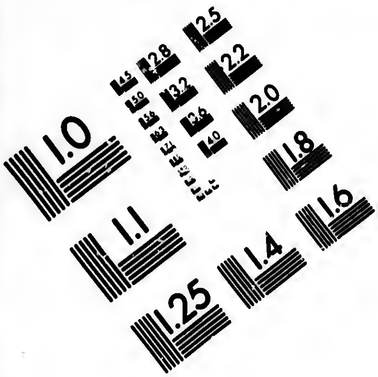

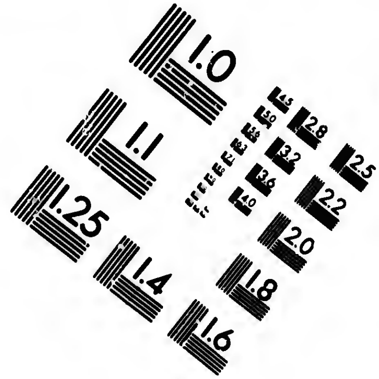

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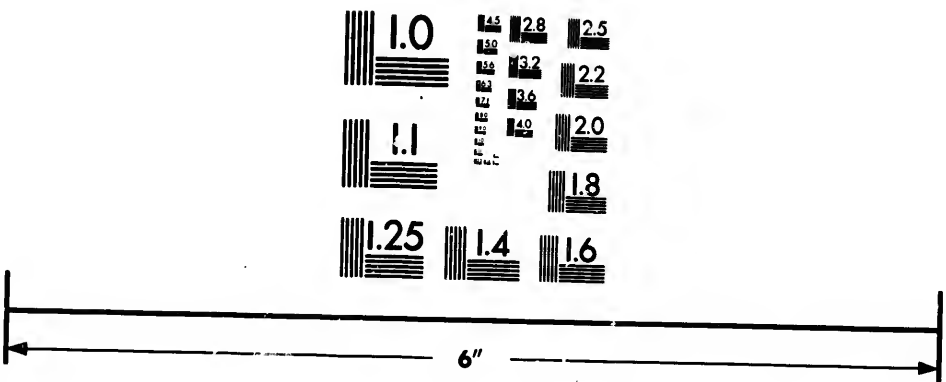

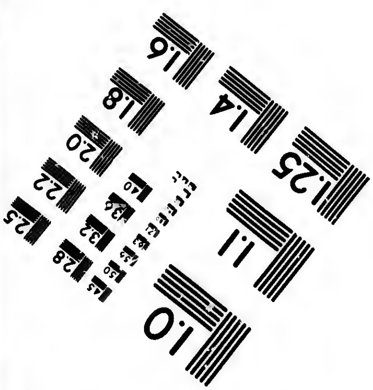

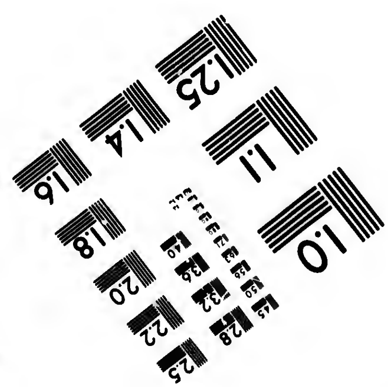

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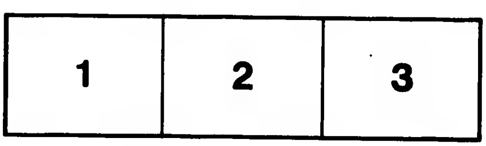

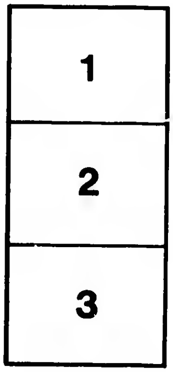

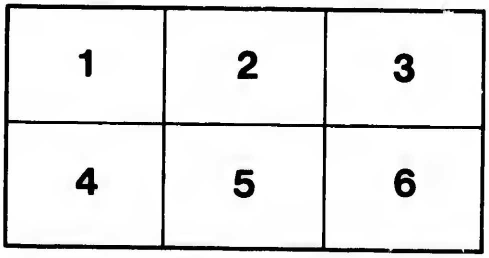

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Canadian Society of Civil Engineers.

INCORPORATED 1887.

TRANSACTIONS.

CONCRETE AS A SUBSTITUTE FOR MASONRY IN BRIDGE WORK.

BY M. MURPHY, M. Can. Soc. C. E

To be read Thursday, February the 23rd.

