THESIS

ON

SHRINKAGE OF CONCRETE

BY

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THE SCOPE OF THE THESIS

The following conclusions listes below were derived by the committee on cements of the American Society of Civil Engineers, in 1887, from the results Professor George F. Swaine, from M.I.T., obtained by running numerous tests on the effects of hardening upon the volume of concrete. These conclusions are found on page 288 of " Concrete Plain and Reinforced" by Taylor and Thomson.

1. Cement mortars hardening in air diminish in linear dimentions at least to the end of twelve weeks and in most case progressively.

2. Cement mortars hardening in water increase in like manner but to a less degree.

3. The contractions and expansions are greatest in neat cement mortars.

By running as many experiments as possible, with the available instruments and apparatus I could fix up; I got enough results that agree with the first and last of the conclusions stated above. The increase in linear dimentions of concrete when hardened in water, not being as important as its shrinkage, I did not work on the second conclusion.

Though concrete is said to shrink continuously for almost a year most of it happens during the first week. Having got only one form fit to use in my experiments and two Ames dyle ; I took readings only for one week on each form. I had intended to take my readings at the end of one week periods, but from the suggestion of Prof. Sheiry, I took daily readings which also made it possible for me to plot curves of shrinkage against time. I poured six forms in all, four of which were 1:3 mix, one 1:2:3 mix and one pure cement. The order of magnitude of the results obtained, and detailed description of the procedure of the experiments will be stated later on in the thesis.

In a reinforced concrete beam the temperature effect is not so important, as both concrete and steel have got almost equal coefficient of expansion. The effect of shrinkage in hardening is more serious. In case the concrete is not restrained by exterior attachments or reinforcement bars, the shrinkage will introduce no internal stresses in the concrete. If the concrete contained reinforcing bars, as is mostly the case, there will be tension set in the concrete and compression in the steel there being bond between the concrete and steel. The determination of these stresses are shown on page 45 of "Principles of Reinforced Concrete Construction" by Turneaure and Maurer, and is as follows:

Let c = coefficient of contraction of the concrete

f_c = unit stress in concrete (tensile)

f_s = unit stress in steel (compressive)

p = steel ratio

$n = \frac{Es}{Ec}$

Then the net contraction per unit length as measured by the concrete will be $c - f_c/E_c$, and as measured by the steel will be f_s/E_s. These values are equal. Also, for equilibrium, $f_c = pf_s$. From these equations we get:

$$f_s = c\,E_c \frac{np}{1 + np} \qquad (1)$$

and

$$f_s = \frac{f_c}{p} \qquad (2)$$

If, for example, $c = .0003$, $E_c = 2{,}000{,}000$, $n = 15$, $p = 1\%$, then $f_c = 80$ lbs./in.^{2} tesion and $f_s = 8000$lbs./in.^{2} If $p = 2\%$, $f_c = 140$ lbs./in.^{2} and $f_s = 7000$ lbs./in.^{2}

It is doubtful if such large initial stresses actually occur in reinforced concrete due to shrinkage in hardening.

The experiments of a certain Considère on the actual contraction of reinfroced concrete indicate that the deformation is less than the above theory will call for. For example, the observed contraction of about .01% in reinforced mortar would call for a stress of only about 3000 lbs./in.^{2} in the steel and 30 to 60 lbs./in.^{2}. In slowly hardening, with steel in pace, there is probably a gradual adjustment in the concrete which results in less internal stresses than the experiments on plain concrete would indicate. Where the structure is restrained by outside supports which are relatively more rigid than the reinforcing steel, the stresses in the concrete become greater and may easily reach the limit of the tensile strength, thus causing cracks.

A certain Bach has concluded from numerous experiments that reinforced concrete will begin to crack at the same elongation as plain concrete. In practical design the most important question which arises is how far a concrete may be cracked without exposing the steel to corrosive influence. In this respect experience indicates that the minute cracks which appear are of no practical consequence.

If we consider Bach's conclusion to be correct, then no amount of reinforcement can entirely prevent contraction cracks. However, the reinforcement forces these cracks to occur at so frequent intervals that the total deformation occurs without exposing any considerable crack. Besides experience which is the best of all tests, labaratory tests have also shown that reinforcement in beams if used in sufficient quantities may easily make the cracks invisibly small and of no consequence from any practical point of view.

