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The Canadian Engineer

A weekly paper for Canadian civil engineers and contractors

Wood in the Construction of Mill Buildings

Is It a Suitable Material?—Large Factory Built Only Five Years Ago to Be Torn Down and Replaced by Reinforced Concrete—Corrosive Sublimate Suggested as Preservative Where Conditions Are Favorable to Growth of Fungi—Ten Precautions to Be Taken Against Decay

By W. KYNOCH, B.Sc.F., F.E., and R. J. BLAIR, B.A.
Forest Products Laboratories of Canada

FREQUENTLY have the Forest Products Laboratories had occasion to draw attention to the serious financial losses resulting from the ravages of so-called dry rot in mill or factory buildings of wooden construction. Numerous cases in which this trouble has occurred in Canadian buildings have been carefully investigated, and one of these which has been under observation for upwards of a year affords a typical example of a deplorable state of affairs which could have been entirely avoided had those concerned in the erection of the building been guided by the necessary knowledge of the technology of timber and the mechanism of the decay of wood.

From the point of view of the owners of the building, the facts are as follow: Five years ago a large factory building was constructed with heavy timber columns and beams and laminated floors of 2-in. x 6-in. planks, overlaid by ⅞-in. hardwood. The timber was but partially seasoned when installed. The operations carried on in the building are such that the relative humidity in the interior is usually high. Serious decay was first noted about three years after the erection of the factory, and since that time has apparently become steadily worse. The tearing out of practically the whole of the timber construction has now become imperative, and the owners have decided to replace entirely with reinforced concrete at an estimated expenditure of $100,000.

Fig. 1—Rapid Growth and Low Density

The decay of wood is due to the action upon it of low forms of plants known as wood-destroying fungi and bacteria. For practical purposes the bacteria may be ignored. The germs of decay are not inherent in timber; infection must come from outside, and sound wood becomes infected in two ways, namely, by contact with either tissue or spores of a wood-destroying fungus under suitable conditions of temperature, moisture and air supply. It should be noted that this is not merely an interesting theory. It is a hard fact proved beyond dispute by extensive research and thousands of carefully conducted tests, and we can now induce decay in timber at will in the laboratory. A number of kinds of fungi which can be definitely identified are responsible for the destruction of timber in buildings.

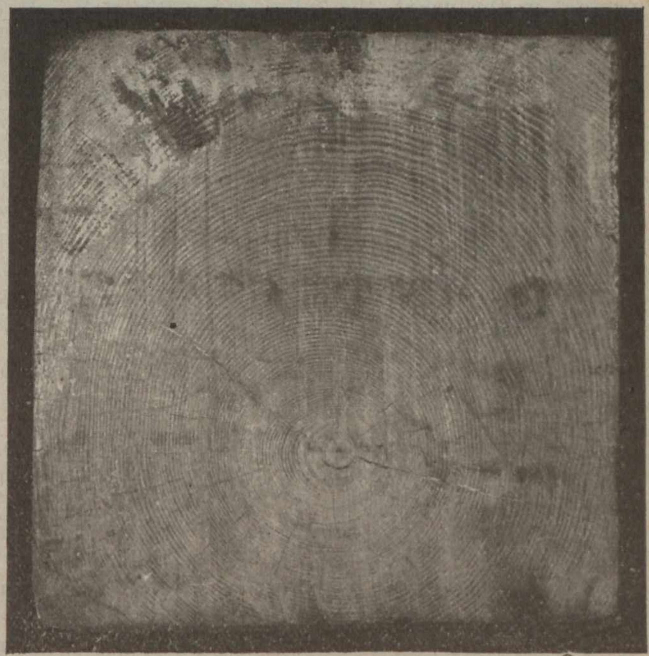

Fig. 2—Slow Growth and High Density

In the particular case under discussion the range of temperature and relative humidity of the air in the factory were such as to provide exceedingly favorable conditions for the growth of several of the most destructive kinds. In addition, the unseasoned state of the timber facilitated decay because it was not even necessary for the wood to absorb water from the humid air before reaching the moisture content permitting the action of the destructive agent,—the moisture was there already. Lastly, a large quantity of the timber used was of the character shown in Fig. 1; that is to say, of rapid growth and low density.

Woods Differ in Powers of Resistance

Different pieces of wood, even of the same species, differ in their ability to resist attack. Fig. 2 shows timber of slower growth and higher density and possessing much greater resistance to wood-destroying fungi. What occurred, therefore, was that timber of low resistance, in a condition to invite decay (*i.e.*, unseasoned), was placed in a building in which the operations to be carried on gave rise to very favorable conditions for the growth of several extremely destructive kinds of fungi. It is therefore obvious that it could have been predicted that, in all human probability, decay of the timber would occur.

Such instances, and they are numerous, raise an important point for the consideration of the engineer. They do not simply happen without warning like an earthquake nor are they due to some mysterious and unknown cause. The cause is known and the trouble can be prevented by proper procedure. Wood initially sound will last for an indefinite period, so far as decay is concerned, if any one of the factors essential to the growth of fungi is lacking or can be effectively controlled. The moisture factor is especially important. If the required amount of moisture is present in the wood, the fungi can grow in it. If it can be kept thoroughly air-dry, their growth is absolutely prevented.

It is, of course, rarely practicable under ordinary conditions to control the moisture content of the wood, the humidity of the air, temperature or air supply. The food supply of the fungus, however, that is the wood itself, can readily be controlled in that by efficient impregnation with a suitable preservative it can be made chemically impossible for the fungus to act upon it. In the particular mill with which we are now concerned, the conditions were so exacting that the timber should without doubt have received efficient preservative treatment.

Use of Preservatives

The selection of the preservative to be used for the treatment of timber for a mill or factory building should depend on the circumstances of the particular case. A material which has been employed in several cases in Canada and the United States is mercuric chloride (corrosive sublimate). This preservative has been in commercial use to a rather limited extent for many years for the treatment of timber for various purposes, both in Europe and on this continent, and has given excellent results.

Before the war, several concerns of which the writers have knowledge treated timber with mercuric chloride for use in their own mill buildings at a cost of about $3.00 per thousand feet B.M. The price of the preservative has since advanced so greatly, however, that it might in some cases prove prohibitive at the present time. Other less costly preservatives which might be used are zinc chloride and sodium fluoride. The laboratories would be glad to furnish, on request, further particulars regarding the use of these materials for the treatment of timber for mill buildings. Timber to be treated with preservatives should always be thoroughly air-dry. Treating green or very wet wood is time and money wasted, as little or no penetration of the preservative can be secured. In the case of large structural timbers, which frequently take years to become seasoned, the outer inch at least should be reasonably dry before treatment.

In mill or factory buildings, or parts of the same, where the operations carried on create very favorable conditions for the growth of fungi, the use of untreated timber, especially timber of low density, or timber containing much sapwood, is inviting disaster. If the timber be efficiently treated, however, there is no objection to the presence of a considerable proportion of sound sapwood or to the use of sound second quality or low density wood, provided that where necessary due allowance be made for the lower strength of the lighter material. The added cost of treatment could therefore in some cases be partially offset by using less costly timber.

It must not be inferred that treatment of timber for mill construction is always necessary. It is only requisite where the conditions are especially exacting. In other cases the use of timber of the proper quality and the observance of the following precautions will give reasonable assurance of immunity from decay:—

Precautions Against Decay

(1) Only dense material of the more durable species should be used, and the proportion of sapwood allowed should be small.

(2) The timber should be carefully inspected as to soundness, density and proportion of heartwood, and material not up to specifications should be rejected.

(3) Planking should be thoroughly seasoned in all cases. In large timbers the outer inch at least should be reasonably dry.

(4) Timber delivered on the work should be piled out of contact with the soil and with any unsound wood.

(5) All reasonable and practicable precautions should be taken to keep the wood as dry as possible before and during construction.

(6) Laminated floors should not be built while the wood is wet. If this is unavoidable, it is advisable to proceed as follows: As soon as the building is completed and the heating plant installed, close all doors and windows, raise the temperature inside the building to, say, 120° F. or as near this as possible, and maintain this condition for several days. If this can be done before building paper, pitch or hardwood flooring is applied over the laminated flooring, so much the better. (In the case of storage or other buildings not provided with heating plants, it is suggested that some temporary means of heating might be used. Where this is not feasible it would be safer to build with treated timber.)

(7) Wood should not be covered with plaster or other materials or painted until at least two years after the building has been occupied.

(8) Construction at joints, where beams enter walls, etc., should be such as to permit of ample ventilation.

(9) Special care should be taken in the construction of roofs when untreated timber is used. It is necessary to have the interior roof planking thoroughly insulated so as to prevent condensation of moisture on it in winter.

(10) An examination of the planking and timbers should be made periodically, say, half-yearly, during the first three or four years after the completion of the building.

That timber frequently becomes infected in the lumber yard and that trouble from decay in mill buildings often arises from the installation of such infected timber is beyond question. Whether infection occurs in the lumber

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ENGINEERS' MEETING AT SASKATOON

FOLLOWING is the program that has been prepared for the first Western Professional Meeting of the Engineering Institute of Canada, to be held August 8th to 10th at Saskatoon:—

Good Roads Session, Thursday afternoon, August 8th—Opening address, by Dr. W. Murray, president, University of Saskatchewan; "Location, Construction and Maintenance of Earth Roads," by H. R. Mackenzie, chief field engineer, Province of Saskatchewan, Highway Department; "Manitoba's Experience," by A. McGillivray, highway commissioner of Manitoba; "Alberta's Experience," by J. D. Robertson, engineer of highways, Department of Public Works, Alberta; "System of Trunk and Feeder Roads," by W. M. Stewart; "Methods of Financing for Good Roads," by W. H. Greene, assistant city engineer, Moose Jaw; "Provincial Policy of Manitoba," by A. McGillivray; "Provincial Policy of Alberta," by L. C. Charlesworth, deputy minister of public works, Alberta; "Provincial Policy of Saskatchewan," by H. S. Carpenter, deputy minister of highways, Saskatchewan; supper at University of Saskatchewan.

Water Supply and Sanitation Session, Thursday evening, August 8th.—"Rural Community Water Supplies," by E. L. Miles, inspecting engineer, Department of Irrigation; "General Water Supply for Saskatchewan," discussion by various branches; "Rural Sanitation," by W. Muir Edwards.

Concrete Session, Friday morning, August 9th.—"Deterioration of Concrete," by B. Stewart McKenzie, consulting engineer, Winnipeg; "Chemistry of Concrete," by A. G. Blackie, city chemist, Winnipeg; "Concrete in Alkali Soil in Saskatoon," by H. McI. Weir, assistant city engineer, Saskatoon; "Observations of Disintegration of Concrete in Edmonton Districts," by J. A. Kelso, industrial chemist, University of Alberta; "Observations of Concrete Failures," by F. C. Field, city chemist, Calgary (paper prepared by a special committee); "Methods of Proportioning Concrete, Based on Recent Experimental Work," by Duff A. Abrams, professor in charge of laboratory, Lewis Institute, Chicago; lunch at University of Saskatchewan; address by Secretary Keith.

Fuel Session, Friday afternoon, August 9th.—"Fuels of Western Canada," by James White, assistant to chairman, Commission of Conservation, Ottawa; "Briquetting of Lignites," by R. A. Ross (report of Honorary Council for Scientific and Industrial Research); "Experiences with Combustion of Lignites," by E. C. A. Hanson, consulting engineer, Winnipeg; "Fuel Transportation," by W. B. Lanigan, assistant freight traffic manager, C.P.R., Winnipeg; banquet, given by the City of Saskatoon; address by the mayor of Saskatoon; address by President Vaughan.

Professional Session, Saturday morning, August 10th. —"Legislation Governing the Status of Engineers," by F. H. Peters, chief engineer, Department of Irrigation, Calgary; "Draft of Proposed Act Concerning Saskatchewan Engineers," by C. P. Richards; "Suggested Legislation in Manitoba," by W. P. Brereton, city engineer, Winnipeg; "Suggested Legislation, Alberta," by W. M. Edwards; "Proposed Co-operation Between the Engineering Institute of Canada and the Canadian Mining Institute," by F. H. Peters.

On Saturday afternoon, August 10th, there will be an excursion to various points of engineering interest. An excursion for visiting members will also be arranged for Thursday morning, August 8th. A ladies' committee has been arranged to look after wives of members, and entertainments will be provided.

CANADIAN ENGINEERING STANDARDS COMMITTEE

UNDER the chairmanship of Sir John Kennedy, there was recently created in Montreal an organization to be known for the present as the Canadian Engineering Standards Committee. Its primary objects are to secure interchangeability of parts; to cheapen manufacture by the elimination of waste entailed in producing a multiplicity of designs for one and the same purpose; to effect improvement in workmanship and design; and, by concentration rather than by diffusion of effort, to expedite delivery and reduce maintenance charges and storage.

The Canadian Government has officially endorsed the establishment of this committee and has appointed as its nominees Lieut.-Col. W. P. Anderson, C.M.G., chief engineer, Department of Marine; Dr. E. Deville, surveyor-general; Dr. A. B. Macallum, F.R.S., chairman of the Honorary Advisory Council for Scientific and Industrial Research; Lieut.-Col. C. N. Monsarrat, consulting engineer, Department of Railways and Canals; Capt. R. J. Durley, M.B.E., representing the Imperial Ministry of Munitions; Major W. J. Keightley, chief inspector of military stores, representing the Department of Militia; E. O. Way, chief inspector of weights and measures, representing the Department of Inland Revenue; and K. M. Cameron, supervising engineer, Department of Public Works.

The Canadian Manufacturers' Association is represented by William Inglis, of the John Inglis Company, Toronto; and P. L. Miller, general manager of Canadian Vickers, Montreal.

The Honorary Advisory Council for Scientific and Industrial Research is represented by Robert Hobson, president of the Steel Company of Canada, Hamilton; Prof. J. C. McLennan, F.R.S., University of Toronto; R. A. Ross, city commissioner of Montreal; Dr. R. F. Ruttan, McGill University; and Arthur Surveyer, consulting engineer, Montreal.

The Institution of Civil Engineers of Great Britain, at whose urgent request this committee was established, and who fathered the movement for the establishment of the British Engineering Standards Committee, is represented by Sir John Kennedy, consulting engineer, Montreal; W. F. Tye, consulting engineer, Montreal; H. H. Vaughan, general manager of the Dominion Bridge Company, Montreal; and Dr. John Bonsall Porter, professor of mining engineering, McGill University.

The Engineering Institute of Canada is represented by G. H. Duggan, managing-director of the Dominion Bridge Company, Montreal; and Dr. L. A. Herdt, professor of electrical engineering, McGill University.

The Canadian Mining Institute is represented by Dr. Alfred Stansfield, professor of metallurgy, McGill University; and F. H. Crockard, formerly president of the Nova Scotia Steel and Coal Company.

At the organization meeting, Sir John Kennedy, to whom the formation of this committee was suggested by the late Sir John Wolfe Barry, was unanimously appointed chairman. H. H. Vaughan and Capt. R. J. Durley were elected as vice-chairmen; Dr. John Porter, honorary secretary-treasurer; F. S. Keith, secretary.

At the urgent request of the British committee, sub-committees on screw thread and airplane parts were created under the chairmanship of H. H. Vaughan and Capt. Durley, respectively. It is intended that other sub-committees shall be appointed as required.

CHEMICAL AND BACTERIOLOGICAL EXAMINATION OF THE LONDON WATERS*

By Sir A. C. Houston, K.B.E., D.Sc.
Director of Water Examination, Metropolitan Water Board.

IN the spring of 1916, when the growth of Fragillaria and Asterionella was very active, a great many laboratory experiments were carried out to see how far multiplication took place in non-algal affected water when artificially "seeded" with very small amounts of water in which algæ or other growths were flourishing, and also what conditions favored and inhibited the occurrence of these changes. In 1917 the matter was again investigated and further information obtained, and the novel procedure was adopted of micro-photographing the growths in the water so as to yield a permanent quantitative and qualitative record of what had actually taken place. There was a time when filtration difficulties were put down to the presence of fish spawn in the water. We now know differently, and within limits can even imitate artificially the operations of Nature, and study the factors favoring or inhibiting the development of algal and other growths. It must not be supposed that the hard Thames, Lee and New River waters are alone susceptible to these growths. In the winter of this year the experiment was tried of inoculating a very soft moorland water with 1 per cent. of Banbury (Walthamstow) reservoir water, which at that time was fostering the growth of Asterionella.

Algal Growths

The size of algal and other growths in water varies according to circumstances, chiefly unknown. For example, sometimes Cyclotella may be so relatively large that it is apt to be confused with Stephanodiscus, and sometimes the converse is true. In much the same way Asterionella may occasionally take on a larger mode of growth.

The water in King George's reservoirs developed a peculiar color in 1916, which persisted until the autumn of 1917, when the south reservoir cleared, but the north reservoir water is still (1918) abnormal in color. Seen in a bottle the color was hardly visible, but when viewed in bulk in the reservoirs it had a decidedly reddish-purple tint. When alum was added to the water, the flocculent precipitate produced was decidedly pink in color. Under the microscope minute cells, like cocci, embedded in a gelatinous material were observed, and there can be little doubt that the red colorization was due to the presence of a Palmella-like growth, comparable to that producing the phenomenon known as "red snow." (? Protoccus Nivialis or Palmella Cruenta). It has frequently been pointed out that in algal treatment the offending growths can be destroyed, yet the risk may remain of other and more resistant growths taking their place. A notable instance occurred in 1917 during the continuous treatment of No. 1 reservoir at the West Middlesex Works with copper sulphate (1 in 4 millions). The growths (Fragillaria, Asterionella, Stephanodiscus, filamentous confervoid growths, etc.) affecting the neighboring reservoirs were almost completely held in check, but a fresh growth, composed of such excessively minute cells that they pass readily through four folds of fine linen, developed abundantly and caused serious blocking of the filters. Incidentally, this result shows that linen filtration results cannot always safely be compared with slow sand filtration.

*From a report for the year ending March 31st, 1918, Metropolitan Water Board, London, Eng.

In August, 1915, a very decided growth of Stephanodiscus occurred in the Stoke Newington reservoirs, causing rapid choking of the filter beds. At the beginning of July, 1917, a very similar growth (Cyclotella) began to develop, but the part played was no longer a passive one. By a judicious combination of chlorine and copper sulphate treatment the filtration difficulties were entirely overcome, no water was wasted, and the use of the reservoirs as settling and purifying agents was practically continuous. The procedure was to shut off the west reservoir for a few days, whilst it was being treated with copper sulphate (1 in 2 millions), and to short-circuit chlorinated water through the east reservoir on to the filter beds. A recrudescence of the growth occurred later on more than one occasion, but it was each time dealt with in a similarly successful manner.

During the January, 1918, flood, when the River Thames was at its worst (January 16-27), Staines stored water was used for filtration purposes. Fortunately the water was in a very good condition, but emphasis must again be laid on the fact that almost insuperable filtration difficulties might arise if the Staines water was badly affected with algal growths coincidently with a heavy Thames flood. It is perfectly true that in the late autumn and in the winter months, when floods are most likely to occur, the growths in the Staines reservoirs are usually at a minimum, but the 1903 summer floods are not easily forgotten. Whilst dealing with Staines reservoir water, attention should be directed to the rather abundant growth in the water, especially about June, 1917, of Glenodinium. In this year (1918) advantage was taken of the mid-January floods to test the "resistance to filtration" of the River Thames daily and also to obtain pictorial records of the state of the water.

It may be practically impossible to close the "intakes" during the whole of a flood, but there is no good reason why the worst water should not be excluded from the storage reservoirs. The chemical and bacteriological qualities of flood water have been so frequently dealt with in previous reports that all that need be said here is that on January 18th, 21st and 22nd the color of the River Thames was actually 428, 452 and 420 respectively, as against an average color of 71 (1906-16). The admission of water of this quality into storage reservoirs is a most undesirable "leavening" process. Our knowledge of growths in reservoir water may be limited—our knowledge of most things is necessarily imperfect, but so far as it goes, it points unequivocally to the exclusion of impure flood water.

Growths in River and Stored Water

In previous reports it has been explained that river water usually contains so few living growths that any difficulty experienced in its filtration is largely due to the presence of amorphous dead matter (*e.g.*, mud and silt). Unless then developmental changes occur in the storage reservoirs, it might be expected that the suspended matters would largely settle out and the outlet water from the reservoirs filter extremely well. This indeed is found to be true in the cases of some of the reservoirs (notably Walton and Chelsea). On the other hand, if developmental changes do occur in the reservoirs, the gain in settlement of the dead suspended matters may be largely, if not entirely, lost by the blocking effect of the new living growths.

Walton and Chelsea are excellent examples of reservoirs which, for some reason or another, have not, so far, favored any luxuriant algal or other growths. The average "filtration figures" based on the examination of samples collected bi-weekly for the calendar year 1917 were remarkably good, namely (Walton) 274 and 270 (Chelsea). The Walton reservoirs have not been in use for very long (since 1911); they have flat clean bottoms, and attention in their design and construction was paid to the desirability of encouraging good circulation of water. The Chelsea reservoirs are old, but the method of circulating water through them appears to be satisfactory.

It should perhaps be added that sometimes the water in these reservoirs (Walton and Chelsea) has shown the presence of a few of the very organisms which in other reservoirs were undergoing rapid multiplication; yet no development occurred, looking as if more of them were needed to start an active multiplication process, or as if some other unknown condition were lacking for their sustained development.

The rôle played by these organisms in connection with water purification is not fully understood. Some of them exercise a useful function in reducing the hardness of water and, within certain limits, in increasing the effectiveness of the protective film formed on the surface of the sand filters. On the other hand, they may sometimes give rise to taste troubles, and when superabundant "seal up" the filter beds so rapidly as to disorganize the whole machinery of sand filtration. In the latter event, although in themselves quite harmless, they may lead to imperfectly purified water being sent into supply, a circumstance which the engineers quite frankly admit. Those who have studied these matters know that the simultaneous occurrence of heavy floods, abundant growths (especially those kinds which readily block filters and give rise to taste troubles) in the reservoirs and increased consumption of water might create embarrassing, if not serious, condition of affairs. Heavy floods almost preclude the alternative use of river water; taste troubles may call for certain filter beds being temporarily thrown out of active use, thus reducing a filtration area already strained to its uttermost, and increased consumption of water, even in normal times, is a factor not to be lightly ignored. These are not gloomy prognostications, they are merely the expressions of opinion of one whose duty it is to try and measure future possibilities. How far algicidal treatment, chlorination of river water, and the use of filters, which can be cleaned as rapidly and as often as the necessities of the case demand, are destined to enter into the problem, must be left for the future to decide.

Chlorination

This year a cautious opinion must be expressed, not of the efficacy of chlorine as a germicidal agent, but of the difficulties still to be overcome of adding this reagent to water in the proper dose. With the particular apparatus used, quite successful results were obtained during the warm weather, but when the air and water temperatures fell below a certain point, troubles were not far to seek. So far as the instrument was concerned, these difficulties were largely overcome by artificially heating the temporary building in which the apparatus was "housed." Yet this procedure availed nothing as regards that part of the instrument which lay outside the building and was indeed immersed in the water. It is now evident, as the result of practical experience during cold weather, that either the gas must be added as a solution to the water to be sterilized, or else some improved form of porous diffuser must be discovered. The matter is still under active investigation.

