THESIS

THE CENTRIFUGAL METHOD OF TESTING THE CONSISTENCY OF CONCRETE OF COMPARISON WITH THE SLUMP CONE TEST

Chester I. Williams

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THE CENTRIFUGAL METHOD OF TESTING THE CONSISTENCY OF CONCRETE AND COMPARISON WITH THE SLUMP CONE TEST

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Chester I. Williams

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Fóllowing is a list of the publications read in preparation for this thesis:

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Notes On Recent Developments In Concrete,
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Fifth edition, 1922.

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Thanks are due to Prof. H. K. Vedder, Prof. of Civil Engineering M. A. C., for his suggestions in the matter of this test; and to Prof. H. B. Dirks, Prof. of Mechanical Engineering M. A. C., for materials rendered.

SECTION A.

A BREIF HISTORY
Of
THE SLUMP CONE TEST

A BREIF HISTORY OF THE SLUMP CONE TEST

In order to have a simple method for determining the proper consistency of concrete in the field the slump test has been devised. It was adopted by the Joint Committee in or about the year of 1920 and for the last three years has been in standard use by the Michigan State Highway Department.

When it was first devised it consisted of a metal cylinder six inches in diameter and twelve inches high, but now a frustrum cone 4"in diameter at the top and 8"in diam.at the bottom,and 12" high has been adopted as the standard. This cone is filled with concrete to be tested,which is carefully worked with a pointed metal rod while being placed,the form is immediately lifted off,and the settlement or slump measured. The proper slump for a mixture to be used in concrete road work is ,½"to 1";for mass concrete work,from 1"to1½"; and for concrete to be used in structures with reinforcing bars,2"to 2½". In some classes of reinforced concrete work it may be deamed advisable to sacrifice a portion of the compressive strength of the concrete in order to obtain increased plasticity,in which case a wetter mixture may be used to make it more fluent at the expense of using more cement. The Michigan State Highway Department recommends the following,-"When concrete of a medium consistency is used either out of choice of the contractor,or as ordered by the District Engineer,the number of units of fine aggregate called for shall be decreased by .5 units and the number of units of coarse aggregate shall be decreased by .75 units, the cement remaining constant and this regulation holds for all grades of concrete. When concrete of wet consistency is used either on written permission or order of District Engineer, the number of units of fine aggregate called for shall be decreased by 1.00 unit and the number units of coarse aggregate by 1.50 units, the cement remaining constant, this regulation holds for all grades of concrete. Slump for different consistencies are as follows:

Dry, giving maximum slump of 2½" as determined by standard test.

Medium, giving maximum slump of 5" as determined by standard test.

Wet, giving maximum slump of 8" as determined by standard test.

PROPORTIONING

The water-ratio is the most important element of a concrete mix. The water-ratio as used in the labratory, is the ratio of the volume of water to the volume of cement in a batch. If 1 cu ft. of water (7.5 gals.) is used for each sack of cement, the water-ratio is called 1.00. The following data will show the relation between consistency and slump:

Mix	Water-ratio	Slump
1:2:4	.90	½"
"	1.00	¾"
"	1.05	1½"
"	1.10	2¼"
"	1.15	4"
"	1.25	6"
"	1.50	7½"

SECTION B.

IMPORTANCE OF CONSISTENCY OF CONCRETE

(EFFECTS OF THE WATER-CONTENT)

(TH[illegible] [illegible] [illegible] TO [illegible])

IMPORTANCE OF CONSISTENCY OF CONCRETE

WATER-RATIO

The proper consistency of concrete will vary with the use to be made of it. If the concrete is to be used for roads a dryer consistency is permissible than for concrete containing reinforcing bars. The use of mechanical tamping and finishing machines in concrete road construction has made it possible to use the dryer consistency economically, but any method which reduces the water content, such as the use of the light roller, will produce benificial results.

The wet sloppy mixtures that are being used in building construction may seem economical but they are certainly extremely wasteful from the designers and owners point of view, since in many instances 50 to 60 per cent of the possible strength of the concrete is being thrown away.

The functions of water in concrete are:

1. Water reacts with cement to form a binding material which unites otherwise non-cohering sand and stone.
2. Water operates to flux both disolved and undisolved cementing substances over the surfaces of sand grains and stone particles (Or pieces of gravel), rendering possible extensive and close adhesion by carring these substances into minute and multitudinous surface irregularities of the particles, where they are absorbed as water is later absorbed and evaporated.
3. Water acts as a lubricant between sand particles and stone particles so that palcement of harsh and irregular materials in molds and forms is rendered easy.
4. Water itself occupies space in the mass.

