence	do	
A. M. Lothrop residence	do	

XXVII. MINNESOTA LIMESTONE

Samples from Kasota, Mantorville, Mankato, and Winona were tested, all of which are dolomitic limestones. Several colors are available including light gray, buff, yellow, pink, and bluish gray. Textures vary from fine to coarse, some being vesicular and are sold as travertine. Some of these, particularly those from Kasota, are capable of taking a polish and find extensive use for interior decoration work. Examples of such use may be found in the Minnesota State Capitol, St. Paul Public Library, and Wisconsin State Capitol Buildings. In the State report of the Geological and Natural History Survey, Vol. I, 1872–1882 the following analyses are given:

	Mankato limestone	Kasota limestone	Mantorville limestone
	Per cent	*Per cent*	*Per cent*
Insoluble	2.82	1.09	1.77
Ferric and alumina oxides	1.39		
Calcium sulphate	6.74		
Calcium carbonate	52.22	49.16	50.20
Magnesium carbonate	36.04	37.53	38.96
Alkalies Na_2O and K_2O		.52	1.06

Quarry operations, according to the State report, began at Kasota in 1868, at Mankato in 1853, and at Mantorville in 1856. Compressive strengths varied from 5,100 to 22,700 lbs./in.^{2} in the dry state and 4,000 to 19,200 in the wet condition. Absorption values ranged from 1.4 to 5.9 per cent by weight. On account of their dolomitic nature the unit weights are somewhat higher than the average for limestone ranging from 147 to 160 lbs./ft.^{3} for the dry stone. The more porous samples gave elastic constants near the average for limestone, while the denser materials gave values somewhat above the average. All samples indicated fairly satisfactory resistance to frost action except one of the yellow stones from Kasota. This showed a tendency to split rather easily parallel to the bedding, and some of the specimens were destroyed by less than 100 freezings. This fact seems to indicate that this stone should not be set on edge in a wall. With all of these limestones the freezing tests reveal a tendency to split parallel to the bedding. The high percentage of calcium sulphate in the analysis given above for Mankato stone and also an appreciable amount of alkalis in those from Kasota and Mantorville indicates that these stones would effloresce under damp wall conditions. Laboratory experiments with blocks of stone set in shallow pans of water showed that this was particularly true for the bluish gray limestone.

The following lists of structures typify the use of various limestones from Minnesota:

SUPPLIED BY MANTORVILLE STONE CO. QUARRY, MANTORVILLE, MINN.

Structure	Location	Year
Courthouse	Mantorville, Minn	1865
Addition	do	1900
St. Mary's Hospital	Rochester, Minn	

SUPPLIED BY BREEN STONE & MARBLE CO. QUARRY, KASOTA, MINN.

EXTERIOR		
Philadelphia Museum of Art	Philadelphia, Pa	
Milwaukee Journal Building	Milwaukee, Wis	
INTERIOR ASHLAR		
State Capitol	St. Paul, Minn	
Union Station	Kansas City, Mo	
Insurance Co. of North America Building	Philadelphia, Pa	
State Capitol	Madison, Wis	

SUPPLIED BY T. R. COUGHLAN CO. QUARRY, MANKATO, MINN.

INTERIOR TRIM		
Memorial Hall, Harkness Quadrangle, Yale University	New Haven, Conn	
State Centennial Memorial Building	Springfield, Ill	
Library at Ames University	Ames, Iowa	
St. Mary's Cathedral	Minneapolis, Minn	
Public Library	St. Paul, Minn	
Lobby, Loew Theater	Broadway and Forty-fifth Street, New York, N. Y.	
EXTERIOR		
Bridgeport National Bank	Bridgeport, Conn	1917
High Bridge (piers)	St. Paul, Minn	1890
Stillwater Prison	Stillwater, Minn	1909
Abutments and piers for C. & N. W. Ry. bridge over Mississippi River.	Blair, Nebr	1882
Link's Club	New York, N. Y	1916
Rochester Savings Bank	Rochester, N. Y	1926
Patterson residence	Dayton, Ohio	1922
Terrace for South Office Building, State Capitol	Harrisburg, Pa	
Museum of Art Building	Fairmont Park, Philadelphia, Pa.	1924–1926
INTERIOR TRIM		
Mortimer Schiff residence	Oyster Bay, Long Island, N. Y.	
Residence, Bertram G. Work	do	
Fountain	Plandome, Long Island, N. Y.	
Mayflower Hotel (lower dining room)	Washington, D. C	
Sarcophagus, President Wilson, St. Albans Cathedral	do	

SUPPLIED BY BIESANZ STONE CO. QUARRY, WINONA, MINN.

Harkness Memorial, Yale University	New Haven, Conn	
Chicago Trust and Savings Bank Building	Clark and Monroe Streets, Chicago, Ill.	
Agricultural College library	Ames, Iowa	
Federal Reserve Bank Building	Minneapolis, Minn	
State Teachers College	Winona, Minn	
Globe Indemnity Building	Newark, N. J	
Exterior of Telephone Exchange	Brooklyn, N. Y	
Peter Stuyvesant Hotel	New York, N. Y	
Macey Department Store	do	
Standard Oil Co	do	
Liggett Building	Madison Avenue and Forty-second Street, New York, N. Y.	
Auditorium Metropolitan Life Insurance Building	New York, N. Y	
Mayflower Hotel (fern room and floor of lobby next to main dining room).	Washington, D. C	
Entrance floor to Dexter-Horton Bank	Seattle, Wash	

XXVIII. MISSOURI LIMESTONES

The samples of Missouri limestone tested for this report were from Carthage, Phenix, and Cassville. Similar materials are quarried at Hannibal, Springfield, Ash Grove, Pierce City, Walnut Grove, and Oceola. This is a very dense crystalline limestone which occurs in the lower carboniferous strata. It consists of irregular shaped grains of calcite and shells firmly bound in a mass of calcite. The color is generally gray with a slight bluish tint. Suture joints occur parallel to the bedding and are from 2 to 20 inches apart. Some of these are very prominent and allow an easy parting of the stone, but most of these are so thin and thoroughly interlocked that no appreciable weakness is caused. The stone is often sawed parallel to these joints and the blocks set on edge. This is a very hard limestone which is well illustrated by the fact that the rate of cutting with the usual type of gang saw is only about 2 inches per hour, while the usual rate for the oölitic limestones is from 6 to 8 inches per hour.

The following chemical analysis of this limestone is taken from the Missouri Bureau of Geology and Mines Report, volume 2, second series:

Insoluble	0.69
Oxides of iron and aluminum	.21
Calcium carbonate	98.57
Magnesium carbonate	.65

This material due to its density and crystalline nature is capable of taking a high polish and may be properly classed as a marble. A large part of the product is used in the form of slabs for floors, toilet stalls, and interior wall work. The following trade names are used for this product when marketed in the form of marble: "Napoleon gray," "Carthage," "Colonial gray," "Imperial gray," etc.

Compressive strengths varying from 11,200 to 20,800 lbs./in.^{2} were obtained on the dry stone, and those on the wet stone indicated a reduction of less than 10 per cent. Absorption values are generally less than one-half of 1 per cent, which is somewhat higher than the average absorption of marble. Unit weights range from 160 to 166 lbs./ft.^{3} for the dry stone, and due to the small absorption the saturated stone could not be more than 2 pounds heavier. Freezing tests have indicated a high resistance to frost action, none of the specimens being near the critical stage after 1,200 freezings. These tests indicate that frost action proceeds more rapidly along the suture joints than in other parts of the stone.

The following buildings exemplify the use of the Carthage limestone:

SUPPLIED BY CONSOLIDATED MARBLE & STONE CO. QUARRY, NEAR CARTHAGE, MO.

Structure	Location	Year
EXTERIOR		
St. Scholastica's Convent	Fort Smith, Ark	1924
Masonic Temple (first story)	Champaign, Ill	1912
German-American National Bank	Pekin, Ill	1914–15
Pullman School (basement story)	Pullman, Ill	1914
Belle Plaine Mausoleum	Belle Plaine, Iowa	1914
Administration Building, College of Emporia	Emporia, Kans	1916
Library	Topeka, Kans	1916
Mayo Clinic Building	Rochester, Minn	1912
Education Building, Southwest Missouri State Teachers College	Springfield, Mo	1923
Science Building, Southwest Missouri State Teachers College	do	1925
First Presbyterian Church	Kearney, Nebr	1921
First National Bank (front)	Portales, N. Mex	1918
Pawhuska Community Mausoleum	Pawhuska, Okla	1925
Federal Reserve Bank (base course)	Houston, Tex	1921
Central Fire Station and City Hall	Paris, Tex	1920
First National Bank (front)	Winnebago, Wis	1916
INTERIOR		
Blum Building (main entrance and elevator lobby)	Michigan Boulevard, Chicago, Ill.	1922
New Wrigley Building (main entrance and elevator lobby)	Chicago, Ill	1923
Maryland Casualty Building	Baltimore, Md	1921
INTERIOR WALL WORK		
Brown Club and Office Building	Louisville, Ky	1924
Cass Technical School	Detroit, Mich	1921
Culver Stockton School	Canton, Mo	1924
Holy Trinity School	Duquesne, Pa	1924
Salvation Army Building	Pittsburgh, Pa	1924

XXIX. NEW YORK LIMESTONE

Only one sample from New York was tested for this report, which was the Onondaga limestone. This was from the Indian Reservation Quarry near Syracuse. It is a very dense bluish-gray limestone which has been used locally in several public buildings, churches, etc. It is semicrystalline and takes a good polish. According to the State geologist reports it occurs in beds which average 2 feet in thickness. The only reference to composition that has been found is as follows:

	Per cent
$CaCO_3$	96
$MgCO_3$	1.26
Insoluble	1.52

The stone approximates the density of marble and is among the strongest tested in this series. The high modulus of elasticity indicates that it is a very rigid material. The weight per cubic foot in the dry state is 168 pounds, and the tests indicate a very low absorption.

The following buildings in Syracuse were built of limestone from the Indian Reservation Quarry:

Structure	Year	Structure	Year
Post Office	1887	City Hall	1889
St. Mary's Cathedral	1874	All Saints' Church	1923
St. Paul's Church	1884	Machinery Hall, Syracuse University	1907
Old Courthouse	1857	Lester Baker Steel Building, Syracuse University	1903
May Memorial Church	1884	Hall of Languages, Syracuse University	1872
Reform Protestant Dutch Church	1881		

XXX. TEXAS LIMESTONE

Three samples of limestone were tested from Cedar Park and Lueders, Tex. The Cedar Park stone is a very light cream-colored stone of medium texture, light weight, and quite soft. Those samples from Leander were rather fine grained, yellowish gray in color, and much harder than the Cedar Park stone.

The Cedar Park stone gave compressive strengths varying from 2,500 to 3,900 lbs./in.^{2} in the dry state and 1,900 to 3,400 wet. Absorption by weight values ranged from 9.8 to 12.3 per cent. The average weight per cubic foot in the dry state was 117 pounds, which is the lowest unit weight found for any of the materials tested in this series. The modulus of elasticity is also low, indicating that where heavily loaded, as may be the case in columns, an appreciable deformation would occur. Considering the high absorption and low strength of this material its resistance to frost action is remarkable, since all the tests required more than 800 freezings to cause failure. Disintegration occurs by splitting the stone in the direction of bedding and also by exfoliation of the surface in thin layers.

The Lueders limestone indicated compressive strengths from 7,600 to 14,700 lbs./in.^{2} dry and 3,300 to 8,500 wet. Absorption by weight values ranged from 3.5 to 6.9 per cent, and the weight per cubic foot dry varies from 139 to 145 pounds. The elastic constants for the softer sample of this stone were near the average for limestone, while the hard sample gave a rather high value. The softer sample indicated rather low resistance to frost action, while the hard sample appears to be equal to or better than the Cedar Park stone. Disintegration was mainly by exfoliation, which detached shell-shaped fragments from the surface about one-quarter inch thick.

The following list of structures illustrate the use of the limestone from Cedar Park and Lueders:

SUPPLIED BY THE BEDFORD CARTHAGE STONE CO. QUARRY, CEDAR PARK, TEX.

Structure	Location
Post Office	Austin, Tex.
Library building	Do.
Sterling residence	Bayridge, Tex.
Herman Hospital	Houston, Tex.

SUPPLIED BY THE BEDFORD CARTHAGE STONE CO. QUARRY, LUEDERS, TEX.

Administration building, A. and M. College	College Station, Tex.
Masonic Home dormitory	Fort Worth, Tex.
Polytechnic High School	Do.
James S. Hogg, jr., High School	Houston, Tex.
Jefferson Davis, jr., High School	Do.
Citizens State Bank	Do.
Woodrow Wilson School	Do.
High-school building	Jacksonville, Tex.
Administration building, Southern Texas State Teachers College	Kingsville, Tex.
Administration building, Western Texas Technological College	Lubbock, Tex.
Textile and Engineers Building	Do.
Home Economics Building	Do.
Science and Library Building	Nacogdoches, Tex.

XXXI. KANSAS LIMESTONE

One sample of limestone from Kansas was included in this series of tests; namely, the limestone from Silverdale, Cowley County. This is a buff limestone of uniform texture which has been quarried at intervals for the past 25 years. It could probably not be classed as an oölitic limestone, although when smoothly finished numerous fossils are revealed which are about the size and shape of wheat grains. It dissolves readily in cold, dilute hydrochloric acid, leaving a dark-colored residue amounting to over 4 per cent of the total weight. This residue is apparently a mixture of clay, quartz grains, and a small amount of organic matter. When the stone is leached with a 5 per cent solution of sodium carbonate a small amount of brown matter is brought to the surface, which indicates that the stone may stain to a slight extent under some conditions of use. However, the reports on past usage of this stone state that it has never given trouble in this way. The physical tests show properties very similar to those of the widely used oölitic limestones. Weathering tests indicate that its resistance to frost is somewhat below the average for this class of stone. This material has been used locally in several important buildings and is said to show good weathering qualities. The following list of structures illustrate its use.

United States post office, Topeka, Kans.
United States post office, Hutchinson, Kans.
City waterworks building, Topeka, Kans.
Episcopal Church, Topeka, Kans.
Episcopal Church, Salina, Kans.
St. James Episcopal Church, Wichita, Kans.

This stone takes a good hone finish and is used with good effects for interior work.

XXXII. CONCLUSIONS

1. The compressive strength of 130 samples tested for this report, representing materials from seven States and 42 quarries, varied between 2,500 and 28,000 lbs./in.^{2} Tests made on the stone in both the dry and wet conditions indicate that, as a rule, limestone is about 10 per cent weaker when thoroughly wet than when dry.

2. Transverse strength, tensile strength, and shearing strength bear a rather definite ratio to the compressive strength, but some materials have planes of weakness which influence these properties to a greater extent than they do the compressive strength.

3. Absorption values expressed by the weight ratio vary from 0.03 to 12 per cent. The absorption of limestone is proportional to the total pore space, but when the stone is once thoroughly dry a long period of soaking is necessary to completely fill the pores. Absorption tests on several specimens which were soaked for six months showed that the pores were less than nine-tenths filled. In the two weeks' immersion test the average saturation obtained was 0.7.

4. Impact tests were made to compare the toughnesss properties of the different limestones, which gave values ranging from 3 to 7. The materials showing more resistance to this test are less apt to become defaced in the lower parts of buildings where subjected to accidental impact.

5. Modulus of elasticity measurements in compression show values ranging from 1,500,000 to 12,400,000, which indicates that the rigidity of this class of materials varies from one-twentieth to approximately one-third that of structural steel. The average ratio of E determined from the flexure test to E determined from the compression test in this series was found to be 0.75.

6. Thermal expansion measurements over a temperature range of approximately 300° C. indicate that the rate of expansion increases with the temperature; hence the assumption of linear expansion for this material is erroneous. For normal seasonal temperature ranges the coefficient of expansion for the typical limestones may be taken as 0.000005 per degree centigrade, which is about one-half that of structural steel or reinforced concrete. It has been shown that higher stress may be produced in the stonework of a stone-faced, steel-frame building by differential expansion of the materials than is ordinarily the case from dead loads.

7. Studies of the permeability of limestone and comparison of this property with porosity values indicate that the rates at which water will flow through different stones are not proportional to the porosity values.

8. Unit weight measurements indicate that the larger part of the limestones now in use for building purposes vary from 140 to 150 lbs./ft.^{3}, with an average of approximately 146, only the densest limestones reaching the weight of 168 pounds.

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9. Discolorations are mainly from two causes, viz, those which penetrate from external sources and those which are leached from the stone. Brown discolorations, which frequently occur over large areas of limestone buildings, are usually due to organic impurities in the stone.

10. Efflorescence is due mainly to three causes: First, water-soluble salts in the masonry being leached out by percolating water; second, soluble salts in the ground water being carried up into the lower parts of buildings by capillarity; third, water-soluble salts from soot which are leached into the stone by rains. The more common salts found in efflorescence on masonry are sodium sulphate, magnesium sulphate, and calcium sulphate. The disintegrating effects of efflorescence is due to the wedging action of crystals forming in the pores of the stone.

11. Freezing tests indicate a great difference in the resistance of various limestones to frost action. The less resistant materials were disintegrated by 100 freezings, while some withstood 2,900 freezings Although high strength and high density appear to favor the resistance of stone to frost action, tests indicate that these determinations are not always reliable for judging the resistivity to such action.

12. Artificial weathering tests which are intended to simulate the action of frost by causing a salt to crystallize in the pores are not always dependable.

13. Chemical weathering due to the acid condition of rain water is not usually appreciable except on delicate carved parts of the limestone which are freely exposed.

