Mr. J. Grant said, at this stage he would simply point out the form of moulds used in the experiments. No. 1, Table 1, was the first form, and was used previous to 1865. It would be perceived that the angles were very sharp, which was the cause of irregular fractures. After some experience the original form of mould was modified, as shown in No. 2, Table 1, in which the angles were rounded off, and which had been in use for several years. This was the form which had been used throughout the experiments described in this Paper, except where otherwise mentioned. At the same time other experiments, given in Table 1 of the Paper, were made with a variety of other moulds differing in length, shape and sectional area. Some, instead of being broken between clips, as shown in Plate 2 of his former Paper, were broken by means of knife edges inserted in holes, as shown in Plate 4, attached to that Paper. Further experiments were made with the fiddle-shaped mould, No. 10, Table 1, which did not break uniformly at the neck; the slightest distortion making it break in a diagonal line. Some other experiments were detailed in the Paper; but these were sufficient to explain their general character.

Mr. H. E. Towle said, in 1856 he was employed to take charge of works, where there had been a large quantity of the American Rosendale cement in store for a long time; and it became a question whether it should be used or rejected. It was determined that experiments should be made to ascertain the character of the cement, and some curious results were developed. This cement, in the United States, corresponded to the Portland cement of England. He tried the cement with various proportions of sand and lime paste, making up eight batches altogether. In making these experiments he desired to ascertain what effect working and reworking the mortar had upon its strength. He tried the mortar re-mixed daily for twenty days, and daily stuck bricks together transversely, and after five months pulled them apart, measuring the strain as carefully as possible. In these experiments he found it advisable to make a distinction between cohesion and adhesion. Cohesion was the quality which made the particles of a substance stick together between themselves; adhesion was the force which united the material to something else. Now, if bricks or stones were stuck together with mortar which did not adhere to the brick as strongly as it did to itself, all expense in making the component parts of that mortar more cohesive was wasted; and therefore there was a limit to the expense to be incurred for this purpose. Reverting to the re-mixing of the mortar, he found that the maximum strength was obtained after ten times mixing and re-mixing. He certainly did not advocate mixing and re-mixing twenty or any other number of times; nevertheless this fact about this particular kind of hydraulic mortar might serve as a suggestion to others endeavouring to render the subject less obscure. Newark Rosendale cement was sold in barrels of a capacity of 4 cubic feet, and each barrel contained on an average 300 lbs. of cement. The weight of the barrels when empty averaged 25 lbs. each. A weight of 300 lbs. of Rosendale cement required $1\frac{95}{100}$ cubic foot of water to reduce it to a stiff paste, and produced $3\frac{6}{10}$ cubic feet of pure cement mortar in a state of stiff paste, weighing 117 lbs. per cubic foot. The volume of 300 lbs. of cement unpressed was $4\frac{3}{4}$ cubic feet; and as sold in the barrels 4 cubic feet.

1 Barrel Rosendale cement . .	4	cubic feet.
1 Box lime paste, 2 feet by 2 feet by $\frac{3}{4}$ foot	3	„
5 Boxes sand, damp and loose . .	15	„
Total . .	22	

produced a batch of 17 cubic feet of good mortar, weighing 124 lbs. per cubic foot:

Lime paste weighed, per cubic foot .	84 lbs.
Cement „ „ .	117 „

A block of unslaked lime 1 cubic foot in volume weighed $91\frac{43}{100}$ lbs., and when slaked by the addition of water, and reduced to a thick paste, the volume increased to 3·047 cubic feet. A bushel of this lime, as purchased coarse and fine together, weighed 75 lbs., and when reduced to a state of stiff paste increased in volume to $2\frac{193}{1000}$ bushels.

Lieut.-Colonel Scott, R.E., remarked that Mr. Grant had brought up the strength of Portland cement to a pitch which a few years ago was thought impossible; but he was not quite certain that in carrying it so far danger might not be incurred which at first sight might hardly be suspected. Persons who were in the habit of using large quantities of Portland cement were aware that at times it expanded to an extraordinary degree. This was due generally to too large a quantity of chalk having been used in its preparation. A few years ago, on examining some cases where great strength was aimed at by the manufacturer, he found that where the clay was reduced to 18 or 19 per cent. instead of 22 or 23 per cent. very extraordinary expansion occurred. By the exposure of such cement to the air, the tendency to expand might be, no doubt, greatly modified, but by demanding cement of extreme strength engineers undoubtedly ran into this danger. With a larger proportion of clay there was greater safety, though somewhat less strength. A remark had been made that it was of no use getting the cohesive strength of the cement greater than the adhesion of the cement to the materials that were to be joined together by it. If that were right, and in the use of Portland cement the strength of the bricks in ordinary use was exceeded, he thought engineers might be content to go no further and avoid the danger he had pointed out. As to the instance cited of cement mortar when beaten up afresh, though first losing strength, afterwards becoming stronger again, he thought it might be explained by assuming that the cement might have contained some particles which had an expansive tendency. In using hydraulic lime-mortar the lime was slaked, and thus was obtained a hydrate of lime mixed with sand, and in the work a solidification occurred, partly from the action of the atmosphere and partly from the slaked lime entering into fresh combination with the silex, thus forming slowly a hydrated silicate without expansion; but if particles of unslaked lime were mingled with this, inequality of action resulted, inasmuch as the particles of unslaked and slaked lime were in a different condition. In using lias lime, for instance, unless it was ground to a fine powder and the slaking allowed to go on some time before use, the work was apt to get distorted, because those particles which were uncombined with water expanded in the work when hydration took place and burst it. In the experiments alluded to he thought that something of this kind had occurred. There was continued expansion of some of the lime particles through slaking, till the material was brought wholly into the state of hydrated silicate of lime, when it again gained in strength by the quiet and gradual rearrangement of the particles, such as occurred with hydraulic limes, without any disturbing element.

