

SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 3856.*)

“The Physical Properties of Building-Material.”

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SOME years ago, one of the Authors, having been consulted by a county council as to the cause or causes of the collapse of a masonry structure, which had been subjected to severe stresses under rather abnormal conditions, engaged in a series of experiments to elucidate these causes, and was greatly impressed by the considerable variation in the strength of structural material when dry and when soaked with water. Since, upon investigation in printed records of tests, but little data relating to the physical treatment of the specimen previous to testing was available, it seemed to the Authors that a series of experiments in which such data were carefully recorded might be not without interest. Accordingly they engaged in a lengthy investigation, under constant conditions and with building material of known record, to determine the influence of interstitial water on the strength of stone, brick, concrete and other material. At the same time other properties were determined, namely, the effect of previous subjection to high temperatures for definite periods on the strength of the stones when either rapidly cooled by quenching in cold water, or else slowly cooled in air; the various coefficients of heat expansion; the variation in the rate of expansion at certain fixed temperatures on various stones; the permanent swelling of the stones after being subjected to high temperatures; and, finally, the specific heats and the electrical conductivities of the selected series were measured.

The determination of the electrical conductivity of wet and dry stone was not included in the original scheme of the Authors' work, but while the experiments were in progress the Authors had the privilege of a visit from Sir William Preece, K.C.B., Past-President Inst. C.E., who very kindly suggested that the scope of the research

should be enlarged so as to include a determination of the electrical resistance of the stones under various conditions. The Authors gladly complied with his suggestion as soon as the necessary apparatus had been installed.

DESCRIPTION OF THE STONES.

It was necessary, in order to keep the research within moderate limits, to select a few typical building-stones that were in general use. Accordingly experiments were conducted upon five sandstones, a quartzite, six oolitic freestones, a crinoidal limestone, two chalks (merely for comparison), six marbles and two granites, and one other allied rock of igneous origin. The stones are described in detail in Table I of the Appendix.

The Portland, Monks Park, Boxground, Bath and Bradford stones are all members of the great oolite series, and are not greatly dissimilar in chemical composition or in density of the material, but differ in compactness of arrangement. Thus if the net volume is taken as the gross volume less the porosity, and the specific gravity is then increased in the ratio of the gross to the net volume, the amended or net densities will be found to give very similar figures.

The specimens of upper chalk from Micheldever and Mottisfont, Hampshire, were included in the series, not because they were of any use whatever as building-stones, but because they had high percentage porosities and therefore afforded a comparison with the calcareous freestones.

The marbles are all of uniformly high density and have low percentage porosities, and were all originally limestones having been altered by regional or contact metamorphism.

METHOD OF CONDUCTING THE EXPERIMENTS.

The records given throughout the Paper are the means of a series of experiments conducted under identically similar conditions and giving results in fairly close agreement with one another, every variation being at once checked by a fresh series of determinations.

The tests for the transverse stresses were all conducted upon carefully dressed prisms, 6 inches long and 1 inch square, most of which were polished upon one face. This face was laid on thin rubber over two knife-edges placed exactly 4 inches apart, and the load was applied at the centre by means of a stirrup, carrying a scale-pan, in which the load was increased at a uniform rate and without shock,

by constant increments of 5 lbs. each, until rupture ensued, the stress being calculated from the customary formula, $f = \frac{M y}{I}$.

In the compression test, cubes of 1-inch side were carefully prepared and crushed in an Olsen triple-lever testing-machine, the load being applied by hand and measured on an arm by means of a jockey-weight; this recorded from 0 to 500 lbs. by constant increments of 4 lbs., and from 0 to 15,000 lbs. by the addition of small weights to a scale-pan suspended from the end of the balance-arm.

The specimens were dried in a steam-oven maintained at about 98° C. for 6 hours, or for a longer period, until there was no appreciable reduction in weight when cooled to a normal temperature. They were then soaked under water for several days, until there was no further appreciable increase in weight, care being taken to wipe all adherent moisture from the surfaces after removal from the water-tank.

Specimens subjected to high temperatures were maintained in a horizontal electric furnace for definite periods ranging from 2 to 24 hours, and at constant temperatures ranging from 100° C. to 800° C. At the end of this period of treatment they were withdrawn from the furnace and slowly cooled in air or rapidly cooled by immersion in cold water.

This furnace, closed at one end and open at the other, was constructed of metal bars fitted into end-plates, which served as a supporting frame for porcelain plates, round which a coil of platinum wire was wound. This in turn was covered by asbestos cloth, but as the porcelain fused and cracked, the cloth was replaced by asbestos millboard, and as the resistance varied considerably (the voltage being constant) the millboard was also subsequently discarded. It was found on dismantling the furnace that the wire was rather corroded and that lines of brown stains, not unlike iron rust in colour, had developed wherever the wire had touched the millboard or the cloth. The frame was next encased in mica, the platinum wire was coiled over this and covered by similar sheets of mica, and the whole was then wrapped in several thicknesses of asbestos cloth. As the resistance still varied, however, the commercially-pure platinum wire was replaced by chemically-pure wire, after which but little trouble was experienced in maintaining steady conditions.

In the expansion experiments short lengths of a specimen were heated in a vertical electrical furnace, similar to the one just described, except that it was of smaller capacity and had both ends open. The cross sectional area of the stones being about 1 square inch a clearance was left all round the stone, when in the furnace, of about $\frac{1}{8}$ inch.

The furnace was connected, in series with an adjustable resistance and an ammeter, to the terminals of a 100-volt circuit. A temperature of 100° C. could thus be obtained with a current of slightly over 1 ampere, and a temperature of 300° C. could be obtained in about 15 minutes. Each experiment was arranged to last 3 or 4 hours, so as to ensure a uniform heating of the test-piece; and the temperature, maintained constant for any length of time by adjusting the resistance, was measured directly by means of a thermometer placed in the furnace. To measure the expansion it was necessary to design an apparatus which should be capable of magnifying the expansion produced at a low temperature, to such a degree as to make its measurement easy, while at the same time the magnifying arrangement should be practically unaffected by the high temperature of the heater.