For the period April 1st, 1917, to March 31st, 1918, 23,426 million gallons have been treated during 315 days (West Middlesex supply) and 313 days (rest of Staines supply) out of a total of 365 days. The intermissions, of course, were caused by floods, when the water was too turbid for filtration purposes and stored water had to be used instead. The proportions were 84.3 per cent. raw water and 15.7 per cent. stored water during the year. The estimated saving of coal amounts to about £15,227. The cost of the chloride of lime was about £3,485. The net saving thus amounts approximately to £11,742. The dose has varied according to circumstances, but was usually 0.5 in 1 million (1 in 2 millions), in terms of available chlorine. With bleaching powder (chloride of lime) of 33 per cent. strength this equals 15 lbs. per 1 million gallons. Considerable success, however, has also been obtained with smaller doses, 0.33 in 1 million (1 in 3 millions), or 10 lbs. of material per million gallons. On the whole, the latest results point to a probable reduction rather than an increase in the average dose. As regards bacteriological results, all that is now aimed at is to produce at least as good a result by chlorination of raw river water, as if the river water had been stored in the Staines reservoirs instead of being chlorinated. The Staines stored water 10 cc. B. coli standard is 60 per cent. "negatives" (40 per cent. "positives"). That is, if 100 10 cc. cultures are made of Staines stored water, 60 of them, on the average, contain no B. coli, and 40 of them contain this microbe. Taking a period embracing the bad winter months, namely, from October, 1917, to the end of March, 1918, the average chlorinated raw river water result works out at 83 per cent. "negatives" and 17 per cent. "positives," figures which show that better results, as judged by the B. coli test, can be obtained by chlorination than by storage. Despite the magnitude of the treatment (70 to 80 million gallons treated daily), no complaints have been received as regards taste. There are, however, other factors requiring consideration.

All the results exceed their respective averages except East London (Sunbury), Kempton Park and Grand Junction (Kew) in respect of the albuminoid nitrogen test. Slight increases of color are of no importance. The higher figures for the ammoniacal nitrogen and permanganate tests are relatively unimportant having regard to the waters' history and bacteriological results. A more tangible objection to the use of chlorinated river water is that such water is appreciably harder than stored water, not on account of the treatment, but because storage undoubtedly exercises a softening influence on hard waters. It is indeed possible to soften waters artificially by seeding them with minute quantities of other waters affected with growths. It should also be noted that the non-chlorinated waters generally have yielded slightly higher results chemically this year as compared with the 1906-16 averages.

So far, only the bacteriological results of the chlorinated river water have been dealt with, and it is now desirable to consider briefly the quality of the final product. Here we are met with a number of perplexing factors. It is true that we start with a chlorinated water in which most of the B. coli have been destroyed; but this water enters reservoirs in which fish and other forms of life abound, and which attract the presence of many birds. The discharges of these animals commonly contain B. coli in large number, practically indistinguishable from those of river water origin. Hence, even if all the B. coli in the river water entering the reservoirs were destroyed, some of these microbes are likely to be found in the reservoir water as the result of the presence of these forms of life. As a matter of fact, the pre-filtration waters have yielded slightly better results since chlorination was started, but the improvement has not been as well marked as the result of the examination of the water after chlorination might have led one to expect. Lastly, there is the possibility that a water previously subjected to chlorination may, for some reason or other, not filter so well as one which has not been exposed to any such treatment.

The 1917-18 results (obtained by chlorination) are slightly better than the 1906-16 averages (pre-chlorination period).

The results during the summer months showed some deterioration, thus helping to bring down the year's average. This may have been due in part to increased consumption of water, and, therefore, increased rates of filtration, but the excessively heavy rainfall during this period must also not be forgotten. The natural inference would be that the flood water, despite chlorination, was to blame, but during, at all events, the worst periods Staines stored water was actually being used, so that this explanation is not wholly convincing. There are puzzling features associated with heavy rainfall which might almost be said to suggest the possibility of some unknown factors sometimes operating unfavorably on the condition of the filtered waters. This might arise, for example, if unpurified adventitious water could in any way reach the supply after its filtration. From source to consumer a waterworks should be absolutely free from the entrance of adventitious water. By adventitious water is meant water which has no real relation to the source of supply. Such water may pierce the armor of the purification works at a number of points. It may be pure or impure, but it is apt to be a secret and most undesirable addition to the supply. Again, January was an unfavorable month from a filtration point of view. Up to about the middle of the month the cold was intense, and this meant running taps, burst pipes, waste of water generally, increased rates of filtration, and practical difficulties in connection with filtration. Later, heavy rain and floods further complicated the position, although here again during the worst period the treatment was stopped and Staines stored water used for supply purposes.

Altogether the year was a trying one, and the works not affected by chlorination showed in their output some falling off in quality. If, as seems clear, more B. coli in river water are killed by chlorination than by storage, the presumption is that, given equal chances of purification afterwards, and no fresh contaminations, the former water would be, at all events, not less safe to drink than the latter. Against this must be set the circumstances that storage has an important "levelling" influence or "equalizing" effect. In the present case the chlorinated water is stored in the West Middlesex (considerable storage capacity), Grand Junction (only slight storage capacity), Kempton Park (considerable storage capacity, if in use), and Sunbury (very slight storage capacity) reservoirs before being filtered. It is a sufficiently noteworthy achievement to effect a clear saving of nearly £12,000 a year by substituting chlorinated for stored river water, without attempting to plead that the former process conferred not only equal, but additional security to the consumer.

There is at least one more aspect of the question deserving of consideration. Chlorination might save pumping charges and be satisfactory chemically, bacteriologically, and in relation to health. If, however, the effect of using chlorinated river water instead of stored water led to serious "blocking" of the sand filters, this might be urged legitimately as an objection to the method. There can be no doubt if Walton or Chelsea stored water could be passed down the Staines aqueduct instead of Staines stored water, the foregoing argument would meet with considerable support, as unquestionably these stored waters filter much better than river water.

Staines stored water, however, is quite different, inasmuch as it develops from time to time the abundant growth of Asterionella, Fragillaria, Cyclotella, etc. On these occasions Staines stored water filters much worse than river water.

In the 1915-16 year the influence of Staines stored water was paramount, the filtration difficulties being acute in the spring and likewise in the summer. It is true that in the spring of 1916 the results were unsatisfactory, but in point of fact this antedates the start of the chlorination treatment. It might be supposed that the winter floods would entirely annul the advantages gained in the spring and the summer. This, however, is not the case, for when the floods are at their worst stored water is again used, and at this period of the year algal troubles are usually at a minimum.

The West Middlesex No. 6 reservoir water shows a widely different result, and the reason is not far to seek. The storage here is considerable; the reservoirs contain the "seeds," so to speak, of past growths, and the effect of the chlorination has been largely lost. In consequence, a redevelopment of growths occurs, although, happily, not attaining the dimensions previously encountered. There would thus seem to be full confirmation of the writer's previous prophecies that probably a chlorinated water would filter best if not stored too long subsequent to chlorination. It is not disputed that in interfering, or seeming to interfere, with the laws of Nature there may be many disappointments, but on the evidence so far available the creation of purely artificial conditions has resulted in the saving of a large sum of money and the partial solution of many filtration difficulties. These results have been attained without inconvenience, annoyance, or semblance of danger to the public.

It is, perhaps, too early to speak of post-war conditions. Presumably the cost of pumping will fall in far greater ratio than the cost of chlorination. Even so, the margin will always be in favor of chlorination, and there the matter may be left temporarily at rest. Perhaps one word of caution should be added, namely, that the problems connected with chlorination and sterilization may appear simple to the inexperienced and irresponsible, but they are nevertheless of anxious moment to those who have had experience in these matters and who carry the responsibility of acting in an advisory capacity. The trite phrase that "matters have now passed the experimental stage" must not be allowed to obscure the fact that few things are so perfect as to be insusceptible to radical improvement.

Super-Chlorination and De-Chlorination

The two great factors which militate against successful chlorination are extreme cold and short contact. Separately, and still more in conjunction, they tend to prevent sterilization, or if sterilization takes place owing to a super-dose, the water is apt to have a chlorinous taste and to contain active chlorine. By a super-dose is meant a dose in excess of what is actually required under more favorable working conditions. It is always best to provide for so prolonged a contact that however cold the water may be, the active chlorine will have disappeared and the water at the same time have been sterilized. In practice, however, for one reason or another, this may be impossible, and in these cases, especially during very cold weather, super-chlorination and de-chlorination may be of advantage. There is another curious circumstance bearing on the question. It has sometimes been observed in the laboratory (anticipating what follows) that when working with minute doses of chlorine, too slight to produce the familiar chlorinous taste, a slight "iodoform-like" taste develops. This occurs sometimes after a water has been de-chlorinated, at other times it is noticeable only before de-chlorination, yet again it may occur both before and after de-chlorination. On the other hand, no taste, unless perhaps the original taste, has ever been observed after gross chlorination and de-chlorination. Hence in certain cases there may, so far as taste is concerned, be an advantage in heavily chlorinating a water and then de-chlorinating it.

On the whole, speaking of the samples neutralized with SO_2, neither temperature nor time appeared to be dominating factors as regards questions of taste.

Next in respect of dose, the amounts (in terms of available chlorine) were as follow: 1 in 15,625, 31,250, 62,500, 125,000, 250,000, 500,000 and 1,000,000 respectively.

The outstanding feature was that with the stronger doses (far greater than would ever be required in practice), despite the extremely noticeable and practically unbearable chlorinous taste of the non-neutralized samples, the ones neutralized with SO_2 were completely free from any taste. Indeed, the slight earthy flat taste of the river water often noticed appeared to be removed or disguised, not infrequently, by super-chlorination and SO treatment. Apart from cost of materials and the circumstance that the substances (Cl and SO_2) are not separately innocuous in other than minute doses, the indication is that a combined (in sequence) super-chlorination and SO_2 treatment may be actually advantageous from the point of view both of taste and of sterilization. When, however, the case is regarded from the economic aspect and in relation to the undesirability of using in other than infinitesimal doses substances which apart are not, in the uncombined form, natural ingredients of water, the matter assumes a different complexion. Unfortunately, it is just when the minor doses come to be considered that many of the difficulties arise. Sometimes with, sometimes without SO_2 de-chlorination, but quite as often with as without, taste results are obtained, which lead to nebulous conclusions. Perhaps the most difficult cases are those where an initial taste, faint, fresh and not actively unpleasant in itself, passes gradually into the ill-defined region of substitution, where the final products, whatever their true composition may be, are most unpalatable. All dogmatic statements on the question of taste, especially if made irrespective of particular cases, should be received with extreme caution. The statement that no taste troubles arise when liquid chlorine is used appears, on current knowledge, to be equally indefensible. Many laboratory experiments have been made with bleach solution and chlorine water both of the same strength in available chlorine. These liquids added to New River water have both produced very similar tastes, although in individual experiments sometimes the one and sometimes the other seemed to yield the most satisfactory results as regards absence of taste. At all events, the writer is certainly not prepared to say, on the information at his disposal, that the use of liquid chlorine abolishes taste troubles.

The chlorination of the New River water is a separate problem from that of the River Thames, and indeed the objects sought to be attained are so fundamentally different as almost to amount to a converse proposition. In the case of the Thames the object is to avoid pumping charges and to render the river water as pure after chlorination as if it had been stored in reservoirs.

Chlorination of Raw New River Water

In the case of the New River the storage is entirely inadequate, and the rate of filtration is about double that practised at the other works of the Board. Owing to the New River containing a large proportion of well water, the filtered water results are good, often exceptionally good, for about three-fourths of the year, although this must be ascribed in part to the pure well water "masking" the impurities in the river water. The three critical months are normally November, December and January. Then, chiefly due to floods and to some extent cold weather, which in a variety of ways is prejudicial to good filtration, the results deteriorate markedly. With inadequate storage the exclusion of impure flood water is a physical impossibility, and the rate of filtration cannot be slowed down if the normal supply is to be maintained. There seemed to be no way of remedying this state of affairs, as regards the New River, except by providing additional storage capacity and increasing the filtration area at an enormous cost. If, however, as stated last year, it were possible, by the judicious use of sterilizing agents, to smooth over, or perhaps wipe out, the effects of flood, it might be contended, with some show of reason, that a case had been made out for at least delaying, if not removing, the necessity for the construction of these expensive works. During the year's work, by the exercise of constant vigilance and care, practically no complaints as regards taste were received, but on at least one occasion the treated water was on the border-line in this respect. The New River contains, on the average (1906-16) B. coli in 1 c.c. (or less) in 44.7 per cent. and in 10 c.c. (or less) in 87.6 per cent. of the samples examined. Taking the period January 17th to 28th, 1918, during the height of the floods, as an illustration of what can be effected by sterilization, the positive B. coli results were only 27.5 per cent. in the 10 c.c. cultures; that is, there were fewer samples containing B. coli in the treated water in 10 c.c. (27.5 per cent.) than samples containing B. coli in 1 c.c. (44.7 per cent.) of the untreated water on the year's average. As a matter of fact, during the flood period the water before treatment contained B. coli in 1 c.c. in 85 per cent. of the samples.

To combine safety with a tasteless water, in the case of the New River, is a most difficult problem. If it were possible to sterilize the water *after* filtration, many of the difficulties would disappear. In such cases the consumer is always ingesting the current taste, if taste there be, and stoppage of the treatment is almost immediately followed by a return to normal conditions. When chlorination is practised before filtration, more of the chemical is usually required, and filters, as was observed by the writer as far back as 1905 (Lincoln) have an *ad*sorptive effect. All may go well for a time, and then, without any definite warning, a taste may develop, which usually persists for some considerable time, even if the treatment is stopped altogether. Unfortunately, the manner of distribution of the New River supply subsequent to filtration renders post-filtration chlorination a very doubtful proposition. This is the more to be regretted if there is any possibility of fresh contamination taking place at any stage subsequent to the chlorination of the raw New River water. Obviously pollutions occurring after chlorination must not be placed to the discredit of the sterilization process.

Before leaving consideration of the New River results, some reference should be made to a widely current belief that cold *per se* accounts for the falling off in the bacteriological results during the winter. Moreover, there are glaring inconsistencies to be explained away on a cold-weather basis. For example, in December, 1906, 1907, 1909, 1910, 1911, 1912, 1914 and 1915, the bacteriological results were far from satisfactory, often most unsatisfactory in a relative sense, although the temperature for the month in question was 1.9, 2.8, 1.3, 4.9, 5.0, 6.1, 2.7 and 4.2 respectively above the average for that month. Nevertheless, although temperature is seemingly not the direct vital governing cause of bad results, it is a most potent indirect factor in influencing unsatisfactory "findings." Nor are the reasons far to seek. Intensely cold weather may interfere seriously with filter bed operations, and may, through burst pipes, taps left running, etc., lead to greatly increased consumption of water, which inevitably means increased rates of filtration, with consequent deterioration of the supply.

Algal Policy

At the very commencement of the year 1918 two of the Walthamstow reservoirs (East and West Warwick) showed slight evidence of the beginning of growths of Asterionella, etc. An immediate decision as regards treatment seemed to be imperative, and, in consultation with the engineering department, it was agreed to adopt measures to restrain forthwith the growths in the reservoirs already affected, and to anticipate development as far as possible in the other non-affected ones by treating the raw Lee water as it entered the first (High Maynard) of the chain of reservoirs in the Lee Valley, and continuing such treatment, according to the daily consumption of water, until the time of the year had passed when these troubles are especially active and seriously embarrass the work of sand filtration.

The whole of the water from these reservoirs (excepting Banbury and Lockwood) eventually passes down the East London aqueduct to be filtered at Lee Bridge (Clapton). The laboratory filtration figures for the critical month of March were 122 c.c. per minute in 1916, 77 in 1917, and 239 in 1918. It is too early to speak with assurance yet, but the results so far obtained are most gratifying, assuming always that laboratory results can be trusted to indicate actual sand filtration experiences. The cost of copper sulphate has gone up greatly from a pre-war cost of £21 17s. 6d. to £64 2s. 6d. a ton, but the price of labor and the extraordinary difficulty of securing extra assistance for filter-bed work probably goes far to counterbalance this disadvantage. It remains, however, for the engineering department to estimate the increased cost to the board when filter beds choke up in a few days instead of working for several weeks or even months. The matter, for a variety of reasons, is not a proportional one, and so the "number of acres of filter beds cleaned" is not necessarily the true criterion of the actual expenditure incurred. It is desirable, however, that some approximate figures should be available to compare with the cost of treatment, which involves no calculations beyond the price of the chemical, the number of gallons treated, and the working expenses associated with such treatment. For example, with a dose of 1 in 4 millions (= 2.5 lbs. per million gallons) the war price would be about 1s. 5d. per million gallons of water treated. The balance in favor, or the reverse, of artificial algicidal treatment does not end here, for filtration difficulties, as is freely admitted by the engineers, tend in the direction of a less pure water being supplied to consumers, apart from questions of taste, which are liable to develop at any time. The writer considers that some note should also be taken of the circumstance that serious filtration troubles may, and indeed do, turn the attention of the staff, in more than one department, from other matters which are of equal, if not more pressing, importance in the interests of the Board. The subject is neither simple nor unimportant, and demands a policy of imagination rather than one of stagnation.

Of course, it may be said that there is no proof that the good filtration results were really due to the treatment. Against this there is the evidence of what took place in March and April of last year, when the filtration difficulties were almost insurmountable. Further, a comparison between Banbury reservoirs (untreated water) and East London aqueduct (treated water) on the same date (March 14th, 1918) shows a great growth of Asterionella, Cyclotella, and some Fragillaria in the former, and hardly any growth in the latter. The presumption is very strong that the East London aqueduct water would have presented a parallel picture to the one of the Banbury reservoir water, had not treatment been promptly put into operation.

ENGINEERING MEETING AT HALIFAX

FOLLOWING is the tentative programme announced for the third general professional meeting of the Engineering Institute of Canada, to be held September 11th to 13th, inclusive, at Halifax, N.S. :—

Wednesday morning session—Address of welcome by the Lieutenant-Governor of Nova Scotia; Address by the Mayor of Halifax; Business, if any; Papers; Lunch at the Green Lantern.

Wednesday afternoon session—Automobile trip to terminals and devastated area; tea at Waegwoltic.

Thursday morning session—Papers; Luncheon given by the Commercial Club.

Thursday afternoon session — Papers; Excursion around harbor.

Thursday evening session—Paper on the "Quebec Bridge" by G. F. Porter.

Friday morning session—Papers.

Friday afternoon session—Excursion.

J. L. Allan, A. J. Barnes and J. W. Rowland are the members of the committee on papers; L. H. Wheaton, P. A. Freeman and R. McColl are the entertainment committee; W. P. Morrison, F. H. MacKenzie and J. R. Freeman are the committee on transportation and hotels.

According to a statement by E. M. Dechene, deputy minister of the Department of Lands and Forests, Province of Quebec, an investigation of the water power development in that province has already revealed a total of 810,000 h.p. developed, not including hardly any of the plants under 1,000 h.p. capacity. Including the smaller plants, Mr. Dechene estimates that the grand total will reach 850,000 h.p. A detailed statement showing developments for each river will be given out by the department at a later date.

The National Research Council of the United States, acting as the Department of Science and Research of the Council of National Defense, has appointed a committee to investigate the fatigue phenomena of metals. Professor H. F. Moore, of the Engineering Experiment Station of the University of Illinois, is chairman. The committee is charged with the responsibility of developing a knowledge of the strength and durability of metals subjected to repeated stresses, such as ship structures, crank shafts of aircraft engines and heavy ordnance. It is expected that much of the experimentation required will be done in the laboratories of the University of Illinois at Urbana under the personal direction of Prof. Moore.

EFFECT OF TIME OF MIXING ON THE STRENGTH OF CONCRETE

By Prof. Duff A. Abrams

(Continued from last week's issue)

THE data of the tests are given in Tables 6 to 10 inclusive.* Notes accompanying the tables give details of the mixes, etc., for each series. Only average values are given for compressive strength and wear, except in Series 81, where the results of individual tests are given. Values for compressive strength are the average of four or five tests from the same batch; in Series 97, "Effect of Temperature of Mixing Water," duplicate batches were mixed on different days. In Series 96, "Effect of Rate of Rotation of Mixer Drum," triplicate batches were mixed on different days for one consistency, for the purpose of studying the uniformity of such tests.

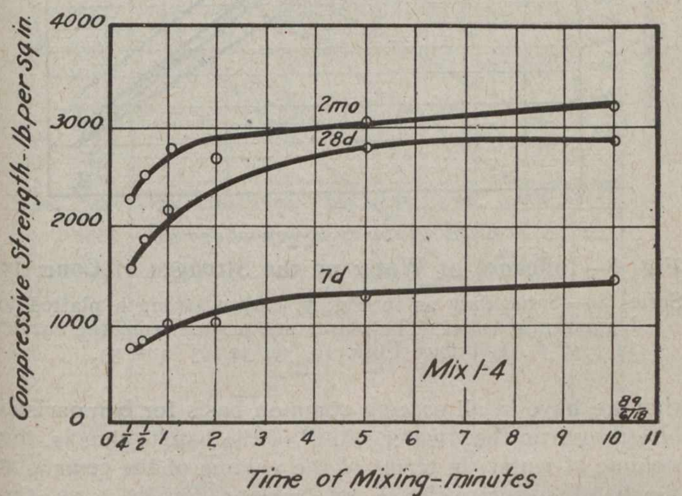

Fig. 4—Effect of Time of Mixing on the Strength of Concrete

Series 89—Each value is the average of 24 compression tests of 6 by 12 in. cylinders from batches of 6 different consistencies. Compare Figs. 21, 23, 25, 27 and 29.

*See supplement inserted in centre of this issue.

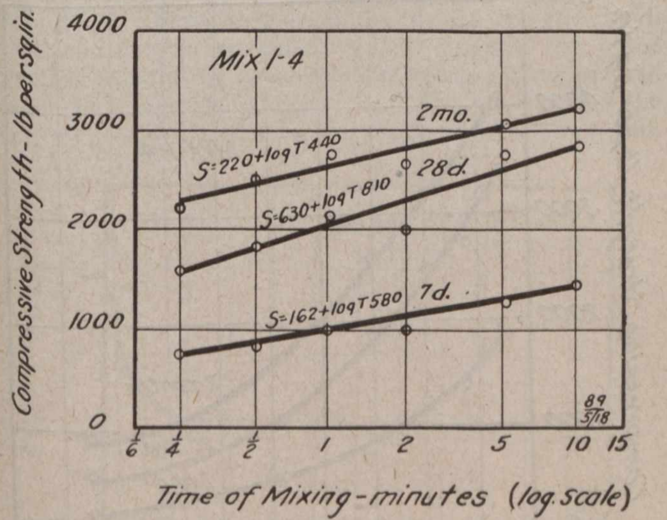

Fig. 5—Effect of Time of Mixing on the Strength of Concrete

Series 89—Same data as in Fig. 4, except time of mixing is platted to logarithmic scale. The equations require that time be expressed in seconds. Compare Fig. 30. Error: Equation for 2 mo. curve should read S = 1650 + 550 log T.

Most of the data from the tests have been platted in diagrams. In several instances curves have been platted for only a portion of the values; for instance, more emphasis has been given to the 28-day than to the 7-day tests.

Owing to numerous instances of overlapping in the different test series it seems best to discuss the data under several headings, instead of taking up each series separately.

Effect of Consistency on the Strength of Concrete

The remarkable influence of the quantity of mixing water on the strength and other properties of the concrete has been demonstrated very forcefully in all series in which variations in consistency were introduced. Owing to the importance of this factor in any consideration of the tests, the discussion of the effect of consistency is given first.