He now would say a few words on a subject which merited attention from engineers. There was a new mode of using lime which had been adopted in the buildings at South Kensington. If in the ordinary slaking of lime just sufficient water was added to bring it to a dry impalpable powder, this powder would have a bulk sometimes much greater than that of the original lime, and if made into paste would, when it dried, exhibit a considerable degree of porosity. It could be imagined that if the lime, instead of being slaked, were ground to powder and induced to set as cement, with its original density, much greater strength would be attained in the solidified mortar. In the use of lime the combination with water took place first, and then subsequently the solidifying action went on. If it was hydraulic lime a silicating process was set up after slaking, and a fresh arrangement of particles took place. In the case of cements the slaking and the setting went on simultanously, and the water entered at once into combination with the cement to form a stone-like substance. If by any means lime could be induced to combine with the water slowly, so as not to burst with the heat, a much better result would follow than from the ordinary way of using it. This, in fact, was what he had accomplished by the mode in which he was now making mortar, and his general method of procedure was as follows, the lime used at Kensington being ordinary grey lime finely ground. First of all he mixed 5 per cent. of plaster of Paris, as compared with the quantity of lime to be used, in a bucket of water, making a milk of sulphate of lime. He then threw this into the pan of a mortar-mill and added the ground lime gradually, and instead of the lime slaking as it would when treated with water only, the lime showed no symptoms of slaking, and was brought to a thin paste without any sensible increase of temperature. When that was done he added sand, and for most purposes as much as 6 parts of sand to 1 of lime. In thin brickwork he obtained far greater strength with grey lime treated in this way, with 6 parts of sand, than with Portland cement with 4 parts of sand. He did not say the same results would follow the use of grey lime in very damp situations or under water; in such situations another set of phenomena came into play; but he spoke of cases where the carbonic action of the atmosphere was chiefly depended on to bring about the hardening of the mortar. The process he had described would not give setting property under water if the lime did not possess it before. It might indeed be thought that he destroyed the water-setting property by the plaster of Paris, which was itself soluble, but that was not the case. The quantity of plaster of Paris did not exceed 0·75 per cent. of the mortar; and in three or four weeks crystallised out in the pinhole cavities in it, where it showed itself in little crystalline spangles or plates. In proportion as the percentage of clay increased in the lime employed, so this became more suitable for mortar to be used under water. Puzzuolana was at one time largely imported into this country. At that time it was not known that there were large beds of a material in England which made excellent pozzuolana. He believed that with his process the puzzuolana of this country would come into use. He had examined the shales of the lias beds, notably those of Leicester, and he found by the use of this material calcined, and a small quantity of common chalk lime, treated as described with a milky solution of sulphate of lime, he got under certain conditions, viz., by experiments with small blocks and by putting a few bricks together, greater strength than he could get out of Portland cement. He spoke of such instances as those mentioned only. His experiments had so far extended only to such cases. He had only to add that in using this new method of mortar-making (which he termed the selenitic method) for plastering the walls in the galleries of the Exhibition Building at South Kensington, he employed 6 parts of sand to 1 part of lime, and for the finishing coat 1 part of lime with 4 parts of sand.

Mr. Bramwell said that when, five years ago, Mr. Grant brought before the Institution a Paper on this subject,[1] and pointed strongly towards the improvement that he thought would be derived from increasing the weight of the cement, Mr. Bramwell threw doubts upon the probability of such a result, since, from experiments he had made, he believed, if the weight of the cement were alone considered, it would hold out a premium for bad grinding, and that badly-ground cement meant inferior cement. He was glad to find this opinion corroborated in the present Paper: for Mr. Grant now said that, with cement of 113 lbs. per bushel when unsifted, he got a strength of 375 lbs. per square inch, but when sifted the same cement, weighing only 110½ lbs. per bushel, gave an increase of strength reaching to as much as 427 lbs. He thought this abundantly justified what he stated five years ago, that the mere test of weight alone was a premium for bad grinding, and calculated to mislead. He also, at the same time, gave instances in which large variation of strength was occasioned by an extremely small variation in the amount of water with which the cement used in the sample was gauged. He was glad now to hear Mr. Grant state that the proportions, both of water and cement, were determined by weight in the mixing of the samples tested.

Mr. Bazalgette remarked that he could not understand how it was possible to manufacture cement of too good a quality. The improved manufacture of Portland cement up to the present time had been promoted by the careful experiments of Mr. Grant. Portland cement concrete could now be used with advantage and safety where brickwork and stonework were formerly used, thus effecting a large economy in engineering works. In the Southern Thames Embankment the cost was reduced to nearly one-third of what it would have been had the embankment continued to be constructed in brickwork behind the granite facing. A further

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxv., p. 136 *et seq.*

portion of embankment was on the point of commencement on the north side of the river, and this also it was intended to construct with granite facing and concrete backing without any brickwork, which he believed, owing to the good quality at which Portland cement had now arrived, would be quite as strong, and probably would form a more homogeneous mass than if constructed in brick work. The Paper had drawn attention to the fact that Roman cement was two-thirds the price of Portland cement, but that its strength was only one-third; therefore it was more advantageous to use Portland than Roman cement. He did not notice whether the Author had made any comparison between Portland cement and lias lime mortar; but as far as his experience went, Portland cement was so superior to the ordinary limes used for mortar in brickwork that the cement became the cheaper material of the two. For instance, he had in his experiments added in bulk the quantity of lime required to bring it up to the same price as a less quantity of Portland cement; and he found, using it in that way in mortar, that Portland cement produced much stronger brickwork than was produced by the use of the proportionately increased quantity of lime.

