

FREEZING AND THAWING TESTS OF CONCRETE

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SYNOPSIS

The scope and purpose of this investigation is covered in the early part of the report by a statement of the following questions: (1) What weathering conditions are the major factors causing deterioration of concrete?, (2) To what cycles of freezing and thawing may concrete be subjected in service?, (3) How shall the deterioration of concrete subjected to freezing and thawing be measured?, (4) What are the effects of various curing treatments prior to freezing?, (5) What cycle of freezing and thawing should be used?, (6) Can the effect of aggregates on the durability of concrete be predicted by a freezing and thawing test?

The report offers some data obtained in connection with research directed toward producing a yardstick by which some accelerated measure of concrete durability may be obtained

The data presented are based on tests made on concretes fabricated from a fixed mortar of good quality and coarse aggregates of varying quality. The freezing and thawing cycle used is of a fixed length of 12 hr., using varying thawing and freezing temperatures

The needs for co-operative standardization work in this field and accurate control of test conditions are stressed.

During the past two decades, a great mileage of highway improvements has been constructed and a sufficient time has elapsed to permit engineers to inventory the results of their work. Only a few years ago it was assumed that the various types of mixtures used in pavements were sufficiently well understood and of such quality that the major concern of designers should be to provide for the loads and stresses to be imposed by traffic. More recent observations, however, have shown that our knowledge does not permit us to predict with certainty the life of our improvements with or without traffic loading. In many cases the effects of weathering have been so severe as to destroy expensive improvements long before they have served sufficient traffic to justify their construction. Indeed, this situation has become so grave that the combined efforts of the various national engineering and materials groups have been enlisted to study the fundamental problems involved. The art pauses to consult the sciences.

Some phases of the "lack of durability" problem are of major concern to the State Highway Department of Missouri, and current researches are under way to find economical solutions. In our studies, we early learned that we could not gauge the success of remedial efforts with the measurement methods available. A durability "yardstick" was needed, and, by trial and elimination, we finally selected the "freezing and thawing" test as the one best adapted to our use. In the absence of a standardized test, we were forced to explore some of the possibilities and limitations of this type of test. Due to the nature of our particular problem, all of our work on this test has been confined to the effects of coarse aggregate on durability and the indications from our data may or may not be as applicable to other types of disintegration. The fol-

¹ The term durability, throughout this paper, is intended to mean "resistance to freezing and thawing" and does not include resistance to other types of disintegrating influences

lowing presentation will attempt to picture our plan of attack and some of our data. We are reporting some measure of progress and not completed research.

Our presentation will be in the form of questions, which seem pertinent to this problem, and, supplementing these questions, we will present some data and a very limited discussion. Study of some of the graphs presented will show that the

show typical pavement disintegration which we feel certain we have traced to unsound coarse aggregate.

The left hand picture in the bottom row shows laboratory specimens 12 by 12 by 5 in. on which we have attempted to duplicate, under control, the disintegration pictured above. These specimens have been subjected to many cycles of heating and cooling and wetting and dry-



Figure 1

possibilities of speculative discussion have by no means been exhausted. Our present aim, however, is limited to giving some idea of the scope of the problem and to stimulating some interest in its ultimate cooperative solution.

What Weathering Conditions Are the Major Factors in the Deterioration of Concrete?

We certainly do not pretend to know the answer but the question is pertinent and ultimately must be answered.

The two pictures at the top of Figure 1,

ing without any visible evidence of deterioration.

The lower center picture shows duplicate slabs subjected to freezing and thawing and, at 17 cycles the same cracking pattern is evident as appears in the pavement disintegration.

The lower right hand picture shows four duplicate beams similar to those used in collecting the data to be shown later. These beams show the same disintegration pattern at 10 cycles of freezing and thawing.

These pictures are shown as an indication of why we believe we are consistently duplicating under control in the laboratory, by accelerated tests, the same type of disintegration that we are experiencing in the field. The controlled laboratory cause is at least a possibility for consideration in our search for field causes.

To What Cycles of Freezing and Thawing Is Concrete Subjected in Service?