Suppose we have a concrete wall which is 100 ft. long, according to my results, the amount of shrinkage is about .01%, and if there were only one crack it would have a size of about one inch which is very considerable. The usage of reinforcement would force the concrete to crack at small intervals, resulting in minute cracks wich would be of no practical consequence. Larger the amount of steel used smaller the cracks will be.

The bond strength furnished by the rods will govern the size and distribution of the cracks. The distance between cracks must be sufficient to develop a bond strength equal to the tensile strength of the concrete. Therefore, the size and spacing of the cracks will vary inversly as the bond.

Page 258 of "Principles of Reinforced Concrete Construction" by Turneaure and Maurer, says that in calculating the requiste amount of steel, the temperature stress in the steel itself must be considered. This will add to its shrinkage stress, so that its total stress will be equal to its temperature stress plus the stress necessary to crack the concrete. If, for example, the assumed drop in temperature be 50° C., the temperature stress in the steel=

$$50 \times .0000065 \times 30 \times 1,000,000 = 9,750 \text{ lbs./in.}^2$$

If the tensile strength of the concrete be 200 lbs./in.^{2} , and the assumed allowed stress (elastic limit) in the steel be 40000 lbs./in.^{2} , then the stress available = 40,000 - 9,750 = 30,250 lbs./in.^{2} , and the required percentage of steel = $p = \frac{200}{30,250}$ = .0066. If the elastic limit be 60,000 lbs. per square inch, the steel ratio $p = \frac{200}{60,000 - 9,750}$ = .004 . For the purpose here considered obviously a high elastic limit steel is desirable, and in order to distribute the deformation as much as possible , a mechanical bond is advantageous. Using the form bars, that is, bars with irregular surfaces, which provide a mechanical bond with the concrete, are more effective than smooth bars and steel of high elastic limit is advantageous.

Temperature changes also introduce cracks in concretes. Concrete having a very small tensile strength a small change in temperaturewill produce cracks. The usage of a ratio of .002 to .004 of steel for temperature and shrinkage reinforcement is practical. The coefficient of expansion of concrete is aorund .0000055 and elastic limit is 2,000,000. Therefore the stress per degree Fahrenheit is .0000055 x 2,000,000 = 11 lbs. / sq. in. The tensile strength of concrete being 300 lbs./ sq. in. , a fall of $\frac{300}{11}$ = 27° F. is sufficient to cause a crack. Therefore concrete poured in cold wheather will shrink less than concrete poured in hot wheather.

Shrinkage of concrete may be practically prevented by keeping it wet during hardening.

PROCEDURE OF EXPERIMENTS AND RESULTS

The setting of the apparatus shown on page was arranged by myself. All of the parts besides the form and the two Ames dyle , were prepared by me in the machineshop. That is, the vetical bars holding the by means of an aluminium plate and a screw, theplate at the bottom of the form, the bolt and horizontal bar which passes through it, and the small screww at the bottom. The projection of the aluminium piece screwed to the vetical bar has a vertical slot of 1/2 inch, which makes it possible to set a needle of the Ames dyle on the zero point and have the bar exactly horizontal. The disk of the Ames dyle , on which the divisions are shown can be rotated; therefore after the form was poured and the bolt,holding the horizontal bar, set in place I saw to it that the needles of Ames dyle were slightly moved downwards so that there would be no possibility of there being a clearance between the top of the needles and the ends of the bar.