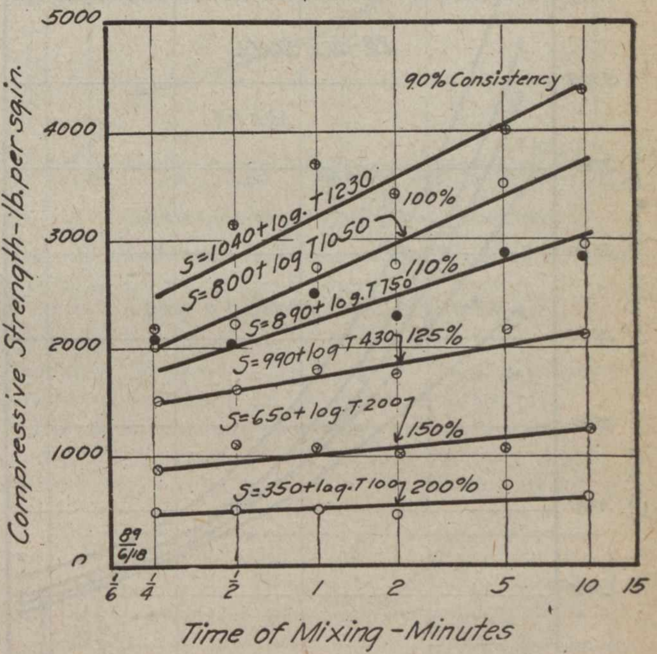

Fig. 6—Effect of Time of Mixing on the Strength of Concrete

Series 89—28-day tests. Each value is the average of 24 tests. Similar curves may be drawn from the data for tests made at 7 days and 2 months. The equations require that time of mixing be expressed in seconds. Compare Figs. 22, 24, 26, 28 and 30.

Many different methods have been used for indicating the consistency of concrete:

(1) Total water as a percentage of the weight of the dry materials.

(2) Total water as a percentage of the weight of the finished concrete.

(3) Total water as a percentage of the weight of the cement.

The first method is the one which is universally used in cement and mortar tests. In the tests made in this laboratory we have preferred to express the water in terms of the volume of the cement, considering 94 lbs. of cement as 1 cu. ft. This method of indicating the water content of concrete is not essentially different from (3). However, since volumetric measurements are used for cement and aggregate, it seems desirable to use volumes for the water also, for sake of uniformity. Methods (1) and (2) above are objectionable, since with the same quantity of water, widely different values are obtained, due to variation in the unit weights of the aggregate.

Under "Test Pieces," in last week's issue, a list was given of the factors which determine the quantity of water which must be placed in the batch. Remember that all of the water used should not be credited to the cement; a certain quantity will be absorbed by the aggregate. In some instances the absorbed water is a considerable proportion of the whole amount. The water absorbed by the aggregate should be deducted in computing the volume of water which affects the action of the cement.

For given concrete materials (that is, cement, water and aggregate) the amount of water which affects the cement may be varied in the following ways:

(1) For the same mix and same grading of aggregate use different quantities of water, thus producing concretes of varying degrees of "wetness."

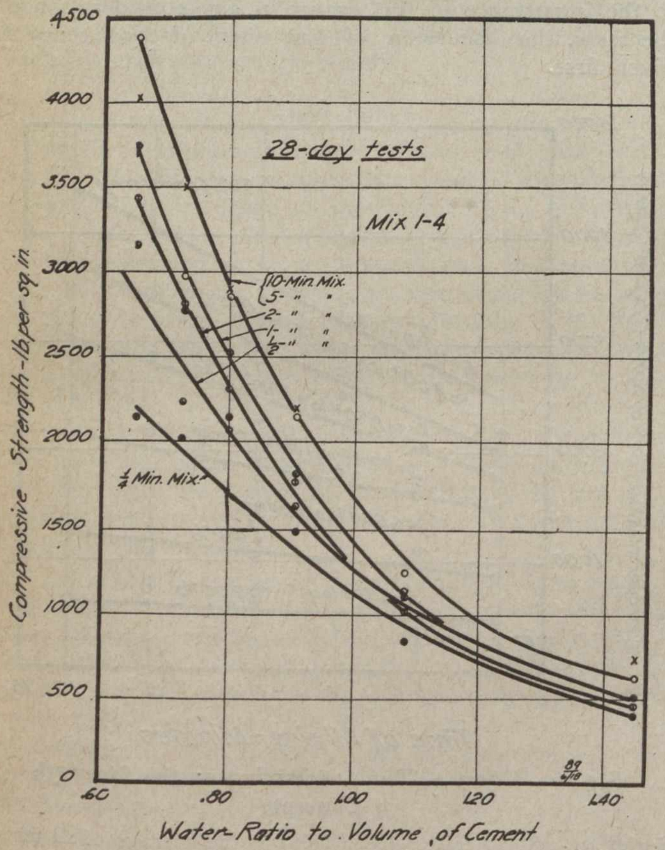

Fig. 7—Influence of Water on the Strength of Concrete
Series 89—Water-strength curves for each time of mixing. Each value is the average of 4 tests from the same batch. Water content calculated as a ratio of the volume of cement. Similar curves may be drawn from data for tests made at 7 days and 2 months. Compare Figs. 9, 31, 33, 44 and 52.

(2) Change the quantity of cement (the mix) with the same grading of aggregate, mixing to the same plastic condition. The richer mixes will, of course, require a smaller percentage of water as compared to the cement than the lean mixes.

(3) With the same mix and the same relative plasticity, change the grading of the aggregate from coarse to fine, etc. The mixes with a preponderance of fine material will require most water.

(4) Any combination of two or all of the above methods may be used simultaneously; for instance, we may wish to compare a stiff 1:2 mix, using sand graded 0-28 with a wet 1:5 mix, using aggregate graded 0-1½ in.

In (4) every factor which affects the strength (the quantity of cement, grading of aggregate and relative consistency) has been changed. It will be shown below

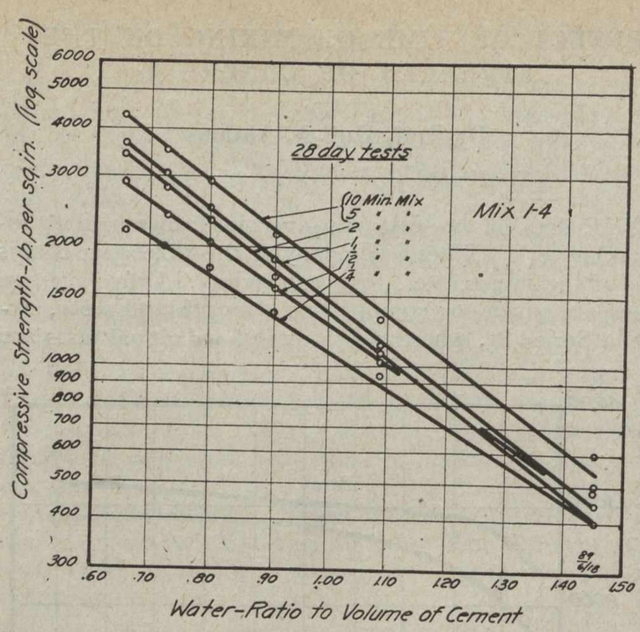

Fig. 8—Influence of Water on the Strength of Concrete
Series 89—Same data as in Fig. 7, except strength platted to logarithmic scale. The points are platted from the curves in Fig. 7. Compare Figs. 10, 32, 34, 45 and 53.

that we have in all cases a common basis for comparison of strength in the "water ratio" of the batch; that is, the volume of water, in terms of the volume of the cement in the batch using one sack of cement (94 lbs.) as the equivalent of 1 cu. ft.

In series 89 the mix and grading of aggregate were maintained constant, but the water content was varied from a rather stiff mix to a very wet one. In this series both compression and wear tests were made. The influence of water on the strength of concrete in this series is shown in Fig. 7. It is seen that the strength decreases with the water content. If the values are platted to a logarithmic scale of strengths, as in Fig. 8, this relation is expressed by a straight line. The path of these curves is expressed by an equation of the form,

$$S = \frac{A}{B^x} \qquad (1)$$

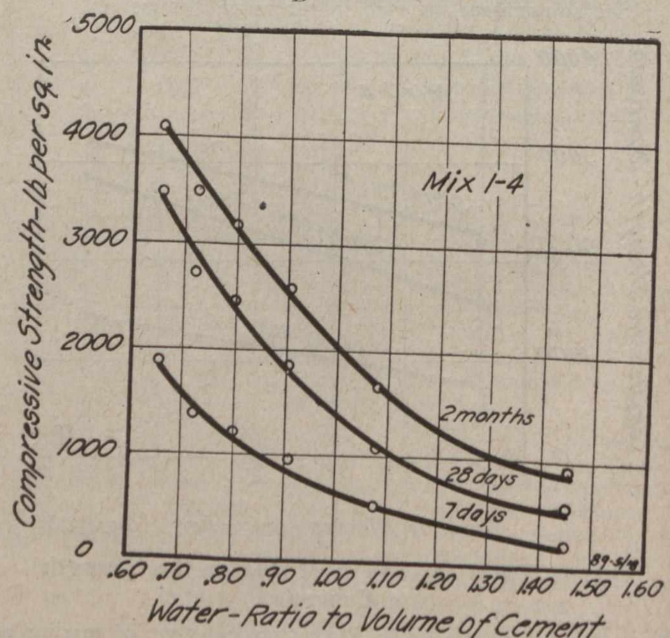

Fig. 9—Influence of Water on the Strength of Concrete
Series 89—Each point is the average of 24 tests, from 6 times of mixing. Compare Figs. 7, 31, 33, 44 and 52.

Where S = compressive strength at a given age.
x = water ratio of the cement.
A and B are constants for a given cement and given conditions of test.

A similar set of curves is platted in Fig. 10, a separate curve being drawn for each age. The change in water

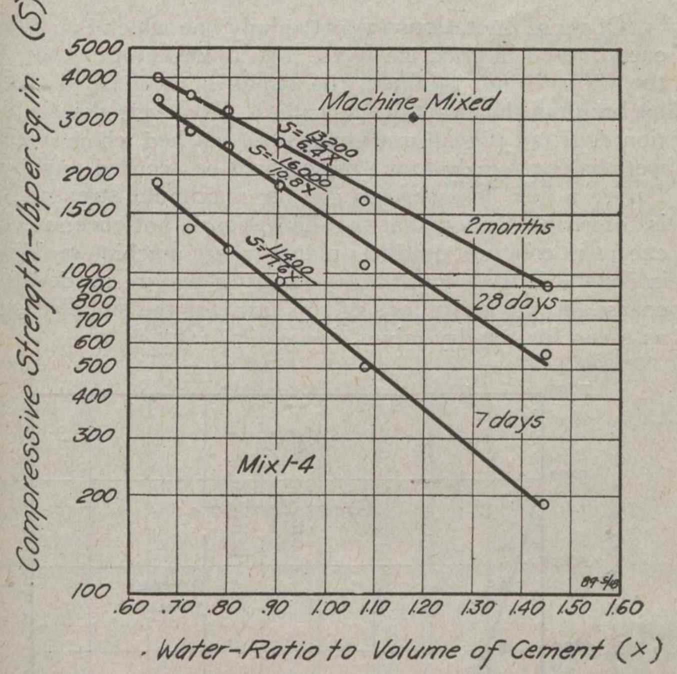

Fig. 10—Influence of Water on the Strength of Concrete

Series 89—Same data as in Fig. 9, strength platted to logarithmic scale. The points are platted from the curves in Fig. 9. Each value is the average of 24 tests, from 6 times of mixing. Compare Figs. 8, 10, 32, 34, 45 and 53.

content in this series was made in accordance with method (1) mentioned above.

In Series 93 the water content was varied on account of differences in the mix, using aggregate of a given grading, and also due to differences in the grading, using concrete of a given mix. In both instances the concrete was mixed to the same plasticity. The influence of water on the compressive strength in this series is shown in Figs. 31-34. Separate curves are drawn for the hand-mixed and machine-mixed concrete. It will be noted here that exactly the same relation exists as was pointed out above in discussing Series 89. The variation in the water content in these tests was made in accordance with

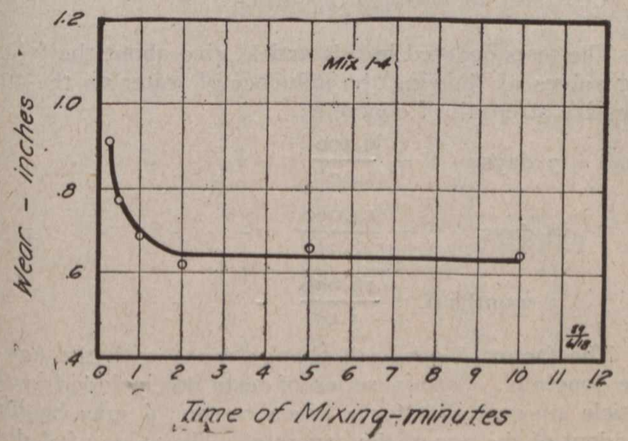

Fig. 11—Effect of Time of Mixing on the Wear of Concrete

Series 89—Age 2 mo. Each value is the average of 30 tests from 6 different consistencies.

methods (2) and (3) mentioned above. Figs. 44, 45, 52 and 53 show the same influence of water on the strength of concrete from still other series of tests. The curves in Fig. 52 are sensibly straight lines, since the range of constituencies is very narrow. It is the narrow range in consistencies which has been generally used in tests that has led to the erroneous conclusion that the strength of concrete is a linear function of the amount of water used. The relation is, of course, sensibly a linear one for any narrow range in consistency. This means simply that the tangent to any point of the curves in Figs. 7, 9, etc.,

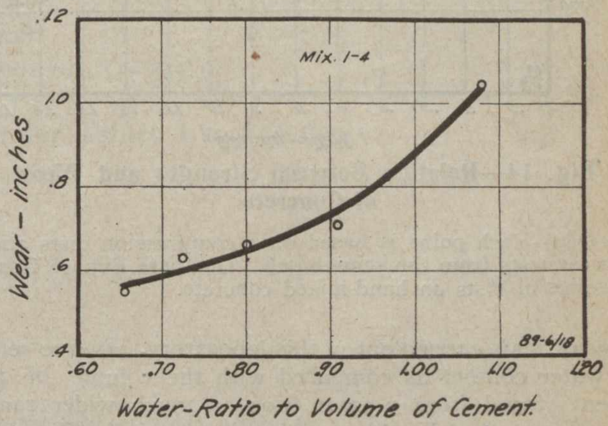

Fig. 12—Influence of Water on the Wear of Concrete

Series 89—Age 2 mo. Each point is the average of 30 tests, from 6 different times of mixing.

is sensibly the same as the curve. The true relation for all parts of the range are given by equation (1).

The water content expressed as a fraction of the volume of the cement in the batch is the only satisfactory criterion for strength of concrete made up of given

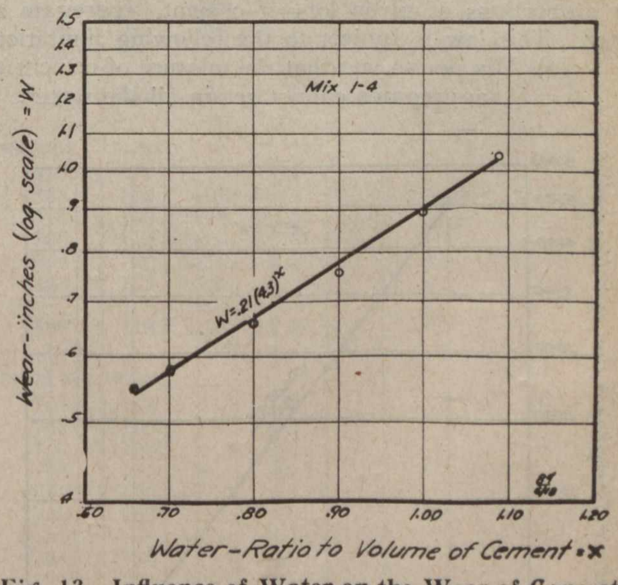

Fig. 13—Influence of Water on the Wear of Concrete

Series 89—Same data as in Fig. 12, except depth of wear is platted to logarithmic scale.

materials mixed in widely different proportions. It will be seen from the tests included in this article that it makes no difference why the water content is changed; the result is exactly the same in the end. This change in water may be due to changing the plasticity of the mix or the use of richer mixes or aggregates of different gradings, or combinations of these factors. The influence of water on the strength of concrete discussed above has been brought out in the same way by probably a dozen different

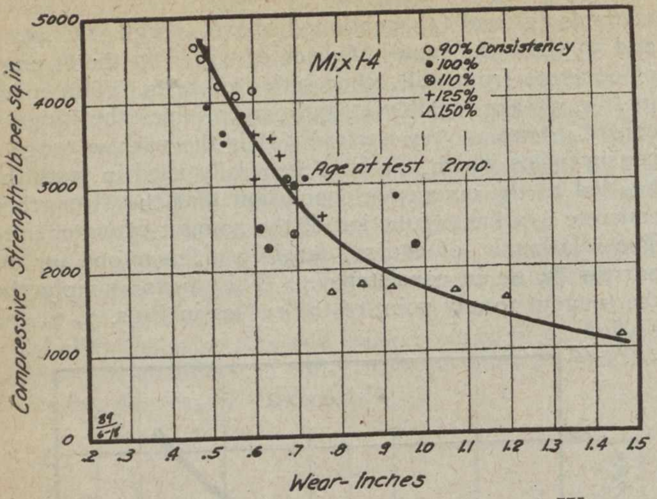

Fig. 14—Relation Between Strength and Wear of Concrete

Series 89—Each point is based on 4 compression tests and 5 wear tests from the same batch. Compare Fig. 16 from a series of tests on hand-mixed concrete.

series of tests carried out in this laboratory. In one series the water content as compared with the volume of the cement varied from 0.35 to 4.00—a much wider range than was covered by the tests herein reported. (See *The Canadian Engineer*, June 6th, 1918.)

The constants in equation (1) may be determined directly from the diagrams given in Figs. 8, 10, 32, 34, 45 and 53. The constant A is determined by projecting the curve to the left to intersection with the ordinate at zero water content. B is the slope of the straight line derived by platting the strengths to a logarithmic scale.

Equation (1) given above may be considered as expressing the law of concrete strength for variations in the proportions of given lots of cement, aggregate and water. This law is subject to the following limitations:

(*a*) Mix not so wet that the mixture of cement and aggregates cannot retain all the water.

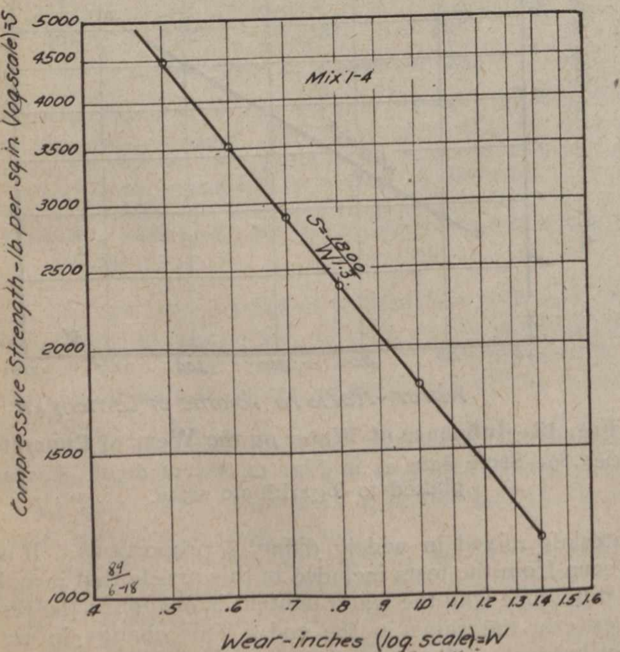

Fig. 15—Relation Between Strength and Wear of Concrete

Series 89—Same data as in Fig. 14; both strength and depth of wear platted to logarithmic scale. Compare Fig. 17.

(*b*) Mix not too dry for maximum strength for the condition under which the concrete is placed. (That is, the concrete is in a plastic condition.)

(*c*) Aggregate grading not too coarse for maximum strength with the quantity of cement and water used.

Of these limitations (*a*) is the only one which is usually encountered in concrete work. In mixes so wet that all the water is not retained, the strength will be a little higher than the equation indicates. However, this condition does not prevail until mixes are reached which are so wet that extremely low strength will be secured anyhow. Before a mix becomes too dry for maximum strength, it is so harsh-working that this limitation is not encountered except in concrete products plants where machine molding is done. It is seldom that the aggregates are graded too coarse for the limitations of this law, for the same reason as given for the dry mixes.

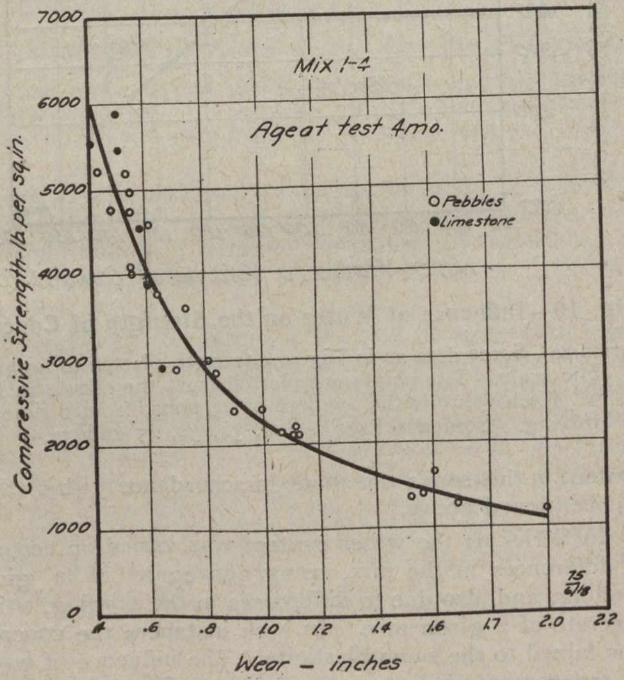

Fig. 16—Relation Between Strength and Wear of Concrete

Series 75—Data similar to Fig. 14; 1-4 hand-mixed concrete; age 4 mo. Each value is based on 5 compression tests and 5 wear tests. Detailed data from Series 75 (Effect of Consistency and Curing Conditions on the Wear of Concrete) not given in this article.

The tests covered in this article give about the following values as showing the influence of water on the compressive strength of concrete:

$$\text{7 days} \quad S = \frac{9{,}200}{14.0^x} \qquad (3)$$

$$\text{28 days} \quad S = \frac{14{,}000}{8.2^x} \qquad (4)$$

$$\text{3 months} \quad S = \frac{16{,}600}{5.9^x} \qquad (5)$$

The factor A does not change much with the age of the concrete. Certain series of tests not included in this article suggest that for a given cement A may be independent of the age of the concrete. The value of A does, however, depend on the quality of the cement. B varies widely with the age of the concrete, time of mixing and other conditions.

TABLE 10

EFFECT OF TEMPERATURE OF MIXING WATER ON THE STRENGTH OF CONCRETE—(Series 97)

Compression tests of 6 by 12-in. cylinders.
1-4 mix by volume.
Each batch mixed 1 min.—18 revolutions.
Mixing was begun after all materials were in the drum.
Specimens made in steel forms.
Cylinders stored in damp sand; tested damp.
Each value is the average from tests of 5 cylinders from the same batch.
All values in a horizontal line are from a single batch of concrete.
15 cylinders were made from each batch; the 1st, 4th, 7th, 10 and 13th were tested at 7 days; the 2nd, 5th, 8th, 11th and 14th, at 28 days, etc.

