CHAPTER 6
CONSTRUCTION CONSIDERATIONS

6-1. Effect of construction procedures on design.

a. Design decisions must be approached not as isolated technical questions but as a system of interrelated elements under broad design, construction, operational and maintenance facility requirements.

b. The tentative construction schedule and procedures should be kept in mind during all phases of the design procedure and should provide input influencing design decisions. The facility location and its environment, the relative urgency of the project and of desired completion data to meet user needs and the type and scope of the effort will indicate the type and amount of construction to be accomplished under adverse seasonal conditions. The progress and efficiency of the work during such periods will depend on how well the designer has anticipated and adapted the design to the conditions.

c. Site accessibility and working conditions may affect choice of type of foundations. Access to remote sites by sea or river may be possible only during a short period in the summer. In permafrost areas overland access may be possible only in winter after the annual thaw zone has solidly refrozen. Aircraft landing facilities may severely restrict the size and type of aircraft which can land at the site. This may limit the sizes and types of construction equipment which can be brought in by air. For small to moderate size construction jobs, the cost of improving the aircraft landing facilities may be prohibitive. Landings on ice cannot be made during the ice break-up and early freeze-up periods. Heavy aircraft cannot land on floating ice until middle or even late winter. Tractor train operations on ice are similarly limited. Access roads and granular working mats may be easy to place in winter when the terrain is frozen but much more difficult to construct in summer. On the other hand, if the facility construction is small and can be completed in winter, roads and working mats may not be needed at all except for facility operational purposes. Under proper scheduling, pile installation equipment can work on compacted snow or frozen ground in late winter or early spring at maximum efficiency, without the use of granular work mats. As described in paragraph 4-8d, this same period of maximum cooling of the ground in depth (February through May) is the most effective time for installation of slurried piles intended to freeze back naturally. However, if it is not possible to install the piles in the critical months and it is a marginal permafrost area, it will be necessary to use artificial refrigeration to assist freezeback or to choose another type of foundation, and this must be reflected in the plans, specifications and cost estimates. .As has been described by Dickens and Gray[138], it is possible to construct footing type foundations in the summer months with satisfactory results; however, such type construction may involve quite different labor, materials, and equipment requirements with different transportation, housing, maintenance and supply problems than would apply in winter.

d. Through proper design and construction, a foundation may be installed in permafrost with minimum disturbance to the thermal regime and with rapid healing of thermal damage caused by construction. However, the construction procedure adopted will be a major factor in determining the amount of environmental damage and therefore the damage-corrective provisions in the plans and specifications, as well as costs.

6-2. Excavation.

a. In permafrost areas, excavation should be avoided as much as possible in the foundation design because of the increased disturbance of the thermal regime and the increased effort required when frozen ground must be handled. During the summer, excavations in finegrained permafrost for placement of footings may experience very rapid thaw and softening on exposure and it is almost impossible to install footings and to complete backfill under these conditions without experiencing at least some short-term settlement of the base of the footing, even though gravel fill or insulation is placed quickly at the bottom of the excavation to minimize this effect. Therefore, such excavations are much more easily accomplished when air temperatures are below freezing, preferably in the early fall when the annual frost zone is completely thawed and most easily excavated through. At subarctic locations, excavation of soil above the permafrost table may not be a major problem during the early part of the freezing season, especially if ground-freezing is minimized by an insulating cover of snow, moss, or other material. As the winter progresses and depth of freezing increases, excavation becomes more difficult, unless the excavated materials are very coarse and well-drained. Winter construction involving excavation is handicapped by frozen ground conditions, the difficulties of operation of equipment and handling of frozen materials at very low temperatures, reduction of daylight hours and work season, and lowered worker efficiency at low temperatures.

b. Special equipment such as heavy rippers, systematic drilling and blasting or possibly pre-thawing of the frozen layer may be required to accomplish the work. Where excavation is in permafrost, this situation applies year-round. Frozen soils may have strength properties equivalent to those of lean concrete at only moderately low temperatures; at very low temperatures the compressive strength may exceed 3,000 psi. Excavation of frozen soils at low temperatures may be comparable to excavating concrete of low to moderate strength. Frozen rock is stronger than when unfrozen. By comparison ice may be comparatively easy to excavate. A special problem is introduced by the tendency of frozen excavated materials of appreciable moisture content to adhere to equipment surfaces at below-freezing temperatures or to exhibit fluid or semi-fluid properties when thawed. A number of research studies have been performed on methods of penetrating, disengaging and handling frozen materials[56,57,81,96,97]. Near-surface frozen materials may be easier to excavate or penetrate in the summer months. However, excavation in winter is in some aspects easier than in summer, because drainage and dewatering problems are reduced or eliminated. If shaped up prior to the first freeze, haul roads become as smooth and strong as pavement when frozen, requiring little maintenance except snow plowing.