TABLE 1.—*Identification of laboratory numbers*

ALABAMA

Sample received	Reference No.	Laboratory No.	Grade	Trade name	Producer	Location of quarry
Dec., 1923	1	49,412	----------	Alabama limestone	Reed Bros. Stone & Monument Co.	Russellville, Ala.
Do	2	49,915	----------	do	do	Waco, near Russellville, Ala.
Apr., 1916	3	8,907	----------	Rockwood Alabama limestone.	Rockwood Alabama Stone Co.	Russellville, Ala.
June, 1924	4	49,924	----------	do	do	Do.
Nov., 1926	5	52,036	----------	do	do	Aday, quarry, Russellville, Ala.
July, 1926	5a	52,243	----------	do	do	Russellville, Ala.

ILLINOIS

Sample received	Reference No.	Laboratory No.	Grade	Trade name	Producer	Location of quarry
June, 1924	6	49,914	----------	Quincy (Ill.) limestone.	Rodder & Greenman Stone Construction Co.	Quincy, Ill.
Oct., 1924	7	50,255	----------	Joliet (Ill.) limestone.	Swan, Medin & Co	Joliet, Ill.

TABLE 1.—*Identification of laboratory numbers*—Continued

INDIANA

Sample received	Reference No.	Laboratory No.	Grade	Trade name	Producer	Location of quarry
Oct., 1917	8	19,851	AA5	Statuary buff	Consolidated Stone Co.[1]	Dark Hollow.[2]
Do	9	19,852	AA9	do	Furst-Kerber Cut Stone Co.[1]	Needmore.[2]
Do	10	19,853	AA10	do	J. Hoadley & Sons Co.[1]	Hunter Valley.
Do	11	19,854	AA16P	do	W. McMillan & Son [1]	Peerless.[2]
Do	12	19,855	AA16S	do	do.[1]	Sanders.[3]
Do	13	19,856	AA23	do	Shea & Donnelly Co.[1]	Eureka.[2]
Do	14	19,857	A2	Select buff	Bedford Stone & Construction Co.	Bedford.
Aug., 1923	15		A4	do	Chicago & Bloomington Cut Stone Co.	Bloomington.
Oct., 1917	16	19,858	A5	do	Consolidated Stone Co.[1]	Dark Hollow.[2]
Aug., 1923	17		A5	do	do.[1]	Do.[2]
Do	18		A5H	do	do.[1]	Hunter Valley.[4]
Do	19		A6	do	Crescent Stone Co.[1]	Do.[4]
Oct., 1917	20	19,859	A7	do	Doyle Stone Co. (Inc.) [1]	Dark Hollow.[2]
Do	21	19,860	A8	do	Empire Stone Co	Sanders.[3]
Aug., 1923	22		A8	do	do	Do.
Oct., 1917	23	19,861	A9	do	Furst-Kerber Cut Stone Co.[1]	Needmore.[2]
Aug., 1923	24		A9	do	do.[1]	Do.[2]
Oct., 1917	25	19,862	A10	do	J. Hoadley & Sons Co.[1]	Hunter Valley.[4]
Aug., 1923	26		A10	do	do.[1]	Do.[4]
Oct., 1917	27	19,863	A11	do	Hunter Bros. Co	Do.
Do	28	19,864	A13	do	Ingalls Stone Co	Peerless.[2]
Do	29	19,865	A13R	do	do	Oölitic.[2]
Aug., 1923	30		A14Z	do	Indiana Quarries Co.[1]	Horseshoe.[2]
Oct., 1917	31	19,866	A14X	do	do.[1]	Do.[2]
Do	32	19,867	A14Y	do	do.[1]	Do.[2]
Do	33	19,868	A16P	do	W. McMillan & Son [1]	Peerless.[2]
Do	34	19,869	A16RX	do	do.[1]	Reed Station.[2]
Do	35	19,870	A16RY	do	do.[1]	Do.[2]
Do	36	19,871	A16S	do	do.[1]	Sanders.[3]
Aug., 1923	37		A17S	do	do.[1]	Do.[3]
Oct., 1917	38	19,872	A19	do	National Stone Co.[1]	Clear Creek.[3]
Aug., 1923	39		A19	do	do.[1]	Do.[3]
Oct., 1917	40	19,873	A23	do	Shea & Donnelly Co.[1]	Eureka.[2]
Aug., 1923	41		A23	do	do.[1]	Do.[2]
Oct., 1917	42	19,874	B2	Standard buff	Bedford Stone & Construction Co.	Bedford.
Do	43	19,875	B5	do	Consolidated Stone Co.[1]	Dark Hollow.[2]
Do	44	19,876	B7	do	Doyle Stone Co. (Inc.) [1]	Do.
Do	45	19,877	B8	do	Empire Stone Co	Sanders.[3]
Do	46	19,878	B9	do	Furst-Kerber Cut Stone Co.[1]	Needmore.[2]
Do	47	19,879	B10	do	J. Hoadley & Sons Co.[1]	Hunter Valley.[4]
Do	48	19,880	B11	do	Hunter Bros. Co	Do.[4]
Do	49	19,881	B16P	do	W. McMillan & Son [1]	Peerless.[2]
Do	50	19,882	B16R	do	do.[1]	Reed Station.[2]
Do	51	19,883	B16SX	do	do.[1]	Sanders.[3]
Do	52	19,884	B16SY	do	do.[1]	Do.[3]
Do	53	19,885	B19	do	National Stone Co.[1]	Clear Creek.[3]
Do	54	19,886	B23	do	Shea & Donnelly Co.[1]	Eureka.[2]
Do	55	19,887	C2	Rustic buff	Bedford Stone & Construction Co.	Bedford.
Do	56	19,888	C5	do	Consolidated Stone Co.[1]	Dark Hollow.[2]
Do	57	19,889	C8	do	Empire Stone Co	Sanders.[3]
Do	58	19,890	C9	do	Furst-Kerber Cut Stone Co.[1]	Needmore.[2]
Do	59	19,891	C10	do	J. Hoadley & Sons Co.[1]	Hunter Valley.[4]
Do	60	19,892	C14	do	Indiana Quarries Co.[1]	Oölitic.[2]
Aug., 1923	61		C14X	do	do.[1]	Horseshoe.[2]

[1] Merged into the Indiana Limestone Co. May, 1926.
[2] Near Bedford.
[3] Midway between Bedford and Bloomington.
[4] Near Bloomington.

TABLE 1.—*Identification of laboratory numbers*—Continued

INDIANA—Continued

Sample received	Reference No.	Laboratory No.	Grade	Trade name	Producer	Location of quarry
Oct., 1917	62	19,893	C16P	Rustic buff	W. McMillan & Son [1]	Peerless.[2]
Do	63	19,894	C16S	do	do.[1]	Sanders.[3]
Do	64	19,895	C19	do	National Stone Co.[1]	Clear Creek.[3]
Do	65	19,896	C23	do	Shea & Donnelly Co.[1]	Eureka.[2]
Do	66	19,897	D2	Select gray	Bedford Stone & Construction Co.	Bedford.
Do	67	19,898	D5	do	Consolidated Stone Co.[1]	Dark Hollow.[2]
Aug., 1923	68		D5	do	do.[1]	Do.[2]
Oct., 1917	69	19,899	D7	do	Doyle Stone Co. (Inc.) [1]	Do.[2]
Do	70	19,900	D8	do	Empire Stone Co	Bloomington.
Aug., 1923	71		D11	do	Hunter Bros. Co	Hunter Valley.[4]
Do	72		D12	do	Imperial Stone Co.[1]	Bedford.
Aug., 1923	73		D14Z	do	Indiana Quarries Co.[1]	Horseshoe.[2]
Oct., 1917	74		D14X	do	do.[2]	Do.[2]
Do	75	19,902	D14Y	do	do.[2]	Do.[2]
Do	76	19,903	D16S	do	W. McMillan & Son [1]	Sanders.[3]
Aug., 1923	77		D18	do	Monroe County Oölitic Stone Co.[1]	Do.[3]
Do	78		D19	do	National Stone Co.[1]	Clear Creek.[3]
Oct., 1917	79	19,904	D20	do	C. S. Norton Blue Stone Co.	Spider Creek.[2]
Aug., 1923	80		D22	do	Perry Stone Co	Ellettsville.[4]
Oct., 1917	81	19,905	D23	do	Shea & Donnelly Co.[1]	Eureka.[2]
Aug., 1923	82		D23	do	do.[1]	Do.[2]
Do	83		D24	do	Star Stone Co.[1]	Hunter Valley.[4]
Oct., 1917	84	19,906	E5	Standard gray	Consolidated Stone Co.[1]	Dark Hollow.[2]
Do	85	19,907	E7	do	Doyle Stone Co. (Inc.) [1]	Do.[2]
Do	86	19,908	E19	do	National Stone Co.[1]	Clear Creek.[3]
Do	87	19,909	E23	do	Shea & Donnelly Co.[1]	Eureka.[2]
Do	88	19,910	F2	Variegated	Bedford Stone & Construction Co.	Bedford.
Do	89	19,911	F5	do	Consolidated Stone Co.[1]	Dark Hollow.[2]
Do	90	19,912	F7	do	Doyle Stone Co. (Inc.) [1]	Do.[2]
Do	91	19,913	F8	do	Empire Stone Co	Sanders.[3]
Do	92	19,914	F14X	do	Indiana Quarries Co.[1]	Horseshoe.[2]
Do	93	19,915	F14Y	do	do.[1]	Do.[2]
Do	94	19,916	F16P	do	W. McMillan & Son [1]	Peerless.[2]
Do	95	19,917	F23	do	Shea & Donnelly Co.[1]	Eureka.[2]
Do	96	19,918	G5	do	Consolidated Stone Co.[1]	Dark Hollow.[2]
Do	97	19,919	G7	do	Doyle Stone Co. (Inc.) [1]	Do.[2]
Do	98	19,920	G23	do	Shea & Donnelly Co.[1]	Eureka.[2]
Do	99	19,921	H2	Special grade	Bedford Stone & Construction Co.	Bedford.
Do	100	19,922	H10	do	J. Hoadley & Sons Co.[1]	Hunter Valley.[4]
Aug., 1923	101		L10	Statuary buff	do.[1]	Do.[4]
July, 1923	102	48,889			Sample from Salem, Ind.[5]	
Sept., 1927	103	IX-9-93	A49R	Select buff	Ingalls Stone Co	Romona.[6]
Do	104	IX-9-94	B49R	Standard buff	do	Do.[6]
Aug., 1923	105		A44	Select buff	Reed-Powers Cut Stone Co.	Victor.[3]
Do	106		A22	do	Perry Stone Co	Ellettsville.[4]

KENTUCKY

Sample received	Reference No.	Laboratory No.	Grade	Trade name	Producer	Location of quarry
Jan., 1922	107			Bowling Green stone.		Bowling Green, Ky.
June, 1915	108	5,845		do	Bowling Green & Green River Stone Co.	Do.
Oct., 1915	109	7,308		do	do	Do.
Apr., 1925	110	50,749		do	Bowling Green Quarries Co.	Do.
Do	111	50,750		do	do	Do.

[1] Merged into the Indiana Limestone Co. May, 1926.
[2] Near Bedford.
[3] Midway between Bedford and Bloomington.
[4] Near Bloomington.
[5] This was a very fine-grained, dense limestone approximating marble in texture. It has not been worked for building purposes.
[6] Romona-Stinesville Section.

(Insert at page 562)

Addendum to Table 1.—*Identification of laboratory numbers* [a]

ALABAMA

Sample received	Reference No.	Laboratory No.	Trade name	Producer	Location of quarry
January, 1928	5b	99,223	Rockwood Alabama limestone	Rockwood Alabama Stone Co.	Aday Quarry, Russellville.
May, 1928	5c	99,288	do	do	Do.
Do	5d	99,289	do	do	Do.

INDIANA

Sample received	Reference No.	Laboratory No.	Trade name	Producer	Location of quarry
February, 1928	41a	99,234	Shawnee limestone	Shawnee Stone Co.	Quarry No. 1, Bloomington.
Do	41b	99,235	do	do	Quarry No. 2, Bloomington.
May, 1928	41c	99,303	Select buff	Indiana Oolitic Limestone Co.	Bloomington.
Do	54a	99,304	Standard buff	do	Do.
Do	83a	99,305	Select gray	do	Do.
Do	87a	99,306	Standard gray	do	Do.
March, 1928	106a	99,252	St. Paul stone	St. Paul Quarries Co.	St. Paul.

FLORIDA

Sample received	Reference No.	Laboratory No.	Trade name	Producer	Location of quarry
April, 1928	135	99,282			New Port Richey.

[a] Samples received and tested since the original issue of this paper.

[1] Physical Properties of the Principal Commercial Limestones Used for Building Construction in the United States, by D. W. Kessler and W. H. Sligh. Extra copies of the original paper may be purchased from the Superintendent of Documents, Washington, D. C., at 30 cents per copy.

TABLE 1.—*Identification of laboratory numbers*—Continued

MINNESOTA

Sample received	Reference No.	Laboratory No.	Grade	Trade name	Producer	Location of quarry
June, 1924	112	49, 844		Buff travertin	Mantorville Stone Co	Mantorville, Minn.
Do	113	49, 845		Blue travertin	do	Do.
Do	114	49, 846		Pink fleuri	Breen, Stone & Marble Co.	Kasota, Minn.
July, 1926	114a	52, 150		Golden Buff Kasota.	do	Do.
June, 1924	115	49, 847		Yellow fleuri	do	Do.
July, 1926	115a	52, 151		Pink buff Kasota	do	Do.
Jan., 1925	116	50, 467		Mankato cream	T. R. Coughlan Co	Mankato, Minn.[1]
Do	117	50, 468		Mankato gray	do	Do.[1]
Do	118	50, 469		Kato	do	Do.[1]
Feb., 1925	119	50, 540		Travertine	Biesang Stone Co	Winona, Minn.
Do	120	50, 541		Winona free stone	do	Do.
Do	121	50, 542		Winona marble	do	Do.
Sept., 1915	122	6, 982			Babcock & Wilcox	Kasota, Minn.

MISSOURI

Sample received	Reference No.	Laboratory No.	Grade	Trade name	Producer	Location of quarry
July, 1915	123	6, 119		Napoleon gray	Phenix Marble Co	Phenix, Mo.
Sept., 1915	124	6, 981			Cassville Marble & Lime Co.	Cassville, Mo.
June, 1924	125	49, 848		Seneca marble	Consolidated Marble & Stone Co.	Near Carthage, Mo.
Do	126	49, 849		do	do	Do.
May, 1925	127	50, 615		Center Creek gray marble.	The Carthage Marble & Building Stone Co.	3 miles southwest of Carthage, Mo.
Do	128	50, 616		do	do	Do.

NEW YORK

Sample received	Reference No.	Laboratory No.	Grade	Trade name	Producer	Location of quarry
Dec., 1924	129	50, 350		Onondaga gray limestone.	Jones Cut Stone Co	Indian reservation (near Syracuse), N. Y.

TEXAS

Sample received	Reference No.	Laboratory No.	Grade	Trade name	Producer	Location of quarry
July, 1924	130	49, 922		Leander	Cedar Park Stone Co	Leander, Tex.
Do	131	49, 923		do	do	Do.
Apr., 1925	132	50, 685		Cedar Park stone	Bedford Carthage Stone Co.	Cedar Park, Tex.
Do	133	50, 686		Lueders stone	do	Lueders, Tex.

KANSAS

Sample received	Reference No.	Laboratory No.	Grade	Trade name	Producer	Location of quarry
Nov., 1926	134	52, 585		Silverdale		Silverdale, Cowley County, Kans.

[1] Similar materials produced by Fowler and Pay from an adjoining quarry.

NOTE.—The test samples as described in Table 1 were selected by the producers or their authorized agents under instructions to supply material representative of their average product. Where two or more distinct types or grades were produced from the same quarry and placed on the market under separate designations the producer was asked to submit an average sample of each. All samples of Indiana limestone except serial Nos. 103 and 104 were obtained through the Indiana Limestone Quarrymen's Association. In the selection of these samples the officers of this association cooperated with its members in selecting and grading the material for the purpose of securing greater uniformity. The samples were received at the Bureau of Standards on the dates indicated.

