which the mixture of cement and Puzzolan is replaced by the same weight of pure cement.

Allow the Puzzolan mortar to harden in the presence of moisture.

It is as yet impossible to suggest detail rules for the acceptance and control of Puzzolan cements. The recommendation is made, however, that their ability to resist the decomposing action of the salts in sea-water be compared to the resistance of pure cements by means of the test with sulphate magnesia already referred to.*

VARIOUS PLASTERS AND COATINGS

Various methods have been tried to prevent sea water from wetting masonry too soon, either by coating the work with materials designed to obstruct the pores, or by covering it with a layer more or less thick and more or less impermeable, consisting usually of a rich mortar, clay, bituminous materials, etc.

This method of protecting the work is generally rather costly and is not applicable to all kinds of construction. Besides, it presents this disadvantage, that if by accident there is any break in the continuity of the covering, the sea water finds a passage towards the heart of the masonry and creeps in from one place to another, so that often the coating offers only an illusory security.

In certain cases, a coating is formed spontaneously by the carbonization of the lime in the parts of the mortar near the free surface, and this action is aided by the development of sea organisms such as sea-weed and shellfish. This cause, together with the differences in the saltness and the temperature of the water, and the course of the ocean currents, is the one which is most often called upon to explain why mortars decompose more quickly in some regions than in others.

* See also Annales des Ponts et Chaussées, 1908, I, p. 107

CHAPTER XVII

LAYING CONCRETE AND MORTAR IN FREEZING WEATHER

The results of practise and experiment with cements exposed to frost, which are discussed more in detail in the following pages, may be summarized as follows:

(1) Most Natural cements are completely ruined by freezing. (See p. 320.)

(2) The setting and hardening of Portland cement in concrete or mortar is retarded, and the strength at short periods is lowered, by freezing, but the ultimate strength appears to be but slightly, if at all, affected. (See p. 321.)

(3) A thin scale is apt to crack from the surface of concrete walks or walls which have been frozen before the cement in them has hardened. (See p. 320.)

(4) Frost expands Natural cement masonry and settlement results with the thawing. (See p. 320.)

(5) Heating the materials hastens setting and retards the action of frost. (See p. 323.)

(6) Salt lowers the freezing point of water, and in quantities up to 10% of the weight of the water does not appear to affect the ultimate strength of the concrete or mortar. (See p. 324.)

(7) In practise concrete work should be avoided if possible in freezing weather, because of the difficulty and expense of attaining perfect results. (See p. 320.)

EFFECT OF FREEZING

Numerous experimental tests have been made, chiefly in the United States, where the effect of frost is a more serious question than in England, France, or Germany, to determine the effect of freezing temperatures upon hydraulic cements. Although the conclusions of different experimenters are not in perfect accord, it is the generally accepted belief, corroborated by tests under the most practical conditions and by the appearance of concrete and mortar in masonry construction, that the ultimate effect of freezing upon Portland cement concrete and mortar is to produce only surface injury.

In their practise and research the authors have never discovered a case, either in laboratory work or in practical construction, where Portland cement concrete or mortar laid with proper care has suffered more than surface disintegration from the action of frost. They do not wish to imply, however, that it is always expedient to lay Portland cement masonry in freezing weather, for the expense of laying is increased, and it is much more difficult to satisfactorily mix and place the materials. Mortar for brick and stone masonry freezes in the tubs and in the joints, while in laying concrete the surface freezes unless measures are taken to prevent it, and any dirt or "laitance" which rises to the surface of wet mixtures is hard to remove. It is a well-known fact that a thin crust about $\frac{1}{16}$ inch thick is apt to scale off from granolithic or concrete pavements which have frozen, leaving a rough instead of a troweled wearing surface, and the effect upon concrete walls is often similar. It may be stated as a general rule that concrete work should, if possible, be avoided in freezing weather, although if circumstances warrant the added expense, with proper precaution and careful inspection mass concrete may be laid with Portland cement at almost any temperature.