He did not clearly understand the distinction drawn in the course of the discussion between adhesion and cohesion. As he understood the argument, it was contended that, with harder and better cement, its power of adhering to stone or bricks would not increase in proportion to its increased power of holding together its own particles in one mass. He was, however, of opinion that if this argument had reference to cement uniting brickwork or stone, it would be found if the face of the materials to be united were rough and absorbent, the cement could penetrate the face of the brick or stone, combine with and lay hold of it, and have the same affinity to the brick or stone as to itself; and that this power of combining the whole mass together would under such conditions increase proportionately with the increased strength of the cement, so that the adhesion and the cohesion would increase at the same time and in the same proportion. He thought therefore if the strength of the cement was increased, and the building materials to be united were suitable, both the adhesion and the cohesion would also be increased, and the whole structure strengthened. The Paper led to this practical result—that by attention to the production of good Portland cement the cost of engineering works might be reduced, particularly those of large bulk, to less than half that which had been spent upon similar works before its introduction.

Mr. W. Parkes said he had lately had the opportunity of making some experiments with Portland cement, from which he had drawn conclusions similar to those of Mr. Bramwell. Every one who had to do with Portland cement must feel indebted to Mr. Grant for the attention he had given to the subject and the results he had made public; but though the former Paper was of great use, he found the conclusions given by Mr. Grant were also liable to great abuse. Those conclusions were apparently so simple that people who were not altogether well versed in the subject were apt to suppose that they could test cement, and know good from bad by the simple application of the rules. He concurred with Mr. Grant that two of the qualities of good cement were high specific gravity and high tensile strength; but he thought it would be inexpedient to push those principles to extremes. Good cement was generally heavy and strong, but it did not always follow that the quality was proportionate to the weight, or to the tensile strength, or to the two combined. In the case of some Portland cement, lately required for sea-work in India, the Government had, under his advice, applied for tenders from several manufacturers of repute, and the three lowest tenders were accepted. It happened that the cement supplied by those three makers differed, to some extent, in the points under consideration. One being a heavy cement weighing about 120 lbs. to the bushel, equal to a tensile strain of 800 lbs. to 1000 lbs., on a sectional area of 2·25 square inches; another, weighing about 108 lbs. to the bushel, which bore a strain of 600 lbs. or 700 lbs.; and the third was intermediate between the two in weight, viz., about 114 lbs. to the bushel; but the tensile strength was, on the whole, greater than that of the heavier cement. The superintendent of the works was, in the first instance, favourably disposed towards the heavier cement, with high tensile strain; but after testing it, by exposing blocks of concrete to the action of the sea during a monsoon, he was unable to say that one cement was practically better than the other, as judged by this test. Subsequently he had the means of applying another practical test, by cutting into the blocks. According to this test, he gave the preference to the first heavy cement, as being decidedly harder than the other two. As to the two others, he could not say which was the best. But, on the whole, there was probably no great practical difference between the three cements.

He would mention another fact, to show that weight and tensile strength did not always go together. A firm of cement manufacturers requested him to test some cement which had been condemned, and he applied the ordinary tests to it. In the first place, he weighed it, and found the weight to be $101\frac{1}{2}$ lbs. to the bushel. This was very light, and he expected to find a very weak cement; he noticed, however, one remarkable fact in making up the test blocks. He adopted the plan, which Mr. Grant now recommended, of using exact proportions of cement and water; but he measured the cement and the water, instead of weighing them. With this light cement he found this curious result. The measure he adopted had a capacity about 50 per cent. greater than that of the test-block mould, and this quantity of heavy cement in powder was sufficient, when worked up with water, to fill the mould, and even left a little excess after the mould was filled; but with the light cement it was not enough; the contraction of bulk was greater, so that it required a larger measure of that light cement to fill the mould than it did of the heavier material. When he broke the test-blocks he was surprised at the strength—the several breaking strains were 680 lbs., 600 lbs., 600 lbs., 585 lbs., and these did not give the full strength, for they were taken out of the mould while soft. Two other samples, which were kept in the mould till quite hard, were equal respectively to 960 lbs. and 840 lbs., which, for cement of only 101 lbs. to the bushel, was, he thought, very high indeed. Now, if the virtue of that cement was in proportion to its tensile strength, it was not in proportion to the weight.