For the last five years the author has been using concrete as a substitute for masonry, with a fair degree of success. With a few introductory observations, his paper will be confined to remarks on the theory and practice of Portland cement concrete as a building material, and to its employment in the construction of highway bridges, and other works coming within the scope of his own supervision in the Province of Nova Scotia.

In Nova Scotia, as well as in other new countries, the improvised wooden bridges of the early settlers supplied their wants for crossing rivers and streams, and, as at each successive stage of progress their numbers necessarily increased, the desirability of more permanent construction became more and more important. The frequent replacement of these timber structures taxed the Provincial resources to such an extent, that it became urgent to adopt means whereby the annual drain on the revenue for their renewal and maintenance might be lessened.

In 1883, an Act authorizing a Provincial Loan of $506,000 was passed for rebuilding the old wooden bridges where advisable, with materials such as stone and iron. Encouraged by the successful operation and results of this measure, the Government provided two further grants of $250,000 each, in the years 1885 and 1887, respectively, making one million of dollars available towards rebuilding those bridges in a more substantial form. Even with the additional votes of the two years last named, two-thirds of the highway bridges of the whole Province could not be erected in the permanent manner contemplated. Nor was it desirable that they should all be erected of iron superstructure, because there were many instances where wooden structures or cheap pile bridges could subserve more economically and accommodate equally well the public requirements. In positions favorable for solid foundations; in places where rapid currents are spanned; in situations prone to ice-jams, necessitating longer spans; and in saline water where the *teredo navalis* or the *lignoria lignorum* are active, all things else being equal, iron bridges on stone concrete and iron supports were preferred, whilst in locations of an alluvial nature, in peaty or marshy deposits, or in quicksands, or where fresh water streams keep aloof or exclude those destructive agents, and where artificial foundations would be necessary, but too expensive, wooden structures or cheap pile bridges or other bridges of wood suited to the situation were adopted.

In carrying out the public works in any country, it is desirable as far as possible, to use the material of the district, and though Nova Scotia can furnish both free stone and granite of excellent quality, it cannot furnish either of them, in the majority of instances with the means at the disposal of the engineer. If stone suitable for masonry could be had so that the work could be performed for eight or nine dollars per cubic yard, that material was invariably used; if it could not, concrete was substituted.

In the construction of these highway or public road bridges, concrete has borne an important part. It was at first—in 1883—employed sparingly and with hesitation, but of late it has been used largely and with much confidence. Its use, for the support of the superstructure of iron bridges, was prompted by necessity, because of the scarcity of materials suited for ashlar masonry, the cost of transportation, the want of skilled workmen, and the rapidity with which it could be erected with ordinary labor.

This leads to the more immediate object of this paper, which is to introduce to the notice of the Society what has been done in Nova Scotia towards the substitution of concrete for masonry, and the results so far observable.

The introduction of concrete was at first treated as an expensive innovation. It was not expected to receive favorable public consideration, and it did not. It was alleged that in the climate of Nova Scotia it was an impracticable intrusion and would not suit its intended purpose, and although it could not be said to be an experiment, because it had been used so largely in other countries, still it was commented upon with disfavor. Nevertheless, concrete piers have been erected in the most exposed positions, in the midst of strong currents, without any external coating of wood or stone, where they are exposed to ice-floes, to blows from timber-drives, and in some instances, to undermining by scour, with comparatively favorable results. Exposure to sudden alternations of temperature has so far produced no visible damaging effect. Violent blows strike more impotently than upon masonry, and it is not so liable to fragmentary slips or segregations because of its monolithic character.

Out of forty-four iron bridges, with spans varying from 50 to 160 feet, supported by concrete piers thus exposed, there are three piers showing marks of abrasion, but not to such extent as to need repair. Two of these defects are traceable to faulty workmanship and poor material. The third one, however, exhibits unmistakable symptoms of disintegration, and requires special notice. It will be referred to further on.