c. Excavation at the face of the pit with a dipper shovel is less affected by winter weather than excavation by scrapers, although when the seasonal frost layer reaches a thickness of perhaps 1 1/2 to 2 feet the soil may form slabs large enough to break a shovel boom unless the operator is careful. Various types of trench cutting equipment, as well as drop and pneumatic hammers, may be used for cutting through or breaking up frozen soil in small areas. A snow cover over the area to be excavated limits the depth of frost penetration, especially if the ground is covered early enough in the season and the snow is undisturbed. In the lower latitudes of the cold regions, black polyethylene sheeting placed over limited areas has been found effective in limiting freezing or promoting thawing by its absorption of solar radiation. Each day the surface cover should be removed only in the areas which are to be worked in that day. In addition, for local areas the ground may be covered with hot sand and tarpaulins or treated with salt and covered with hay and tarpaulins 3 or 4 days before excavation. Salt in the soil moisture lowers its freezing point. Fires may also be built over the areas to be thawed. This method is slow and inefficient but has been used to thaw up to 2 or 3 feet of frozen ground.

d. In the early winter, borrow areas, once opened, must be worked continuously from day to day or the frozen material will build up in thickness and be difficult to remove as well as present the problem of frozen inclusions in the fill. As the winter progresses and depth of freezing increases, excavating becomes more difficult and may require special equipment or possibly pre thawing of the frozen layer to accomplish the work.

e. Handling of frozen soil from excavations is often a problem because of the tendency of frozen lumps to freeze to each other or to the handling equipment when temperatures are between about 15° and 32 F, or to thaw into mud in above-freezing temperatures.

f. Excavation of borrow areas in frozen soil in the spring and summer can also be accomplished by removal of thawed material periodically to promote thawing of underlying layers. On the other hand, if such incremental thaw depths of wet, soft materials are allowed to become deep enough to interfere with movement of construction equipment, construction may be seriously delayed or halted.

g. Frozen ground, including frozen soil and highly fissured frozen bedrock, often can be broken more economically and faster with a heavy bulldozer equipped with a sturdy ripper than with the use of explosives if a large area has to be excavated and the ground temperature is marginal (30 ° to 32 °F). Operation over a large area allows maximum assistance to be gained from daily thaw increments in summer.

h. Deep formations of frozen material can be thawed to assist excavation. Cold water pumped into jets, placed in a grid fashion at 12 to 16-feet spacing, has been used successfully in thawing operations and is the most economical technique. Hot water and steam jets may also be used in a similar manner. Small electrically heated probes have local value. When excavation of permafrost is required, the surface should be stripped early in the summer to expose the frozen material. Stripping of vegetative cover and removal of the annual thaw zone material in late summer or early fall will permit excavation to start at the permafrost table at the start of the following thaw season rather than at the top of the then frozen annual thaw zone, but removal of the overlying cover will have caused more intensive cooling of the permafrost during the winter, tending to slow the daily rate of excavation. In areas where the annual thaw zone is 12 to 18 inches under moss surface cover, 3 to 5 inches of thawed materials may be removed each day during the warm months and 25 feet may be excavated in a 100-day summer operation[114]. At bases where long-range construction plans are known, it may be desirable, under certain conditions, to clear, strip, and provide drainage of future construction sites where permafrost excavation will be required as far in advance of construction as possible to minimize possible future subsidence and to make excavation easier. However, pre-thawing of finegrained soils to appreciable depth is likely to be impractical; for example, it may produce too soft or liquid a condition for the available construction equipment to operate effectively. Any introduction of heat into permafrost must be very carefully controlled and is generally inadvisable at a structure site.

i. Rock excavation presents no more difficult a problem at air temperatures between 32° and 0°F than at temperatures above freezing, except that rock containing appreciable moisture is likely to be difficult to transport and handle between 15 ° and 32°F because of its tendency to freeze to surfaces. Blasting and mucking operations should be coordinated because the blasted rock, providing many channels for moisture penetration such as from snow or rain, can freeze into a mass which must be reblasted. As noted above, large rippers may be effective in some rock. Rock, if in large pieces or without moisture, seldom freezes to truck bodies; however, this can be a major problem with moist soil or rock containing fines, especially if hauled a considerable distance. To control this, many contractors in Canada have equipped their dump truck bodies with muffler extension pipes to heat the bodies with otherwise lost engine heat.

6-3. Embankment and backfill.

a. All personnel responsible for design and construction of projects to be constructed in cold climates should be aware of the extent to which construction of embankments, fills, and backfill may at the same time be both possible and limited. On the one hand, placement of embankments may be accomplished most readily in winter when the ground is frozen, if the natural surface is impassable in the summer, provided suitable fill materials are used. On the other hand, construction of load-bearing fill which will be used to support an overlying facility may be difficult to accomplish successfully in the winter season because of the problems of freezing of moist material before it can be compacted or of excluding lumps of frozen materials which may result in later thaw-settlement. It is impossible to compact most soils to specified densities with available equipment and techniques when the soil temperature drops below about 30°F, that is, after the soil has frozen. However, successful embankment, fill, or backfill placement under winter conditions, at very low ambient temperatures, has been accomplished by stockpiling very clean, gravelly materials in the summer months in such a way as to promote drainage to very low water contents; such material can be handled and placed with effectiveness acceptable for many purposes under the coldest temperatures. It is possible that dry, clean gravels may also sometimes be found naturally at very low moisture contents in the borrow pit. Dry, crushed or broken rock may be placed even more effectively under all temperatures. In one especially urgent situation a compacted fill foundation for a large structure was built in mid-winter by the expedient use of a very large inflated shelter into which frozen borrow was trucked, spread in shallow layers, each of which was TM 5-852-4/AFM 88-19, Chap. 4 allowed to thaw, then compacted by conventional procedures before spreading of the next layer of frozen material. The Corps of Engineers Alaska District reports that be using procedures designed to insure the most favorable results, moist thawed silts have been borrowed and placed at 95 percent of modified AASHTO density during 0° to 30°F weather using heavy vibratory compactors. They suggest that vibratory grid roller or vibratory sheepsfoot compaction should be most effective. Similar experiences have been reported in New England with sheepsfoot roller compaction using rapid processing to achieve compaction before significant freezing. Others have concluded that the minimum practical and economical temperature for placing common backfill is about 20 °F and for placing granular materials, 15°F[113]. Success is any of the recorded cases of successful below-freezing embankment placement has depended on one or more of the following alternatives: rapid and continuous placement so as to achieve compaction before freezing, use of CaCI,, added in advance, to lower the freezing temperature, or use of dry, cohesionless, non-frost susceptible materials.