In this apparatus then the extensometer consisted of an aluminium lever, 1 yard long, having an Γ section. A balance-weight was attached to one end of the lever, and close to this end were two short brass cross-bars, one riveted to the lever, the other resting under it and kept in position by means of distance-screws, which latter also served to vary the sensibility of the arrangement when necessary. Two brass screws passed vertically through the first cross-piece, and their steel ends, ground to a fine point, rested on the bottom of two small cavities drilled in a plate-glass platform; this formed the fulcrum of the lever and a similar screw passed through the other brass cross-piece and rested, during the experiment, on the surface of the specimen. The lever being balanced, exerted little or no pressure upon the test-piece, and while the apparatus was light it was at the same time massive in the neighbourhood of the fulcrum; so that even when the temperature of the specimen was about 300° C., the part of the apparatus immediately above it remained sensibly at the same temperature throughout the experiment.

The deflections of the end of the lever were read at low temperatures by observing a fine mark on it with a microscope, reading to $\frac{1}{2500}$ inch. Readings were also taken at all temperatures by means of a cathetometer.

The same apparatus was employed to investigate the permanent swelling of the stones. After subjection to a temperature of 300° C. for some hours, the specimens were allowed in this case to cool in air for 12 hours before the lengths were measured.

Experiments were also conducted to determine the variation in the electrical resistance of the stones, when soaked in water and when thoroughly dry. Each specimen was connected in series with a battery and a Thomson astatic high-resistance galvanometer, and the deflection was compared with that obtained when a standard

high resistance was substituted for the stone, special care being taken to insulate every part of the apparatus. The samples were identical with those used in the expansion determinations. The ends of each specimen were fitted into sockets, cut into blocks of wood, a space being left behind the end of the stone which was filled with mercury. Each block of wood was mounted on a separate block of paraffin wax, and connection with the rest of the circuit was made with amalgamated copper strips. The electromotive force employed was 100 volts for the dry and 2 volts for the wet stones, and the resistance was measured in each case after 2 minutes' electrification.

RESULTS OF THE EXPERIMENTS.

Effect of contained Moisture.—Numerous determinations have been made and published of the porosity of most rocks, but little work seems to have been done in determining the direct influence of the water retained in the pores of the stone on its strength. So far as the Authors are aware the only previously recorded researches on this point are those of Delesse, Tournaire and Michelot,¹ in which they demonstrated that chalk and carboniferous limestone sustained much greater rupturing pressures when dry than when thoroughly soaked with water; there are also those of the U.S.A. engineers at Watertown arsenal.² In these latter experiments, which do not directly bear upon the question under review, the diminution in strength of stones was noted after repeated immersion alternately in hot and cold water-baths, maintained at temperatures of 100° and 0° C., respectively, the results being as follows:—

Class of Stone.	Final Strength in Terms of the Original Strength of each Class.
Granite	0·837
Sandstone	0·669
Limestone	0·588
Marble	0·462

This depreciation of strength, however, is due more to variations of temperature than to the presence of water, as the extreme variation in the depreciation of the strength takes place in those rocks—the granites and marbles—which are possessed of the least capacity for storing interstitial water.

The compressive and transverse stresses at rupture for various materials when dry and when thoroughly soaked are given in Table II of the Appendix. It will be noticed that there is a

¹ A. Delesse and A. de Lapparent, *Revue de Geologie*, p. 15. Paris, 1875–76.

² Report on Tests of Metals, etc., made at Watertown Arsenal; Washington, D.C., 1890, etc.

depreciation in strength in almost every case when the stone is soaked, but the depreciation is much more marked for the calcareous freestones when subjected to either stress, and in the case of the sandstones when subjected to transverse stress.

In a general way, the depreciation in strength in a thoroughly soaked stone is directly proportional to its porosity or to its capacity for storing interstitial water; but as one would reasonably expect, in the case of two stones of identical porosity, the depreciation in strength is less where the pores are large and open than where they are more numerous and of smaller cross section. This is because the application of pressure to a sample of the former type more or less readily expels the contained water, preventing any appreciable rise of pressure in the interstitial water; but in the latter case only the water near the surfaces will be readily expelled and the remainder will tend to be imprisoned. The disruptive force of the water, pressing on the boundaries of any pore, will be directly proportional to the measure of the impeded flow in the restricted channels leading from that pore, or to the length of the pores leading to the free surface.

That the depreciation in strength is directly dependent upon the amount of contained water is proved by an inspection of the eighth column of Table II, which is compiled from average selections of a very considerable series of experiments on partially soaked or normal stone. In this, it will be noted, the strengths of stones in a condition intermediate between thoroughly dry and thoroughly soaked is in general intermediate to the strengths of those stones under their extreme conditions.

The Bureau of Forestry of the United States Department of Agriculture, in continuation of the investigations on the influence of dryness on the strength of timber, initiated by Bauschinger¹ over 20 years ago, and which they have been conducting for some years past, have recently issued a bulletin recording the influence of re-soaking on the strength of various timbers; and as their conclusions on the strength of timber are in agreement with those of the Authors in regard to stone, it may not be inappropriate to refer to them here. They found that the strength of unseasoned red spruce increased over four times after a thorough drying at about 100° C., but that the strength decreased as the fibres reabsorbed moisture from the atmosphere; they further determined that the fibre saturation-point of various species has a definite value, and that, while the strength depreciated, prolonged soaking in cold

¹ Mittheilungen aus dem Mech. Tech. Lab. in München, 1883 and 1887.

water did not reduce the strength below that of the fibre saturation-point, but that the strength of re-soaked wood was nearly always less than that of green wood.

Effect of Heat.—The depreciation in the strength of stones subjected to high temperatures for longer or shorter intervals and slowly or rapidly cooled is shown in Tables III and IV of the Appendix.