In Figure 2, we have shown the number of two types of temperature cycles which have occurred in Missouri, based on a 5 year average. The left hand map shows

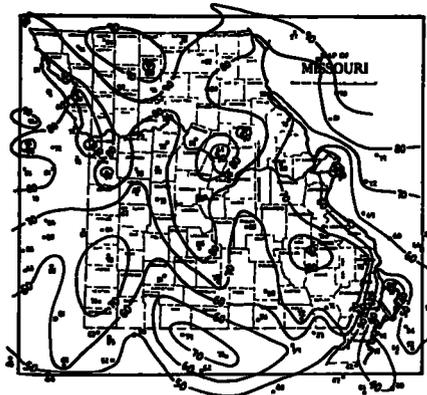


CHART SHOWING NUMBER OF TEMPERATURE CYCLES PER YEAR CROSSING 32° F
BASED ON 5 YEAR AVERAGE 1931-1936

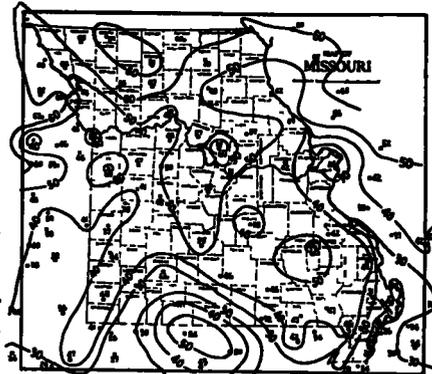


CHART SHOWING NUMBER OF TEMPERATURE CYCLES PER YEAR CROSSING THE BAND FROM 28° TO 32° F
BASED ON 5 YEAR AVERAGE 1931 - 1936

Figure 2

those cycles crossing 32°F. and the right hand shows them crossing the temperature band of 28°F. and 32°F.

In the first case we see a minimum of 35 cycles and a maximum of 90. In the second we see a minimum of 20 cycles and a maximum of 60.

Some of the interesting points about these data are:

1. That we have so many cycles.
2. That the range is so great.
3. That considering a narrow band instead of a single temperature can so greatly reduce the number of cycles

It immediately becomes apparent that

we need to know at what temperature or over what range of temperatures the detrimental freezing effects occur, since, from the data shown, we have a greatly reduced number of injurious cycles if we require a temperature cycle of 32°F. to 28°F. or some other temperature to produce an effect as compared to simply reaching a temperature of 32°F. As yet, we do not believe that we know the answer to this question, but it can be answered.

Figure 3 shows the temperature conditions which existed in a concrete pavement during four days of this year (1940)

for typical air temperatures. Temperatures are shown for the air and for the top, middle and bottom portions of the pavement slab. The temperature record for the middle of the slab was available for only the last 2½ days of the 4-day period. During the period shown, the air temperature crossed the 32°F. point once. The top of the slab crossed 7 times, the middle (for the shorter time interval) 5 times and the bottom only 3 times. The complete cycles are, of course, one-half of these figures. Thus, we see that the contour of air temperatures does not tell the story completely. We need to correlate air temperatures with concrete temperatures,

establish the effects of time and evaluate the effects of rest periods. Also the situation is probably complicated by differential stresses tending toward lamination, and cloudiness of the sky and snow or ice coverage and reflective qualities of the pavement surface are possible factors.

appreciable loss of material by sloughing.

Other investigators have pointed out that loss in strength is a more logical basis for measuring deterioration and that flexural strength is more affected than compression strength

