FRITZ ENGINEERING LABORATORY
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BETHLEHEM, PENNSYLVANIA
THE EFFECTS OF CLAY ON THE
COMPRESSIVE STRENGTH, PERMEABILITY,
AND DURABILITY OF CONCRETE

by

G. W. Parkinson

June 30, 1931
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THE EFFECTS OF CLAY ON THE COMPRESSION STRENGTH,
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I - INTRODUCTION

The tests herein reported were made to determine the
effect of additions of clay on the workability, compressive
strength, permeability, and durability of concrete. These
tests were initiated, and substantially supported by Hugh L.
Cooper and Company, Inc. of New York City, while the balance
of the expenses were contributed by Lehigh University. The tests
were carried out at the Fritz Engineering Laboratory of Lehigh
University.

II - SCOPE OF TESTS

1. Series A, B, C, and D - The investigation was com-
posed of two parts, the first part included Series A, B, C, D,
E, and F, and the second part included Series G, H, I, J, K,
and L. The former are described in Table 1, and the latter in
Table 2.

Series B and D are similar to Series A and C except
that 10% of the cement used in Series A and C respectively,
was replaced with clay. Series E and F also are similar to
Series A and C, except that 7.5% of the fine aggregate used in Series A and C was replaced by clay.

There were 56 compression, and 40 permeability specimens in each of Series A, B, C, and D, and four compression and four permeability specimens in Series E and F, making a total of 400 specimens in the first part of the programme.

Each of Series A, B, C, and D was divided into the groups indicated below.

(a) Twenty compression and 20 permeability specimens were stored in air until tested. Of these, 5 compression and 5 permeability specimens were tested at each of the ages of 60, 180, 360, and 720 days.

(b) Twenty compression and 20 permeability specimens were moist-cured until put into the freezing and thawing tank. Five of these were tested at each of the ages, and after each had received the number of cycles indicated below:

<table>
<thead>
<tr>
<th>Age, Days</th>
<th>Freezing and Thawing Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>15</td>
</tr>
<tr>
<td>180</td>
<td>30</td>
</tr>
<tr>
<td>360</td>
<td>45</td>
</tr>
<tr>
<td>720</td>
<td>60</td>
</tr>
</tbody>
</table>
Originally, five moist-cured compression and five permeability specimens for each age in each series were to be subjected to a definite number of cycles of freezing and thawing, and then tested. But the early tests indicated that the number of cycles of freezing and thawing were not sufficient to produce any appreciable disintegration. The method of testing was then changed to the following: In every case three of the five specimens were tested as outlined in the original programme. The remaining two specimens, both air and moist-cured, in the 180-day tests of Series A, B, C, and D, were frozen and thawed for an indefinite number of cycles, and inspected periodically for disintegration.

(c) Twelve compression specimens in each series were moist-cured until the day of the test. These were tested at the ages of 60, 180, 360, and 720 days.

(d) At least four compression cylinders in each series were moist-cured and tested at the age of 28 days.
2. **Series E and F** - There were four compression and four permeability specimens in each of Series E and F. These specimens were cured in air only, and were tested at the age of 60 days only.

3. **Series G, H, I, J, K, and L** - The six series were divided into three groups, each having a different sand and gravel ratio. One series in each group was made without clay and the other contained an amount of clay equal to 3% of the total aggregate. These series are tabulated in Table 2. The water content was maintained constant at eight gallons per sack. The sand and gravel, in the proper proportion, were added to this paste until all series were brought to the same workability as measured by the Smith-Conahey apparatus.

The two conditions of curing used in each series are indicated in the table below.

<table>
<thead>
<tr>
<th>Curing for Series G, H, I, J, K, and L</th>
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</thead>
<tbody>
<tr>
<td>Time in Molds</td>
</tr>
<tr>
<td>Hr.</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>24</td>
</tr>
<tr>
<td>24</td>
</tr>
</tbody>
</table>
In the seven-day tests for each of the six series, there were seven compression, seven permeability, and seven freezing-and-thawing specimens. Only four of the seven permeability specimens were successfully tested, because difficulties were encountered in sealing the specimens into the units. Four specimens of each type (compression, permeability, and freezing-and-thawing) were made for the 28-day tests.

Five additional batches were made in each of series G, H, I, J, K, and L, and segregation tests were made on these batches. The method of making segregation tests will be outlined in the section on Segregation Tests.

III - MATERIALS

1. Cement - The cement used in the tests was a Standard Portland Cement, furnished without charge, by the Lehigh Portland Cement Company of Allentown, Pennsylvania. The cement was stored in tight metal containers, each holding about one sack of cement. A small quantity of calcium chloride in a glass jar was placed on top of the cement. Any moisture in the air in contact with the cement, collected in these jars, and after approximately fifteen months' storage, the cement was free from lumps, indicating that very little moisture had combined with the cement.
2. **Clay** - The clay was obtained from the National Bureau of Standards and was the same as that used in tests being made by them for the Cooper Company. It was originally procured from the Westport Brick Company of Baltimore, Maryland, and was classified by the Bureau of Standards as "medium plastic". This classification was entirely arbitrary and is based upon the results of tests of several clays, in which the material was forced through a die. The clay was mixed with the mixing water, and care was taken to see that the mixture was free from lumps.

3. **Fine Aggregate** - Both fine and coarse aggregate were furnished without charge by the Warner Company, members of the National Sand and Gravel Association.

The sand is a natural river sand, having an average specific gravity of 2.60 and an average fineness modulus of 2.75. The sieve analysis curve of this aggregate is shown in Fig. 1.

4. **Coarse Aggregate** - The coarse aggregate was a gravel having a specific gravity of 2.60. The aggregate was screened into four sizes, 1/4 to 3/8, 3/8 to 3/4, 3/4 to 1-1/2, 1-1/2 to 2 in. Each size was stored in a separate bin. The different sizes were recombined so as to give a
straight line gradation curve for the aggregate used in Series A, B, C, D, E, and F. The coarse aggregate in Series G, H, I, J, K, and L, was composed of fifty per cent 1/4 to 3/8, and fifty per cent 3/8 to 3/4 in.

In Series A, B, C, D, E, and F, with the approval of the Cooper Company, a constant ratio of sand to gravel of 34 to 66 was maintained; instead of providing a volume of mortar 15% in excess of the voids in the coarse aggregate, as originally specified. This departure was made because preliminary tests indicated the original specification would produce a harsh working under-sanded mixture.

IV - MIXING

All materials were measured by weight.

The specimens in Series A, B, C, D, E, and F, were made from batches mixed in a small mixer. All the dry ingredients were placed in the mixer, which was then rotated for one minute, the water was added and mixing was continued for an additional three minutes.

Two batches were required for each set of specimens. These batches were mixed separately and placed in a galvanized iron canoe (container) and were mixed by hand until the mix was quite uniform.
The specimens in Series G, H, I, J, K, and L, were mixed by hand. One batch contained enough concrete for one compression, one permeability, and one freezing-and-thawing specimen.

V - SPECIMENS AND CURING

1. Specimens - All compression specimens were 6 by 12-in. cylinders. The bottom of these specimens required no capping, as they were cast on smooth steel plates. The tops were capped with neat cement.

The permeability specimens in Series A, B, C, D, E, and F were 6 in. in diameter and 4 in. thick. This thickness was determined mainly by the maximum size of the aggregate, which was 2 in. The permeability specimens in Series G, H, I, J, K, and L, were 6 in. in diameter and 2 in. thick, with aggregate of a maximum size of 3/4 in.

The regular compression and permeability specimens in Series A, B, C, D, E, and F, were subjected to freezing and thawing, and were tested either in compression or in permeability at the completion of the freezing and thawing. The freezing and thawing specimens in Series G, H, I, J, K, and L, were cubes 4 by 4 by 4 in. These specimens were used for freezing and thawing alone.
2. Curing - The specimens in Series A, B, C, D, E, and F, that were moist-cured were left in the molds for 24 hours, then removed from the molds, marked, and weighed. These specimens were then stored in a moist room, where the temperature was maintained at 70°F, until the day of the test, or until they were placed in the freezing and thawing tank.

The air-cured specimens in Series A, C, B, D, E, and F, were removed from the molds when they were 48 hours old, and were marked and weighed. They were then stored in air until the day before the test, when they were placed in water until tested for compressive strength. This was done so as to bring both the air-cured and moist-cured specimens to the same condition for testing. Otherwise the air-cured specimens would be tested dry and the moist-cured specimens would be saturated, and tests (1) have shown that a specimen tested dry had a higher compressive strength than a similar specimen tested wet.

For Series G, H, I, J, K, and L, two types of curing were used. The specimens tested at an age of seven days were left in the molds 24 hours and then stored in the moist room until the day of the test. The 28-day compressive strength specimens were left in the molds 24 hours, then stored in the

* Refers to list of references, p.41
moist room for six days, and then stored in air until approximately eight hours before testing. They were then immersed in water until the time of testing.

VI - APPARATUS AND METHOD OF TESTING

1. Compression Tests - The compression specimens were tested in a 300,000-lb. Tinius Olsen testing machine which had previously been calibrated and found to be satisfactory.

2. Workability Tests, Series A, B, C, D, E, and F - The original specification stated that "The consistency of the concrete mixture should be such that workmen walking on green concrete will track never more than 8 in. or less than 3 in." This apparently referred to penetration into the surface of a large mass of concrete. The penetration under the same load and bearing area evidently would be less for a small mass. To make the requirement definite and to bring the tests within the range of laboratory procedure, the specifications were later modified so that a block having a bearing area of 3 by 12 in. and carrying a total weight of 160 lb. should penetrate between 1 and 3-1/2 inches into the surface of a mass of fresh concrete 20 in. in diameter and 16 in. deep. This is understood to be the same procedure as is being used at the Bureau of Standards in a similar test. The container and apparatus
are shown in Fig. 2. Even this quantity of concrete was too great to permit frequent tests, and an effort was made to determine an approximate relation between the slump and penetration of the block mentioned above. For this purpose a very dry mix of concrete without clay was prepared on which the slump and penetration were measured. It was then re-mixed with the addition of a small amount of water, and the slump and penetration were again measured. This was repeated until the penetration was beyond the range specified.

The results obtained are plotted in Fig. 3. This figure indicates that for specimens without clay the penetration was approximately proportional to the slump. For the specimens with clay not enough slump tests were made to determine the relation between slump and penetration. However, the few results available indicate that for an average slump of a little less than two inches, the penetration was approximately twice as great as the penetration for the specimens in which no clay was used. The concrete with clay was more easily placed than the concrete without clay. This was so evident as to indicate an improvement in workability due to the addition of clay.

Since it was not practicable to make frequent penetration tests, the concrete was kept within the specified penetration limits by holding the slump at about two inches.
3. Smith-Conahay Penetration Apparatus - Mixes containing clay appeared to be more workable than mixes without clay, even though both had the same slump. This indicates that the slump test is not suitable for detecting small differences in workability. The apparatus developed by Messrs. G. A. Smith and George Conahay was used for controlling the workability in Series G, H, I, J, K, and L, because from a study of the data presented in their paper (2), it appeared to be an improvement over other methods of measuring workability.

The apparatus is shown in Fig. 4. With this device, three parallel rods, attached to a spider, are driven into the concrete by means of a miniature pile driver, and the number of blows required for a given penetration is used as a measure of the workability.

