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Canadian Society of Civil Engineers.

INCORPORATED 1887.

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A CUBIC YARD OF CONCRETE.

BY HENRY F. PERLEY, M. CAN. SOC. C. E.

To be read Thursday, 9th November, 1893.

With the disappearance of timber from the more settled parts of Canada, and consequently its increase in cost, other materials will eventually have to be used in the construction of our public and other works. Heretofore, timber has taken the lead as a constructive material, by reason of its existence everywhere throughout the Dominion, the ease with which it could be obtained, and its apparent cheapness when compared with other and much more durable materials. Except in Canada and the United States, the use of timber has been to a very great extent abandoned, and in its stead, iron, steel, stone and concrete are used, the two first principally in superstructures, and the latter two in foundations and superstructures as well; and of all these materials it would appear that concrete has proved to be the cheapest and most advantageous to use in the construction of break-waters, wharves, dock-walls, sub-aqueous foundations, etc.; and the day is not far distant when it will be fully comprehended that all large and important works in Canada will, to a very great extent, have to be constructed with that material.

The object of this paper is not to point out where concrete can be advantageously used, nor to show that, though entailing a larger initial expenditure, it eventually becomes, where depreciation through natural decay and wear and tear, and the consequent cost of repairs are taken into account, cheaper than timber; for a solid structure of concrete is better in every way than the wooden boxes filled with loose stone, constructed by private as well as public enterprise, which pass and serve as wharves, breakwaters, bridge-piers and abutments, etc., throughout the length and breadth of our country; but merely to make a few remarks on the composition and character of concrete as a constructive material, without any reference to its use, or its cost, in both of which cases the question of locality becomes an important factor.

Concrete is an homogeneous mass,—in fact, an artificial stone, formed by the admixture of lime, or cement with gravel, broken stone, sand, etc., in fixed proportions, the strength and durability of the compound being directly in proportion to the qualities of the lime or cement employed, the nature of the stone, sand, etc., selected, and the manner of their admixture and mode of deposit *in situ*.

For the purpose of this paper, the subject has been divided into four parts as follows:—

1. Cement.
2. Components (stone, sand, etc.).
3. Mixing.
4. Deposit.

1. CEMENT.

In concrete, cement—for the use of lime will not be considered—takes the leading place, and on its goodness the goodness of the resulting mass depends, always provided that the other components are good and the mixing, etc., has been honestly done.

By cement is meant that substance, either a natural or an artificial production, which possesses the property, when mixed with water, of setting in comparatively short periods, either in the air or in fresh or salt water, and also of attaining greater strength and solidity with an advance in age, and these properties are possessed in their fullest extent by what are classed as *Portland Cements*. It is true that certain cements bearing local names, but not manufactured in the same manner as the Portlands, possess the same properties, but only to a certain extent, and often that extent is so small as to preclude their use in any important work.

Portland cement is an artificial product, resulting from the mixing of certain classes of limestone or chalk with clay of a suitable quality, in fixed proportions, and calcining and grinding the product. In the south of England the hard chalks and clay deposit from the beds of several rivers are used, but in the north of England and on the Continent, limestone and field clay are the components, the proportions not varying far from 72 per cent. of stone to 28 per cent. of clay.*

On analysis, a sample of good cement should show the following constituents —

Silica	22.23	per cent.
Iron oxide	4.32	"
Alumina	7.22	"
Calcium oxide	60.59	"
Magnesia	1.10	"
Sulphuric acid	1.00	"
Carbonic acid	0.80	"
Water combined with lime	1.05	"
Insoluble and other matters	1.69	"
	100.00	

In the above there are three constituents, which, when they exceed a certain percentage, are objectionable, viz.: magnesia, when it exceeds $1\frac{1}{4}$ per cent., and sulphuric and carbonic acids, when they exceed $1\frac{1}{2}$ per cent. Another objectionable element which cannot be detected by analysis exists in the shape of *free lime*, but it is asserted that the measure of carbonic acid is the measure of the amount of free lime.†

Lately in England there has come into use a cement made from "slag," or the refuse from the blast furnaces in the smelting of iron, it having been found to contain generally all the chief ingredients found in Portland cement; but all slags are not equally adapted, for those which disintegrate and fall to powder spontaneously are wholly unfit, but they have been made use of by unscrupulous manufacturers, especially in Europe, for the purposes of adulteration.

The following is an analysis of good slag given in the "Proc. Inst. C. E., Vol. 105, p. 221."

Silica	24.10	per cent.
Iron oxide	0.93	"
Alumina	16.30	"
Calcium oxide	46.53	"
Magnesia	2.08	"
Sulphuric acid	2.05	"
Carbonic acid	0.65	"
Water combined with lime	6.45	"
Insoluble and other matters	0.94	"
	100.03	

It will be noted that there is a deficiency in calcium oxide (lime), but this is made up in the process of manufacture, which is freely quoted as follows:—"The slag, as it emerges from the blast furnace, is passed through a stream of water, which reduces it to a spongy and readily crushed material known as 'slag-sand,' which is ground to a

* G. F. White—"Proc. Inst. C. E., Vol. 62, p. 185."

† A pamphlet on Portland Cement, by W. W. Maclay, C. E.

fine powder between mill-stones. As no slag in itself contains a sufficient amount of lime to produce cementitious action, the requisite amount is made up by the addition of 25 per cent. of the mixture of slaked lime, obtained from pure or fat limes, which in the act of slaking fall into an extremely fine powder, finer than can be produced by any mechanical means.