Ref. No.	Date Mixed (1918)	Temperature C° Mixing Water	Aggregate	Concrete	Air	Test for Consistency Penetration inches	Compressive Strength lb. per sq. in. 7d.	28d.	3m.	Mean Error Per cent. 7d.	28d.	3m.
						Relative Consistency 90%—Water .68 of Volume of Cement						
1	1–31	0	13.0	12.3	13.5	1.0— 1.3	1420	3660	4940	7.4	3.6	7.3
2	2–7	0	14.0	13.5	15.0	1.0— 2.0	1680	3250	4750	4.1	5.4	6.1
3	1–31	10	13.0	13.5	14.0	1.0— 1.3	1450	3250	4990	4.1	8.7	3.2
4	2–7	10	14.0	14.5	15.0	1.0— 2.0	1870	3540	4820	5.0	5.6	3.4
5	1–31	20	13.0	15.5	15.0	1.0— 1.3	1470	3440	5050	10.8	11.6	2.4
6	2–7	20	14.0	16.0	15.0	1.0— 2.0	1620	3290	4590	4.7	3.8	13.2
7	1–31	30	13.0	17.0	15.5	1.0— 1.3	1490	3660	5130	13.9	11.1	2.0
8	2–7	30	14.0	18.2	15.0	1.0— 2.0	2090	3610	4850	4.0	5.2	5.8
9	1–31	40	13.0	19.0	14.7	1.0— 1.3	1490	3410	4830	5.8	8.6	6.9
10	2–7	40	14.0	19.8	15.2	1.0—	2090	3560	4790	10.0	7.8	5.4
11	1–31	50	13.0	21.0	15.0	1.0— 1.3	1450	3410	4630	6.9	6.7	7.0
12	2–7	50	14.0	22.5	15.5	1.0—	1820	3390	4690	5.3	2.5	3.1
13	2–1	60	12.5	20.0	12.8	0.5— 1.3	1680	3460	5130	6.1	10.7	6.8
14	2–7	60	14.0	23.0	15.7	1.0—	1880	3630	4740	15.2	9.4	12.3
15	2–1	70	12.5	23.0	14.0	0.5— 1.3	1600	3500	5030	8.1	9.6	4.7
16	2–7	70	14.0	25.5	15.8	1.0—	2040	3540	4880	7.3	4.1	4.7
17	2–1	80	12.5	25.0	15.0	0.5— 1.3	1550	3350	4710	14.5	8.2	6.0
18	2–7	80	14.0	27.0	16.5	1.0—	2110	3800	4820	13.5	3.0	5.1
19	2–7	90	14.0	28.0	15.7	1.0—	1810	3320	4450	10.8	7.3	10.2
20	2–9	90	15.5	28.0	15.5	1.0—	2120	3520	4660	4.1	9.8	11.0
21	2–11	100	14.0	29.2	15.0	1.0—	1970	2930	4320	3.6	12.2	7.4
21A	2–12	100	14.5	30.5	15.0	1.0—	1540	3050	3480	9.4	13.1	13.3
		Average	13.6	21.0	15.0		1740	3440	4740			
						Relative Consistency 100%—Water .76 o Volume of Cement						
22	1–30	0	14.0	11.5	13.5	2.0— 3.5	1120	3030	4580	3.7	3.4	5.7
23	2–6	0	12.5	11.0	14.0	2.0— 2.5	1430	3310	4650	6.8	5.1	3.9
24	1–30	10	14.0	13.0	14.0	2.0— 3.5	1200	3000	4370	3.5	3.1	12.1
25	2–6	10	12.5	13.0	14.0	2.0— 4.0	1240	3070	4420	8.3	3.5	3.7
26	1–30	20	14.0	15.5	14.5	2.0— 3.5	1170	3010	4270	6.6	3.4	5.3
27	2–6	20	12.5	15.5	14.2	2.0— 5.0	1330	3150	4490	2.5	3.5	4.3
28	1–30	30	14.0	17.6	14.5	2.5— 5.0	1260	3000	4390	5.9	6.4	8.2
29	2–6	30	12.5	18.0	14.2	2.0— 3.0	1260	2980	4390	7.3	2.6	4.4
30	1–30	40	14.0	19.5	14.5	2.5— 5.5	1210	2960	4500	3.5	5.2	4.9
31	2–6	40	12.5	20.5	14.2	2.0— 4.0	1540	3240	4610	7.2	4.7	6.1
32	1–30	50	14.0	22.0	14.8	2.0— 3.0	1150	2990	4430	3.5	2.4	2.8
33	2–6	50	12.5	22.5	14.7	2.0— 2.5	1590	3400	4580	8.8	3.8	10.2
34	1–30	60	14.0	24.2	15.0	2.0— 3.5	1180	3100	4220	7.4	4.3	6.9
35	2–6	60	12.5	23.8	14.7	1.0— 2.0	1530	3340	4680	11.5	5.7	4.1
36	1–30	70	14.0	27.0	15.3	2.0— 4.0	1210	3100	4120	7.1	10.7	11.2
37	2–6	70	12.5	27.0	15.0	1.0— 2.5	1480	3160	4510	8.6	7.6	4.9
38	1–30	80	14.0	28.5	15.5	1.0— 1.5	1200	3050	4230	15.8	1.9	8.5
38A	2–6	80	12.5	28.3	15.3	1.0— 2.0	1480	3090	4180	7.2	2.8	8.9
40	2–6	90	12.5	31.6	15.7	1.0— 2.0	1170	2870	3980	19.6	11.6	4.5
41	2–9	90	15.5	29.0	15.5	1.0—	1990	3460	4180	5.4	4.0	11.7
42	2–11	100	14.0	30.0	15.0	1.0—	1830	3160	4520	3.2	6.2	6.9
42A	2–12	100	14.5	33.5	15.2	1.0— 2.0	1610	2690	4410	7.5	9.0	8.1
		Average	13.4	22.3	14.8		1360	3060	4360			
						Relative Consistency 110%—Water .83 of Volume of Cement						
43	1–29	0	12.0	9.5	13.0	4.0— 8.0	960	2720	4340	5.3	2.3	6.2
44	2–4	5	9.0	9.5	9.5	4.0— 7.0	1050	2720	4270	4.8	6.9	1.8
45	1–29	10	12.0	12.0	13.0	4.0— 8.0	1110	2940	4590	5.6	4.7	1.2
46	2–4	15	9.0	11.5	9.5	4.0— 7.0	1000	2610	3860	9.5	9.4	8.5
47	1–29	20	12.0	15.0	13.0	4.0— 8.5	980	2580	4010	5.8	3.7	6.9
48	2–4	25	9.0	14.0	9.5	4.0— 8.0	1000	2790	3830	7.7	7.8	7.6
49	1–29	30	12.0	17.2	13.0	4.0— 8.5	1000	2560	4120	2.3	4.7	5.8
50	2–4	35	9.0	17.0	9.0	4.0— 7.5	1190	2730	3870	11.4	2.0	2.4
51	1–29	40	12.0	20.0	13.0	4.0— 8.5	1130	2740	4440	6.2	9.3	3.6
52	2–4	45	9.0	19.8	8.8	4.0— 9.0	1180	2420	4210	8.5	9.4	7.8
53	1–29	50	12.0	22.3	13.0	4.0— 7.0	1000	2920	4290	11.0	3.8	6.1
54	2–4	50	9.0	22.0	8.5	4.5— 8.0	1050	2610	3810	3.8	13.0	7.0
55	1–29	60	12.0	24.5	13.0	4.0— 7.0	1040	2720	4300	6.0	4.8	7.6
56	2–4	60	9.0	23.5	10.0	3.0— 6.0	1050	2550	3710	7.9	7.8	10.1
57	1–29	70	12.0	27.0	13.5	3.0— 6.0	1090	3010	4370	12.3	10.6	10.2
58	2–4	70	9.0	26.0	10.5	3.0— 4.5	1130	2700	4030	15.1	6.2	5.2
59	1–29	80	12.0	31.0	13.7	3.0— 6.0	960	2450	3850	7.0	7.4	9.6
59A	2–4	80	9.0	28.2	10.8	2.0— 3.0	1170	2610	3810	13.6	4.1	16.6
60	1–29	85	12.0	34.0	13.7	3.0— 6.0	1170	2700	4190	10.3	14.5	7.8
61	2–4	91	9.0	32.0	11.2	2.0— 3.5	1110	2890	3840	2.9	9.7	5.9
62	2–9	90	15.5	30.0	15.5	4.0— 6.0	1320	2520	3820	7.4	5.3	14.3
63	2–11	100	14.0	34.8	15.0	1.0— 2.0	1520	2880	4240	3.9	4.6	9.9
63A	2–12	100	14.5	34.7	15.0	2.0— 3.5	1480	3080	4300	6.2	4.5	9.0
		Average	11.0	22.5	11.9		1120	2720	4090			
						Relative Consistency 125%—Water .95 of Volume of Cement						
64	2–5	0	10.5	9.0	11.5	3.0— 4.5	900	2550	3980	6.3	3.4	12.6
64A	2–8	0	15.0	12.0	16.0	8.0—10.0	890	2100	3430	8.8	5.0	5.5
65	2–5	10	10.5	10.5	11.5	8.0—11.0	740	2080	3300	10.4	15.9	7.6
65A	2–8	10	15.0	13.0	16.0	8.0—10.0	890	1860	3280	5.5	6.7	7.1
66	2–5	20	10.5	14.0	12.0	8.0—11.0	720	1830	3160	4.3	12.6	9.2
66A	2–8	20	15.0	16.5	16.0	8.0—10.0	850	1710	3250	11.8	8.5	8.8
67	2–5	30	10.5	15.5	11.7	8.0—11.0	810	2080	3560	10.4	4.3	8.8
67A	2–8	30	15.0	19.0	16.0	8.0—11.0	1030	1900	3320	7.9	12.8	7.8
68	2–5	40	10.5	19.0	12.0	8.0—11.0	840	1990	3310	9.1	9.8	5.5
68A	2–8	40	15.0	22.0	16.0	8.0—11.0	1120	2170	3760	5.8	4.5	6.5
69	2–5	50	10.5	22.2	12.0	8.0—11.0	990	2410	3680	8.2	12.4	2.5
69A	2–8	50	15.0	24.5	16.0	8.0—11.0	1170	2210	3610	8.4	8.4	10.3
70	2–5	60	10.5	25.3	12.3	8.0—11.0	1070	2500	3660	3.7	11.8	8.3
70A	2–8	60	15.0	27.5	16.0	8.0—11.0	1030	2280	3450	5.7	7.1	3.8
71	2–5	70	10.5	28.0	12.3	8.0—11.0	880	2200	3430	8.7	9.5	1.6
71A	2–8	70	15.0	30.5	16.0	8.0—11.0	1160	2310	3620	12.4	7.6	5.7
72	2–5	80	10.5	31.0	12.5	8.0—11.0	1010	2540	3740	7.0	5.5	5.3
72A	2–8	80	15.0	32.0	16.5	8.0—11.0	820	1790	2790	7.2	6.3	7.2
73	2–5	90	10.5	33.5	12.5	8.0—11.0	980	2610	3910	11.8	4.6	6.9
73A	2–8	90	15.0	36.0	16.7	8.0—11.0	980	2180	2800	7.6	7.3	12.1
74	2–11	100	14.0	33.7	14.5	5.0— 9.0	1050	2210	3300	7.9	4.0	11.0
74A	2–12	100	14.5	35.5	15.0	7.0—10.0	920	2100	3480	5.1	10.6	5.3
		Average	12.9	23.2	14.3		950	2160	3450			

TABLE 11

See Reverse Side of This Page

TABLE 12

EFFECT OF TIME OF MIXING ON THE STRENGTH OF CONCRETE

Based on 28-day compression tests of 6 by 12-in. cylinders.
The values given in the table are percentages of the strength of the same concrete mixed for 1 min.
These values may be expressed by an equation of the form

$$P = k + n \log. t$$

When P = percentage of strength of 1-min. mix
t = time of mixing in seconds
k and n are constants, which depend on the mix, consistency, age and other conditions of the test.
This equation is only another form of (6) above.

Mix	Series No.	Relative Consistency Per cent	Size of Agg.	Strength at Different Mixing Periods as Compared with the Strength at 1 min. (P) ¼m. 15s.	½m. 30s.	¾m. 45s.	1m. 60s.	1½m. 90s.	2m. 120s.	5m. 300s.	10m. 600s.	Comp. strength 28 days in 1-min. mix lbs. per sq. in	Values of Constants in Equation (k)	(n)
1-4	89	90	0-1¼	77	89	95	100	106	112	127	138	3200	+32	39
1-4	89	100	0-1¼	76	88	95	100	107	112	128	141	2650	+28	40
1-4	89	110	0-1¼	81	91	97	100	106	110	123	133	2230	+43	32
1-4	89	125	0-1¼	87	93	97	100	104	106	115	122	1750	+61	22
1-4	89	150	0-1¼	86	93	97	100	104	107	117	124	1000	+58	24
1-4	89	200	0-1¼	90	95	98	100	103	105	112	118	560	+69	17
1-2	93	110	0-1¼	86	93	97	100	104	107	117	124	3450	+57	24
1-3	93	110	0-1¼	76	88	96	100	107	113	129	131	2700	+29	40
1-4	93	110	0-1¼	81	91	97	100	106	110	123	133	2230	+43	32
1-5	93	110	0-1¼	78	89	96	100	107	112	127	138	1800	+33	38
1-6	93	110	0-1¼	78	89	96	100	107	112	127	138	1550	+33	38
1-7	93	110	0-1¼	76	88	95	100	107	113	129	141	1300	+28	41
1-9	93	110	0-1¼	79	89	96	100	106	110	124	135	900	+38	35
1-15	93	110	0-1¼	62	81	92	100	111	119	144	163	350	—12	63
1-5	93	110	0-14	28	64	85	100	120	136	184	222	250	—116	122
1-5	93	110	0-8	39	70	89	100	120	133	176	208	340	—87	107
1-5	93	110	0-4	50	75	90	100	114	125	159	184	440	—49	100
1-5	93	110	0-⅜	79	90	96	100	106	110	125	135	840	+38	35
1-5	93	110	0-¾	73	87	94	100	108	114	132	146	1200	+20	45
1-5	93	110	0-1¼	78	89	96	100	107	112	127	138	1800	+33	38
1-5	93	110	0-2	81	91	96	100	106	109	122	131	1900	+44	32

Tables 6 to 12, inclusive

Forming portion of article on

Effect of Time of Mixing on Strength of Concrete

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N.B.—See last week's issue of The Canadian Engineer for Tables 1 to 5 inclusive.

TABLE 6

UNIFORMITY OF MACHINE-MIXED CONCRETE—(Series 81)

Compression tests of 6 by 12-in. cylinders;
1-4 mix by volume;
Aggregates—sand and pebbles; graded 0-1¼ in.
Time of mixing 1 minute.
Specimens stored in damp sand.
The cylinders in a batch were numbered consecutively; the odd numbers tested at 7 days, the even numbers at 28 days.

Ref. No.	Water Relative Consistency	Ratio to Cement by Vol.	Compressive Strength lb. per sq. in. 7 days	28 days	Mean error *P.C. 7 days	28 days	Weight lb. per cu. ft.	Density	Yield
A	100	.78	1340	2640			147.5	.804	1.121
			1330	2520					
			1310	2500					
			1320	2420					
			1390	2470					
			1380	2440					
			1340	2340					
			1340	2480	2.3	3.8			
B	115	.89	990	1920			146.5	.790	1.142
			990	1990					
			1000	2020					
			1010	2010					
			960	2050					
			1010	2030					
			990	1860					
				2120					
			990	2000	1.8	4.0			
C	130	1.00	870	1580			146.0	.778	1.160
			950	1890					
			920	2020					
			1000	1810					
			970	2110					
			890	2160					
			1080	2200					
				1920					
			950	1960	7.5	10.5			

*Computed from formula $E = \frac{100}{A}\sqrt{\frac{\Sigma v^2}{n-1}}$ Where v is the difference of any value from average, n is the number of values, A is the average.

TABLE 7

A STUDY OF THE TIME OF MIXING CONCRETE—(Series 89)
(Effect of Consistency)

Mix 1-4 by volume.
Compression tests made on 6 by 12-in. cylinders.
Wear tests made in Talbot-Jones rattler; specimens consisted o[illegible] 8 by 5 in. thick; 10 wear blocks in a ring were run for 1800 revolutio[illegible] a charge of 200 lb. cast iron shot.
From each batch 12 cylinders and 5 wear blocks were tested at ages shown, the specimens being numbered in the order of molding.

Kind of Specimen	Specimens Tested at a Given Age 7-day	28-day	2-mo
Compression Cylinders	2, 6, 10, 14	3, 7, 11, 15	4, 8, 12, 16
Wear Blocks	—	—	1, 5, 8, 13, 17

Cylinders stored in damp sand; tested damp. Wear blocks stored in damp sand until 2 days prior to test.

Ref. No.	Time of Mixing min.	Tests of 6 by 12-in. Cylinders: Compressive Strength lb. per sq. in. 7d.	28d.	2m.	Mean Error per cent. 7d.	28d.	2m.	Av	Weight lb. per cu. ft.	Density	Yield	Wear Tests at 2 months: Depth of Wear Ins.	Mean Error Per cent.
		Relative Consistency 90%—Water .655 of Volume of Cement											
1	10	2510	4370	4660	1.9	2.0	4.1	2.7	158.0	.871	1.036	.46	10.2
2	5	2230	4020	4520	4.2	7.9	4.0	5.4	158.0	.871	1.036	.48	4.0
3	2	1740	3440	4060	1.2	9.9	15.3	8.8	157.5	.868	1.040	.56	6.0
4	1	1840	3750	4130	9.2	5.2	12.5	9.0	157.5	.868	1.040	.60	8.4
5	½	1620	3180	4190	8.0	8.6	7.4	8.0	156.0	.860	1.049	.52	7.9
6	¼	1260	2140	2880	31.4	32.0	20.5	28.0	153.0	.844	1.070	.69	19.9
Avge.		1870	3480	4070	9.3	10.9	10.6	10.3	157.0	.864	1.045	.55	9.4
		Relative Consistency 100%—Water .725 of Volume of Cement											
7	10	1640	2930	3960	4.0	3.5	7.5	5.0	156.0	.856	1.055	.49	16.9
8	5	1750	3520	3810	3.2	4.0	20.4	9.2	156.5	.857	1.052	.57	9.0
9	2	1460	2800	3500	5.0	4.6	8.2	5.9	156.0	.856	1.055	.53	5.7
10	1	1380	2780	3620	5.7	4.2	9.8	6.6	156.0	.856	1.055	.53	5.7
11	½	1130	2210	3080	5.7	7.6	6.7	6.7	155.0	.851	1.061	.72	8.3
12	¼	1000	2020	2860	22.6	19.3	9.2	17.0	153.0	.839	1.077	.93	20.2
Avge.		1390	2710	3470	7.7	7.2	10.3	8.4	155.4	.852	1.059	.63	11.0
		Relative Consistency 110%—Water .800 of Volume of Cement											
13	10	1520	2860	3640	12.8	12.5	8.5	11.3	156.5	.852	1.062	.60	7.2
14	5	1500	2900	3550	6.4	3.6	7.8	5.9	156.5	.852	1.062	.64	7.4
15	2	1090	2300	3070	14.2	11.4	7.2	10.9	155.5	.845	1.068	.60	5.4
16	1	1160	2520	3350	4.9	8.8	5.9	6.5	155.5	.845	1.068	.66	8.9
17	½	880	2060	2620	24.1	16.2	13.0	17.8	154.5	.842	1.074	.76	25.5
18	¼	1060	2140	2790	21.4	28.0	22.6	24.0	153.0	.834	1.086	.70	16.0
Avge.		1200	2460	3170	14.0	13.4	10.8	12.7	155.2	.845	1.070	.66	11.7
		Relative Consistency 125%—Water .910 of Volume of Cement											
19	10	1260	2140	2980	.9	14.5	13.1	9.5	154.5	.833	1.084	.69	11.6
20	5	1200	2170	3030	7.6	15.5	4.6	9.2	155.0	.835	1.081	.68	11.5
21	2	1030	1800	2500	14.1	7.8	12.0	11.3	153.5	.827	1.091	.61	13.0
22	1	900	1830	2250	9.9	8.6	16.8	11.8	153.5	.827	1.091	.63	4.5
23	½	710	1640	2400	17.8	22.9	5.8	15.5	154.0	.830	1.088	.69	8.7
24	¼	690	1510	2250	25.0	44.6	42.5	37.4	153.0	.825	1.095	.98	27.6
Avge.		960	1850	2570	12.6	19.0	15.8	15.8	153.9	.830	1.088	.71	12.8
		Relative Consistency 150%—Water 1.080 of Volume of Cement.											
25	10	690	1240	1820	5.4	9.0	7.4	7.3	153.0	.810	1.115	.85	9.4
26	5	560	1090	1780	12.1	21.6	5.6	13.1	152.5	.808	1.118	.92	12.7
27	2	480	1030	1750	9.3	8.5	6.1	8.0	153.5	.814	1.110	.78	20.5
28	1	500	1090	1740	12.1	9.2	8.8	10.0	152.5	.808	1.118	1.06	17.4
29	½	500	1120	1690	4.2	17.2	12.9	11.4	152.0	.806	1.120	1.19	8.4
30	¼	340	880	1200	29.0	36.2	21.7	29.0	151.5	.803	1.125	1.46	2.4
Avge.		510	1080	1660	12.0	17.0	10.4	13.1	152.5	.808	1.118	1.04	11.8
		Relative Consistency 200%—Water 1.450 of Volume of Cement											
31	10	260	620	1110	26.9	31.8	28.4	29.0	149.0	.764	1.181	—	—
32	5	260	730	1040	18.0	25.4	28.2	23.9	150.0	.768	1.176	—	—
33	2	160	460	720	10.8	15.6	12.1	12.8	148.0	.759	1.190	—	—
34	1	150	510	880	11.5	6.7	5.8	8.0	149.0	.764	1.181	—	—
35	½	160	500	940	14.0	15.7	4.5	11.4	148.0	.759	1.190	—	—
36	¼	150	460	840	36.0	42.4	29.0	35.8	147.0	.752	1.200	—	—
Avge.		190	560	920	19.5	22.9	18.0	20.1	148.5	.761	1.186	—	—
		Grand Average for All Consistencies											
	10	1450	2570	3210	7.8	10.9	10.9		155.0	.834	1.085	.64*	10.1*
	5	1280	2470	3040	8.3	11.7	11.2		154.0	.835	1.084	.66*	8.7*
	2	1010	2020	2670	9.8	9.9	9.7		154.0	.831	1.089	.62*	9.3*
	1	1010	2140	2760	8.3	7.4	9.4		154.0	.830	1.089	.69*	9.0*
	½	840	1820	2500	14.0	14.9	9.1		153.0	.827	1.094	.77*	14.0*
	¼	790	1610	2230	26.7	32.9	27.0		152.0	.819	1.106	.91*	17.0*

*Does not include 200% Consistency.

TABLE 8

A STUDY OF THE TIME OF MIXING CONCRETE—(Series 93)

(Effect of Mix and Size of Aggregate)

Compression tests of 6 by 12-in. cylinders.
Mix by volume.
Concrete in this series was mixed to 110% relative consistency.
Aggregates—sand and pebbles from Elgin, Ill.
Mixing was begun after all materials were in the drum.
Machine-mixed cylinders made 16 in a batch; 4 for test at each age. In the order of making No. 1, 5, 9 and 13 were tested at 7 days; No. 2, 6, 10 and 14 at 28 days, etc.
Only one batch of machine-mixed concrete was made for each mix, grading and time of mixing. The mixing of the batches for a given mix and grading were distributed over a period of 4 weeks. All the 10-min. batches were mixed first, the 5-min. next, etc.
Hand-mixed specimens were made for comparison with machine-mixed concrete.
Specimens stored in damp sand; tested damp.