Considering a stone as a collection of crystals or grains of various sizes and possessing dissimilar physical properties, or in other words having varying rates of expansion in the directions of the several crystallographic axes,¹ then upon heating, each particle or constituent crystal commences to expand proportionally to the increase of temperature along each of its three axes, displacing in varying amount those particles in its immediate vicinity. The individual particles are also materially depreciated by the abrasion of contiguous particles, and in addition, the cementing material or matrix may have been crushed out, ruptured, or chemically changed. This action takes place whether the range of temperature is large or small, and thus frequent alternations of temperature through a small range for a lengthy period (as in the ordinary diurnal variation of temperature for a period of years) may be eventually as destructive as a single exposure to a considerable range of temperature for a short period, as in the case of a building exposed to fire. In general, the depreciation may be still greater if the stone is rapidly cooled by being brought into contact with water (as in the case of a jet of cold

¹ In the following Table is shown this expansion for four common crystals, which are arranged in the order of the rates of axial expansion and not in the customary crystallographic order:—

COEFFICIENTS OF HEAT EXPANSION.²

Crystal.	Cubical.	Axial.		
		Axis of Maximum Expansion.	In Terms of the Maximum Axial Expansion Coefficient as 1·00.	
Quartz	0·000036	0·0000138	0·55	0·55
Hornblende . .	0·000028	0·0000095	0·89	0·08
Feldspar (adular) .	0·000018	0·0000156	0·19	0·04
Calcite	0·000020	0·0000262	0·21	0·21

² G. P. Merrill, "Stones for Building and Decoration," pp. 434–5, New York, 1903; and H. Landolt and R. Börnstein, "Physikalisch-chemische Tabellen," p. 201. Berlin, 1905,

water from a hose turned upon a burning building) than if it is slowly cooled in air; this is clearly brought out in Table III.

For the reasons already mentioned one would expect the depreciation in strength to be less for a stone composed of particles of a uniform size and material than for a stone composed of irregularly-sized particles of dissimilar materials, and this point is borne out by the behaviour of grey and red granite described in Table I. The former had uniformly small crystals of feldspar while the latter had large ones, in both cases surrounded by small crystals of other materials, and the crushing and transverse strengths of these after subjection to a high temperature with slow cooling are in the ratios of 1 to 0.25 and 1 to 0.47 respectively.

The matrix, if not the grains, must have undergone considerable changes in composition, since some specimens, such as the Yorkstone, changed in colour from a pale yellow to a terra-cotta red, probably due to an alteration in the oxide of iron; while others, such as the oolites and marbles, developed a chalky dulness. In a few cases the more loosely-textured stones, such as the Doultong stone, disintegrated in the furnace or immediately upon removal therefrom, although every care was taken in handling them to prevent this. Several others preserved their form until the first trivial load had been applied, when they immediately collapsed. The expansions of the several stones are shown in Table V, and it is interesting to note the very marked variation in the values of the coefficients, not only for the several stones, but also for the various ranges of temperature to which the same stone was subjected—a point which will be again referred to. This is also indicated diagrammatically for several of the principal stones and for mild steel in *Fig. 1*.

The Authors have also—in Table VI—compared the expansions of the several stones with that of mild steel, and have calculated the stresses likely to be set up in one element of a composite structure when subjected to a considerable range of temperature as in a conflagration. It must be understood that this Table is only comparative, the stress being calculated for any one material by assuming the other material in contact with it did not alter in temperature.

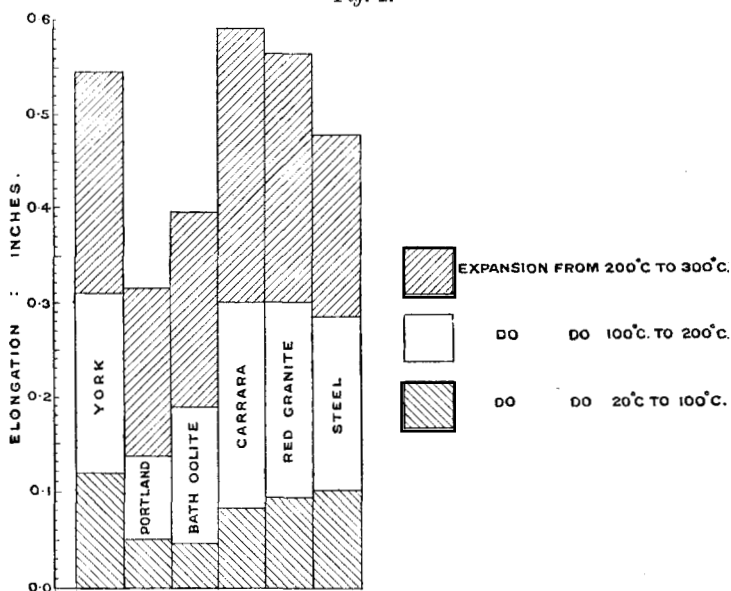
The permanent swelling of the stones is shown in column 5 of Table V, and it is interesting to note that while the majority give positive results, a few afford negative values, probably due to flaking off of the surface, or to a crystallographic rearrangement or tendency to orientation of the particles during heating and cooling.

The specific heats and thermal conductivities of the several stones are duly set out in the last column of Table V and in Table VII respectively, and call for no remark.

Electrical Properties.—For the electrical tests the stones were previously submitted to a fairly high temperature for about 8 hours. It was found that, although the apparatus could measure about 20,000 megohms, the resistance was in some cases much greater than this; but after the stone had been exposed to the atmosphere of the laboratory for a few minutes and had taken up moisture there was a considerable increase in its electrical conductivity.

Concordant and comparative results for perfectly dry stones were unattainable and would be of little practical worth, even if such measurement had been possible, as the condition of perfect dryness

Fig. 1.



COMPARATIVE ELONGATIONS OF COLUMNS 10 FEET LONG OF VARIOUS MATERIALS.

can never be realized under normal conditions. Under the circumstances the Authors consider it sufficiently accurate to say that the order of the specific resistance for the stones in a dry condition varied from about 10 megohms per centimetre cube in sandstone and limestone to 1,000 megohms per centimetre cube and over, in marble and granite.