"After the mixture of the slag-sand and lime, a charge is passed into a metal cylinder about $4\frac{1}{2}$ ft. in diameter, partly filled with iron or steel balls from 1 to 2 ins. diameter This cylinder revolves horizontally and slowly, and in consequence of the crushing and pounding action of the balls, the friction between them, and the very complete intermixture of the ingredients caused by the rotary motion, the particles of lime and slag are most intimately united and reduced to a smooth silky powder, resembling to the touch the finest flour. After remaining in the drum for about one hour, the contents are withdrawn, and the cement is ready for use.

"The under-mentioned results were obtaining in testing samples of slag-cement at the Royal Testing establishment for Building Materials, Berlin, Germany.

Mixture.	Tensile strength per sq. inch. 7 days.	Tensile strength per sq. inch. 28 days.	Compressive strength per sq. inch. 7 days.	Compressive strength per sq. inch. 28 days.	Remarks.
	lbs.	lbs.	lbs.	lbs.	The briquettes were one day in the air, the remainder in water.
Neat.	647	692			
1 ct. 3 sand.	427	509	3,376	4,269	

"In colour, slag-cement is lighter than Portland, and, owing to its fine grinding and partly to a lower specific gravity both of the slag and the lime, the weight per cubic-foot seldom exceeds 75 lbs." *

The process of manufacturing Portland Cement need not be described, as it is now well known, but it differs materially from that adopted for slag-cement, and it is at once apparent that it is a much more extended and therefore a more extensive process.

The goodness of Portland cement depends:—

(1) On the proper constituents of the materials employed;

(2) Upon their being properly mixed in the right proportions;

(3) On the exact amount of calcination;

(4) The degree of fineness to which the clinker is reduced by grinding;

(5) The thoroughness with which it has been sieved to obtain only the finest particles, and the rejection of all coarse parts; and

(6) A careful air-slaking for at least one month, to permit the cement to cool and purge itself of free-lime.†

Uniform fineness is almost an absolute necessity, and in passing a sample through a sieve of 76 meshes per linear inch, or 5776 inches per square inch, not more than 6 per cent. of residue should remain on the sieve. All coarse particles, such as small lumps of unground or partially ground clinker, are not of any cementitious value, indeed it is better to use more coarse sand in concrete than such particles, because they can only be regarded in practice as sand, as they reduce the effective proportion of the cement.

To show the effect of coarse and therefore inert particles in cement in the manufacture of concrete, take a specification which requires concrete to be made with 6 parts of broken stone, 2 parts of sand, and 1 part of cement, the product being known as 6 to 1 concrete, and suppose that a sample of the cement supplied, on being sieved through a standard sieve, leaves a residue of 20 per cent. of coarse particles, then the actual available amount of cement is 80 per cent., and the mixture becomes $7\frac{1}{2}$ to 1, instead of 6 to 1, as called for.

* Proc. Inst. C. E., vol. 105, p. 221 et seq.

† Vide General Scott's paper in Proc. Inst. C. E., vol. 62, p. 70 et seq.

The authorities* consulted in the preparation of this paper agree on the necessity of demanding a properly ground cement, for exactly in the degree that it is not so, is its value as cement thrown away, as the particles of hard clinker which will not pass through a 2500 mesh sieve, will not give any good results. In Germany—and it may here be stated *par parenthèse*, that the German Portland cements give, as a rule, better results than those of English make, fine grinding being required—the recognized standard is that the residue must not exceed 20 per cent. on a sieve of 900 meshes per square centimetre, or 5806 meshes per sq. inch, but an article which will only leave 10 per cent. is supplied. In England the residue left on a sieve of 2850 meshes per sq. inch varies from 15 to 27 per cent.

The weight of cement per cubic foot cannot be taken as an indication of its strength, for a heavily burnt clinker, if coarsely ground, will produce a heavier article per cubic foot than the same clinker will when finely ground, but the latter article will give the better results in use.

The average weight of a cubic foot of Portland Cement, when filled into a measure from a hopper with an average drop or fall of 18 inches, may be taken as 85 lbs; and, according to Fresenius, its specific gravity should vary but very little from 3.10.

There are two modes of testing cement,—the chemical and the mechanical. Relative to the first, a writer† remarks that " although chemistry has enabled definite conclusions to be drawn as to the constitution of cement, and the value of the various materials used in its manufacture, it cannot be said that for the purpose either of the maker or user it is of much practical service in rapidly testing the finished product in the market. Chemical analysis requires a special technical knowledge and skill which is not often available, and a chemical analysis in itself is not a sufficient criterion of the worth of a cement. It is possible to get an article which from a chemical point of view may be perfect, and yet in practical use may be worthless. In the manufacture, in controlling the operations of the factory, chemistry cannot be too highly valued; but in dealing with the finished article it is unnecessary and the ultimate test is its adaptability and economic worth as a material of construction, and this cannot be made by any better method than by an examination of its behaviour when in intimate conjunction with water and sand or other aggregates, thus placing it under conditions as nearly similar as possible to those under which it is used."

Setting aside then the consideration of a chemical analysis, the mechanical test is within the compass of every person using cement in large quantities, or of the engineer having charge of works in the construction of which cement is an important factor.