The first function of water cited above is basic and essential to the manafacture of concrete.

If there is insufficient water ,obviously its reaction with cement will prematurely cease;and if there is too much water,it is equally obvious that the cementing products will be too dialute to develope preper strength since cement depends for its early strength and a considerable part of its latter strength upon the hardening of amorphous or glue-like substances. Undue dialution of these substances is readily possible,but it is accompanied by impairment of strength,just as glue may be valuable adhesive when of preper consistency,while the same glue, if too dilute,may be useless for like purposes altho later evaporation may gradually restore its cementitious value. Cement depends further for its strength upon interlacing crystals;and crystalization takes place only from saturated or supersaturated solutions. If,therefore,excess water is added,such strength as these crystals may confer is futher imparied. The influence of water in greater or less quanities is very prominant in labratory tests for tensil or compressive strength.

The second function of water cited above-it acts as a carrier or flux of cementing substances-is obvious. In bringing sand,stone and cementing substances into intimate contact,it acts physically in a manner analogous to its earlier chemical role.

Inevitably,however,this desirable function is closely dependent upon its fourth function-vis.,its occupancy of space. It is readily seen that if the minute irregularities in the surface of stone are first filled with water,and,because of initial excess of water,the cementing solution is then too weak,a strong, intimate attachment of cement will be inhibited,both because the irregularities are already filled and also because of excess dialution.

Furthermore, water, particularly when charged with gelatinous aluminates from cement, has ability to occlude a very high percentage of air. This air, as minute bubbles, firmly attaches itself to sand and stone. It also remains between particles to such an extent as oftimes to completely isolate a lagge percentgge of the materials. Given excess water, therefore, and a certain amount of occluded air, detriment to the concrete is sure to arise from the primary fault in an increasing ratio. This explains to a large degree the lower strengths with prolonged mixing in present type machines found by some investigators.

The function of water as a lubricant of concrete is very important, but its importance can be overestimated, particularly when balanced against the detrimental effects which may and often do result. It is not necessary to add great quanities of water to concrete to make it easy flowing if the concrete is suffieiently mixed. The more concrete is mixed, the smoother working it becomes and the less water is superficially evident. Cement is continually hydrating in mixing action; and in process of hydration, large quanities of hydrated lime are formed. This has a very pronounced effect in lubrication, and furthermore keeps the mass coherent. Excess water on the other hand, promotes seperation of the constituent materials, offsetting the good effects of hydration and rendering the concrete extremely harsh in working and difficult to handle. More mixing, therefore, or more efficient mixing devices, should be relied upon for easy placing, rather than excess water.

Voids caused by excess water are very harmful. From the study of concrete under a microscope it is evident that the more uncombined water, the more voids in the set concrete. Conversely, the more voids, the less the closeness the compacting of sand and stone; and the less this compacting, the less the density, strength, durability, and value of the hardened mass.

The space loss refered to is only a small part of the ultimate damage. Physical stress due to loading may be the least intense of the stresses to which the concrete is subjected. Physical or chemical and physico-chemical stresses set up in the mass after hardening, through disruptive freezing, or thru percolating waters alone or carrying chemically active agents, are of far greater intensity. Each pore or void is a potential aid to such destructive agents; and enlarged by enitial attact, soon become an active aid or abettor. First loss, therefore, may be of minor importance. Induced weaknesses, argumenting primary defeciencies, must be reconed with to an increasing degree.

Days work planes.-Perhaps the commonest evidence, to be found on every hand, as to the effects of excess water in concrete are "days work planes". In the early life of a structure such as a butress wall, these planes are hidden either by a smooth mortor surface at contact with forms, or by a later-applied wash or coat of cement plaster. But as months pass and the structure is subjected to water action in greater or less degree, from one source or another, these planes are made more and more evident by seepage along them. When such seepage is in quanity, it may be detected as a film of water, or, with rapid evaporation, by crystaline deposits. Excess water also causes large "lattance" places which will allow water seepages.

Waterproof Concrete.-It is difficult to find a truly waterproof field concrete, largely because excess water is

so generally used in mixing. The majoriety of structures are of such size that they cannot be poured continously. This necessarily means stoppage of work for greater or less intervals. Stoppage of work with wet concrete always means a layer of "laitance". There are also small voids in the concrete due to excess water which tend to make the concrete less waterproof.