He was glad to find the Author now insisted that extreme care was necessary in making these tests. Generally speaking, the makers tested their cement at their own works, and employed for that purpose a man called a sampler, who had little else to do but test the cement as it was made; and those men, from long practice, had acquired so much skill that, though they performed the operation in a very rough manner, they obtained pretty regular results. But when the cement was sent to the consumer, and the consumer wished to test it for himself, he necessarily employed a person of less skill to make up the test-blocks, and it was almost impossible to get consistent results. There would sometimes be a difference of 100 per cent. or 150 per cent., without any apparent cause, in the breaking strain of two bricks made from the same sample. Consistent results could only be obtained by adopting exact proportions of cement and water. He had made some experiments to illustrate this. In one experiment, he used $\frac{4}{10}$ths of a pint of water for each test-block, when the breaking weight in four cases was 970 lbs., 980 lbs., 1000 lbs., and 980 lbs. After that, he made up two more samples, mixed with $\frac{1}{2}$ pint of water, instead of $\frac{4}{10}$ths of a pint, and those broke with 590 lbs. and 370 lbs. Two others, made up with $\frac{9}{20}$ths of a pint, broke with 750 lbs. and 375 lbs. Other experiments, giving similar results, led to the conclusion that it was most important to reduce the quantity of water to a minimum, and for this purpose to have it accurately measured. He would mention a case in which neglect of this precaution had nearly led to serious results. Part of the cement which he sent out to India had been tested by himself before shipment, and the samples broke at a little over 800 lbs. When the cement arrived at its destination, the works had been stopped for a time, and 400 tons of cement were left on hand. This was transferred to another work at Bombay, and when it arrived there the Engineer who was to employ it was directed to test the cement. The tests were made, and the results were given in a strongly-worded despatch to the India Office, stating that the cement was good for nothing; inasmuch as the tests gave as its tensile strength only 248 lbs. on the brick; and that its employment in the work would not be permitted. He thereupon recommended that some samples of the cement should be sent home for further tests. On its arrival it was found to be damaged by damp, to which it had been naturally exposed in its three voyages and various transhipments; nevertheless, the test-blocks made from it bore strains of 660 lbs., 690 lbs., and 800 lbs., showing that there was no great deterioration of the cement. There could be no doubt that the tests at Bombay were not made with the necessary precautions; but he was convinced that there was at present a very prevalent ignorance as to their necessity, which he hoped would be removed now that Mr. Grant had brought the weight of his authority to insist upon them. Properly employed the tests were most valuable, but in the hands of inexperienced persons they were worse than useless. He would also express his opinion, that it was a mistaken practice to record only average results. All records should give individual results, by which alone the value of the tests could be judged.

The weight test was one which also required to be applied with due precaution. The rough mode employed by the makers of shovelling the material into a bushel measure was safe enough if always carried out by the same person, and he a careful and experienced one; but it was possible, by an almost involuntary increase of force, to increase the density 2 or 3 per cent., and by an increase such as could not be prevented by a specification, to increase it 10 or 12 per cent. The employment of a hopper, as described by Mr. Grant, was the best precaution against this source of error.

There was another point, however, in which care was required.

He had alluded to some very light cement on which he had experimented. The makers had assured him that this cement, when manufactured, was of much greater density. This led him to experiment on other samples; and he found in four cases that cement taken fresh from the manufactory or from the cask was heavier by respectively $6\frac{1}{2}$ lbs., 7 lbs., $4\frac{1}{2}$ lbs., and $2\frac{3}{4}$ lbs. per bushel than it was after two or three days' exposure to the air; though in this latter state it was in better condition for employment in practical work. It was, therefore, necessary to specify that the density should be determined when the cement was fresh from the manufactory, and not at any subsequent time.

Mr. G. F. WHITE observed that, as one of a numerous body of cement manufacturers, he desired to express his obligations to Mr. Grant for the continuance of his investigations into the subject of Portland cement. It was needless to say that the manufacturers themselves were anxious and critical investigators of the products they turned out, and had their attention constantly directed to their improvement. He might say that in his own works there were recorded thousands of experiments for years past on the strength of cement; but he could well understand that no trials made by a manufacturer on his own material could have for the members of the Institution the same value as those conducted by an independent engineer. His own observations on the subject of Roman cement enabled him to corroborate the remarks of Mr. Grant as to that material. It was the fact that even after five years this cement did not attain to a greater tensile strength than 100 to 120 lbs. on the square inch, which was less than a third of the strength of Portland cement. This sufficiently accounted for what was at one time a large manufacture having dwindled down to nothing, Portland cement. having entirely superseded it. The same remark would, in great measure, apply to Medina cement, which was but a variety of Roman cement with rather more lime in it; and which, though valuable for under-water work, where rapid setting was indispensable, had on the other hand the disadvantage which attached to all quickly crystallizing cements of attaining to only a moderate degree of ultimate hardness. He fully agreed with the Author of the Paper as to the superiority of the moulds made with curved instead of straight shoulders, as tending to reduce the inequality of the strain, and to bring the pressure of the lever more equally on the centre of the brick to be tested. With respect to the wide differences of the results obtained by different experimenters on the same cement, there was no doubt that different modes of gauging were adopted by different manipulators, some using more and others less water to mix the cement. Something too might be due, in the case of long voyages, to the cement having become slow setting from staleness; but the mode of testing and the machine used was at the bottom of the difficulty, and it would be highly desirable that some rule of universal application should be adopted in order to put an end to these differences. Persons who had used Portland cement for the arches of tunnels or bridges would have noticed the milky exudation referred to by Mr. Grant, in cases where there was much moisture above the arch. The appearance, indeed, was not confined to cement but often showed itself where lime mortar was present. He considered that the milk of lime so formed was, in both cases, attributable to the mechanical action of the moisture, which released a minute quantity of the uncombined lime, and caused it to exude. If there had been an excess of lime, in the sense intended by Mr. Grant, the water would have slaked it and ruptured the brickwork; but he gathered that no bad results had followed these appearances. It was, however, a subject well worthy of further investigation. Concurring as he did in the main with Mr. Grant's conclusions, that concentration of burning and tensile strength had a direct and significant relation to one another, he still maintained that, inasmuch as cement weighing 120 and 125 lbs. to the bushel could only be obtained by the admixture of excessive proportions of lime, there was always the liability to disintegration of the mortar if any of the lime were in a free state. He could not avoid noticing the fact that the strength of the mortar made with the heavy cement did not bear the same relation to mortar made of the light cement as the two cements did to one another when mixed pure. This seemed to show that it would be fairer to test the cement with, say, 2 parts of sand in the way it was going to be used in the work, after the manner usually adopted by the French engineers. If Mr. Grant, in addition to the other services he had rendered, could point out how good cement could be made with less fuel, and thus lighten a burden which was at present their *bête noir*, he would be conferring a lasting obligation on cement manufacturers in helping them to cheapen the cost and improve the quality of their fabrication at one and the same time.