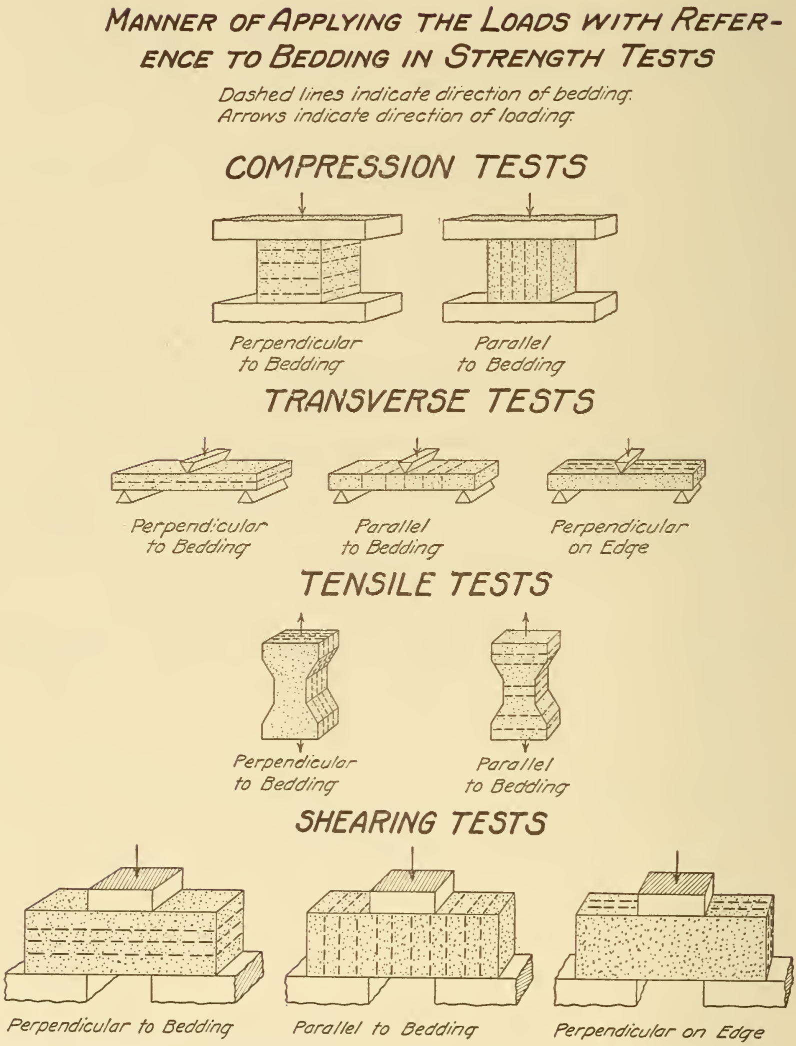

Fig. 25.—*Manner of applying loads with reference to the natural stratification in various strength tests*

TABLE 2.—*Compressive strength tests (specimens dry)*

Reference No.	Number of tests made	Average stressed area in square inches	Manner of testing	Compressive strength in pounds per square inch			Remarks
				Highest	Lowest	Average	
1	2	3.14	Perpendicular [1]	7,600	6,900	7,250	Cylindrical specimens.
2	3	2.99	do	14,600	13,200	13,900	Do.
	3	2.99	Parallel [1]	12,300	11,300	11,700	Do.
3	2	6.04	Perpendicular	5,000	5,100	5,050	Cubical specimens.
	2	5.26	Parallel	5,700	5,000	5,350	Do.
4	3	3.30	Perpendicular	10,300	9,000	9,700	Cylindrical specimens.
	6	2.99	Parallel	11,600	9,600	10,500	Do.
5	3	3.31	Perpendicular	9,300	8,100	8,600	Do.
	3	3.32	Parallel	9,500	6,500	8,100	Do.
6	3	3.33	Perpendicular	19,400	15,600	18,000	Do.
	3	2.99	Parallel	21,500	16,600	19,600	Do.
7	3	2.99	Perpendicular	22,700	21,500	22,100	Do.
	3	2.99	Parallel	26,500	21,900	24,400	Do.
8	2	7.64	Perpendicular	8,200	5,600	6,900	Cubical specimens.
	2	6.83	Parallel	8,800	7,900	8,350	Do.
9	2	5.13	Perpendicular	5,600	5,300	5,450	Do.
	2	4.58	Parallel	4,100	5,000	4,550	Do.
10	2	5.02	Perpendicular	6,200	5,600	5,900	Do.
	2	4.91	Parallel	4,600	4,300	4,450	Do.
11	2	5.16	Perpendicular	8,100	7,600	7,850	Do.
	2	5.19	Parallel	7,300	5,500	6,400	Do.
12	2	5.86	Perpendicular	7,400	6,600	7,000	Do.
	2	5.87	Parallel	8,500	8,000	8,250	Do.
13	2	4.86	Perpendicular	6,700	5,600	6,150	Do.
	2	5.34	Parallel	6,500	5,400	5,950	Do.
14	2	5.46	Perpendicular	8,600	8,100	8,350	Do.
	2	5.63	Parallel	9,200	8,800	9,000	Do.
16	2	4.86	Perpendicular	6,400	6,300	6,350	Do.
	2	5.28	Parallel	6,500	5,000	5,750	Do.
20	2	5.52	Perpendicular	7,800	7,200	7,500	Do.
	2	5.54	Parallel	8,100	7,300	7,700	Do.
21	2	5.72	Perpendicular	6,000	5,400	5,700	Do.
	2	5.66	Parallel	4,700	4,600	4,650	Do.
23	2	6.18	Perpendicular	5,400	5,300	5,350	Do.
	2	6.10	Parallel	4,500	4,100	4,300	Do.
25	2	7.46	Perpendicular	7,400	7,000	7,200	Do.
	2	6.40	Parallel	6,300	5,800	6,050	Do.
27	2	5.62	Perpendicular	6,900	5,500	6,200	Do.
	2	6.81	Parallel	6,600	4,000	5,300	Do.
28	2	5.97	Perpendicular	8,500	6,800	7,650	Do.
	2	5.64	Parallel	6,800	6,000	6,400	Do.
29	2	5.54	Perpendicular	10,400	8,800	9,600	Do.
	2	5.66	Parallel	8,800	7,900	8,350	Do.
31	2	5.90	Perpendicular	7,000	6,800	6,900	Do.
	2	6.23	Parallel	7,800	6,300	7,050	Do.
32	2	6.09	Perpendicular	9,100	8,400	8,750	Do.
	2	5.63	Parallel	8,100	8,000	8,050	Do.
33	2	5.76	Perpendicular	6,600	6,100	6,350	Do.
	2	5.79	Parallel	5,600	5,500	5,550	Do.
34	4	5.72	Perpendicular	10,200	7,600	9,000	Do.
	4	5.70	Parallel	8,700	7,400	8,200	Do.
35	2	5.64	Perpendicular	8,700	7,800	8,250	Do.
	2	5.70	Parallel	8,200	7,200	7,700	Do.
36	2	5.92	Perpendicular	9,500	9,500	9,500	Do.
	2	5.10	Parallel	8,100	8,100	8,100	Do.
38	4	5.93	Perpendicular	8,500	6,500	7,400	Do.
	4	5.74	Parallel	6,100	5,400	5,800	Do.
40	2	6.36	Perpendicular	6,900	6,000	6,450	Do.
	2	5.62	Parallel	6,900	6,500	6,700	Do.
42	2	5.30	Perpendicular	4,400	3,100	3,750	Do.
	2	4.91	Parallel	4,400	2,700	3,550	Do.

[1] Compressive strength "perpendicular" signifies that the load was applied perpendicular to the natural stratification, and "parallel" indicates that the load was applied parallel to the stratification. (See fig. 25.)

TABLE 2.—*Compressive strength tests (specimens dry)*—Continued

Reference No.	Number of tests made	Average stressed area in square inches	Manner of testing	Compressive strength in pounds per square inch			Remarks
				Highest	Lowest	Average	
43	2	5.38	Perpendicular	7,200	5,700	6,450	Cubical specimens.
	2	5.48	Parallel	5,800	5,500	5,650	Do.
44	2	6.14	Perpendicular	9,900	7,900	8,900	Do.
	2	5.78	Parallel	7,900	7,100	7,500	Do.
45	2	5.98	Perpendicular	4,700	4,600	4,650	Do.
	2	5.68	Parallel	5,500	3,700	4,600	Do.
46	2	5.44	Perpendicular	7,400	5,900	6,650	Do.
	2	5.21	Parallel	6,300	6,100	6,200	Do.
47	2	6.64	Perpendicular	9,100	8,300	8,700	Do.
	2	5.96	Parallel	7,800	6,400	7,100	Do.
48	2	5.28	Perpendicular	8,000	6,900	7,450	Do.
	2	5.78	Parallel	6,300	4,800	5,550	Do.
49	2	5.20	Perpendicular	6,500	6,500	6,500	Do.
	2	5.44	Parallel	6,400	6,200	6,300	Do.
50	2	5.38	Perpendicular	5,200	5,000	5,100	Do.
	2	5.30	Parallel	4,700	4,100	4,400	Do.
51	2	5.75	Perpendicular	5,800	5,200	5,500	Do.
	2	5.85	Parallel	4,700	4,200	4,450	Do.
52	2	5.82	Perpendicular	5,400	3,900	4,650	Do.
	2	5.08	Parallel	7,100	3,500	5,300	Do.
53	2	5.18	Perpendicular	4,100	3,700	3,900	Do.
	2	5.24	Parallel	3,600	2,800	3,200	Do.
54	2	5.26	Perpendicular	9,200	8,900	9,050	Do.
	2	5.21	Parallel	7,600	6,700	7,150	Do.
55	2	5.44	Perpendicular	8,500	7,300	7,900	Do.
	2	5.54	Parallel	6,900	6,000	6,450	Do.
56	2	5.72	Perpendicular	5,400	5,300	5,350	Do.
	2	4.65	Parallel	4,600	4,300	4,450	Do.
57	2	5.26	Perpendicular	6,000	3,100	4,550	Do.
	2	5.03	Parallel	6,400	4,300	5,350	Do.
58	2	5.73	Perpendicular	5,700	5,200	5,450	Do.
	2	5.72	Parallel	5,400	3,900	4,650	Do.
59	2	5.22	Perpendicular	8,200	4,000	6,100	Do.
	2	5.34	Parallel	7,300	4,200	5,750	Do.
60	2	6.02	Perpendicular	4,100	4,000	4,050	Do.
	2	5.95	Parallel	4,100	3,900	4,000	Do.
62	2	5.47	Perpendicular	6,300	5,900	6,100	Do.
	2	4.94	Parallel	5,700	5,500	5,600	Do.
63	2	6.02	Perpendicular	5,600	5,500	5,550	Do.
	2	6.10	Parallel	5,300	4,400	4,850	Do.
64	2	5.95	Perpendicular	7,200	6,300	6,750	Do.
	2	4.84	Parallel	5,800	5,600	5,700	Do.
65	2	5.84	Perpendicular	8,200	7,300	7,750	Do.
	2	6.09	Parallel	6,900	6,000	6,450	Do.
66	2	5.49	Perpendicular	10,500	9,800	10,150	Do.
	2	5.85	Parallel	9,900	9,400	9,650	Do.
67	2	4.97	Perpendicular	7,400	7,300	7,350	Do.
	2	5.66	Parallel	6,800	5,500	6,150	Do.
69	2	5.83	Perpendicular	9,500	8,700	9,100	Do.
	2	5.46	Parallel	6,900	6,500	6,700	Do.
70	2	5.30	Perpendicular	11,100	11,000	11,050	Do.
	2	4.82	Parallel	9,300	4,500	6,900	Do.
72	3	3.33	Perpendicular	11,400	10,600	11,000	Cylindrical specimens.
	3	3.30	Parallel	9,800	8,600	9,200	Do.
74	2	6.12	Perpendicular	8,900	7,500	8,200	Cubical specimens.
	2	6.06	Parallel	7,500	6,400	6,950	Do.
75	2	5.82	Perpendicular	7,700	7,300	7,500	Do.
	2	5.38	Parallel	7,500	7,000	7,250	Do.
76	2	5.84	Perpendicular	7,000	6,500	6,750	Do.
	2	5.35	Parallel	5,900	5,400	5,650	Do.
79	2	5.92	Perpendicular	9,100	9,100	9,100	Do.
	2	5.50	Parallel	8,600	8,000	8,300	Do.
80	7	2.89	Perpendicular	9,400	6,600	8,000	Cylindrical specimens.
	7	2.88	Parallel	7,800	4,500	5,500	Do.

TABLE 2.—*Compressive strength tests (specimens dry)*—Continued

Reference No.	Number of tests made	Average stressed area in square inches	Manner of testing	Compressive strength in pounds per square inch			Remarks
				Highest	Lowest	Average	
81	2	5.60	Perpendicular	8,400	6,600	7,500	Cubical specimens.
	2	5.47	Parallel	6,600	6,400	6,500	Do.
84	2	5.52	Perpendicular	7,500	5,800	6,650	Do.
	2	5.16	Parallel	5,600	5,200	5,400	Do.
85	2	5.64	Perpendicular	10,600	10,200	10,400	Do.
	2	5.56	Parallel	9,400	8,900	9,150	Do.
86	2	5.46	Perpendicular	4,900	4,300	4,600	Do.
	2	5.46	Parallel	4,300	3,200	3,750	Do.
87	2	6.02	Perpendicular	7,300	6,100	6,700	Do.
	2	6.27	Parallel	6,400	5,400	5,900	Do.
88	2	5.69	Perpendicular	8,100	7,900	8,000	Do.
	2	4.96	Parallel	8,500	6,900	7,700	Do.
89	2	6.06	Perpendicular	10,200	9,300	9,750	Do.
	2	5.84	Parallel	9,400	8,200	8,800	Do.
90	2	5.87	Perpendicular	8,700	7,700	8,200	Do.
	2	5.41	Parallel	8,300	7,200	7,750	Do.
91	2	5.48	Perpendicular	4,000	3,400	3,700	Do.
	2	5.85	Parallel	2,900	2,500	2,700	Do.
92	2	5.99	Perpendicular	7,100	6,700	6,900	Do.
	2	5.86	Parallel	5,700	5,000	5,350	Do.
93	2	5.20	Perpendicular	6,100	5,600	5,850	Do.
	2	5.18	Parallel	6,500	4,900	5,700	Do.
94	2	6.12	Perpendicular	8,700	7,900	8,300	Do.
	2	5.62	Parallel	6,800	6,100	6,450	Do.
95	2	6.00	Perpendicular	8,200	7,600	7,900	Do.
	2	5.80	Parallel	6,800	5,600	6,200	Do.
96	2	7.36	Perpendicular	8,700	8,500	8,600	Do.
	2	6.02	Parallel	7,200	6,200	6,700	Do.
97	2	5.75	Perpendicular	10,200	9,200	9,700	Do.
	2	4.95	Parallel	8,100	7,900	8,000	Do.
98	2	5.57	Perpendicular	5,600	5,600	5,600	Do.
	2	5.53	Parallel	6,500	4,300	5,400	Do.
99	2	8.14	Perpendicular	16,300	15,100	15,700	Do.
	2	7.21	Parallel	17,500	17,400	17,450	Do.
100	2	6.04	Perpendicular	10,200	9,500	9,850	Do.
	2	6.06	Parallel	9,900	7,600	8,750	Do.
102	1	3.14	Perpendicular	28,400	----------	28,400	Cylindrical specimens.
103	3	3.21	do	7,200	6,700	6,900	Do.
	3	3.20	Parallel	8,300	7,900	8,100	Do.
104	3	3.27	Perpendicular	8,300	7,900	8,100	Do.
	3	3.30	Parallel	8,300	7,800	8,000	Do.
105	6	3.40	Perpendicular	11,400	8,900	9,800	Do.
	6	3.40	Parallel	13,600	9,200	12,100	Do.
108	2	5.58	Perpendicular	4,500	3,700	4,100	Cubical specimens.
	2	6.43	Parallel	3,100	2,700	2,900	Do.
109	2	5.52	Perpendicular	4,700	4,300	4,500	Do.
	2	5.26	Parallel	4,700	3,700	4,200	Do.
110	3	3.36	Perpendicular	7,400	6,400	6,900	Cylindrical specimens.
	4	3.33	Parallel	6,600	5,700	6,300	Do.
111	3	3.37	Perpendicular	6,500	6,200	6,300	Do.
	4	3.32	Parallel	6,300	5,600	6,000	Do.
112	3	2.99	Perpendicular	15,700	9,500	11,700	Do.
	6	2.99	Parallel	14,400	11,300	12,600	Do.
113	7	2.99	Perpendicular	13,900	8,300	11,500	Do.
	6	2.99	Parallel	13,100	8,900	11,200	Do.
114	3	2.99	Perpendicular	22,700	19,600	21,300	Do.
	3	2.99	Parallel	18,800	17,100	17,900	Do.
114a	3	3.29	Perpendicular	16,100	14,000	15,000	Do.
	3	3.30	Parallel	11,300	9,200	10,000	Do.
115	3	2.99	Perpendicular	12,700	10,900	12,000	Do.
	6	2.99	Parallel	13,500	9,400	11,300	Do.
115a	3	3.31	Perpendicular	16,600	12,700	15,200	Do.
	3	3.31	Parallel	15,600	12,600	14,300	Do.
116	4	3.15	Perpendicular	17,100	11,600	14,500	Do.
	5	3.00	Parallel	14,800	10,400	13,000	Do.
117	3	3.10	Perpendicular	11,100	10,200	10,700	Do.
	4	3.02	Parallel	14,400	12,200	13,300	Do.

TABLE 2.—*Compressive strength tests (specimens dry)*—Continued

Reference No.	Number of tests made	Average stressed area in square inches	Manner of testing	Compressive strength in pounds per square inch			Remarks
				Highest	Lowest	Average	
118	5	3.40	Perpendicular	16,100	12,200	14,200	Cylindrical specimens.
	5	3.01	Parallel	14,700	10,900	13,000	Do.
119	4	3.07	Perpendicular	21,300	11,300	17,000	Do.
	4	2.99	Parallel	12,800	5,900	8,900	Do.
120	5	2.97	Perpendicular	14,400	8,400	11,100	Do.
	3	3.08	Parallel	13,200	12,000	12,600	Do.
121	4	2.99	Perpendicular	11,200	7,700	9,600	Do.
	3	2.99	Parallel	9,500	8,200	8,700	Do.
122	2	5.16	Perpendicular	15,500	12,300	13,900	Cubical specimens.
	2	4.56	Parallel	10,600	5,100	7,850	Do.
123	2	5.11	Perpendicular	12,300	11,200	11,800	Do.
	2	5.27	Parallel	12,400	12,100	12,250	Do.
124	2	5.06	Perpendicular	13,100	12,100	12,600	Do.
	2	5.07	Parallel	12,300	11,500	11,900	Do.
125	3	2.99	Perpendicular	18,000	15,400	16,900	Cylindrical specimens.
	3	2.99	Parallel	17,800	16,700	17,200	Do.
126	3	2.99	Perpendicular	15,700	14,500	15,100	Do.
	3	2.99	Parallel	14,700	13,000	13,900	Do.
127	3	3.06	Perpendicular	20,400	20,000	20,200	Do.
	3	3.24	Parallel	20,200	18,500	19,600	Do.
128	3	3.06	Perpendicular	20,800	17,800	18,900	Do.
	3	3.05	Parallel	20,200	19,500	19,900	Do.
129	3	3.02	Perpendicular	19,000	17,400	17,900	Do.
	3	3.02	Parallel	19,100	17,900	18,700	Do.
130	3	2.99	Perpendicular	11,500	10,600	11,000	Do.
	5	3.11	Parallel	10,200	7,600	8,700	Do.
131	3	2.99	Perpendicular	13,100	10,300	11,700	Do.
	3	2.99	Parallel	14,700	10,500	12,400	Do.
132	3	2.95	Perpendicular	2,700	2,500	2,600	Do.
	4	3.27	Parallel	3,900	2,800	3,400	Do.
133	3	2.95	Perpendicular	9,400	8,300	8,900	Do.
	3	3.32	Parallel	9,100	8,200	8,600	Do.
134	3	3.23	Perpendicular	6,800	6,600	6,700	Do.
	3	3.18	Parallel	6,800	5,600	6,300	Do.