Ref. No.	Mix by Vol.	Water: Ratio to Cement by Vol.	Aggregate: Range in Size	Aggregate: Weight lb. per cu. ft.	Aggregate: Density	Time of Mixing min.	Compressive Strength lb. per sq. in. 7d.	28d.	3m.	Concrete: Weight lb. per cu. ft.	Density	Yield
					Machine-Mixed Concrete							
1	1–2	.60	0–1¼	130.0	.780	10	2440	4410	5960	153.4	.803	1.276
2						5	2420	4080	6220	151.5	[illegible]	1.293
3						2	1760	3550	5180	152.8	.79[illegible]	1.281
4						1	1330	3400	5060	152.0	.794	1.286
5						½	1420	3160	5160	150.0	.784	[illegible].305
6						¼	1180	2970	4690	150.2	.786	1.[illegible]3
	Average						1760	3600	5380	151.6	.793	1.291
7	1–3	.70	0–1¼	130.0	.780	10	2100	3760	4980	154.0	.823	1.143
8						5	1720	3480	5260	153.2	.820	1.148
9						2	1390	3300	4960	152.8	.816	1.152
10						1	980	3000	4760	153.2	.821	1.148
11						½	840	2300	4360	152.7	.816	1.153
12						¼	810	2060	4000	151.2	.809	1.164
	Average						1310	2990	4720	152.8	.818	1.151
13	1–4	.81	0–1¼	130.0	.780	10	1380	2380	3730	153.2	.831	1.085
14						5	1340	2730	4100	153.2	.831	1.085
15						2	1090	2310	4330	154.0	.835	1.080
16						1	760	2320	3430	153.4	.832	1.083
17						½	650	2060	3850	153.5	.833	1.082
18						¼	600	1820	3240	152.2	.826	1.092
	Average						960	2270	3780	153.2	.831	1.084
19	1–5	.91	0–1¼	130.0	.780	10	1380	2600	3460	154.1	.830	1.057
20						5	1170	2340	3460	153.5	.826	1.062
21						2	590	1370	2620	153.2	.824	1.064
22						1	490	1670	2620	153.3	.825	1.063
23						½	460	1490	2880	152.6	.820	1.060
24						¼	460	1520	3150	153.0	.823	1.065
	Average						760	1830	3030	153.3	.825	1.062
25	1–6	1.01	0–1¼	130.0	.780	10	1260	2370	3510	154.4	.849	1.013
26						5	860	1910	3150	153.2	.844	1.020
27						2	760	1910	3040	153.5	.845	1.018
28						1	440	1450	2640	153.1	.843	1.021
29						½	450	1340	2270	153.3	.845	1.019
30						¼	400	1440	2320	153.0	.842	1.022
	Average						700	1740	2820	153.4	.845	1.019
31	1–7	1.10	0–1¼	130.0	.780	10	1020	1920	2880	154.8	.857	.991
32						5	780	1640	2790	153.1	.847	1.002
33						2	790	1870	3110	153.8	.852	.997
34						1	480	1420	2160	153.0	.847	1.002
35						½	440	1240	2280	153.2	.848	1.001
36						¼	350	1020	1700	152.8	.845	1.004
	Average						640	1520	2490	153.4	.849	1.000
37	1–9	1.32	0–1¼	130.0	.780	10	650	1240	2040	154.5	.861	.969
38						5	460	1100	1990	153.2	.854	.977
39						2	480	1110	1980	153.9	.859	.972
40						1	220	720	1370	151.3	.844	.989
41						½	280	720	1400	149.1	.831	1.003
42						¼	260	810	1460	150.0	.837	.997
	Average						390	950	1710	152.0	.848	.984
4[illegible]	1–15	1.94	0–1¼	130.0	.780	10	320	530	950	150.0	.843	.963
[illegible]						5	250	560	970	149.9	.842	.964
[illegible]						2	150	360	570	144.7	.814	.998
[illegible]						1	140	460	910	143.7	.808	1.005
[illegible]						½	110	310	470	142.6	.803	1.012
4[illegible]						¼	110	240	390	141.8	.797	1.018
	Average						180	410	710	145.4	.818	.993
49	1–5	1.57	0–14	104.0	.624	10	240	490	990	131.6	.665	1.084
50						5	160	380	940	129.0	.653	1.105
51						2	130	430	810	129.3	.654	1.102
52						1	110	280	560	128.0	.648	1.112
53						½	70	200	400	126.3	.640	1.128
54						¼	20	50*	110	125.0	.632	1.140
	Average						120	310	640	128.2	.649	1.112
55	1–5	1.51	0.8	110.0	.660	10	280	580	1080	134.0	.688	1.101
56						5	230	580	1200	131.8	.677	1.118
57						2	180	480	920	131.1	.672	1.126
58						1	140	470	1060	132.0	.677	1.118
59						½	80	250	490	129.5	.665	1.139
60						¼	30	100*	230	127.5	.654	1.157
	Average						160	410	830	131.0	.672	1.126
61	1–5	1.43	0–4	115.0	.690	10	370	760	1400	137.0	.710	1.108
62						5	310	670	1620	133.0	.690	1.140
63						2	180	520	1060	134.9	.700	1.124
64						1	200	650	1630	135.5	.703	1.119
65						½	110	220	610	133.2	.691	1.138
66						¼	50	180	270	131.8	.684	1.150
	Average						200	500	1100	134.2	.696	1.130
67	1–5	1.25	0–⅜	122.5	.741	10	500	1020	2030	141.8	.753	1.114
68						5	460	1090	2100	144.5	.767	1.093
69						2	310	1000	1970	143.6	.762	1.100
70						1	280	1000	2200	142.5	.757	1.108
71						½	230	760	1590	141.0	.748	1.120
72						¼	160	500	1090	141.7	.752	1.115
	Average						320	890	1830	142.5	.756	1.108
73	1–5	1.08	0–¾	126.5	.759	10	840	1700	2830	150.8	.812	1.053
74						5	510	1590	3010	149.6	.806	1.062
75						2	460	1390	2900	150.5	.811	1.055
76						1	380	1300	2640	147.9	.796	1.074
77						½	360	1000	2400	147.5	.794	1.077
78						¼	250	840	1840	146.8	.791	1.082
	Average						470	1300	2600	146.8	.802	1.067
79	1–5	.82	0–2	128.5	.771	10	1410	2300	3290	157.2	.867	1.002
80						5	980	2260	3540	156.6	.863	1.006
81						2	790	2020	3320	156.7	.864	1.005
82						1	740	2000	3260	155.5	.858	1.012
83						½	560	1780	2700	155.0	.855	1.016
84						¼	600	1560	2810	149.8	.827	1.051
	Average						850	1990	3150	155.1	.856	1.015

*All specimens broken in removing forms; strength interpolated from other tests.

TABLE 8a

A STUDY OF THE TIME OF MIXING CONCRETE

	Time of Mixing min.	Concrete: Compressive Strength lb. per sq. in. 7d.	28d.	3m.	Weight lb. per cu. ft.	Density	Yield
Grand Average of All Mixes and Aggregates—Machine-Mixed Concrete							
Ref. No. 1, 7, 13, 19................	10	1010	1860	2800	148.6	.799	1.068
Ref. No. 2, 8, 14, 20................	5	830	1750	2880	147.5	.794	1.077
Ref. No. 3, 9, 15, 21................	2	650	1540	2630	147.5	.793	1.077
Ref. No. 4, 10, 16, 22................	1	480	1440	2450	146.7	.790	1.082
Ref. No. 5, 11, 17, 23................	½	430	1200	2200	145.6	.784	1.090
Ref. No. 6, 12, 18, 24................	¼	380	1080	1950	144.8	.779	1.097
Grand Average of 0-1¼ Aggregates and All Mixes—Machine-Mixed Concrete							
Ref. No. 1, 7, 13, 19, 25, 31, 37 & 43.	10	1320	2400	3560	153.8	.837	1.062
Ref. No. 2, 8, 14, 20, 26, 32, 38 & 44.	5	1120	2230	3490	152.6	.832	1.069
Ref. No. 3, 9, 15, 21, 27, 33, 39 & 45.	2	880	1970	3220	152.3	.830	1.070
Ref. No. 4, 10, 16, 22, 28, 34, 40 & 46.	1	600	1800	2870	151.6	.827	1.075
Ref. No. 5, 11, 17, 23, 29, 35, 41 & 47.	½	580	1580	2830	150.9	.822	1.079
Ref. No. 6, 12, 18, 24, 30, 36, 42 & 48.	¼	520	1480	2620	150.5	.821	1.083
Grand Average of 1-5 Mixes and All Aggregates—Machine-Mixed Concrete							
Ref. No. 19, 49, 55, 61, 67, 73 & 79...	10	720	1350	2150	143.8	.761	1.074
Ref. No. 20, 50, 56, 62, 68, 74 & 80...	5	550	1270	2280	142.6	.755	1.084
Ref. No. 21, 51, 57, 63, 69, 75 & 81...	2	380	1030	1940	142.8	.755	1.082
Ref. No. 22, 52, 58, 64, 70, 76 & 82...	1	330	1050	2000	142.1	.752	1.087
Ref. No. 23, 53, 59, 65, 71, 77 & 83...	½	270	810	1580	140.7	.745	1.097
Ref. No. 24, 54, 60, 66, 72, 78 & 84...	¼	220	680	1360	139.4	.738	1.109

TABLE 8b

HAND MIXED CONCRETE

Hand-mixed concrete cylinders were made at the same time as the machine-mixed batch of the same composition. The same materials were used. Specimens made by the same men, and stored and tested under identical conditions.
Each cylinder was proportioned and mixed in a separate batch.
These specimens bear Ref. No. 200 higher than the machine-mixed concrete of the same kind. The making of the 4 cylinders in a set was distributed over the same period as the machine-mixed concrete.

Ref. No.	Mix by Vol.	Water: Ratio to Cement by Vol.	Aggregate: Range in Size	Aggregate: Weight lb. per cu. ft.	Aggregate: Density	Time of Mixing min.	Compressive Strength lb. per sq. in. 7d.	28d.	3m.	Concrete: Weight lb. per cu. ft.	Density	Yield
201	1–2	.60	0–1¼	130.0	.780	—	1560	3380	5060	151.9	.792	1.290
207	1–3	.70	0–1¼	130.0	.780	—	1300	2780	4200	152.4	.814	1.155
213	1–4	.81	0–1¼	130.0	.780	—	940	2180	3660	153.0	.828	1.087
219	1–5	.91	0–1¼	130.0	.780	—	760	1950	3480	154.1	.843	1.040
225	1–6	1.01	0–1¼	130.0	.780	—	580	1670	3090	154.4	.851	1.012
231	1–7	1.10	0–1¼	130.0	.780	—	530	1430	2550	153.8	.852	.997
237	1–9	1.32	0–1¼	130.0	.780	—	360	1030	1870	152.5	.850	.983
243	1–15	1.94	0–1¼	130.0	.780	—	190	440	800	146.8	.826	.983
	Average............						780	1860	3090	152.4	.832	1.068
249	1–5	1.57	0–14	104.0	.624	—	140	380	870	128.8	.653	1.104
255	1–5	1.51	0–8	110.0	.660	—	160	500	950	132.2	.679	1.116
261	1–5	1.43	0–4	115.0	.690	—	180	600	1320	136.2	.709	1.114
267	1–5	1.25	0–⅜	123.5	.741	—	270	900	1720	143.0	.760	1.104
273	1–5	1.08	0–¾	126.5	.759	—	440	1260	2550	151.0	.815	1.056
219	1–5	.91	0–1¼	130.0	.780	—	760	1950	3480	154.1	.843	1.040
279	1–5	.82	0–2	128.5	.771	—	670	2000	3500	156.5	.863	1.006
	Average............						370	1080	2060	143.1	.760	1.077

TABLE 9

EFFECT OF RATE OF ROTATION OF MIXER DRUM—(Series 96)

Compression tests of 6 by 12-in concrete cylinders.
Time of mixing, 1 minute.
Mixing was begun after all materials were in the drum.
Specimens made in steel forms.
All [illegible]ders stored in damp sand; tested damp.
[illegible]value is the average from tests of 4 cylinders from the same batch.
16 cylin[illegible] were made from each batch; the 1st, 5th, 9th and 13th were tested at 7 days; 2d, 6th, in a horizontal line are from a single batch of concrete. [illegible]h and 14th at 28 days; etc.

Group	Ref. No.	Date Mixed (1918)	Mix by Vol.	Relative Consistency	Ratio to C'm't by Vol.	Agg.	R.P.M. of Mixer Drum	Compressive Strength lb. per sq. in. 7d.	28d.	3m.	Weight lb. per Cu. Ft.	Density	Yield
	7	1/23	1-5	100	.83	0-1¼							
	8						15						
	9						18	1250					
1	10						21	1120	2630	3870	154.7	.850	1.030
	11						25	1050	2800	4150	155.3	.855	1.025
	12						30	1000	2720	3880	155.2	.856	1.022
													1.023
	Average							1120	2670	4160	155.4	.854	1.023
													1.025
	1	1/22	1-5	110	.91	0-1¼	8	680	1830	2910	153.1	.840	
	2						15	740	2140	3410	154.3	.844	1.025
2	3						18	790	2340	3800	154.4	.845	1.038
	4						21	740	2210	3560	153.8	.841	1.042
	5						25	680	2000	2890	154.4	.845	1.038
	6						30	680	1940	2830	153.9	.843	1.041
	Average							720	2080	3220	154.0	.843	1.041
	13	1/24	1-5	110	.91	0-1¼	8	620	1620	2550	153.7	.842	1.041
	14						:5	700	1880	3370	155.2	.849	1.032
3	15						18	820	2050	3420	155.3	.850	1.031
	16						21	760	2200	3490	155.1	.849	1.032
	17						25	820	2150	3560	155.0	.848	1.033
	18						30	740	1670	3380	155.2	.850	1.031
	Average							740	1930	3300	154.9	.848	1.033
	31	1/26	1-5	110	.91	0-1¼	8	660	1790	2770	153.5	.840	1.043
	32						15	840	2160	3230	154.4	.845	1.038
4	33						18	850	2110	3290	155.1	.850	1.032
	34						21	820	1880	2980	155.0	.849	1.033
	35						25	850	1980	3180	154.7	.846	1.037
	36						30	950	2160	3040	155.6	.851	1.030
	Average							830	2010	3080	154.7	.847	1.036
	19	1/25	1-5	125	10.4	0-1¼	8	480	1290	2420	152.7	.827	1.060
	20						15	540	1470	2670	153.1	.831	1.056
5	21						18	610	1500	2940	154.5	.838	1.047
	22						21	540	1390	3120	153.4	.832	1.054
	23						25	610	1510	2810	153.8	.834	1.051
	24						30	540	1300	2660	154.0	.835	1.050
	Average							560	1410	2770	153.6	.833	1.053
	25	1/28	1-5	150	1.21	0-1¼	8	310	880	1580	151.7	.809	1.082
	26						15	300	850	1650	153.1	.816	1.072
6	27						18	350	920	1800	153.0	.815	1.073
	28						21	360	1020	1760	152.2	.814	1.078
	29						25	380	1020	1970	153.2	.818	1.071
	30						30	480	1140	1920	153.0	.816	1.074
	Average							360	970	1780	152.7	.815	1.075
	Grand Average of All Consistencies												
	Ref. No. 1- 7-13-19-25-31						8	650	1660	2680	153.2	.835	1.050
	2- 8-14-20-26-32						15	720	1860	3130	154.2	.840	1.044
	3- 9-15-21-27-33						18	780	1930	3250	154.7	.842	1.040
	4-10-16-22-28-34						21	720	1890	3210	154.2	.840	1.044
	5-11-17-23-29-35						25	730	1910	3080	154.4	.841	1.042
	6-12-18-24-30-36						30	730	1820	2950	154.5	.842	1.042
	Grand Average of 110% Consistency												
	Ref. No. 1-13-31						8	650	1750	2740	153.4	.841	1.043
	2-14-32						15	760	2060	3340	154.6	.846	1.036
	3-15-33						18	820	2170	3500	154.9	.848	1.030
	4-16-34						21	770	2100	3340	154.6	.846	1.036
	5-17-35						25	780	2040	3180	154.7	.846	1.036
	6-18-36						30	790	1920	3080	154-9	.848	1.034
	Grand Average of All 110% Consistency and All R.P.M.												
	Ref. No. 1 to 6, 13 to 18, and 31 to 36							760	2010	3200	154.5	.846	1.037

TABLE 10

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TABLE 11

EXAMPLE OF INFLUENCE OF WATER ON THE STRENGTH OF CONCRETE

Values calculated from equation,

$$S = \frac{A}{B^x} = \frac{14000}{8.2^x}$$

Where S = Compressive strength
x = Water ratio
A and B are constants whose values depend on quality of cement and other conditions.

The water ratio is equivalent to the cubic feet of water to 1 sack (1 cu. ft.) of cement.

The strengths given in the table are about what would be expected from a 1-4 mix for usual consistencies, etc. The strength values are solely for comparative purposes in showing the influence of changing the water ratio. The table is based on the following assumptions: Mix 1-4, relative consistency 110%, aggregate graded 0-1¼ in., mixed 1 min.

Water in a 1-Bag Batch: Gallons	Water Ratio (x)	Relative Consistency Percent.	Compressive Strength of Concrete at 28 days: lb. per Sq. In. (S)	Relative Strength Percent.
5.75	.77	100	2770	100
6.0	.80	104	2600	94
6.25	.84	109	2400	87
6.5	.87	113	2250	81
7.0	.94	122	1950	70
7.5	1.01	131	1670	60
8.0	1.07	139	1470	53
9.0	1.21	157	1100	40
10.0	1.34	174	830	30
12.0	1.60	208	480	17
15.0	2.00	260	200	7

If in equation (4), $x = 1.00$ (that is, 1 cu. ft. water to 1 sack of cement, due allowance being made for water held or absorbed by aggregate) we find $S = 1,710$ lbs. per square inch; if $x = 0.77$, $8.2^x = 5.06$, $S = 2,770$ lbs. per square inch.

Let us compute by this means the effect of using 1 lb. (1 pint) more or less water than necessary in a 1-bag batch of concrete. Assume $x = 0.77$, which is about the quantity of water which should be used in concrete for road construction (that is, about 5.75 gallons per 1-bag batch). We found above that $x = 0.77$ gives a strength for the average conditions of these tests of 2,770 lbs. per square inch. 1 lb. of water = .016 cu. ft. For an increase of 1 lb. we should then have $x = 0.786$, $8.2^x = 5.25$, and $S = 2,670$ lbs. per square inch, a decrease in strength of 100 lbs. per square inch or about 3 per cent. For the same relative consistency we may say that for small changes in cement content the strength is proportional to the quantity of cement in the batch. We are led, then, to the amazing conclusion that 1 pint more water than necessary in a 1-bag batch produces the same effect as if we should leave out 3 lbs. of cement. If a gallon more water than necessary is put in a 1-bag batch it means that approximately 25 per cent. of the cement is thereby wasted.

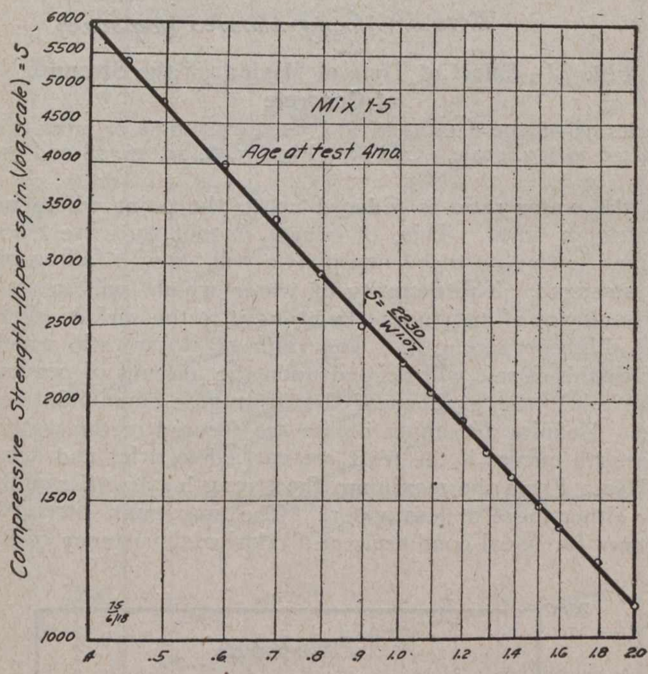

Fig. 17—Relation Between Strength and Wear of Concrete

Same data as in Fig. 16; both strength and depth of wear platted to logarithmic scale. Compare Fig. 15.

Table 11 shows the influence of water on the strength of concrete for a typical case. The values in the table are about what would be expected from a well-graded mix of 1 : 4 (or in usual terms 1 : 1½ : 3 or 1 : 2 : 3) concrete.

These tests give us an entirely new conception of the function performed by the various constituent materials. The use of a coarse, well-graded aggregate results in no gain in strength unless we take advantage of the fact that the amount of water necessary to produce a plastic mix can be reduced. In a similar way we may say that the use of more cement in a batch does not produce any beneficial effect except from the fact that a plastic, workable mix can be produced with relatively less water.

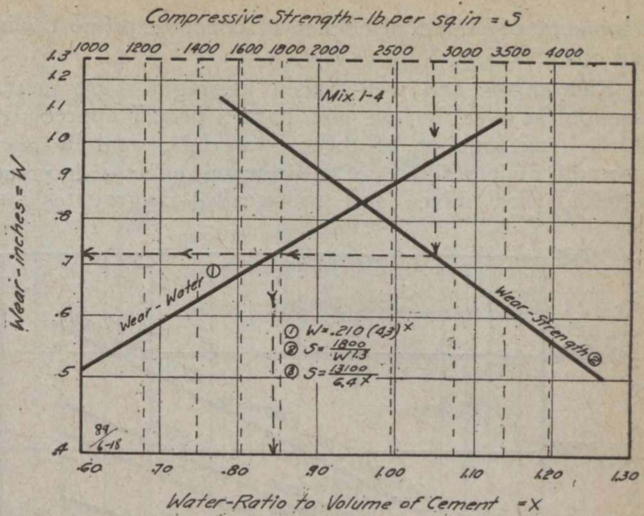

Fig. 18—Influence of Water on the Strength and Wear of Concrete

Series 89—A combination of Figs. 13 and 15. The strength-water relation may be platted on the same diagram if desired; equation (3) gives the relation for these tests.

The reason a rich mixture gives a higher strength than a lean one is not that more cement is used but because the concrete can be mixed (and usually is mixed) with a quantity of water which is relatively lower for the richer mixtures than for the lean ones. If advantage is not taken of the fact that in a rich mix relatively less water can be used, no benefit will be gained as compared with a leaner mix. In all this discussion the quantity of water is compared with the quantity of cement in the batch (cubic feet of water to 1 sack of cement) and not to the weight of the dry materials or of the concrete as is generally done.