b. During freezing weather, earth handling and placement of ordinary soils should be continuous to avoid formation of thick layers of frozen material which will not thaw quickly if incorporated into the embankment. The foundation or surface of the fill should be checked for frozen material before proceeding with the next lift. All frozen material should be removed. It should not be disced in place. If poor-drainage material is used, the temperature of the material should be above freezing and it should be placed and compacted at the proper moisture content. The fill should than either be protected from freezing or all frozen material removed before additional backfill is placed. Under no circumstances should frozen material, from stockpile or borrow, be placed in fill or backfill which is to be compacted to a specified density. Extreme precautions should be taken regarding the possible entrance of excess water from wastewater, curing water, or during thaws into areas of compacted fill. The use of additives, such as calcium chloride, will lower the freezing temperature of soil, but they will ordinarily also change the compaction and moisture requirements'. Experience with salt has been mixed. Therefore, additives should not be used unless a prior laboratory study of compaction and additive percentage requirements is made. If used, additives must be incorporated before freezing.

c. Although construction schedules may necessitate the placement of permanent fill or backfill during or immediately preceding periods of freezing weather, every effort should be made, whenever construction schedules permit, to schedule placement of backfill in periods of favorable weather conditions.

d. In permafrost areas, deep fills constructed with thawed materials may require up to many years to freeze to the ultimate thermally stable condition, if placed by single-step construction. When this slow, long-term freezing is likely to result in undesirable frost heaving, consideration should be given to placement of fill in annual increments, each of which will freeze completely during the winter following its placement. The result will be a more immediately stable foundation, upon completion. An example of this procedure was the two stage construction of a runway extension embankment at Sondrestrom Air Base, Greenland[103]. Inorganic soils are very often covered with living "tundra mat," a mantle of moss and peat. In permafrost areas this material should usually be left in place during the placement of fill, thus preserving to a limited extent its value as an insulating layer. The natural cover around a construction site should be protected from disturbance by construction equipment, to minimize subsequent degradation. Cutting of the tundra mat by heavy tracked vehicles is a common source of local thawing and subsequent ponding of water, erosion and degradation of permafrost.

e. The design should take into account the possible frost heave of backfill and the effect of such heave on footings, structural elements, utility connections and walls. Backfill adjacent to walls should be non-frost susceptible in situations where frost heave or frost thrust damage might otherwise occur.

f. Determination of construction material availability is an essential element in the design effort. If special materials such as non-frost-susceptible backfill are only accessible at specific times of the year, this may be a critical factor in design decisions.

6-4. Placing concrete under freezing air or ground temperature.

a. General. Under freezing conditions, concrete placement should conform to standard procedures, but additional special precautions should be employed as needed to assure good results[22,115,203].

(1) As a general rule, concrete should not be placed in direct contact with ground or rock at temperatures below 33 °F. If the concrete section is thin and the temperature of the ground well below freezing, the concrete may freeze or at least may not set and harden properly. If the concrete section is massive, its heat of hydration will generate ample heat for strength gain and prevention of freezing but this heat may at the same time thaw the ground for some depth and this may result in settlement and formation of voids even while work is in progress, if ground ice is present. The concrete may be fractured, foundation bearing capacity may be reduced, and it may become impossible to maintain foundation grade lines. Thaw water may pipe up through the fresh concrete before set if a pressure head can develop, destroying its water-tightness. If the section is heavy enough so that only a thin layer of poor mortar is produced on the face of the concrete by the low temperatures, it may sometimes be acceptable to place concrete directly against frozen soil, provided the soil supporting the foundation is not susceptible to settlement on thaw. When underlying soils contain sufficient ice so that settlement will occur on thaw, special pads of wood, gravel and/or rigid insulating material or their combinations, of adequate bearing strength, should be used between the frozen ground and the concrete course to protect the frozen ground from thawing and to aid in retention of heat by the concrete. Wherever concrete must rest on or adjacent to frozen soil, strong consideration should be given to the use of precast sections to avoid the problems of protection, to insure quality construction and to minimize work schedule problems. On important work, refrigeration pipes placed within a granular course have been employed to maintain the 32 °F point on the temperature gradient at the proper position between the underlying permafrost and overlying newly cast concrete. Electrical heating cable may also be used where supply of heat is necessary. Artificial refrigeration placed within the concrete has much more limited utility, as such refrigeration cannot be turned on until the concrete has gained minimum required strength and in this time excessive thaw settlement of underlying materials may occur if ground ice is present.