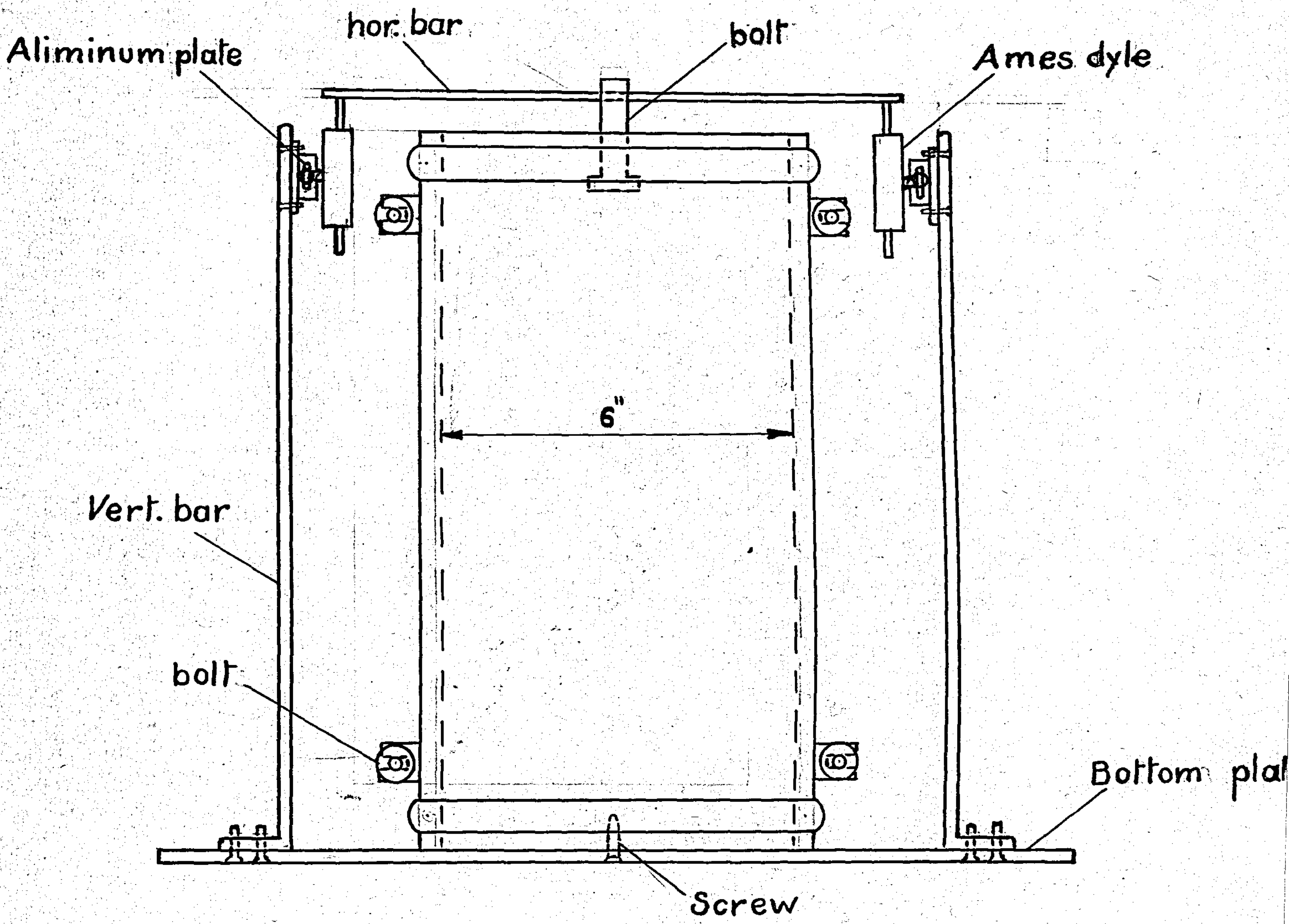
The form used is made of two parts; it can be opened into two vertically which makes the removal of the form without effecting the needles of the Ames dyle possible. The two parts are held together by means of four bolts as shown on the sketch. The small vertical bolt on which the concrete is poured prevents horizontal motion of the bulk of concrete when removing the form. The form is cylindrical having a hight of 12 inches and a diameter of 6 inches. The bolt and iron bar passing through it are made heavy enough to be able to make the needles of the dyle deflect under its own weight. The bolt has also got a big enough bearing area on the concrete so that it would not sink by its own weight. Considering the properties of the bolt the mixes were not made very wet, and were compacted before adjusting the bolt.

The inside surface of the forms and the part of the plate at the bottom on which concrete was poured were greased with ordinary machine oil, which prevented the concrete from sticking to the iron. Twenty-four hours after the pouring of the concrete, the form was removed and from then on, daily readings were taken for a week which are shown in tabular form on page 10 .

The Engineering building being closed, I could not obtain readings on Sundays.

The cement used was Turkish Kurt Cement, the sand and broken stone from Sapanca. Broken stone was used in only one mix.

The operation of the apparatus is very simple. The amount of shrinkage is recorded on the Ames dyle , due to the downward motion of the horizontal bar while the concrete is shrinking, the disk of the Ames dyle is divided into 100 parts, each division reading 1/1000 of an inch.