Floor Surfaces.-Excess water also caused unsatisfactory floor surfaces. The water which arises to the top of the floor is the cause of "laitance",which weakens its power to withstand the attacts of abrasion and impact,these later being the severest service to which it is subjected.

Bond.-Excess water prevents the bonding of new concrete to old. This is due to the existance of a light,chalky,insecure material,substituted at the critical plane for a substance which should be durable and secure.

Cold Weather.-Dilution by excess water further increases the dangess of concreting in cold weather,as is evident by frequent winter failures.

It may not be possible to reduce the amount of water to the ratio necessary to give the maximum strength,but it certainly can be cut down below the amount commonly used, and the additional strength thus gained will be of advantage in the design of concrete structures. The designing engineer figures on a compressive strength of 650 lbs. per. sq. in. and expects to get a factor of safty of three,but does not get it with a sloppy mixture. By cutting down the water to the propsr ratio, a factor of safty of five or six can be secured, or the present allowable unit stresses can be raised.

The exact amount of water required for any particular mixture of aggregates to obtain the greatest strength in the concrete cannot be given,because of the impossibility of determining the amount which will produce a workable mix and also because of the varying moisture content of the aggregates. However, a few approximate quanities for different proportions of well graded aggregates up to 1½ in. in size,may be given to form a basis for trial of the particular mixture at hand.

cement	mix	water
1 sack	1:2:4	6 to 6½ gals.
1 "	1:2:3	5¾ to 6 " .
1 "	1:1½:3	5½ to 6 " .

SECTION C.

THE CENTRIFUGAL APPARATUS FOR TESTING THE CONSISTENCY OF CONCRETE

THE CENTRIFUGAL APPARATUS FOR TESTING THE CONSISTENCY OF CONCRETE

The Centrifugal Method for Testing the Consistency of Concrete is a method originated by myself, and with the cooperation of Professor H.K.Vedder ,Professor of Civil Engineering, M.A.C., I devised an apparatus, which, altho rather crudely constructed, enabled me to carry out the following experiments; and proved to my satisfaction the implicit advantage of this method over the now standard method, of the Slump Cone Test. See fig. below.

The original centrifugal apparatus.

This apparatus works somewhat on the principle of the cream seperator. As the container revolves, the concrete in the container is acted upon by a force, centrifugal force, which not only tends to condense the concrete; but forces the heavier material to the outside, and the lighter then remains to the inside. The specific gravity of cement is app.3.1 and that of sand and gravel 2.6 to 2.7, so that in the process of revolving of the materials; the cement, sand, and gravel are forced into a compressed state to the outside while the water ,the excess which is not used in filling up the void of the compressed material or united chemically with the cement,will remain to the inside. This water is mostly excess wateras far as water which is needed for the ultimate of the concrete is concerned;altho when this water is drained off, as it does immediately upon stopping the machine,the remaining concrete is of a very dry consistency,depending upon the r.p.m. at which the machine was run. If the machine was run at 250 r.p.m. as it was in most of my experiments,even then the concrete remaining would be of too dry a consistency to slump any or by far too dry to pour into form work so that this water which was drained off could not be called all excess water. Theoretically,at least,that stage of r.p.m. might be produced which would, after the experiment had been run and the water drained off, leave the remaining mixture of the property consistency for a certain kind of construction work (the proper consistency varying for different kinds of construction work),but practically I believe it would be hard to have the machine work consistant at such a low speed as this would require. It is better,in my mind to standardise the machine at a greater speed,say 250r.p.m. or more,at which speed it is sure to be more consistent in the tests. I have also found out that for a real sloppy mixture a greater speed than 250 r.p.m. is required to obtain the desired results,however,for any slump up to a 3½ or 4" this speed is sufficient to seperate the water reasonably well from the concrete,and be consistent in so doing. This apparatus would reach a speed of 400r.p.m. when empty by turning the crank at 200 r.p.m. a ratio of 2 to 1 gear. For the tests I used a gallon of the concrete mixture and with this in the container I could not reach a speed of much more than 300 r.p.m.,however I did not consider it necessary to use even as great a speed as this in the tests.