(Insert at page 568)

ADDENDUM TO TABLE 2.—*Compressive strength (specimens dry)*

(All tests made on cylindrical specimens)

Reference No.	Number of tests	Average stressed area in square inches	Manner of testing	Compressive strength in pounds per square inch		
				Highest	Lowest	Average
5b	2	3.30	Perpendicular	9,000	8,500	8,750
	3	3.30	Parallel	8,900	8,400	8,700
5c	3	3.28	do	11,300	10,200	10,900
5d	3	3.31	do	10,700	9,600	10,300
41a	3	3.34	Perpendicular	14,200	13,400	13,900
	2	3.30	Parallel	12,300	12,300	12,300
41b	2	3.27	Perpendicular	8,100	7,800	7,950
	2	3.27	Parallel	7,500	7,000	7,250
41c	3	3.33	Perpendicular	10,000	9,600	9,800
	3	3.33	Parallel	8,000	6,400	7,100
54a	3	3.33	Perpendicular	8,200	7,500	7,900
	3	3.32	Parallel	8,600	6,200	7,000
83a	2	3.28	Perpendicular	8,700	8,400	8,550
	3	3.28	Parallel	6,600	6,200	6,400
87a	3	3.22	Perpendicular	5,900	5,200	5,600
	3	3.23	Parallel	5,800	5,300	5,600
106a	2	3.32	Perpendicular	25,500	23,400	24,450
	2	3.30	Parallel	25,700	25,600	25,650
135	3	3.32	Perpendicular	22,600	20,800	21,500
	3	3.32	Parallel	24,700	17,200	20,100

[illegible]

TABLE 3.—*Compressive strength tests* (*specimens wet*)

Reference No.	Number of tests made	Average stressed area in square inches	Manner of testing	Compressive strength in pounds per square inch			Remarks
				Highest	Lowest	Average	
1	4	3.14	Perpendicular [1]	8,400	6,400	7,600	Cylindrical specimens.
2	3	2.99	do	11,200	9,300	10,400	Do.
	3	2.99	Parallel [1]	8,700	8,000	8,500	Do.
3	2	5.00	Perpendicular	4,300	4,000	4,150	Cubical specimens.
	2	5.73	Parallel	4,500	4,300	4,400	Do.
4	3	3.29	Perpendicular	7,900	6,900	7,300	Cylindrical specimens.
	3	2.99	Parallel	10,800	8,900	9,700	Do.
5	3	3.33	Perpendicular	8,000	6,600	7,400	Do.
	3	3.33	Parallel	7,600	6,700	7,200	Do.
6	3	2.99	Perpendicular	19,000	17,400	18,400	Do.
	3	2.99	Parallel	20,600	16,500	18,800	Do.
7	3	2.99	Perpendicular	22,700	18,200	20,500	Do.
	4	3.14	Parallel	17,700	14,500	16,200	Do.
8	2	6.23	Perpendicular	9,600	9,000	9,300	Cubical specimens.
	2	5.14	Parallel	9,100	8,400	8,750	Do.
9	2	5.75	Perpendicular	4,200	4,000	4,100	Do.
	2	5.14	Parallel	3,500	3,400	3,450	Do.
10	2	5.39	Perpendicular	4,800	3,500	4,150	Do.
	2	5.23	Parallel	4,400	4,300	4,350	Do.
11	2	5.25	Perpendicular	6,500	5,200	5,850	Do.
	2	5.28	Parallel	7,000	5,900	6,450	Do.
12	2	6.22	Perpendicular	7,300	6,900	7,100	Do.
	2	5.95	Parallel	7,400	5,400	6,400	Do.
13	2	5.74	Perpendicular	6,600	6,300	6,450	Do.
	2	5.96	Parallel	6,500	6,000	6,250	Do.
14	2	6.48	Perpendicular	9,600	8,300	8,950	Do.
	2	5.88	Parallel	9,400	9,000	9,200	Do.
16	2	5.15	Perpendicular	5,900	5,600	5,750	Do.
	2	5.64	Parallel	5,600	5,000	5,300	Do.
20	2	5.48	Perpendicular	7,100	6,700	6,900	Do.
	2	5.18	Parallel	6,200	6,200	6,200	Do.
21	2	5.17	Perpendicular	6,300	5,900	6,100	Do.
	2	5.78	Parallel	5,600	5,200	5,400	Do.
23	2	5.90	Perpendicular	5,000	4,000	4,500	Do.
	2	5.37	Parallel	3,800	3,700	3,750	Do.
25	2	7.88	Perpendicular	6,700	6,500	6,600	Do.
	2	7.18	Parallel	5,700	5,400	5,550	Do.
27	2	5.42	Perpendicular	5,400	5,300	5,350	Do.
	2	5.78	Parallel	4,500	4,500	4,500	Do.
28	2	5.74	Perpendicular	6,800	6,300	6,550	Do.
	2	5.74	Parallel	6,900	6,400	6,650	Do.
29	2	5.29	Perpendicular	8,700	7,500	8,100	Do.
	2	5.44	Parallel	7,200	7,000	7,100	Do.
31	2	5.46	Perpendicular	7,000	5,300	6,150	Do.
	2	5,52	Parallel	7,400	6,100	6,750	Do.
32	2	5.84	Perpendicular	9,200	8,800	9,000	Do.
	2	5.80	Parallel	9,500	7,800	8,650	Do.
33	2	4.97	Perpendicular	7,000	6,300	6,650	Do.
	2	5.45	Parallel	5,800	5,500	5,650	Do.
34	2	5.40	Perpendicular	8,100	6,000	7,050	Do.
	2	5.48	Parallel	7,500	7,200	7,350	Do.
35	2	6.89	Perpendicular	8,200	7,400	7,800	Do.
	2	6.62	Parallel	6,800	6,500	6,650	Do.
36	2	6.06	Perpendicular	9,100	8,400	8,750	Do.
	2	6.00	Parallel	7,300	7,300	7,300	Do.
38	2	6.16	Perpendicular	6,100	5,500	5,800	Do.
	2	6.34	Parallel	5,600	4,100	4,850	Do.
40	2	6.10	Perpendicular	7,500	6,500	7,000	Do.
	2	5.78	Parallel	6,000	5,800	5,900	Do.
42	2	5.13	Perpendicular	6,400	6,300	6,350	Do.
	2	4.85	Parallel	6,000	3,700	4,850	Do.

[1] See footnote 1, p. 565.

TABLE 3.—*Compressive strength tests (specimens wet)*—Continued

Reference No.	Number of tests made	Average stressed area in square inches	Manner of testing	Compressive strength in pounds per square inch			Remarks
				Highest	Lowest	Average	
43	2	5.45	Perpendicular	6,400	6,000	6,200	Cubical specimens.
	2	5.11	Parallel	5,000	4,700	4,850	Do.
44	2	5.62	Perpendicular	8,800	7,800	8,300	Do.
	2	5.80	Parallel	8,800	6,300	7,550	Do.
45	2	6.10	Perpendicular	8,600	4,000	6,300	Do.
	2	5.68	Parallel	4,800	4,700	4,750	Do.
46	2	5.52	Perpendicular	7,100	5,800	6,450	Do.
	2	5.29	Parallel	5,800	5,500	5,650	Do.
47	2	5.95	Perpendicular	8,600	6,600	7,600	Do.
	2	5.68	Parallel	7,100	7,000	7,050	Do.
48	2	5.20	Perpendicular	7,200	7,100	7,150	Do.
	2	5.70	Parallel	5,700	5,500	5,600	Do.
49	2	5.73	Perpendicular	6,200	5,400	5,800	Do.
	2	5.18	Parallel	7,600	5,200	6,400	Do.
50	2	5.99	Perpendicular	6,000	4,700	5,350	Do.
	2	4.74	Parallel	6,400	4,500	5,450	Do.
51	2	5.83	Perpendicular	5,300	4,800	5,050	Do.
	2	5.93	Parallel	4,800	4,500	4,650	Do.
52	2	5.31	Perpendicular	6,000	5,400	5,700	Do.
	2	5.26	Parallel	4,300	3,800	4,050	Do.
53	2	5.12	Perpendicular	3,400	3,100	3,250	Do.
	2	5.36	Parallel	3,100	3,000	3,050	Do.
54	2	6.08	Perpendicular	8,000	7,700	7,850	Do.
	2	5.76	Parallel	7,300	7,100	7,200	Do.
55	2	5.53	Perpendicular	9,500	7,100	8,300	Do.
	2	5.54	Parallel	9,000	7,400	8,200	Do.
56	2	5.36	Perpendicular	5,300	4,700	5,000	Do.
	2	4.70	Parallel	5,100	4,200	4,650	Do.
57	2	5.41	Perpendicular	4,000	3,000	3,500	Do.
	3	5.52	Parallel	4,200	3,000	3,500	Do.
58	2	5.66	Perpendicular	6,100	5,900	6,000	Do.
	2	5.62	Parallel	4,700	4,600	4,650	Do.
59	2	5.54	Perpendicular	7,200	5,700	6,450	Do.
	2	4.93	Parallel	6,600	6,100	6,350	Do.
60	2	5.99	Perpendicular	4,100	3,900	4,000	Do.
	2	5.92	Parallel	3,400	3,700	3,550	Do.
62	2	5.56	Perpendicular	5,600	5,200	5,400	Do.
	2	5.15	Parallel	5,100	4,800	4,950	Do.
63	2	5.70	Perpendicular	5,300	5,300	5,300	Do.
	2	5.96	Parallel	5,400	4,700	5,050	Do.
64	2	5.63	Perpendicular	6,500	5,800	6,150	Do.
	2	5.34	Parallel	5,200	5,000	5,100	Do.
65	2	5.44	Perpendicular	6,200	5,800	6,000	Do.
	2	4.93	Parallel	5,200	5,100	5,150	Do.
66	2	5.94	Perpendicular	9,400	8,700	9,050	Do.
	2	6.20	Parallel	7,800	7,700	7,750	Do.
67	2	4.84	Perpendicular	7,000	6,900	6,950	Do.
	2	4.82	Parallel	6,200	6,100	6,150	Do.
69	2	5.52	Perpendicular	8,100	6,700	7,400	Do.
	2	5.08	Parallel	6,800	6,400	6,600	Do.
70	2	5.32	Perpendicular	9,100	7,500	8,300	Do.
	2	5.36	Parallel	8,600	7,700	8,150	Do.
74	2	5.90	Perpendicular	7,000	6,500	6,750	Do.
	2	5.06	Parallel	7,300	6,800	7,050	Do.
75	2	5.72	Perpendicular	8,000	6,600	7,300	Do.
	2	6.30	Parallel	7,800	6,900	7,350	Do.
76	2	5.99	Perpendicular	6,000	5,500	5,750	Do.
	2	6.16	Parallel	5,000	3,800	4,400	Do.
79	2	6.00	Perpendicular	10,200	8,800	9,500	Do.
	2	5.67	Parallel	7,800	6,400	7,100	Do.
81	2	5.27	Perpendicular	8,000	7,700	7,850	Do.
	2	5.06	Parallel	6,600	6,200	6,400	Do.
84	2	6.18	Perpendicular	7,900	5,900	6,900	Do.
	2	5.90	Parallel	5,600	5,400	5,500	Do.

TABLE 3.—*Compressive strength tests (specimens wet)*—Continued

Reference No.	Number of tests made	Average stressed area in square inches	Manner of testing	Compressive strength in pounds per square inch			Remarks
				Highest	Lowest	Average	
85	2	5.42	Perpendicular	9,600	9,500	9,550	Cubical specimens.
	2	5.33	Parallel	8,900	8,800	8,850	Do.
86	2	5.02	Perpendicular	4,700	4,500	4,600	Do.
	2	4.98	Parallel	3,700	3,400	3,550	Do.
87	2	6.05	Perpendicular	6,800	6,100	6,450	Do.
	2	5.74	Parallel	6,300	5,500	5,900	Do.
88	2	5.52	Perpendicular	8,700	7,400	8,050	Do.
	2	5.34	Parallel	7,900	6,600	7,250	Do.
89	2	6.26	Perpendicular	8,200	8,200	8,200	Do.
	2	5.90	Parallel	8,100	7,600	7,850	Do.
90	2	5.78	Perpendicular	8,500	8,400	8,450	Do.
	2	5.89	Parallel	7,500	7,100	7,300	Do.
91	2	5.74	Perpendicular	2,800	2,800	2,800	Do.
	2	6.12	Parallel	3,100	2,700	2,900	Do.
92	2	5.92	Perpendicular	5,600	5,000	5,300	Do.
	2	5.94	Parallel	5,400	4,300	4,850	Do.
93	2	5.18	Perpendicular	5,500	4,900	5,200	Do.
	2	5.20	Parallel	4,700	3,900	4,300	Do.
94	2	6.26	Perpendicular	7,400	7,400	7,400	Do.
	2	5.86	Parallel	6,700	6,200	6,450	Do.
95	2	5.93	Perpendicular	7,900	7,700	7,800	Do.
	2	5.65	Parallel	5,800	4,900	5,350	Do.
96	2	6.04	Perpendicular	8,600	7,200	7,900	Do.
	2	5.76	Parallel	6,400	6,300	6,350	Do.
97	2	6.52	Perpendicular	9,100	8,500	8,800	Do.
	2	5.80	Parallel	8,000	7,100	7,550	Do.
98	2	5.42	Perpendicular	6,600	5,800	6,200	Do.
	2	5.12	Parallel	6,000	5,900	5,950	Do.
99	2	6.10	Perpendicular	13,900	11,600	12,750	Do.
	2	6.16	Parallel	13,000	13,000	13,000	Do.
100	2	5.92	Perpendicular	8,500	7,700	8,100	Do.
	2	6.02	Parallel	7,300	6,900	7,100	Do.
108	2	5.26	Perpendicular	4,100	3,900	4,000	Do.
	2	5.41	Parallel	3,100	3,100	3,100	Do.
109	2	5.48	Perpendicular	3,600	3,400	3,500	Do.
	2	5.87	Parallel	4,200	3,500	3,850	Do.
110	3	3.35	Perpendicular	5,600	5,200	5,400	Cylindrical specimens.
	3	3.35	Parallel	5,400	4,900	5,200	Do.
111	4	3.18	Perpendicular	5,300	4,700	5,100	Do.
	3	3.35	Parallel	4,900	4,200	4,500	Do.
112	3	2.99	Perpendicular	11,600	9,400	10,300	Do.
	3	2.99	Parallel	12,900	8,700	11,100	Do.
113	3	2.99	Perpendicular	8,800	6,500	7,600	Do.
	3	2.99	Parallel	9,900	7,200	8,400	Do.
114	3	2.99	Perpendicular	17,100	15,300	16,000	Do.
	3	2.99	Parallel	16,000	14,100	14,800	Do.
114a	3	3.32	Perpendicular	12,000	9,600	10,800	Do.
	3	3.30	Parallel	8,700	6,500	7,600	Do.
115	3	2.99	Perpendicular	11,700	9,400	10,500	Do.
	3	2.99	Parallel	8,600	7,900	8,100	Do.
115a	3	3.27	Perpendicular	13,100	10,400	12,000	Do.
	3	3.32	Parallel	11,500	9,100	10,400	Do.
116	3	3.11	Perpendicular	13,100	12,800	12,900	Do.
	3	2.99	Parallel	10,300	9,600	9,900	Do.
117	3	3.10	Perpendicular	11,700	9,300	10,400	Do.
	3	3.02	Parallel	8,700	6,800	7,800	Do.
118	3	3.40	Perpendicular	12,800	10,900	11,800	Do.
	3	3.05	Parallel	10,300	9,200	9,700	Do.
119	4	3.04	Perpendicular	16,100	7,600	12,500	Do.
	5	3.00	Parallel	19,200	4,000	8,800	Do.
120	4	2.99	Perpendicular	14,600	10,100	12,000	Do.
	4	3.02	Parallel	18,700	10,900	14,100	Do.
121	3	2.99	Perpendicular	9,300	8,300	8,800	Do.
	3	2.99	Parallel	9,100	9,000	9,050	Do.