Sketch of Apparatus

SNRINKAGE IN INCHES (1)

Mix.	Fri.	Sat.	Sun.	Mon.	Tues.	Wed.	Thurs.
I:3							.0100
I:3							.0095
I:3	.0030	.0050	.____	.0075	.0085	.0090	.0090
I:3	.0025	.0045	.____	.0070	.0080	.0085	.0085
I:3	.0035	.0060	.____	.0085	.0095	.0100	.0150
I:3	.0035	.0060	.____	.0085	.0095	.0100	.0150
I:3	.0025	.0045	.____	.0070	.0080	.0090	.0090
I:3	.0030	.0050	.____	.0075	.0085	.0095	.0095
Pure cement	.0085	.0130	.____	.0210	.0240	.0260	.0300
	.0090	.0180	.____	.0260	.0290	.0330	.0350
I:2:3	.0010	.0020	.____	.0025	.0025	.0025	.0025
	.0010	.0020	.____	.0025	.0025	.0025	.0025

(1) Forms were poured on Thursdays.

COMPUTATIONS

Average shrinkage of each form:

<u>1:3 Mixes</u>

$$\frac{.0100 - .0095}{2} = .00975 \text{ inch.}$$

$$\frac{.009 - .0085}{2} = .00875 \text{ inch.}$$

$$\frac{.0150 - .0150}{2} = .0150 \text{ inch.}$$

$$\frac{.0090 - .0095}{2} = .00925 \text{ inch.}$$

<u>Pure cement</u>

$$\frac{.0300 - .0350}{2} = .0325 \text{ inch.}$$

<u>1:2:3: Mixes</u>

$$\frac{.0025 - .0025}{2} = .0025 \text{ inch.}$$

The bottom of the bolt set in the concrete being 11 inches from the bottom of the form, the deflection per inch is found by dividing the average deflection by 11.

<u>1:3 Mixes</u>

$$\frac{.00975}{11} = .000886 \text{ inch./inch.}$$

$$\frac{.00875}{11} = .000796 \text{ inch./inch.}$$

$$\frac{.0150}{11} = .001360 \text{ inch./inch.}$$

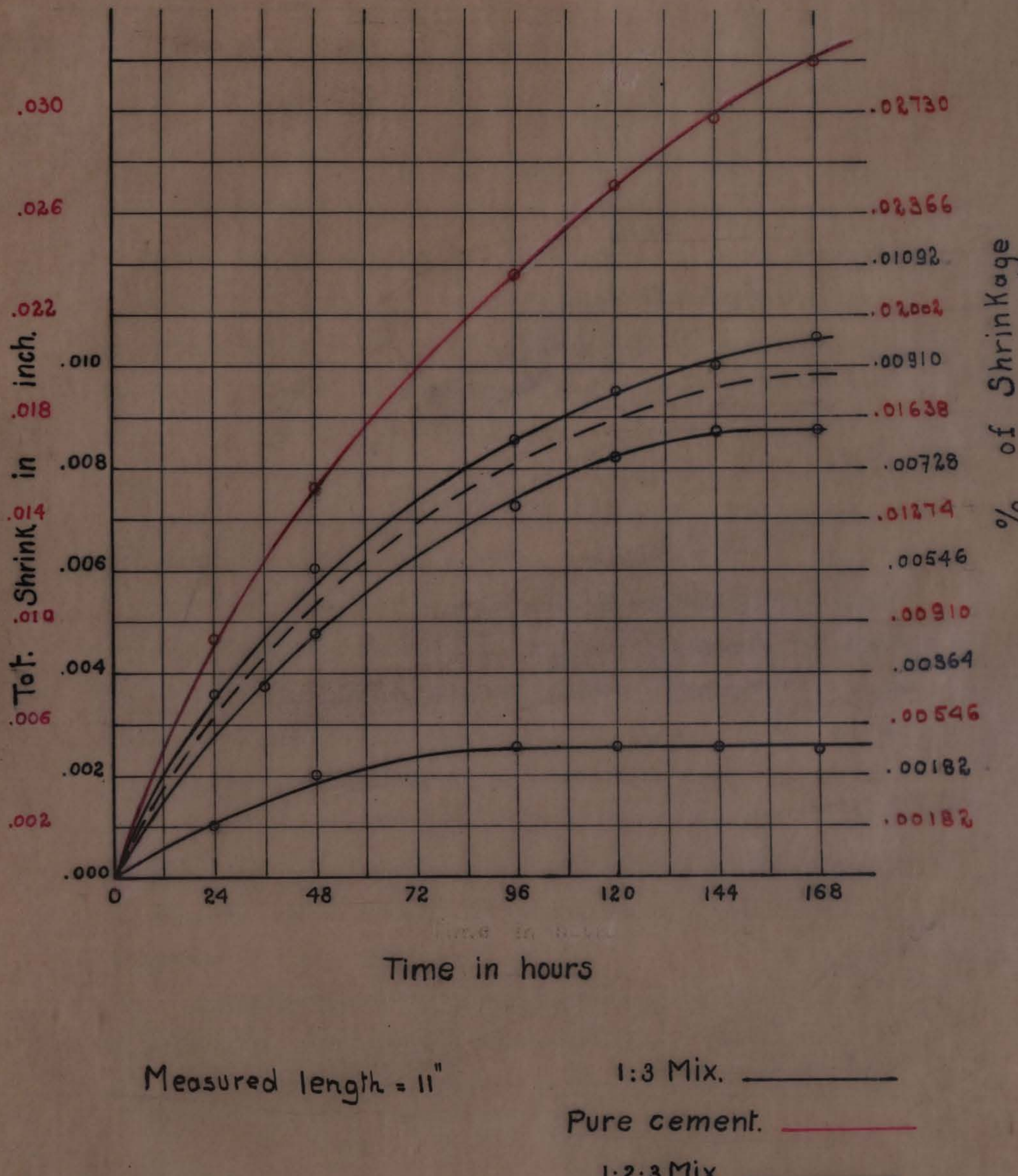
$$\frac{.00925}{11} = .000840 \text{ inch./inch.}$$