When I first constructed the machine I made a governor for on the top of it with which I could regulate the speed, but later I found that it was just as easy and sufficiently accurate to regulate the speed by counting the number of r.p.m. and made the machine less complicated. This governor was also used to open the valve in the bottom of the container to let the water drain out when the machine reached a certain speed. It lifted a core in the funnel shaped sieve thru which the water was allowed to drain out.But this I also found to be unnecessary for the concrete would not go thru the holes when first put into the container,and the minute you started to revolve the container the concrete was thrown away from the center and there was no danger of it percolating down thru the drain;also there was no use of the valve being opened at a certain speed for the water would not run out anyway untill the machine stopped and the water allowed drain off. While the machine was in operation,the water as well as the other material was thrown away from the center of the container and hence could not drain out,but upon stopping the machine,the water, being to the inside,would rush out the drain in the center of the bottom of the container.This water was conveyed thru a rubber tubing to a graduated tube,graduated in cc.,then the volumn in c.c. could be read. It would take about a minute with this machine for the water to all drain out.This water seemed practically clear and free from any cement,whatsoever.

SECTION D.

COMPARISON OF CENTRIFUGAL AND SLUMP CONE TESTS

COMPARISON OF CENTRIFUGAL AND SLUMP CONE TESTS

Now that we are convinced of the necessity of securing a method,whereby we can test the consistency of concrete,it becomes a question as to which method is the most consistent as well as being practical for field work. First,let us be sure that we know the meaning of the word consistency. Consistency, as defined and adopted by the Am. Soc. Test. Mat.,is"The degree of solidity of Fluidity of bituminous materials". This degree of solidity or fluidity of concrete depends almost entirely upon the amount of"excess water" contained in the mixture. It does not depend entirely upon the"water-ratio",because with the same water ratio a 1:2 mix will be more fluent than a 1:2:4 mix. The water-ratio being the ratio of the amount of water to the amount of cement,by volume.If there are 7.5 gals of water per sack of cement the water-ratio is one.

The two main factors in consideration of the consistency of a mixture arethe water content and proportion of mix. Of course one cannot use the same water-ratio for different mixes and expect to get the same consistency.Also the time of mixing is an important factor in determining the consistency of concrete. With the time of mixing ,water-ratio,and mix all constant the consistency should also be constant. However this will not hold true with the Slump Cone test,as experiments have proven,so let us look into some of the causes of such a large discreptency.

1. The Slump Cone test neglects,to a large extent,the very thing upon which the consistency of concrete mostly depends, namely,the water content. When the concrete is taken from the mixer and placed into the Slump Cone,it is put in a little at a time and worked with an iron rod to settle the concrete well

in place and not leave any large voids. While this is being done, a lot of the excess-water will seep out from the bottom of the cone, depending upon the amount of puddling done with the rod and the time it takes to fill the cone and withdraw it; thus, leaving a concrete of a different consistency than the original which was placed into the cone. This concrete will then slump according to its consistency after a portion of the water has run out, but it would slump a great deal more if all this water were retained. Due to the fact that this amount of water which drains off will vary a great deal, even when the mix and water-ratio are constant, the consistency also changes, and the slump will vary as may be seen in the results of my experiments. The personal element here has a

2. The personal element here has a great deal to do with the varriation of the slumps. No two persons will puddle the concrete the same amount or carry thru the operation of the Slump Cone test the same. Thus the concrete in one case will be well settled into place, while in the other case it may contain more voids which will cause the concrete to slump more when the cone is removed.

3. Different mixes will not slump the same even though one mix may contain as much excess water as the other. That is to say, a 1:2:4 mix will not slump as much as a 1:2 mix of the same consistency, the mix containing the gravel will not settle down as smoothly and evenly as that containing only fine particles of sand and cement. The mix containing the gravel is very apt to cave down on one side only, then again, it may hold together and settle very little, or it may settle very unevenly, the mix and water-content being the same in each case.

CENTRIFUGAL METHOD.-Now let us look into the Centrifugal Test for Consistency of Concrete and compare it with the slump cone.

1. There is no chance for any excess water to escape only into the graduated tube where it is measured in cubic centimeters.

2. Two mixes of the same consistency will give off the same amount of excess water regardless of the mix,for it is the excess water which regulates the fluidity of the mixture. There is no puddling of this concrete,but centrifugal force takes the place of this as I explained in the previous chapter. This force gives the mixture a certain density and forces out the excess water,which stays to the inside and drains off when the machine is stopped.The r.p.m. being constant with different trials,the force will also be constant, and the density of the mix will be the same,and the excess water given off will be constant.