The mere use of richer mixes has encouraged a feeling of security, whereas in many instances nothing more has been accomplished than wasting a large quantity of cement, due to the use of a great excess of mixing water. The universal acceptance of this false theory of concrete has exerted a most pernicious influence on the proper use of concrete materials and has proven to be an almost insurmountable barrier in the way of progress in the de-

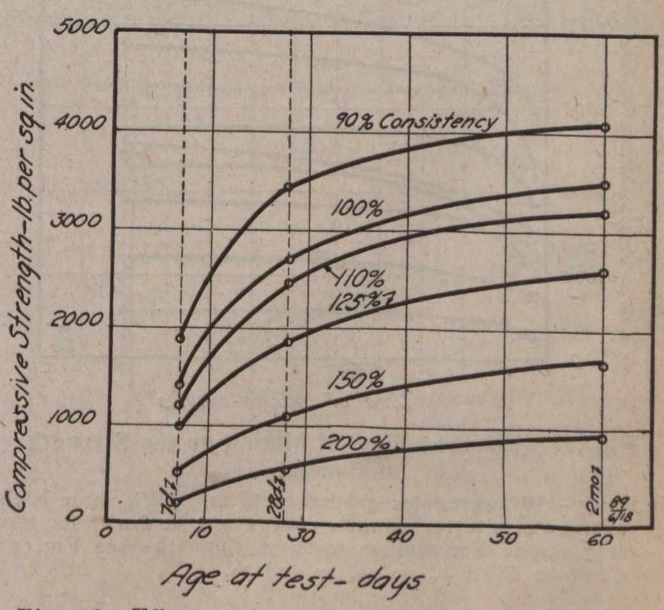

Fig. 19—Effect of Age on the Strength of Concrete

Series 89—Each point is based on 24 tests obtained from averaging 6 times of mixing. Compare Figs. 21 and 35.

velopment of sound principles of concrete proportioning and construction.

Rich mixes and well-graded aggregates are just as essential as ever, but we now have a proper appreciation of the true function of these materials, and a more thorough understanding of the injurious effect of too much water. Rich mixes and well-graded aggregates are,

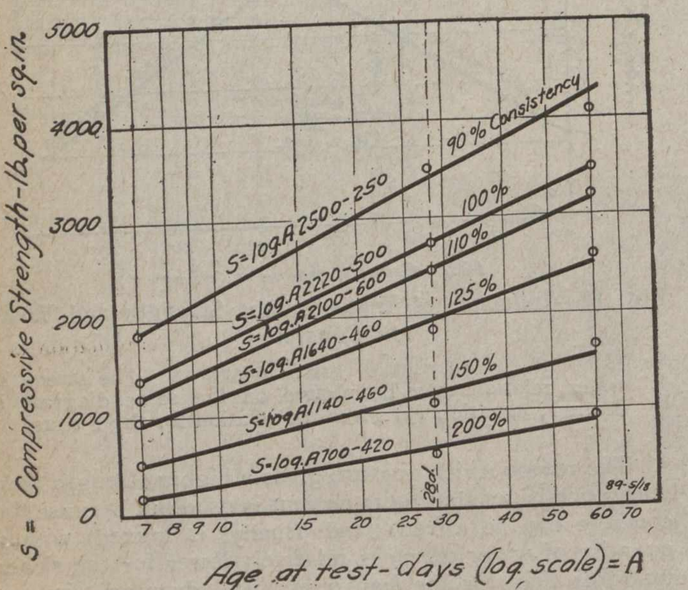

Fig. 20—Effect of Age on the Strength of Concrete

Series 89—Same data as in Fig. 19, except age platted to logarithmic scale. Compare Figs. 22, 36 and 46.

after all, only a means to an end; namely: to produce a plastic, workable concrete with a minimum quantity of water as compared with the cement used. Workability of concrete mixes is of fundamental significance. This factor is the only limitation which prevents the reduction of cement and water in the batch to much lower limits than are now practicable. The importance of any method of mixing, handling, placing and finishing concrete which

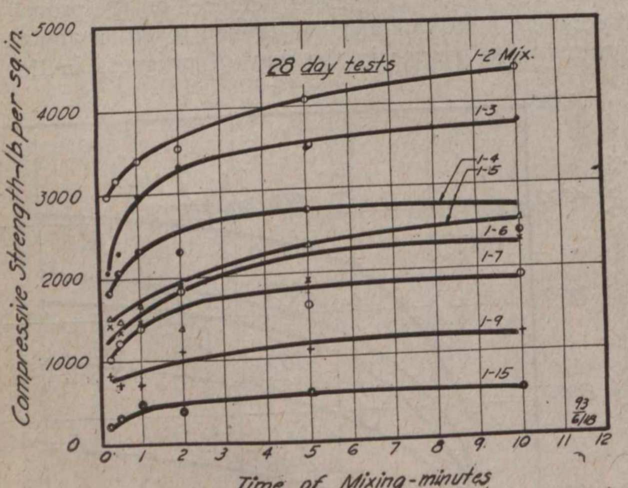

Fig. 21—Effect of Time of Mixing on the Strength of Concrete

Series 93—All aggregates graded 0-1¼ in. Each value is the average of 4 tests. Similar curves may be drawn for tests at 7 days. For similar tests at 3 months see Fig. 23. Compare Figs. 4, 23, 25, 27 and 29.

will enable the builder to reduce the water content of the concrete to a minimum is at once apparent.

If equation (1) is interpreted literally we should be led to the conclusion that the concrete increases in strength

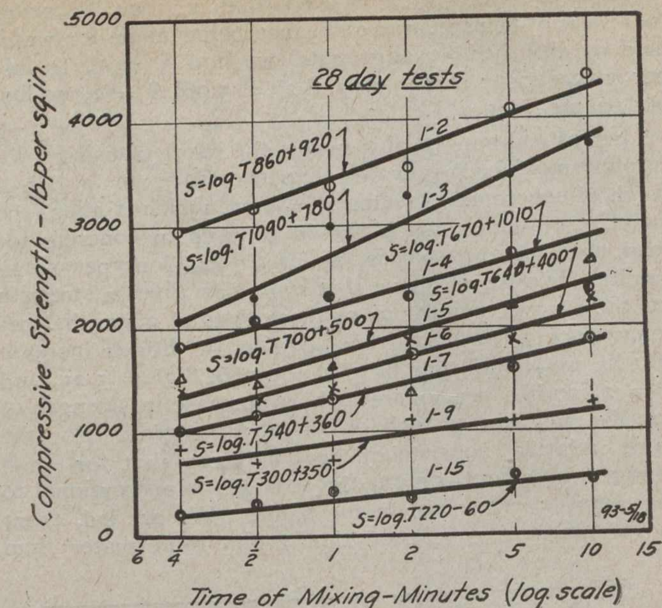

Fig. 22—Effect of Time of Mixing on the Strength of Concrete

Series 93—Same data as in Fig. 21, except time of mixing is platted to log. scale. Compare Figs. 5, 6, 24, 26, 28 and 30.

as the water ratio is reduced up to the point where no water is used. This, of course, is not the case since mixes so dry as to be non-plastic will show a falling-off in strength. The quantity of water which will permit only a trace of moisture to be brought to the surface gives the highest strength. The value of water ratio which gives this result will depend upon the amount of cement (the mix), the grading of the aggregate, manipulation, etc. Definite maximum points are secured in the water-strength curves if the tests are carried to drier and drier mixes. From the maximum the strength falls off rapidly for either more or less water. The maximum strength occurs for usual conditions at a relative consistency of 85

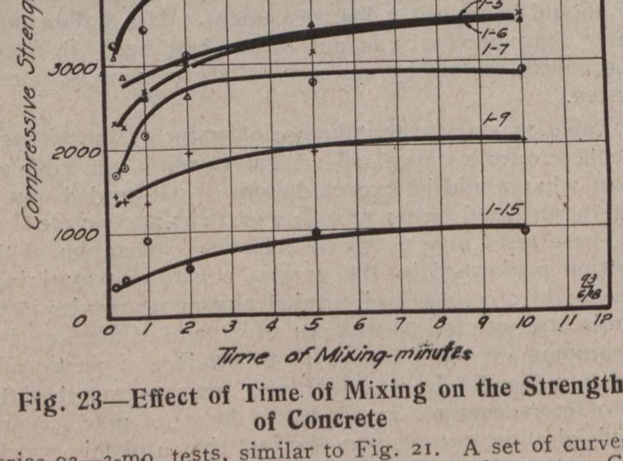

Fig. 23—Effect of Time of Mixing on the Strength of Concrete

Series 93—3-mo. tests, similar to Fig. 21. A set of curves of the same kind may be platted for the 7-day tests. Compare Figs. 4, 21, 25, 27 and 29.

to 90 per cent., based on the method of determining consistency used in these tests. For a typical water-strength curve, showing values for dry mixes, see Concrete Highway Magazine, April, 1917.

Few engineers or contractors fully realize the injurious effects produced by using too much mixing water in concrete. We frequently hear the following arguments in favor of the very wet mixes:—

(1) The excess water does no harm since it runs off and evaporates.

(2) While very wet concrete is weak at early ages it gains in strength more rapidly than the drier mixes.

(3) The richer mixes used in reinforced concrete buildings and in road construction are less affected by excess water than ordinary mixes.

Let us examine these statements in view of the tests included in this report. The excess water does not run off until such a quantity has been used that all of it can-

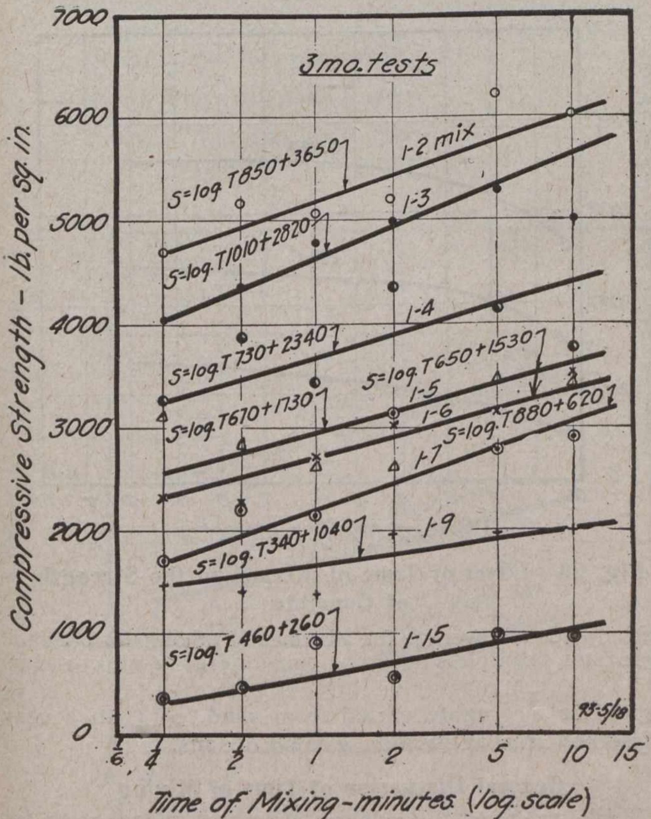

Fig. 24—Effect of Time of Mixing on the Strength of Concrete

Series 93—Same data as in Fig. 23, except time of mixing platted to log. scale. Compare Figs. 5, 6, 22, 26, 28 and 30.

not be held by the concrete. This condition comes at about 200 per cent. relative consistency, that is, about double the water used for concrete of good quality. At this consistency we find a strength of about 20 per cent. of what should be secured. There was every opportunity for the water to run off in these tests. Some of the water evaporates but it has already done the damage.

It was formerly believed that there was no truth in claim (2). It now appears from these tests that the wetter mixes do increase in strength somewhat more rapidly than the drier ones, but the difference in rate is not of sufficient importance to justify placing any confidence in this claim. A slight difference in rate cannot counteract a handicap of 300 per cent. to 400 per cent. in strength due to too much water in the original mix.

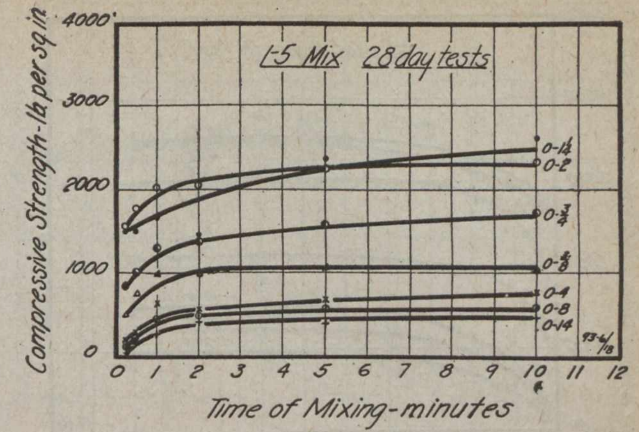

Fig. 25—Effect of Time of Mixing on the Strength of Concrete

Series 93—1-5 mix, 28-day tests, different gradings of aggregate. For similar tests at 3 months see Fig. 27. Compare Figs. 4, 21, 27 and 29.

The exact interpretation of claim (3) hinges entirely on what constitutes excess water. For a given increase in quantity, that is, a certain number of pints, the richer mixes are more affected than the lean ones. This is shown by the steeper slopes of the curves in Fig. 9, etc., for the drier mixes or the mixes which for any reason have a lower water ratio. The effect which would be produced by a given change in plastic condition for rich or lean mixes would depend on many other factors. There is no reason to believe that the conditions would ever be noticeably more favorable in the rich mixes.

The only safe rule to follow with reference to water in concrete is to use the smallest quantity of mixing water which will give a plastic or workable mix, then provide plenty of moisture for the concrete during the period of curing which follows setting and hardening of the cement.

The reason for the injurious effect of too much water in concrete is undoubtedly found in the fact that the particles of cement are pushed farther and farther apart and from the aggregate particles to which they should adhere as water is added to the batch. Soon a condition is reached where practically no strength is obtained. If the water content is increased to three or four times the volume of the cement, the strength is negligible (whether in neat cement or concrete). Beyond this range the mass

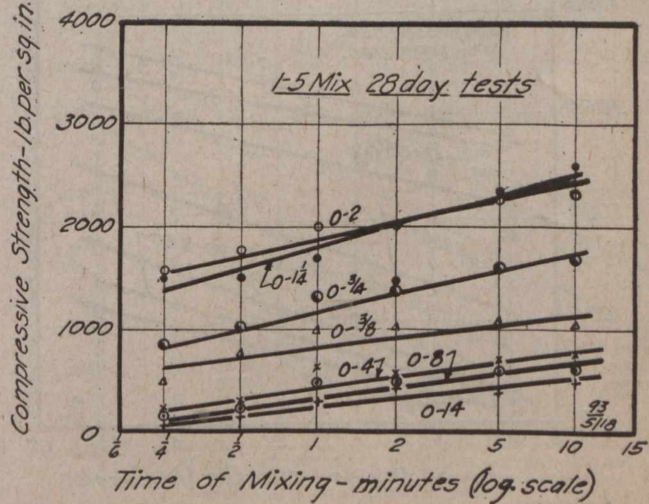

Fig. 26—Effect of Time of Mixing on the Strength of Concrete

Series 93—Same data as in Fig. 25, except time of mixing platted to log. scale. Compare Figs. 5, 6, 22, 28 and 30.

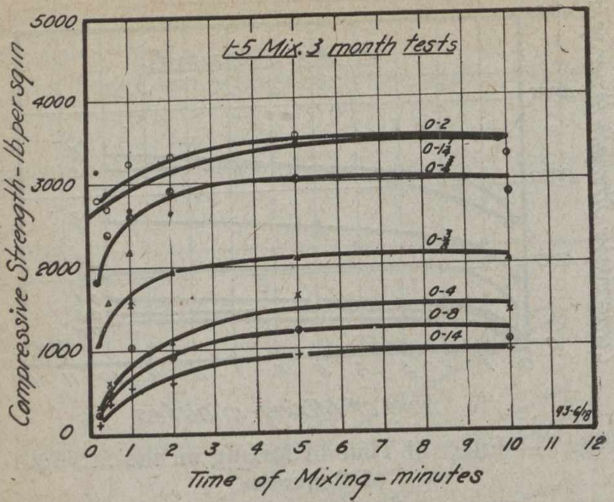

Fig. 27—Effect of Time of Mixing on the Strength of Concrete

Series 93—3-mo. tests, similar to Fig. 25. Compare Figs. 4, 21, 25 and 29.

never hardens. The cement is fully hydrated, but it offers no resistance to stress. In this instance the particles have been separated beyond the range of molecular action. These considerations furnish a method of determining the law of molecular attraction for a material of the nature of portland cement.

A brief discussion of the influence of water on the strength of concrete, based on a series of tests which is not included in this article, was given by the writer in *The Canadian Engineer* for June 6th, 1918. A more complete presentation of this work is now being prepared for publication.

It is interesting to note that the strength of timber is affected by changes in water in exactly the same manner as concrete. Any addition of moisture above the bone-dry condition causes a reduction in strength. The law of change in strength is of exactly the same form as our equation (1). This fact connotes a remarkable similarity

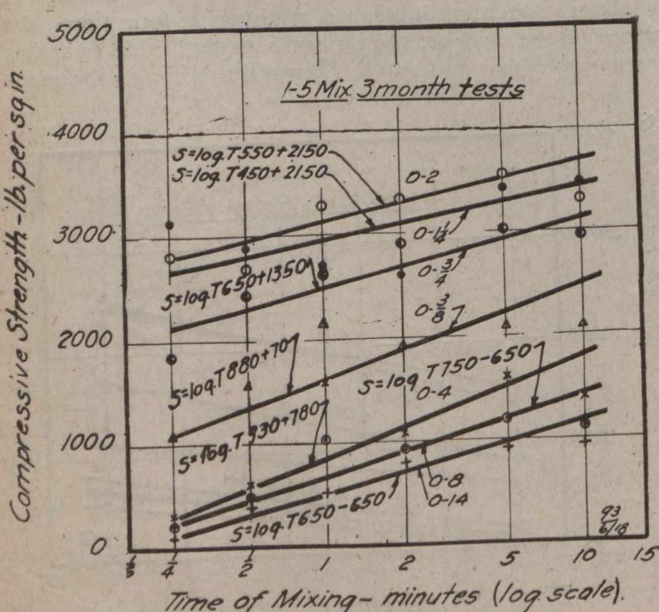

Fig. 28—Effect of Time of Mixing on the Strength of Concrete

Series 93—Same data as in Fig. 27, except time of mixing platted to log. scale. Compare Figs. 5, 6, 22, 26 and 30.

in the molecular structure of timber and concrete. (For discussions of timber tests, see reports of U.S. Forest Service, and Forest Products Testing Laboratory, or consult recent reference books on materials of construction.)

Effect of Time of Mixing on Strength

Tests were made on the effect of time of mixing for mixing periods of 15 seconds to 10 minutes in both Series 89 and 93. In Series 89 the mix and the grading of the aggregate remained constant (1:4 mix, aggregate 0-1¼ ins.) but the amount of mixing water varied from what we call 90 per cent. relative consistency to 200 per cent. This corresponds to a range in the water content from a rather stiff to a very wet mix, and a water ratio of 0.65 to 1.45. In Series 93 two variations in the proportions were made. In the first group of tests the grading of aggregates remained constant, (0-1¼ ins.) but the mix was varied from 1:2 to 1:15. In the second group in this series the mix remained constant (1:5) but the grad-

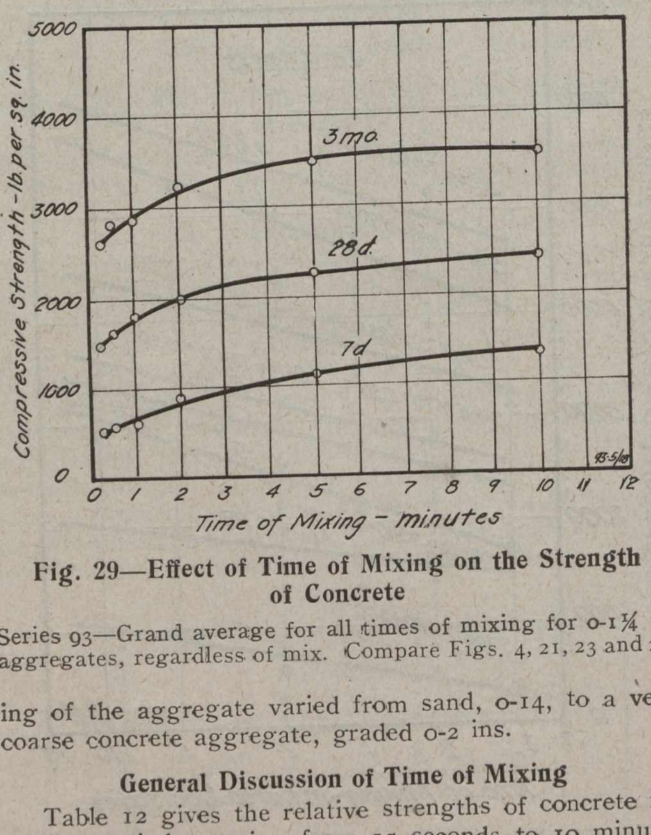

Fig. 29—Effect of Time of Mixing on the Strength of Concrete

Series 93—Grand average for all times of mixing for 0-1¼ in. aggregates, regardless of mix. Compare Figs. 4, 21, 23 and 27.

ing of the aggregate varied from sand, 0-14, to a very coarse concrete aggregate, graded 0-2 ins.

General Discussion of Time of Mixing

Table 12 gives the relative strengths of concrete for mixing periods varying from 15 seconds to 10 minutes for representative ranges of the variables. The values are based on the general trend of values from these tests. The percentages are referred to the strength of the same concrete mixed 1 minute. This period was chosen for comparison for the reason that 1 minute is generally specified as a minimum mixing time for first-class concrete such as that used in road and building construction.

The effect of time of mixing on the strength of concrete is shown graphically in many of the diagrams. It is seen that the strength increases with increased time of mixing in every instance. In all of the tests the strength increases rapidly for the first few seconds of mixing with a gradual reduction in the rate of increase. The relation between strength and mixing-time gives a smooth curve if the values are platted to direct scale. The tests show a consistent relation in all cases between the time of mixing and the other factors. This relation can be expressed by an equation of the form,

$$S = k + n \log. t \qquad (6)$$

where S = compressive strength of the concrete,
t = time of mixing, and
k and n are constants whose values depend on mix, consistency, grading of aggregate, age and other conditions of the tests. If this equation is platted using the logarithm of the time and a direct scale of strength we secure a straight line. Due to an error in the diagrams, the abscissae of the curves are platted in minutes and the equations expressed in seconds. The use of seconds is preferable, since it avoids the use of negative logarithms.

By means of this equation we are able to estimate the relative change in strength which will be produced by a certain change in the mixing period. For the condition of these tests the constants in equation (6) become $k = 900$, $n = 750$. This assumes a 1:4 mix, relative consistency 110 per cent., aggregate graded 0-1¼ ins., age at test, 28 days. If we wish to compare the strength of the concrete for 1½-minute mixing with that mixed 1 minute we shall have for 1 minute:—

$$S = 900 + 750 \log. 60 = 900 + 750 \times 1.778 = 2,230 \text{ lbs. per square inch} \qquad (7)$$

For 1½ minutes we shall have:—

$$S = 900 + 750 \log. 90 = 900 + 750 \times 1.954 = 2,360 \text{ lbs. per square inch} \qquad (8)$$

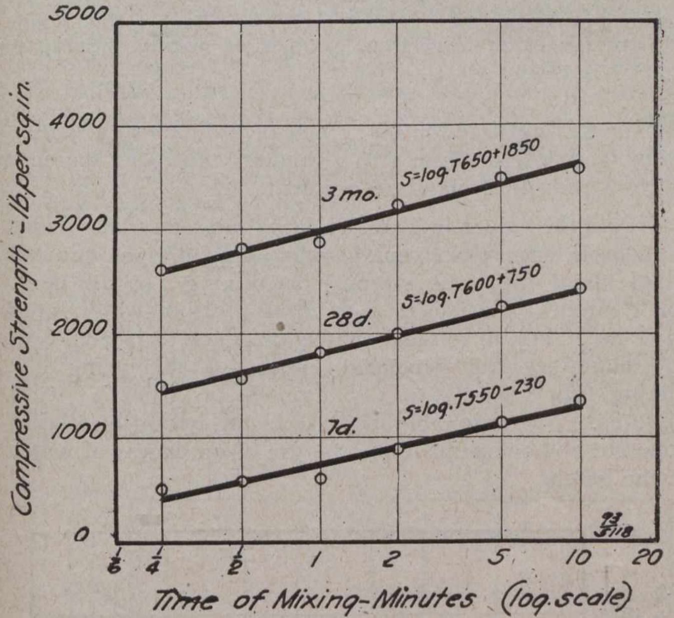

Fig. 30—Effect of Time of Mixing on the Strength of Concrete

Series 93—Same data as in Fig. 29; time of mixing platted to logarithmic scale. Compare Figs. 5, 6, 22, 26 and 28.