<u>Pure cement</u>

$$\frac{.00325}{11} = .00296 \text{ inch./inch.}$$

<u>1:2:3 Mixes</u>

$$\frac{.0025}{11} = .000280 \text{ inch./inch.}$$



.030
.026
.022
.018
.014
.010
.006
.002
.010
.008
.006
.004
.002
.000
Tot. Shrink. in inch.
.02730
.02366
.01092
.02002
.00910
.01638
.00728
.01274
.00546
.00910
.00364
.00546
.00182
.00182
% of ShrinKage
0
24
48
72
96
120
144
168
Time in hours
Measured length = 11"
1:3 Mix.
Pure cement.
1:2:3 Mix.

CONCLUSION

The results obtained, graphs drawn, and ratio of the mixes used, show that the shrinkage is nearly proportional to the amount of cement per unit volume. The sand and stone not being effected, that is not shrinking, the reason for these results is acertained. These results agree with the last of the three conclusions stated at the beginning of the thesis which says: "The contractions and expansions are greatest in neat cement mortars."

Many discussions about the shrinkage of concrete are not found in books, but the development of cracks due to shrinkage being of great importance, ways of pouring concrete and using mixes which will give the minimum of cracks are continuously being worked on.

Recently a mthod of placing concrete by vibration has been applied and has proved to be quite successful. Barges, which are floating bodies have been built of concrete, which was poured and set by vibration. As the walls of such a structure have to be very thin, for its being light, they must be highly reinforced. The government factory being shear in all sections the design of such a structure is not very simple. These barges were seen to be in perfect condition fifteen years after their construction. There were five cracks developed on the surfaces, but these had not caused any rusting of the reinforcement or other trouble.

Producing concrete for long life service in sea water, combined with the necessity for water tightness, demands the utmost of compactness. This was attained by the vibration method being used.

Test made on concrete cylinders which were set for 28 days under continuos and heavy vibration have shown that hhese brike far above the strength of their companion check cylinders, which were rodded and cured under standard conditions. The average being double in strength and correspondingly high density.

This shows that even where impermuousness is necessary concrete can be used. Therefore, if enough reinforcement and proper mixes are used, the shrinkage effects can be reduced to no practical consequence. But in case shrinkage is not cared for, serious trouble , such as the failure of the structure are apt to occur.

THE END

BIBLIOGRAPHY

Concrete Plain and Reinforced, by Taylor and Thomson.

Principles of Reinforced Concrete Construction, by Turneaure and Maurer.

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