Durability of concrete as affected by low air temperature at time of placing
by Floyd D Swenson

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of Master Of Science in Civil Engineering
Montana State University

Abstract:
In this study, plain and air-entrained concrete specimens made with two Montana aggregates were subjected to storage temperatures varying from 45° F. to 5° F. immediately after casting for a period of 24 hours. The concrete specimens were subsequently given 27 days curing at 70° and 100 per cent humidity. At the total age of 28 days freezing and thawing cycles were started on the specimens. One freezing and thawing cycle consisted of 24 hours in a freezer with an air temperature of approximately 5° F. and 24 hours in a water bath at a temperature of 70° F. At the end of about 50 such freezing and thawing cycles, one-half of the specimens were tested to failure in compression, the other one-half continued, the freezing and thawing cycles.

An attempt was made to estimate the detrimental effects of the initial storage temperatures and of the freezing and thawing cycles and to correlate these results with conclusions drawn from similar tests by other authors, Besults from this study show a decrease in compressive strength up to 30 per cent from that of normally cured concrete of the same age due to the initial storage temperature. The percentage of decrease was generally higher for the lower, values of storage temperature, Two appendixes are attached giving a brief outline of the con- siderations involved in making freezing and thawing tests, and of the mechanism of disintegration.

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ABSTRACT

In this study, plain and air-entrained concrete specimens made with two Montana aggregates were subjected to storage temperatures varying from 45° F. to 5° F. immediately after casting for a period of 24 hours. The concrete specimens were subsequently given 27 days curing at 70° F. and 100 per cent humidity. At the total age of 28 days, freezing and thawing cycles were started on the specimens. One freezing and thawing cycle consisted of 24 hours in a freezer with an air temperature of approximately 5° F. and 24 hours in a water bath at a temperature of 70° F. At the end of about 50 such freezing and thawing cycles, one-half of the specimens were tested to failure in compression, the other one-half continued the freezing and thawing cycles.

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Two appendixes are attached giving a brief outline of the considerations involved in making freezing and thawing tests, and of the mechanism of disintegration.

INTRODUCTION

Purpose

The purpose of this thesis was to determine the effect of low temperature on the strength and durability of concrete. The concrete was exposed to temperatures varying from 45° F. to 5° F. immediately after casting. An attempt was made to provide test conditions which would approximate those which might occur during concreting operations in the field. This study endeavors to indicate the strength and durability which can be expected of concrete exposed to these temperatures.

Importance

Concrete is normally placed during warm or moderate weather to preclude the possibility of harm or damage to the concrete due to the action of cold weather. Edward E. Bauer states:

> Whenever it is anticipated that the air temperature at the point of placement is likely to fall below 40° F. during the 24 hour period after placing concrete or below 30° F. during the succeeding 6 days, it is recommended that protective measures be taken (......).[1]

To provide some arbitrary standard of strengths to use in cold weather concreting operations, the American Concrete Institute has suggested that a minimum strength of 500 pounds per square inch be attained before freezing to prevent permanent damage.[2]

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[1] Edward E. Bauer, Plain Concrete, (3d. ed.; New York: McGraw-Hill Book Company, Inc., 1949), 200-201.

[2] Ibid.

Thus in the northern climates, where the temperatures are more or less severe, the placement of concrete must be suspended during a large portion of the year or, as an alternative, the freshly placed concrete must be protected from freezing. The various procedures for the cold-weather protection of concrete are: (1) heating of the mixing water, (2) heating of the water and the aggregates, (3) protective covering of fresh concrete, (4) heated enclosure for the structure, and (5) the use of admixtures to lower the freezing point of the water. Any or several of these precautionary operations may be used depending on the climate and temperature conditions affecting a specific project.[3]

A detailed description of the above mentioned methods will not be attempted. However, even with the use of these protective measures, concrete is occasionally frozen before a minimum strength has been attained. Most specifications state that any concrete so frozen must be removed and replaced regardless of the conditions under which it was frozen. While these specifications doubtless have merit, there is a possibility that much concrete removed under these conditions might well have retained enough strength or has the ability to subsequently gain sufficient strength to meet all the strength and durability requirements for some concreting work. Thus, if a method of accurately predicting the ultimate strength of prematurely frozen concrete could be devised,

[3]John H. Bateman, Materials of Construction, (Toronto: Pitman Publishing Corporation, 1950), 198.

a saving in time and money would result, and more economical concrete work could be obtained.