The abutments and piers were erected within a skeleton frame work closely boarded against the face as the work proceeded upwards. They were built of Portland cement rubble concrete faced with Portland cement fine concrete. The facing of fine concrete was generally six inches in thickness, but varied to a width of nine inches in rapid currents or where liable to more severity than is due to ordinary exposure. The Portland cement rubble concrete was composed of one part of gravel or small stones not exceeding one inch in diameter, five parts of large stones, weighing 20 lbs. and upwards, two parts of sand, and one part of Portland cement. In mixing the concrete, the gravel, sand, and cement were turned over three times whilst dry. Water was then added and the material again turned over at least three times and well agglomerated before being placed in the work. The gravel, sand, and Portland cement for the fine concrete were first mixed to form a matrix or body of concrete, and the large stones of the rubble concrete were placed therein by hand. These stones were placed end upwards, two inches apart, and the spaces between them grouted up solid with the matrix to form a compact mass, and any holes or cavities in the work were run full and flush with Portland cement compo, consisting of two parts of sand and one of cement. The fine concrete facing was kept at least six inches higher than the rubble concrete, and united with it so as to form one homogenous mass. In every instance the top of the pier or abutment was finished with fine concrete for a depth of one foot six inches, and the shoes of the iron truss posts were laid thereon without the usual bridge seats of stone.

The width of piers at top finish varied from three feet to four feet six inches, according to the superincumbent weight they had to bear. In piers of twenty feet in height the hardening or "set" was sufficiently rapid to allow six laborers working on each pier to proceed to completion without intermission, the progress being from two to three cubic yards per man per day.

The concrete work for the last three years has been executed by the Government's own engineers and workmen, without the intervention of contractors, a system which, however inapplicable in some countries, has been found to answer well in Nova Scotia. Upon the proper composition and incorporation of the ingredients which enter into the concrete, and which are mixed up and set with the rubble stone in the work, will depend the requisite adhesion and stability, and although reliable contractors were always available, still it was considered more advisable to carry out the work by men working by the day and trained under proper supervision until they become sufficiently skilful and as interested as the engineer in the success of the undertaking.

A 160 feet span, 15 feet roadway, loaded 80 lbs. per square foot, ½ weight of bridge and load =76000 lbs. Taking this weight distributed over an area of three feet square by the bed plates, and the cohesion of the cement itself, we should have a weight supported equal to about 51 pounds to the square inch, or quite within the margin of safety even for comparatively freshly set concrete. Since an abutment, to fail only by reason of a direct pressure from the weight of the bridge, could only do so by the crushing of the particles of cement together, and since this crushing could not take place without first rupturing the face of abutment at its point of least resistance, we may take this point as a measure of our bearing capacity, that is, take the distance from centre of pressure to nearest face of abutment as one half of our available width and this width squared as our bearing area. For a bridge of this size the width thus found would not be less than four feet, and the distributed weight would be 34 lbs. per square inch on the walls, which are battered 1 in 6 or 1 in 8.

The use of concrete for over ground work in Nova Scotia commenced with the filling in of the voids in crib-work abutments constructed of closed faced timber work. It was next employed *en masse* for abutments and bridge piers that stood divested of all outer shield or covering; also for retaining walls exposed in like manner, and later for the building of arched bridges. Examples of abutments and piers of concrete work can now be seen in every county in the Province. The retaining wall is built with alternating arched panels and buttresses. It stands in front of the Provincial Building in the city of Halifax. An arched concrete bridge of two small spans of fourteen feet each, is built from the shingle sand of the sea beach at Cow Bay, near Halifax, and there is an oblique arch of 30 feet span at Acadia Mines, Londonderry. The author is aware that these are small examples to refer to, still it should be considered that the aim of the paper is merely to bring to the notice of the Society how exposed surfaces of concrete have so far withstood the climate, and to what extent concrete may be relied upon as a substitute for masonry.

The concrete work forming the arches was built in courses radiating same as dressed stone in courses for arch work, so as to prevent any horizontal tendency to set flakey as the work went on. Each course was moulded on the lagging of centers, by securing theron a board in the true radial line between soffit and extrados, and the concrete was placed therein in its final position to form the course. When sufficiently set the board was removed and placed again for the next succeeding course. A setting templet, the same as masons make use of when laying voussoirs or arch stones on centres, gave readily the inclination of the board. The foreman in charge was cautioned not to allow any course to be partially filled up and allowed to set before the whole was completed. In this way each course was expected to have the same consistence throughout. The concrete used in the arches was of the same admixture as described in this paper as "fine concrete." The writer, however, considers that rubble concrete can be made use of for arched work as advantageously and far more cheaply, if the rough stone concrete and grout are conformably and proportionately equalized and adjusted.