The concrete was placed in three layers, into the cylindrical container 8-1/2 in. in diameter and 12 in. deep. Each layer was rodded 25 times. Then the top was placed on the container so that the points of the rods were in contact with the surface of the concrete, with the hammer resting upon an anvil carried on top of the rods. The hammer was raised through a fixed distance which remained constant for successive blows. It was then tripped and fell between two guide rods, the hammer striking an anvil and driving the
rods into the concrete. This operation was continued until the rods had penetrated a distance of 11 in. into the mass of concrete. The total work in inch-pounds is the workability figure and is given by the equation:

\[ W = p(R_w + H_w) + nH_w \]

- \( p \) = penetration of rods in inches = 11
- \( R_w \) = weight of rods in pounds = 1.903
- \( H_w \) = weight of hammer in pounds = 1.022
- \( n \) = the number of blows
- \( h \) = drop of hammer in inches = 5

Substituting the values which apply to the apparatus used, the equation then becomes:

\[ W = (32.175 + 5.113n) \]

Series G, H, I, J, K, and L, were brought to the same workability as measured by this apparatus and the results obtained will be discussed later.

4. Segregation - While making workability determinations using the Smith-Conahey apparatus, it was noticed that the rate of penetration for mixes without clay decreased much more rapidly as the rods neared the bottom than for mixes with clay. This difference in behavior is shown in Fig. 5, and was probably caused by segregation of the aggregate in the mixes without clay. To verify this, segregation tests were made on mixes in Series G, H, I, J, K, and L.
The segregation tests were made by two different methods.

For the first method used, the concrete was placed into the container (8-1/2 in. diameter and 12 in. deep) in three layers and each layer was rodded 25 times. Then a workability test was made with the Smith-Conahay apparatus and the number of hammer blows for each inch of penetration was recorded. A segregation index was calculated by taking the ratio of the number of hammer blows required to obtain the penetration from 9 to 11 in. to the number of blows required for the first 9 in. of penetration.

A layer of concrete (approximately 1 in. deep) was taken off the top and was designated as the Top Sample. The concrete was removed from the container until approximately 1 in. remained in the bottom. This was collected and designated as the Bottom Sample. The ingredients of these samples were then determined with the Dunagan Buoyancy apparatus shown in Fig. 6, in the following manner. The sample was weighed first in air, and then in water. The sample was then placed in a nested No. 4 and 100 sieve and was sieved in water. This separated it into three sizes. The material retained on the No. 4 and the 100, and that passing the 100 sieve. The first was assumed to be gravel, the second sand, and the third cement. However, some silt
and clay passed the 100 sieve and some of the cement was retained on the 100 sieve. Preliminary determinations provided approximate correction factors to be applied to allow for these items. The gravel was weighed submerged, then the gravel and sand. The weight in air was obtained by multiplying the submerged weight by \( \frac{x-1}{x} \), when \( x \) is the specific gravity of the material. The weight of the water was obtained by subtracting the total weight of the dry materials from the total weight of the sample.

Two separate determinations on each of Series G, H, I, J, K, and L, were made using this method. This involved mixing 12 batches and making 24 determinations with the Dunagan apparatus.

The second method differed from the first in two respects; (a) each of the three layers was jigged into place by raising and dropping the container twelve times, through a distance of approximately one inch, and (b) in determining the ingredients, the total sample was weighed wet, and alcohol was mixed with the wet concrete and ignited. While the alcohol was burning, the concrete was stirred until all the moisture was driven off. The materials were then sieved dry. It is believed that the water-cement ratio was determined more accurately by the latter than by the former method. Three determinations on each of Series G, H, I, J, K, and L, were made by this method.
5. **Permeability Apparatus** - It was originally intended to use permeability specimens that were 12 in. in diameter and 4 in. thick. One unit was assembled to accommodate specimens of this size. This apparatus proved to be very large and it was difficult to remove the specimens, by heating the sealing compound and the specimen had to be jacked out. This procedure required considerable time in testing the specimen.

At the suggestion of Mr. Inge Lyse of the Portland Cement Association, the size of the permeability specimens was changed to 6 in. in diameter and 4 in. in thickness, since this form of specimen had been found to be satisfactory in tests made by the Portland Cement Association. Testing units made to accommodate this size could be used to test specimens having a greater range in thickness than the specimens first tried.

Fig. 7 shows a general layout of the permeability apparatus.

The pressure was furnished by means of a Curtis air compressor. This machine is equipped with an automatic switch which starts the compressor when the pressure in the storage tank falls to 130 lb. per sq.in. and stops when the pressure reaches 160 lb. per sq.in.
A Foster reducing valve was placed in the pipe line leading from the air storage tank to the water storage tank. This valve can be adjusted to obtain any pressure between 10 and 180 lb. per sq. in.

An automatic recording pressure gage was connected on the low-pressure side of the reducing valve and thus a continuous record of the pressure on the specimens was obtained.

Details of a permeability unit are shown in Fig. 6. The mixture used in sealing the specimens into the units was the same as that used by the Portland Cement Association. It is composed of 30% paraffin and 70% rosin. This drawing also indicates the method of supporting the funnel used to collect the water that leaked through a given area of the specimen.

Rust formed in the piping of the permeability apparatus, and was deposited on the surface of the specimen. This, of course, tended to fill the pores and reduce the leakage. A miniature sand filter was first tried to overcome this difficulty. This reduced the amount of rust collecting on the specimen, but did not entirely eliminate it.

Two plies of heavy duck were next used in the units, but these failed to collect all the rust. However, by using a filter paper between the two plies of duck it was possible to keep the surface of the specimens free from rust. The
amount of water passing through the specimen was measured. In order to secure more information on the methods of measuring permeability, one unit was equipped with a graduated glass tube for measuring the input, in addition to the output.

It was expected that after the specimens had become saturated, the rate of input and output would be equal. Fig. 9 and 10 show the observed input and output on two specimens, one for 260 hr., and the other for 178 hr. It was found that the difference between the rates of input and output continually became smaller, up to about 40 hr. After that time the difference in rate remained constant at about 0.4 cc. per hr. for one specimen (Fig. 9) and 0.65 cc. per hr. for the other specimen (Fig. 10). It appeared possible that the 40-hr. period marked the time at which the specimen became saturated and that the constant difference in rates of input and output beyond that time represented leakages through the connections.

To secure further information on this feature, a steel plate was sealed in the unit instead of a concrete specimen, and the input was measured.

On starting the test, the graduated glass was filled to the top before any pressure was applied. When the pressure was applied the water was lowered at once through a distance indicating an input of 60 cc. (Fig. 11). On release of the
pressure, the water rose again to a point indicating an input of only 18 cc. The tube was then refilled, and when the pressure was reapplied, an input of 47 cc. was indicated. From this point on, readings were taken both under pressure and with the pressure released. The readings for zero pressure are indicated by the lower curve, and for full pressure (100 lb. per sq.in.) by the upper curve. Since the upper curve represents more closely than the lower, the conditions under which the readings of output were taken, in the permeability tests, the upper curve was used in comparing the input with the difference between input and output for the permeability specimens, although it is not known that it represents the actual input any more closely than the lower curve.

At the beginning, a small leakage through one of the threaded joints was observed. A total of 14 cc. of water from this leak was observed in 16 hr. Later this leak apparently became sealed, and after 40 hr. the rate of input became practically constant at 0.38 cc. per hr.

The similarity between the behavior with the permeability specimen and that with the steel plate makes it appear that about 40 hr. was required for the rate of leakage through the connections to become constant.
The correct interpretation as to leakage through connections is not known, but it seems evident that with the apparatus used, the measurement of output constituted a more reliable measurement of leakage than the measurement of input.

6. **Freezing and Thawing Equipment** - The freezing and thawing tests were conducted in the Chemistry Building of Lehigh University, as the Chemistry Department placed their York Refrigerating Plant at the disposal of the Fritz Engineering Laboratory. This plant was modified to adapt it to freezing and thawing of concrete specimens.

The specimens were immersed in fresh water, in cans whose diameter was 1/4-in. greater than the diameter of the specimen, and the cans were then placed in the freezing tank and cold brine circulated around them.

7. **Freezing and Thawing Tests** - A trial was made to determine the length of time required to freeze the specimens. The temperature was taken at the center of a 6 by 12-in. cylinder, with a mercury thermometer. The curves in Fig. 12 show the temperature at the center of a 6 by 12-in. cylinder. This indicates that operating the refrigerator for approximately one hour was sufficient to freeze the specimens. The refrigerator was, however, operated for approximately 3 to 4 hours.
The brine was then drained out of the freezing tank into the brine storage tanks. The covers were removed from the freezing tank and the cans were allowed to stand in air (at room temperature) which was circulated by an electric fan for approximately 20 hours. One complete cycle of freezing and thawing was obtained every 24 hours.

It is difficult to measure quantitatively the amount of disintegration that occurs in a specimen. Reduction in strength due to freezing and thawing is not a reliable means of measuring the amount of disintegration, as most specimens subjected to freezing and thawing showed an increase in compressive strength, even though considerable disintegration had occurred.

The specimens were weighed before and after freezing, but the moisture content of the specimens is a large item, and even when the surface appears to be quite badly disintegrated the loss in weight is very small.

The most satisfactory method has been to photograph the specimens before and after freezing, but with this method it is difficult to make quantitative comparisons.
VII - WORKABILITY TESTS

The discussion of the relation between slump and the penetration of 3 by 13-in. bearing area carrying a load of 160 lb. has already been presented.

The Smith-Conahey penetration apparatus was used for measuring the workability of Series G, H, I, J, K, and L and the results are given in Table 3. These results show a wide variation in the workability figure for any particular series. The average variations from the means for the six series, are given in this table, and these range from 18.6 to 40%, while the maximum variation from the mean ranges from 66 to 146%. The tests on Series G, H, I, J, K, and L, show that the variation between individual determinations was less for the mixes with clay than for the mixes without clay. The average variation of the workability figure from the average for the mixes with clay is 23%, and for mixes without clay it is 34%.

Seven penetration tests were made on a standard Ottawa sand to determine the variation between individual results on a material that is very uniform. The container was filled with dry Standard Ottawa sand which was neither rodded nor vibrated into place, as it was thought that either operation would introduce a variable that could not be completely controlled. The average variation of the workability figure
from the average was, for this case, 6.4%. The writer believes that it is reasonable to expect variations as large as those obtained in Series G, H, I, J, K, and L, in a material as variable as concrete, when an average variation from the mean of 6.4% was obtained on a material as uniform as Standard Ottawa Sand.

Series G, H, I, J, K, and L, are thought to have been of approximately equal workability, since the variation between the averages for the different series was less than the variation between different determinations on the same mix. The average variation from the mean for any one series ranged from 18.6 to 48%, while the average variation of the mean of each series from the average for all determinations was 16.8%.

Slump tests were made on the mixes used in Series G, H, I, J, K, and L, and Fig. 13 shows typical slumps for these series. These mixes had approximately the same workability as measured by the Smith-Conahey apparatus, though the slump varied from one to seven inches. The slump was always less for the mixes containing clay than for corresponding mixes without clay. This fact, together with experience gained in mixing and working the concrete, indicates that the mixes containing clay had a greater tendency to stick together and resist deformation.
It is impossible, from the data obtained, to arrive at any conclusion as to the relative merits of the two methods of measuring workability. The results obtained by the Smith-Conahey penetration apparatus do show, as will be pointed out later, the effects of segregation.

VIII - SEGREGATION TESTS

1. Method No. 1 - The results of segregation tests for the first method, in which the material was jiggled into the forms, and the ingredients were separated by sieving and weighing in water, are given in Table 4. Fig. 14 shows the water-cement and water-gravel ratios for the samples taken from the top and bottom of the container. The curves show a wide difference between the water-cement ratio in the top and bottom samples, and this difference is slightly greater for mixes without clay than for those with clay. It has previously been pointed out that experimental errors are accumulated in the determination of the water content, and this tends to make the water-cement ratio determined by the method rather unreliable.