Previous Work

The work that has been conducted in the past can be placed in two classifications: (1) laboratory or experimental, and (2) construction experience and observation. As compared to other concrete studies, relatively little information is available on this subject. What data is available from different sources is not in good agreement, there being two distinct beliefs: (1) that concrete which has been frozen at an early age suffers little damage, and (2) that frozen concrete suffers a loss in strength in the range of 40 to 60 per cent. A principle reason for these differences of opinions is that results from two very similar tests sometimes have very little correlation to each other, and as a consequence, the types of tests used are not standardized. This is as it should be, at least until sufficient knowledge has been built up to provide a standardized test an assurance of success. In construction, no attempt is made to control conditions as in a laboratory, and opinions and results can be expected to differ.

The following quotation by A. M. Gunzberg, written for the Engineering News, August 6, 1931, illustrates a construction experience that is unique and has been received with various degrees of belief. It is presented here in its entirety to provide a thorough knowledge of the method used.

Concreting during severe winter weather in the open air, with the purpose of forcing the concrete to freeze before setting begins, has been carried on in Russia under special methods devised by the author, who states that since 1905 he has used these methods in the Ukraine for many large concrete and reinforced buildings, which have all proved satisfactory. Concrete placed in this manner is protected to keep it in a frozen condition until spring. -- Editor.

At the moment before actual setting of concrete the cement grains are enveloped in a thin molecular film of water and the greater the proportions of water in the mix, the lower will be the strength of the concrete. If cold water is used, the volume will be less than with heated water but the strength will be greater. If the concrete freezes while setting, it will become a rigid nonelastic mass consisting of sand, cement and ice particles, and such a mass will fail after thawing. But by allowing the concrete to freeze before setting it will be in normal condition after thawing, so that setting can then begin and proceed to completion.

As the concreting must be done rapidly, the forms must not be deep and the reinforcing bars must be so arranged that the concrete will flow freely and fill the forms quickly without voids. It is absolutely necessary for the concrete to freeze before setting begins. The cement is cold, the aggregate must be cold and dry and the water must have a temperature of 40 to 50 deg. F. The less water there is, the better the concrete. The concrete is mixed in a sheltered location and is placed quickly in thin layers, each layer being thoroughly but rapidly tamped so that there will be no separation, or frost plane, between the layers, the fundamental requirement being continuous placing and complete freezing of the entire mass.

As soon as the placing is completed the form is covered with boards. Concrete slabs are covered with sand or straw, over which water is poured and allowed to freeze, to prevent any thawing and consequent setting action in the concrete. When it is necessary to stop work before completion, before starting again, warm water is to be poured over the frozen surface, which is then scraped and roughened before the new concrete is placed.

The most difficult and most important operation is the wetting of concrete in the spring while thawing, as the very dry northern winds in the Ukraine during winter can evaporate moisture even from the frozen concrete. Thus it will be so dry that it cannot set and it is necessary to apply water, but the water must be applied very carefully in order not to wash out the cement.

Winter concreting by methods that employ the heating of materials and keeping the concrete warm so that it will set properly have the disadvantage of giving too high a temperature for proper setting, with the result that the freezing method ties up the form work for a considerable time, this objection is slight in comparison with the advantages of getting the concrete placed during the severe winter. The freezing method is not employed near the end of the cold season when alternate spells of cold and warm weather may be expected.[4]

While the method just described is not recommended by the author for general use, it is interesting to note that this type of work has been satisfactorily carried on, and that the frozen concrete evidently suffered no great ill effects. However, Mr. Gunzberg stresses that in order to obtain concrete of good strength, these points must be complied with: (1) Concrete must freeze before setting begins, (2) frozen concrete must be protected from alternate freezing and thawing, and (3) care must be taken to provide subsequent good curing after final thawing.