In other words, the strength after 1½-minute mixing is 6 per cent. greater than at 1 minute. Theoretically equation (6) says, using the constants found in (7) and (8), that for the conditions of these tests we have a strength of 900 lbs. per square inch at a mixing time of 1 second (log. 1 = 0) and that the strength increases 750 lbs. per square inch for each succeeding number of seconds corresponding to a logarithmic increase of unity. Thus for

10 seconds (log. 10 = 1), $S = 900 + 750 = 1,650$ lbs. per square inch.

100 seconds (log. 100 = 2), $S = 900 + (2)750 = 2,400$ lbs. per square inch.

In other words, there is the same increase in pounds per square inch from 1 to 10 seconds, from 10 to 100 seconds, and from 100 to 1,000 seconds. A similar interpretation can be placed on other equations of this form.

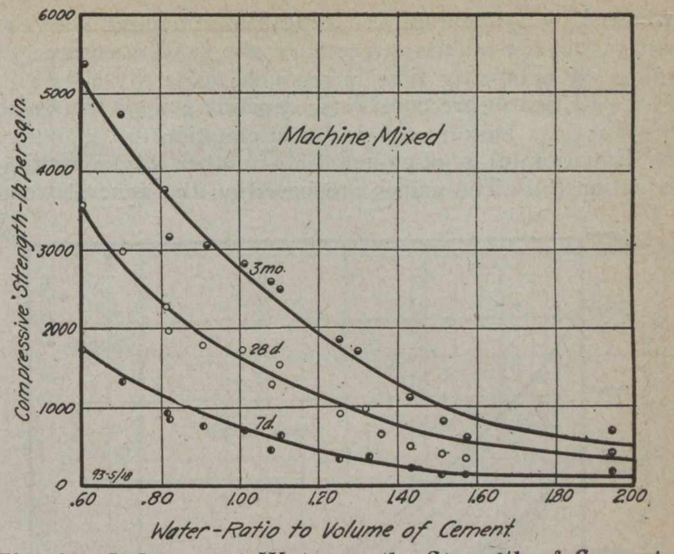

Fig. 31—Influence of Water on the Strength of Concrete

Series 93—Includes all tests of machine-mixed concrete in Series 93. Each point is the average of 6 different times of mixing for each mix and grading. Compare Figs. 7, 9, 33, 44 and 52.

This equation expresses the law of change in strength for different mixing periods. It indicates the true relation up to the maximum period covered by these tests; that is, 10 minutes. The maximum time to which this relation may hold was not determined, but it is obvious that it cannot be continued beyond the period at which setting of the cement begins. An equation of this form is useful in making it possible to calculate the effect of mixing for periods of time not covered by the tests.

The values in Table 12 show what may be expected from varying the time of mixing of concrete to different consistencies, mixes, etc. The strengths have been reduced to a percentage of the strength of the same concrete at 1-minute mixing. These values are expressed by the equation:—

$$P = l + m \log. t \qquad (9)$$

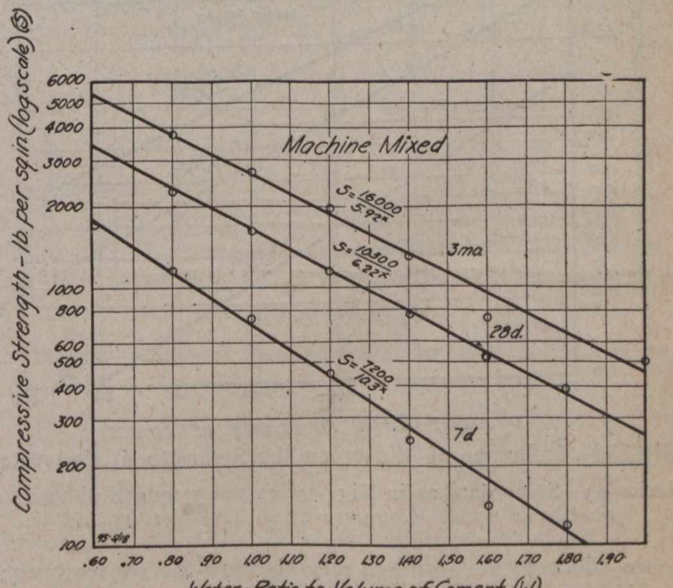

Fig. 32—Influence of Water on the Strength of Concrete

Series 93—Same data as in Fig. 31, except strength platted to logarithmic scale. The points are platted from the curves in Fig. 31. Compare Figs. 8, 10, 34, 45 and 53.

where P = percentage of strength as compared with the 1-minute strength of the same concrete;
t = mixing time in seconds; and
l and m are constants, depending upon the same factors as k and n in equation (6).

Equation (9) is, of course, only another way of writing equation (6). The values are based on the general trend

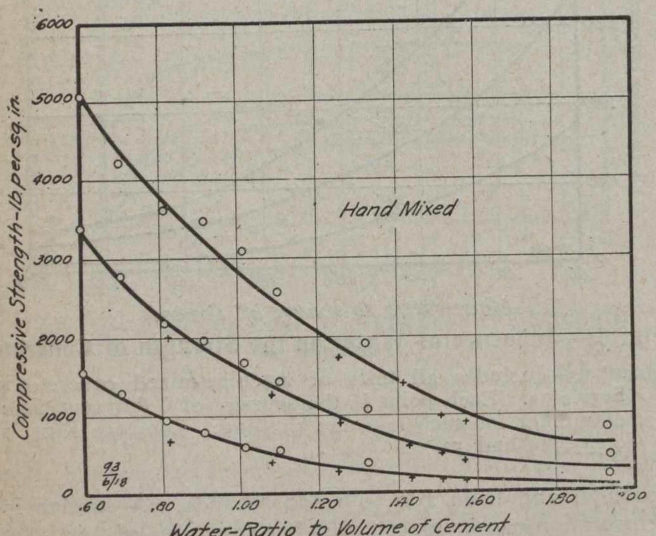

Fig. 33—Influence of Water on the Strength of Concrete

Series 93—Hand-mixed concrete in Table 8. Each value is the average of 4 tests made on different days. Compare Figs. 7, 9, 31, 44 and 52.

of the results found in these tests. It should be borne in mind that these values do not necessarily represent conditions for mixers of other types or sizes.

Concrete of Different Consistencies

The tests in Series 89 show the effect of time of mixing when concrete of different consistencies is used. The relative values in Table 12 show that the drier mixes are

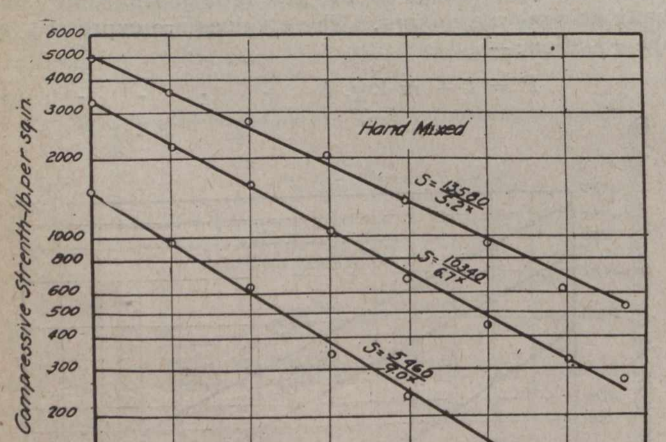

Fig. 34—Influence of Water on the Strength of Concrete

Series 93—Same data as in Fig. 33, except strength platted to logarithmic scale. Compare Figs. 8, 10, 32, 45 and 53.

more affected by continued mixing than the wetter ones; for instance, from ½ to 2-minute mixing we find an increase from 89 to 112 per cent. for 90 per cent. consistency and from 98 to 105 per cent. for 200 per cent. consistency. For the usual range in consistencies which should be aimed at in most work, say, 100 to 125 per cent., chang-

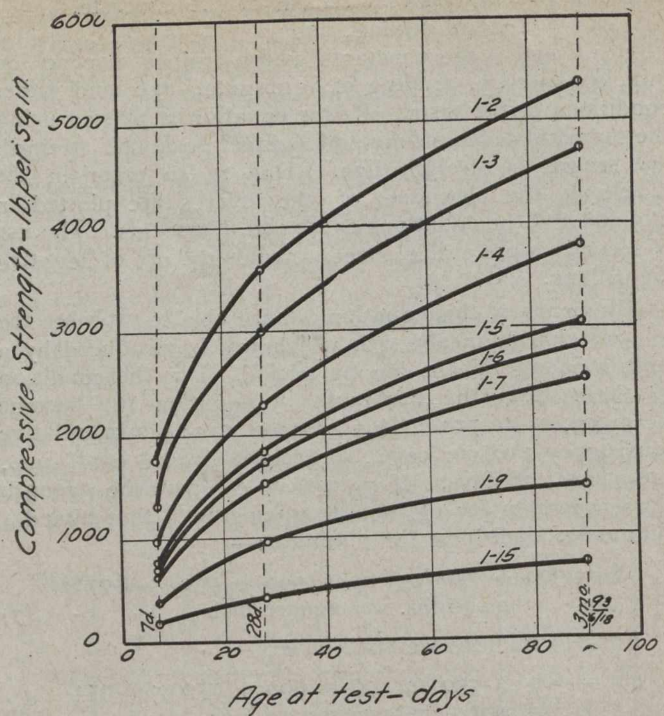

Fig. 35—Effect of Age on the Strength of Concrete

Series 93—Aggregates graded 0-1¼ in. Each point is the average of 24 tests from 6 times of mixing. Compare Figs. 19 and 38.

ing the mixing time for a 1:4 mix of ordinary aggregates from ¾ to 1½ or from 1 to 2 minutes causes an increase in the strength of about 10 per cent.

From the values in Table 12 it will be seen that mixing a concrete of 125 per cent. consistency for 10 minutes gives about the same strength as mixing 110 per cent. for 1 minute; the use of 2 to three pints of water more than necessary in a 1-bag batch of concrete is sufficient to counteract the beneficial effects of increasing the mixing time from ¾ to 1½ minutes or from 1 to 2 minutes. No reasonable increase in the period of mixing concrete will compensate for the use of an excess of water in the batch.

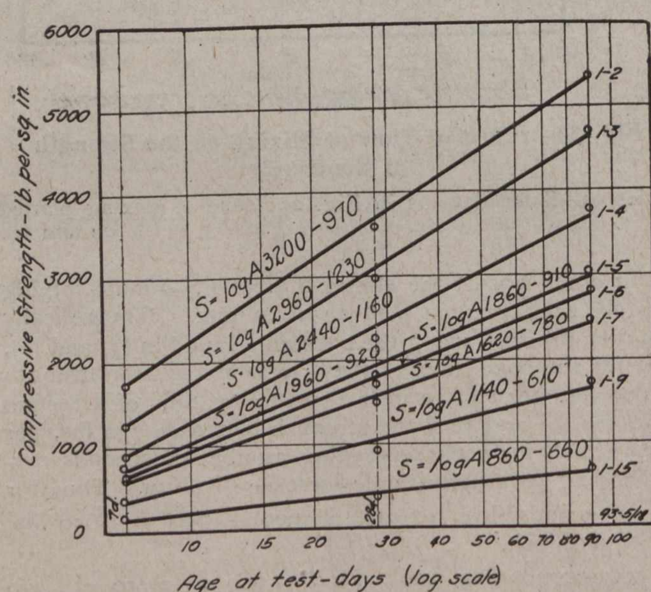

Fig. 36—Effect of Age on the Strength of Concrete

Series 93—Same data as in Fig. 35, except age is platted to logarithmic scale. Compare Figs. 20, 37, 39 and 46.

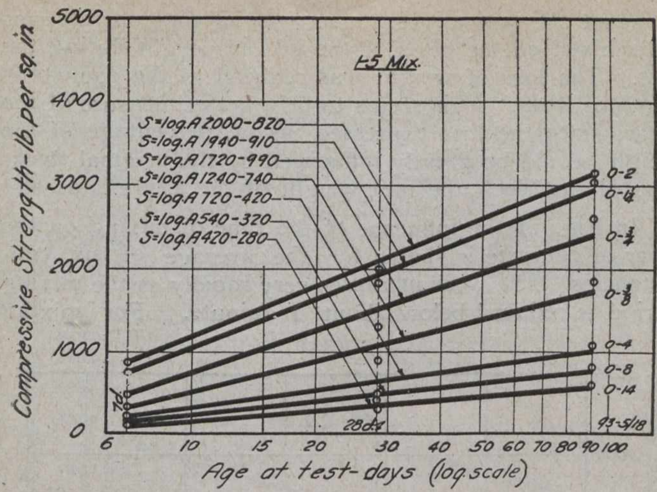

Fig. 37—Effect of Age on the Strength of Concrete

Series 93—1-5 mix, size of aggregate variable. Each point is the average of 24 tests based on 6 times of mixing for each grading. Age platted to logarithmic scale. Compare Figs. 20, 36, 39 and 46.

Concrete With Different Quantities of Cement

See Series 93, (Figs. 21 to 24) and Table 12. The lean mixes show a much greater relative increase in strength with continued mixing than do the rich mixes. The mixes tested varied from 1 : 15 to 1 : 2. For mixing periods from ¾ to 1½ minutes or from 1 to 2 minutes the increase in strength at 28 days was about 19 per cent. for the leanest mixes and 7 per cent. for the richest. These percentages are based on the strength at 1-minute mixing. These percentages are not sensibly different for ages of 7 days or 3 months.

Concrete With Aggregates of Different Sizes

See Series 93 (Fig. 25 to 28) and Table 12. Concrete with aggregates of small sizes is more affected by continued mixing than similar concrete with aggregates graded up to coarser sizes. The sizes tested ranged from 0-14-mesh to 0-2 ins. For instance, from ½ to 2 minutes we find an increase from 64 to 136 per cent. for 0-14

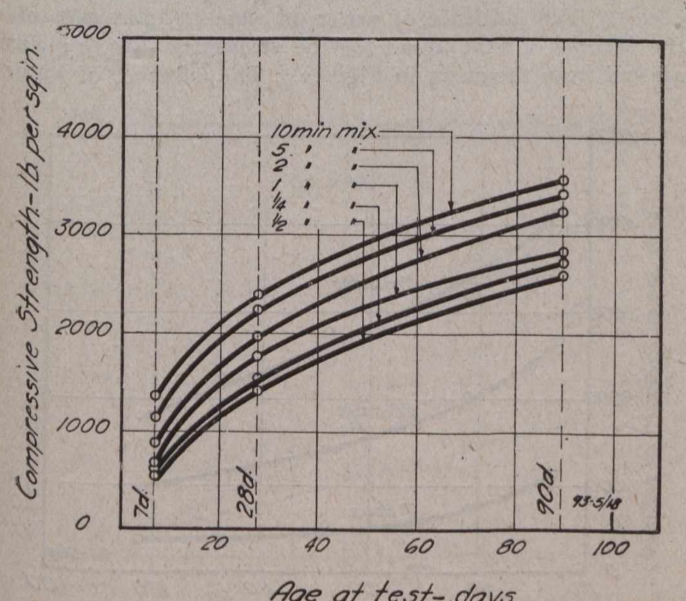

Fig. 38—Effect of Age on the Strength of Concrete

Series 93—All aggregates graded 0-1¼ in. Each point is the average of 32 tests; 8 different mixes. Compare Figs. 19 and 35.

aggregates, and from 91 to 109 per cent. for 0-2-in. aggregates. While the concrete made of fine aggregates increases in strength more rapidly with time of mixing than the coarse, it is not feasible to compensate very great changes in the size and grading of the aggregate by additional mixing. For instance, in order to obtain the same strength as given for a 1-minute mix of 0-1¼-in.

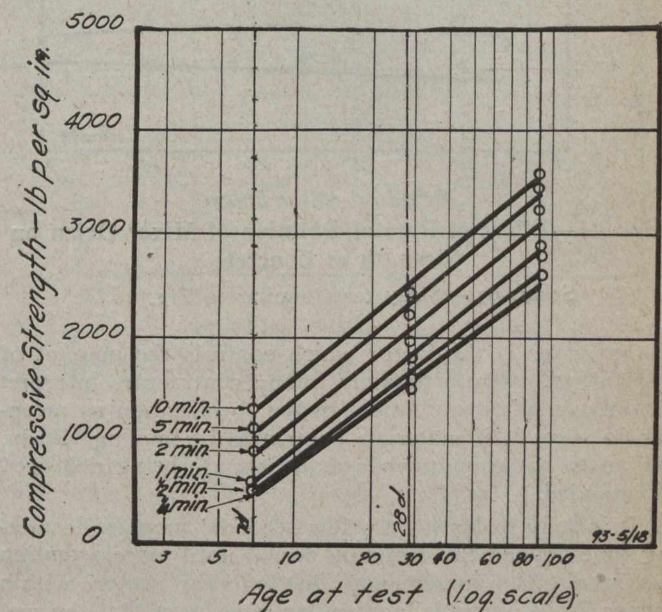

Fig. 39—Effect of Age on the Strength of Concrete

Series 93—Same data as in Fig. 38; age is platted to logarithmic scale. Compare Figs. 26, 36, 37 and 46.

concrete, we would have to mix 0-¾-in. concrete of the same mix for 10 minutes. This, of course, is only an indirect influence of the water ratio occasioned by differences in size and grading of the aggregate.

Further Remarks on Time of Mixing

If the evidence of these tests is a satisfactory guide, it appears that there has been a tendency to over-estimate the beneficial effects of increased mixing. It is shown that with this mixer the increase in strength which accompanied increases in mixing time from ¾ to 1½ minutes or

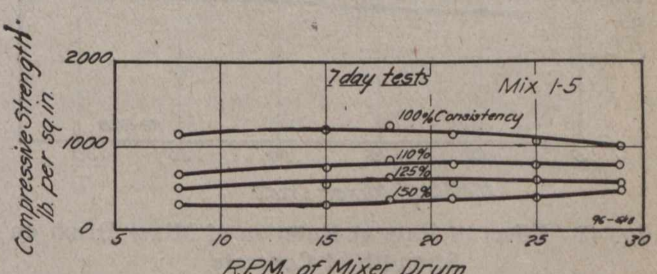

Fig. 40—Effect of Rate of Rotation of Mixer Drum on Strength of Concrete

Series 96—1-5 mix; 7-day tests. In general the values are the average of 4 tests. The 110% consistency was mixed in triplicate on different days; each value on this curve is the average of 12 tests.

from 1 to 2 minutes for usual concrete is only about 10 per cent. of the 1-minute strength. It seems doubtful if the increased cost of mixing each batch ¾ to 1 minute longer is justified by an increase of 10 per cent. in strength. It is the writer's belief that if concrete is mixed one full minute after all materials are in the drum, we are getting about the maximum efficiency if the output

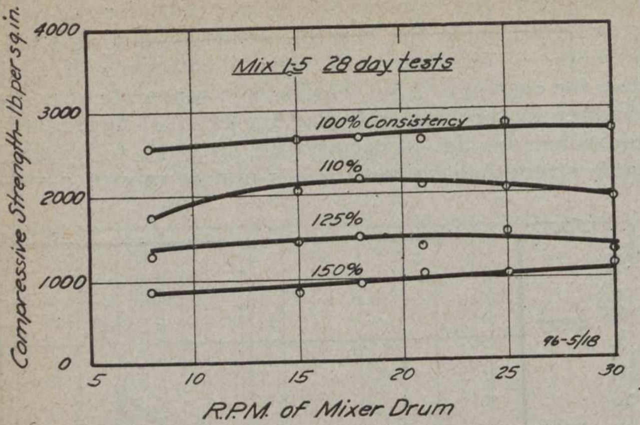

Fig. 41—Effect of Rate of Rotation of Mixer Drum on Strength of Concrete

Series 93—28-day tests similar to Fig. 40.

of the mixer is the factor which controls the amount of work done. Unfortunately, many contractors interpret a 1-minute mix requirement in the specification as meaning 60 seconds if materials happen to be moving slowly, and 10 to 30 seconds when materials are being delivered as intended.

It is folly to insist on a few seconds' increase in mixing time beyond the 1-minute period until more attention has been given to reducing the mixing water within proper limits; especially since we have seen that the wet mixes show decidedly less benefit from continued mixing than the drier ones. A statement made above will bear

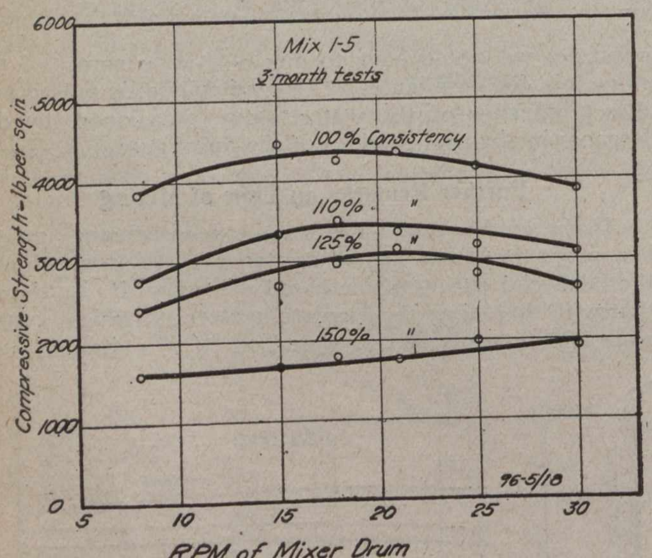

Fig. 42—Effect of Rate of Rotation of Mixer Drum on Strength of Concrete

Series 93—3-month test similar to Figs. 40 and 41.

repetition, namely: No reasonable increase in the mixing time will compensate for an excess of water in the batch.

Wear Tests of Concrete

Wear tests of concrete were made at the age of 2 months in Series 89 on a 1:4 mix, aggregates consisting of gravel graded 0-1¼ ins. This mix conforms closely to that generally used in concrete road construction. The blocks were stored in damp sand until two days preceding the test, when they were removed to the open room and permitted to dry out. This was done in order that the loss in weight of the blocks during the test might not influence the indications. The wear of the concrete was determined on the basis of the loss in weight during the test. The loss of weight was reduced to the equivalent depth of wear. This seems to be a better measure of the wear, since the loss expressed as a percentage of the weight would be greatly influenced by the original thickness of the block, the unit weight of the aggregates, etc.