Our own data indicate that the flexural

COMPARISON OF AIR AND INTERNAL PAVEMENT TEMPERATURES

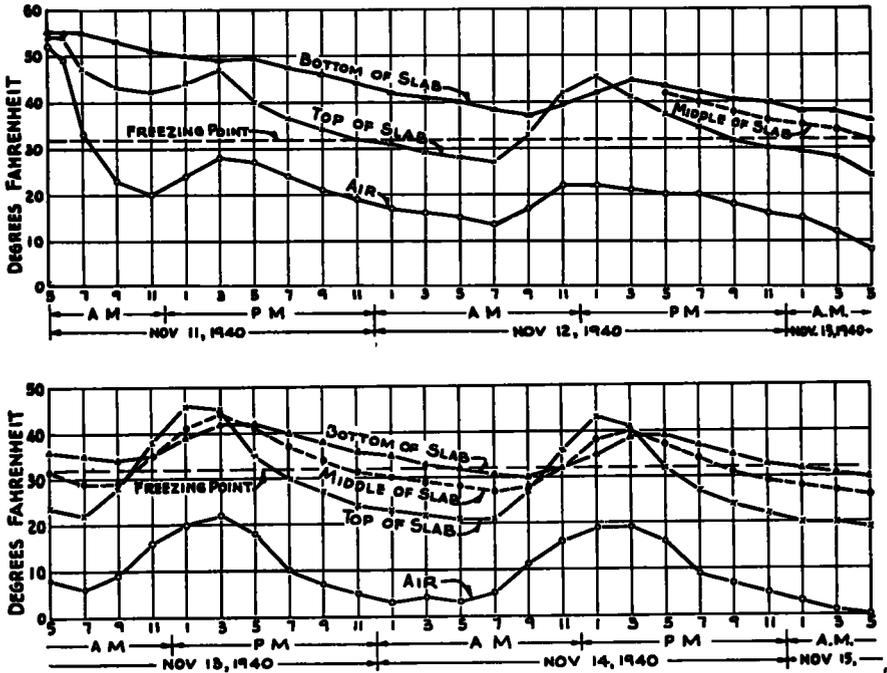


Figure 3

How Shall the Deterioration of Concrete Subjected to Freezing and Thawing Be Measured?

Many attempts have been made quantitatively to measure concrete deterioration by weighing the material sloughed or brushed off after successive cycles of freezing and thawing. This procedure, in our opinion, has not been very satisfactory. The results are not duplicable and recent investigations indicate that, in most cases, concrete will have deteriorated enough to seriously impair its serviceability long before it shows any

strength is affected sooner and in much greater degree than the compressive strength.

In as much as many thin section structures, such as pavements, are subjected to flexural stress and since flexural strength is a much more sensitive measure of deterioration than compression, it seems logical to use it as a "yardstick." There is one serious drawback. In order to measure the effect of a certain number of freezing and thawing cycles, the specimens must be destroyed. Hence to trace the progress of disintegration through a

large number of cycles, a great many specimens must be fabricated and tested. Indeed the number required will generally tax the facilities for storing, handling and freezing of most research organizations. In addition, the assumption that large numbers of specimens are the same in characteristics often proves incorrect.

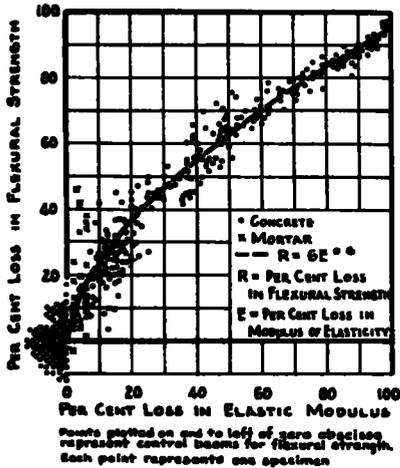
To our rescue has come, through the adaptive genius of several current research workers, a test for loss in elastic modulus, the loss being determined by dynamic measurement. This test measures a quality of the concrete that is as specific as strength and the test can be

This is the determination of the change in volume or length. The curve on the right (Fig 4) shows the relationship between the flexural strength and the change in length measured after various cycles of freezing and thawing. The same type of relationship seems to hold as is the case between flexural strength and modulus of elasticity shown in the left hand curve.

What Are the Effects of Various Curing Treatments Prior to Freezing?

Figure 5 compares the effects of some of the possible variations in curing on the laboratory disintegration of concrete.

RELATION OF LOSS IN FLEXURAL STRENGTH TO LOSS IN MODULUS OF ELASTICITY



RELATION OF LOSS IN FLEXURAL STRENGTH TO CHANGE IN LENGTH

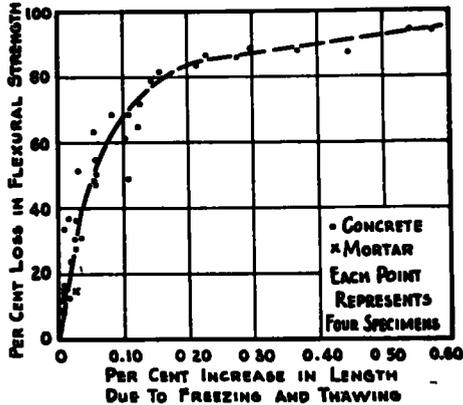


Figure 4

made without injury to the specimen. Furthermore, it is closely related to the flexural strength as may be seen from the curve on the left in Figure 4 in which the ordinate shows the flexural loss and the abscissa shows the loss in elastic modulus. Data obtained can be directly correlated with modulus of rupture by checking preliminary and final results by actual flexural breaks

Another test apparently lends itself to measurement of deterioration and should receive further study and consideration

The upper set of block diagrams shows the comparison for an aggregate having a good service record and the lower for one having a poor service record.

In the left hand column is shown the time in moist room, in the second, the time drying in air, and the third shows the time soaked in water. The age at initial freezing is shown in the fourth column and the block diagrams at the right show the percentage loss in flexural strength after 10 cycles of freezing and thawing.