The symptom of failure in the piers of one bridge already referred to, occurs in a tidal stream at Petite Rivière, in Lunenburg County. Two piers of concrete support an iron bridge of 100 feet span. At low tide there is not more than one foot of water. Ordinary neap tides rise five feet, springs generally about six and one half feet. The outer shell or matrix of fine concrete, where exposed to the tidal fluctuations, exhibits fissility, and will crumble at a slight blow. Above high tide it is solid and impervious. Two fragments cut from pier above and below tide are exhibited for examination. The bridge was erected in the summer of 1885, about eighteen months ago. Although erected by a careful foreman and with the usual component parts of material for submerged work, viz., two of gravel, one of sand, and one of cement, it never attained the same degree of coherence as other work of the same character, and it has now become so friable as to point to the necessity of renewal at no very distant day. The concrete work in fresh water streams, as well as in salt and brackish water, had already given such evidence of permanancy that one was loath to acknowledge a failure, or with M. Vicat, ascribe the result to the presence of magnesia in the sea water, which acts injuriously on the lime. In this instance the failure cannot be attributed to carelessness in the selection and admixture of the concrete ingredients employed in building, because the disintegration and brittleness extend upwards only as far as the tides reach. Above that level it is compact and firm. There is no sulphur or sulphate of lime in the neighborhood. The gravel and sand are from the slates and quartzites of the Lower Siluvian or Cambrian formation, the auriferous rocks of Nova Scotia.

Now Portland cement being a mixture of chalk and clay, which is supposed to be burned to the extent of driving off the carbonic acid thus becoming a hydraulic lime, nevertheless through imperfect calcination may not form a cement which would resist the action of salt water, although it might succeed well enough in fresh water. Again, if there was any sulphate of lime in the clay it would not at once enter into combination with the lime, and would be likely to cause the disintegration experienced at Petite Rivière.

If the material from which the Portland cement is made was under burnt or imperfectly decarbonated, and contained an excess of free or disengaged lime, which, not being united with the silica and alumina, would absorb moisture largely, and would fall to pieces in water; in this case, says Mr. G. F. White, the silicate of lime and alumina had not been formed, and the result would be an incomplete cement characterized by a light yellow color, moderate specific gravity, immediate setting, and imperfect induration.

Three briquettes of the cement employed at Petite Rivière bridge, after seven days' setting gave a tensile test of 329½, 358, and 396 lbs. respectively to the square inch. The color and gravity were not noted at the time. The cement was quite fresh.

Portland cement is not always uniform; its manufacture requires much care; it is not free from risk, though its employment both in fresh and sea water, above and below water, is generally satisfactory. There have been no visible signs of expansion and increase of bulk, or unusual contraction, which is presumably owing to careful manipulation and having been used in small quantities.

The author has employed the Medina cement, made by Messrs. Francis, of London, in pointing and repairing the sea walls retaining the embankment at Bray Head, on the Dublin, Wicklow and Wexford Railway, and the sea walls of the Dublin and Kingstown Railway, when resident engineer on those lines of railway, with a greater degree of success than when Portland cement was employed. The rapid setting of the natural cement proved more advantageous, up to the level of high water, than the too slowly setting Portland or artificial cement, during the operation of tide work. It was considered better to employ both, the natural cement for pointing and lipping up to ordinary high water, and the artificial cement from that point upwards, and the result seemed to justify the practice. When the exposed surface of the base of the piers of Petite Rivière bridge becomes more abraded, or when renewal is necessary, it is contemplated to submit the Medina to a similar test beside the Portland.