The difference in the water-aggregate ratio in the top and bottom samples were very small for the mixes with clay and quite large for those without clay. Either the difference in water-cement or water-gravel ratio between the top and bottom samples can be taken as an indication of the amount of segregation. These differences, together
with the segregation index are plotted in Fig. 15. The segregation index indicates that there was less segregation in the mixes containing clay than in those without, and this is verified by determining the separate ingredients. The correspondence between the segregation index and the difference in water-cement ratio is only fair, while the relation between the segregation index and the water-gravel ratio is quite good.

2. Method No. 2 - The results obtained by the second method, where the concrete was jugged into the container, and the ingredients were separated by sieving and weighing after drying the batch, are given in Table 5. The results (Fig. 16) indicate that there was less segregation in the mixes containing clay than in those without clay. In this case, however, the correspondence between the segregation index and the difference in water-cement ratio is closer than that between the segregation index and the difference in water-gravel ratio. The results show that clay was effective in reducing the segregation, and also that the segregation index obtained by using the Smith-Conahey apparatus gave an approximate measure of the extent of the segregation.
IX - COMPRESSION TESTS

1. The Effects on the Compressive Strength of Substituting Clay for Cement - The results of tests for two conditions of curing (air-curing, and moist-curing followed by freezing and thawing) and four ages, 28, 60, 180, and 360 days are given in Table 6, and plotted in the upper curves of Fig. 18. These tests indicated that for the condition of curing used, substituting clay for 10% of the cement produced a reduction in strength for all the ages. In general, the reduction in strength was greatest for the richest mix. The average of specimens in Series E had a compressive strength that was 97.5% of the average of all specimens in Series A, while the specimens in Series D had a strength that was 78.8% of the specimens in Series C. The curves also show that the specimens which received moist curing followed by freezing and thawing were always higher in strength than the air-cured specimens. The effects of freezing and thawing on the compressive strength will be discussed in more detail in the section on Durability.

2. The Effects on the Compressive Strength of Substituting Clay for 7.5% of Sand - Series E and F were similar to Series A and C except that seven and one-half per cent of the sand used in Series A and C was replaced in Series E and F with an equal weight of clay. This
substitution of clay for sand caused a 25% reduction in strength in the mix with 6.0 sacks of cement per cubic yard (Series C and F) and a reduction of only 3% in the mix containing 5.0 sacks of cement per cubic yard (Series A and E). See Table 7 and Fig. 19.

This indicates that the probable reduction in strength caused by the use of dirty sands would be much less for a lean than for a rich mix. It appears that present limitations on the clay content of sand are justified, and that careful tests should be made on sands containing clay before using them; as tests (3) indicated that some clays caused a greater reduction in strength than others.

3. The Effects of Additions of Clay on the Compressive Strength - The previous sections dealt with the effects of clay when a certain amount of either cement or sand was replaced by an equal weight of clay, but this section deals with the effects of clay on the compressive strength of concrete, when clay was added to the mix as an extra ingredient and did not replace either cement or sand.

The results obtained are given in Table 8 and are plotted in Fig. 20. The mixes with clay were higher in strength at seven days than the corresponding mixes without clay. The 28-day tests, however, showed that for the 40-60 sand-gravel ratio, the mix with clay was lower in strength than the mix
without clay, while for 35-65 and 30-70 sand-gravel ratios there was no appreciable difference in strength between the mixes with and without clay. The section on segregation showed that the clay aided materially in reducing the segregation of the materials in the mixture, and even though it did not improve the compressive strength at 28 days, its use, especially in the under-sanded mixes (those with sand-gravel ratios of 35-65 and 30-70) would reduce the difficulties encountered in placing such mixes. It is possible that the use of clay may be beneficial in concretes made from aggregates that are deficient in sand, or sands lacking in the finer sizes.

X - PERMEABILITY TESTS

1. The Effect on the Permeability of Concrete of Substituting Clay for Cement - The permeability specimens that were moist-cured until the beginning of the freezing and thawing tests, will be designated as moist-cured specimens, regardless of the fact that during the permeability test all specimens received moist curing.

Tests were made on the moist-cured specimens in Series A, B, C, and D at the ages of 60, 120, and 360 days, and under pressures of 20, 60, and 100 lb. per sq.in. respectively, and these specimens were impermeable throughout the duration of the test.
The air-cured specimens, after being removed from the molds, were stored in the laboratory until the day of the test. These specimens gave measurable leakages and allow a comparison to be made of the permeability of specimens with and without the substitution of clay for 10% of the cement.

The results obtained for each age will be discussed separately. The average curve for each series is obtained by averaging the results of five permeability tests.

The results of the 60-day tests on Series A, B, C, and D, are plotted in Fig. 21. The leakage in each of Series A and B (5 and 4.5 sacks of cement) was considerably greater than the leakage in Series C and D (6 and 5.4 sacks of cement). The leakage in the specimens having 10% of the cement replaced by clay was slightly greater than that in specimens having no clay. The indication is, that in its effect on permeability, the clay partially, but not wholly, compensated for the cement which it replaced.

As a result of replacing 10% of the cement by clay the increase in permeability was approximately the same for the two cement contents used, but the reduction in strength was greater in the rich than in the lean mixes.
The results of the 180-day permeability tests are plotted in Fig. 22. The difference in leakage between the specimens in Series A and B, and that of the richer ones of Series C and D, was much less in the 180-day tests than in the 60-day tests. It is not known whether it was the increase in age or the increase in pressure on the test specimens that brought the leakages to nearer the same value.

The specimens with clay showed greater leakages than the corresponding ones without clay except that of the two leaner mixes, Series B (with clay) showed less leakage during the first 50 hours than the corresponding Series (A) which had no clay substitution.

For this age the increase in leakage in the specimens with 10% cement replaced by clay was greater for the specimens made from the richer of the two mixes.

The results of the 360-day tests are given in Fig. 23. For the first 90 hours the specimens in Series A (without clay) showed slightly greater leakages than those in Series B (with clay), but after this time the conditions were reversed.

Except for the first 50 hours, the richer specimens without clay (Series C) showed considerably greater leakages than the corresponding ones with clay (Series D). No satisfactory explanation has been found for this difference in behavior, between the specimens tested at the age of 60 and 180 days, and those tested at 360 days. There is a general indication, however, that with increase in age, the permeability
of the richer specimens (Series C and D) approached that of the leaner ones (Series A and B). The increased pressure under which the later tests were made may, however, be a factor in producing the result.

3. The Effect on the Permeability of Concrete, of Substituting Clay for 7.5% of Sand - Fig. 24 indicates that with a cement content of 5.0 sacks per cubic yard, the fine aggregate containing 7.5% of clay (Series E) produced concrete of lower permeability than concrete made with clean sand (Series A). With a cement content of 6.0 sacks per cubic yard, concrete made with clean sand (Series C) had lower permeability than one made with sand containing clay (Series F).

It is interesting to note the relation between permeability and compressive strength. The compressive strength of Series E was 97% of that of Series A, and the permeability of Series E was approximately half of that of Series A. The compressive strength of Series F was 75% of that of Series C, and the permeability of Series F was approximately double that of Series C.

These tests indicated that for the mix containing 5.0 sacks of cement per cubic yard of concrete, sands containing 7.5% of clay had little effect on the compressive strength and resulted in an improvement in impermeability. In a mix of 6.0 sacks per cubic yard, the same amount of clay would produce a decided reduction in strength and an increase in permeability.
This seems to indicate that lean mixes would probably benefit by the use of sand containing up to 7.5% of clay, while rich mixes would be impaired thereby.

3. The Effects of Additions of Clay on the Permeability of Concrete - The results of the 7 and 28-day tests on Series C, H, I, J, K, and L (having cement contents of 5.4, 5.5, 5.4, 5.1, 5.7, and 5.3 sacks per cubic yard respectively), are given in Fig. 25 and 26, and show the effect of adding an amount of clay equal to 3% of the total aggregate for each of three different sand-gravel ratios (the water-cement ratio in each series was eight gallons per sack of cement, and all series were brought to the same workability as measured by the Smith-Conahay apparatus). In each case, the mixes containing clay showed a decrease in permeability over the mixes without clay, and the greatest decrease occurred in the mix having a 30-70 sand-gravel ratio.

This series of tests indicated that additions of clay did not increase the permeability of mixes in which the sand-gravel ratio was 40-60, and that for the under-sanded mixes having sand-gravel ratios of 35-65 and 30-70 the addition of clay equal to 3% of the total aggregate did produce marked improvement in the impermeability of the concrete.
4. The Relation of Permeability to Compressive Strength - It has been generally assumed that concrete having high compressive strength would also have low permeability. The data here yields some information on the relation between compressive strength and permeability.

Fig. 27 shows the compressive strength and permeability results for the Series A, B, C, and D, at the ages of 60, 180, and 360 days. In the 60 and 180-day tests, the specimens of high compressive strength showed low permeability, which was also true in a general way for the 360-day tests, but this condition did not hold for small variations in strength.

The curves in Fig. 28 show the compressive strength and permeability results for Series G, H, I, J, K, and L at the ages of 7 and 28 days. The differences in compressive strength for the various series were small, but the variations in the permeability for the different series were very large. This would indicate that factors which have very little effect on the compressive strength may have a marked effect on the permeability.

It appears that the curing, or lack of it, has a much greater effect on the permeability than on the compressive strength of a specimen, and it is possible that
specimens which have equal strengths, may differ greatly in permeability. It appears that for a given curing condition the compressive strength may be a criterion of the probable permeability.

XI - DURABILITY TESTS

The durability of concrete depends on the particular conditions to which it is exposed, and in these tests the resistance to freezing and thawing was used as a measure of this property. The tests indicate the relative durabilities of the concretes when exposed to freezing and thawing, but do not necessarily indicate their resistance to other conditions that produce disintegration.

1. Tests on Series A, B, C, and D - The moist-cured compression and permeability specimens were subjected to 15, 30, and 45 cycles of freezing and thawing, and were tested at the ages of 60, 180, and 360 days respectively. In every case the effects of freezing and thawing on the moist-cured specimens were very slight, and even for those subjected to from 75 to 100 cycles it was not sufficient to remove the original surface, as an examination of Fig. 30 to 41 will show. It must be remembered that these concretes were of fairly rich mix, and had long periods of moist curing prior to the freezing and thawing, and so do not represent the average field concrete.
The curves in Fig. 29 show the compressive strength of specimens subjected to freezing and thawing and also for those that received moist curing alone. It will be noticed that generally the moist-cured specimens without freezing and thawing were lower in strength than corresponding specimens subjected to freezing and thawing.

2. 180-day Tests on Series A, B, C, and D - Two compression specimens from each of Series A, B, C, and D, for both conditions of curing (air and moist curing) were put into the freezing tank and subjected to freezing and thawing, and inspected periodically. The specimens were capped and tested in compression at the completion of the freezing and thawing tests. The results of the compression tests are given in Table 9.

Photographs of the specimens at various stages of the durability tests are shown in Fig. 30 to 41 inclusive. These tests showed the specimens that were moist-cured for approximately 150 days to be very resistant to the action of freezing and thawing, while similar specimens that had received air curing alone had much less resistance to the freezing and thawing action. An examination of the photographs shows the specimens without clay to be slightly more resistant to freezing and thawing than corresponding specimen with clay; as the latter usually started to disintegrate before the former.
3. Quantitative Measurements of Disintegration

The photographs yield valuable information regarding the effects of freezing and thawing on concrete; but it is very desirable to be able to measure quantitatively the effects of freezing and thawing.

Professor C. H. Scholer in his paper (4), used the number of cycles required to give complete disintegration as a measure of the durability, and arbitrarily defined complete disintegration to have been reached when the specimen was reduced to one-third or less of its original size. He also used the number of cycles required to produce a 25% reduction in strength as a measure of durability.