Mr. J. A. M'Connochie inquired whether in Mr. Parkes' experiments, where unequal quantities of water were used in mixing the test-blocks, the time allowed for setting was the same in each case? It appeared to him that the time allowed for setting should be regulated by the quantity of water used, if a comparison were to be drawn from the experiments as to the relative ultimate strength of the cement. He recently had occasion to send several thousand tons of Portland cement to Bombay for the drainage works, and in the case of one shipment a similar report reached him as that referred to by Mr. Parkes, that the cement on its arrival did not stand the tests it had been subjected to before it left this country. He believed that this resulted from the cement having been put into casks before it had sufficiently cooled, and that it had consequently deteriorated during the voyage. This was of great importance in sending Portland cement to hot climates, and on its arrival it should be removed from the casks, spread out, and turned over to cool.

The result of an extended series of tests which he had made entirely confirmed Mr. Grant's conclusions, that the two important features to be sought for in Portland cement were weight and fineness; and that as cement possessing these properties was slower in setting, tests at a longer period than seven days were more satisfactory where they could be obtained, for although several samples of unequal weights might attain nearly the same strength in the seven days' test, the heavier and slower setting would ultimately be decidedly the stronger.

He had adopted a different breaking section in his test-moulds from that of Mr. Grant, retaining the same sectional area of 2·25 square inches, but disposed in a depth of 2·25 inches by 1 inch wide, in place of $1\frac{1}{2}$ inch square. He found that with this section the blocks broke in nearly all cases in the smallest section, and not at the shoulders, as so often happened even with Mr. Grant's improved pattern.

He was surprised to find from Mr. Grant's experiments that cement mixed by hand was double the strength of that ground in a mortar-mill. He believed that this must be due to the materials having been mixed for an excessive time (thirty minutes) in the mill; if six or seven minutes were tried he expected the result would be reversed, and that the cement ground in the mill would be superior to hand-mixed.

In the case of a dock wall recently built at the Surrey Commercial Docks, he specified Portland cement for concrete block facing to weigh 116 lbs. to the bushel, with a breaking weight of 350 lbs. per square inch at seven days in water. The contractors delivered a cement procured from Messrs. Lee, Son and Co. exceeding the specification, and weighing 120 lbs. to the bushel, with a breaking weight of 440 lbs. per square inch at seven days. Finding this to be the case he abandoned blue lias lime for the concrete backing, and substituted Portland cement concrete mixed in the proportion of 1 of cement to 12 of sand and gravel. This proved entirely satisfactory. He mentioned this as an illustration to show that the idea which had been advanced, that it was unnecessary to seek for a cement stronger than the materials to be cemented, was, even on the ground of economy, an erroneous one, as the additional cost per ton of a heavy and strong over a light and weak cement was trifling compared with the saving resulting from being able to use a greater quantity of sand with it. A valuable property of Portland cement, which had not been alluded to, was that the work executed with it scarcely ever suffered from frost.

It was to be regretted that, with one or two exceptions, the rule of thumb still so largely prevailed in the manufacture of Portland cement, and he believed that by raising the standard of quality still higher than Mr. Grant had yet done, the manufacture would be improved and cement more uniform in quality be produced.

Mr. W. Parkes replied that in all his experiments the time allowed for the cement to set had been uniformly seven days.

Lieutenant W. Innes, R.E., described some experiments on which he had been engaged. The cement used was sampled out of a large quantity supplied for War Department Works, and was of a high average weight and tensile strength. Weighed in the ordinary manner it would have been from 118 lbs. to 120 lbs. per bushel; the weights given in the following tables were lower, having been got by sliding the cement into the measure down a piece of board. Each result given was the mean of not less than ten experiments, all due precautions having been taken with the manipulation, and the specimens broken by tension in one of Adie's machines, similar to those used by the Metropolitan Board of Works.