The mechanical test may be divided as follows:

Specific gravity.
Weight per cubic foot.
Fineness.
Tensile strength.
Adhesive strength.
Compressive strength.

SPECIFIC GRAVITY.

The determination of the specific gravity of a sample of cement requires only a small amount of inexpensive apparatus, and the result is obtained in a few minutes. The apparatus required consists of a glass flask to hold 100 cubic centimetres when filled to a mark on the neck, and a burette with a glass stop-cock, to hold the same quantity, graduated to 1-10 of a c.c. The *modus operandi* will then be: thoroughly dry a quantity of cement, (4.4 oz. will answer), and from it weigh out

* John Newman, " Notes on Concrete and Works in Cement."
General Scott, " Proc. Inst. C. E.," vol. 62, p. 202.
M. Meyer, " " " p. 224.
Dr. Michaelis, " " " p. 233.
J. A. Spoor, " Engineering," 14th August, 1885, p. 145.

† J. A. Spoor, " Engineering," 14th August, 1885, p. 145.

100 grammes. Fill the burette with the best quality of turpentine or coal oil to the 100 c.c. mark, then draw off into the flask, say, 60 c.c., after which, through a funnel, deposit the cement in the flask, which fill from the burette until the fluid reaches the mark on the neck; read off by means of the graduated scale the quantity of fluid left in the burette, and dividing 100 by that quantity, the result is the specific gravity. For example, the burette shows that 67.5 c.c. were required to fill the flask to the mark on its neck; then 100—67.5=32.5 c.c., the quantity remaining in the burette, and 100 ÷ 32.5=3.077, the specific gravity required. Of course this is only a rough-and-ready way of determining specific gravity, but with care and practice, results approaching correctness can be obtained. An apparatus known as Schumann's gives good results, but the process is somewhat tedious, and there is always a chance of breaking the joint between the graduated stem and the flask, in which case the test becomes useless.

WEIGHT PER CUBIC FOOT.

As previouly stated, the weight of a certain measure of cement cannot be taken as an index of the results to be obtained from its use, but the purpose of this sub-test is to determine the average weight for calculating and estimating cost, as will be referred to hereafter.

FINENESS.

In Germany a code of regulations exists under which cement must be manufactured, and for fineness of grinding it is stipulated that the residue left in a sieve of 5806 inches per square inch must not exceed 20 per cent., and, as previously stated, it is ground so fine that the residue does not exceed 10 per cent. In England no standard exists, and as a consequence the cement is coarser, the objection to fine grinding being the extra expense, which competition will not warrant. If a finely ground cement is offered, its fineness is dependent upon two things: (1) that it is a good article and well ground; or (2) that the article has been "over-clayed" and lightly burnt. A quotation is applicable here*: "Lightly burnt cement at 7 or even 28 days may appear to be superior to the heavy, which is with difficulty gound as fine as the lightly burnt; but in the long turn, the heavy, if not coarsely ground, will surpass the lighter article; and if the heavily burnt were as finely ground as the light, it would be a great deal stronger from the beginning, the time of setting being the same. Fine cement, as it takes more sand, goes further than the coarse, and it is also much safer where it verges on the blowing point from an excess of lime. By whatever process fineness is secured, the effective quality of the cement is improved, but the coarse, and generally the stronger, part should be re-ground and mixed with the finer. Heavy clinker ground fine will, when tested, give higher results than lighter cement of equal fineness obtained by sifting. The difference in strength of coarse and fine cements is not ascertained by testirg them neat, for of the two the coarser would generally appear to be the stronger, and it is only when mixed with sand that this can be seen."

For concrete, as for mortars, cement cannot be ground too fine, and as cement should be sold by weight, and not by the barrel (which last in the English market is an uncertain quantity), it is by weight combined with fineness and testile strength when mixed with sand, that the relative economical value of different cements can be obtained.

TENSILE STRENGTH.

Anomalous as it may seem, Portland cement, except in rare cases, or under very exceptional circumstances, is not used neat, and yet heretofore all tests to ascertain its strength have been made with blocks, specially prepared from neat cement alone. Happily a change has taken place, and the German system now obtains of making the blocks (briquettes) out of a mixture of cement and (normal) sand, in the pro-

* Grant, "Proc. Inst. C.E.," Vol. 62.

portion of one part of the former to three parts of the latter, thus approximating the resulting mass to the mortar actually used on works. English manufacturers and English engineers did not at first take kindly to this radical departure from the old groove, but it has been accepted, and, it may be said, with advantage to the user. When cement is mixed with sand its strength is reduced, or, in other words, neat cement is stronger than any mixture that can be made with sand, and therefore, to comply with a standard fixed as the tensile strength of a mixture of one of cement and three of sand, the cement must be of a high quality.

Formerly for testing the strength of cement the briquette was, at its smallest part, $1\frac{1}{2}$ inches square, or $2\frac{1}{4}$ square inches in area. Of late years the shape of the briquette has been changed, the smallest part being 1 inch square, or 1 square inch in area, thus facilitating the manufacture and testing of a greater number of briquettes during a day, and the use of smaller and more easily operated testing apparatus and appliances.