Most Natural cements, on the contrary, are seriously injured by frost especially by alternate freezing and thawing, and while occasional cases are on record, especially in heavy stone masonry in which the weighted joints have thawed slowly, where Natural cement mortar has been laid in freezing weather without serious results, numerous examples might be cited where even after several years the concrete or mortar was but slightly better than sand and gravel. Mr. Thompson has observed this result in Natural cement mortar laid during the comparatively warm winter of North Carolina on days when the temperature was considerably above freezing at the time of laying, and also in the cold climate of Maine where the mortar froze as it left the trowel and did not thaw until spring.

The settlement of the masonry when thawing is often a serious characteristic of Natural cements. Stone masonry walls laid in freezing weather in Natural cement mortar may settle as much as ½ inch in the height of a window jamb.

Experiments upon Natural cement mortars have not positively confirmed the judgment reached by nearly all engineers experienced in construction in freezing weather. Occasional tests are recorded in which such mortars, especially when subjected to a uniformly cold temperature and then suddenly thawed, have attained full strength, but these are insufficient to warrant the use of any except Portland cements when frost is likely to occur before the mortar is thoroughly dry.

The prevention of injury from frost in certain cements may be due, at

least in part, to the internal heat produced when setting. In the interior of a large mass, some cements, especially high grade Portlands, attain a high temperature. (See p. 130.)

Freezing Experiments. An extensive series of experiments upon frozen mortars has been conducted by Mr. Thomas F. Richardson, at the Wachusett Dam in Massachusetts. The results of tests extending up to one year showed that although briquettes mixed 1 part cement to 3 parts sand had less strength at the end of seven days than those which had not been frozen, the frozen specimens after longer periods, especially at the end of one year, gave as high and often higher strength than those which were kept at ordinary temperatures. The conclusion was reached, therefore, that Portland cement mortar is not permanently injured by freezing.

Mr. Richardson's experiments were conducted in the middle of the winter of 1902. He gives the following description* of the tests:

Two bags of Portland cement were thoroughly mixed together and all the briquettes were made from cement from these bags. Masonry work on the Wachusett Dam was in progress during the period, and briquettes were made each week and submitted to the same conditions as the masonry, the molds being filled with mortar and placed out doors in the air, not in water, immediately after filling.

Briquettes were made at the same time as the ones exposed to the weather, and kept in the laboratory, either in the air or in water, those in the air approximating more closely the conditions which obtained on the masonry construction at the dam. About ½ of the briquettes out doors were exposed to temperatures as low as 9° above zero in the first 24 hours, and some of them to temperatures as low as 12° below zero in the first week. Salt was used in most of the experiments, the quantity ranging from 4 to 16 pounds per barrel of cement, the average being about 6 pounds or about 3% by weight of water. Our experiments indicate that 8 pounds of salt per barrel of cement is sufficient, even in the coldest weather, and the results from 4 pounds are very nearly as good; 16 pounds do not seem to give quite as good results.

The following table gives the average results of the experiments:

Effect of Frost upon Tensile Strength of 1:3 Mortar. (See p. 321.)
BY THOMAS F. RICHARDSON.

Briquettes Kept	No. of Briquettes	Tensile Strength, lb. per sq. in.				
		7 d.	28 d.	3 mo.	6 mo.	1 yr.
Water in laboratory	20	268	304	359	370	401
Air in laboratory	20	298	352	364	392	517
Out doors, below freezing	80	139	238	344	435	627

*Kindly furnished by Mr. Richardson for this Treatise.

The briquettes were made in sets of 5, consequently 4 experiments are shown for water and air in laboratory, and 16 for out doors.

In France similar results have been reached by Mr. P. Alexandre* as to the effect of temperatures slightly above freezing.

Mr. Charles S. Gowen† also has concluded from his tests that "there is no indication that freezing reduces the ultimate strength of the mortar, although it delays the action of setting."