3. There is no personal element to enter in here as there is in the puddling of the concrete in the slump cone.

PER CENT ERROR .-The test results that I obtained showed about a 100% variation in the Slump Cone test as compared to an 8% variation of the Centrifugal test. See report #2 .

Report #1 on Tests

Monday, May 5th.

This was only a rough test to find out how the machine worked. I made no measure of materials used only approximated a 1:2:4 mix. Machine did not work good due to not being solid. It jumped around too much at a speed of 200 r.p.m.

Wednesday, May 7th.

After machine was made more solid, I was able to reach a speed of 400 r.p.m. with it when empty, or 300r.p.m. with machine full without the machine jumping around much. A speed of 250 I find is enough. I made no measure of water used in the following tests.

Slump Cone	Centrifugal Machine			
slump	amount of 1:2:4 mix.	time.	speed. r.p.m.	water given off.
$\frac{1}{2}$"	1 gal	1 min.	280	22 cc
$\frac{1}{4}$2	1 "	1 "	250	16 cc
$\frac{3}{4}$"	1 "	1 "	"	25 cc

Report #2 on Test

This machine, due to the rough method of construction, is not as consistent as it should be or as it would be, had it been constructed under A-1 conditions. One reason for that is that it is not as solidly built as it should be to run smoothly and true. The method of draining the water off is not ideal. There is an unnessary amount of surface which has to be wet all of which probably accounts for the slight varriation in results. For this experiment, I have been using gravel and sand just as it came from a construction job and have not tried to be at all technical with the experiment. I have used a 1:2:4 mix by volume. This test shows the inconsistency of the slump test.

Test Results

Slump Cone	Amount of 1:2:4 mix.	Water used in cc.	Time.	R.P.M.	Water seperated in c.c.	No.
$2\frac{1}{2}$"	1 gal	850	1 min.	250	35	a.
3"	"	900	"	"	50	b.
1/8"	"	700.	"	"	0	c.
0"	"	"	"	350	1	d.
$\frac{3}{4}$"	"	825	"	250	29	e.
$\frac{1}{2}$"	"	800	"	"	25	f.
$1\frac{1}{2}$"	"	"	"	"	25	g.
$\frac{3}{4}$"	"	"	"	"	26	h.

In comparing tests No. c and d it can be readily seen that a little variation in speed would not make a greal deal of difference in the results. Notice the slump in tests f,g,andh;if the average slump be taken as 1"($\frac{1}{2}$" to $1\frac{1}{2}$") and it varies 1" that is 100% variation.While the mixConsistency test varies but 1 cc in a range of 25cc or about a 4% variation.Notice in tests e and f,eand g,e and h;altho the slump is greater than in f,it is less than in g or h,and there are 25 cc. more water in the former,the Centrifugal test shows 4 cc more water drained off proving there is more excess water in it.

Report #3 on Test

Slump	Mortar 1:2:4	Water	Time	R.P.M.	Water off.	No.
$1\frac{1}{4}$"	1 gal	800	1 min.	250	26 cc.	a.
1"	"	"	"	"	25 cc.	b.
$\frac{3}{4}$"	"	"	"	"	27 cc.	c.
$2\frac{1}{2}$"	"	900	"	"	48 cc.	d.
3"	"	"	"	"	50 cc.	e.
$\frac{1}{4}$"	1:2 mix. "	1100	"	"	10 cc.	f.
$1\frac{1}{2}$"	"	1300	2"	"	32 cc	g.

a,b,andc are practically the same as f,g,and h of Report #2.

f and g are of a 1:2 mix.One gallon of this mix takes a considerable more cement and hence a lot more water.

Report # 4 on Tests

Slump	Mortar 1:2:4	Water cc	Time	R.P.M.	Water off. cc.	No.
$\frac{1}{2}$"	1 gal	825	1 min	250	29	a.
1"	"	"	1 "	"	27	b.
$\frac{3}{4}$"	"	"	"	"	28	c.
$\frac{1}{2}$"	"	"	"	"	$27\frac{1}{2}$	d.
3"	"	875	"	"	48	e.
$2\frac{1}{2}$"	"	"	"	"	50	f.
$3\frac{1}{4}$"	"	"	"	"	49	g.
3"	"	"	"	"	51	h.