In the preparation of briquettes, all are agreed that whether of neat cement or of an admixture of cement and sand, only a certain percentage of water, say 20 per cent. by weight for neat cement, and 10 per cent. for sand and cement—is required; and that the mixture should be pressed solidly into the moulds. Apparatus has been devised and used in the Engineering Department of the State University of Iowa, U. S.,* for making briquettes in which the pressure exerted on the compound is placed at 150 lbs., and it is claimed that the briquettes made in it give more *even results* on being tested.

An excess of water weakens both cement mortar and concrete, and no more should be used than is necessary to work up either into a plastic mass and make it fit for use; more than the proper quantity produces porousness, and retards the process of setting and hardening.

Relative to the making of briquettes, the following has been freely condensed from a paper by the late John Grant, to be found in Proc. Inst. C. E., Vol. 62, p. 122.

To make 10 briquettes of 1 inch square section for a "neat" test, 3.2 lbs. of cement are required; for a "sand test," 1 lb. of cement and 3 lbs. of sand must be provided. With newly ground and quick setting cements it is important to ascertain if they are fit for immediate use, in which case *two* cakes of neat cement, 2 or 3 inches in diameter, and about $\frac{1}{2}$ inch thick, with thin edges, should be made, and the time noted in minutes in which they set sufficiently to resist the impression of the finger-nail. One of these cakes, when hard enough, should be placed in water, and examined daily to see if it shows any tendency to "fly" by cracks of the slightest kind beginning, and being widest at the edges. With slow setting cements, however, cracks on the surface, beginning at the centre, are merely the result of the surface drying too rapidly upon exposure to a draught or to external heat. The second cake should be kept in air and its colour and behaviour noted.

The sand to be used should be washed and dried, and only that portion which will pass through a sieve of 20 and be caught on a sieve of 30 meshes to the lineal inch should be used. For briquettes of 3 of sand and 1 of cement, 10 per cent. of the weight of the united cement and sand will serve, but when of neat cement, then, as previously stated, the water should be increased to 20 or 25 per cent. Sufficient water must, however, be used to make a stiff paste and nothing more. A number of pieces of wet blotting-paper, a little larger than the mould, may be laid on the slate, marble or glass bench, and a mould placed on each. The moulds are then filled......the mortar being beaten till all the air has been driven out and has become elastic, the surplus being cut off and the surface left smooth. Dr. Michaëlis of Berlin recommends what is known as the gypsum-plate process, which, however, is not adapted for very quick-setting cements nor for briquettes made with a mixture of sand. The cement is mixed with from 30 to 35 per cent.

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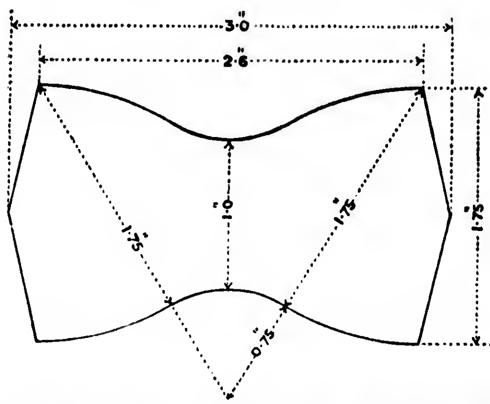
*Pop. Science Monthly, March, 1891.

water, and poured into moulds resting on sheets of wet blotting-paper laid upon plates of plaster of Paris, the moulds being tapped or shaken. About 50 per cent. of the water is quickly absorbed, and if necessary more cement is added, and the surface having been smoothed with a trowel or knife, the briquettes are dexterously dropped out of the mould. This process is a very quick one, and Dr. Michaelis claims for it that it leaves only the amount of water which is required by the cement for setting properly, and that greater uniformity is attained than by any other process. The briquettes can thus be made denser, taking more cement, and breaking frequently under a strain about 50 per cent. higher, or even more. Mr. Grant, however, questioned this, as he had not succeeded in getting more uniformity from briquettes prepared in the manner described than from those made according to his own process.

When the moulds have been filled, the briquettes are numbered, covered with damp cloths, and set aside till they have set sufficiently to be removed from the moulds; after which they remain, still covered with the damp cloths, in the air, for 24 hours from the time of making, and are then placed in water tanks, there to remain, the temperature of the room ranging from 60° to 70° Fahr., until required for testing.

The form of the test briquette approved by the American Society of Civil Engineers, and adopted in all standard cement tests, is shown as follows:



For breaking this briquette there are many machines in existence, and each maker claims superiority for his machine over all others, but there is one uncertainty about them all that no two or more of them using the same make of briquette give the same result—all differ; and as there is not a standard to which reference can be made, it only remains for the purchaser to choose for himself and select what he considers to be the best machine.