(2) Plans to protect fresh concrete from freezing and to maintain temperature at not less than the specified permissible minimum should be made well in advance of expected freezing temperatures. All necessary equipment and materials should be ready for use at the site of the work before concrete placing is permitted. It is too late to start assembling protective devices and materials after concrete placing has commenced and the temperature begins to approach the freezing point. The complications which these measures introduce can be greatly reduced by maximum employment of prefabricated components and members.

(3) "Concrete which is not allowed to freeze and which is placed at low temperatures above freezing, and receives long-time natural curing, develops higher ultimate strength, greater durability, and less thermal cracking than similar concrete placed at higher temperatures. A high concrete temperature as placed will impair these good properties, although it may expedite small jobs and finishing in cold weather."[115] Concrete mixed and placed at a high temperature also requires excessive mixing, requires a higher water content to maintain a specified consistency, and usually results in quick setting. Rapid moisture loss from hot concrete surfaces or high temperature differentials at the surface may cause shrinkage cracking. Heating the

materials to inordinately high temperatures before mixing or over-zealous use of hot air blowers to protect against freezing are, therefore, not proper solutions to cold weather concreting. Rather the materials should be heated to maintain a concrete placing temperature not less than shown in table 6-1, but not over 70°F after placing. The air, water, and forms in contact with the concrete surfaces should be maintained at not less than 50 °F throughout the curing period specified for the type of cement used in the concrete. Accurate periodic concrete temperature readings should be taken during setting and curing to obtain a quantitative measure of the actual degree of protection afforded. Ice or snow on reinforcing steel and within forms must be removed before placing concrete. Hot air heaters of various types or live steam may be employed to warm reinforcement, forms or ground just before concrete is placed.

b. Air entraining agents. An approved air entraining agent should be used to produce a proper number, size and spacing of air bubbles in concrete which will be exposed to weathering. Concrete must have a satisfactory entrained air-void system in order to resist freezing and thawing if the concrete is in an environment where critical saturation with water may exist at the time freezing may occur. If the environment is quite severe, the concrete should be protected from freezing until it has matured sufficiently to have developed a compressive strength such as would be indicated by test of 6-inch by 12-inch cylinders of 4000 to 4500 psi. If the air-entraining agent is either an approved air-entraining addition to the cement or an air-entraining admixture incorporated into the concrete mixture at the time of batching, it may be assumed with normal concrete mixtures that the air-void system will be adequate, provided the

Table 6-1. Effect of Temperature of Materials on Temperature of Various Freshly Mixed Concrete[203]

Subject to controlling criterion that the thickness of section shall not be less than 5 times the maximum size of rock.

[Temperatures in degrees F]

		Thin sections								Mass concrete							
Approximate maximum size of rock		¾ inch				1½ inches				3 inches				6 inches.			
Approximate percent of sand		40 percent				35 percent				30 percent				25 percent.			
Weight of sand for batch		1,200 pounds				1,100 pounds				1,000 pounds				900 pounds.			
Weight of rock for batch		1,800 pounds				2,100 pounds				2,400 pounds				2,700 pounds.			
Weight of water for batch		300 pounds				250 pounds				200 pounds				150 pounds.			
Weight of cement for batch		600 pounds				500 pounds				400 pounds				300 pounds.			
Minimum temperature of fresh concrete AFTER PLACING and for first 72 hours		55				50				45				40			
Minimum temperature of fresh concrete AS MIXED, for weather.[2]	Above 30° F	60				55				50				45			
	0 to 30° F	65				60				55				50			
	Below 0° F	70				65				60				55			
Minimum temperature of materials to produce indicated temperature of freshly mixed concrete.	Cement[3]	35	10	10	−10	35	10	10	−10	35	10	10	−10	35	10	10	−10
	Added water	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140
	Aggregate water[4]	38	95	50	61	35	100	46	55	33	105	43	52	33	113	40	48
	Sand	38	95	50	61	35	100	46	55	33	105	43	52	33	113	40	48
	Rock	38	[1] 10	50	61	35	[1] 10	46	55	33	[1] 10	43	52	33	[1] 10	40	48
Temperature of freshly mixed concrete		60	65	65	70	55	60	60	65	50	55	55	60	46	50	50	55
Maximum allowable GRADUAL drop in temperature in 24 hours at end of protection, degrees F		50				40				30				20			

[1] Rock at temperatures below freezing is assumed to be surface dry and free of ice.
[2] For colder weather a greater margin is provided between temperature of concrete as mixed and the required minimum temperature of fresh concrete in place.
[3] Cement temperature has been considered the same as that of average air and of unheated materials.
[4] The amount of free water in the aggregate has been assumed equal to one-fourth of the mix water.