It would have required a large number of cycles of freezing and thawing to reduce the specimens used at Lehigh University to one-third their original size.

Test data obtained from these tests indicated that the compressive strength often increased, even though the specimen had disintegrated considerably. These results are given in Table 9. This shows that half of the specimens tested increased in compressive strength, even though they were frozen and thawed. For these specimens, reduction in compressive strength would have been a very poor indication of the extent of disintegration.
The specimens were weighed before and after freezing and thawing and it was hoped that the change in weight would prove useful as a quantitative measure of disintegration. The specimens, if air-cured, were immersed in water for 24 hours prior to weighing, and the moist-cured specimens were weighed while in the saturated condition. The results secured by this method, for series A, B, C, and D, are given in Table 10. The reduction in weight proved to be very small, and would be seriously affected by any variation in moisture content of the specimens.

Table 10 shows that the reduction in weight during freezing and thawing was greater for the air-cured than for the moist-cured specimens, and shows that the reduction in weight did give some indication of the amount of disintegration. It is not possible to draw any conclusion regarding the effects of clay on the durability of the concrete, from the reduction in weight given in this table.

The reduction in weight of the freezing and thawing specimens in Series G, H, I, J, K, and L, are given in Table 11. From a study of the data it was impossible to find any relation between the reduction in weight during freezing and thawing and either the compressive strength or permeability of specimens made from the same batch. The average reduction in weight for the specimens having seven days moist curing only was 12.9% for the specimens without clay, and 15.1% for those with clay, but the specimens having seven days moist
and 21 days air curing prior to the beginning of the freezing and thawing tests, the average reduction in weight was 7.1% for the specimens without clay and 7.5% for those with clay. While the evidence is not conclusive, this trend seems to indicate that the specimens without clay had a slightly greater resistance to freezing and thawing than those with clay.

The absence of a satisfactory method of measuring the extent of the disintegration, makes it very difficult to study the factors that affect durability.

**X - SUMMARY**

The results obtained from the tests are summarized briefly in the following statements.

(1) For a given slump, concretes having the clay plus cement were more workable than corresponding mixes in which the cement content alone equalled the sum of the clay and the cement in the former mix.

(2) The workability results obtained by using the Smith-Conahey penetration apparatus showed a wide variation in values between individual determinations on the same mix. This seems to indicate that this method would not be suitable for detecting small differences in workability.
(3) The segregation tests indicated that the addition of clay as an extra ingredient to the mix, reduced the amount of segregation considerably.

(4) Tests also showed that segregation plays an important part in the value of the workability figure as determined with the Smith-Conarney penetration apparatus.

(5) The segregation index, calculated from the results obtained in the workability determination, gave an approximate indication of the amount of segregation in a mix.

(6) The substitution of clay for 10% of the cement resulted in a reduction in compressive strength, and there was some indication that the reduction in strength was greater for the rich than for the lean mixes.

(7) The use of sands containing 7.5% of clay resulted in a 3% reduction in compressive strength when the cement content was 5.0 sacks per cubic yard and in a 25% reduction when the cement content was 6.0 sacks per cubic yard. The use of sand containing 7.5% of clay resulted in a decrease in permeability for the former mix, and in an increase in permeability for the latter mix. The results indicated that in lean mixes the use of sands containing 7.5% of clay had very little effect on the compressive strength, and gave a decrease in permeability, while for rich mixes the use of the same sand resulted in a considerable reduction in strength, as well as an increase in permeability.
(8) The addition of clay in amounts equal to 5% of the total aggregate, did not materially affect the compressive strength of the concrete. With this addition, the specimens tested at 7 days showed a marked improvement in impermeability, while for the 28-day tests there was very little change in impermeability in the mixes containing clay, except in the mix having the lowest sand-gravel ratio where the improvement was very marked.

(9) The compressive strength may be an indication of the permeability of concrete, provided the concretes have received the same treatment. However, the compressive strength will be no indication of the probable permeability if the curing conditions differ.

(10) The air-cured specimens (of low compressive strength) were less durable than the moist-cured specimens (of high compressive strength). While the evidence is not conclusive, there were indications that the mixes having 10% of the cement replaced by clay were less durable than the mixes without clay.
LIST OF REFERENCES

1. STUDY OF METHODS OF CURING CONCRETE
   H. F. Connerman

2. THE MEASUREMENT OF WORKABILITY OF CONCRETE
   George A. Smith

3. TESTS OF POWDERED ADMIXTURES IN CONCRETE
   D. A. Abrams
   A.S.T.M. Proceedings, Part II, Vol. 29, 1929, p. 618

4. SOME ACCELERATED FREEZING AND THAWING TESTS ON CONCRETE
   C. H. Scholer
TABLE 1 - MIXES USED IN SERIES A, B, C, D, E, AND F

Slump was constant at two inches

<table>
<thead>
<tr>
<th>Series</th>
<th>Cement sacks per cu. yd.</th>
<th>Water gal. per sack</th>
<th>Clay lb. per cu. yd.</th>
<th>Proportions by Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5.0</td>
<td>6.9</td>
<td>0 3/8 6</td>
<td>0 0.106 2.36 4.57</td>
</tr>
<tr>
<td>B</td>
<td>4.5</td>
<td>7.7</td>
<td>45 3/8 6</td>
<td>1 0.106 2.60 5.00</td>
</tr>
<tr>
<td>C</td>
<td>6.0</td>
<td>5.6</td>
<td>0 3/8 6</td>
<td>1 0 1.92 3.72</td>
</tr>
<tr>
<td>D</td>
<td>5.4</td>
<td>6.6</td>
<td>55 3/8 6</td>
<td>1 0.106 2.10 4.44</td>
</tr>
<tr>
<td>E</td>
<td>5.0</td>
<td>7.3</td>
<td>76 3/8 6*</td>
<td>1* 0.175 2.13 4.48</td>
</tr>
<tr>
<td>F</td>
<td>6.0</td>
<td>6.3</td>
<td>73 3/8 6*</td>
<td>1* 0.141 1.80 3.64</td>
</tr>
</tbody>
</table>

* In Series E and F the clay replaced 7.5% of the sand, and in order to show a constant sand-gravel ratio the clay must, in these cases, be considered as part of the sand.
TABLE 2 - MIXES USED IN SERIES G, H, I, J, K, AND L

Water Content In All Series - Eight Gallons Per Sack Of Cement

All Mixes Have Approximately The Same Workability, As Measured
By The Smith-Conahey Penetration Apparatus

<table>
<thead>
<tr>
<th>Series</th>
<th>Cement Sacks per cu.yd.</th>
<th>Clay Added per cent of Total Aggregate</th>
<th>Sand - Gravel Ratio</th>
<th>Mix by Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>5.4</td>
<td>0</td>
<td>40-60</td>
<td>1 0 2.40 3.60</td>
</tr>
<tr>
<td>H</td>
<td>5.5</td>
<td>3</td>
<td>40-60</td>
<td>1 0.172 2.28 3.43</td>
</tr>
<tr>
<td>I</td>
<td>5.4</td>
<td>0</td>
<td>35-65</td>
<td>1 0 2.06 3.86</td>
</tr>
<tr>
<td>J</td>
<td>5.1</td>
<td>3</td>
<td>35-65</td>
<td>1 0.189 2.20 4.08</td>
</tr>
<tr>
<td>K</td>
<td>5.7</td>
<td>0</td>
<td>30-70</td>
<td>1 0 1.85 3.85</td>
</tr>
<tr>
<td>L</td>
<td>5.3</td>
<td>3</td>
<td>30-70</td>
<td>1 0.180 1.90 4.20</td>
</tr>
</tbody>
</table>
# TABLE 3 - SUMMARY OF WORKABILITY RESULTS WITH SMITH-CONAHEY APPARATUS

## Work Required To Obtain 11-inch Penetration In Inch-Pounds

<table>
<thead>
<tr>
<th>Determination Number</th>
<th>Series</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>Average</th>
<th>Variation in Average Percent</th>
<th>Minimum Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td></td>
<td>447</td>
<td>354</td>
<td>149</td>
<td>257</td>
<td>214</td>
<td>184</td>
<td>277</td>
<td>184</td>
<td>312</td>
<td>520</td>
<td>487</td>
<td>354</td>
<td>164</td>
<td>344</td>
<td>452</td>
<td>314</td>
<td>66</td>
<td>31.2</td>
</tr>
<tr>
<td>H</td>
<td></td>
<td>487</td>
<td>247</td>
<td>225</td>
<td>307</td>
<td>175</td>
<td>262</td>
<td>235</td>
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<td>267</td>
<td>277</td>
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<td>272</td>
<td>352</td>
<td>286</td>
<td>266</td>
<td>285</td>
<td>85</td>
<td>20.8</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>327</td>
<td>194</td>
<td>232</td>
<td>338</td>
<td>302</td>
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<td>502</td>
<td>219</td>
<td>382</td>
<td>307</td>
<td>133</td>
<td>117</td>
<td>297</td>
<td>266</td>
<td>111</td>
<td>23.2</td>
<td></td>
</tr>
<tr>
<td>J</td>
<td></td>
<td>527</td>
<td>478</td>
<td>564</td>
<td>375</td>
<td>233</td>
<td>441</td>
<td>374</td>
<td>641</td>
<td>450</td>
<td>404</td>
<td>588</td>
<td>573</td>
<td></td>
<td>465</td>
<td>54</td>
<td>18.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td></td>
<td>538</td>
<td>564</td>
<td>312</td>
<td>236</td>
<td>292</td>
<td>238</td>
<td>139</td>
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<td>385</td>
<td>452</td>
<td>242</td>
<td>127</td>
<td>122</td>
<td>779</td>
<td>209</td>
<td>316</td>
<td>146</td>
<td>46.</td>
</tr>
<tr>
<td>L</td>
<td></td>
<td>358</td>
<td>236</td>
<td>295</td>
<td>229</td>
<td>317</td>
<td>287</td>
<td>467</td>
<td>598</td>
<td>511</td>
<td>621</td>
<td>242</td>
<td>462</td>
<td>267</td>
<td>317</td>
<td>352</td>
<td>77</td>
<td>28.4</td>
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</table>
### Table 4 - Segregation Tests, Dunagan Buoyancy Apparatus

Concrete Rodded Into The Container

Each Value Is The Average Of Two Determinations

<table>
<thead>
<tr>
<th>Series</th>
<th>Location of Sample</th>
<th>Average Weight of Material per 1000 Gr. of Concrete</th>
<th>Water Cement Ratio by wt.</th>
<th>Water Gravel Ratio by wt.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Water  Cement  Sand  Gravel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Top</td>
<td>39.5  132  306.5  460.5</td>
<td>0.754</td>
<td>0.216</td>
</tr>
<tr>
<td></td>
<td>Bottom</td>
<td>67.3  114  342  476</td>
<td>0.590</td>
<td>0.141</td>
</tr>
<tr>
<td>H</td>
<td>Top</td>
<td>85    158.5  316  445</td>
<td>0.556</td>
<td>0.191</td>
</tr>
<tr>
<td></td>
<td>Bottom</td>
<td>84    145  321  451</td>
<td>0.580</td>
<td>0.186</td>
</tr>
<tr>
<td>I</td>
<td>Top</td>
<td>94.8  138  293  472.5</td>
<td>0.685</td>
<td>0.200</td>
</tr>
<tr>
<td></td>
<td>Bottom</td>
<td>68.5  116.5  500  507</td>
<td>0.588</td>
<td>0.155</td>
</tr>
<tr>
<td>J</td>
<td>Top</td>
<td>78.5  145  298  466</td>
<td>0.540</td>
<td>0.168</td>
</tr>
<tr>
<td></td>
<td>Bottom</td>
<td>71.0  143.5  306  475</td>
<td>0.495</td>
<td>0.149</td>
</tr>
<tr>
<td>K</td>
<td>Top</td>
<td>118.2  167.5  260  455</td>
<td>0.704</td>
<td>0.260</td>
</tr>
<tr>
<td></td>
<td>Bottom</td>
<td>68.6  116  275  526</td>
<td>0.592</td>
<td>0.130</td>
</tr>
<tr>
<td>L</td>
<td>Top</td>
<td>77.3  149  239  544</td>
<td>0.550</td>
<td>0.142</td>
</tr>
<tr>
<td></td>
<td>Bottom</td>
<td>78.2  137.5  265.5  517</td>
<td>0.569</td>
<td>0.151</td>
</tr>
</tbody>
</table>
### TABLE S - SEGREGATION TESTS - SILVED

