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# Cold Weather Masonry Construction

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*J.I. Davison*

## Please note

Masonry construction, once a seasonal operation carried out only during favourable weather between spring and fall, now continues for twelve months of the year. On large projects it is common to see masons working in heated enclosures in shirt-sleeve conditions despite sub-zero temperatures outside. On smaller projects, where the amount of masonry may be insufficient to justify the cost of a proper enclosure, masons often work without protection, using cold weather techniques that include the use of warm mortar and dry masonry units.

Heated enclosures, which have eliminated many of the problems of winter construction ensure full compliance with the cold weather masonry requirements of most building codes, which stipulate that when the mean daily temperature at the job site falls below 40°F mortar, water and masonry units shall be maintained at a temperature not less than 40°F during laying, and that masonry shall be protected from freezing for 48 hours after laying.

Excellent results have also been obtained with cold weather procedures that disregard the temperature requirements cited above but carefully observe the requirements that "no frozen materials nor materials containing ice shall be used" and "uncompleted masonry exposed to the weather shall be covered completely on the top surface with an adequate waterproofing material, except when construction is in progress."

The major problem common to all building trades in winter is the inability of the worker to achieve optimum production in cold temperatures. The heated enclosure technique (**CBD 7**) is the best way to solve many cold weather problems; it is also the best answer to improving worker efficiency in areas where severe weather conditions prevail.

A second problem, caused by the freezing of water, affects a more limited number of trades using "wet" processes such as are found in the masonry, concrete and plaster trades. Failure to understand the nature of this problem can result in serious damage, which may prove substantially more expensive to correct than the original cost of the proper procedures. A discussion of frost action as it applies to masonry laid up in cold weather illustrates the necessity of observing certain precautions and explains the success of procedures not as yet accepted by all building codes.

### Internal Structure of Masonry

Masonry includes all construction made up of masonry units (stone, clay bricks, concrete blocks, etc) and mortar. The units are laid up with plastic mortar, and as the mortar hardens (cures) it binds the mass together into a monolithic structure. When the mortar has properly cured, the masonry usually possesses adequate durability to withstand normal exposure for many years. Any problems of cold weather masonry construction occur between the placing of plastic mortar in the wall and the point at which it acquires sufficient strength to withstand the detrimental effects of freezing.

Plastic mortar contains cementitious materials, aggregate and water. Sand is commonly used as the aggregate, and in hardened mortar the sand particles are bound together by the cementitious materials, just as the units are bound together by the mortar in the masonry wall. Cementitious materials include portland cement or lime, or one of a number of combinations of these materials. Cement cures by hydration in the presence of water (**CBD 116**). The hydration products bond with each other and with the aggregate particles (sand) and finally become hardened mortar with relatively high compressive strength. During the curing process of the cement component, strength increases, and the number and size of the voids decrease, as does the water content as it is consumed by the hydration reaction. This reaction is retarded at lower temperatures and is one of the problems of cold weather masonry; the initial setting period, during which the mortar is vulnerable because of its low strength, is longer in cold weather owing to the slower rate of cement hydration.

Lime cures by a carbonation process involving carbon dioxide from the air. It is much slower than the cement hydration reaction. Complete curing can take many months and the final strength is far less than that achieved by cement. This is illustrated by the range in the minimum strength requirements in CSA Standard A179, Mortar for Unit Masonry, where values increase from 75 psi for the predominantly lime mortar (Type K) to 2500 psi for the predominantly cement mortar (Type M). Lime mortars also have a higher degree of porosity than cement mortars. The carbonation of lime, a very slow process under optimum conditions, is, like the hydration of cement, retarded by winter temperatures.

Water serves a dual purpose in masonry mortars. It is required for the hydration of the cement and it provides the degree of workability necessary for the mortar to flow into all the cracks and crevices of the unit and form the maximum bond. More water is required for the latter purpose than for the hydration reaction. Thus, following placement in a wall, masonry mortars are low in strength and high in water content. This vulnerable period is prolonged in winter by slower curing at lower temperatures.

Natural stone, clay brick and tile, concrete brick and block are all porous, and when they come into contact with mortar they immediately start to extract water by capillary suction. The amount of water removed from the mortar depends on the total porosity of the unit and the size and shape of the pores. A unit with a large number of fine pores may absorb more water than one with a larger capacity of larger pores. The absorption characteristics of the unit will determine the final extent of its bond with the mortar. In warm summer weather the combination of water lost to a high suction unit and that lost by evaporation may be sufficient to reduce mortar workability to a level at which it is not capable of forming a complete bond, leaving unbonded areas that provide open channels for rain penetration to the interior. The same unit may perform satisfactorily in cold weather because it can reduce the water content of a mortar to safe levels in the relatively short period before freezing occurs.