There is at present an iron bridge under construction to replace the Victoria Bridge, Bear River, consisting of a swing span 160 feet in length, two fixed spans of 125 feet each, and one of 100 feet. The swing span is to revolve on a circular pier 24 feet in diameter, entirely constructed of concrete. Each pier for the fixed spans consists of two wrought iron cylinders five feet each in diameter filled with concrete, coupled together by laced channel beams and lateral bracing, and sheathed between main tubes to prevent lifting or displacement by ice floes. It is, however, the circular or concrete pier that comes more properly within the bounds of these remarks, and to this alone shall reference be made here. There is 18 feet of water at ordinary low tide in the navigable channel; spring tides rise 26 feet. The *Lignoria* are here so active that the bearing power of piles, or of timber submerged below the level of low water, is, where exposed, affected if not destroyed within six years. The supports of the old wooden structure had to be renewed twice within a period of twelve years. The new bridge is being placed immediately above the old one, and if founded on piles similarly unprotected would be no less reliable. The river bed here is characteristic for instability and increasing change caused by the rapid currents of the Bay of Fundy tides on gravel beds and loose deposits, pointing to piles as most desirable. For these reasons, as well as one no less obvious, viz., limited means, it was decided to adopt piles driven at three feet apart centers over the whole base of pier, and protect them with a circular envelope of concrete three feet in thickness. The hexagonal circuit of close piling shewn by figure No. 2, is driven merely as a mould to retain the outer wall of concrete whilst it is being erected. The piles are to be cut at the level of low water spring tides, the intervening spaces between them filled up with small stones, and the usual platform of 12" x 12" timber framed thereon, thus completing the base of the circular pier up to the level of low water. The concrete superstructure from that point upwards to finish is a frustrum of a cone having a solid vertical central pillar 4' x 4 to support the pivot, and four walls 2'-6" each in width radiating therefrom to outer circular wall or periphery, which is 2'-6" wide at top and increases downwards with a batter of 1 in 8. The four voids thus left in the body of the prism have vertical sides to within four feet of the top, where they corbel to an apex and are covered with two feet of fine concrete. The swing span which is to turn on the centres, and is made to revolve on live rollers, will be lifted on its center pivot by the usual screw device or central press, thus relieving the rollers of part of their weight. There will be during the operation of turning 118,596 lbs. superimposed on the four feet square wall or pillar of concrete, or 51½ lbs. to the square inch. Figure No. 2 gives the form and details of this pier. With respect to the three feet wall surrounding the piles under water, it will be filled up with concrete lowered in paper bags, each containing a cubic foot of fine concrete. This mode of placing concrete under water between piles, or within iron tubes where the intervening spaces are small, has been practised in Nova Scotia very successfully. The iron tubes of the Avon bridge, at Windsor, have been filled up to the level of low water in this manner. The bags cost $1.35 per hundred or 36 cents per cubic yard additional for their use. They are made of rough brown paper well stiffened with glucose, which is immediately destroyed by immersion, the residue helping to assist the induration and strength of the concrete, whilst there is very little if any of the cement lost by submergence. Rubble concrete can also with care be placed under water in alternating courses of fine concrete and stone, by lowering the stone so that they would not rest against or upon each other and lowering a course of fine concrete in bags thereon.

An objection may perhaps be raised to the circular pier of Victoria bridge being built of concrete, on the ground that the piers of the Petite Rivière bridge have already exhibited symptoms of failure owing to the action of sea water. It must, however, be admitted that this failure is but one contrasted with many that have proved successful, and, moreover, that within the limits of those phenominal fluctuations characteristic of the Bay of Fundy, concrete has, so far as it has yet been employed, given satisfaction. On the other hand, the author is not aware of any one instance where an ashlar masonry structure, erected within the same tidal influence, is not more or less a failure. The railway bridge that carries the Windsor and Annapolis Railway over the Avon River at Windsor is an instance. The bridge is supported by eight piers and two abutments of freestone ashlar masonry, and consists of nine spans of lattice truss, six of which are 160 ft. each, the other three, or shore spans, being smaller. There is very little water—not more than from two to three feet—in the stream at low water. Neap tides rise about 24 feet, ordinary springs four or five feet higher. The piers of this bridge have been a source of annoyance and expense to the Railway Company. The water penetrates the body of the masonry at high tide, and not being able to escape as fast as the tide recedes, or to escape altogether, a severe frost operating upon it adds at every successive reflux its expansive influence to the already tottering face stones. The result is, that notwithstanding repeated repairs, the piers will have to be altogether taken down and reconstructed. In view of such a tendency to displacement as shewn in this instance, as well as in another similar instance no less prominent, experience would lead one to select the concrete as most advisable to adopt in this particular locality. Owing to its homogenous character it will be more impermeable to water, less susceptible to displacement by frost, and, in this case, more coherent and endurable as a support.

But it may be asked, what is the justification for the employment of concrete at all above ground in lieu of stone. Why, the fact that walls and bridges are produced which perform the service expected of them at a much less expense than masonry, that by the utilization of materials otherwise inoperative, such as the shingle of the beaches and streams, and the boulders encumbering the surface, permanent bridges can be readily built with the assistance of ordinary labor; that by the employment of concrete limited means will yield more desirable results, that evidence exists that such adoption would secure at low cost works of great efficiency, is sufficient to justify the use of concrete as well as the introduction of the subject here. Local conditions largely modify local architecture and requirements. Down here by the sea the Trenton limestone of Montreal cannot be had in adjacent quarries, neither will the necessity of its adoption warrant its introduction. Materials at home must suffice to supply the needs at home. If stone cannot be had, or if it is of too refractory a nature to be made available, brick must take its place, and for the same reason concrete may in many situations be introduced as a substitute for stone as well as brick.