Concrete Jigged Into The Container

Each Value Is The Average Of Three Determinations

<table>
<thead>
<tr>
<th>Series</th>
<th>Location of Sample</th>
<th>Weight of Material per 1000 gr. of Concrete Water Cement Ratio</th>
<th>Water-Cement Ratio</th>
<th>Water-Gravel Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Water Cement Sand Gravel by wt. by wt.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Top</td>
<td>128 117 292 464 1.09 0.276</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bottom</td>
<td>84.8 111 251 553 .76 .153</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>Top</td>
<td>92.5 98.8 350 458 .94 .197</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bottom</td>
<td>92.5 104 359 448 .85 .197</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Top</td>
<td>136 116 266 461 1.17 .282</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bottom</td>
<td>76.2 110.5 320 492 .69 .155</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>Top</td>
<td>87.2 100 312 500 .872 .175</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bottom</td>
<td>83.4 113 323 478 .735 .174</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>Top</td>
<td>161 105.5 229 482 1.715 .375</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bottom</td>
<td>79 126 274 525 .526 .150</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>Top</td>
<td>86.2 112.5 239 540 .765 .160</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Bottom</td>
<td>85.5 107.5 292 514 .795 .166</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Series</td>
<td>Curing</td>
<td>Per Cent Clay Substituted for Cement</td>
<td>Average Compressive Strength 1b. per sq. in. 720 days 28 60 180 360 / 28 60 180 360 720 days</td>
<td>Strength Ratio</td>
</tr>
<tr>
<td>--------</td>
<td>--------</td>
<td>-------------------------------------</td>
<td>---------------------------------------------------------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>A</td>
<td>Air</td>
<td>0</td>
<td>1750 1630 1560 1870 100 100 100</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Air</td>
<td>10</td>
<td>1535 1520 1410 1560 98 94 85</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Air</td>
<td>0</td>
<td>2920 2980 2900 2890 100 100 100</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Air</td>
<td>10</td>
<td>2270 1990 2360 2270 78 67 78</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Moist</td>
<td>0</td>
<td>3500 3580 4080 4170 100 100 100</td>
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</tr>
<tr>
<td>B</td>
<td>Moist</td>
<td>10</td>
<td>3120 3260 3673 3940 9250 69 85 64</td>
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</tr>
<tr>
<td>C</td>
<td>Moist</td>
<td>0</td>
<td>4970 4320 5230 4740 5910 100 100 100</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Moist</td>
<td>10</td>
<td>3933 3690 4260 4100 4920 79 85 67</td>
<td></td>
</tr>
</tbody>
</table>
**TABLE 7 - THE EFFECT ON THE COMPRESSIVE STRENGTH OF SUBSTITUTING CLAY FOR 7.5% OF THE SAND**

Slump - Two Inches.  Curing - Stored In Air Only

<table>
<thead>
<tr>
<th>Series</th>
<th>Cement sacks per cu.yd.</th>
<th>Percent of Clay in Sand</th>
<th>Water Content gal. per sack</th>
<th>Average Compressive Strength 60 days</th>
<th>Strength Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5.0</td>
<td>0</td>
<td>6.9</td>
<td>1750</td>
<td>100</td>
</tr>
<tr>
<td>B</td>
<td>5.0</td>
<td>7.5</td>
<td>7.3</td>
<td>1700</td>
<td>97</td>
</tr>
<tr>
<td>C</td>
<td>6.0</td>
<td>0</td>
<td>5.6</td>
<td>2020</td>
<td>100</td>
</tr>
<tr>
<td>D</td>
<td>6.0</td>
<td>7.5</td>
<td>6.3</td>
<td>2200</td>
<td>75</td>
</tr>
</tbody>
</table>
### Table 8 - The Effect on the Compressive Strength of Additions of Clay Equaling 3/5 of the Total Aggregate

Water-Content in Each Series Was 8 Gal. Per Sack of Cement

The Mixes Have Approximately the Same Workability, As Measured

By The Smith-Conahey Penetration Apparatus

<table>
<thead>
<tr>
<th>Series</th>
<th>Sand-Gravel Ratio</th>
<th>Clay Added Percent of Total Aggregate</th>
<th>Average Compressive Strength 1b. per sq. in.</th>
<th>Strength Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>7 days</td>
<td>28 days</td>
</tr>
<tr>
<td>G</td>
<td>40 - 60</td>
<td>0</td>
<td>1630</td>
<td>3130</td>
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<tr>
<td>H</td>
<td>40 - 60</td>
<td>3</td>
<td>1740</td>
<td>3300</td>
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<td>I</td>
<td>35 - 65</td>
<td>0</td>
<td>1565</td>
<td>3140</td>
</tr>
<tr>
<td>J</td>
<td>35 - 65</td>
<td>3</td>
<td>1830</td>
<td>3110</td>
</tr>
<tr>
<td>K</td>
<td>30 - 70</td>
<td>0</td>
<td>1440</td>
<td>2840</td>
</tr>
<tr>
<td>L</td>
<td>30 - 70</td>
<td>3</td>
<td>1770</td>
<td>2890</td>
</tr>
<tr>
<td>Series</td>
<td>Freezing and Thawing Cycles</td>
<td>Type of Curing</td>
<td>Compressive Strength lb. per sq.in.</td>
<td>Strength Ratio</td>
</tr>
<tr>
<td>--------</td>
<td>----------------------------</td>
<td>---------------</td>
<td>-----------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Specimen After Freezing</td>
<td>Specimen Without Freezing</td>
</tr>
<tr>
<td>A</td>
<td>103</td>
<td>Air</td>
<td>2710</td>
<td>1660</td>
</tr>
<tr>
<td>B</td>
<td>103</td>
<td>Air</td>
<td>2250</td>
<td>1410</td>
</tr>
<tr>
<td>C</td>
<td>104</td>
<td>Air</td>
<td>2635</td>
<td>2900</td>
</tr>
<tr>
<td>D</td>
<td>104</td>
<td>Air</td>
<td>2770</td>
<td>2260</td>
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<tr>
<td>A</td>
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<td>Moist</td>
<td>3935</td>
<td>4170</td>
</tr>
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<td>103</td>
<td>Moist</td>
<td>3690</td>
<td>3940</td>
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<tr>
<td>C</td>
<td>104</td>
<td>Moist</td>
<td>4330</td>
<td>4740</td>
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<tr>
<td>D</td>
<td>104</td>
<td>Moist</td>
<td>4350</td>
<td>4100</td>
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<tr>
<td>Series</td>
<td>Type of Curing</td>
<td>Average Relative Weights Before Freezing</td>
<td>Average Relative Weights After 103 Cycles of Freezing</td>
<td>Average Percent Reduction in Weight</td>
</tr>
<tr>
<td>--------</td>
<td>----------------</td>
<td>----------------------------------------</td>
<td>---------------------------------------------------</td>
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</tr>
<tr>
<td>A</td>
<td>Air</td>
<td>100</td>
<td>97.2</td>
<td>2.8</td>
</tr>
<tr>
<td>B</td>
<td>Air</td>
<td>100</td>
<td>94.5</td>
<td>3.5</td>
</tr>
<tr>
<td>C</td>
<td>Air</td>
<td>100</td>
<td>93.1</td>
<td>6.9</td>
</tr>
<tr>
<td>D</td>
<td>Air</td>
<td>100</td>
<td>93.1</td>
<td>6.9</td>
</tr>
<tr>
<td>A</td>
<td>Moist</td>
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<td>99.3</td>
<td>0.7</td>
</tr>
<tr>
<td>B</td>
<td>Moist</td>
<td>100</td>
<td>101.0</td>
<td>1.0</td>
</tr>
<tr>
<td>C</td>
<td>Moist</td>
<td>100</td>
<td>97.9</td>
<td>2.1</td>
</tr>
<tr>
<td>D</td>
<td>Moist</td>
<td>100</td>
<td>98.9</td>
<td>1.1</td>
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### Table 11 - Change in Weight of Specimens During Freezing and Thawing

<table>
<thead>
<tr>
<th>Series</th>
<th>Moist Curing Days</th>
<th>Air Curing Days</th>
<th>Average Relative Weights Before Freezing</th>
<th>Average Relative Weights After Freezing</th>
<th>Average Reduction In Weight percent</th>
</tr>
</thead>
</table>

#### 119 Cycles of Freezing and Thawing

<table>
<thead>
<tr>
<th>Series</th>
<th>Moist Curing Days</th>
<th>Air Curing Days</th>
<th>Average Relative Weights Before Freezing</th>
<th>Average Relative Weights After Freezing</th>
<th>Average Reduction In Weight percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>7</td>
<td>0</td>
<td>100</td>
<td>87.5</td>
<td>12.5</td>
</tr>
<tr>
<td>H</td>
<td>7</td>
<td>0</td>
<td>100</td>
<td>87.3</td>
<td>12.7</td>
</tr>
<tr>
<td>I</td>
<td>7</td>
<td>0</td>
<td>100</td>
<td>85.6</td>
<td>14.4</td>
</tr>
<tr>
<td>J</td>
<td>7</td>
<td>0</td>
<td>100</td>
<td>81.4</td>
<td>18.6</td>
</tr>
<tr>
<td>K</td>
<td>7</td>
<td>0</td>
<td>100</td>
<td>88.3</td>
<td>11.7</td>
</tr>
<tr>
<td>L</td>
<td>7</td>
<td>0</td>
<td>100</td>
<td>85.1</td>
<td>14.1</td>
</tr>
</tbody>
</table>

#### 78 Cycles of Freezing and Thawing

<table>
<thead>
<tr>
<th>Series</th>
<th>Moist Curing Days</th>
<th>Air Curing Days</th>
<th>Average Relative Weights Before Freezing</th>
<th>Average Relative Weights After Freezing</th>
<th>Average Reduction In Weight percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>7</td>
<td>21</td>
<td>100</td>
<td>93.5</td>
<td>6.5</td>
</tr>
<tr>
<td>H</td>
<td>7</td>
<td>21</td>
<td>100</td>
<td>93.4</td>
<td>6.6</td>
</tr>
<tr>
<td>I</td>
<td>7</td>
<td>21</td>
<td>100</td>
<td>93.7</td>
<td>6.3</td>
</tr>
<tr>
<td>J</td>
<td>7</td>
<td>21</td>
<td>100</td>
<td>92.1</td>
<td>7.9</td>
</tr>
<tr>
<td>K</td>
<td>7</td>
<td>21</td>
<td>100</td>
<td>91.3</td>
<td>8.7</td>
</tr>
<tr>
<td>L</td>
<td>7</td>
<td>21</td>
<td>100</td>
<td>91.7</td>
<td>8.3</td>
</tr>
</tbody>
</table>
Fig. 1  Sieve Analysis of Fine Aggregate.
Fig. 2 - Penetration Apparatus
Fig. 3. Relation between Slump & Penetration.
Fig. 4 - Smith-Conahey
Penetration Apparatus
Fig. 5 Curves for Rate of Penetration: Each Point Average of Six Tests
Fig. 6 - Dunagan Buoyancy Apparatus
Fig. 9 Relation between Input and Output Readings on Specimen G-7.6.
Fig. 10 Relation between Input and Output Readings on Specimen G-7.5
Input Readings under a pressure of 100 lb. in.