In the case of each aggregate, the first two results were to be anticipated, the effect of freezing being less on the older and longer cured beams. The result in the third case might also be anticipated, reflecting either greater age or an effect of a longer drying period.

The fourth result with each type aggregate, however, is very interesting. As compared, for example, with No. 2, the beams were given the same moist room and laboratory air treatment but were soaked in water for 14 days instead of 4 days. Water curing is considered ideal and the beams were older, yet the strength loss was considerably greater.

Figures 6 and 7 show in a different manner the fallacy in overlooking or neglecting the effects of pretreatment prior to freezing and thawing. Figure 6 shows such effects on a good limestone and Figure 7 shows the same for a poor type gravel. The relative relationship of the two types of aggregate can be reversed, if desired, by proper selection

In each case we have certainly provided more than the minimum curing required for field concrete pavement construction and yet the difference in quality is beyond the zone of experimental error and may reflect some fundamental behavior of water and concrete. Perhaps we will find that concrete is a much more sensitive product than we have assumed it to be, and that the beneficial effects of water may be discounted under certain conditions. Good concrete placed in a nice dry place seldom causes any argument.

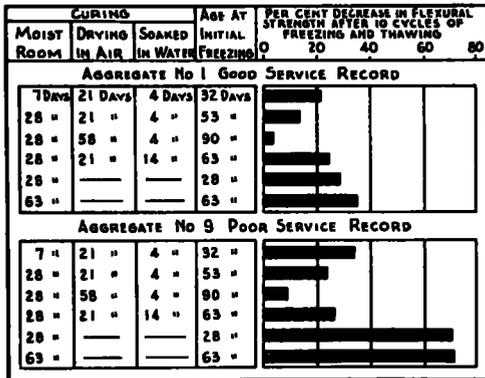


Figure 5

Perhaps we had better study closely the effect of moisture content at the time of freezing.

Then in the next two cases we note an increased loss in strength. Here we are led to suspect that the absence of the drying interval is the decisive factor. Other data which we have would tend to confirm this opinion.

Looking at No. 3 in the lower tabulation for poor aggregate as compared to No 6, we find that for the same concrete and same number of freezing cycles the first has lost less than 10 per cent of its strength while the other has lost more than 65 per cent. The same tendency is present in the case of the good aggregate.

What Cycle of Freezing and Thawing Should Be Used?

Investigators are using various kinds of cycles. Some freeze in brine, others in water or air, and varying maximum and minimum temperatures are used. Some control only the temperatures of the freezing unit, neglecting to determine the interior temperature of the concrete. Some rely on visual manifestations of breakdown while others attempt some form of quantitative measurement.

The curves on Figure 8, show time temperature relations for typical freezing and thawing cycles based on maintaining the freezing unit at two fixed temperatures, 25°F and 0°F, the concrete charge being kept constant and the time of complete cycle kept constant at 12 hours while the thawing temperatures were varied from 90°F to 40°F. The temperatures shown throughout the range of freezing and thawing for all of the data presented in this paper are internal concrete temperatures electrically measured and automati-

cally recorded Freezing was in air and thawing in water.

The points illustrated by these curves are:

1. That for the same thawing temperature, lowering the freezing temperature increases the time the specimen remains in the freezing zone

longer time for dehydration. Progressive dehydration seems to us to be at least part of the explanation of the comparative results obtained from various freezing cycles in air. Should some degree of dehydration be permitted in our test since it occurs in nature, or should it be prevented for the sake of accelerated results?