The resistances were again measured after the stones had been soaked in water for a period ranging from 20 to 30 hours, care being taken to wipe all adherent moisture from the surfaces before the tests were actually carried out.

The resistances are shown in Table VIII, and it will be noted from a study of these that there is a very considerable increase in the conductivity of a soaked stone; for instance, the resistance of one specimen dropped from more than 20,000 megohms to less than 0.1 of a megohm when soaked with water, corresponding with an increase in its conductivity of over 200,000 times that when dry. It will also be noted that there is a considerable variation in the specific resistances of the various stones, the marbles being the poorest conductors, as one would expect.

With a view to determining how far the variation in the resistances was attributable to the presence of contained water, the third and fourth columns of Table VIII were prepared, the values therein given being calculated as follows:—

If R denotes the measured resistance in ohms,

S " " specific resistance of stone and contained water,

l " " length,

a " " cross-sectional area,

x " " equivalent cross-sectional area of the pores = $\frac{v}{l}$,

V " " volume of the stone,

v " " " " pores of the stone,

s " " specific resistance of the water in the pores,

then approximately $R = \frac{Sl}{a} = \frac{s l^2}{v}$,

or $\frac{s}{S} = \frac{v}{l^2} \times \frac{l}{a} = \frac{v}{l a} = \frac{v}{V} = \text{porosity}.$

It was assumed that the pores were continuous and uniformly distributed throughout the length, and that the electric current passed mainly through the water in the pores. The specific resistance of the water portion of the circuit was calculated and found to be practically of the same order as the specific resistance of water charged with slight traces of salt in solution.¹ The differences are not greater than one would expect in the circumstances, for, owing to the varying degree of solubility of the rock constituents, the water cannot be of the same degree of purity in the pores of all the various specimens.

Although moisture was always known to aid the conduction of electricity, no proof of actual measurement has been previously

¹ Prof. J. A. Fleming in his Royal Institution lecture on "Researches in Radiotelegraphy," in June, 1909 (*Nature*, vol. lxxxii, p. 141), gives the specific resistance, in ohms per centimetre cube, of fresh water as 10^4 to 10^5 , and of sea water as 10^2 .

published, so far as the Authors are aware, although it has an important bearing on cases of engineering practice.

To afford an idea of the relatively small resistance offered by blocks of saturated masonry, the resistance of a foot cube of the several stones has been calculated and tabulated in the last column of Table VIII, and the results are interesting and significant.

GENERAL CONCLUSIONS.

Having detailed the method of conducting the experiments and the results derived therefrom, the Authors propose to deal with the questions of practice upon which these experiments have some bearing. In the following remarks they point out that much of the present day, so-called fireproof design is anything but fireproof, the value of a building once ravaged by a conflagration being materially depreciated, even if it does remain standing and sufficiently stable to be fitted with new floors and roofs. The defects of composite structures are also emphasized, such as those in reinforced-concrete, and those built of skeleton steel supporting a masonry framework. The latter are more or less modern in origin, having been introduced by Jenny, Wilson and Gilbert in Chicago, Philadelphia and New York respectively, in the years 1882, 1887 and 1888; more recently they have been introduced in Great Britain and are much in evidence in London, Manchester, and other large cities at the present time.

From time to time, various theories have been put forward attributing the disintegration of buildings to the action of germs, carbonic-acid gas, oxides of sulphur and their derivative acids, salt, wind, frost, rain and alternations of temperature. Judging from the Authors' experiments, it is to these two latter causes probably that a considerable, or even the major, share in the destruction of masonry may be attributed. The rain has a two-fold action, the falling rain abrading the surface, and the infiltrating portion not only destroying the cohesion between the grains and having a feeble solvent action, but also carrying weak solutions of organic acids, alkaline carbonates and oxides of sulphur into the stone, which by subsequent evaporation become fairly strong and potent solutions. A compact stone, therefore, composed of grains of uniform size and material, will be much more resistant to disintegration than a porous one, not only because its storage capacity and the measure of the strength-depreciation of the matrix set up by the complex chemical reactions between it and the contained solution will be less, but also because the intensity of the disruptive force of crystallization within the pores will be diminished.

Ap[ro]pos of this subject, it may be as well to remark here that much of the so-called renovation is greatly to be deprecated; in cleaning, for instance, the air-hardened surface is removed and a second equally hard surface can never be formed, owing to the insufficiency or lack of quarry-sap remaining in the stone. Equally so, coating with paraffin or with alkaline silicates, such as those of sodium or potassium, which form a skin by decomposition of the silicate in the presence of carbonic-acid gas, may be in part removed by the rain before this action is sufficiently far advanced; or if it forms and the stone is not thoroughly dry, a variation in the volume of the interstitial water from changes of temperature will cause this skin to peel off. Fluosilicates used in combination with calcium carbonate appear to provide the most suitable coatings, since the carbonic-acid gas formed in the reaction tends to escape through the pores. Thus, while the walls are protected by the treatment, a certain amount of free passage is left for the subsequent escape of the interstitial water, which is a decided and material improvement on the impervious skin formed by the application of the alkaline silicates.

It is evident that structures wholly immersed in water, such as piers, breakwaters, etc., or continually in contact with water on one face only, such as dams, sea-walls, etc., or exposed on one face only so that moisture driven against them may be freely absorbed, as in the case of walls, etc., have not that strength which tabular statements of strengths compiled from laboratory experiments, irrespective of the physical condition of the test-piece, would lead one to believe. Fortunately, though the depreciation in crushing strength of the igneous rocks commonly used in dams and breakwaters is but slight, and as large factors of safety are generally used in the design of such structures, this defection of strength is not appreciable; but in cases where a low factor of safety has been used in the determination of the dimensions, the depreciation is of such magnitude that it may seriously affect the stability of the structure, especially if it happens to be subjected subsequently to incidental and unconsidered stresses.