(Courtesy of Bureau of Reclamation, U.S. Dept of Interior) air content of the freshly mixed concrete meets the requirements of the applicable specifications. Specifications are generally based on the concept of having an air content in the mortar fraction of approximately 9 percent; hence, the total air content of the concrete that should be obtained diminishes as the proportion of mortar diminishes, which it will do as the quantity of aggregate increases as the maximum size of aggregate increases.

c. High early strength cement. The alternative use of high early strength cement, Type III, is generally permitted by the specifications. As the name implies, high early strength cement increases the rate at which concrete gains strength, thereby reducing the length of time that the concrete surfaces must be protected. Therefore, its use is beneficial, either alone or as a supplement to heated materials during cold weather. The same end result can usually be obtained by increasing the cement factor for Type I and II cement by about 30 percent. However, shrinkage characteristics may not permit this addition.

d. Accelerators. The permissible substitution of high early strength cement, Type III (except when Type V is specified), will produce the desired acceleration of the rate at which the concrete gains strength more positively than a chemical accelerator. "Calcium chloride, other salts or other chemicals in the mix in permissible amounts will not lower the freezing point of concrete to any significant degree. To avoid use of harmful materials, any such attempt to protect concrete from freezing should not be permitted."" However, calcium chloride may sometimes be needed as an accelerating agent, and when its use is approved, not more than 2 percent of calcium chloride, by weight of the cement, should be allowed. The calcium chloride should be measured accurately and added to the batch in solution in a portion of the mixing water with an acceptable commercially manufactured automatic dispenser[22]. The following precautions must be observed in use of calcium chloride:

1. It must not be used where sulphate resistance cement (Type V) is specified. Type III cement with a limitation of 5 percent tricalcium aluminate may be used where sulphate resistance is needed.
2. It must not be added directly to the mixing water in the dry state; it should be added in solution only.
3. It must not be used in prestressed concrete.
4. It must not be used where zinc or aluminum is present or when subject to sulphate conditions contained in the aggregate or present in the environment.

e. Heating the materials.

(1) It is not difficult to maintain the temperature of freshly mixed concrete within a ten degree range above the minimum temperature specified and desired. Although it is difficult to heat aggregates uniformly or to a predetermined temperature, the temperature of the mixing water can be adjusted readily by blending hot water or steam with cold water to maintain the temperature of the freshly mixed concrete within the desired 10 °F range.

(2) Making the basic assumption that the specific heat of both the cement and aggregate can be accurately enough represented by the factor 0.22 (0.2 may be used for rapid field computation) and knowing that the specific heat of water is I, reasonably accurate estimates of temperature of freshly mixed concrete can be made from the following equation:20

$$T = \frac{0.22\,(T_aW_a + T_cW_c + T_mW_m)}{0.22\,(W_a + W_c) + W_f + W_m} \qquad \text{(Equation 16)}$$

T = Temperature of concrete, °F.
Tc = Temperature of cement, °F.
Tm = Temperature of mixing water, °F.
T_f = Temperature of free moisture in aggregates, °F.
T_a = Temperature of aggregate, °F.
W_c = Weight of cement, lbs.
W_m = Weight of mixing water, lbs.
W_f = Weight of free moisture in aggregates, lbs.
W_a = Weight of aggregates, lbs.

(The temperature of all water including the moisture in the aggregates must be above 32°F, as ice absorbs 144 Btu's of heat per pound in melting and has a specific heat of only 0.5.) The above equation does not take into account any heat loss to the air during mixing, transporting, and placing or any heat gain in hydration of the cement. Based on temperatures computed from this equation (using 0.2 for specific heat of cement and aggregate), table 6-1 from the Bureau of Reclamation Concrete Manual[203] shows the effect of temperature of materials on temperature of various freshly mixed concretes.

(3) Cement as taken from usual storage is rarely under 32°F. Heating cement should not be used as a method of raising the concrete temperature. Cement containing frozen lumps should not be used since the chunks indicate the presence of moisture.

(4) Heating the mixing water is generally considered the most practical and efficient means for obtaining the desired placing temperature of concrete dur-

ing cold weather. Water is not only easy to heat, but each pound of water has roughly 4 1/2 times as many heat units per degree Fahrenheit as are stored in a pound of aggregate or cement. Mixing water is usually heated in auxiliary tanks connected to the water measuring tank. Heating can be accomplished most rapidly by injecting live steam into the water; however, electric and oil or gas burning heaters are acceptable. The mixing water should be heated under such control and in such quantity and the storage tanks and lines should be insulated to the degree that no appreciable fluctuation of the temperature can occur.

(5) Cement coming in contact with hot water or hot aggregate may experience flash set. To avoid the possibility of flash set when either aggregate or water is heated to a temperature in excess of 100°F, water and aggregate should come together first in the mixer in such a way that the high temperature of one or the other is reduced before cement is admitted. If the mixer is loaded in this sequence, water temperature up to the boiling point may be used, provided aggregate is cold enough to reduce temperature of the mixture of water and aggregate to appreciably less than 100°F; in fact, this temperature should rarely exceed 60° to 80°F[115].

(6) When air temperature is below freezing often one or more of the aggregates, as well as the water, must be heated to produce the desired minimum temperature of the freshly mixed concrete. The heating of all the aggregates is the more desirable method since it insures that no ice, snow or frozen chunks are present. However, if the coarse aggregate is dry and free of ice, snow, or frozen chunks, the heating of only the sand and water may be sufficient to produce the desired temperature.