Although the history of rubble concrete dates as far back as the history of architecture, the introduction of Portland cement to the admixture of concrete may be said to be the history of our own times. In England, George Semple in 1774, Dr. Higgins in 1775 to 1779, Smeaton in 1756, and Parker in 1796, by their respective investigations, reduced the practice of concreting gravel with lime to a system. Semple having studied the works of Alberte, who explained the system used by the ancient Romans in building walls in coffer-dams or cases of small materials grouted, proposed to follow the same plan in foundations of bridges. Dr. Higgins' book on mortars gives the effect of earth and metallic oxides on bones and chalk limes, and on concreting gravel with lime for surfaces of roads, etc. Smeaton's work on the Eddystone Lighthouse taught the properties of English limestones and compared them with pozzuolana and tarras, and Parker took out a patent for making cements obtained from certain stones or argillaceous productions or nodules of clay. This stone was termed Sheppystone, from being found near that island. The stones were burnt in kilns and afterwards ground to powder. It was called Roman cement, and was used in preference to Aberthaw, Halling, or Dorking hydraulic limes or cements. This Roman cement was used almost universally until eclipsed by the Portland cement of Messrs. Bazley, White & Co. In France and in Holland the application of béton seems to have been contemporaneous with England, and has been much more extensively practised in the erection of monolithic structures during the present century. The report of the Jury of the Paris International Exhibition of 1855 awarded M. Vicat, a distinguished French Engineer, a "Medal of Honor," and observed that he had devoted himself entirely to the study of the theory of the action of limes with silicious materials, and had successfully demonstrated that France possessed all the elements of the pozzuolanas, and by the simple admixture of calcined or raw clays with lime, artificial cements could be obtained for hydraulic purposes. He discovered nearly three hundred quarries in France whence hydraulic cements could be obtained.

The manufacture of Portland cement, first called artificial cement, is attributed to experiments commenced in 1826 by Major-General Sir Charles Pasley, and continued through a series of years.* It is composed of two simple ingredients, clay and chalk. It is principally manufactured on the Thames and Medway. In white chalk districts the clay forms 25 per cent. to 30 per cent. of the whole bulk, and in grey chalk districts 16 to 23 per cent. Much care is required in the selection of the clay, so that it will be free from sand. These proportions still vary with the character of the lime, and are the result of experience gained in its daily manufacture and use, extending over a period of fifty years.

Messrs. White, of London, were the first to make and introduce this artificial compound as a cement. They, however, dropped the word artificial, and placed it on the market under the name of Portland cement, whether from its resemblance when set to Portland stone, or because the word artificial might be injurious to its introduction, is not generally known.

Up to 1856, the use of Portland cement in Great Britain was comparatively limited, Roman and Medina cements being more extensively adopted, whilst in France and other parts of Europe, Portland cement manufactured in England was steadily gaining favor, having been used extensively for large harbor and dock works. The extensive adoption of this material by the Metropolitan Board of Works, in 1858, in the construction of sewers, drew the attention of Engineers to its value and importance. In December, 1865, Mr. John Grant, M. Inst. C. E., in one of the most able and useful papers that has been written on Portland cement, entitled "Experiments on strength of cement, chiefly in reference to the Portland cement used in the Southern Main Drainage Works"* (London), gave the results of 15,000 experiments made by

* Vide Minutes of Proceedings Inst. C. E., vol. 25

him from 1858 to 1876, whilst Divisional Engineer in charge of that district of the great system of drainage for the metropolis. Since that time almost every engineering text book quotes from Mr. Grant's paper on the strength and properties of Portland cement.

The recapitulation of some of the results and experiments shewn by tables is as follows:—

1. Portland cement has been proved to be suitable for hydraulic works.
2. The longer it is in setting the more the strength increases.
3. Neat cement is stronger than an admixture with sand.
4. Cement mixed with one, two, three, and four parts of sand may be said to be at the end of one year, approximately $\frac{3}{4}$, $\frac{1}{2}$, $\frac{1}{3}$ and $\frac{1}{4}$ respectively of the strength of neat cement.
5. The cleaner and sharper the sand the greater the strength.
6. The less water is used in working it up the better.
7. Salt water is as good for mixing Portland cement as fresh water.