For many years past, buildings constructed of incombustible material have commonly, but erroneously, been described as fireproof. Thus, for instance, a floor of steel and concrete or a wall of dissimilar masonry and steel may be much less fire-resistant than a floor composed of solid oak beams, or a wall of brickwork. Fire-insurance experts and captains of fire-brigades have frequently testified to this, and to quote one of many such reports, Chief Officer Tozer of the Birmingham City Fire Brigade, reporting on a serious fire in a

corner-building in Jamaica Row in April, 1906, said, "a round-nosed building is always looked upon by firemen as being dangerous in the event of a serious fire, owing to there being no binding in the brickwork, and the risk is much more serious when the ironwork is unprotected . . . until some law is passed making it compulsory for all ironwork to be protected a similar result to that which occurred in Jamaica Row is bound to take place."

Information is not lacking as to the strength and expansion of the more common metals used in construction. Professor C. Bach¹ has shown that the ultimate tensile strength of mild steel decreases considerably with increase of temperature, the strengths at 500° and 550° C. being 0·63 and 0·50 of that at 20° C. respectively. Mr. V. Petrin² has similarly demonstrated that the tensile strengths of iron at 300°, 500° and 700° C. are respectively 0·9, 0·7 and 0·2 of that at ordinary temperature, or, say, 15° C. considered as unity. Again, according to Professor J. B. Johnson³ the ultimate tensile strengths of wrought iron at 480° C. and 590° C. are respectively 0·71 and 0·34 of that at ordinary temperatures.

At high temperatures, steel, masonry and concrete have different rates of expansion, setting up considerable stresses in addition to those due to the normal loads and at a time when the metal is least able to withstand any increment. Further, according to the researches of Captain T. Grut,⁴ of the Danish Royal Engineers, Portland cement cubes, hardened in water for a week and in air from 2·5 to 3 months, and subjected to different temperatures ranging from 100° C. to 1,000° C., when tested in compression on cooling, depreciated in strength according to the temperature to which they had been previously subjected, amounting to 0·85, 0·46 and 0·12 of the strength at normal temperature, at 500° C., 700° C. and 1,000° C. respectively, probably due in part to dehydration and in part to molecular stress.

In many structures different stones are used for the mere sake of colour or texture contrasts, in order to produce an architectural effect, but such a building is less fire-resistant than a monolithic or single-stone masonry structure. Thus, for instance, from the value given in Table V, the samples of red granite and Yorkstone for the

¹ *Engineering*, vol. lxxxi (1906), p. 401. Also Minutes of Proceedings Inst. C.E., vol. clvi, p. 496.

² Minutes of Proceedings Inst. C.E., vol. clv, p. 495.

³ Quoted in diagrammatic form in W. C. Popplewell, "Experimental Engineering," vol. ii, p. 350. Manchester, 1901.

⁴ E. Svenson. "Eisenbetonversuche in Dänemark." International Congress on Testing Materials, Copenhagen, 1909.

small range of temperature from 20° to 300° C. showed the following relative expansions:—

Range of Temperature.	Expansion in Terms of that for the Granite.			
	Taking 20° C. as Unity.		Taking each Stage as Unity.	
	Granite.	Yorkstone.	Granite.	Yorkstone.
° C.				
20 to 100	1·00	1·21	1·00	1·21
100 „ 200	1·66	1·59	1·00	0·95
200 „ 300	2·12	1·84	1·00	0·87

If two such dissimilar materials as these quoted occur in a course of masonry exposed to the heat of a severe conflagration, the material with the greater expansion coefficient would at the higher temperature receive a greater share of the stresses than that it bears under normal conditions and at a time when its strength is materially depreciated; with the result that it spalls, or in some cases totally fails. This result is borne out by examination of the havoc wrought by a conflagration in such structures as have come under the Authors' observations.

With regard to reinforced-concrete, the variable expansion of the two materials at high temperatures would seem to render them unsuitable to withstand a severe conflagration, and there is also the uncertainty in ascertaining, from observation, the exact measure of the damage where the conflagration has not been sufficiently severe to ensure its complete destruction. Even moderate changes of temperature are not infrequently accompanied by cracks and fissures, and in addition incipient strains may be set up by shocks or loads while the concrete is hardening.

This uncertainty as to its strength is perhaps shared by the Local Government Board, since they generally limit their loans in reinforced-concrete works to 15 years, instead of to 30 years as in the case with structures of brick and stone.

It is hardly necessary to emphasize the danger of electrolytic corrosion being set up by stray currents in the steelwork of a modern skeleton-steel-frame structure, and reinforced-concrete is, of course, open to the same objection. Professor C. L. Norton¹ showed in some of his recent experiments that steel covered with concrete was not immune from electrolytic corrosion, and similar conclusions are

¹ *Engineering News*, vol. li (1904), p. 29.

emphasized by Mr. A. A. Knudson¹ in a recent Paper on the corrosion of both iron and steel in concrete. There seems to be plenty of evidence that this corrosion may be set up not only by direct currents, but also by alternating currents.²

The presence of considerable numbers of modern, skeleton steel-framed structures in large towns constitutes a grave risk, for the conduction of stray currents between portions of the steelwork and the lighting mains in buildings seems almost inevitable; in addition there is a considerable risk of conflagration set up by leakage through damp walls causing short-circuiting, and the presence of steelwork intensifies this risk. There is evidence to show that a number of fires can be traced to the leakage from lighting circuits causing electrolytic corrosion of gas-pipes.³ Uninsulated tramway returns, and electric-lighting and power-circuits provide plentiful sources of stray currents under ordinary working conditions, and also during temporary breakdowns.⁴ There has been much controversy of late in the United States and in Europe on the best means of preventing electrolytic corrosion of gas- and water-mains, and amongst the methods of protection which have been suggested and tried, are those of enshrouding such pipes in a non-conducting material. A covering, however, to be effective should be impervious to moisture and continuous, but as such a material is not obtainable or not likely to long continue in this condition, a flaw is bound to develop somewhere, and once a water-path has been set up electrolysis is bound to ensue. An investigation as to the electrical conductivity of wet and dry material would thus have entirely obviated the expenditure of the considerable sums of money which have been thrown away in futile attempts to prevent electrolytic corrosion by means of coverings of various kinds.