TABLE 3.—*Compressive strength tests (specimens wet)*—Continued

Reference No.	Number of tests made	Average stressed area in square inches	Manner of testing	Compressive strength in pounds per square inch			Remarks
				Highest	Lowest	Average	
122	2	5.47	Perpendicular	8,900	6,900	7,900	Cubical specimens.
	2	4.38	Parallel	8,100	7,700	7,900	Do.
123	2	5.12	Perpendicular	12,200	11,700	11,950	Do.
	2	5.08	Parallel	17,200	15,000	16,100	Do.
124	2	5.20	Perpendicular	11,500	10,200	10,850	Do.
	1	5.06	Parallel	9,800		9,800	Do.
125	4	3.14	Perpendicular	16,900	14,100	15,400	Cylindrical specimens.
	3	2.99	Parallel	16,100	14,800	15,200	Do.
126	3	2.99	Perpendicular	14,300	13,300	13,700	Do.
	5	2.99	Parallel	17,000	[2] 10,500	14,200	Do.
127	3	3.07	Perpendicular	18,700	17,500	18,100	Do.
	3	3.04	Parallel	20,000	18,500	19,400	Do.
128	3	3.05	Perpendicular	18,600	17,100	17,600	Do.
	3	3.05	Parallel	18,700	16,800	17,500	Do.
129	4	2.99	Perpendicular	16,700	12,500	14,800	Do.
	3	2.98	Parallel	18,200	17,000	17,500	Do.
130	3	2.99	Perpendicular	7,100	7,000	7,050	Do.
	3	2.99	Parallel	7,500	7,000	7,300	Do.
131	3	2.99	Perpendicular	7,900	7,500	7,700	Do.
	3	2.95	Parallel	8,500	6,800	7,900	Do.
132	3	2.91	Perpendicular	2,100	1,900	2,000	Do.
	3	3.29	Parallel	3,400	2,600	2,900	Do.
133	3	2.96	Perpendicular	6,100	4,900	5,600	Do.
	4	3.28	Parallel	6,100	3,300	5,200	Do.
134	3	3.21	Perpendicular	4,900	4,400	4,600	Do.
	3	3.23	Parallel	4,800	4,100	4,600	Do.

[2] Crowfoot seam running vertically through specimen.

TABLE 4.—*Transverse tests (modulus of rupture)*

Reference No.	Number of tests made	Manner of testing	Modulus of rupture in pounds per square inch		
			Highest	Lowest	Average
1	8	Perpendicular [1]	1,300	980	1,150
2	2	do	1,580	1,520	1,550
	2	Parallel [1]	790	780	785
3	2	Perpendicular	1,260	1,090	1,175
	2	Parallel	1,020	990	1,005
4	4	Perpendicular on edge.[1]	1,690	1,480	1,610
	1	Parallel	1,300	-------	1,300
5	2	Perpendicular	1,110	1,070	1,090
	3	Parallel	920	830	870
6	1	Perpendicular	630	[2]	630
7	2	do	2,530	2,520	2,525
	2	Parallel	2,060	1,850	1,955
8	2	Perpendicular	1,720	1,720	1,720
	2	Parallel	1,240	1,230	1,235
9	1	Perpendicular	-------	-------	1,100
	2	Parallel	980	940	960
10	2	Perpendicular	1,010	980	995
	2	Parallel	650	580	615
11	2	Perpendicular	1,460	1,400	1,430
	2	Parallel	970	940	955
12	2	Perpendicular	1,470	1,330	1,400
	2	Parallel	1,260	1,260	1,260
13	2	Perpendicular	1,520	1,460	1,490
	2	Parallel	1,100	1,110	1,105
14	2	Perpendicular	2,200	1,420	1,810
	2	Parallel	1,520	1,490	1,505
16	2	Perpendicular	1,280	1,260	1,270
	2	Parallel	1,010	980	995
20	2	Perpendicular	1,390	1,390	1,390
	2	Parallel	980	940	960
21	2	Perpendicular	1,140	1,100	1,120
	2	Parallel	940	930	935
23	2	Perpendicular	920	770	845
	2	Parallel	460	420	440
25	2	Perpendicular	1,350	1,230	1,290
	2	Parallel	1,050	1,010	1,030
27	2	Perpendicular	980	920	950
	2	Parallel	580	580	580
28	2	Perpendicular	1,520	1,220	1,370
	2	Parallel	980	950	965
29	2	Perpendicular	1,490	1,310	1,400
	2	Parallel	1,160	960	1,060
31	2	Perpendicular	1,050	900	975
	2	Parallel	1,130	1,070	1,100
32	2	Perpendicular	1,520	1,500	1,510
	2	Parallel	1,340	1,300	1,320
33	2	Perpendicular	1,440	1,360	1,400
	2	Parallel	1,080	1,040	1,060
34	2	Perpendicular	1,480	1,470	1,475
	2	Parallel	1,140	1,130	1,135
35	2	Perpendicular	1,820	1,300	1,560
	2	Parallel	1,280	1,170	1,225
36	2	Perpendicular	1,330	1,310	1,320
	2	Parallel	1,100	1,080	1,090
38	2	Perpendicular	1,060	1,010	1,035
	2	Parallel	1,070	950	1,010

Reference No.	Number of tests made	Manner of testing	Modulus of rupture in pounds per square inch		
			Highest	Lowest	Average
40	2	Perpendicular	1,320	1,190	1,255
	2	Parallel	1,000	930	965
42	2	Perpendicular	800	790	795
	2	Parallel	860	830	845
43	2	Perpendicular	920	860	890
	2	Parallel	1,170	1,040	1,105
44	2	Perpendicular	1,360	1,350	1,355
	2	Parallel	1,410	1,260	1,335
45	2	Perpendicular	910	770	840
	2	Parallel	630	580	605
46	2	Perpendicular	1,330	1,160	1,245
	2	Parallel	1,130	1,020	1,075
47	2	Perpendicular	1,290	1,260	1,275
	2	Parallel	830	810	820
48	2	Perpendicular	1,050	1,000	1,025
	2	Parallel	680	550	615
49	2	Perpendicular	1,310	1,140	1,225
	2	Parallel	1,100	1,090	1,095
50	2	Perpendicular	1,040	970	1,005
	2	Parallel	970	910	940
51	2	Perpendicular	1,150	1,100	1,125
	2	Parallel	880	880	880
52	2	Perpendicular	1,000	970	985
	2	Parallel	1,300	1,270	1,285
53	2	Perpendicular	750	660	705
	2	Parallel	560	510	535
54	2	Perpendicular	1,260	1,130	1,195
	2	Parallel	1,230	1,100	1,165
55	2	Perpendicular	1,190	1,060	1,125
	2	Parallel	1,010	980	995
56	2	Perpendicular	1,060	1,000	1,030
	2	Parallel	880	840	860
57	2	Perpendicular	860	730	795
	2	Parallel	600	600	600
58	2	Perpendicular	1,080	1,080	1,080
	2	Parallel	920	880	900
59	2	Perpendicular	1,380	1,220	1,300
	2	Parallel	1,200	1,190	1,195
60	2	Perpendicular	990	870	930
	2	Parallel	680	650	665
62	2	Perpendicular	1,160	1,080	1,120
	2	Parallel	1,030	1,020	1,025
63	2	Perpendicular	960	850	905
	2	Parallel	950	930	940
64	2	Perpendicular	1,120	980	1,050
	2	Parallel	960	860	910
65	2	Perpendicular	1,610	1,530	1,570
	2	Parallel	1,280	1,240	1,260
66	2	Perpendicular	1,800	1,560	1,680
	2	Parallel	1,140	1,080	1,110
67	2	Perpendicular	1,420	1,370	1,395
	2	Parallel	1,030	1,030	1,030
69	2	Perpendicular	1,640	1,560	1,600
	2	Parallel	1,170	1,030	1,100
70	2	Perpendicular	1,140	950	1,045
	2	Parallel	970	960	965

[1] Modulus of rupture "perpendicular" signifies that the load was applied perpendicular to the natural stratification and "parallel" indicates that the load was applied parallel to the stratification. "Perpendicular on edge" signifies that the specimen was placed with the stratification vertical and the load applied perpendicular to the direction of the stratification. (See fig. 25.)

[2] Broke 1 inch from center line along an incipient strain line.

TABLE 4.—*Transverse tests* (*modulus of rupture*)—Continued

Reference No.	Number of tests made	Manner of testing	Modulus of rupture in pounds per square inch		
			Highest	Lowest	Average
74	2	Perpendicular	1,280	1,220	1,250
	2	Parallel	1,150	1,090	1,120
75	2	Perpendicular	1,700	1,560	1,630
	1	Parallel	1,220	-------	1,220
76	2	Perpendicular	1,290	1,100	1,195
	2	Parallel	960	860	910
79	2	Perpendicular	1,370	1,340	1,355
	2	Parallel	1,380	1,330	1,355
81	2	Perpendicular	1,390	1,290	1,340
	2	Parallel	1,160	1,150	1,155
84	2	Perpendicular	1,340	1,330	1,335
	2	Parallel	1,480	1,420	1,450
85	2	Perpendicular	1,740	1,640	1,690
	2	Parallel	1,620	1,520	1,570
86	2	Perpendicular	1,120	1,080	1,100
	2	Parallel	890	780	835
87	2	Perpendicular	1,290	1,230	1,260
	2	Parallel	1,330	1,140	1,235
88	2	Perpendicular	1,520	1,280	1,400
	2	Parallel	1,450	1,410	1,430
89	2	Perpendicular	1,710	1,630	1,670
	2	Parallel	1,180	1,050	1,115
90	2	Perpendicular	1,570	1,510	1,540
	1	Parallel	1,320	-------	1,320
91	2	Perpendicular	1,100	990	1,045
	2	Parallel	650	630	640
92	2	Perpendicular	1,400	1,260	1,330
	2	Parallel	1,590	1,520	1,555
93	2	Perpendicular	1,240	1,200	1,220
	2	Parallel	1,110	1,070	1,090
94	2	Perpendicular	1,370	1,360	1,365
	2	Parallel	1,220	1,180	1,200
95	2	Perpendicular	1,190	1,110	1,150
	2	Parallel	1,070	900	985
96	2	Perpendicular	1,230	1,010	1,120
	2	Parallel	1,400	1,310	1,355
97	2	Perpendicular	1,570	1,450	1,510
	2	Parallel	1,500	1,410	1,455
98	2	Perpendicular	1,230	1,060	1,145
	2	Parallel	980	860	920
99	2	Perpendicular	2,180	1,850	2,015
	2	Parallel	2,010	1,960	1,985
100	2	Perpendicular	1,320	1,110	1,215
	2	Parallel	1,330	1,170	1,250
103	3	Perpendicular	1,290	1,230	1,260
104	3	do	1,250	1,110	1,160
108	2	do	930	770	850
	2	Parallel	580	520	550
109	2	Perpendicular	1,220	1,100	1,160
	2	Parallel	920	770	845
110	2	Perpendicular	870	860	865
	2	Parallel	730	700	715
111	2	Perpendicular	860	790	825
	2	Parallel	710	690	700
112	4	Perpendicular	1,290	970	1,080
	2	Parallel	1,220	1,210	1,215
113	2	Perpendicular	1,440	1,280	1,360
	4	Parallel	1,420	1,120	1,290
114	2	Perpendicular	2,050	1,940	1,995
	2	Parallel	1,950	1,780	1,865
114a	2	Perpendicular	1,450	1,450	1,450
	2	Parallel	1,570	1,170	1,370
115	4	Perpendicular	1,310	1,100	1,230
	2	Parallel	780	510	645
115a	2	Perpendicular	1,780	1,640	1,710
	2	Parallel	1,270	1,070	1,170
116	2	Perpendicular	1,650	1,480	1,565
	2	Parallel	1,640	1,540	1,590
117	2	Perpendicular	1,230	1,080	1,155
118	2	do	1,750	1,550	1,650
	1	Parallel	1,140	-------	1,140
119	2	Perpendicular	1,070	840	955
	2	Parallel	590	510	550
120	2	Perpendicular	1,340	1,140	1,240
	3	Parallel	880	780	840
121	2	Perpendicular	810	600	705
	2	Parallel	800	760	780
122	2	Perpendicular	2,440	1,980	2,210
	2	Parallel	2,310	1,960	2,135
123	2	Perpendicular	2,940	1,960	2,450
	2	Parallel	1,580	1,450	1,515
124	2	Perpendicular	2,280	1,720	2,000
	2	Parallel	1,550	1,480	1,515
125	5	Perpendicular	2,500	[3] 1,130	1,700
	2	Parallel	1,870	1,870	1,870
126	2	Perpendicular	2,470	1,780	2,120
	2	Parallel	2,360	[4] 720	1,540
127	2	Perpendicular	2,710	1,780	2,245
	2	Parallel	2,190	1,520	1,855
128	2	Perpendicular	2,600	2,150	2,375
	2	Parallel	1,830	1,580	1,705
129	2	Perpendicular	1,690	1,550	1,620
	4	Parallel	1,760	[5] 860	1,430
130	2	Perpendicular	1,480	1,160	1,320
	2	Parallel	1,250	1,160	1,205
131	4	Perpendicular	2,420	1,140	1,630
	2	Parallel	2,140	1,890	2,015
132	4	Perpendicular	840	510	640
	4	Parallel	540	390	470
133	4	Perpendicular	1,200	1,020	1,120
	4	Parallel	1,330	870	1,090
134	3	Perpendicular	1,140	1,020	1,100
	3	Parallel	1,060	960	1,010

[3] Three specimens broke along strain lines.
[4] Broke along seam.
[5] Broke along crowfoot seam.

TABLE 5.—*Tensile tests*

Reference No.	Number of tests made	Average area in square inches	Manner of testing	Tensile strength in pounds per square inch		
				Highest	Lowest	Average
2	3	1.02	Perpendicular [1]	400	350	380
4	3	1.04	do	400	310	340
9	3	1.11	Parallel [1]	450	400	420
11	3	1.12	Perpendicular	600	590	595
43	3	.97	(?)	520	310	430
46	3	1.11	Perpendicular	570	530	550
47	3	1.15	do	630	530	580
48	2	1.04	(?)	440	410	430
49	3	1.09	Parallel	480	440	460
56	3	1.05	do	380	340	370
58	3	1.14	do	560	420	480
59	3	1.13	do	560	460	500
85	3	1.08	Perpendicular	540	470	500
100	3	1.02	(?)	680	470	600
112	3	1.01	Perpendicular	320	260	280
113	3	1.06	do	520	180	330
114	3	1.10	do	[2] 990	690	890
115	3	1.03	do	600	430	520

[1] Tensile tests are designated "perpendicular" when the specimens were so prepared that the fracture occurred perpendicular to the stratification and "parallel" when the fracture occurred parallel to the stratification. (See fig. 25.)

[2] Did not break at this stress.

38831°—27——6

TABLE 6.—*Shearing tests (with punching apparatus)*

Reference No.	Number of tests made	Average thickness in inches	Average shearing area in square inches	Manner of testing	Shearing strength in pounds per square inch		
					Highest	Lowest	Average
2	2	1.06	6.66	Perpendicular [1]	3,240	3,060	3,150
	3	.86	5.40	Parallel [1]	3,370	1,650	2,780
4	4	.93	5.84	do	2,730	2,440	2,540
5	4	.98	6.16	Perpendicular	2,380	2,130	2,250
	6	.84	5.28	Parallel	2,410	1,160	2,030
6	3	.95	5.97	do	3,780	3,460	3,620
7	2	1.03	6.47	Perpendicular	4,340	3,340	3,840
	4	1.03	6.47	Parallel	4,740	4,160	4,440
10	4	1.02	6.40	Perpendicular	1,480	1,360	1,430
	4	1.17	7.34	Parallel	1,160	670	930
11	4	1.03	6.45	Perpendicular	2,220	1,700	1,920
	4	1.17	7.36	Parallel	1,610	1,270	1,460
12	4	1.02	6.42	Perpendicular	2,510	2,310	2,380
	5	1.26	7.89	Parallel	1,870	1,150	1,500
13	4	1.03	6.46	Perpendicular	2,120	1,190	1,720
	2	1.03	6.45	Parallel	1,310	1,180	1,245
14	4	1.05	6.60	Perpendicular	2,700	1,310	2,010
	4	1.07	6.72	Parallel	2,270	1,430	2,000
16	4	1.05	6.60	Perpendicular	1,850	1,650	1,730
	4	1.05	6.62	Parallel	1,560	1,140	1,330
23	4	1.24	7.78	Perpendicular	1,400	1,150	1,290
	4	1.00	6.30	Parallel	1,480	1,310	1,380
28	4	1.02	6.42	Perpendicular	1,710	1,490	1,580
	4	1.26	7.92	Parallel	2,070	1,510	1,780
33	5	1.29	8.12	Perpendicular	1,970	1,320	1,720
	4	1.04	6.56	Parallel	2,060	1,320	1,630
36	5	1.24	7.78	Perpendicular	3,090	2,240	2,630
	4	1.03	6.50	Parallel	2,360	1,380	1,850
46	4	1.00	6.26	Perpendicular	2,040	1,460	1,690
	4	1.12	7.06	Parallel	1,450	1,170	1,290
48	4	1.01	6.34	Perpendicular	2,340	1,510	1,780
	2	.98	6.18	Parallel	1,440	1,310	1,375
49	5	1.23	7.70	Perpendicular	2,030	1,680	1,860
	4	.99	6.23	Parallel	1,680	1,200	1,440
51	4	1.09	6.84	Perpendicular	1,830	1,190	1,550
	4	1.05	6.58	Parallel	1,480	1,150	1,300
53	2	1.18	7.45	do	1,370	1,310	1,340
54	4	1.05	6.60	Perpendicular	2,370	2,020	2,170
	5	1.27	7.95	Parallel	2,430	1,610	2,090
70	4	1.05	6.60	Perpendicular	2,300	1,530	2,020
	5	1.18	7.42	Parallel	2,040	1,130	1,720
92	4	1.16	7.32	Perpendicular	2,160	1,160	1,710
	4	1.02	6.46	Parallel	1,850	1,400	1,570
93	4	1.13	7.07	Perpendicular	2,180	1,220	1,720
	4	1.05	6.59	Parallel	2,050	1,700	1,920
95	5	1.29	8.08	Perpendicular	2,310	1,660	2,080
	4	1.01	6.34	Parallel	1,740	1,510	1,640
97	5	1.30	8.15	Perpendicular	2,560	1,490	2,140
	4	1.03	6.50	Parallel	2,100	1,330	1,690
110	3	2.03	12.76	Perpendicular	1,550	1,240	1,360
	4	2.02	12.69	Parallel	1,550	1,020	1,260
111	4	2.00	12.57	Perpendicular	1,550	960	1,230
	4	1.97	12.38	Parallel	1,220	990	1,090
112	3	.96	6.03	Perpendicular	2,590	1,980	2,240
	2	.99	6.22	Parallel	2,650	2,540	2,590
113	2	1.01	6.35	Perpendicular	3,080	2,280	2,680
	4	1.02	6.41	Parallel	2,810	1,950	2,320
114	3	.98	6.16	Perpendicular	3,360	2,570	2,940
	4	1.03	6.47	Parallel	2,740	2,370	2,590
114a	4	1.12	7.04	Perpendicular	3,380	2,970	3,130
	6	1.05	6.60	Parallel	2,860	1,650	2,220

[1] Shearing strength "perpendicular" signifies that the specimen was sheared perpendicular to the natural stratification and "parallel" that the specimen was sheared parallel to the stratification. (See fig. 25.)