It is now twenty years since Mr. Grant's paper was published, and the results then announced are for the most part in accord with the experience of to-day. The information thus realized has not only assisted in establishing Portland cement as being the best for employment where great tenacity and permanency are indispensible requirements, and where hydraulic properties are desirable, but it has also contributed to raise the standard of its manufacture. The seven results quoted above are picked out from twenty-two obtained from many thousands of tests, and those selected are numbered arbitrarily for reference here. They are, however, the results of extended experiments with cements furnished to meet the requirements of a high standard, where four millions of bushels were wanted, and where manufacturers vied with each other in the home market in the production of the best material on account of the large sales anticipated. These results serve as desirable examples. The question is how to arrive at or maintain that degree of excellence by judicious selection. If the cement is required in sufficiently large quantity to warrant shipment direct from the producer, the problem of selection becomes easy. But when, in this country, the engineer or contractor wants Portland cement in comparatively small quantities, and too frequently wants it immediately, where the best tests of time and futurity are not available, being too remote for immediate selection, the solution becomes more difficult. In this case, in the humble opinion of the writer, it would be safer to select from a well known brand of a respectable manufacturer, than from any conditional test he is aware of.

There are at least two indispensable tests which cement must bear thoroughly before it can be pronounced good. One is adhesive strength at various ages neat and mixed, the other resistance to water.

* Vide observations on limes, calcareous cements, mortars, etc., by C. W. Pasley, London, 1838.

The following are the usual tests applied, and they are in some instances unreliable.

(*a*) For fineness by sifting and residue. The importance of having cement finely ground is generally acknowledged as a concomitant to a test for weight. Imperfect calcination or an excess of lime, or an incomplete light cement would, however, be more easily pulverized and would give a finer test from less grinding.

(*b*) For strength by breaking or a certain resistance to tensile strain. The test from briquettes after having been set seven days will be in favor of quick induration, which is in itself objectionable; extend the time to four weeks, the test will be found more reliable. If the cement is coarsely ground, considered comparatively, the tests will be equally good, yet coarsely ground cement is objectionable. Again, a small excess of lime will not affect the maximum strain in the machine, still the excess of lime may be injurious.

(*c*) For weight. Weight, specific gravity, and color are important elements. Until the same mode of ascertaining the weight is more generally adopted, or a more universal means is established so as not to be affected by the question as to whether the cement was more or less compact in the measure, the present means of testing will be unreliable for comparison.*

* Vide remarks of Mr. F. I. Bramwell, p. 136, 137, vol. 25 Trans. Inst. C. E.

(*d*) Immersion in water. By making two parts of cement paste, one to be put in water, the other to be set in the open air. If there is an undue quantity of clay, the cake put in water will assume a buff color. If there is too much chalk or if it is overburnt to the point of danger, cracks will be visible round the edge of the cake in the air. There must, however, be quite an excess of one or the other before these tests will be noticeable.

It has been frequently alleged by manufacturers and others that Portland cement can be made to pass all these tests and yet may have an excess of lime or sulphate of lime, and afterwards prove to be dangerous. However, enough is now known of the qualities of Portland cement, as well as its manufacture and behavior under different conditions, to direct the engineer in its application under the varying circumstances that may arise in the course of his practice. But it occurs to the author, as it has no doubt to several others, that in case of emergency a more practical and reliable test than any now available is necessary to enable the purchaser to arrive at least at a more approximate value of Portland cement, and here chemical tests suggest themselves. Mr. Henry Reid gives a chemical analysis for a good average Portland cement, capable of passing the following six tests, viz.,—weight 112 lbs. per imperial bushel, strength 300 lbs. tensile per sq. inch, texture 2500 atoms or a sieve (50 guage) to a square inch, hydraulicity, after six days immersion perfect without crack or fracture, color by an air sample grayish blue or steel grey. Such a quality of cement would produce with a moderate divergence of range the following analysis of the main ingredients:—

Lime	60.05
Magnesia	1.17
Alumina	10.84
Silica	24.31
Alkalies	1.54

Adopting the above or the best standard, the skilful chemist might determine practical tests for excesses or injurious ingredients, which are generally beyond the province of the otherwise actively employed engineer. For emergency, some more practical test than any at present available is required.

Passing over results 1 and 2, and taking 3 and 4 as factors determining measure of admixture, and adopting the theory of all good concrete, which is to coat every particle of stone and gravel with a film of the cement, the deduction from the theory would be that the more intimate the union the more perfect would be the concrete resulting from the combination, and since in a perfect Portland cement the admixture of lime and clay (3) with neat cement is stronger than an admixture with sand, it follows that the more cement is employed, the stronger and better the concrete.