The first testing machine was made by Patrick Adie of London, England, and for many years it remained the only machine, but as time advanced it was considered that the briquette used with it, with its minimum area of 2.25 square-inches, was too large; and as the results obtained had, for the sake of comparison, to be reduced to the standard of one square-inch, the shape was modified and the size reduced to give a minimum area of one square-inch, and this led to the introduction of small, compact machines, in which the traveling weight and the long graduated bar of the Adie machine was replaced by compound levers, and the gradual increase of strain obtained by means of the flow of water or fine shot into receptacles, or by the use of a worm wheel raising a heavily weighted lever, or by a screw acting in conjunction with a spring balance, etc.; and yet in all of these there was a cause for complaint, viz., the clamps in which the briquettes are placed and through which the strain is transmitted; for though theoretically the briquette is supposed to break in the middle, where its area is a minimum, in practice only a percentage do so, the cause being traced to (1) the shape of the clamps where they grip the briquette, or (2) the strain not being transmitted in a direct line. It is not purposed to discuss the merits of the testing machines in use, or what is the proper sort of clamps to employ, to do so would require an intimate acquaintance with each machine and the results obtained by it, results which could not be compared with any degree of satisfaction with the results of other machines. For instance, it is claimed by H. Faija, Ass. M. Inst. C. E. (Vide Proc. Inst. C. E., vol. 75, p. 216) that the strain on the briquette should be applied at an even and regular speed, and he suggests that the standard speed should be 100 lbs. applied in 15 seconds, or a little slower, and certainly not slower than 100 lbs. in 30 seconds, *on account of the length of time which a test would occupy*, as if the saving of a few seconds of time is of more importance than the determination of the correct tensile strength of the cement under examination.

The following table has been extracted from Mr. Faija's paper, for the purpose of showing that the *speed* with which weight is applied is an important factor, and that it is possible to obtain results from the same sample of cement which are totally at variance with each other and, it may be said, are not trustworthy.

"Summary of Results of Experiments to determine the difference obtained by applying the weight to the briquette, when testing for Tensile Strength at different speeds:—

Number of Briquettes.	Speed	Average Result.
	lbs. secs.	lbs.
129	100 in 1	560.75
129	100 " 15	506.43
145	100 " 15	452.20
145	100 " 30	430.96
90	100 " 30	417.27
90	100 " 60	403.05
40	100 " 60	416.75
40	100 " 120	400.87

From the foregoing results it will be seen that the increase per cent. due to increased speed of applying the strain is as follows:—

Taking the lowest speed of 100 lbs. in 120 seconds as a starting point, by applying the strain at the rate of—

100 lbs. in 60 seconds, the increase is 3.960 per cent.
" " 30 " " 7.488 "
" " 15 " " 12.416 "
" " 1 " " 23.142 "

It is plain to see from the above statement that it is possible to give a fictitious strength value to a cement, and at the same time to justify the mode by which it was obtained, hence the speed with which weight should be applied should be a fixed factor.

The question, what is the standard tensile strength of Portland cement in Canada? remains unanswered, and each engineer, following the practice of his English brother and American cousin as well, is left free to fix, in his specifications, the minimum strength per square inch he requires. To show the want of uniformity on this point, the following statements are taken from "Proc. Inst. C.E., vol. 62, p. 216." It was highly desirable that engineers' and architects' specifications should be more uniform.........The vagueness and the curious variety of divergence which characterised them (the specifications) were remarkable.........and it was difficult to imagine that this state of things could be allowed to continue much longer, displaying as it did a backwardness on the part of those concerned, in comparison with German engineers, who had been so much later in entering the field, and who, from being disciples, now appeared as teachers and examples. The evidence of this was furnished by published rules, adopted by the Society of Architects of Berlin, the Society of Builders of Berlin, the German Society for the manufacture of bricks, earthenware, lime and cement, and the Society of German cement manufacturers.

In 21 specifications examined there were 13 varieties of test for fineness, 10 varieties for weight per bushel, and 13 varieties for tensile breaking strain 7 days after gauging, the weights varying from 200 to 444 lbs. per square inch, or in all 37 variations in tests."

In fixing a standard of weight per square inch as the minimum test strain, there are several things to be considered and determined, viz :—

1. Whether the test shall be with neat cement; or
2. With a mixture of sand and cement; if so
3. The proportions of sand to cement to be x to 1; and
4. The cement to be fine enough to pass through a sieve of x meshes per square inch, leaving a residue not exceeding x per cent by weight;
5. The sand to be of a standard quality (which requires defining), or to be such as is generally used;
6. The quantity of water to be used in mixing to be x per cent. of the weight of the cement, or of the mixture of sand and cement;
7. Test briquettes to be made of a standard form (to be defined) in a stated temperature;
8. The briquettes to remain one day in air, covered with a damp cloth, and 7, or 28, or x days in water, kept at x° Fahr.;
9. In testing, to use —'s machine, and to stipulate:
10. That the strain shall be applied at the rate of x lbs. in x seconds; and
11. To fix the number of briquettes which must be broken to obtain an average of the strain exerted.

So much for uniformity which is not obtained in Canada, for there will be as many variations in the results obtained as there are variations in the materials employed, the manner adopted in making the briquettes, and in the testing machines used, for no two of the latter using the same make of briquette will give the same results, and in fact very variable results are obtained from the same machine. As an illustration of this, the following has been taken from a pamphlet* on Portland Cement.

COMPARATIVE TESTS OF THE SAME CEMENT.

Tensile Strength per square inch, obtained by					
A. Southam.	H. Faija.	Gordon & Co.	Eastwood (1)	Eastwood (2).	Gibbs.
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
290	*389	466	† 372	† 570	525

* Broken at the rate of 100 lbs. in 15 seconds.
† Made up by the same gauger.

COMPRESSIVE STRENGTH.

Neat cement is but rarely used where it is subjected to compression, and cubes one inch square crush under weights which vary with the nature of the cement of which they are composed, their age, and the mode of applying the stress; and roughly it may be taken as varying from 7 to 10 times the tensile strength of the sample tested.