Input Readings under zero pressure

Note: A steel plate was substituted for the concrete Specimen.

Fig. 11. Input Readings with a Steel plate in the Unit.
Fig. 12 Time-Temperature Relation in Freezing and Thawing Tests.
Clay - Per Cent of Total Aggregate

Fig. 13 - Typical Slumps for Series G, H, I, J, K, and L
Fig. 14 Water-cement & Water-gravel Ratio (by Weight) for Samples from Top & Bottom Separation by Sieving in Water.
Fig. 15 Relation between Difference (by Weight) Water-cement & Water-gravel Ratio and the Segregation Index.
Fig. 16 Water-cement & Water-gravel Ratio (by weight) for Samples from Top & Bottom Separation by Dry Sieving.
Fig. 17. Relation between Difference (by weight) in Water-Cement & Water-gravel Ratio and the Segregation Index.
Fig. 18  
The Effect on Compressive Strength of Replacing 10% of the Cement with Clay.

Compressive Strength, lb per sq.in.

With Clay, Series B & D.  
Without Clay, Series A & C.

Moist Curing followed by Freezing

Age days:
0  5  9  30  60  120  180  360
**Figure 19.** The Effect on Compressive Strength of Replacing 7.5% of Sand with Clay

**Figure 20.** The Effect on Compressive Strength of Adding an Amount of Clay Equal to 3% of Total Aggregate
Fig. 22. The Effect on Permeability of Replacing 10% of the Cement with Clay.

Fig. 21. The Effect on Permeability of Replacing 10% of the Cement with Clay. Age 60 days. Pressure 20 lb. per sq.in. 6 by 4 in. Disc. Air Cured.
Fig 23: The Effect on Permeability of Replacing 10% of Cement with Clay. Age 360 days. Pressure 100 lb. per sq. in.
Fig. 24: The Effect on Permeability of Replacing 7.5% of Sand with Clay. Age 60 days. Pressure 20 lb per sq.in. Air Cured. Numbers in Parenthesis indicate Sacks of Cement per cyd of Concrete.
Fig. 26. The Effect on Permeability of Adding Clay Equal to 3% of the Total Aggregate Age 28 days. Pressure 100 lb. per sq.in. 6 by 2 in Disc.
Fig. 27: Relation between Compressive Strength and Permeability.
Fig. 28. Relation between Compressive Strength and permeability.

Compressive Strength 1 lb. per sq. in.

Total Leakage in 100 hr. c.c. per sq. ft.
Fig. 29 The Effect of Freezing and Thawing on Compressive Strength.
Fig. 30 - Specimens B 2.4, A 2.4, EF 2.4, AF 2.4
Before Freezing and Thawing
Fig. 31 - Specimens B 2.4, A 2.4, BF 2.4, AF 2.4

After 25 Cycles of Freezing and Thawing
Fig. 32 - Specimens B 2.4, A 2.4, BF 2.4, AF 2.4

After 75 Cycles of Freezing and Thawing
Fig. 33 - Specimens B 2.5, A 2.5, BF 2.5, AF 2.5

Before Freezing and Thawing
Fig. 34 - Specimens B 2.5, A 2.5, BF 2.5, AF 2.5

After 25 Cycles of Freezing and Thawing
Fig. 35 - Specimens BF 2.5, AF 2.5, B 2.5, A 2.5

After 103 Cycles of Freezing and Thawing
Fig. 36 - Specimens D 2.4, C 2.4, DF 2.4, CF 2.4

Before Freezing and Thawing
Fig. 37 - Specimens D 2.4, C 2.4, DF 2.4, CF 2.4

After 45 Cycles of Freezing and Thawing
Fig. 38 - Specimens C 2.4, D 2.4, CF 2.4, DF 2.4

After 103 Cycles of Freezing and Thawing
Fig. 39 - Specimens C 2.5, D 2.5, DF 2.5, CF 2.5

Before Freezing and Thawing
Fig. 40 - Specimens D 2.5 and C 2.5
After 32 Cycles of
Freezing and Thawing
APPENDIX

The appendix contains a copy of the original specifications furnished by Hugh L. Cooper and Company, Inc., and copies of correspondence relating to authorized modifications of these specifications.
SPECIFICATIONS GOVERNING
CONCRETE TESTS TO BE MADE FOR THE PURPOSE OF DETERMINING
THE VALUE OF REPLACING 10% OF THE CEMENT BY AN EQUAL
AMOUNT OF CLAY

JANUARY 29, 1929.
The purpose of this investigation is to study the effect of replacing 10 per cent of the cement by weight with clay on concretes containing 5 and 6 bags of cement per cubic yard. The investigation will be limited to four series of tests, namely:

SERIES A. In which the quantity of cement used will be at the rate of 5 bags of cement per cubic yard of concrete and no clay is used in the mix.

SERIES B. In which the quantity of cement used will be at the rate of 4.5 bags of cement per cubic yard of concrete plus 45 lbs. of clay per cubic yard of concrete.

SERIES C. In which the quantity of cement used will be at the rate of 6 bags of cement per cubic yard of concrete and no clay used in the mix.

SERIES D. In which the quantity of cement used will be at the rate of 5.4 bags of cement per cubic yard of concrete plus 55 lbs. of clay per cubic yard of concrete.

In each series there will be forty (40) specimens for compression tests and thirty-two (32) specimens for permeability tests, making a total of two hundred and eighty-eight (288) specimens in the four series.
PROPORTIONS.

The proportion of sand to coarse aggregate in all mixtures will be such that the volume of mortar will be 15 per cent greater than the volume of the voids remaining in the coarse aggregate after being compacted by rodding.

CONSISTENCY.

The consistency of the concrete mixture shall be such that workmen walking on green concrete will track never more than 3 inches or less than 2 inches. The resulting water cement ratio shall be determined for each mix for purposes of record.

WATER.

Water used for mixing shall be suitable for drinking.

CEMENT.

All cement used shall conform to the Standard Specifications and Tests for Portland Cement (Serial Designation: C9-26) A.S.T.M. The brand of cement however shall be the same throughout all the tests.

CLAY.

Clay when used as an admixture shall be a clay that has been used successfully in the manufacture of good house brick. The clay shall be mixed thoroughly into the mixing water before the water is added to the
cement and other aggregates. The clay shall be des-
cribed for purposes of record.

FINE AGGREGATE.

Fine aggregate shall be natural sand and shall
be from the same source throughout the tests. All sand
shall pass a No. 4 sieve and be tested in accordance
with Standard Method of Test for Sieve Analysis of
Aggregates for Concrete (Serial Designation: C41-24)
A.S.T.M., and also be tested for organic impurities in
accordance with Standard Method of Test for Organic
Impurities in Sands for Concrete (Serial Designation:
C40-27) A.S.T.M.

COARSE AGGREGATE.

Coarse aggregate shall be considered as all
aggregate passing through a 2 inch mesh sieve and
retained on a No. 4 sieve. Coarse aggregate shall be
either crushed stone or gravel but shall not be a mix-
ture of both nor shall it be altered throughout the
entire series of tests. Coarse aggregate shall be test-
ed in accordance with Standard Method of Test for Sieve
Analysis of Aggregates for Concrete (Serial Designation:
C41-24) A.S.T.M.

MIXES.

The mixes used shall be reported by weight
rather than volume and the Standard Method of Test for
Unit Weight of Aggregate for Concrete (Serial Designation:
C39-27) A.S.T.M. shall be followed in this determination.

**COMPRESSION TESTS.**

Compression tests shall be conducted to conform to the Standard Methods of Making Compression Tests of Concrete (Serial Designation: C39-27) A.S.T.M., except as modified by any part of these specifications.

Concrete may be mixed by hand or by machine. If machine is used the machine shall be rotated for a period of three minutes after the introduction of the mixing water.

Concrete test specimens shall be removed from the molds 24 hours after molding, marked, weighed and stored in damp sand, under damp cloths or in a moist chamber for 7 days.

Twenty specimens from each series are to be stored in the laboratory, five of each of which shall be tested to destruction 60 days, 6 months, one and two years after molding.

Twenty specimens from each series are to be stored in water and are to be removed only for freezing or testing. Of these, last named twenty specimens, five are to be frozen and thawed through fifteen cycles and tested 60 days after molding; five are to be frozen and thawed through thirty cycles and tested at 6 months; five are to be frozen and thawed through forty-five cycles and tested at one year, and five are to be frozen and
thawed through sixty cycles and tested at two years of age.

PERMEABILITY TESTS.

Preparation of specimens for permeability tests shall be in accordance with that outlined for compression specimens.

Size of specimens shall be preferably 4 inches thick and 12 inches in diameter.

After seven days curing in the curing room, sixteen specimens from each series shall be stored in water, being removed only for freezing or testing. The sixteen remaining specimens shall be stored in the laboratory. The sequence of tests for each series shall be as follows:

1st TEST.

4 specimens which have been frozen and thawed through 15 cycles are to be tested under 20 lbs. pressure per square inch for a period of 7 days beginning 60 days after molding.

4 specimens which have not been frozen shall be tested under 20 lbs. pressure per square inch for a period of 7 days beginning 60 days after molding.

2nd TEST.

4 specimens which have been frozen and thawed through 30 cycles are to be tested under 60 lbs. pressure per square inch for a period of 7 days beginning 6 months after molding.
4 specimens which have not been frozen shall be tested under 60 lbs. pressure per square inch for a period of 7 days beginning 6 months after molding.

3rd TEST.

4 specimens which have been frozen and thawed through 45 cycles are to be tested under 100 lb. pressure per square inch for a period of 7 days beginning one year after molding.

4 specimens which have not been frozen shall be tested under 100 lbs. pressure per square inch for a period of 7 days beginning one year after molding.

4th TEST.

4 specimens which have been frozen and thawed through 60 cycles are to be tested under 140 lbs. pressure per square inch for a period of 7 days beginning two years after molding.

4 specimens which have not been frozen shall be tested under 140 lbs. pressure per square inch for a period of 7 days beginning two years after molding.

On Appendix A herewith is shown a proposed apparatus for testing simultaneously four specimens of the size suggested.

Each specimen before being put into the apparatus has the top surface coated with heavy asphalt, except for the 6" diameter circle where the pressure is to be applied. The asphalt shall be allowed to harden before the specimen
is put in contact with the rubber seal of the apparatus.

The amount of water penetrating the specimens shall be read from the gage glass at intervals of not more than three hours during the first day of each test and as often thereafter as the individual in charge of all tests deems necessary to illustrate the progress of penetration. The pressure shall be maintained as nearly uniform as possible. A range of plus or minus 10 lbs. from the stipulated pressure will be permitted.

The results from permeability tests shall be in the form of pressure-time-area data, convenient for plotting thereto.

The method and apparatus above proposed for measuring permeability is to be considered as a suggestion only and may be discarded for any better method you may decide upon.

PROCEDURE TO BE FOLLOWED FOR FREEZING AND THAWING.

Specimens shall be kept in water until they are withdrawn for immediate subject to low temperature. After being subjected to a temperature ranging between plus 10 degs. to minus 10 degs. Fah. for not less than 24 hours, the specimen shall be allowed to thaw in water for a similar period in a room where the temperature is between 60 and 75 degs. Fah. The periods may be increased but should not be decreased from that stated above.
The permeability apparatus here represented in diagrammatic form allows for the testing of four specimens simultaneously. Each specimen is retained between two flanges, the top one having a 6" dia. pressure area and the bottom one having a six inch free opening. Bolts retain the specimen tightly between the flanges. The test pressure is created by the air compressor and the amount of water penetrating into the specimen is measured by the gage glass on the measuring tanks. Each measuring tank can easily be calibrated to any unit desired. The arrangement of valves and gages shown allows four specimens to be tested simultaneously, each under a different pressure. This, however, is a refinement and if the pressure is the same, four gages and four valves may be eliminated.
HUGH L. COOPER & CO., INC.
101 Park Avenue
New York March 28th, 1929.