Next taking result (4) cement mixed with an equal quantity of sand is $\frac{7}{8}$ of the strength of neat cement, with 2 parts $\frac{1}{2}$ the strength, with 3 parts of sand $\frac{1}{3}$ of the strength, and with 4 parts of sand $\frac{1}{4}$, but with 5 parts of sand it is about $\frac{1}{6}$ of the strength of neat cement. It would appear that the proportions are maintained up to the intermixture with four parts of sand, but very perceptibly loses with a greater or fifth measure, and this fourth intermixture is practically a proper limit. Fine concrete for external employment in this climate should not be more than three or four parts of gravel to one of cement. With this proportion a coat of solid lime will be deposited round each grain of sand and gravel. When freshly mixed each particle will be embedded in a saturated solution. If three to one and fine sharp sand is used, the absorption of the water will cause a contraction, in mortar, of between ⅕ and ¼ of its bulk, which will increase its solidity and draw all the particles together. When the mortar or fine concrete is rich in perfectly formed cement this theory stands the test of practice, its impermeability to water after the hardening or "set" has taken place being a prominent feature. Setting is the work of hours or days, induration is the action of months and years, making the mass still stronger (2) and preventing injury from the expansive influence of freezing. Stones sufficiently solid and impervious themselves to be safe from congelation by frost may be safely introduced into the body of the mass in the manner shewn by Figure No. 3, without very materially affecting its stability, whilst at the same time they largely contribute to fill up and form the desirable bulk and reduce the expenditure within practical and economical limits.

It is almost a universal opinion that Portland cement is frequently spoilt in its manipulation with other ingredients by an excess of water in the mixture (5). This theory is proven practically by almost every one moulding cement paste into briquettes. Where concrete is turned over and mixed in troughs by hand, the disastrous habit of avoiding exertion in mixing by repeated doses of water, is too prevalent among the workmen. If the pasty material is too adhesive to fill up all voids round the stones, a dose of well tempered compo may be resorted to. This latter increment is against the true theory of concrete, and should be sparingly and carefully introduced.

Salt water is as good for mixing Portland cement as fresh water (7). This theory holds good in practice for concrete placed in salt water. Owing to the frequent and abnormal changes of temperature in the climate of Nova Scotia in the months of February and March, efflorescence is more noticeable on exposed surfaces where salt water has been used in mixing. In the opinion of the author fresh water sand and fresh water are preferable, and their use would likely be attended with better results in this country.

So much has been said and written respecting slags and their value in hydraulic mortar, that the author has recently paid some attention to their supposed hydraulic properties, and the result leaves little doubt on his mind that they are not reliable as an hydraulic agent. The following analysis of the slag from the furnaces of the Steel Company of Canada, at Londonderry, was supplied by John Sutcliffe, Esq., Manager.

	4	5	23	35	37	39
Silica	38.066	37.21	32.35	37.81	35.47	33.96
Alumina	15.289	11.05	10.74	8.62	10.30 }	9.79
Ferrous Oxide	0.310	0.80	1.06	1.95	0.99 }	
Manganous Oxide	0.381	1.01	0.44	3.55	2.78	1.00
Lime	36.148	42.92	47.60	42.99	43.71	49.60
Magnesia	7.012	4.24	4.01	3.43	2.43	4.56
Calcic Sulphide	2.451	2.239	3.15	2.09	1.44	
Potash			0.13			
Soda			0.08			
	99.657	99.499	99.56	100.44	99.82	98.91

4—Grey slag.
5—Grey slag. Hot and fluid
23—Grey stony slag, white face
35—Grey cinder.
37—Grey cinder, white face, hot, fluid
39—White, very dry cinder.

The results obtained from tensile tests in a Fairbank's Testing Machine were no better than a Portland cement intermixture with sand would be. They were as follows,—

		lb	lb	lb
Pure cement	set 28 days	448	386	505
1 slag to 1 cement	" 28 "	182	257	288
2 " 1 "	" 28 "	212	215	245
3 " 1 "	27 "	77	96	126
4 " 1 "	" 27 "	106	113	121
5 " 1 "	" 26 "	38	54	
6 " 1 "	" 23 "	23	27	

The barrel of slag supplied, from which the briquettes were made, shewed the silica in a vitrified condition also fused silicate of lime already formed with the alumina burnt to a white dry cinder. These tests will be continued on greyer and heavier slag; it is hoped in time to supplement this paper with better results.