The compressive strength of concrete will vary with the nature and proportions of the materials used in its manufacture. The following table is extracted from "Proc. Inst. C.E., Vol. 32, p. 297, to show the difference in strength due to the nature of the materials used, as all the blocks were made in the proportion of 6 to 1, and were 12 inches square, one-half of the number made being kept for 12 months in the air, and the remainder the same length of time in water, prior to testing.

* "Some Information on Portland Cement," Howard Fleming, N.Y.

1 part of cement to 6 parts of sand.	Weig't per cu. ft.	Weight of Materials.			Weight of Blocks.		Crushed at			
		Ce-ment.	Ag're-gates.	Wa-ter.	In water.	In air.	Blocks in air.		Bl'ks in water	
							tons.	lbs.	tons.	lbs.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	p.sq.ft.	per sq. in.	per sq. ft	per sq. in.
Sand and gravel.......	96.4	18.08	122.48	8.00	150.0	141.6	80.5	1408	91.0	1416
Cubes of Portland stone	......	19.20	102.40	11.60	140.5	127.8	118.0	1835	138.5	2148
" " granite..	90.6	18.48	116.48	10.40	147.5	143.5	113 2	1760	96.5	1501
Broken pottery........	88.3	17.28	106.64	14.00	139.5	129.0	109.2	1699	136.5	2123
" slag...........	83.6	16.88	98.32	12.80	131.5	122.5	110.5	1719	111.0	1725
" flints......	98.4	16.24	111.28	11.60	141.3	131.9	116.0	1804	126.0	1960
" glass....	93.75	18.96	124.08	10.40	155.5	147.7	99.0	1540	112.5	1750

ADHESIVE STRENGTH.

It is claimed by some writers* that the testing of briquettes made of x parts of sand to 1 part of cement for tensile strength is really a test of the adhesive strength of the cement used, for sand not having any adhesive strength in itself, it follows that the (tensile) strength of the briquette must lie in the force with which the cement adheres to and binds the grains of sand together, and converts loose and disconnected materials into a solid and coherent mass.

In a paper published in the "Proc. Inst. C. E.," Vol. 71, p. 251, Mr. T. J. Mann states that the principal test adopted by him is one of "adhesion," which has given him, after some years of use, satisfactory results, and he explains the mode adopted and the apparatus used to obtain them; but his advice apparently has not been adopted, engineers and others resting content with the results obtained from tensile tests.

In determining the stress of adhesion, much depends upon the fineness of the cement, for the finer it is ground the fewer the coarser particles which are not any better than sand. To show this, a table has been copied from Mr. Mann's paper.

EFFECT OF COARSE PARTICLES ON THE CEMENTITIOUS ADHESIVE STRENGTH.

"Age of samples, twenty-eight days."

Percentage of coarse particles.	0 fine only.	20	40	80	100 coarse only.
Average adhesive strength in lbs. per square inch.........	101	84	57	34	18

Percentage of coarse in the unsifted cement, 49. Cohesive strength of the sifted after 7 days, 430 lbs. per square inch. Number of tests 20, plates, sawn limestone.

*T. Mann, "Proc. Inst. C. E.," Vol. 71, p. 251.

It must be stated that Mr. Mann used a sieve of 176 meshes per linear inch, or 30,976 meshes per square inch, which is simply too fine for practical use, however well it may answer for experimental tests.

No standard can be fixed for adhesive strength, as a variation must take place with the quality of the cement used and the proportion of sand employed ; and its determination is only necessary in the case of walls or structures resisting lateral pressure, and even then no fixed rule can be applied, for the strength of any joint against sliding must, at the very least, be equal to the adhesive strength of the mortar joint, plus the weight of the mass above the joint in the terms of the co-efficient of friction.

2. COMPONENTS.

By the term *components* is to be understood the materials used with cement in the manufacture of concrete, and they generally consist of gravel, broken stone, bricks and sand, all of which should be clean and sound in texture. Gravel from the pit or from the sea-shore should be screened through ⅜ inch screens, to remove the sand and small pebbles, the residue consisting of stones not more than two and a half inches in their greatest diameter. Where pit-gravel contains earthy matter, it must be washed as well as screened, in which case the resulting sand should not be used unless again washed. Gravel (shingle) from a sea-beach is generally clean, especially when found *dry*, but it has happened that a poor quality of concrete has been made with it, where the pebbles have been coated with a slimy deposit, due to the evaporation of the sea-water, which prevents the adhesion of the cement.

The best material for concrete is a compact stone broken into cubes or pieces to pass through a two and a half inch ring, a material with which all are acquainted, and can be obtained in almost any locality.

Sand is a necessary component in concrete, and should never be omitted, but it must be sharp and clean and entirely free from earthy particles, and coarse enough to pass through a twenty mesh, and be retained on a thirty mesh sieve. If dirty, it should be thoroughly washed before using, and if soft and fine it should be rejected.

3. MIXING.

Where a solid and impervious mass of concrete is required, the components selected must be mixed in certain proportions. Specifications generally read that the concrete required shall consist of so many parts of broken stone, or gravel, to one part of cement, or so many parts of broken stone, or gravel, and so many parts of sand to one part of cement. In these the word "parts" is an indefinite term, and may mean a cubic foot, or a bushel, or a fixed weight per unit, or even a barrel or a wheel-barrow load.