The effect of different uniform temperatures upon neat cements and mortars is illustrated in Fig. 111, which is selected and adapted by the authors from a series of experiments by Mr. J. E. Howard‡ at the Watertown Arsenal. The results with both neat cements and mortars show but

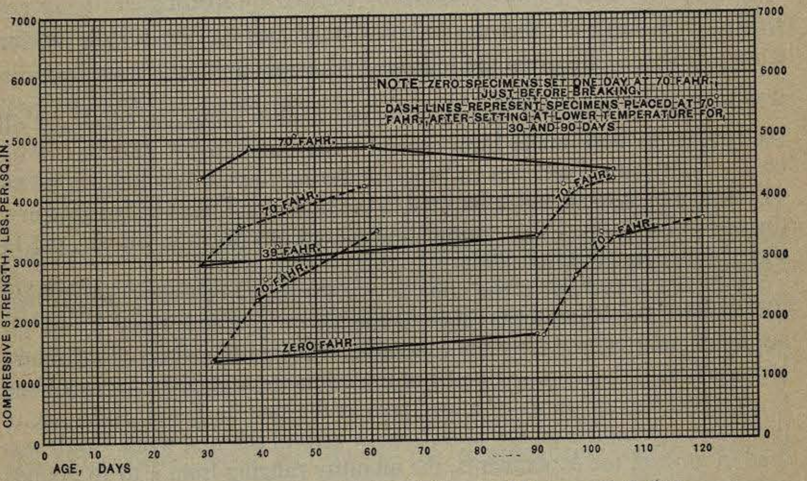

FIG. 111.—Strength of Neat Portland Cement Mortar, 2-inch Cubes, Set in Air at Different Temperatures. (*See p.* 322.)

slight increase in strength while the specimens are maintained at 0° Fahr. (—18° Cent.), but a decided increase in strength as soon as they are subjected to a higher temperature. The zero cubes were removed from the freezer and allowed to set one day at 70° Fahr. (21° Cent.) before breaking.

Cold retards setting. Prof. Tetmajer§ found, for example, that 1:3 Portland cement mortar which attains its initial set at 2¾ hours and its final set at 8½ hours when mixed at 65° Fahr. (18° Cent.), at a temperature of freezing reaches its initial and final set at 21 and 38 hours respectively.

*Annales des Ponts et Chaussées, 1890, II, pp. 302 and 422.

†Proceedings American Society for Testing Materials, 1903, p. 393.

‡Tests of Metals, U. S. A., 1901, p. 530.

§Johnson's Materials of Construction, 1903, p. 616.

METHODS OF CONSTRUCTION IN FREEZING WEATHER

Certain classes of concrete construction, such as foundations or heavy walls, whose face appearance is of no consequence and which will have opportunity to thaw and then thoroughly harden before loading, may be laid in freezing weather with first-class Portland cement, but it is absolutely necessary to thoroughly remove all dirt and frozen "laitance" (see p. 393) before placing fresh concrete. This is a much more difficult matter than would appear, because frozen dirt has the same appearance as set concrete.

In the case of structures which must not be permitted to freeze, work may often be conducted by maintaining the atmosphere artificially above the freezing point. In temperatures only a few degrees below freezing, it is a common practise to heat the materials, the heat tending both to accelerate the setting of the cement and to lengthen the time before the mixture becomes cold enough to freeze. The addition of salt lowers the freezing point of the water, and therefore of the concrete or mortar.

Protection from Frost. The method of maintaining masonry above the freezing point depends upon the character of the structure.

In building construction, the reinforced concrete must be kept from freezing and maintained at a fairly high temperature to permit proper hardening. A common plan is to cover a floor as soon as laid with clean straw, free from manure, to a depth of about 12 inches, and then protect the columns and girders underneath by temporary canvas walls surrounding the entire building, heating the enclosed space with stoves.†

A dam was constructed at Chaudiere Falls, P. Q.* when the temperature was 20° below zero. A house 100 feet long by 24 feet wide was built over a portion of the dam in sections about 10 feet square, bolted together, and heated by sheet-iron stoves about 18 inches in diameter by 24 inches high, burning coke. The concrete was mixed and laid in this house, which, when one portion of the dam was completed, was taken down and erected in another place.