(7) Heating aggregates can be accomplished most satisfactorily by the use of steam in a closed system of coils in the aggregate storage bins. A closed system of steam coils tends to dry the aggregates and bring about a uniform moisture content. Open steam jets should be avoided if possible because of the resulting fluctuation in moisture content of the materials so heated. If, however, emergency conditions require the thawing of fairly large quantities of aggregates at extremely low temperatures, or if railroad car or truck loads of aggregates must be thawed before unloading, then steam jets may be the only practical method. In such instances, thawing should be accomplished as far in advance of batching as possible, the car or truck loads unloaded and stockpiled, and thereafter the steam should be cut to the minimum that will prevent freezing and the stockpiles covered with tarpaulins to help maintain a uniform temperature, promote a more uniform moisture content, and prevent the formation of a frozen crust on the surface of the stockpiles. Variations in the moisture content and temperature of the aggregates after thawing with steam jets will require control of the total mixing water on an individual batch adjustment basis which is difficult to obtain. Heated air in pipes, or hot water in a closed system of coils, have also been used to keep aggregates ice-free.

(8) Whatever method is used, the average temperature of an individual batch of aggregates should not exceed 150 °F[115] and no aggregate should be heated above 212°F[115] as such a temperature may cause incipient cracking of the aggregate".

f. Mixing, transporting and placing. The mixing, transportation, and placement of concrete should be accomplished with the minimum possible temperature loss[179]. The batching plant, or the batching and mixing plant, if the concrete is centrally mixed, should be made heatable, if possible, or at least must be protected from the wind. The transporting and mixing, if not centrally mixed, and the placing must be done as quickly as possible so as not to allow the concrete to cool below the desired placing temperature. The heat losses during mixing, transporting, and placing are difficult to determine with any degree of accuracy; however, authoritative sources indicate hourly temperature losses as high as 15 percent of the difference between concrete and surrounding air temperature during this period. Consideration should be given to large transport volumes and insulated and covered transport vehicles to keep this temperature loss to a minimum. Protection from the wind during placement will also materially reduce the heat loss through convection.

g. Protection of concrete in the curing period. Protection required for concrete during the curing period will range from none in on-surface construction in summer to use of insulated forms, heated covers or complete heated enclosures, depending on the severity of environmental conditions and the nature of the item involved. Problems such as work protection and heating of materials can often be minimized through proper schedule planning. Since most of the heat of hydration of cement is developed in the first few days after mixing, protection is intended primarily to conserve the heat being developed and quick application of protection for the freshly placed concrete is therefore of primary importance.

(1) *Insulation.* Forms preferably should be well insulated before concrete is placed. Unformed surfaces, and uninsulated formed surfaces, should either be covered with adequate insulating blankets or covered by vented shelters heated to maintain the desired temperatures. The thickness of the insulating blanket to be used against the forms or against the surface of the concrete must be adequate to maintain the desired temperature of the concrete under the extremes of low temperature and concurrent wind conditions to be expected during the curing period. Efforts to protect in-

adequately insulated concrete surfaces after the onset of extreme low temperatures are seldom successful due to the press of other work during such critical periods. It should be remembered that, to be effective, the insulating material must be kept in close contact with the concrete or formed surface and air should not be permitted to circulate between it and the concrete. Particular attention should be given to assure that edges and corners are provided with extra protection. Protection of the insulating material with heavy moisture proof canvas or plastic sheeting from wind, rain, snow, or other wetting is essential. The insulation should have a conductance of not more than 0.25 Btu/hr-ft^2-°F and should be maintained in such a condition that this value is not exceeded during the period of protection. As a general rule, concrete includes in forms and/or adequate protective insulation[202] will not lose enough moisture to require additional curing water. Table 6-2 from the Bureau of Reclamation Concrete Manual[203] is a useful guide to insulated forms using bat or blanket insulation. Polystyrene or polyurethane foam equivalents require less thickness than bat or blanket insulation and are more suitable for re-use. On larger projects special commercial insulated forms of plywood and foamed plastic board may be considered. Various substitute materials as well as foamed-in-place techniques may be used. Insulation can usually suffice without supplementary heat down to an ambient air temperature of, say, 25°F; this value, and also rule-of-thumb temperature estimates, involve considerable uncertainty because convection losses depend strongly on wind speed and because such variables as type of cement and the thickness of concrete section are also involved.

(2) Heating of forms. Below about 25 °F ambient temperature, heat is advisable, together with the insulation. Forms may be heated by steam jacketing or electrically. A recent product for efficient electrical heating consists of panels of woven glass, coated with graphite and impregnated with epoxy resin. The panels are readily incorporated into the insulation of the formwork or may be sandwiched with plastic protection.

(3) Heated enclosures. A number of types of heated enclosures may be used to protect concrete from loss of heat. Live steam is considered the best heating agent since it also insures that the exposed concrete surfaces are not subjected to moisture evaporation[132]. The enclosures must be reasonably tight and securely braced against wind and snow loading with particular care given to tightness of openings in the enclosure. The use of hot air blowers is the second best method of heating the air in an enclosure. Rapid drying of the concrete surface will result from hot air, however, and the curing surfaces must be kept damp. The use of open fires and salamanders, while still in somewhat general use, should be avoided wherever possible due to possible damage to concrete from direct exposure to heat and from strong $C0_2$ atmosphere[157]. The harmful effects of $C0_2$ can be avoided by the use of heaters which do not create combustion gases in the heated area or by the removal of gases from oil burning heaters through proper venting to the atmosphere. Membrane curing compound applied to exposed surfaces of concrete is helpful for preventing detrimental effects of $C0^2$ but should not be used as a substitute for venting oil burning heaters. Heaters also create severe safety problems due to the hazards of fire and asphyxiation. Passage of electric current through the concrete or reinforcement for heating purposes is a Soviet technique that has serious complications and drawbacks in danger to personnel and possible local overheating of concrete; it is not recommended. Any mechanical devices used to maintain heat after placing should be backed up by standby equipment.