Skepticism of the results of Mr. Gunzberg is evidenced in a discussion of the subject some years later. Mr. R. B. Young of the Hydro-Electric Power Commission, Ontario, Toronto, states:

> It (the previous article) is very intriguing and I have made several attempts to obtain like results in the laboratory but have failed. I have never been able to freeze concrete in a way that did not get internal segregation of the mixing water into ice crystals. As long as that condition exists, I do not see how we can expect to have concrete as durable as it would otherwise have been, unless something is done to reconsolidate the concrete and eliminate pores left by these ice crystals. Further, in our tests we have never been able to get anything like 95 per cent of the original strength out of a test cylinder that was first quick frozen, then thawed out and cured normally.[5]

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[4]A. M. Gunzberg, "Frozen Concrete Used in Russian Buildings," Engineering News, CVII (August 6, 1931), 207.

[5]R. B. Young, "1942 ACI Convention Quiz Session," American Concrete Institute Journal, XIV (November 1942), 127-129.

Since Mr. Young does not mention the conditions under which his tests were conducted, it is difficult to correlate his results with others. Nevertheless, he is very emphatic in stating that he has never been able to get a high percentage of original strength from frozen concrete in any of his tests. His conclusions are somewhat borne out by tests conducted at the Minnesota Highway Department. Their results show that freezing concrete immediately after casting is the worst condition that might occur. Specimens subjected to freezing for sixteen hours immediately after casting and thereafter cured at 70° F. under burlap exhibited a strength of only 69 per cent of the unfrozen samples, while if the storage temperature was maintained at 40° F., the specimens exhibited only 31 per cent of the unfrozen samples. However, they did find that concrete is not greatly harmed by frost after 24 to 72 hours curing if subsequently given good curing, and that two weeks freezing has little if any more effect than sixteen hours freezing except that concrete gains little strength while frozen.[6]

Further experimental results reported by H. H. Scofield may be summarized as follows:

(1) Concrete frozen immediately after placing attains on the average of about 50 per cent of the strength of the normal unfrozen concrete at the same age.

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[6] W. H. Batchelder, "Significant Tests of Frost Action on Concrete," Engineering News, CI (December, 1928), 882.

(2) There is some indication that dry concretes suffer less injury than wet concretes, especially at early stages.

(3) There is some indication that older concretes have less proportionate loss of strength due to immediate freezing than those tested at earlier periods.

(4) There is little difference between a rich mix and a lean mix in their resistance to immediate freezing.

(5) The results seem to indicate that dry concretes (2 in. slump) may be frozen solid without practical injury if cured for 24 to 48 hours in room-dry conditions before freezing.[7]

H. H. Scofield's conclusions summarize very nicely the opinions of most authorities, as a majority agree that freezing cannot occur without injury to freshly poured concrete. However, the minority staunchly contends that no harm is done by freezing provided the concrete is frozen before actual setting begins. E. A. Hagy supports A. M. Gunzberg in this report:

> In the year 1930, in the construction of a hotel in Cincinnati, we had a condition of about three weeks of close to zero weather, and we poured footingsof three to five yards. We did not make any attempt whatever to protect the concrete, we just poured it and let it freeze, and after three weeks it thawed out and the concrete seemed just as plastic as when we poured it. Then we commenced to take care of it, after it thawed once. We had made cylinders at the time it was poured and protected them all. We made cylinders from

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[7] H. H. Scofield, "How Freezing and Thawing Affect Concrete," Concrete, XLV (July, 1937), 12-13.

this frozen concrete after it became plastic and cured them, and after a six months period, there was not over a five per cent difference in the compressive strength of the two concretes. (.....) I believe that no damage was caused by the concrete freezing in the plastic state.[8]

Another experience was cited by H. C. Watts of a concrete slab on the ground frozen after it was freshly poured at a temperature of eight above zero. After 14 years of use, the concrete was in good condition.[9]

The difficulty in interpreting these results is complicated by the lack of knowledge of the extent of the freezing damage to the concrete. It is possible that the concrete in the field structures discussed had been damaged, but that it retained sufficient strength to remain completely satisfactory.