TABLE 6.—*Shearing tests (with punching apparatus)*—Continued

Reference No.	Number of tests made	Average thick-ness in inches	Average shearing area in square inches	Manner of testing	Shearing strength in pounds per square inch		
					Highest	Lowest	Average
115	4	0.91	5.72	Perpendicular	2,960	2,220	2,690
	4	1.01	6.35	Parallel	2,720	2,000	2,290
115a	6	.99	6.22	Perpendicular	3,870	2,480	3,080
	4	1.08	6.79	Parallel	3,290	2,880	3,120
116	4	1.00	6.28	Perpendicular	3,530	2,890	3,130
	4	1.10	6.91	Parallel	3,070	2,190	2,720
117	4	1.53	9.61	Perpendicular	2,390	1,790	2,210
	2	.78	4.90	Parallel	1,920	1,720	1,820
118	5	1.02	6.41	Perpendicular	3,480	2,880	3,140
	2	1.02	6.41	Parallel	2,620	2,260	2,440
119	4	.91	5.72	Perpendicular	3,320	1,420	2,240
	4	1.01	6.35	Parallel	3,190	1,740	2,460
120	4	1.18	7.41	Perpendicular	2,930	1,620	2,350
	6	.91	5.72	Parallel	2,680	1,050	1,940
121	4	1.04	6.53	Perpendicular	2,300	920	1,490
	4	1.02	6.41	Parallel	1,610	1,270	1,480
125	6	1.01	6.35	Perpendicular	3,390	2,350	3,100
	3	1.00	6.28	Parallel	3,050	3,000	3,030
126	4	1.01	6.35	Perpendicular	2,880	2,140	2,600
	4	1.04	6.50	Parallel	3,740	2,470	3,120
127	8	.98	6.16	Perpendicular	4,250	3,070	3,580
	1	1.10	6.91	Parallel	3,050	----------	3,050
128	4	1.00	6.28	Perpendicular	4,260	2,550	3,180
	4	1.02	6.41	Parallel	3,280	2,460	2,920
129	4	1.06	6.66	Perpendicular	3,530	3,210	3,320
	7	.95	5.97	Parallel	3,540	2,010	2,910
130	4	.99	6.22	Perpendicular	1,690	1,270	1,420
	4	1.04	6.53	Parallel	1,760	1,420	1,590
131	8	.97	6.10	Perpendicular	2,610	1,540	2,090
	4	1.03	6.47	Parallel	2,300	2,080	2,190
132	7	1.50	9.42	Perpendicular	970	720	830
	10	1.56	9.80	Parallel	980	580	800
133	7	1.39	8.73	Perpendicular	2,110	1,110	1,680
	8	1.52	9.55	Parallel	2,260	1,160	1,810
134	6	.96	6.03	Perpendicular	2,060	1,500	1,850
	6	1.06	6.66	Parallel	1,960	1,300	1,600

TABLE 7.—*Shearing tests* (*with Johnson apparatus*)

Reference No.	Number of tests made	Average thickness in inches	Average shearing area in square inches	Manner of testing	Shearing strength in pounds per square inch		
					Highest	Lowest	Average
2	2	0.96	6.62	Perpendicular [1]	2,150	2,100	2,125
	1	1.00	6.96	Parallel [1]	1,640		1,640
4	4	.96	6.75	Perpendicular	2,400	1,620	2,090
6	1	1.00	6.12	do	2,990		2,990
15	7	1.95	7.78	do	1,100	880	1,000
	7	1.92	7.50	Perpendicular on edge.[1]	1,180	740	1,030
18	10	1.95	7.56	Perpendicular	2,280	1,560	1,900
	9	1.95	7.60	Perpendicular on edge.	1,800	1,340	1,640
19	10	1.96	7.70	Perpendicular	2,230	1,750	1,910
	9	1.96	7.73	Perpendicular on edge.	1,740	1,160	1,460
22	8	2.02	8.17	Perpendicular	1,490	910	1,200
	6	2.03	8.20	Perpendicular on edge.	1,620	1,160	1,360
24	10	1.95	7.59	Perpendicular	2,820	2,030	2,380
	10	1.94	7.54	Perpendicular on edge.	2,070	1,520	1,760
26	7	1.98	7.78	Perpendicular	1,810	1,470	1,670
	7	1.96	7.71	Perpendicular on edge.	1,640	1,480	1,570
30	7	2.03	8.29	Perpendicular	2,000	1,190	1,590
	7	2.04	8.34	Perpendicular on edge.	1,520	1,300	1,450
37	7	2.02	8.17	Perpendicular	1,830	1,420	1,650
	7	2.04	8.26	Perpendicular on edge.	1,870	1,420	1,610
39	7	1.96	7.74	Perpendicular	1,490	1,070	1,250
	7	1.96	7.86	Perpendicular on edge.	1,180	980	1,090
41	10	1.98	7.81	Perpendicular	2,540	2,030	2,290
	10	1.97	7.67	Perpendicular on edge.	1,880	1,240	1,640
61	6	1.99	7.92	Perpendicular	1,790	1,380	1,540
	6	1.99	7.93	Perpendicular on edge.	1,420	1,150	1,290
68	10	1.93	7.43	Perpendicular	2,230	1,860	2,060
	10	1.94	7.51	Perpendicular on edge.	2,030	1,440	1,720
71	7	1.96	7.55	Perpendicular	1,590	1,410	1,510
	7	1.99	7.78	Perpendicular on edge.	1,660	1,110	1,350
73	14	2.01	8.05	Parallel	1,840	1,340	1,600
77	7	1.99	7.86	Perpendicular	1,170	890	1,020
	7	1.98	7.97	Perpendicular on edge.	1,270	1,080	1,170
78	7	2.04	8.31	Perpendicular	1,440	1,050	1,240
	7	2.04	8.35	Perpendicular on edge.	1,310	1,170	1,240
80	7	1.98	7.89	Perpendicular	2,270	1,480	1,910
	6	2.00	8.26	Perpendicular on edge.	2,210	1,520	1,750
82	7	1.99	7.90	Perpendicular	1,830	1,630	1,700
	7	2.00	7.92	Perpendicular on edge.	1,580	1,320	1,450
83	7	2.01	8.02	Perpendicular	1,490	1,230	1,370
	7	2.00	7.98	Perpendicular on edge.	1,500	1,160	1,300
101	7	2.00	7.97	Perpendicular	2,180	1,740	1,950
	7	2.01	8.03	Perpendicular on edge.	2,130	1,680	1,910
112	2	.95	5.02	Perpendicular	3,450	3,450	3,450
	2	.97	5.00	Parallel	2,820	2,110	2,465
113	3	.96	3.91	Perpendicular	3,120	2,580	2,860
	2	1.04	4.03	Parallel	2,720	2,700	2,710
115	1	1.00	4.14	Perpendicular	3,010		3,010
	2	.98	6.84	Parallel	2,430	2,190	2,310
125	3	1.05	6.59	Perpendicular	2,950	2,260	2,670
	1	1.06	4.24	Parallel	4,580		4,580

[1] Shearing strength "perpendicular" signifies that the specimen was sheared perpendicular to the natural stratification and "parallel" that the specimen was sheared parallel to the stratification. "Perpendicular on edge" signifies that the specimen was placed with the stratification vertical and the shearing edge applied perpendicular to the direction of stratification. (See fig. 25.)

TABLE 8.—*Impact tests*

Reference No.	Manner of testing	Height in centimeters, test number					
		1	2	3	4	5	Average
2	Perpendicular [1]	5	5	5			5
4	do	4	4	5			4
5	do	5	5	5			5
6	do	8	7	9			8
7	do	6	7	8			7
15	do	3	3	3			3
22	do	4	4	3			4
26	do	4	3	4			4
30	do	4	4	3			4
37	do	3	3	3			3
39	do	3	3	3			3
41	do	5	4	4			4
68	do	4	4	3			4
71	do	3	3	3			3
77	do	4	3	3			3
78	do	3	3	3			
80	do	4	5	5			3
82	do	5	4	4			5
83	do	2	4	4			4
101	do	4	4	4			3
							4
110	do	3	4	4			4
111	do	3	3	3			3
112	do	3	4	2			3
113	do	4	4	4			4
114	do	3	4	5			4
114a	do	4	4	4			4
115	do	5	4	4			4
115a	do	3	3	4			3
116	do	4	4	3			4
117	do	3	3	3			3
118	do	4	4	3			4
119	do	4	4	5			4
120	do	3	[2] 2	4			3
121	do	2	1	2			2
125	do	4	5	5			5
126	do	6	5	6			6
127	do	6	7	6			6
128	do	7	7	7			7
129	do	6	5	5			5
130	do	4	3	3			3
131	do	6	5	4	5	6	5
132	do	3	3	3			3
133	do	4	4	5			4
134	do	4	4	4			4

[1] Impact tests "perpendicular" signifies that the direction of the impact was perpendicular to the natural stratification.
[2] Seam crack in one end of specimen.

TABLE 9.—*Modulus of elasticity from compression tests*

Reference No.	Number of tests made	Gauge length in inches	Condition	Manner of testing	Modulus of elasticity in millions of pounds per square inch		
					Highest	Lowest	Average
2	1	7	Dry	Perpendicular [1]	4.2		[2] 4.2
	5	7	do	Parallel [1]	6.4	4.9	5.5
4	[3] 8	10.5, 7.5	do	do	6.3	5.2	5.8
	6	10.5	Wet	do	5.4	5.1	5.2
7	6	10	Dry	Perpendicular	8.5	7.6	8.1
	5	5	do	Parallel	5.6	4.8	5.3
10	4	9.5	do	Perpendicular	3.5	3.2	3.3
11	4	9.5	do	do	4.5	4.1	4.3
12	3	9.5	do	do	4.6	4.5	4.55
13	4	9.5	do	do	4.8	4.3	4.5
14	4	9.5	do	do	5.7	5.3	5.4
16	3	9.5	do	do	4.9	4.6	4.8
23	3	9.5	do	Parallel	3.7	3.5	3.6
28	4	9.5	do	Perpendicular	4.8	4.3	4.5
33	4	9.5	do	Parallel	4.4	4.0	4.2
36	3	9.5	do	do	5.0	4.7	4.9
46	3	9.5	do	Perpendicular	4.5	4.1	4.3
48	4	9.5	do	do	4.9	3.8	4.2
49	3	9.5	do	Parallel	4.5	4.3	4.4
51	3	9.5	do	do	3.3	3.3	3.3
54	3	9.5	do	do	5.6	5.3	5.4
70	4	9.5	do	Perpendicular	5.5	5.1	5.3
92	4	9.5	do	Parallel	4.5	3.9	4.1
93	3	9.5	do	do	5.0	5.0	5.0
95	4	9.5	do	do	4.8	4.0	4.4
97	3	9.5	do	do	5.3	4.8	5.1
110	6	6.5	do	Perpendicular	3.5	3.2	3.4
	8	10.5	do	Parallel	4.6	3.8	4.1
111	6	10	do	Perpendicular	3.6	3.0	3.2
	6	7	do	Parallel	4.0	3.6	3.9
112	4	9.5	do	Perpendicular	4.7	4.2	4.5
	6	7.5	do	Parallel	4.6	3.6	4.2
113	6	7	do	Perpendicular	3.9	3.5	3.7
	6	7	Wet	do	3.2	3.0	3.1
	4	9.5	Dry	Parallel	4.5	3.8	4.2
114	7	7.5	do	Perpendicular	7.7	6.1	7.0
	4	10	do	Parallel	7.0	6.7	6.8
114a	5	10	do	Perpendicular	7.5	6.3	7.0
	5	10	do	Parallel	7.1	6.4	6.8
115	1	7	do	Perpendicular	5.7		5.7
	3	10	do	Parallel	4.7	4.4	4.5
115a	6	10	do	Perpendicular	6.4	5.3	6.0
	6	10	do	Parallel	6.6	5.6	6.3
116	6	10	do	Perpendicular	4.6	4.1	4.5
	7	8	do	Parallel	4.5	4.1	4.3
118	6	9.5	do	Perpendicular	7.0	6.3	6.6
	6	10.5	do	Parallel	7.5	6.1	6.9
119	6	11	do	Perpendicular	5.5	4.8	5.3
	8	7	do	Parallel	4.0	3.1	3.7
120	6	7.5	do	Perpendicular	4.1	3.4	3.8
	[3] 12	7, 10.5	do	Parallel	5.8	4.6	5.3
121	6	6	do	Perpendicular	4.6	3.9	4.3
125	3	10.5	do	do	7.9	7.2	7.6
	[3] 5	6.5, 11	do	Parallel	10.3	8.1	9.7
	5	11	Wet	do	10.3	8.7	9.4
126	3	10.5	Dry	Perpendicular	7.8	7.1	7.5
	1	9.5	do	Parallel	7.6		7.6
127	3	6	do	do	11.0	10.4	10.6
128	5	10.5	do	Perpendicular	9.9	9.4	9.6
	7	6	do	Parallel	11.8	9.9	10.6
129	4	7	do	Perpendicular	11.4	11.0	11.2
	4	10	do	Parallel	12.4	9.7	11.1
130	[3] 12	6, 10	do	do	4.2	3.7	4.1
	5	10	Wet	do	3.4	3.1	3.2
131	5	6	Dry	do	6.7	6.0	6.3
132	6	7	do	Perpendicular	1.7	1.5	1.6
	6	10.5	do	Parallel	2.4	2.2	2.3
133	6	6.5	do	Perpendicular	4.4	4.0	4.2
	6	10.5	do	Parallel	4.5	4.2	4.3
134	5	9	do	Perpendicular	3.4	3.2	3.3
	5	9	do	Parallel	3.3	3.2	3.25

[1] Modulus of elasticity "perpendicular" signifies that the load was applied perpendicular to the natural stratification, and "parallel" indicates that the load was applied parallel to the stratification. (See fig. 25.)
[2] Modulus of elasticity $=4.2\times1{,}000{,}000=4{,}200{,}000$.
[3] 2 specimens.

TABLE 10.—*Modulus of elasticity from transverse tests*

Reference No.	Number of tests made	Manner of testing	Modulus of elasticity in millions of pounds per square inch: Highest	Lowest	Average
1	4	Perpendicular [1]	2.3	1.7	[2] 2.0
2	5	do	5.2	4.4	4.8
4	4	Perpendicular on edge [1]	5.3	2.8	4.2
	1	Parallel [1]	3.6		3.6
5	2	Perpendicular	2.6	2.6	2.6
	3	Parallel	1.2	1.2	1.2
6	1	Perpendicular	2.9		2.9
7	2	Parallel	5.7	5.5	5.6
11	1	do			3.8
12	1	do			4.2
14	1	do			5.0
16	1	do			3.7
28	1	do			4.1
33	1	Perpendicular			3.8
36	1	do			6.0
46	1	Parallel			3.1
49	1	Perpendicular			4.2
51	1	do			2.3
53	1	Parallel			3.8
54	1	do			4.7
70	1	do			4.3
92	1	Perpendicular			2.8
93	1	do			3.5
95	1	do			4.7
97	1	do			4.4
103	3	do	3.6	2.8	3.17
104	3	do	3.2	3.0	3.08
110	2	do	1.7	1.3	1.5
111	2	do	1.6	1.2	1.4
112	3	do	4.0	3.1	3.4
	2	Parallel	5.0	3.3	4.1
113	2	Perpendicular	5.2	4.8	5.0
	4	Parallel	5.3	3.2	4.2
114	2	Perpendicular	4.4	4.1	4.25
	2	Parallel	6.2	5.8	6.0
114a	2	Perpendicular	4.8	4.4	4.6
	2	Parallel	7.0	5.5	6.25
115	4	Perpendicular	5.6	3.1	4.2
	2	Parallel	3.0	2.5	2.75
115a	2	Perpendicular	3.9	2.8	3.35
	2	Parallel	2.6	2.1	2.35
116	2	Perpendicular	3.4	2.9	3.15
	2	Parallel	4.5	3.2	3.85
117	2	Perpendicular	3.9	3.7	3.8
118	2	do	5.6	5.3	5.45
	1	Parallel	5.4		5.4
119	2	Perpendicular	1.4	1.2	1.3
	2	Parallel	1.7	1.5	1.6
120	2	Perpendicular	1.6	1.5	1.55
	3	Parallel	1.0	.8	.9
121	2	Perpendicular	.7	.7	.7
	2	Parallel	.7	.6	.65
125	2	Perpendicular	11.0	9.8	10.4
	2	Parallel	7.8	6.5	7.15
126	2	Perpendicular	7.6	6.4	7.0
	1	Parallel	4.5		4.5
127	3	Perpendicular	6.4	5.2	5.9
128	2	do	8.4	8.2	8.3
	2	Parallel	9.5	6.6	8.05
129	2	Perpendicular	5.5	5.4	5.45
	4	Parallel	5.8	3.2	4.6
130	2	Perpendicular	3.7	3.3	3.5
	2	Parallel	4.1	4.0	4.05
131	3	Perpendicular	5.1	3.4	4.0
132	3	do	2.0	.9	1.5
	2	Parallel	1.1	1.0	1.05
133	4	Perpendicular	3.8	2.2	3.1
	2	Parallel	4.1	3.4	3.75
134	3	Perpendicular	2.9	2.9	2.9
	3	Parallel	2.85	3.0	2.9

[1] Modulus of elasticity "perpendicular" signifies that the load was applied perpendicular to the natural stratification, and "parallel" indicates that the load was applied parallel to the stratification. "Perpendicular on edge" signifies that the specimen was placed with the stratification vertical and the load applied perpendicular to the direction of stratification. (See fig. 25.)