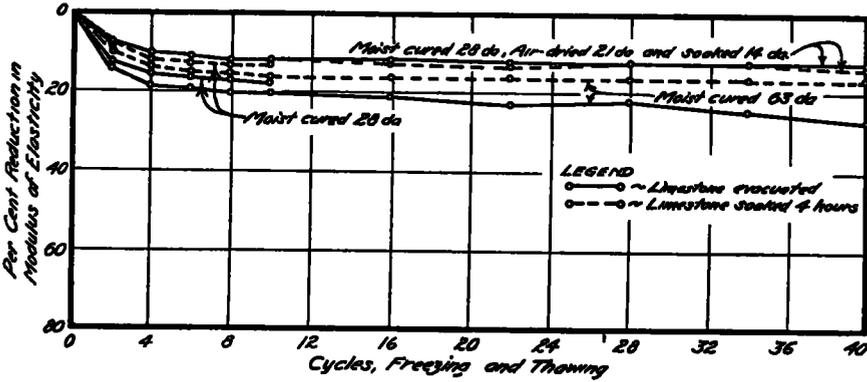


Figure 6

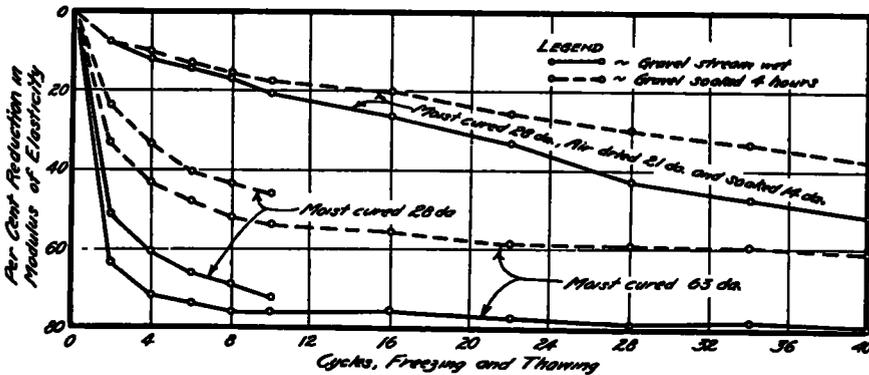


Figure 7

2. Due to the method of manipulation, there was no appreciable difference in time required for the various specimens to reach the thawing temperatures.

3. Since the freezing was in air and the thawing in water, and it seems to be easier to dehydrate concrete in cold air than cause absorption in water, placing the specimens in cold air from the higher thawing temperatures naturally gives a

Figure 9 shows the effects of various freezing and thawing temperatures on the deterioration of concrete.

On the ordinates at the left are shown the percentage reductions in elastic modulus. (Equivalent, for our purpose, to the reduction in strength—See Fig 4.)

On the abscissa at the bottom are shown the number of cycles. At the top are shown the various thawing tempera-

tures used, and at the right are shown the freezing or cooling temperatures. For example, the upper left hand diagram

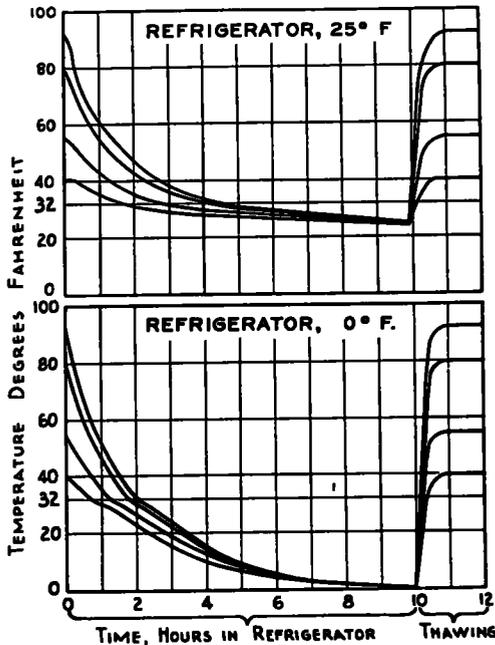


Figure 8

shows the results of from 0 to 40 cycles of cooling three different concretes to 37°F. in air and warming to 90°F. in water. The next diagram to the right shows the same concretes cooled at 37°F. and warmed to 80°F. in water.

It was very interesting to discover that, under such treatment, a considerable progressive loss in strength could be obtained and that a consistent difference in types of concrete was indicated. As might be expected, the wider range produced the greater effect. The lower diagrams show the same concretes frozen at successively lower temperatures and at thawing temperatures varying from 90°F. to 40°F. The only known difference in the concretes was the type of coarse aggregate used. In all cases No. 1 was an aggregate with a good service record, No. 7 was one with a rather poor record and No 9 one with a very poor record

These data seem to have some very interesting implications.