Owing to its low coefficient of porosity, marble, free from metallic veins, affords one of the best materials to be used in the construction of switchboards; but the Authors' experiments sufficiently indicate the necessity of thoroughly drying the slabs and then coating or impregnating them over the whole surface, and not on one face only,

¹ Proceedings American Inst. of Electrical Engineers, February, 1907, pp. 133-48; also Minutes of Proceedings Inst. C.E., vol. clxx, p. 459; also A. S. Langsdorf, *Ibid.*, vol. clxxviii, p. 397.

² E. Wilson. "Alternate Current Electrolysis." *The Electrician*, vol. lv (1905), p. 826.

³ "Wiring of Buildings," *Electrical Engineer*, vol. xliii (1909), p. 93. L. M. Waterhouse, "Conduit Wiring," *Ibid.*, p. 110.

⁴ Report of Commission of German Gas- and Water-Companies for investigation of Earth Currents, *The Electrician*, vol. lvii (1906), p. 533. H. Sibley, "Report on Electrolysis," *Journal Mechanical Engineers*, Ithaca, N.Y., May, 1905.

with some non-conducting material. This may be varnish or enamel applied in one or two, or preferably three, thin coats. A knowledge of the values of the electrical resistances of stones and rocks has also an important bearing on the transmission of electromagnetic waves, as was indicated by Prof. J. A. Fleming in his recent lecture at the Royal Institution.¹

The Paper is accompanied by two tracings and a number of Tables, from which the Figure in the text and the following Appendix have been prepared.

¹ "Researches in Radiotelegraphy," *Nature*, vol. lxxxii (1909), p. 141.

APPENDIX.

TABLE I.—DESCRIPTION AND PROPERTIES OF THE VARIOUS STONES.

Stone.	Description.	Specific Gravity	Weight per Cubic Foot.	Porosity.
			Lbs.	Per Cent.
<i>Sandstones.</i>				
Yorkstone.	One of the finest-grained, pale-yellow, millstone grits of the Leeds district	2.16	135	12.0
Red Mansfield	{ Fine-grained, chocolate-red, calcareous sandstone from permian formation } round Nottingham	2.18	136	15.0
Aspatia	{ Compact, close-grained, chocolate-red sandstone from permian formation, } on Cumberland coast, locally known as St. Bees sandstone	2.01	125	7.6
Quartzite	Compact, pink, metamorphosed permian from Ashby-de-la-Zouch	2.95	134	2.9 ¹
Soft Daresbury	{ Lower keuper from Cheshire, more friable and lighter in colour than } the hard variety	1.79	112	16.6
Hard "	Lower keuper from Cheshire	1.85	116	17.7
<i>Limestones and Calcareous Freestones.</i>				
Douling stone	{ Loose-textured, light-brown, sandy, limestone of the inferior oolite from } Shepton Mallet, Somersetshire	2.07	129	14.5
Portland base bed	Close-grained, uneven textured, calcareous freestone	2.18	136	12.8
Monks Park	Compact, close-grained, calcareous freestone	2.01	128	20.5
Boxground	Fine, granular, cream-coloured stone	1.91	119	22.3
Bradford oolite	{ Fine-grained, cream-coloured, shelly, calcareous freestone from Winsley, } near Bradford-on-Avon	1.76	110	22.2
Bath oolite	Pale-yellow, calcareous freestone	1.93	120	17.8
Hopton Wood stone	{ Compact, crinoidal, carboniferous limestone, of uniform texture, from } Wirksworth, Derbyshire	2.26	141	8.4
Micheldever chalk . . . . .	. . . . .	1.55	97	46.8
Mottisfont " . . . . .	. . . . .	1.61	101	45.9

¹ Owing to occasional fissures rather than to interstitial pores.

TABLE I—continued.

Stone.	Description.	Specific Gravity.	Weight per Cubic Foot.	Porosity.
			Lbs.	Per Cent.
<i>Marbles.</i>				
Carrara	Fine-grained, white saccharoidal marble	2.34	146	0.78
Rouge Royal	{ Dull-red, variously-spotted, flecked and veined with white and grey, from Cerfontaine, Belgium	2.21	138	0.93
St. Anne's	{ Deep bluish-black, with short interrupted veins of white, from Biesme, Belgium	2.53	158	0.74
Dove	Very fine-grained, pale blue, from Couillet, Belgium	2.51	157	0.87
Black	Fine-grained, dense black, from Dinant, Belgium	2.54	159	0.73
Belgian granite	Dense black, encrinital marble from Soignies, Belgium	3.11	194	1.06
<i>Granites and Igneous Rocks.</i>				
Red granite	Fairly coarse-grained from Peterhead,	2.52	157	0.28
Grey granite	Fine-grained from Aberdeen	2.69	168	0.12
Diabase	Dark-green rock from Brora	2.61	163	0.24
<i>Sundry Material.</i>				
Portland cement (neat)	Soft, red Hampshire bricks	2.18	135	10.3
Fareham Rubbers		1.67	105	26.7

TABLE II.—STRENGTH OF VARIOUS STONES WHEN DRIED AND WHEN SOAKED.