h. Protection after the curing period. After the specified curing and protection period, the insulation and forms or the enclosure should be removed only after careful review of the temperature observations made and recorded throughout the period and the results of the test specimens. When it is assured that the concrete has attained the desired strength, the protective and curing measures may be discontinued. Rapid chilling of the concrete surface must be avoided to preclude shrinkage cracking and serious damage to the structure. Care should be used to avoid the rapid exposure of large areas of fresh concrete to low ambient temperatures. This can be accomplished by the gradual removal of the forms in the presence of a source of heat, the dissipation of which is prevented by tarpaulins or similar sheltering devices, by removal of forms and immediate application of insulation, by slow reduction of heat supplied to enclosures, and preferably by delaying removal of forms or other protection until suitable temperatures prevail. The time, trouble, and expense of heating the materials, and using protective measures during the mixing, transporting, placing and curing of the concrete will be wasted if the stability, durability and soundness of the structure are jeopardized by a lack of concern at this last stage. The temperature of the concrete should not be allowed to decrease at a rate of more than 2 °F/hr.

i. Temperature records. A comprehensive temperature record should be kept during and after the period of protection and included in the permanent records of the job. The temperature of the heated and unheated materials and the freshly mixed concrete should be a part of this record. It is desirable to obtain the temperature history of the interior concrete for each part of the structure during and after the necessary period of protection and until the concrete temperature stabilizes. This can best be accomplished with thermocouples; however, the embedment of this-walled

Table 6-2. Insulation Requirements for Concrete Walls and for Concrete Slabs and Canal Linings Placed on the Ground[203]

A. Concrete walls; concrete placed at 50F.

Wall thickness, feet	Minimum air temperature allowable for these thicknesses of commercial blanket or bat insulation, degrees F			
	0.5 inch	1.0 inch	1.5 inches	2.0 inches
Cement content—300 pounds per cubic yard				
0.5	47	41	33	28
1.0	41	29	17	5
1.5	35	19	0	−17
2.0	34	14	−9	−29
3.0	31	8	−15	−35
4.0	30	6	−18	−39
5.0	30	5	−21	−43
Cement content—400 pounds per cubic yard				
0.5	46	38	28	21
1.0	38	22	6	−11
1.5	31	8	−16	−39
2.0	28	2	−26	−53
3.0	25	−6	−36	...
4.0	23	−8	−41	...
5.0	23	−10	−45	...
Cement content—500 pounds per cubic yard				
0.5	45	35	22	14
1.0	35	15	−5	−26
1.5	27	−3	−33	−65
2.0	23	−10	−50	...
3.0	18	−20	...	...
4.0	17	−23	...	...
5.0	16	−25	...	...
Cement content—600 pounds per cubic yard				
0.5	44	32	16	6
1.0	32	8	−16	−41
1.5	21	−14	−50	−89
2.0	18	−22	...	...
3.0	12	−34	...	...
4.0	11	−38	...	...
5.0	10	−40	...	...

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Table 6-2. (cont.)

Slab thickness, feet	Minimum air temperature allowable for these thicknesses of commercial blanket or bat insulation, degrees F			
	0.5 inch	1.0 inch	1.5 inches	2.0 inches
Cement content—300 pounds per cubic yard				
0.333	[1]	[1]	[1]	[1]
0.667	[1]	[1]	[1]	[1]
1.0	47	42	35	29
1.5	37	19	−1	−21
2.0	26	−5	−37	−70
2.5	16	−27	−72	...
3.0	6	−51	...	...
Cement content—400 pounds per cubic yard				
0.333	[1]	[1]	[1]	[1]
0.667	50	49	47	46
1.0	42	30	17	5
1.5	29	1	−27	−56
2.0	16	−28	−72	−117
2.5	3	−58	...	...
3.0	−10	−86	...	...
Cement content—500 pounds per cubic yard				
0.333	[1]	[1]	[1]	[1]
0.667	47	42	35	30
1.0	37	19	0	−19
1.5	21	−16	−54	−92
2.0	5	−51	...	...
2.5	−13	...	...	...
3.0	−26	...	...	...
Cement content—600 pounds per cubic yard				
0.333	[1]	[1]	[1]	[1]
0.667	43	34	24	14
1.0	31	7	−18	−42
1.5	13	−33	−80	−127
2.0	−5	−74	...	...
2.5	−22	...	...	...
3.0	−42	...	...	...