Heating the Materials. Where hand-mixing is employed, an arrangement used on the Newton, Mass., sewers is useful. Sand for one or more batches is placed in a bottomless box containing a coil of steam pipe, the exhaust end of which is then extended to the mixing platform and arranged to discharge through the bottom of the platform into the bottomless box employed for measuring the stone, so that the latter is heated by the exhaust steam. The cement is warmed by piling the bags on top of the sand box.

† Transactions American Society Civil Engineers, Vol. LX, 1908, p. 453.

* *Engineering News*, May 7, 1903, p. 402.

An ordinary sand heater, such as is used for asphalt materials, may also be employed, and the stone heated by steam from a hose. A modification of the sand heater,* arranged to form the combined water, sand, and stone heater illustrated in Fig. 112, has been used on the New York Central Railroad.

Experiments by Mr. Thomas F. Richardson† tend to show that heating the materials of mortar has but little, if any, permanent effect upon its strength.

Addition of Salt. Because of its cheapness salt is most commonly employed to lower the freezing point of water. Other materials, such as

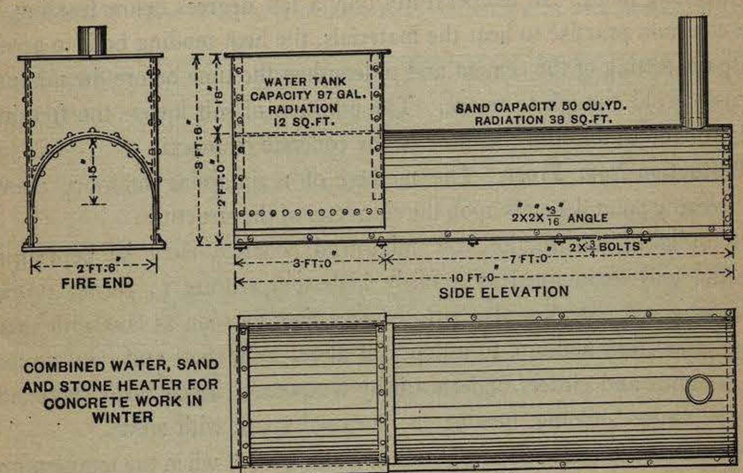

FIG. 112.—Combined Water, Sand, and Stone Heater for Concrete Work in Winter. (*See p.* 324.)

glycerine, alcohol, and sugar, have been experimentally employed, but these appear to have a tendency to lower the strength of the mortar.

Salt has been more extensively employed in mortars than in concretes. Rules have been formulated for varying the percentage of salt with the temperature of the atmosphere. Prof. Tetmajer's‡ rule, for example, reduced to Fahrenheit units, requires 1% by weight of salt to the weight of the water for each degree Fahrenheit below freezing.

A rule frequently cited in print, which practical tests by the authors have proved to be entirely inadequate, is to require one pound of salt to 18 gallons of water for a temperature of 32° Fahr. and an increase of one

*George W. Lee in *Engineering News*, March 19, 1903, p. 246.

†Report Metropolitan Water and Sewerage Board, 1904, p. 110.

‡Johnson's Materials of Construction, 1903, p. 615.

ounce for each degree of lower temperature. For 16° Fahr. this corresponds to but slightly more than 1% of the weight of the water, an amount too small to be effective. Since the temperature of the air usually cannot be determined in advance, an arbitrary quantity is as suitable as a variable one. In the New York Subway work in 1903, 9% of salt to the weight of the water was adopted. On the Wachusett Dam, during the winter of 1902, 4 pounds of salt were used to each barrel of cement. For 1:3 mortar this corresponded to about 2% of the weight of the water.

Experiments show that ordinary "quaking" concrete in proportions 1: 2½: 5 requires about 130 pounds of water per barrel of Portland cement, hence 10% of salt in average concrete is equivalent to 13 pounds per barrel of Portland cement. Ordinary 1: 2½ mortar requires about 120 pounds of water per barrel of Portland cement, hence 10% of salt in average mortar is equivalent to about 12 pounds salt per barrel of Portland cement. Salt is sometimes added in sufficient quantity to "float a potato" or an egg. According to tests of the authors, about 15% of salt to the weight of the water is required to float a potato, and about 11% to float an egg.