Table I. (p. 320) showed the tensile strength at three weeks and three months of mortars composed of cement with two parts of seven different substances, including four varieties of sand, stone dust, clay ballast, and smiths' ashes. The whole of the sands, &c., had the grains above $\frac{1}{12}$th of an inch in diameter sifted out before use, to avoid the uncertainty caused by larger grains in results got from a section only $1\frac{1}{2}$ inch square. The proportion of each which would have been rejected by a sieve of 2,500 meshes per square inch was inserted, to give some idea of the different degrees of fineness, but what was actually used was not so sifted. *Cæteris paribus*, coarse sand gave better results than fine, both as regards strength and bulk of mortar produced (*a* and *b*, Table I.); and of mortars attaining nearly the same ultimate strength, that made with the finest sand set the slowest (*b* and *e*, Table I.). The great

TABLE I.

GIVING RESULTS of EXPERIMENTS on MORTARS of PORTLAND CEMENT and Various Kinds of SAND, &c., made with one measure of the former to two of the latter.

	Sands, &c. Physical Characteristics.				100 Parts of Mortar contained			Ultimate Tensile Strength.				Remarks.
								At Three Weeks' Immersion.		At Three Months' Immersion.		
	Per cent. of Voids dry.	Per cent. of Voids wet.	Shrinkage on wetting.	Per cent. above $\frac{1}{50}$ inch diameter	Cement.	Sand	Water.	Lbs. per Sq. Inch.	Proportional.	Lbs. per Sq. Inch.	Proportional.	
	Neat cement.			31	141	..	39	450	1·00	529	1·00	Inserted for comparison with the other mortars.
a	38	34	6	94	38	76	18	140	·31	249	·47	A sea-sand, with roughish and uneven grain, chiefly silicious and quite clean. Mortar very short and incoherent; strength of different samples somewhat variable.
b	41	34	11	76	40	80	24	94	·21	175	·33	A silicious pit-sand, quite clean, with smooth, uniform, semi-transparent grains. Mortar somewhat "short," strength very uniform.
c	32	19	16	15	40	80	34	108	·24	248	·47	A silicious pit-sand, containing a number of minute shells and a small quantity of some orange-colouring matter; grains semi-transparent, brownish yellow, and of unequal size. Mortar rather "short;" strength tolerably uniform.
d	46	34	18	56	42	84	22	165	·37	254	·48	Portland stone dust, a mixture of roach and whitbed; grains rough and irregular, quite clean. Mortar tolerably coherent; strength very uniform.
e	43	36	11	8	39	78	31	60	·13	193	·36	Drifted sea-sand, with pure silicious, semi-transparent, and almost colourless grains, and quite clean. Mortar rather short; strength tolerably uniform.
f	64	52	25	56	44	88	44	38	·08	91	·17	Smiths' ashes, containing, however, a good deal of unburnt coal-dust; grain rough and irregular. Mortar moderately coherent, set slowly, and apt to shrink and crack; strength very uniform.
g	50	40	17	40	48	96	39	269	·59	355	·67	Clay ballast, burnt and ground, of a pale brick-red colour, with a rough uneven grain, and containing a good deal of dust. Mortar very coherent, apt to shrink and crack; strength very uniform.

difference seemingly caused by a small mixture of minute shells was very noticeable. The high results obtained with burnt clay (*g*) might probably be due to its acting as a puzzuolana with the free lime in the cement. Mortar made with this substance was very coherent, and resisted the washing action of water when green better than any other; but the bulk of mortar produced from a given quantity of material was very small, and it had the disadvantage of cracking and shrinking if allowed to dry before it was well set. The low result got with the coal ashes was unexpected, and might have been due to its containing a good deal of unburnt coal dust; this admixture however was not uncommon.

The two remaining tables showed the results of experiments on the effect of coarseness of grain on the properties of cement.

Table II. (p. 322) showed the strength at three and six months, and with from 0 to 3 parts of sand, of mortars made from cement of three degrees of fineness, viz., as received from the manufacturer, and the same after being passed through sieves of 1,300 and 2,500 meshes per square inch, which rejected about 20 and 30 per cent. respectively. The weight per bushel and the strength of the neat cement were both diminished by sifting, the coarsest being heaviest and strongest and the finest lightest and weakest; but when gauged with one or more parts of sand the order of strength was reversed, the fine cement giving the best results. With three parts of sand and at six months the finest cement attained ·47, whilst the coarsest attained only ·29 of their respective strengths neat at the same age.

Table III. (p. 323) showed the strength at three and six months of neat cement varying in fineness from what would all pass through a sieve of 2,500 meshes per square inch down to that of which 70 per cent. would be rejected. The same cement was used for all, being first sifted and then remixed in the proportions given. At three months the strength increased with the quantity of coarse grains up to 40 per cent. of the latter; when the cement contained more than this proportion the results, though high, were variable; at six months the strength increased with the quantity of coarse grains up to the highest proportion tried, viz., 70 per cent. Had it not been expected that the maximum strength would have been reached with a much smaller or no proportion of coarse grains higher proportions would have been tried, but there would have been considerable difficulty in gauging the coarse cement freed or nearly so from the fine, as it was as harsh and incoherent as so much gravel.

TABLE II.

RESULTS of EXPERIMENTS on the effect of the Coarse Particles ($\frac{1}{50}$th of an inch and upwards in diameter) of heavy PORTLAND CEMENT.