## Nature of Frost Damage to Mortar

The most serious problems associated with cold weather masonry result from the freezing of water. If masonry units are wet and frozen when they are used, it is difficult to obtain a satisfactory bond with the mortar and equally difficult to build a wall that is straight and level because the units tend to slide in the mortar.

The familiar crows-foot pattern on the surface of a mortar joint indicates freezing. The pattern results from the formation of ice crystals and remains after the ice melts. Appearance of the crows-foot pattern does not necessarily mean that deterioration has occurred, however. A mortar joint exhibiting a distinct crow's-foot pattern was recently examined. It is in perfectly sound condition after thirty years service.

Shelling of the mortar surface and general crumbling or powdering of mortar are evidence of advanced deterioration due to freezing. One of the more dramatic failures is the extrusion of frozen "fingers" of mortar, a result of the freezing of weak, slow-setting lime mortars. Masonry walls that have been frozen may also twist or bow under the influence of warm sun in the late winter. This is believed to be caused by thermal expansion and thawing of one side of the wall. In the Scandinavian countries it is normal practice to drape tarpaulins over the wall to prevent differential thawing on sunny days in late winter.

### Other Winter Problems

Not all winter problems result from freezing. Serious corrosion of metal wall ties and reinforcing bars has been traced to the calcium chloride used to accelerate the setting time of mortars during cold weather.

Efflorescence (**CBD 2**) on masonry walls is usually at a peak during the late winter months. The low temperatures normal at this time create conditions that bring all the water in the masonry to the surface before changing it to vapour (evaporation), and salts that may have been present in solution are left behind on the wall. Masonry completed during cold weather is particularly susceptible because water "built in" during construction dries out slowly in the late winter period.

### Mechanism of Frost Damage to Masonry

The primary mechanism responsible for frost damage to mortar is that resulting from the expansion of water when it changes to ice on freezing. This expansion is accompanied by a 9 per cent increase in volume. Thus, if the voids in the mortar are saturated in excess of 91 per cent, they are unable to accommodate the extra volume caused by the formation of ice and pressures exceeding the strength of a fresh mortar can develop. These expansive forces can disrupt the bond between mortar and masonry unit, creating rain penetration problems; or they can disrupt the bond between binder and aggregate, causing a complete breakdown (crumbling) of the mortar.

It has been suggested that ice lensing, the mechanism responsible for heaving of fine grained soils, might cause damage to mortar. This is considered possible but not probable. Fresh mortar that has not hydrated might develop ice lenses if the mortar were saturated and if a temperature gradient were maintained through the mortar. Normal precautions, however, ensure that mortar will not be saturated and in most cases no sustained thermal gradient exists during the masonry construction period. If hydration is well advanced, the nature of the mortar has changed in such a way that ice lensing is not considered a primary cause of deterioration even if moisture and temperature conditions are favourable. Where ice lensing has occurred it appears to be a secondary mechanism of destruction that develops after the mortar has been cracked or crumbled by normal frost action or some other mechanism. There is no record of ice lensing in sound, dense mortar.

Frost damage can occur in masonry units. Those used for exterior masonry will seldom reach a degree of saturation sufficiently high to bring about freezing damage during cold weather construction. If freezing should occur the units will usually possess sufficient strength to resist the expansive forces. Back-up units, however, may have lower strength values and may sometimes be exposed to low temperatures during winter construction. If they should reach a high degree of saturation there is potential danger of frost damage.

### Moisture Content of Mortar

Significant research on cold weather masonry has recently been carried out in Scandinavia. It indicates that freezing is not necessarily detrimental to mortar and that the most important factor is the moisture (water) content at the time of freezing. It has been found that if bricks with a sufficiently high suction rate are used the moisture content will be lowered to a point where the pore system of the unit can accommodate the expanded volume of ice. When the ice thaws the hydration process resumes and the end result equals and sometimes surpasses the quality of mortars cured normally. This is supported by many examples of superior compressive strength values for mortars that were frozen, then thawed, and allowed a normal curing period.

These findings explain the role of warm mortar and dry units in the cold weather masonry technique. Warm mortar ensures a sufficient delay before the temperature drops to the freezing point to permit brick suction to extract sufficient water from the mortar. The bricks must be dry because the maximum effect of their suction is required to reduce the moisture content to a satisfactory level in the short time available.