In Fig. 11 the influence of the time of mixing on the wear of concrete is shown for the average of six consistencies. The wear increases very rapidly as the mixing period is reduced below about 1 minute. For mixing

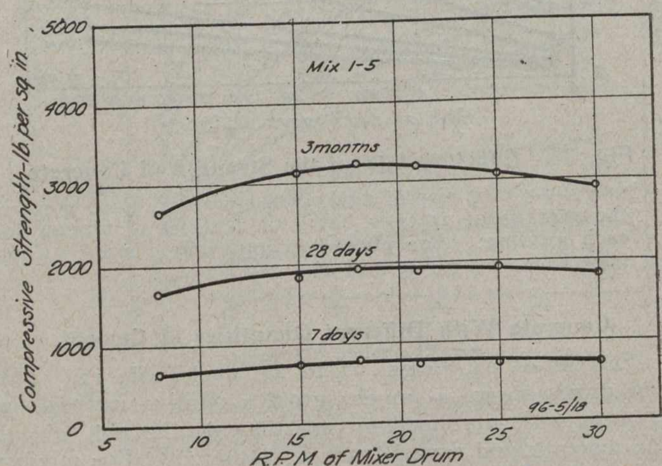

Fig. 43—Effect of Rate of Rotation of Mixer Drum on Strength of Concrete

Series 96—Each curve is the average of all consistencies for a given rate.

periods between 2 and 10 minutes there was practically no variation in the wear. The average wear ranged from 0.65 in. for the longer periods of mixing to 0.9 in. for 15-second mixing. It should be borne in mind that in Fig. 11 the six consistencies were averaged.

Fig. 12 shows the influence of water ratio of the concrete on the wear. Here the tests at different times of mixing are averaged. The average wear in this case ranges from 0.55 to 1.1 ins., being highest for the wet mixes. The influence of water on wear is approximately the reverse of that found for the strength. Fig. 13 was platted from the curve in Fig. 12. The influence of water

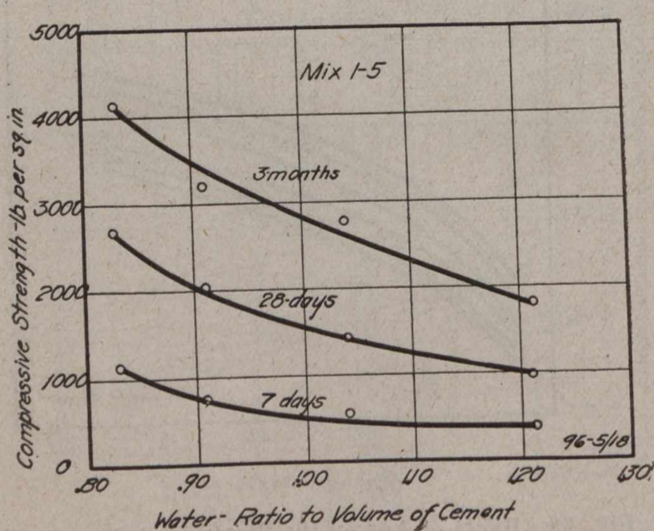

Fig. 44—Influence of Water on the Strength of Concrete

Series 96—Each point is the average of all rates of rotation for a given consistency. Compare Figs. 7, 9, 31, 33 and 52.

content on the wear can be expressed by an equation of the form,

$$W = a\,b^x \qquad - \quad - \quad - \quad - \qquad (10)$$

where W = depth of wear in inches;
x = water ratio; and
a and b are constants whose values depend on age and other conditions of the test.

It is seen that this relation is of the same form as the equation for strength, except that the exponent which

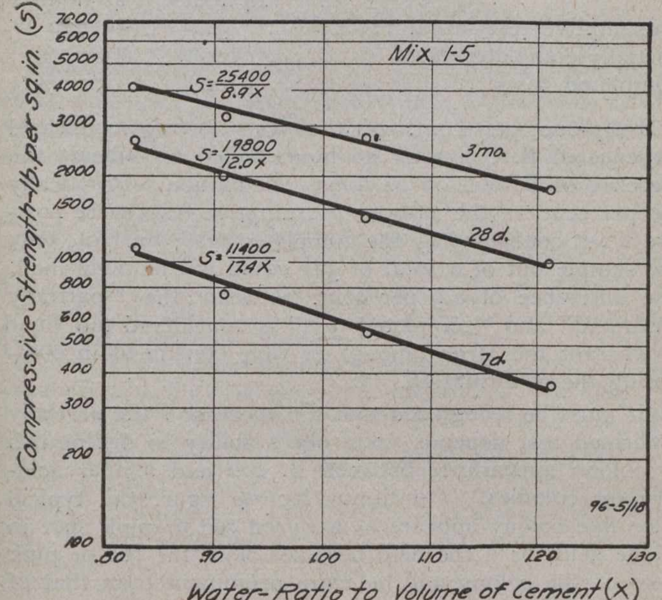

Fig. 45—Influence of Water on the Strength of Concrete

Series 96—Same data as in Fig. 44, except strength is platted to logarithmic scale. Compare Figs. 8, 10, 32, 34 and 53.

expresses the water ratio now appears in the numerator instead of in the denominator; in other words, increase in the ratio (within the range of plastic mixes) increases the wear and decreases the strength.

For the conditions of these tests, equation (10) becomes

$$W = 0.21\ (4.3)^x \qquad - \quad - \quad - \qquad (11)$$

Small changes in the water ratio exert an important influence on the wear. The wear increases at a more and more pronounced rate as the water is increased.

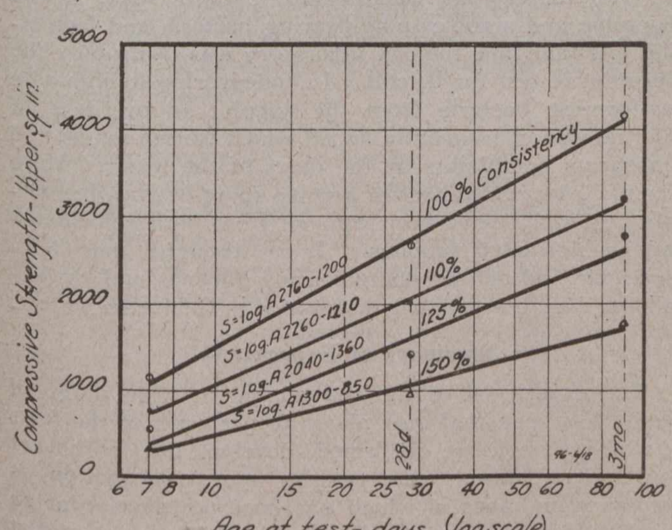

Fig. 46—Effect of Age on the Strength of Concrete

Series 96—Each point is the average of all rates of rotation for each consistency. Age platted to logarithmic scale. Compare Figs. 20, 36, 37 and 39.

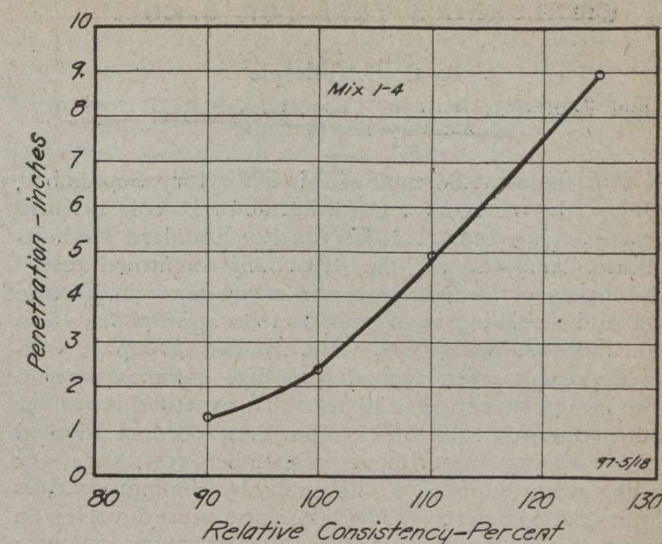

Fig. 47—Penetration Test for Consistency of Concrete

Series 96.

We have sufficient data for a study of the relation between the wear and compressive strength of concrete for a given age. This relation is shown in Fig. 14. Here each consistency is platted separately. The results of an earlier series of tests made in the same machine on 1 : 5 hand-mixed concrete, at the age of 4 months from Series 75 (details not given in this article) are shown in Fig. 16. The relation between strength and wear of concrete may be found by considering equations (1) and (10) simultaneously. If this is done and the values of the constants

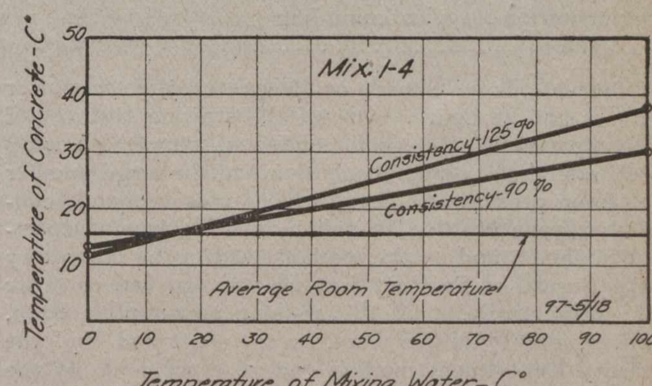

Fig. 48—Temperature of Concrete Produced by Mixing Water at Different Temperatures

Series 97—Consistencies between 90 and 125% are omitted.

found in these series substituted in the equation, we shall have:—

$$\text{For Series 89} \quad S = \frac{1{,}800}{W^{1.3}} \qquad - \quad - \qquad (12)$$

$$\text{For Series 75} \quad S = \frac{2{,}230}{W^{1.07}} \qquad - \quad - \qquad (13)$$

where S = compressive strength in lbs. per sq. in.; and
W = depth of wear in inches.

These relations are shown in Figs. 15 and 17. It will be noted that this form of equation gives a straight line if both variables (S and W) are platted to logarithmic scales.

These equations are most useful in estimating the probable wearing resistance of a concrete of known strength.

(Concluded in the next issue. For Figures 49 to 53, inclusive, see next issue)

CALIFORNIA'S TEST FOR B. COLI*

By C. G. Gillespie

Chief Engineer, Berkeley Laboratory, State Bureau of Sanitary Engineering.

SINCE the establishment of this laboratory, September, 1915, the method for the isolation of B. coli in water samples has been that described in Standard Methods of Water Analysis as the "partially confirmed test," and consists of fermentation and enrichment in lactose broth and streaking on litmus lactose agar plates from broth tubes showing gas. The B. coli group is considered present when typical colon-like colonies develop on the litmus lactose agar plates. This method is similar to but in one particular differs from the procedure adopted by the Treasury Department on October 21st, 1914, for drinking water supplied to the public by common carriers in interstate commerce. The latter procedure involves an additional step over that used in this laboratory, namely: fishing and transplanting of a colon-like colony from the lactose litmus agar plates into a lactose broth tube, to confirm the gas-forming property.

Comparison of Methods

A comparison of the two methods on a large number of water samples from various sources shows the following results:—

	24 hours.	48 hours
Presumptive test— Total number	382	782
Partially confirmed test— Typical colon-like colonies	97.1%	76.1%
Treasury Department method— Fermentation of typical colon-like colonies	97 %	73.4%

Observations were made on the presumptive test after 24 hours and 48 hours. One of the striking features of this comparison is the small number of samples showing B. coli after but 24-hour incubation and the large number of 24-hour presumptive tests which on subsequent confirmation gave positive B. coli by the Treasury Department methods, and by the method used in the laboratory of the Bureau of Sanitary Engineering, 97 and 97.1 per cent., respectively. Of the 48-hour presumptive tests, however, only 73.4 per cent. were confirmed by the Treasury Department method and 76.1 per cent. by the method of this bureau. A difference of 2.7 per cent. is noted in the two methods. It is doubtful whether this difference is of sufficient importance to justify the extra work involved in obtaining the lower and doubtless more correct percentage. The "partially confirmed test" is on the safe side at any rate.

The latest Standard Methods of Water Analysis published by the American Public Health Association, 1917, defines the B. coli group as including all non-spore-forming bacilli, which grow aerobically on solid media and which produce gas in lactose broth. The B. coli tests are grouped under three headings: (1) the presumptive test, consisting only of gas production in lactose broth; (2) the partially confirmed test, consisting of plating a portion of the broth tubes showing gas on litmus lactose agar or endoes media and noting the formation of "typical colon-like colonies"; (3) the completed test, which consists of fishing typical colonies from the litmus lactose agar plates for demonstration of non-spore-forming bacilli and formation of gas in lactose broth.

*From "Bulletin" of State Board of Health.

It was deemed advisable to make a comparison of the three methods and determine the certainty with which the "typical colon-like colony" can be recognized and which of the three methods is most desirable for California conditions, with a view to reducing the work in the laboratory to a minimum without sacrificing the accuracy of the demonstration of B. coli. The following comparison was obtained from an entirely different series of water samples than those given in the preceding table:—

	24 hours.	48 hours.
Presumptive test—total	321	776
Partially completed tests	100%	82.1%
Completed tests	100%	81.2%

Fifty-one per cent. of the tests giving confirmed presence of B. coli after 48 hours failed to indicate the presence of B. coli on 24 hours' incubation. Practically 100 per cent. of the 24-hour presumptive tests were positive when confirmed by the completed test; in fact, only one sample out of a total of 321 could not be confirmed. The difference of 0.9 per cent. between the "partially confirmed" and "completed test" is considered too small to warrant the large amount of time consumed in completing the confirmation.

It must be recognized that the success of the partially confirmed test depends upon one's ability to distinguish by colony appearance between B. coli and similar acid-forming colonies. On litmus lactose agar, the typical colon-like colony appears as a raised red or pink spot in a blue field, or if the field becomes acid, the red or pink color of the colony will be more prominent than that of the field. The colonies on the surface are fat, glistening and smooth with a regular outline. Small deep red colonies with a deep red or brick-colored centre or irregular outline are usually not B. coli. On endo media, the colonies are raised with a regular outline, deep red and with a highly metallic sheen.

On the large number of 48-hour presumptive tests which the Bureau found negative on further confirmation, a large percentage were waters treated with chlorine gas, though the same observation applies to well waters, large reservoirs and streams. The positive presumptive tests in these cases may be attributed to either anaerobic or aerobic lactose-splitting spore-bearing bacilli, which are highly resistant to chlorine. B. welchii was isolated from the river supply at Sacramento, Cal., in 1916, as the anaerobic and aerobic spore-bearing bacteria and lactose-bile. At that time the city laboratory was using only the presumptive test for B. coli. In endeavoring to eliminate gas-forming bacteria from the supply, an overdose of chlorine was consequently added which caused tastes and subsequent complaints by the users of the water. More recently a larger number of aerobic spore-bearing lactose-splitting bacilli have been isolated from both chlorinated and unchlorinated supplies. It is thought that both anaerobic and aerobic spore-bearing bacteria and lactose-splitting bacilli are widely distributed in California waters.

Summary of Experiences

The experience of the Bureau on a wide range of waters has been that only about 50 per cent. of the tests in which B. coli are confirmed, develop gas within 24 hours' incubation. Forty-eight hours' incubation is necessary on tubes in which gas does not develop at 24 hours. However, practically all tubes showing a gas at the end of 24 hours were later confirmed for B. coli. Of those showing gas on 48 hours' incubation less than 85 per cent. could be confirmed.

(Concluded on page 118)

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Principal Contents of this Issue

ENGINEERING STANDARDS COMMITTEE

As the result of a happy suggestion made some time ago to Sir John Kennedy, an Engineering Standards Committee has been organized in Canada. Fortunately, the suggestion was made to the right man. Sir John was quick to recognize its value, and persistent in his efforts to interest others in the idea. The enthusiasm of a number of other engineers in Montreal was aroused and they helped Sir John to secure the support of departments of the government, the universities, the Canadian Manufacturers' Association, the Canadian Mining Institute, the Engineering Institute of Canada and other important technical bodies. An organization has now been effected with strong membership, representing the various engineering interests.

The work of this committee will be of real importance to economic production in Canada. In fact, Canada's future position in foreign markets and the extent of her overseas trade will depend in no small measure upon the success of the work which this committee is ambitious to accomplish. It desires to standardize engineering practice as applied to industry.

In organizing this committee Sir John Kennedy has added merely another page to a long record of usefulness to the community, and has proven once again that a proper selection was made when he was honored by knighthood as the dean of Canadian engineers.

The Canadian committee has been patterned upon the British Engineering Standards Committee. The latter works in conjunction with the Board of Trade, and is representative of the whole engineering industry of Great Britain. It is competent to examine all proposals for improved standards and to make proper recommendations upon which new developments can be correctly founded. From the time of its inception, about sixteen years ago, the British committee has carried on this work with proper appreciation of the interests of both producers and users.

Co-operation will be arranged with the Engineering Standards Committee of the United States, recently established, and by this means Great Britain, Canada and the United States will be linked together in work which will help to stimulate allied trade and to resist German penetration. There is a great difference between some of the methods in vogue in Great Britain and those followed in the United States. Canada, having selected the best ideas from both countries, is in a unique position. The Canadian committee will be of great use in harmonizing British and American standards. The work of the three committees will increase the industrial supremacy of the English-speaking nations.

TO CONVERT BEE-HIVE OVENS

An apparatus for converting bee-hive coke ovens into by-product recovery ovens, without altering or destroying the oven structure, has been recently issued in the United States. If this process be successful it will be of great economic importance, as the bee-hive ovens of the internal combustion type are generally considered to be very wasteful.

Assuming that the invention is successful, a problem has now been solved upon which engineers have worked for the past fifty years without reaching a practical solution. Instead of costly and entire reconstruction of the ovens, the inventor claims it is now possible to convert the existing bee-hive coke ovens at comparatively small expense into ovens which will save the by-products.

Canada has some modern by-product ovens, but the greater number of ovens in Canada are of the bee-hive type, so there will no doubt be a considerable market in this country for this invention, if successful. At the beginning of this year there were approximately 1,874 bee-hive ovens in Canada, 240 Bernard ovens, 30 Bauer ovens, 620 Otto Hoffman ovens, 224 Koppers ovens, 60 Solvey ovens and 101 Mitchell ovens. The principal owners of bee-hive ovens are the Crow's Nest Pass Coal Co., Limited, with nearly a thousand ovens, and the Canadian Collieries (Dunsmuir), Limited, with a little less than half that number. The chief owners of by-product recovery ovens are the Dominion Iron & Steel Co., Limited, Sydney, N.S.

EFFECT OF TIME OF MIXING ON STRENGTH OF CONCRETE

In this week's issue appears the second and principal portion of Prof. Duff A. Abrams' article on "The Effect of Time of Mixing on the Strength of Concrete," the first or introductory portion having been printed in last week's issue. Nearly every civil engineer and contractor has occasion at some time to design in concrete, to prepare specifications for structures including some concrete construction, or to inspect or report upon concrete work. Prof. Abrams' investigations and conclusions will therefore be of very general inte est. The laboratory of which he is in charge has probably completed more experimental and research work in regard to concrete than has any other laboratory. They have made over 50,000 tests just on the effect of size and grading of aggregates. Their research work in connection with sands and water content have been of special value, and have been productive of some very interesting and novel conclusions.

The article was originally written for the American Concrete Institute, to be presented at the annual meeting recently held in Atlantic City, but was not published by that Institute as it was not received in time for the making of the very large number of illustrations required or for the setting up of the detailed tables requiring difficult and expensive typography. We are, therefore, presenting this material for the first time that it has appeared anywhere in print, we believe; its value, not only for present reading but particularly for reference purposes, will no doubt be appreciated by all those who expect to be brought into contact at any time with any form of concrete construction.

The Structural Materials Research Laboratory is maintained jointly by the Lewis Institute of Chicago and the Portland Cement Association. The example of that association in bearing so great a part of the cost of Prof. Abrams' work is worthy of much commendation. We understand that Prof. Abrams has an entirely free hand in following and making public any line of investigation or research which he feels will be of value to users of cement, increase efficiency in concrete design or add to the present sum of knowledge in regard to cement as a material of construction.

PERSONALS

Major WILLIAM T. WILSON, of the Royal Engineers, has been awarded the Military Cross for exceptional bravery in action.

W. K. GWYER has been appointed district engineer to the Public Works Department, government of British Columbia, with headquarters at Penticton, B.C.

GEORGE A. MOUNTAIN, chief engineer for the Board of Railway Commissioners of Canada, has resumed his official duties after a long absence due to illness. Mr. Mountain's health has been entirely restored.

R. S. STRONACH, of the Dominion Parks Branch, Department of the Interior, has been appointed resident engineer at Jasper Park, Alta. Mr. Stronach was recently discharged from military service, having been invalided home from France last fall suffering from gas poisoning.

Lieut.-Col. T. V. ANDERSON, D.S.O., has been gazetted commandant of the Engineers' Training Corps at Seaforth, England, with the rank of Assistant Director of Signals. Col. Anderson is a son of Col. W. P. Anderson, C.M.G., chief engineer of the Department of Marine, Ottawa.

J. M. WARDLE, formerly highway engineer with the Dominion Parks staff, has been appointed superintendent of the Rocky Mountain Park, succeeding the late S. J. Clarke. Mr. Wardle is a graduate of Queen's University and has been with the Dominion Parks staff for the past four years, acting since 1915 as chief highway engineer.

F. E. ESPENSCHIED, who has been a member of the engineering staff of the Hydro-Electric Power Commission of Ontario for the past seven years, has resigned to become assistant chief engineer of the Combustion Engineering Corporation, New York City, manufacturers of mechanical stokers and furnaces. Mr. Espenschied graduated from Cornell University in 1905, entering the employ of the Western Pennsylvania Railway Co. In 1910 he was appointed general manager of the Interstate Light and Power Company at Galena, Ill., and in the following year he came to Canada and joined the Hydro staff.

U.S. HIGHWAY COUNCIL

IT is announced that in the future all functions of United States Government agencies relating to streets and highways will be co-ordinated in a body called the United States Highways Council, with the intention of eliminating delays and uncertainty incident to the present method of taking up each problem with a separate department of the government. This council will be composed of the following persons:—

Lieut.-Col. W. D. Uhler, War Department; C. G. Sheffield, Fuel Administration; Richard L. Humphrey, War Industries Board; G. W. Kirtley, Railroad Administration; L. W. Page, chairman, Department of Agriculture; and J. E. Pennybacker, secretary.

The Council has adopted a form of application for relief in highway matters which is to be submitted to the government through the respective state highway departments. All of these departments have been supplied with copies of the application form. This form emphasizes as of first importance the maintenance of existing streets and highways; second, the reconstruction of badly damaged streets and highways; and last, new construction justified by war or economic necessity.

CALIFORNIA'S TEST FOR B. COLI

(Continued from page 116)

Samples developing gas in 48 hours in lactose broth must be fished and streaked on litmus lactose agar or endo media for further confirmation. The presence of typical colon-like colonies on the plate is for all practical purposes sufficient evidence of the presence of B. coli.

The subsequent inoculation of lactose broth tubes by such colonies and determination of the lactose-splitting property is practically unnecessary, but is advised for the inexperienced technician.

WOOD IN THE CONSTRUCTION OF MILL BUILDINGS

(Continued from page 96)

yard it is usually due to the existence of conditions which foster the growth of fungi, such as the following:—

(1) Location of yard in a damp, low-lying situation, or neglect to provide proper drainage.

(2) Allowing decaying waste wood to accumulate in the yard and to form centres for the distribution of infection.

(3) Using partially decayed foundation timbers for lumber piles, whereby disease is transmitted to sound lumber piled on same. (Foundation timbers should preferably be thoroughly impregnated with creosote oil.

(4) Piling lumber too near the ground, thus retarding circulation of air where it is most needed and keeping timber in the lower part of the piles in a favorable condition for infection.

(5) Using diseased spacers in lumber piles.

(6) Permitting diseased timber to remain as part of permanent structures in the yard.