Quality of Cement used.		Ultimate Tensile Strength at Three Months.								Ultimate Tensile Strength at Six Months.							
		Net.		1 Sand.[2] 1 Cement.		2 Sand.[2] 1 Cement.		3 Sand.[2] 1 Cement.		Net.		1 Sand.[2] 1 Cement.		2 Sand.[2] 1 Cement.		3 Sand.[2] 1 Cement.	
Fineness, &c.	Weight per Bushel.	Lbs. per Inch.	Proportion.	Lbs. per Inch.	Proportion.	Lbs. per Inch.	Proportion.	Lbs. per Inch.	Proportion.	Lbs. per Inch.	Proportion.	Lbs. per Inch.	Proportion.	Lbs. per Inch.	Proportion.	Lbs. per Inch.	Proportion.
	lbs.																
Cement as received from the manufacturers	116	504	1·00	286	·57	117	·35	103	·20	527	1·00	350	·66	229	·43	151	·29
The same passed through a sieve of 1,296 meshes per square inch which rejected 20 per cent.[1]	162	457	1·00	324	·71	212	·46	143	·31	492	1·00	424	·86	281	·57	173	·35
The same passed through a sieve of 2,500 meshes per square inch which rejected 30 per cent.[1]	99	449	1·00	377	·84	250	·56	173	·39	486	1·00	439	·90	323	·66	228	·47

REMARKS.—The finest cement set quickest, required most water in gauging, and gave the most coherent mortar: it gave the smallest bulk of mortar from a given quantity of materials.

[1] These percentages are given by weight.

[2] The proportions were measured in light dry powder.

Table III.

Results of Experiments on the effect of the Coarse Particles ($\frac{1}{50}$th of an inch and upwards in diameter) of heavy Portland Cement.

Quality of Cement used	Ultimate Tensile Strength in lbs. per Square Inch. Kept in Water Three Months.	Ultimate Tensile Strength in lbs. per Square Inch. Kept in Water Six Months.	Remarks.
Neat cement, of which none was rejected by a sieve of 2,500 meshes per square inch	464	492	The same cement was used for the whole series, being first all sifted, and then remixed in the proportions shown. As received from the manufacturer it weighed about 117 lbs. per bushel, and contained more than 30 per cent. which failed to pass a sieve of 2,500 meshes per square inch.
Ditto 10 per cent. ditto ditto	482	508	The percentages are all given by weight.
Ditto 20 ,, ditto ditto	499	510	The ultimate chemical composition of the fine and coarse grains was almost identical.
Ditto 30 ,, ditto ditto	507	515	
Ditto 40 ,, ditto ditto	500	520	
Ditto 50 ,, ditto ditto	490	525	
Ditto 60 ,, ditto ditto	512	527	
Ditto 70 ,, ditto ditto	489	535	

Supposing the results given in Tables II. and III. to be trustworthy, they would seem to indicate a necessity for modifying the present weight test and adding one for fineness, for the heaviest cements were also the coarsest (heavy cement often contained 30 per cent. of grains upwards of $\frac{1}{50}$th of an inch in diameter), and coarse cement, though it gave a high tensile strength neat, did not bear sand well; so that a cement giving good results with the usual weight and strength tests might give a weaker mortar when used (as it almost always was) with sand, than one not passing the tests so well. This had an important bearing on what had been remarked on as to the doubtful advantage of a cement stronger than the building material; the advantage of such a cement should be its capacity for sand, but much of this was lost by coarseness of grain.

A specific gravity test would probably be better than the common weight test, if some convenient method of applying it were devised; or if the weight test were retained it might be applied to a sample passed through a sieve of some fixed degree of fineness; the standard would probably in such a case have to be reduced, as it seemed doubtful whether it would be possible to manufacture a fine cement of the high weight per bushel now thought necessary, though of equally fine cements the heaviest would doubtless be the best.

Mr. G. H. Phipps said he could not subscribe to the argument, that there was no use in having a cement stronger than the materials to be held together, as he thought there were many cases where a material possessing that property was exceedingly useful. For instance, in brick abutments for arched bridges it was always an important matter to secure the courses from sliding horizontally upon each other at the base of the skewbacks at the springing of the arch. This, he thought, could be better secured with a cement of high cohesive power, as when considered in relation to the cross joints, as well as the horizontal ones, any fracture had to pass through a considerable quantity of the cement itself, as well as to strip it off the bricks. He thought it a great advantage to be possessed of a material combining the properties of great adhesion and cohesion, and which at the same time when reduced in strength by various admixtures of sand, could be brought down nearly to the cost of common mortar.

Mr. B. Latham observed, through the Secretary, that in considering the question of the strength and durability of cement or mortar the attention of engineers should be directed not only to the necessity of providing a material of great cohesive strength, but also one which, when applied in certain positions, should resist the influence of certain chemical forces tending to destroy it, when the inevitable result would be a failure in the work executed. During the last two or three years he had found that sewers which had been constructed for about seventeen or eighteen years, the brickwork of which was set in various kinds of lime and cement, and in some cases in a mixture of both, were failing, and many yards of such sewers had fallen in. On examination of these defective sewers he had found that every particle of cement or lime which had been used in the mortar had disappeared from the joints, leaving nothing but the sand to hold the work together. This failure was due to the fact that sewer-water contains a certain percentage of ammonia; the ammonia, when brought into contact with ordinary lime, was converted into nitrous and nitric acid, which, in its turn, attacked the lime, forming nitrates and nitrites, which were extremely soluble, and which were washed out either by the sewage or by the infiltration of subsoil water into the sewers, leaving nothing but the sand in the joints. Cements and limes, intended to be used in such a position as to be exposed to chemical influence, should, in addition to the tests recommended by Mr. Grant, be subjected to a standard solution of nitric acid, in order to ascertain whether or not the material was suitable for the particular class of work for which it was required. Portland cement was the best material for resisting the chemical action of sewage; on the other hand, lime made from chalk was the worst. Therefore there was a possibility of carrying the manufacture of Portland cement to such a point that, in order to secure a great tensile strength, so much chalk might be used in its manufacture as to render it unsuitable to resist the chemical action of the matters with which it might be brought into contact. He had some years ago adopted the mode of constructing sewers recommended by Mr. Grant, viz., with an internal ring of brickwork, the external portion of the sewer being formed in concrete; and during the last six or seven years he had constructed several miles of such sewers, and could bear testimony not only to their efficiency, but to their great strength and durability, and to the cheapness of their construction. In the case of a sewer at Croydon, which was 4 feet in internal diameter, the inner circle being formed of a 4½-inch ring of brickwork, and the external portion of the sewer consisting of 6 inches of concrete, the sewer was constructed at 40 per cent. less cost than would have been the case had the whole work been executed in 9-inch brickwork.