## Mortar vs Concrete

Scandinavian research also points to a major difference between mortar and concrete. When a mortar is placed in masonry it immediately loses water through the suction of the units. Concrete, on the other hand, is placed in non-absorbent metal or oil-soaked wooden forms so that its water content remains high for curing purposes. Thus concrete, with a higher degree of saturation, is more vulnerable to damage if freezing occurs at an early age. This is significant because many cold weather masonry regulations, which have changed very little through the years, were originally based (in the absence of data on mortar) on studies carried out between 1923 and 1935 on the effect of low temperature on concrete.

## Effect of Change in Mortar Design

Certain beneficial changes in the design of mortars for cold weather work become obvious from previous discussion establishing the superior strength of cement over lime mortars and the importance of early strength during cold weather. The function of lime in masonry mortars is to improve water retentivity and workability. This is most important in warm summer weather when mortars, under the influence of faster drying by evaporation and an above-average rate of hydration, tend to lose some of the workability so essential for complete bond. As colder weather approaches it is advisable to replace some of the lime with cement in the interest of obtaining higher early strength to resist the forces that can develop if freezing occurs. The reduction in workability is minimized by slower drying and a reduced hydration rate at the lower temperatures. Thus masons who may use a Type O mortar (1 part cement to 2 parts lime) in the summer will switch to a Type N mortar (1 part cement to 1 part lime) in the winter. Recommended mortar designs for summer and winter work can be compared in Appendix B of CSA Standard A179, Mortar for Unit Masonry.

## Effect of Admixtures

The use of admixtures as set accelerators (calcium chloride) and for lowering the freezing temperature (propyl alcohol) should not be encouraged despite the fact that these materials have some merit if used judiciously within certain limits. Their misuse can produce undesirable side effects (e.g. calcium chloride contributes to the corrosion of metal wall ties and reinforcing bars). The excellent results that may be obtained with correct use of the basic mortar materials make additives superfluous.

Air entraining agents, an integral component of packaged masonry cements often used in cold weather masonry construction, should be mentioned although they are not strictly in the same category as the above materials, which are normally added at the mixer. The beneficial effect of entrained air on the durability of hardened concrete (**CBD 116**) is well established, and the possibility of increased protection in mortars against damage from freezing at an early age is frequently mentioned. It must be pointed out, however, that at present there is no experimental evidence to support this view.

## Recommended Practice

Field observations of excellent masonry laid up without protection from low temperatures plus explanations emerging from research studies are bringing about a reappraisal of regulations in many countries. In Scandinavia, where masonry construction without protection has been permitted to minimum temperatures of 14 to 21°F for many years, there are suggestions of further relaxations. It has been established that masonry can be laid up satisfactorily at temperatures lower than those at which the masons can work without protection. The new recommendations of the Structural Clay Products Institute in the United States outline procedures for masonry construction without protection down to 20°F. They recommend the use of Types M, S, and N cement-lime mortars containing high early strength cement. When the mean daily temperature is between 20 and 25°F, auxiliary heat (salamanders) is recommended, and windbreaks should be used if the wind exceeds 15 mph. Heated enclosures are recommended when the temperature drops below 20°F. Similar recommendations are included in the new CSA Masonry Code of Practice.

Quality masonry will only be obtained if recommendations are carefully followed. Masonry units and mortar materials stored on-site must be well covered to keep them dry; thawing a frozen sandpile at the start of the day's work is time-consuming and results in lost production. Bagged cementitious material also must be well covered and stored on a raised platform to keep it from wicking up ground moisture that could start a hydration reaction with the cement. In preparing warm mortar, the logical material to heat is the water because of its high specific heat and because it is relatively easy to do. The water should be heated to the 150 to 180°F range. In mild temperatures this will be sufficient to warm the mortar, but when the temperature falls below 32°F the sand should be heated also. A temperature of 70°F is considered satisfactory. The temperature of warm mortar should be between 70 and 120°F there is danger of flash setting above this temperature. It is most essential to protect partially completed masonry against the weather at the end of the day's work.

## Concluding Statement

Provision of a heated enclosure continues to be the best method of avoiding the problems encountered during cold weather masonry construction. Quality work can, however, be obtained by masons working without protection provided certain precautions are taken. The successful use of these procedures has been corroborated by recent research and will ultimately be reflected in relaxed regulations. This will enable cold weather masonry to continue on small projects where the cost of heated enclosures cannot be justified.