1. The lower the temperature of freezing for any thawing temperature used,

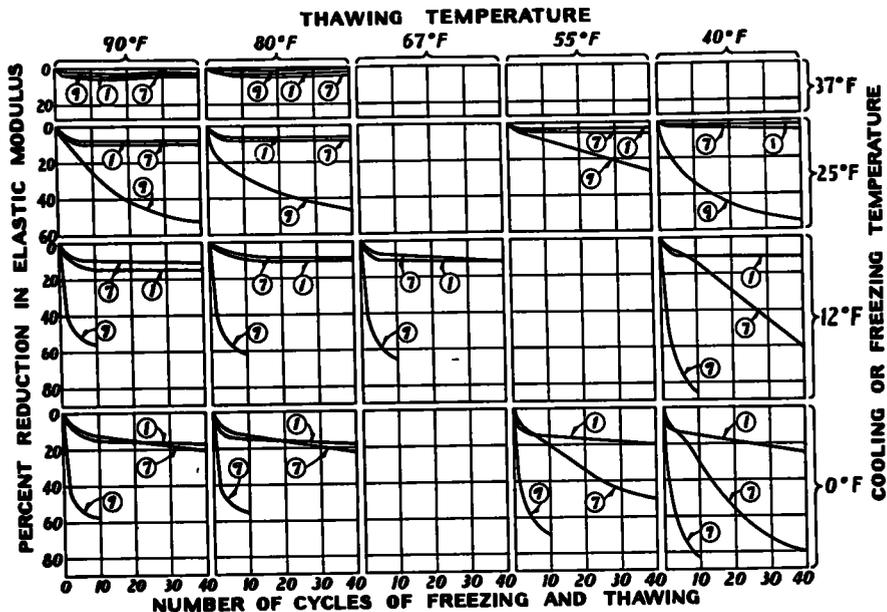


Figure 9

the quicker the reduction in strength of the poorest concrete—No. 9.

2. In general, the lower thawing temperatures gave greater reduction in strength for the same freezing temperatures

type of separation is shown between the good and bad aggregates, the separation becoming more pronounced as we look from right to left or going from the higher thawing temperatures to the lower.

In other words, the 40°F thawing tem-

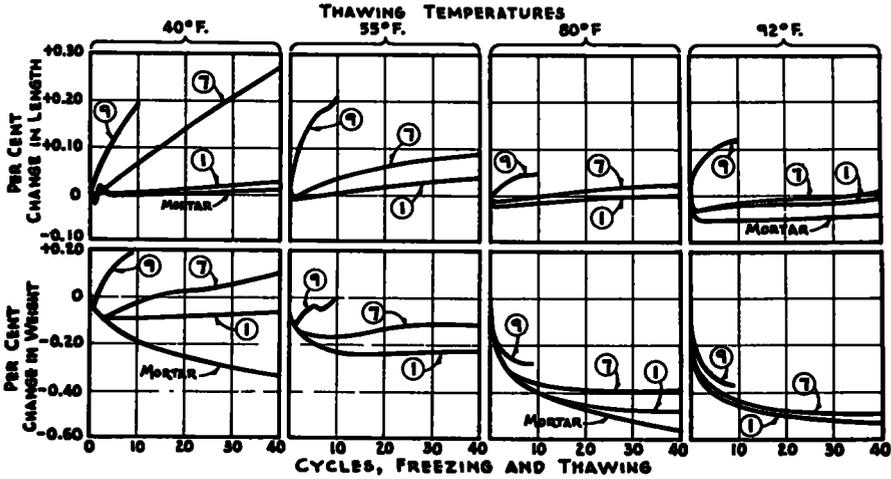


Figure 10

3. Only the lower thawing temperatures coupled with the lower freezing temperatures were able to consistently show up the intermediate grade, poor aggregate.

4. A relatively small number of cycles would seem to develop the tendency as well as continuing the test to destruction of the concrete. (The implications of No. 3 and additional data caused us to adopt 40°F. thawing temperature and 0°F. freezing temperature rather than some higher temperature for our further work.)

On Figure 10 is presented in reverse order the same type of picture using, however, different measurements. In the top row are shown the changes in length of the same concretes at varying thawing temperatures and 0°F. freezing temperature. In the bottom row are shown the changes in weight under the same conditions and for the same materials.

Mortar is shown for only two thawing temperatures. In each case the same

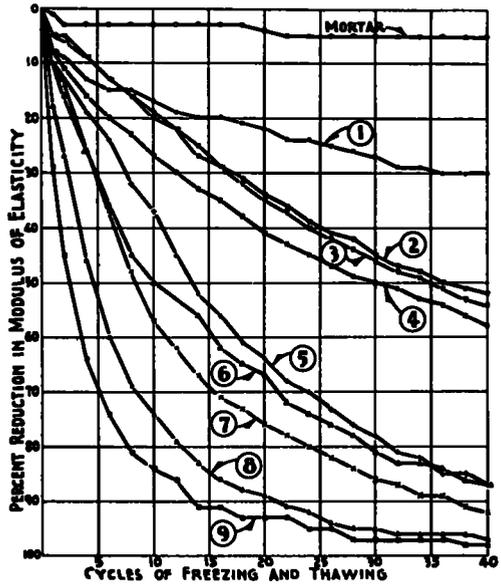


Figure 11

perature, freezing at zero, is very quickly and definitely reflecting the known service

behavior of the concrete and the higher thawing temperatures seem to make a slower and poorer separation.