It is asserted that in proportioning the amount of cement to stone, a given weight rather than a given bulk should be used, bulk being affected by the weight and degree of fineness, as a cement of eighty lbs. per cubic foot will be larger in bulk than one of ninety lbs., but the system of using a cubic foot as the unit of measure is certainly the most convenient and gives equally as good results.

Assuming a cement weighing 85 lbs. per cubic foot, and a mixture of broken stone and sand weighing 2835 lbs. per cubic yard, or 27 cubic feet, then :—

Number of cubic feet of		Will be equal to	
Cement.	Stone.	By bulk.	By Weight.
3.00	27.0	1 to 9	1 to 11.12
3.37	"	1 to 8	1 to 9.89
3.86	"	1 to 7	1 to 8.64
4.50	"	1 to 6	1 to 7.41
5.40	"	1 to 5	1 to 6.15
6.75	"	1 to 4	1 to 4.94

For solid concrete, there are two proportions in the materials used which should be determined:—

(1) The voids in the gravel or stone, and the quantity of sand to fill them; and

(2) The voids in the sand, and the amount of cement to fill them.

Taking stone broken into pieces which will pass through a two and a half inch ring, and be stopped by one 2 inches in diameter, the *solids* will average about 52 per cent., and the *voids* 48 per cent.

The voids in dry sharp silicious sand will average about 40 per cent.; but where the sand is compressed in water, its volume can be reduced 12½ per cent.

When dry sand and cement are mixed together, contraction takes place, and in one of sand and one of cement it amounts to 16.66 per cent. of the original volume, in two to one the contraction is 15 per cent., and in three to one 13.81 per cent. When mixed with water, further contraction to the extent of 10 per cent. takes place, and, according to Sandeman, "Proc. Inst. C. E.," Vol. 54, p. 251, the ratio of contraction of dry materials is 34.43 per cent.

Adopting this percentage, to produce one cubic foot of *set* concrete would require 1.525 cubic feet of *dry* materials, and one cubic yard will require 27 × 1.525=41.175 cubic feet.

Assuming that an impermeable Portland cement concrete is required, experience has shown that such can be made by using one part of cement, two and one half parts of clean, sharp, silicious sand, and five and one-half parts of sound compact stone, broken into cubes averaging from two to two and one-half inches square. The quantities of each material required to make one cubic yard of concrete *set* in place can be determined as follows:

A *part* will be equal to 27 ÷ 5.5=4.909 cubic feet.

Cement = 4.909 × 1		= 4.91	cubic	feet.
Sand = " × 2.5		= 12.27	"	"
Stone = " × 5.5		= 27.00	"	"
	Total	44.18	"	"

The contraction or shrinkage will therefore be = 44.18—27.00, or 17.18 cubic feet = 38.88 per cent., and the results will be as 61.12 to 100, or it will take 1.636 cubic yards of materials to make one cubic yard of concrete *set* in place.

The composition of this assumed "cubic yard of concrete" is as follows:—

4.91 cu. ft. of cement	× 85 lbs	= 417.35 lbs.	= 10.72	per cent.
12.27 " sand	× 85 "	= 1042.95 "	= 26.80	"
27.00 " stone	× 90 "	= 2430.00 "	= 62.48	"

or, it is composed of 10.72 + 26.80 =37.52 per cent. of mortar and 62.48 per cent. of stone.

That the amount of materials provided for mortar is sufficient to fill the voids in the stone is determined thus:—

	c. ft.	c. ft.	c. ft.
Voids in the stone = 27 × 0.48			= 12.96
4.91 of cement and 12.27 of sand		= 17.18	
Shrinkage on admixture dry 17.18 × 0.85 = 14.60			
Further shrinkage or admixture wet 14.60 × 0.90			= 13.14
Excess of mortar			= 0.18

Or the excess of mortar may be determined in another manner:—

	c. ft.	c. ft.
Total quantity of cement—dry measure	= 4.91	
Reduction by wetting = 15 per cent.	= 0.74	
Net quantity		4.17
Total quantity of sand—dry measure	= 12.27	
Reduction for voids = 25 per cent.	= 3.07	
Net quantity		9.20
Total net quantity of mortar		= 13.37
Voids in stone = 27.00 x 48 per cent.		= 12.96
Excess of mortar		= 0.41

Assuming that 5,000 cubic yards of concrete of the foregoing proportions are required, then the quantities of the components to be procured will be as follows—a barrel being taken to contain 370 lbs. of cement:

	lbs.	lbs.	
CEMENT.	417.35 x 5000 =	2,086,750	
	Add for waste, etc., $2\frac{1}{2}$ per cent. =	52,150	
	Total =	2,138,900	= 5,780 bbls.
	c. ft.	c. ft.	
SAND.	12.27 x 5000 =	61,350	
	Add for waste, etc., 5 per cent. =	3,067	
	Total =	64,417	= 3,068 c.y.
STONE.	27.00 x 5000 =	135,000	
	Add for waste, etc., 5 per cent. =	6,750	
	Total =	141,750	= 5,250 c.y.

Given good materials and poor mixing, the result will be poor concrete, and therefore too much care cannot be taken with this operation, whether it be done by hand or machine. Poor results are due to: (1) improperly gauging the materials; or (2) to an excess of water; or (3) an insufficiency of labour in mixing the materials, either dry or wet, or both; or (4) the want of a proper mixing platform.