[2] Modulus of elasticity $= 2.0 \times 1{,}000{,}000 = 2{,}000{,}000$.

TABLE 11.—*Absorption tests*

Reference No.	Number of tests made	Per cent of absorption: By weight, Highest	By weight, Lowest	By weight, Average	By volume, Highest	By volume, Lowest	By volume, Average	Reference No.	Number of tests made	Per cent of absorption: By weight, Highest	By weight, Lowest	By weight, Average	By volume, Highest	By volume, Lowest	By volume, Average
1	4	5.0	4.8	4.9	11.6	11.2	11.4	69	4	4.6	4.2	4.4	10.6	9.7	10.1
2	12	4.9	4.4	4.7	11.6	10.4	11.0	70	14	6.2	4.0	5.3	14.5	9.3	12.4
3	4	4.6	4.1	4.4	10.6	9.4	10.1	74	6	3.5	3.3	3.4	8.3	7.9	8.0
4	16	5.2	3.7	4.5	12.3	8.7	10.6	75	12	4.5	4.0	4.2	10.4	9.3	9.7
5	12	5.5	5.1	5.3	12.8	11.8	12.2	76	4	6.2	5.7	6.0	13.8	12.7	13.4
6	6	.42	.28	.36	1.12	.75	.96	79	10	3.4	2.8	3.1	8.2	6.8	7.5
7	12	2.8	2.1	2.5	7.3	5.4	6.5	81	12	4.6	4.1	4.3	10.7	9.5	10.0
8	12	4.7	4.1	4.4	10.7	9.3	10.0	84	4	3.8	3.3	3.5	9.0	7.8	8.3
9	4	6.9	6.5	6.7	15.0	14.1	14.5	85	4	3.2	3.0	3.1	7.8	7.3	7.5
10	12	6.6	6.1	6.4	14.5	13.4	14.1	86	4	7.6	7.1	7.3	16.6	15.5	16.0
11	4	5.61	5.46	5.53	12.5	12.2	12.3	87	4	3.3	3.0	3.2	7.9	7.3	7.6
12	4	5.6	5.1	5.4	12.6	11.5	12.2	88	9	6.6	3.8	5.2	15.2	8.8	12.0
13	12	4.9	4.5	4.7	11.2	10.3	10.8	89	4	4.5	3.6	4.0	10.5	8.4	9.4
14	11	4.4	4.0	4.2	10.4	9.5	9.9	90	10	5.0	3.2	4.0	11.6	7.5	9.3
16	10	4.9	4.5	4.7	11.3	10.4	10.8	91	4	6.8	6.5	6.6	15.1	14.4	14.6
20	7	4.6	3.8	4.4	10.5	8.7	10.1	92	4	5.7	4.9	5.4	12.8	11.0	12.1
21	4	7.3	6.8	7.0	15.8	14.7	15.2	93	4	4.0	3.6	3.8	9.3	8.4	8.8
23	4	5.1	4.9	5.0	11.5	11.1	11.3	94	4	4.4	4.2	4.3	10.3	9.8	10.1
25	12	5.8	5.4	5.5	13.0	12.1	12.3	95	4	4.14	3.95	4.06	9.6	9.2	9.4
27	12	6.2	5.4	5.8	14.0	12.2	13.1	96	4	3.7	3.3	3.5	8.8	7.8	8.2
28	12	6.2	4.9	5.0	13.9	11.0	11.3	97	6	3.9	3.6	3.8	9.2	8.5	8.8
29	12	4.6	4.4	4.5	10.7	10.2	10.4	98	4	4.8	4.6	4.7	11.0	10.5	10.7
31	4	5.4	5.0	5.2	12.4	11.5	11.9	99	10	2.5	2.3	2.4	6.3	5.8	6.0
32	9	4.7	3.4	4.0	10.7	7.8	9.1	100	4	5.0	4.6	4.8	11.5	10.6	11.0
33	4	5.8	5.2	5.5	13.1	11.8	12.4	102	3	1.4	1.1	1.3	3.7	2.9	3.4
34	4	3.64	3.47	3.57	8.6	8.2	8.5	103	6	6.3	5.8	6.0	13.9	12.8	13.4
35	12	5.1	4.4	4.6	11.7	10.1	10.5	104	6	5.8	5.2	5.4	13.1	11.8	12.3
36	4	4.03	3.87	3.97	9.3	9.0	9.2	108	4	4.8	4.2	4.5	11.0	9.8	10.6
38	6	5.8	4.9	5.2	13.2	11.2	11.9	109	4	4.2	1.8	3.5	9.6	4.1	7.9
40	4	4.4	4.2	4.3	10.1	9.7	9.9	110	12	5.6	4.5	4.9	12.8	10.2	11.3
								111	12	5.8	3.7	4.5	13.4	8.6	10.4
42	11	7.2	5.4	6.2	16.3	12.3	14.1	112	12	5.6	4.0	4.7	13.5	9.6	11.3
43	4	4.5	4.3	4.4	10.4	9.9	10.1	113	9	5.6	4.5	5.2	13.2	10.6	12.2
44	21	4.2	3.3	3.9	10.0	7.8	9.3	114	12	3.7	2.9	3.3	9.3	7.3	8.3
45	4	6.1	5.4	5.9	13.7	12.2	13.2	114a	12	4.6	3.5	3.9	11.5	8.8	9.8
46	4	4.9	4.5	4.7	11.3	10.4	10.9	115	12	5.9	4.0	5.0	14.4	9.7	12.2
47	12	4.6	4.0	4.4	10.6	9.2	10.1	115a	12	3.8	3.0	3.4	9.6	7.6	8.6
48	4	3.94	3.78	3.84	9.1	8.8	9.0	116	12	5.1	3.9	4.4	12.6	9.4	10.7
49	8	6.2	4.6	5.4	13.7	10.1	11.9	117	10	4.0	3.3	3.6	9.8	8.1	8.8
50	12	6.0	5.0	5.2	13.4	11.2	11.6	118	12	2.7	3.3	3.0	8.4	6.8	7.5
51	4	6.2	6.0	6.1	13.7	13.3	13.6	119	12	4.8	1.4	2.9	12.0	3.7	7.2
52	11	5.6	5.2	5.4	12.8	11.9	12.4	120	12	3.7	2.1	3.2	9.0	5.1	7.8
53	9	6.9	3.0	5.6	15.0	6.5	12.2	121	12	5.2	3.9	4.5	12.6	9.4	10.9
54	4	3.9	3.4	3.6	9.0	7.9	8.4	122	4	3.1	2.5	2.8	7.9	6.6	7.2
55	6	5.1	3.3	4.2	12.1	7.8	9.9	123	4	.50	.41	.45	1.31	1.08	1.19
56	12	5.8	5.5	5.7	13.1	12.4	12.9	124	4	.363	.357	.358	.965	.949	.952
57	7	6.9	6.1	6.4	15.5	13.7	14.4	125	12	.92	.43	.52	2.43	1.14	1.39
58	4	4.8	4.2	4.6	11.1	9.8	10.7	126	13	.69	.26	.32	1.83	.69	1.05
59	4	4.9	4.4	4.6	11.3	10.2	10.7	127	12	.51	.44	.47	1.36	1.17	1.25
60	4	6.1	5.6	5.8	13.6	12.5	13.0	128	12	.42	.37	.40	1.12	.99	1.05
62	12	6.1	5.4	5.7	13.5	12.0	12.7	129	14	.10	.02	.07	.28	.04	.19
63	4	5.13	5.00	5.07	11.7	11.4	11.6	130	12	6.7	6.0	6.4	15.2	13.7	14.5
64	12	6.0	5.6	5.8	13.2	12.3	12.8	131	12	5.4	3.5	4.3	12.4	8.1	10.0
65	12	6.0	5.4	5.6	13.4	12.0	12.6	132	12	13.3	9.8	12.3	24.8	18.4	23.0
66	4	4.01	3.88	3.94	9.5	9.3	9.4	133	12	6.9	6.0	6.5	15.3	13.4	14.4
67	8	4.0	3.6	3.8	9.6	8.6	9.1	134	13	9.1	8.6	8.9	19.1	18.0	18.7

(Insert at page 582)

Addendum to Tables 11 and 12.—*Absorption, apparent specific gravity, and weight per cubic foot*

Reference No.	Number of tests	Percentage of absorption by weight			Number of tests	Apparent specific gravity			Weight per cubic foot
		Highest	Lowest	Average		Highest	Lowest	Average	
									Pounds
5b	6	6.1	5.4	5.7	3	2.31	2.28	2.30	144
5c	3	4.7	4.6	4.6	2	2.33	2.33	2.33	146
5d	3	5.5	4.9	5.3	2	2.34	2.33	2.34	146
41a	6	4.9	4.4	4.6	3	2.36	2.34	2.35	147
41b	6	7.3	6.8	7.0	3	2.20	2.19	2.20	138
41c	6	5.1	4.9	5.0	3	2.31	2.30	2.30	144
54a	6	7.2	5.9	6.7	3	2.24	2.18	2.22	139
83a	6	6.4	5.9	6.1	3	2.28	2.25	2.27	142
87a	6	6.1	5.7	5.9	3	2.26	2.25	2.26	141
106a	6	1.4	1.0	1.2	3	2.70	2.68	2.69	168
135	9	5.0	2.8	3.7	6	2.56	2.48	2.51	157

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TABLE 12.—*True specific gravity, apparent specific gravity, porosity, and weight per cubic foot*

Reference No.	Number of tests made	True specific gravity			Number of tests made	Apparent specific gravity			Porosity	Weight per cubic foot
		Highest	Lowest	Average		Highest	Lowest	Average		
										Lbs.
1					4	2.36	2.33	2.34		146
2	4	2.717	2.708	2.713	6	2.364	2.346	2.354	13.2	147
3	4	2.739	2.725	2.732	4	2.297	2.293	2.295	16.0	144
4	4	2.74	2.72	2.73	10	2.42	2.31	2.34	13.7	146
5					6	2.32	2.29	2.31		144
6	3	2.740	2.724	2.734	4	2.680	2.669	2.673	2.23	167
7	4	2.83	2.80	2.82	8	2.64	2.58	2.60	7.8	163
8					4	2.28	2.28	2.28	16.2	142
9	3	2.72	2.71	2.713	4	2.18	2.16	2.17	20.2	136
10					4	2.22	2.19	2.20	19.1	138
11					4	2.24	2.22	2.23	18.0	139
12					4	2.28	2.22	2.26	16.9	141
13					4	2.29	2.28	2.288	15.8	143
14					3	2.38	2.36	2.37	12.9	148
16					3	2.30	2.29	2.297	15.1	144
20					4	2.32	2.27	2.29	15.8	143
21					3	2.19	2.16	2.17	20.2	136
23					4	2.274	2.260	2.264	16.9	141
25					4	2.26	2.22	2.24	17.6	140
27					4	2.26	2.26	2.26	20.4	141
28					4	2.26	2.24	2.25	17.3	141
29					4	2.32	2.31	2.318	14.7	145
31					4	2.31	2.29	2.30	15.4	144
32					2	2.29	2.28	2.285	14.0	142
33					4	2.28	2.25	2.26	16.9	141
34					4	2.379	2.367	2.373	12.9	148
35					4	2.32	2.28	2.29	15.8	143
36	4	2.73	2.70	2.71	4	2.34	2.30	2.32	14.7	145
38					3	2.28	2.28	2.28	16.2	142
40					4	2.32	2.30	2.31	15.1	144
42					3	2.29	2.26	2.27	16.6	142
43					4	2.299	2.294	2.297	15.4	144
44					8	2.40	2.36	2.37	12.9	148
45					4	2.28	2.22	2.25	17.3	141
46					4	2.33	2.31	2.32	14.7	145
47					4	2.32	2.27	2.30	15.4	144
48					4	2.344	2.331	2.338	14.0	146
49					2	2.21	2.20	2.205	19.1	138
50					4	2.24	2.23	2.235	17.6	140
51					4	2.226	2.219	2.224	18.4	139
52					3	2.30	2.29	2.297	15.8	143
53					3	2.18	2.16	2.17	20.2	136
54					4	2.34	2.29	2.32	14.7	145
55	3	2.72	2.72	2.72	4	2.42	2.34	2.37	12.9	148
56					4	2.27	2.25	2.26	16.9	141
57					3	2.26	2.24	2.25	17.3	141
58					4	2.34	2.31	2.32	14.7	145
59					4	2.33	2.28	2.31	15.1	144
60					4	2.24	2.21	2.23	18.0	139
62					4	2.23	2.21	2.22	18.0	139
63	4	2.730	2.721	2.728	4	2.30	2.28	2.29	15.8	143
64					4	2.21	2.19	2.20	19.1	138
65					4	2.24	2.22	2.23	18.0	139
66					4	2.388	2.381	2.384	12.5	149
67					4	2.40	2.38	2.39	12.1	149
69	3	2.71	2.71	2.71	4	2.32	2.30	2.31	15.1	144
70					4	2.37	2.25	2.34	14.0	146
74					3	2.37	2.34	2.36	13.2	148
75					4	2.35	2.30	2.32	14.7	145
76					4	2.23	2.22	2.228	18.0	139
79					4	2.45	2.39	2.42	11.0	151
81					4	2.32	2.31	2.318	14.7	145
84					4	2.38	2.35	2.37	12.9	148
85					4	2.43	2.42	2.428	10.7	152
86					4	2.20	2.18	2.19	19.5	137

TABLE 12.—*True specific gravity, apparent specific gravity, porosity, and weight per cubic foot*—Continued

Reference No.	Number of tests made	True specific gravity			Number of tests made	Apparent specific gravity			Porosity	Weight per cubic foot
		Highest	Lowest	Average		Highest	Lowest	Average		
										Lbs.
87	3	2.73	2.72	2.727	4	2.42	2.39	2.40	11.8	150
88					4	2.32	2.30	2.31	15.1	144
89					4	2.36	2.33	2.34	14.0	146
90					4	2.35	2.30	2.33	13.6	147
91					4	2.23	2.22	2.225	18.4	139
92					4	2.28	2.23	2.25	17.3	140
93					4	2.33	2.30	2.32	14.7	145
94	4	2.725	2.712	2.719	4	2.35	2.33	2.34	14.0	146
95					4	2.332	2.316	2.325	14.7	145
96	2	2.73	2.73	2.73	4	2.374	2.363	2.369	12.9	148
97					3	2.35	2.34	2.347	13.6	147
98	3	2.72	2.70	2.71	4	2.29	2.26	2.28	16.2	143
99	3	2.73	2.72	2.727	4	2.515	2.498	2.504	8.1	156
100					4	2.31	2.29	2.30	15.4	144
102					3	2.63	2.61	2.62	3.67	164
103					6	2.26	2.20	2.22	18.4	139
104					3	2.28	2.27	2.27	16.5	142
108	4	2.73	2.71	2.72	4	2.42	2.29	2.34	14.0	146
109	4	2.72	2.69	2.70	4	2.29	2.25	2.26	16.2	142
110	3	2.705	2.692	2.700	6	2.305	2.287	2.299	14.8	144
111	3	2.70	2.68	2.69	6	2.32	2.27	2.30	14.3	144
112	4	2.84	2.82	2.83	6	2.45	2.39	2.42	14.8	151
113	4	2.839	2.829	2.834	6	2.40	2.31	2.35	17.0	147
114	5	2.81	2.78	2.80	6	2.55	2.51	2.53	9.5	158
114a					6	2.53	2.48	2.51		157
115	4	2.812	2.796	2.802	6	2.45	2.41	2.42	13.5	152
115a					6	2.56	2.51	2.53		158
116	5	2.82	2.79	2.81	9	2.48	2.39	2.44	12.9	153
117	4	2.83	2.81	2.82	10	2.51	2.35	2.47	12.3	155
118	4	2.823	2.803	2.815	12	2.57	2.52	2.55	9.6	159
119	4	2.82	2.79	2.80	12	2.61	2.38	2.53	9.8	158
120	4	2.88	2.85	2.86	12	2.59	2.39	2.43	14.9	152
121	4	2.81	2.78	2.80	12	2.46	2.37	2.41	13.7	151
122	4	2.82	2.80	2.81	4	2.59	2.54	2.57	8.7	160
123					4	2.649	2.641	2.643		165
124	4	2.723	2.713	2.718	4	2.665	2.651	2.661	2.09	166
125	4	2.725	2.714	2.719	6	2.648	2.644	2.645	2.72	165
126	5	2.742	2.707	2.720	6	2.670	2.652	2.658	2.28	166
127	4	2.726	2.699	2.713	12	2.660	2.655	2.657	2.06	166
128	4	2.721	2.701	2.714	12	2.666	2.660	2.663	1.88	166
129	4	2.727	2.716	2.721	9	2.696	2.684	2.690	1.13	168
130	4	2.73	2.70	2.72	6	2.36	2.24	2.27	16.4	142
131	4	2.744	2.732	2.739	9	2.36	2.26	2.31	15.5	145
132	4	2.724	2.708	2.715	6	1.92	1.81	1.87	31.0	117
133	4	2.74	2.71	2.72	6	2.25	2.21	2.22	18.4	139
134	2	2.72	2.72	2.72	7	2.12	2.09	2.10	22.8	131