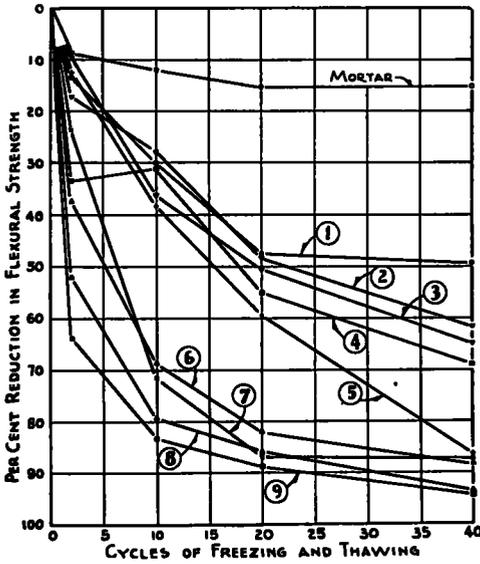


Figure 12

mits the concrete to remain in the freezing zone for a longer time and also gives a shorter time for dehydration of the specimen while the temperature of the concrete is dropping from the thawing temperature to the zone of freezing temperatures.

The gains in volume and in weight are, possibly, simply a result of the formation of fine cracks which fill with ice during the freezing period. It is interesting to note the quite substantial increases in the case of the very poor aggregate as compared to the very low one in the case of the good aggregate, and also the tendency of dehydration to produce a net loss in weight in the case of the mortar and the good aggregate.

Can the Effect of Aggregates on the Durability of Concrete Be Predicted by a Freezing and Thawing Test?

On Figure 11 are shown the reduction in elastic modulus due to freezing, of one

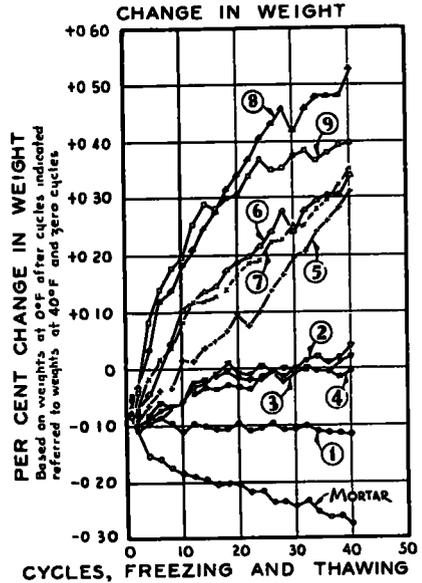
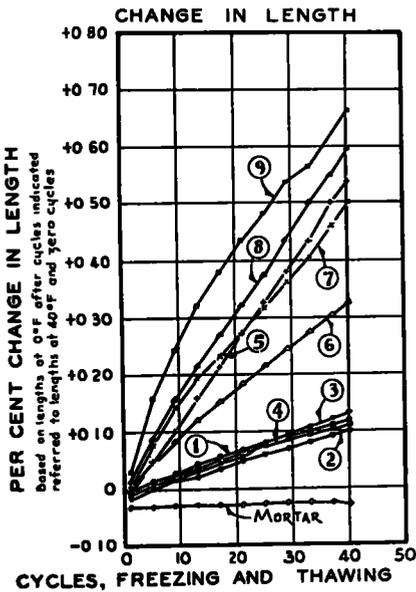


Figure 13

It should be remembered that we are here dealing with a fixed length of cycle and the 40°F. thawing temperature per-

mortar and 9 concretes, the latter differing in type of coarse aggregate.

The aggregates for curves 1, 2, 3 and 4

are all of known good service behavior. The remainder of the curves are for material having poor service behavior with the exception of No. 5 for which we have no service history. The cycle used was freezing in air at 0°F. and thawing in water at 40°F. with a fixed cycle length of 12 hours

It will be noted that there is a definite trend toward separation of the good from the bad even during the earlier cycles. It may be that when additional aggregates are studied they may tend to fill the gap and such an experience may be

nate method of measuring deterioration.

The next graph, Figure 14, shows the change in length of the beams while freezing (left) and while thawing—showing the consistent grouping previously noted.

CONCLUSION

Summing up our presentation, which has been confined to that phase of the durability problem dealing with the freezing and thawing test, we conclude that the questions which we have presented, and many others, are far from answered.