For the manufacture of concrete by hand, a platform is absolutely necessary, for concrete should never be mixed on the ground. If 3-inch deals are used, then a width of 15 feet will be sufficient, the length being dependent upon the number of times the components are turned over dry and wet; for, with some, to have them turned over twice dry and twice wet is held to be sufficient, whilst others maintain that they should be turned over thrice dry and thrice wet.

Each component should be accurately and uniformly measured, and boxes holding the specified amounts of cement, sand and stone should be provided. Assuming a concrete of the proportions hereinbefore stated, and that it is to be mixed in "batches" of one-half of a cubic yard each, then it will be necessary to provide. (1) a bottomless box, 2ft. 10ins. square at the top, 3ft. 2ins. square at the bottom, and 1ft. 6ins. deep, a board on two sides projecting, say, 15 or 18 inches, and trimmed as handles; (2) a box with a bottom to contain 3 cubic feet; and (3) another box to contain $1\frac{1}{4}$ cubic feet.

For use, the first, or stone-box, is placed at the end and to one side of the platform. and is filled to *one-half* its depth with broken stone; on this is placed and spread one box, or 3 cubic feet of sand, and one box or $1\frac{1}{4}$ cubic feet of cement, after which the stone-box is filled flush with its top with stone, and a second deposit of sand and cement is made, when the stone-box is raised by its handles clear of its contents and placed on the opposite side of the platform in readiness for the next "batch."

As soon as the stone-box is lifted, two men attack the heap and turn it over down the platform, when it is again attacked by a second pair of men, who pass it further down. At this point, supposing that a mixing twice dry and twice wet is all that is required, a third pair of men attack the "batch," but here water is applied through a "rose" from a watering-can, and at such a speed as to ensure the delivery of not less than 11 imperial gallons, or, say, 1¾ cubic feet of water. The "batch" is turned a fourth time by another pair of men, by which time it has reached the lower end of the platform, ready to be taken away to the place of deposit. Then the stone-box having been placed on the opposite side of the platform, the filling with components is proceeded with, and as soon as the first pair of men have turned the "first batch" dry, they at once step over in readiness to operate on the second, and so on with each batch in succession; and with this mode of procedure there cannot be any delay, and the concrete will be evenly and thoroughly made. For a mixing gang—assuming that the materials have been placed in proximity to the platform—one sub-foreman, three men filling stone-box, two men filling sand-box, one man filling cement box, one water-boy, and eight men for turning the "batch," or a total of one sub-foreman, fourteen men, and one boy, are required.

To facilitate operations where the amount of concrete to be mixed is large, the sand-box, which will weigh when filled at least 250 lbs., might be hung in a frame on gudgeons, at such a height as to permit its contents being tipped into the stone-box. For the water, a small tank holding 1¾ cubic ft. might be placed opposite the point on the platform where the *third* turning, or the first time wet, is done, the water being conveyed through a hose tipped with a rose-head and stop-cock, which will ensure the distribution of the proper quantity of water.

There are many kinds of "mixing machines" the inventors of which claim that their particular make is *the* best; and the manner of manipulation differs with each machine. For dealing with the manufacture of large quantities of concrete in one spot, as in the making of huge blocks or monoliths, then a machine can be profitably used, but hand-mixing is preferable where it is desirable to make the concrete as near as possible to the place where it is to be deposited, and frequent removals of the concrete gang have to be made.

4. DEPOSIT.

The depositing of concrete in the place it is to occupy is a subject so large as to demand a lengthy paper for its consideration, as it includes, (1) the place, (2) whether the place is dry or wet, (3) whether in still water or subject to tidal influences, (4) whether in blocks up to x tons in weight, which have to be moved into place by ordinary tackle, or powerful appliances or special plant, (5) whether in a wet or plastic state in bags containing up to x tons, dropped into place in water of varying depths in various localities by special plant, (7) or lowered in small sacks to be placed by divers, or (8) simply dropped from a barrow or flat-skip; the exigencies of each case determining the mode of deposit. The limits of this paper will not admit of any further allusion to the *mode* of deposit, but there is one rule which should always be observed, viz.:—that concrete should *never* be dropped into place from a height, for the simple reason that the heavier parts will separate and fall the soonest, and the resulting mass will be formed of alternate layers of coarse and fine materials, and will not be homogeneous and impermeable.

A difference of opinion exists as to the thickness to which concrete should be deposited to ensure sound work, some holding to a maximum thickness of only 3 inches, and others to that of 18 inches. The first appears to be too thin, and the second may be taken as the maximum depth; and if an average of 12 inches be adopted, very good results will be obtained. Some there are who maintain that to obtain impermeable concrete, it should be punned; against this *dictum* it is asserted, that by punning the coarser parts are settled to the bottom, and the mass loses its homogeneity, and all that is necessary is to work it with the edge of a shovel if a necessity for doing so exists, for when setting commences it is not desirable to disturb the materials.

Where concrete has stood for some time and has set, before work is resumed the surface should be cleaned off,—if under water by means of a water jet, and if in the air by being wetted with water and thoroughly brushed, and covered with a thin layer of grout, or sprinkled with dry cement.

In preparing this paper, the object in view was to treat the subject from a practical standpoint, and to be as concise as possible, and it is offered with the hope that the information, or at least some of the information which it contains, may be of value, and have a beneficial effect.