Recent experiments, by Mr. Gowen* and Mr. Richardson,† extending up to a period of one year, tend to show that salt in a quantity corresponding to at least 10% of the weight of the water does not lower the ultimate strength of ordinary mortar. The time of setting, however, is considerably increased and the strength at short periods is lowered. The effect, at laboratory temperature, of 10% salt with 1:3 Portland cement mortar is illustrated in the following table:

Tensile Strength of 1:3 Mortars made with Fresh and Salted Water.
BY CHARLES S. GOWEN.

	1 week.	1 mo.	3 mos.	6 mos.	9 mos.	12 mos
Fresh water used.........	112	183	268	335	351	458
Salted water used.........	68	131	215	266	301	413

In Mr. Richardson's experiments‡ smaller percentages of salt proved beneficial. Portland cement mortar in proportions 1: 3, mixed with 4 and 8 pounds of salt per barrel cement (corresponding respectively to about 2% and 4% of the weight of the water), gave slightly higher tensile strength than the unsalted mortar at all periods from 7 days to one year.

Experiments by Mr. E. S. Wheeler§ indicate that the use of 10% of salt tends to prevent the swelling of briquettes in the molds, even if the specimens freeze.

*Proceedings American Society for Testing Materials, 1903, p. 393.

†Report Metropolitan Water and Sewerage Board, 1903, p. 112.

‡See page 321.

§Report Chief of Engineers, U. S. A., 1895, pp. 2963 to 2971.

Practical Proportion of Salt. Since in practice it is impossible to tell how low the temperature will fall before the concrete sets, Mr. Thompson has adopted the arbitrary rule of 2 pounds of salt to each bag of cement to be used when the temperature is expected to fall several degrees below freezing, and if experience shows that this is not quite sufficient to prevent the frost catching the surfaces, 3 pounds of salt per bag of cement are to be used instead.

The salt can be added most conveniently by putting it into the mixing water. To determine the amount of salt per barrel or per tankful of water, the quantity of water used per bag of cement must be noted and from this the amount can be readily figured.

Calcium Chloride. Experiments indicate that calcium chloride added in quantities not exceeding 2% of the weight of the cement is an effective agent for lowering the freezing point of the concrete. It should be used with caution, however, since a larger quantity than this is likely to so hasten the set as to make the concrete difficult to handle.

CHAPTER XVIII

FIRE AND RUST PROTECTION

Observations of steel imbedded in concrete which has been exposed to fire or to corrosive action, and experimental tests prove conclusively that 1½ to 2 inches of dense Portland cement concrete, made in ordinary proportions, with broken stone, gravel, or cinders, of good quality, and mixed wet, will effectually resist the most severe fire liable to occur in buildings, and will prevent the corrosion of steel even under extraordinary conditions. In members of inferior importance or which are only liable to fire of comparatively low temperature, a less thickness of concrete, in many cases ¾-inch or even ½-inch, will prove effective. (See p. 333.)

In buildings concrete has been found a more effective fire-resisting material than terra-cotta (see p. 333) and fully equal to first-class brickwork. Brickwork cannot exist in a structure except in combination with some other material like steel or wood, which is seriously affected by fire, whereas concrete reinforced with steel may replace not only the brickwork, but also the steel or wood columns and beams.

PROTECTION OF STEEL BY CONCRETE

Tests by Prof. Charles L. Norton

Extended practical tests have been conducted by Prof. Charles L. Norton for the Insurance Engineering Station in Boston. As a result of experiments made in 1902 upon several hundred specimens, he concludes:*

(1) Neat Portland cement, even in thin layers, is an effective preventive of rusting.

(2) Concretes, to be effective in preventing rust, must be dense and without voids or cracks. They should be mixed quite wet where applied to the metal.

(3) The corrosion found in cinder concrete is mainly due to the iron oxide, or rust, in the cinders, and not to the sulphur.

(4) Cinder concrete, if free from voids and well rammed when wet, is about as effective as stone concrete in protecting steel.

In his first series of experiments, round rods of mild steel, soft shee steel, and expanded metal were each imbedded in the center of blocks or

*_Engineering News_, October, 1902, p. 334.