TABLE 13.—*Thermal expansion*

Reference No.	Average coefficient of expansion per degree centigrade between 20 and 50° C.	Reference No.	Average coefficient of expansion per degree centigrade between 20 and 50° C.	Reference No.	Average coefficient of expansion per degree centigrade between 20 and 50° C.
17	0.0000047	30	0.0000055	77	0.0000048
19	.0000053	37	.0000055	78	.0000058
22	.0000044	41	.0000056	80	.0000047
24	.0000052	73	.0000046	101	.0000046

TABLE 14.—*Weathering tests*

Reference No.	Specimen No.	Observed condition of specimens after number of freezings indicated								Remarks
		a [1]	b	c	d	e	f	g	h	
2	1	-------	-------	-------	-------	-------	-------	-------	90	
	2	-------	-------	-------	-------	-------	-------	-------	90	
	3	-------	-------	-------	-------	-------	-------	-------	90	
	4	90	-------	-------	-------	-------	-------	-------	225	
	5	-------	-------	-------	-------	-------	-------	-------	90	
	6	90	-------	-------	-------	-------	-------	-------	225	
	14–20	-------	-------	-------	-------	-------	-------	-------	604	Check tests—Average on 14 specimens.
3	1	50	75	-------	125	-------	-------	150	175	
	2	75	100	-------	125	-------	-------	150	175	
	3	50	75	125	-------	-------	175	200	225	
4	1	-------	-------	-------	-------	-------	-------	-------	90	
	2	-------	-------	-------	-------	-------	-------	-------	90	
	3	225	-------	-------	-------	-------	-------	-------	450	
	4	90	-------	-------	-------	-------	-------	-------	225	
	5	90	-------	-------	-------	-------	225	-------	450	
	6	90	-------	-------	-------	-------	-------	-------	225	
5a	1	285	316	372	405	491	-------	513	548	
	2	-------	-------	285	372	405	437	491	513	
	3	-------	-------	-------	-------	-------	285	316	491	
	4	285	-------	316	372	405	-------	491	513	
	5	372	-------	-------	405	-------	491	548	608	
	6	285	316	-------	405	-------	-------	-------	491	
	7	-------	-------	-------	326	-------	-------	344	365	
	8	-------	-------	-------	-------	326	-------	344	365	
	9	-------	-------	-------	-------	326	344	-------	365	
	10	326	-------	-------	-------	344	-------	-------	365	
	11	344	-------	-------	-------	-------	-------	365	383	
	12	326	-------	-------	344	-------	-------	-------	365	
	13	326	-------	-------	344	-------	-------	365	383	
	14	344	-------	-------	-------	-------	365	422	440	
6	1	-------	-------	-------	-------	-------	-------	-------	-------	Still in "a" condition after 1,781 freezings.
	2	-------							-------	Do.
7	1	1,403	-------	-------	-------	-------	-------	-------	1,627	
	2	1,403	1,627	-------	-------	-------	-------	-------	-------	Still in "b" condition after 1,944 freezings.
	3	1,403	1,627	-------	1,875	-------	1,925	1,944	-------	
	4	895	-------	-------	-------	-------	1,060	1,160	1,677	
	5	895	-------	1,060	1,160	-------	-------	-------	1,975	
	6	895	-------	-------	-------	-------	-------	-------	1,060	
8	1	100	125	-------	-------	-------	-------	-------	-------	Still in "b" condition after 2,643 freezings.
	2	450	475	1,700	-------	-------	-------	-------	-------	Still in "c" condition after 2,643 freezings.
	3	225	250	2,025	2,643	-------	-------	-------	-------	
9	1	100	125	-------	-------	-------	150	200	300	
	2	125	150	-------	200	-------	-------	225	300	
14	1	-------	25	375	475	550	575	625	850	
	2	-------	25	375	400	-------	450	-------	475	
21	1	-------	25	425	1,125	1,200	-------	1,900	2,305	
	2	100	125	1,075	1,900	-------	-------	2,485	2,580	
	3	-------	25	1,900	2,025	-------	2,175	2,305	2,485	
25	1	100	125	1,225	1,600	-------	1,900	2,485	-------	Still in "g" condition after 2,643 freezings.
	2	125	150	200	-------	-------	250	1,175	-------	Do.
	3	25	50	-------	75	100	125	150	175	
27	1	-------	25	-------	-------	-------	125	150	175	
	2	25	50	-------	125	150	200	1,025	1,125	
	3	-------	25	75	100	125	-------	150	175	
29	1	-------	44	75	175	500	575	650	3,005	
	2	-------	44	75	225	425	450	475	500	
	3	-------	44	75	250	-------	400	475	500	

[1] For explanation of the different stages of weathering a, b, c, d, e, f, g, and h see p. 535.

TABLE 14.—*Weathering tests*—Continued

Reference No.	Specimen No.	Observed condition of specimens after number of freezings indicated								Remarks
		a	b	c	d	e	f	g	h	
31	1	225					250	275	300	
	2	125	150				225		250	
	3	125	150	225			250	275	300	
34	1		44	1,575	1,875	2,910				Still in "e" condition after 3,068 freezings.
	2		44	475	1,825					Still in "d" condition after 3,068 freezings.
	3		44	200	1,825					Do.
35	1		44	1,675						Still in "c" condition after 3,068 freezings.
	2		44	550		2,125	2,450			Still in "f" condition after 3,068 freezings.
	3		44	1,825	3,068					
38	1		44				125	175	200	
	2		44			75	100		125	
	3		44				75	150	175	
48	1	75			100				125	
	2		25	50			75		100	
	3		25	75	550	600	725	750	825	
53	1		25	50			75		100	
	2	150			175			200	225	
	3		25				50	75	100	
54	1			44	200	450			500	
	2			44	175	550	650	775	825	
	3			44	200				475	
57	1			44			75	100	125	
	2			44	75		100	125	150	
	3			44		125		150	200	
60	1	25	50	100	125		150		175	
	2		25	50	75				150	
	3		25	50	100				125	
63	1			44	125		225	275	300	
	2			44	175			200	250	
	3			44			175	200	250	
65	1			44	300		325		350	
	2			44	275		300	325	350	
	3			44			75		375	
69	1	725	750							Still in "b" condition after 2,568 freezings.
	2	750	775		1,425	1,725	2,410			Still in "f" condition after 2,568 freezings.
	3	300	325	700	900	1,025	1,200			Do.
74	1	500	525	975	1,200	1,250			1,325	
	2	200			225	250	300		325	
	3	250	275	350	400	475	500	525	550	
79	1	1,050	1,075	2,230	2,568					
	2	1,025	1,050	1,150						Still in "c" condition after 2,568 freezings.
	3	550	600	1,200						Do.
86	1		44						100	
	2		44	75		450	475		500	
	3		44	150			350	375	400	
87	1	700	725	975	1,200	1,250	1,275	1,375	1,525	
	2	650			675	950	1,100	1,200	1,525	
	3	450	475	975	1,025		1,275	1,375	1,525	
89	1		44	1,125	1,725	1,750	1,775	2,450		Still in "g" condition after 3,068 freezings.
	2		44		675	775	825	1,025	1,125	
	3		44	725	825	1,075	1,250	2,600		Do.
91	1		25			75			100	
	2		25						75	
	3		25						75	

TABLE 14.—*Weathering tests*—Continued

Reference No.	Specimen No.	Observed condition of specimens after number of freezings indicated								Remarks
		a	b	c	d	e	f	g	h	
93	1	-------	44	275	-------	-------	-------	300	325	
	2	-------	44	150	275	-------	300	-------	325	
	3	-------	44	150	-------	-------	275	300	325	
94	1	350	-------	375	475	525	600	700	950	
	2	-------	25	375	475	600	950	1,000	-------	Still in "g" condition after 2,568 freezings.
	3	-------	25	950	1,325	1,525	1,625	1,825	-------	Do.
96	1	-------	44	-------	-------	-------	350	450	475	
	2	-------	44	250	300	325	350	375	475	
	3	-------	44	175	275	-------	325	-------	350	
97	1	-------	-------	44	550	600	650	675	725	
	2	-------	-------	44	600	800	825	900	1,000	
	3	-------	-------	44	-------	475	500	550	575	
100	1	100	125	-------	525	550	575	625	650	
	2	100	125	-------	375	400	500	-------	525	
	3	100	125	-------	-------	375	500	-------	525	
102	1	100	125	-------	-------	-------	-------	-------	-------	Still in "b" condition after 1,743 freezings.
	2	450	500							Do.
	3	450	500	-------	-------	-------	-------	-------	-------	Do.
106	1	-------	-------	75	350	-------	-------	-------	-------	Still in "d" condition after 1,593 freezings.
	2	-------	75	350	550	-------	-------	-------	975	
	3	-------	-------	-------	75	-------	-------	-------	975	
107	1	125	150	-------	-------	-------	-------	-------	-------	Still in "b" condition after 1,743 freezings.
	2	100	125	250	-------	-------	-------	-------	-------	Still in "c" condition after 1,743 freezings.
	3	125	150	-------	-------	-------	-------	-------	-------	Still in "b" condition after 1,743 freezings.
108	1	100	125	1,585	-------	-------	-------	-------	-------	Stlll in "c" condition after 1,743 freezings.
	2	200	225	-------	-------	1,000	1,405	1,585	-------	Still in "g" condition after 1,743 freezings.
	3	225	-------	250	1,405	1,585	1,743	-------	-------	
110	1	-------	-------	225	-------	1,329	-------	-------	1,484	
	2	-------	-------	225	-------	-------	-------	-------	625	
	3	-------	-------	225	-------	425	625	890	1,329	
	4	-------	225	-------	-------	-------	-------	-------	1,329	
	5	-------	225	-------	-------	-------	-------	-------	1,329	
	6	-------	225	-------	-------	-------	-------	-------	1,329	
111	1	-------	-------	225	425	-------	-------	-------	-------	Still in "d" condition after 1,646 freezings.
	2	-------	225	425	-------	-------	-------	-------	-------	Still in "c" condition after 1,646 freezings.
	3	225	425	-------	-------	1,577	-------	1,646	-------	
	4	225	425	-------	-------	-------	-------	-------	-------	Still in "b" condition after 1,646 freezings.
	5	225	425	-------	-------	-------	1,646	-------	-------	
112	1	225	-------	-------	-------	-------	-------	450	650	
	2	225	-------	-------	-------	-------	450	650	892	
	3	825	-------	-------	-------	-------	-------	-------	990	
	4	825	-------	-------	-------	-------	-------	-------	990	
	5	825	-------	-------	-------	-------	-------	-------	892	
	6	225	-------	-------	-------	-------	450	825	880	

TABLE 14.—*Weathering tests*—Continued

Reference No.	Specimen No.	Observed condition of specimens after number of freezings indicated								Remarks
		a	b	c	d	e	f	g	h	
113	1	225					450	650	880	
	2	225	450						880	
	3	90						225	450	
	4	90	225						880	
	5	225	450	650					880	
	6	90			225				450	
114	1	825							990	
	2	225		450					990	
	3	225	450						990	
	4	225	450						990	
	5	225	450	990						Still in "c" condition after 1,800 freezings.
	6	90					225		450	
115	1	225							450	
	2								90	
	3	225							450	
	4								90	
	5								90	
	6							90	450	
	7	625							680	
	8	850					1,015		1,115	
	9								225	
	10	625							680	
	11	225							425	
	12								225	
116	1	650							850	
	2	650							850	
	3	450							650	
	4	1,015							1,115	
	5	850							1,015	
	6	450					650		850	
117	1		90	225					650	
	2	225	450	650					850	
	3	90	225		850	1,115			1,193	
	4		90	850					1,193	
	5		90	450			650	850	1,632	
	6		90	450		650	850		1,632	
118	1								1,880	
	2	650		850					1,632	
	3	450		650					850	
	4	450	650							Still in "b" condition after 1,949 freezings.
	5	450	650						850	
	6	450							650	
119	1	450		650	1,627	1,898				
	2	650			850				1,015	
	3	450	650	1,898						
	4	450	650				1,115	1,627		Still in "g" condition after 1,898 freezings.
	5	450	650			1,627			1,898	
	6	450	650	1,627		1,782				Still in "e" condition after 1,898 freezings.
120	1									Still in "a" condition after 1,948 freezings.
	2									Do.
	3									Do.
	4									Do.
	5									Do.
	6									Do.
121	1	1,453					1,677		1,832	
	2	695							895	
	3	1,832	1,948							
	4	1,677	1,832							Still in "b" condition after 1,948 freezings.
	5	1,832	1,948							
	6	1,677	1,832	1,948						

TABLE 14.—*Weathering tests*—Continued

Reference No.	Specimen No.	Observed condition of specimens after number of freezings indicated								Remarks
		a	b	c	d	e	f	g	h	
123----	1	450	500	-------	-------	-------	-------	-------	-------	Still in "b" condition after 1,743 freezings.
	2	175	200	500	1,000	1,125	-------	-------	-------	Still in "e" condition after 1,743 freezings.
	3	325	350	-------	-------	-------	-------	-------	-------	Still in "b" condition after 1,743 freezings.
124----	1	75	100	125	250	-------	-------	-------	-------	Still in "d" condition after 1,743 freezings.
	2	150	175	1,125	-------	-------	-------	-------	-------	Still in "c" condition after 1,743 freezings.
125----	1	-------	-------	-------	-------	-------	-------	-------	-------	Still in "a" condition after 1,898 freezings.
	2	1,403	1,627	-------	-------	-------	-------	-------	-------	Still in "b" condition after 1,898 freezings.
	3	1,782	1,898	-------	-------	-------	-------	-------	-------	
	4	-------	-------	-------	-------	-------	-------	-------	-------	Still in "a" condition after 1,898 freezings.
	5	1,403	1,627	-------	-------	-------	-------	-------	-------	Still in "b" condition after 1,898 freezings.
	6	1,403	1,627	-------	-------	-------	-------	-------	-------	Do.
126----	1	1,403	1,627	-------	-------	-------	-------	-------	-------	Do.
	2	1,403	1,627	-------	-------	-------	-------	-------	-------	Do.
	3	90	225	650	-------	-------	1,403	-------	1,627	
	4	1,015	1,115	-------	-------	-------	-------	-------	-------	Do.
	5	1,015	1,115	1,782	-------	-------	-------	-------	-------	Still in "c" condition after 1,898 freezings.
	6	1,403	1,627	-------	-------	-------	-------	-------	-------	Still in "b" condition after 1,898 freezings.
127----	1	-------	-------	-------	-------	-------	-------	-------	-------	Still in "a" condition after 1,735 freezings.
	2	-------	-------	-------	-------	-------	-------	-------	-------	Do.
	3	-------	-------	-------	-------	-------	-------	-------	-------	Do.
	4	-------	135	-------	-------	-------	-------	-------	-------	Still in "b" condition after 1,735 freezings.
	5	360	560	-------	-------	-------	-------	-------	-------	Do.
	6	-------	-------	-------	-------	-------	-------	-------	-------	Still in "a" condition after 1,735 freezings.
128----	1	-------	-------	-------	-------	-------	-------	-------	-------	Do.
	2	-------	-------	-------	-------	-------	-------	-------	-------	Do.
	3	-------	-------	-------	-------	-------	-------	-------	-------	Do.
	4	-------	-------	-------	-------	-------	-------	-------	-------	Do.
	5	-------	-------	-------	-------	-------	-------	-------	-------	Do.
	6	-------	-------	-------	-------	-------	-------	-------	-------	Do.
129----	1	1,782	1,898	-------	-------	-------	-------	-------	-------	
	2	1,403	1,627	-------	-------	-------	-------	-------	-------	Still in "b" condition after 1,898 freezings.
	3	450	650	-------	-------	-------	-------	-------	-------	Do.
	4	1,015	1,115	-------	-------	-------	-------	-------	-------	Do.
	5	1,627	1,782	-------	-------	-------	-------	-------	-------	Do.
	6	1,115	1,403	-------	-------	-------	-------	-------	-------	Do.
130----	1	90	-------	-------	-------	-------	-------	-------	225	
	2	90	-------	-------	-------	-------	-------	-------	225	
	3	90	-------	-------	-------	-------	225	-------	450	
	4	90	-------	-------	-------	-------	-------	-------	225	
	5	90	-------	-------	-------	-------	-------	-------	225	
	6	90	-------	-------	-------	-------	-------	-------	225	
131----	1	1,015	-------		-------	-------	1,115	-------	1,403	
	2	850	-------	-------	1,015	-------	1,115	-------	1,403	
	3	1,015	-------	-------	1,115	1,403	-------	-------	1,627	
	4	225	-------	-------	-------	450	650	-------	905	
	5	450	-------	-------	-------	-------	650	-------	905	
	6	850	-------	-------	1,015	1,115	-------	-------	1,403	

TABLE 14.—*Weathering tests*—Continued

Reference No.	Specimen No.	Observed condition of specimens after number of freezings indicated								Remarks
		a	b	c	d	e	f	g	h	
132	1		90						850	
	2		90	450					850	
	3		90	650					850	
	4		90	650					850	
	5		90	650				850	1,632	
	6		90	650	1,115		1,408		1,632	
133	1	650							850	
	2	450							650	
	3	650							850	
	4	650							850	
	5	450							650	
	6	650							850	
134	1	96				129	156		288	
	2	96			129	156			288	
	3	96	129		156	217	272	288	322	
	4					96	156	322	356	
	5					96	129		288	
	6	156	217	272			322		356	

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