Prof. W. A. Slater,
Director, Fritz Engineering Laboratory,
Lehigh University, Bethlehem, Penna.

Dear Professor Slater:

Replying to your letters of February 26th and March 18th, permit me to apologize for the delay in doing so. Press of other work had simply forced concrete tests into the background temporarily.

It is very encouraging to have you co-operate with us. As I told you during our recent telephone conversation we would like to extend the scope of the tests outlined in our specifications of January 29th. Experiments made in Russia under our direction has indicated that a larger percentage of clay may be advisable. The Bureau of Standards in Washington is at work on a series of tests which have recently been enlarged in scope. We are desirous of having Lehigh co-operate with us in what might be termed a key series of tests, and which would serve to compare the results of the other colleges which have joined our program. The series is simply this:

A - A series of tests following our specifications of January 29th as closely as possible.

B - A series of tests in parallel to A, as outlined above, but with a clay content equal to 7.5% of the fine aggregate by weight but not replacing any of the cement. The mix to be 5 and 6 bags of cement as in the previous series.

Some of the other colleges are assigned series A and some are asked to conduct series B. The Bureau of Standards is conducting both, and we are asking you to conduct both because we feel assured of competent direction and accurate results. If you can see your way clear to extend the tests as herein outlined and decide to do so, Colonel Cooper has authorized me to advise you that you may call upon us to the extent of $2,000.00 as our participation therein. We trust that this will meet with your favorable consideration.

Yours very truly,

HUGH L. COOPER & CO., INC.

(Signed) R. A. Schroeder

RAS-8
The following change in the original specifications was approved by Mr. R. A. Schroeder of the Hugh L. Cooper Company, in a conference with Professor W. A. Slater, held in the former's office in New York, on July 18, 1929.

The original specifications stated that the consistency of the concrete should be "such that workmen walking on green concrete will track never more than 5 in. nor less than 3 in." This specification was later modified so that a block having a bearing area of 3 by 12 in. and carrying a total load of 160 lb. should penetrate between 1 and 3-1/2 in. into the surface of a mass of fresh concrete 20 in. in diameter and 16 in. deep.
FRITZ ENGINEERING LABORATORY
LEHIGH UNIVERSITY
BETHLEHEM, PENNSYLVANIA

July 23, 1929.

Mr. R. A. Schroeder,
Hugh L. Cooper & Co., Inc.
101 Park Avenue
New York City

Dear Mr. Schroeder:

I am writing you to outline my understanding of the terms under which we are undertaking an investigation of the effect of admixtures of clay in concrete on strength, permeability, and freezing.

The tests are to be carried out in Fritz Engineering Laboratory, Lehigh University, in accordance with your specifications of January 29, 1929, entitled "Specifications Governing Concrete Tests To Be Made For The Purpose of Determining The Value Of Replacing 10% Of The Cement By An Equal Amount Of Clay." In your office on July 18, however, we agreed to certain modifications in the specifications which are as follows:

1. In determining the consistency "such that workmen walking on the green concrete will track never more than 8 inches nor less than 3 inches" it will be necessary to limit the quantities of concrete to be made up to such an extent that the depth of tracking may be influenced somewhat by the proximity of the sides and bottom of the form, but an effort will be made to approach the essential conditions which determine the depth of tracking.

2. For convenience in laying out the program the specimens which are later to be stored in water will be given moist curing until they are 7 days old instead of for 7 days after removal from the mold as specified on page 4 of your specifications. The specimens which are not to be cured in water are to be left in the molds for 48 hours and then stored in air in the laboratory until time for the compression test or the permeability test.

3. For purpose of this investigation 30 days will be considered as a month, 360 days as a year, and 720 days as 2 years.
4. The temperature of the freezing and thawing chambers will be so controlled that the specimens will be frozen throughout within 24 hours and then thawed within the next 24 hours. This will be determined by measuring the temperature in the center of certain 6 by 12-inch cylinders and 4 by 12-inch disks made especially for this purpose. If this is done it is understood that the temperature range of from plus 10 to minus 10 degrees F, as required on page 7 of the specifications, is not significant.

I understand that Lehigh University will have the prior right to publication of the results of this investigation in a Bulletin of Lehigh Institute of Research or before a Technical Society or in a Technical Journal. In such publication we shall give Hugh L. Cooper and Company due acknowledgement for their cooperation and shall expect that in any publication by Hugh L. Cooper and Company due acknowledgement will be given the part performed by Lehigh University.

We do not anticipate that the ordinary stipulations regarding use of material for advertising purposes will have any significance in connection with this investigation. Nevertheless, I am calling your attention to the paragraph on this subject near the top of page 16 of Circular No. 1 of Lehigh Institute of Research, a copy of which I am sending you.

Except for the fact that the financial support of the Hugh L. Cooper Company is limited to the amount of $2000 as stated in previous correspondence and conferences, Circular No. 1 states the conditions under which we are undertaking the work.

I understand that you are prepared to send us a check for $2000, the full amount of your participation in the work. If the foregoing statement is in accordance with your understanding of the terms agreed upon we shall be glad to have a check for this amount at your early convenience. The check should be made payable to Lehigh University. If, in any respect this statement does not coincide with your understanding of the matter I shall hope to hear from you regarding it at an early date.

Yours very sincerely,

Copies to: Dr. Richards
           Prof. Fogg

W. A. Slater
DIRECTOR
October 22nd, 1929.

Prof. W. A. Slater,
Director, Fritz Engineering Laboratory.
Lehigh University, Bethlehem, Pa.

Dear Professor Slater:

Replying to your letter of October 17th, we fully appreciate that 15% mortar in excess of the percentage of voids produces a mix which is on the edge of workability. Our statement of the 15% is specified as a minimum, but on the other hand, we would like to keep it as close to this as produces a satisfactory workable mix.

You are at liberty to increase the quantity of mortar until, in your judgement, the mix becomes satisfactory.

Yours very truly,

Hugh L. Cooper & Co. Inc.

(Signed) R. A. Schroeder
May 21, 1930

Mr. R. A. Schroeder,
Hugh L. Cooper Co., Inc.,
101 Park Avenue,
New York City.

Dear Mr. Schroeder:

Since writing you on April 22 and May 5 we have studied further the problem of the remaining program of freezing, permeability and strength tests of concrete, and I have some suggestions to make. The specimens for two-thirds of the investigation have been made and the tests are under way. That part of the program in which 7.5% of the sand in the concrete was to be replaced with clay makes up the remaining one-third of the entire program. We propose to carry out that portion of this one-third of the program which calls for strength, permeability and freezing tests at 60 days for the air-cured specimens, exactly as specified originally. There seems to be no advantage, however, in carrying it out for the ages greater than 60 days or in carrying it out for the specimens subjected to moist curing throughout the 60 days, since we have been unable to measure any leakage with any of the specimens so cured.

We propose to use coarse aggregate with a maximum size of 3/4 in. instead of 2 in. One of the reasons for trouble with the present series of tests is that the use of 2 in. aggregate necessitates a disc 4 in. thick and this, in turn, makes the specimens so nearly impermeable that we have been unable to measure any leakage in many of the specimens.

In this program we would, as before, make compression, permeability and freezing specimens. We would cure all specimens in the moist room for seven days. Half of them would be tested at seven days for compressive strength, that is, immediately after removing from the moist curing. The other half would be tested at 28 days after seven days moist curing and 21 days dry curing. Likewise, the permeability and freezing tests would begin at seven days and 28 days respectively. The permeability tests would be made as at present, except that we propose to use discs 2 in. instead of 4 in. thick. This would be made possible by using aggregate with a maximum size of 3/4 in. instead of 2 in. We propose in the freezing and thawing tests to continue the freezing and thawing for a longer period than at present with the hope that we can continue it until definite signs of disintegration appear. This would permit a comparison of the resistance to freezing and thawing with the mixes having different amounts of clay.
For the remainder of the program our idea now is to use three different mixes, in all three of which the ratio of the fine aggregate to the coarse aggregate will be different, and in all of which the ratio of the clay to the total aggregate will be constant. This will give a larger ratio of clay to sand for the cases in which the smaller amounts of sand are used, and I think this is in the right direction. Our reason for basing the clay content upon the total aggregate instead of upon the cement is that it does not seem likely that in practice clay will be substituted for cement. The cement quantity will generally be fixed by the strength requirement, and while a stronger concrete may in some cases be obtained with clay than without, one is not likely to substitute clay for cement in order to increase strength.

We propose to use a constant water cement ratio for all mixes and to bring all to the same workability as nearly as can be judged. This workability will be kept within the range formerly specified, that is, a penetration of 1 to 3-1/2 in. with a block 3 by 12 in. resting on the surface of the concrete in a vessel 20 in. in diameter and 16 in. deep and with a weight of 160 lb. on the block.

We would propose making a few preliminary specimens to determine the desirable percentage of clay, but in our program submitted for your comments we have assumed this to be 4% of the total aggregates in all cases. Likewise, we have assumed a water cement ratio which gives 9 gallons of water per sack of cement. With the cement which we are using this gives a strength of about 2000 lb. per sq. in. and requires about 4.3 sacks of cement per cubic yard of concrete.

We propose that in one mix the aggregates shall consist of 50% fine and 70% coarse aggregate, in the second mix 35% fine and 65% coarse aggregate, and in the third mix 40% fine and 60% coarse aggregate.

We are enclosing a tabulated outline of the proposed program which corresponds with the foregoing paragraph. We should like to hear from you at your early convenience in order that there may be no unnecessary delay in going ahead.

The foregoing paragraphs have to do with modification of the portion of the program in which 7.5% of the sand is replaced with clay. In addition to this modification we propose to make a modification in the testing procedure for the specimens already made, of which half have no clay and half have 10% of the cement replaced with clay. In each group there are five companion 6 x 12-in. cylinders.

The present program calls for testing the five cylinders of each group after a specified number of cycles of freezing and thawing. The results to date indicate that three companion specimens for compression are all that are needed in
order to secure consistent results in compression. We propose, therefore, that in each case only three of the five specimens be tested in compression according to the present program, and that the other two be retained for an indefinite number of cycles of freezing and thawing in order to find out how much freezing and thawing is required to produce signs of disintegration.

In the procedure up to the present time we have charged against the $2000 fund which you furnished us the cost of a freezing tank and the cost of the air compressor and permeability apparatus. We have used up about $1000 of the $2000. We are not transferring something over $1000 of this expense to our own account because we believe we can classify it as useful permanent equipment. This gives us about $1000 yet to go on of the fund which you have furnished us.

In addition we have already charged against our own funds about $250 for permanent equipment, which was purchased for this permeability investigation, or jointly for this and other work which we have on hand. The stipend of $1200 which is paid to Mr. Parkinson, the Research Fellow who is engaged on this work, is paid out of Lehigh University funds, so that we are contributing a total of somewhat more than $2000 to this work out of our own funds. I give you this information because I think you will be interested in it and in order to let you see that we are interested enough in the work that we are contributing materially to it.

I am leaving May 23 to be gone about a month and it is desirable that we arrive at a decision before that time as to what should be done. Whether or not I have proposed the best program, it seems certain that some change should be made. I think it might be worth your while to see our set up and discuss matters with Mr. Parkinson. Would it be possible for you to visit us before May 27?