The conditions favoring severe frost damage are concrete of high porosity and low strength, the presence of water within or in contact with the concrete, and cooling to a temperature several degrees below the freezing point over an appreciably long period.[10] Thus a concrete could conceivably be designed which would resist freezing to the extent that it would remain serviceable, while other designs would fail after exposure to freezing.

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[8]E. A. Hagy, "1942 ACI Convention Quiz Session," American Concrete Institute Journal, XIV (November 1942), (127-129).

[9]H. C. Watts, "1942 ACI Convention Quiz Session," American Concrete Institute Journal, XIV (November 1942), 127-129.

[10]A. R. Collins, "Destruction of Concrete by Frost," American Concrete Institute Journal, XVI (June 1945), 726-727.

LABORATORY EQUIPMENT

Concrete Mixer

Mixing of the concrete was accomplished through the use of a laboratory mixer of 1½ cubic feet capacity. The mixer was manufactured by Sears, Roebuck and Company. It is powered by a Dunlap 1/3 h.p. split phase motor operating at 1750 r.p.m. The drum of the mixer rotates at 25 r.p.m.

Specimen Molds

Molds for the 6 in. by 12 in. compression specimens were of cast iron with a removable machined base plate. Steel beam molds, 6 in. by 6 in. by 36 in., were modified to provide two molds for 6 in. cubes. All molds were oiled before use.

Curing Room

The moist closet has the overall dimensions of 18 ft. long by 9 ft. high by 5 ft. wide. All walls are either concrete or concrete block throughout. A wooden door was utilized although the inside surface was completely encased in a sheet metal liner. The sheet metal liner was given one coat of an oil sealer and two coats of waterproof varnish. The moist closet maintained 100 per cent humidity through the use of three ¼ in. fog nozzles mounted at the ceiling. City tap water was used almost exclusively to supply the fog nozzles at a room temperature of 70° F. ± 2° was usually maintained without the addition of hot water. However, during extremely cold weather, tempered water was needed to maintain the required temperature. Although some of the specimens were so placed as to receive the direct spray from the fog nozzles, the flow of water was not sufficient to injure the specimens.

Freezer Chest

The freezing cabinet was manufactured locally by the Intermountain Industries Company to our specifications. Inside dimensions of the cabinet are 19 in. deep by 30 in. wide by 60 in high. A 6 in. layer of spun glass insulation was used on all surfaces and was completely encased in sheet metal. A rack for holding concrete specimens was made to provide four shelves and the floor of the cabinet for storage. Each of the shelves contains cooling coils, these coils providing the cooling of the entire cabinet.

Temperature in the chest was controlled by a pressure controller type mercury switch. The compressor unit was manufactured by York and a 1/3 h.p. Century Capacitor Single Phase Motor at 1750 r.p.m. was used for power.

Storage Tank

A water storage tank 27 in. by 75 in. by 9 in. was provided for the thawing of the frozen specimens. Sufficient water at room temperature (approximately 70° F.) was kept in the tank to completely cover all specimens.

Air Determinator

The percentage of air in the air-entrained specimens was determined by Acme Air Yield Determinator. Directions supplied by the manufacturer were followed in the operation of the determinator.

MATERIALS

Aggregate was secured from two Montana sources, local aggregate from the pit of the Gallatin Sand and Gravel Company at Belgrade, Montana (code letter G), and aggregate from the Bureau of Reclamation plant at Canyon Ferry Dam, Helena, Montana (code letter F).

The coarse aggregate from Belgrade was graded 3/4 in. minus. The aggregate was produced by crushing, which gave a small percentage of flaky particles and a relatively large percentage of fines.

The aggregate obtained from Canyon Ferry Dam was produced by river dredging and consequently the aggregate contained well rounded particles. The aggregate received was well graded in three grades: 3/16 in. to 3/8 in., 3/8 in. to 3/4 in., and 3/4 in. to 1 1/2 in.

For mechanical gradation of aggregates as used, see Table I.

Type II cement was used in all mixes. No specific information is available on the chemical composition of the cement, but no sample tested at Trident, Montana, showed alkali present in quantities greater than 0.8 per cent.

Protex was used as an admixture in the air-entrained concrete. It was added at the rate of one ounce to a sack of cement.