Stone.	Crushing Stress.		Ratio of Strength Soaked to that Dried as Unity.	Transverse Stress from Equation $f = \frac{My}{I}$		Ratio of Strength Soaked to that Dried as Unity.	Ratio of Strength Normal to that Dried as Unity.	Ratio of Transverse Stress to the Crushing Stress taken as Unity.	
	Dried.	Soaked.		Dried.	Soaked.			Dried.	Soaked.
	Lbs. per Sq. In.	Lbs. per Sq. In.		Lbs. per Sq. In.	Lbs. per Sq. In.				
<i>Sandstones and Quartzites.</i>									
Yorkstone . .	8,480	8,280	0·977	1,120	780	0·696	0·876	0·132	0·094
Red Mansfield .	2,520	2,510	0·997	670	500	0·754	0·937	0·266	0·199
Aspatia . .	2,430	2,420	0·998	500	260	0·526	0·834	0·206	0·107
Quartzite . .	3,680	3,660	0·995	2,350	2,320	0·986	0·995	0·639	0·634
Soft Daresbury.	900	400	0·445	130	100	0·769	0·906	0·144	0·250
Hard „ . .	2,020	1,750	0·866	280	90	0·312	0·919	0·139	0·051
<i>Limestones and Calcareous Freestones.</i>									
Douling stone.	1,190	1,180	0·992	320	190	0·606	0·708	0·269	0·161
Portland base bed	4,080	2,960	0·725	1,450	1,030	0·708	0·892	0·355	0·348
Monks Park . .	1,570	600	0·380	630	410	0·644	0·723	0·401	0·683
Boxground . .	940	160	0·171	400	280	0·695	0·758	0·426	1·750
Bradford oolite	860	590	0·691	400	200	0·493	0·886	0·465	0·339
Bath oolite . .	1,140	770	0·675	610	370	0·604	0·910	0·535	0·481
Hopton Wood stone . .	2,920	2,900	0·993	1,000	950	0·948	0·992	0·343	0·327
Micheldeverchalk	390	120	0·310	160	90	0·551	0·747	0·410	0·750
Mottisfont „	290	110	0·366	220	130	0·612	0·938	0·759	1·181
<i>Marbles.</i>									
Carrara . . .	4,450	4,440	0·997	820	760	0·924	0·826	0·184	0·171
Rouge Royal . .	6,420	4,500	0·701	1,930	1,920	0·998	0·999	0·301	0·427
St. Anne's . .	9,250	8,520	0·921	2,240	2,140	0·954	0·990	0·242	0·251
Dove . . .	5,940	5,430	0·914	2,240	1,790	0·800	0·963	0·377	0·330
Black . . .	6,710	6,700	0·999	2,960	2,330	0·788	0·886	0·441	0·348
Belgian granite.	5,460	5,440	0·996	2,110	1,640	0·776	0·993	0·386	0·301
<i>Granite and Igneous Rocks.</i>									
Red granite. . .	5,480	5,100	0·931	1,440	1,430	0·997	0·998	0·263	0·280
Grey „ . . .	5,950	5,940	0·998	2,710	2,540	0·938	0·976	0·456	0·428
Diabase . . .	6,070	6,030	0·994	1,820	1,590	0·874	0·748	0·300	0·264
<i>Sundry Material.</i>									
Portland cement (neat). . .	..	..	..	920	600	0·650	0·731	..	..
Fareham rubbers	970	560	0·574	..	..	..	..	..	..

TABLE III.—STRENGTH AFTER SUBJECTION TO HIGH TEMPERATURES.

Stone.	Crushing Strength as Ratio to Original Strength Dry.		Transverse Strength as Ratio to Original Strength Dry.	
	Slow- cooling.	Fast- cooling.	Slow- cooling.	Fast- cooling.
<i>Sandstones and Quartzites.</i>				
Yorkstone	0·358	0·402	0·646	0·271
Red Mansfield	0·999	0·870	0·625	0·600
Aspatia	0·993	0·992	0·199	0·151
Quartzite	0·712	0·715	0·889	0·927
Soft Daresbury . . . . .	..	..	0·483	..
Hard „ . . . . .	..	..	0·244	..
<i>Limestones and Calcareous Freestones.</i>				
Doultling stone . . . . .	..	..	0·024	0·066
Portland base bed	0·603	0·506	0·665	0·141
Monks Park	0·822	0·743	0·432	0·375
Boxground	0·494	0·543	0·025	0·236
Bradford oolite	0·500	0·403	0·343	0·234
Bath oolite	0·512	0·446	0·349	0·261
Hopton Wood stone	0·572	0·387	0·388	0·289
Micheldever chalk . . . . .	..	..	..	..
Mottisfont „ . . . . .	..	..	..	..
<i>Marbles.</i>				
Carrara	0·647	0·658	0·189	0·086
Rouge Royal	0·550	0·553	0·327	0·236
St. Anne's	0·378	0·447	0·342	0·273
Dove	0·505	0·411	0·077	0·153
Black	0·614	0·702	0·590	0·140
Belgian granite	0·593	0·687	0·456	0·216
<i>Granites.</i>				
Red granite	0·083	0·067	0·099	0·060
Grey „	0·331	0·508	0·112	0·004
Diabase	0·857	0·496	0·238	0·050
<i>Sundry Material.</i>				
Portland cement (neat)	0·683	..	0·216	..

TABLE IV.—EFFECT OF INCREASED PERIOD OF EXPOSURE AND INCREASED TEMPERATURE ON STRENGTH.

Stone.	Transverse Strength. Dry.	Time of Heating.	Tempera- ture.	Reduction of Strength.	Increase of	
					Tempera- ture.	Period.
	Lbs. per Sq. Inch.	Hours.	° C.	Per Cent.	° C.	Hours.
Yorkstone	1,120	6	696	64·5		
		12	728	71·7	32	6
		2	618	42·0		
Red Mansfield	670	6	696	50·5	78	4
		12	728	67·2	32	6
		2	686	28·8		
Portland base bed	1,450	6	796	85·9	110	4
		6	618	75·2		
		12	701	80·3	83	6
Bath oolite	610	18	685	85·1	16	6

TABLE V.—LINEAR COEFFICIENTS OF HEAT EXPANSION, PERMANENT ELONGATION AND SPECIFIC HEATS.