Yours very sincerely

(Signed) W. A. Slater

W. A. Slater
DIRECTOR
OUTLINE OF PROPOSED MODIFIED PROGRAM OF
STRENGTH, PERMEABILITY AND FREEZING TESTS

Cement content in all mixes: 4.3 sacks per cu.yd.
Water 9 gallons per sack of cement
Clay 4% of total aggregate

Workability will be kept constant in all mixes

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Percentage Total Aggregate</th>
<th>Moist-Curing Days</th>
<th>Air-Curing Days</th>
<th>Age Test Days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sand</td>
<td>Gravel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>30</td>
<td>70</td>
<td>7</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7</td>
<td>21</td>
</tr>
<tr>
<td>2</td>
<td>35</td>
<td>65</td>
<td>7</td>
<td>--</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>7</td>
<td>21</td>
</tr>
<tr>
<td>3</td>
<td>40</td>
<td>60</td>
<td>7</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7</td>
<td>21</td>
</tr>
</tbody>
</table>
Mr. R. A. Schroeder of the Hugh L. Cooper Company approved of the proposed programme of tests submitted in our letter of May 21, 1930, except that the water content which was specified to be 9 gallons per sack of cement be reduced to near the maximum of 7.5 gallons per sack permitted by them in construction.

The programme, with the above exception, was discussed and approved in a conference held in Fritz Engineering Laboratory, Lehigh University, Bethlehem, early in June, 1930.
RESULTS AT THE AGE OF TWO YEARS

The average test results obtained at the age of two years are given in Table 12 for the compressive strength and in Table 13 for the permeability. The appearance of the specimens which had been frozen and thawed sixty times before the testing are shown in Fig. 42 to 51. It is noted from the figures that the amount of disintegration is nearly the same for the concrete containing no clay as for the concrete containing clay. The amount of disintegration was very small for all specimens. The effect of the clay on the compressive strength is well illustrated in Table 12. For all types of curing and for both mixes of concrete the specimens containing clay show considerably lower strength than do the specimens containing no clay. It should be kept in mind, however, that whenever clay was used in these specimens, the cement content was reduced by an amount equal to the amount of clay used. The reduction in strength is therefore probably more due to the reduction in cement content in the concrete than to any detrimental effect from the clay content. The reduction in strength is larger (in percentage) for air-cured specimens than for specimens cured moist or cured moist and frozen and thawed sixty times. The sixty cycled of freezing and thawing reduced the strength of the concrete cylinders, both for the mixes containing clay and those containing no clay. This reduction in strength was more marked for lean than for rich concrete.
The effect of the clay on the permeability is shown in Table 13. For the lean concrete mix (5 sacks) the clay had a decided beneficial effect upon the permeability, both for air-cured and frozen and thawed specimens. For the relatively rich mix (6 sacks), however, the clay had little or no effect upon the permeability. Thus the following conclusions may be drawn from the two-year tests.

Substitution of ten per cent of the cement with clay reduced the strength in accordance with what might be expected with such a decrease in cement content.

The substitution of clay seemed to improve the impermeability of lean concrete and to have no effect on richer concrete.

The sixty cycles of freezing and thawing produced a very slight surface disintegration of the concrete specimens, but reduced the strength of the concrete as compared with the strength of specimens cured moist until tested.
### Table 12 - Effect of Freezing and Thawing on the Compressive Strength of Concrete at the Age of 720 Days

<table>
<thead>
<tr>
<th>Series</th>
<th>Cement Content (sacks per cu. yd.)</th>
<th>Clay per cent of Cement</th>
<th>Water Content (gal. per sack)</th>
<th>Compressive Strength (lb. per sq. in.) for Specimens Cured:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Moist &amp; 60 Cycles Freezing &amp; Thawing</td>
</tr>
<tr>
<td>A</td>
<td>5.0</td>
<td>0</td>
<td>6.9</td>
<td>1570, 4670, 3980</td>
</tr>
<tr>
<td>B</td>
<td>4.5</td>
<td>10</td>
<td>7.7</td>
<td>1560, 4550, 3680</td>
</tr>
<tr>
<td>C</td>
<td>6.0</td>
<td>0</td>
<td>5.6</td>
<td>2550, 5190, 5280</td>
</tr>
<tr>
<td>D</td>
<td>5.4</td>
<td>10</td>
<td>6.6</td>
<td>2270, 4930, 4640</td>
</tr>
</tbody>
</table>

* Only one specimen tested

### Table 13 - Effect of Freezing and Thawing on Permeability of Concrete at the Age of 720 Days

<table>
<thead>
<tr>
<th>Series</th>
<th>Cement Content (sacks per cu. yd.)</th>
<th>Clay per cent of cement</th>
<th>Water Content (gal. per sack)</th>
<th>Leakage*, cc. per hour per sq. ft. for specimens cured:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Moist &amp; 60 Cycles Freezing &amp; Thawing</td>
</tr>
<tr>
<td>A</td>
<td>5.0</td>
<td>0</td>
<td>6.9</td>
<td>478, 67</td>
</tr>
<tr>
<td>B</td>
<td>4.5</td>
<td>10</td>
<td>7.7</td>
<td>204, 0.6</td>
</tr>
<tr>
<td>C</td>
<td>6.0</td>
<td>0</td>
<td>5.6</td>
<td>40, 0</td>
</tr>
<tr>
<td>D</td>
<td>5.4</td>
<td>10</td>
<td>6.6</td>
<td>51, 0</td>
</tr>
</tbody>
</table>

* Average for 7 days under a water pressure of 140 lb. per sq. in.
With Clay

Without Clay

Fig. 42 - Specimens BF 4.1 & AF 4.1
After 60 Cycles
of Freezing and Thawing
Without Clay  

With Clay

Moist-Cured

Fig. 43 - Specimens AF 4.2 & BF 4.2  
After 60 Cycles  
of Freezing and Thawing
Without Clay  With Clay
Moist-Cured

Fig. 44 - Specimens AF 4.3 & BF 4.3
After 60 Cycles of Freezing & Thawing
Fig. 45 - Specimens AF 4.4 & BF 4.4
After 60 Cycles
of Freezing and Thawing
Without Clay        With Clay
    Moist-Cured

Fig. 46 - Specimens AF 4.5 & BF 4.5
    After 60 Cycles
    of Freezing and Thawing

After 60 Cycles
Fig. 47 - Specimens CF 4.1 & DF 4.1
Moist Cured - After 60 Cycles
of Freezing and Thawing

Fig. 48 - Specimens CF 4.2 & DF 4.2
Moist Cured - After 60 Cycles
of Freezing and Thawing

No plates on hand for above figures.
Without Clay  
Moist-Cured

With Clay

Fig. 49 - Specimens CF 4.3 & DF 4.3
After 60 Cycles of Freezing and Thawing
Without Clay  With Clay
Moist-Cured

Fig. 50 - Specimens CF 4.4 & DF 4.4
After 60 Cycles
of Freezing and Thawing
With Clay  Without Clay
Moist-Cured

Fig. 51 - Specimens DF 4.5 & CF 4.5
After 60 Cycles
of Freezing and Thawing
In permeability tests being carried on at Lehigh University, the amount of water passing through the specimen has been measured by means of the apparatus shown in Fig. 1. In order to secure more information on the methods of measuring permeability, one unit was equipped with a graduated glass tube for measuring the input, in addition to the output.

It was expected that after the specimen had become saturated, the rates of input and output would be equal. Fig. 2 and 3 show the observed input and output on two specimens, one for 260 hours, and the other for 176 hours. It was found that the difference between the rate of input and rate of output continually became smaller, up to about 40 hours. After that time the difference in rates remained constant at about 0.4 cc per hour for one specimen (Fig. 2), and 0.65 cc per hour for the other specimen (Fig. 3). It appeared possible that the 40-hour period marked the time at which the specimen
became saturated, and that the constant difference in rates of input and output beyond that time represented leakage through connections.

To secure further information on this feature, a unit was rigged up with a metal plate instead of a concrete specimen, and the input was measured.

On starting the test, the graduated glass was filled to the top before any pressure was applied. When the pressure was applied, the water was lowered at once through a distance indicating an input of 60 cc (Fig. 4). On removal of the pressure, the water rose again to a point indicating an input of only 18 cc. The tube was then refilled, and when the pressure was reapplied, an input of 47 cc was indicated. From this point on, readings were taken both under pressure, and with the pressure released. The readings for zero pressure are indicated by the lower curve, and for full pressure (100 lb. per sq.in.) by the upper curve. It is possible that the lower curve represents more accurately than the upper, the actual input, but since the upper curve represents more closely than the lower, the conditions under which the readings were taken in the permeability tests, the upper curve was used in comparing the input with the difference between input and output for the permeability specimens.
At the beginning, a small leakage through one of the threaded joints was observed. A total of 14 cc. of water from this leak was observed in 16 hours. Later this leak apparently became sealed, and after 40 hours the rate of input became practically constant at 0.38 cc. per hour.

The similarity between the behavior with the permeability specimen and that with the metal plates makes it appear that about 40 hours was required for the specimen to become saturated and for the rate of leakage through the connection to become constant.

The correct interpretation as to leakage through connections is not known, but it seems evident that with the apparatus used, the measurement of output constituted a more reliable measurement of leakage than the measurement of input.
COOPER TESTS

The letters A, B, C, or D, designate the Series to which the specimens belong. The details of the mixes in each Series are given in the report to the Cooper Company under date of June 30, 1931.

MOIST-CURED SPECIMENS SUBJECTED TO 60 CYCLES OF FREEZING AND THAWING.

For specimens in this group the letter indicating Series to which the specimen belongs is followed by the letter "F". In every case there is one 6 by 12-in. compression cylinder and one 4 by 6-in. permeability specimen, and both bear the same specimen number. These specimens are to be stored in the moist room until the beginning of the freezing and thawing tests, when both the compression and permeability specimens will be subjected to 60 cycles of freezing and thawing.

AIR-CURED SPECIMENS

Specimens having the letter designating the Series alone, (for example, A 4.2, B 4.2), are specimens that are to receive air curing alone, and these specimens are NOT subjected to freezing and thawing tests. In every case there is one 6 by 12-in. compression cylinder and one 4 by 6-in. permeability specimen, and both bear the same specimen number. The compression specimens in this group are to be immersed in water 24 hours before the compression test.
MOIST-CURED SPECIMENS

Specimens that are to receive continuous moist curing until the day of the test have the letter indicating the Series followed by the letter "W". No permeability specimens are included in this group.

DETAILS OF PERMEABILITY TESTS

The permeability specimens are to be tested under a pressure of 140 lb. per sq.in. and this test is to continue for 7 days.

FREEZING AND THAWING TESTS

The specimens that receive 60 cycles of freezing and thawing before being tested in either compression or permeability, are to be placed in cans and the cans filled with water until the specimen is completely covered.
<table>
<thead>
<tr>
<th>Date Made</th>
<th>Specimen No.</th>
<th>Commence Freezing</th>
<th>Date of Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan. 22, 1930</td>
<td>AF 4.1*</td>
<td>Nov. 2, 1931</td>
<td>Jan. 12, 1932</td>
</tr>
<tr>
<td></td>
<td>A 4.1</td>
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</tr>
<tr>
<td></td>
<td>AW 4.1</td>
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</tr>
<tr>
<td></td>
<td>BF 4.1*</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>B 4.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BW 4.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feb. 1, 1930</td>
<td>AF 4.2*</td>
<td>Nov. 12, 1931</td>
<td>Jan. 22, 1932</td>
</tr>
<tr>
<td></td>
<td>A 4.2</td>
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</tr>
<tr>
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<td></td>
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</tr>
<tr>
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* These specimens are subjected to freezing and thawing.