Mr. J. Grant, in reply upon the discussion, observed that

Mr. Towle, Colonel Scott, and others contended that it did not follow that cement of great cohesive was necessarily of great adhesive strength; in fact, that no advantage was gained by making cement of a strength exceeding that of the materials to be cemented together. It was with the object of settling this point that the B Series of experiments was made. In the tables relating to that series it would be seen that the cohesive varied directly as the adhesive strength of cement; that in fact neat cement was from three to four times the adhesive strength of any mixture of it with four or five times its bulk of sand; and on this account he was prepared to state, in general terms, that cohesive and adhesive strength might be taken as equivalent to each other. For the purpose of cementing together various materials, he need hardly point out that to have strong cement or mortar was not the only thing necessary. For instance, two cubes of glass could not be cemented together, however strong the cement, so that they should adhere with the same tenacity as two bricks or blocks of stone of a porous character, and rough on their faces. It would not be possible, for example, to take such bricks as were recently used for lining the subway from the Houses of Parliament to the adjoining railway station, and to cement their highly glazed china faces together so that it would require the same pull to separate them as it would to separate two stocks, wire cut gault, Fareham red, or other porous bricks, capable of absorbing about $\frac{1}{5}$th part of their weight of water. Whilst on this point he might state that only second in importance, if second, to the strength of the cement was that of seeing that the bricks or stone to be cemented together were thoroughly saturated with water. In hot climates, like that of India, any work being built with cement should be kept wet, and if possible under shelter during its progress and for some time afterwards. Two bricks might be put together dry as they came from the kiln with the strongest cement that could be made, and if not previously soaked in water, these bricks might be separated without the least difficulty, the joint being very little better than if made of dry sand. With bricks which absorbed from 1 lb. to $1\frac{1}{4}$ lb. of water, it was evident that if left to absorb this moisture from the mortar with which they were cemented they took away that which was necessary for crystallizing or setting the cement.

He thought it must be self-evident that, for making concrete, strong cement was much to be preferred to weak. Concrete made of absorbent material, such as broken bricks, stone, or pottery, was much stronger than concrete made of Thames ballast or any other slightly absorbent material. In the D Series of tables it would be found that concrete made of Thames ballast was only from half to two-thirds the strength of concrete made of broken bricks, stone, or pottery. It would be found also that bricks of a somewhat porous character, like the red bricks or the wire-cut gault bricks, and the other varieties shown in Table B, adhered together with a strength double that of bricks like the Staffordshire blue bricks without a frog, or bricks that had a smooth or glazed surface.

On the point of strength it had been pointed out clearly five years ago, and again on the present occasion, that the strength of cement could always be reduced by mixing sand in any proportion.

With respect to the cement or lime mentioned by Colonel Scott, he had the pleasure of going over part of the works at South Kensington, and had also an opportunity of testing the cement in one of the large sewers where it was used in the arch; but he was sorry to say it did not answer the purpose, and was much inferior to lias lime. On a later occasion he made a number of briquettes or moulds of it, as in the case of cement; but it was so weak that it would not bear winding up in the machine. Thus either Colonel Scott was not fortunate enough to have made his comparisons with Portland cement of a good quality, or he had himself been unfortunate enough to meet with an inferior sample of the lime or cement referred to. The objections raised by Mr. Parkes as to the comparative strength of cements of different specific gravities might be valid if the time allowed for the heavier cement was short; in fact, the heavier the cement the longer time it was necessary to give it to set. For experimental purposes, with heavy cements, a month was fairer than a week. For practical purposes, in works carried on in the streets of London, a week was a more convenient time; but for experimental purposes, with different weights of cement, the longer time was much more satisfactory.

As to the strength of cements generally, if it could be made of a high quality it might at any time, as he had stated, be reduced in strength. It was not unlikely at some future, though it might be far distant, time, that many of the sandy districts of Africa and other parts of the world might be irrigated by aqueducts, for the construction of which all the materials necessary would be comparatively small quantities of cement in a concentrated form, to reduce the bulk and cost of freight, mixed with the sand upon the spot.

Mr. VIGNOLES, President, said there was not time for him to express fully his individual opinion on this subject, and he must content himself with observing that he did not concur in all that Mr. Bazalgette and Mr. Grant had propounded, and that there was much to be said upon what had been advanced by Colonel Scott with regard to having too strong an adhesive material. He thought the subject had yet to be considered more fully.