Stone.	Coefficients of Expansion per 1° C.			Permanent Alteration of Length after Heating to 800° C. for 3 Hours and Cooling for 12 Hours.	Specific Heats.
	Between 20° C. and 100° C.	Between 100° C. and 200° C.	Between 200° C. and 300° C.		
<i>Sandstones and Quartzites.</i>	× 10 ⁶ .	× 10 ⁶ .	× 10 ⁶ .	Per Cent.	Calories per Gram
York stone	12·340	16·200	18·780	−0·0092	0·193
Red Mansfield . . .	9·926	15·410	19·020	−0·0014	0·178
Aspatria	9·016	11·400	11·480	−0·0123	0·200
Quartzite	16·200	19·900	19·900	+0·0360	0·225
Hard Daresbury . .	13·480	15·400	18·870	−0·0156	0·189
<i>Limestones and Calcareous Freestones.</i>					
Douling stone . . .	22·370	26·190	26·690	+0·0150	0·168
Portland base bed .	4·944	7·782	14·600	−0·0015	0·189
Monks Park	3·536	8·233	13·420	−0·0016	0·196
Boxground	4·186	9·560	19·240	+0·0397	0·172
Bradford oolite . .	2·513	10·140	13·510	+0·0278	0·216
Bath oolite	4·840	12·270	16·980	+0·0367	0·170
Hopton Wood stone .	8·640	15·620	20·770	+0·0349	0·150
<i>Marbles.</i>					
Carrara	8·758	17·510	24·340	+0·1740	0·204
Rouge Royal	5·759	13·140	15·250	+0·0198	0·200
St. Anne's	4·446	16·320	18·300	+0·0250	0·218
Dove	9·206	19·330	19·330	+0·1290	0·182
Black	4·914	10·520	13·650	+0·0068	0·199
Belgian granite . .	5·231	16·230	19·550	+0·0680	0·208
<i>Granites and Mild Steel.</i>					
Red granite	10·200	16·980	21·600	+0·0488	0·185
Grey „ . . . . .	..	..	..	..	0·166
Diabase	9·660	15·030	15·940	+0·0460	0·181
Mild steel	11·320	15·560	15·560	+0·037	..

NOTE.— + signifies a permanent elongation.

− signifies a permanent contraction.

TABLE VI.—STRESS CAUSED IN A COMPONENT OF A COMPOSITE BUILDING BY A RISE IN TEMPERATURE.

Stone.	Coefficient of Heat Expansion per 1° C.	Values of Young's Modulus.	Stress per 1° C. rise of Temperature.
	× 10 ⁶ .	Lbs. per Sq. In.	Lbs. per Sq. In.
<i>Sandstones and Quartzites.</i>			
York stone	12·340	17,000	0·210
Red Mansfield	9·925	47,700	0·473
Aspatia	9·016	36,000	0·325
Quartzite	16·200	12,100	0·196
Hard Daresbury	13·480	9,000	0·121
<i>Limestones and Calcareous Freestones</i>			
Doultling stone	22·370	14,500	0·324
Portland base bed	4·944	36,100	0·178
Monks Park	3·535	57,700	0·204
Boxground	4·186	37,200	0·156
Bradford oolite	2·513	42,300	0·106
Bath oolite	4·840	29,200	0·141
Hopton Wood stone	8·640	29,100	0·251
<i>Marbles.</i>			
Carrara	8·758	97,900	0·857
Rouge Royal	5·759	116,500	0·671
St. Anne's	4·446	120,300	0·535
Dove	9·206	86,000	0·792
Black	4·914	30,000	0·147
Belgian granite	5·231	137,500	0·719
<i>Granites and Steel.</i>			
Red granite	10·200	50,300	0·513
Diabase	9·660	75,700	0·731
Steel	11·320	32,000,000	360·000

TABLE VII.—THERMAL CONDUCTIVITIES.

Stone.	Thermal Conductivity in C.G.S. Units.
Sandstone (soaked)	0·006 ¹
„ (dry)	0·0056 ¹
„	0·0062 ²
Granite	0·0035 ¹
„	0·0049 ²
Marble	0·0056 ¹
„	0·0071 ³
„	0·005 ⁴

¹ A. S. Herschel, "Thermal Conductivity of Rocks," British Association Report, vol. xlix (1879), p. 58.² F. E. Neuman, *Annales de Chemic*, vol. lxi, p. 185.³ C. H. Lees, "Thermal Conductivity," Philosophical Transactions of the Royal Society, A. 1892, p. 481.⁴ B. O. Pierce and R. W. Wilson, "Thermal Conductivity" Proceedings of the American Academy, vol. xxxiv (1898), p. 1.

TABLE VIII.—ELECTRICAL RESISTANCES.

Stone.	Specific Resistance per Centimetre Cube.			Resistance per Foot Cube of Wet Stone.
	Dry Stone.	Stone separately (Wet).	Assumed Water-Path.	
<i>Sandstones and Quartzites.</i>	Ohms $\times 10^6$.	Ohms $\times 10^3$.	Ohms $\times 10^3$.	Ohms.
Yorkstone	From	20·02	2·4	660
Red Mansfield		17·83	2·7	580
Aspatia		17·77	1·4	580
Quartzite		436·7	1·3	14,300
Hard Daresbury		35·4	6·2	1,160
<i>Limestones and Calcareous Freestones.</i>	10			
Douling stone		43·6	6·3	1,420
Portland base bed		26·7	3·4	870
Monks Park		43·7	8·7	1,430
Boxground		8·8	1·96	290
Bradford oolite		40·0	8·8	1,310
Bath oolite		28·5	4·98	930
Hopton Wood stone		26·0	2·24	850
<i>Marbles.</i>	to 1,000+			
Carrara		258·0	2·1	8,450
Rouge Royal		353·0	3·3	11,500
St. Anne's		541·0	4·0	17,700
Dove		384·0	3·3	12,500
Black		147·0	1·1	4,790
Belgian granite		307·0	3·2	10,000
<i>Granite and Igneous Rock.</i>				
Red granite		371·0	1·04	12,100
Diabase		1,670·0	4·00	54,600