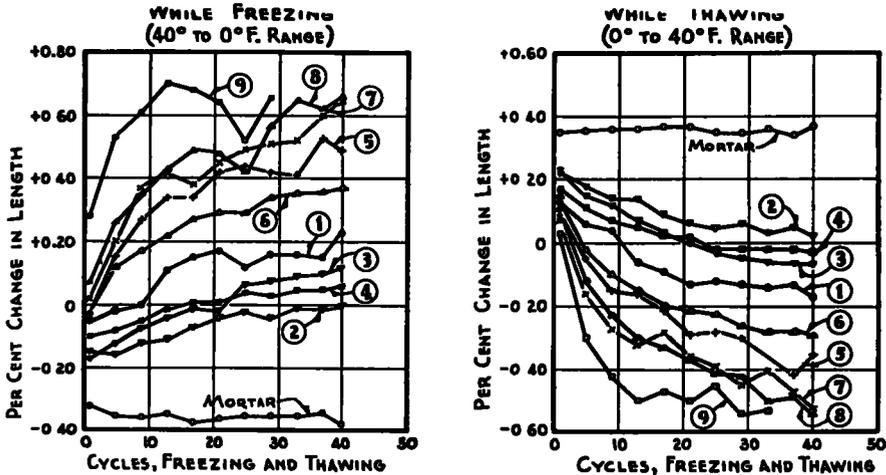


Figure 14

logical if we concede that there are all degrees of durability. It is also interesting to note that so great a deterioration in strength can be produced in good concrete by a very severe accelerated test.

On Figure 12 we see the same general picture as shown by the modulus of rupture tests on the same concretes.

The next graph, Figure 13, shows the same picture measured on the left by changes in length and on the right by changes in weight of the same concretes.

It may be found from further investigation that either or both of these measurements may serve as a check on the strength measurement or even as an alter-

We can see a number of years work ahead for workers in this interesting field of research.

The data which we are submitting are admittedly incomplete, but we believe we have shown some interesting tendencies or trends from our exploratory work. We would stress the need for further cooperative work which can ultimately lead to the standardization of some test which will measure and predict the degree of durability of concrete. In all of this work it is highly important that a quantitative yardstick be developed and that the conditions of test procedure and measurement be carefully controlled.

DISCUSSION ON FREEZING AND THAWING INVESTIGATION

MR. F. B. HORNIBROOK, *National Bureau of Standards*: I was interested in Mr. Reagel's interpretation of the cause of the greater resistance of the specimens thawed at the high temperature, that is, the additional drying out of the specimen which can occur as the specimen is cooling from the higher temperature to the freezing temperature. At the National Bureau of Standards we also have found that specimens thawed at the higher of two temperatures had the greater resistance. However, our specimens were sealed in tight-fitting rubber bags with sufficient water added to keep the specimens wet. Accordingly no drying could occur. We attributed the greater life of the specimens thawed at the higher temperature to the autogenous healing which could take place faster at that temperature.

In line with this, we have noted that specimens tested by the sonic method immediately after the thawing portion of the cycle had a lower modulus than if tested after having stood in the thawing bath overnight. Specimens, severely affected, continued to gain in modulus for several days. As a consequence we adopted a uniform time interval between completion of thawing and the testing of specimens so that consistent results could be obtained.

MR. REAGEL: The only comment I have to make is that we should standardize the conditions of the cycle that we are using. Many things could be done more nearly to simulate field conditions, but the important thing with us was to get a very accelerated cycle. I think we have several years study

ahead to find the cycle that will best determine degree of durability.

PROF. JOHN D. WATSON, *Duke University*: Soil engineers know that frost heaving in soil comes from the development of ice crystals which grow progressively with time. I wonder if any attempt has been made to observe the formation of these ice crystals in the concrete when a temperature only slightly below freezing is maintained in the concrete for a prolonged period of time.

MR. REAGEL: I think it would be difficult to observe that except by checking the weight of the specimens—possibly that would be an indication. We have built up some data of this type. We know that water is distributed in concrete in all different degrees of subdivision or particle size and certain of those quantities freeze first and other more finely divided particles freeze later and it is logical to think that we would have somewhat the same action in concrete as is observed in soil layers

PROF. WATSON. If that is true, then why do you use these rapid freezing and thawing cycles? It seems to me that the laboratory conditions bear too little resemblance to natural conditions.

MR. REAGEL: We have to standardize some cycle. We do not say our cycle is best. It was adopted in order to get accelerated results. We do need to study the test in order to evaluate different variations and arrive at some standard. It will not necessarily be like anything we have used.