Slab thickness, feet	Minimum air temperature allowable for these thicknesses of commercial blanket or bat insulation, degrees F			
	0.5 inch	1.0 inch	1.5 inches	2.0 inches
Cement content—300 pounds per cubic yard				
0.333	[1]	[1]	[1]	[1]
0.667	49	47	44	42
1.0	43	33	22	12
1.5	33	12	−10	−33
2.0	24	−9	−43	−77
2.5	14	−31	−76	...
3.0	5	−52	...	...
Cement content—400 pounds per cubic yard				
0.333	[1]	[1]	[1]	[1]
0.667	46	40	32	26
1.0	37	22	5	−12
1.5	25	−5	−37	−68
2.0	13	−32	−78	...
2.5	1	−59	...	...
3.0	−11	...	...	...
Cement content—500 pounds per cubic yard				
0.333	[1]	[1]	[1]	[1]
0.667	42	32	21	10
1.0	32	10	−13	−35
1.5	17	−23	−63	−103
2.0	3	−55	...	...
2.5	−12	...	...	...
3.0	−27	...	...	...
Cement content—600 pounds per cubic yard				
0.333	[1]	[1]	48	48
0.667	39	24	9	−5
1.0	27	−1	−31	−59
1.5	10	−40	−90	−139
2.0	−8	−78	...	...
2.5	−25	...	...	...
3.0	−43	...	...	...

[1] Owing to influence of cold subgrade on canal linings and other thin slabs, insulation alone will not maintain the temperature of concrete at the specified 50° F minimum for the first 72 hours after placing in cold weather. At such placements, additional heat is necessary to maintain required temperatures in the concrete by using higher placing temperatures, by preheating the ground, by placing electric resistance wire under the insulation, or by other means, depending on the severity of the prevailing weather. Where it is impracticable to supply such additional heat, insulation mats may prevent the concrete from freezing, but as the concrete temperature will probably fall below 50° F, the period of protection should be increased to obtain concrete strengths at the end of the protection period equivalent to the strength of concrete protected at 50° F for 72 hours.

copper tubing into which a common thermometer can be inserted will give fair results. The temperature of the concrete surfaces, the air temperature of any protective enclosure and the outside air temperature should be taken at least twice daily and recorded. Additional readings should be taken whenever the situation warrants. The humidity of heated enclosures should also be recorded. The surface temperature of the concrete should be taken in numerous places including edges and corners. Surface temperature of satisfactory accuracy can generally be obtained by placing a thermometer against the surface under a cover of insulating material until it registers a constant temperature.

6-5. Protection against the environment.

a. General. While it is true that most foundation construction is accomplished in summer in order to provide prepared support so that structures may be erected without seasonal constraints, it is often necessary to extend foundation work into winter seasons. Provisions for protection of construction against winter conditions should be initiated well before the first heavy frost or snowfall and in far northern locations they should be ready at all times. While weather records can indicate the probable date of first freezing temperatures and snow, the possibility of a significantly earlier date should be assumed. Adequate and timely protection of work can often save the expense of removing and replacing damaged material and equipment. Often enclosures for winter protection can be advantageously employed to protect the work also from sun, precipitation, dust, heat and wind, and to provide conditions for maximum worker efficiency.

b. Barriers against temperature, precipitation and wind.

(1) the protection required for winter construction varies with the construction material, the severity of the weather, and the duration and type of the work. As noted in the preceding section, uninsulated forms with tarpaulins and availability of temporary heat if needed may be adequate for some phases of work; others may require insulated forms with supplementary heat. Temporary portable shelters or enclosures may be utilized to enclose all or a portion of the work-9,'94'. Such protection permits the contractor to maintain schedules irrespective of weather and ensures maximum quality and productivity. The efficiency of men, unhampered by extra clothes and the effects of the elements, is often a prime consideration in selecting the type of enclosure to be used.

(2) Enclosures may consist of light portable buildings skidded to or erected over the work site, airinflated shelters, or timber or metal framing covered with transparent plastic films, tarpaulins or canvas, plywood or building board. In addition to cost, enclosure selection should consider amount of light desired, effect of wind and snow, heating, ventilation, portability or reusability, and access openings for equipment and personnel. Winds in excess of 100 mph are common in some areas. Where drifting snow and high winds are prevalent, even the smallest openings must be avoided to prevent filling of the enclosed space with snow. Enclosures or shelters may be self-supporting or extensions to the existing structural framework. Enclosed scaffolds, suspended from outriggers, provide a convenient and easily moved shelter for workmen and material. Standard sections of tubular scaffolding can also be covered to provide an economical shelter, particularly for structures four or five stories in height. Buildings designed as prefabricated structural shells that can be erected on prepared foundations in a matter of hours or at most a few days under even the worst outdoor conditions appear to offer distinct advantages, as interior finishing can thereafter proceed in comfort, with the aid of temporary heat, without need for any special enclosure; the building shell serves as its own protective enclosure.

c. Heating and light for winter work.

(1) In addition to enclosing the work for winter protection, heat must be supplied to protect new concrete from freezing, thaw out and warm aggregates and prevent frost heaving, as well as provide an efficiently comfortable environment for workmen. Like shelters, heating requirements depend on the scope of work to be performed. Heaters range from steam boilers, warm air units and electrical space heaters to oil or gas-fired salamanders. The most commonly used heaters are oilfired space heaters producing up to 800,000 Btu/hr.

(2) While it is desirable to maintain some degree of full-time surveillance on all heating equipment, cokeburning equipment should never be left unattended. Adequate ventilation should be provided for all heating units except electrical ones for the health and safety of workmen and because of fire and other hazards. Some heaters (e.g., those using solid fuels) produce sulfurous acid which produces excessive corrosion. Carbon dioxide, which is produced by all fuel burning units, can damage new concrete". Improper combustion such as from clogging of fuel nozzles in oil-fired units, especially types not vented outside the enclosure, can badly contaminate the enclosure space with soot or atomized but unburned fuel as well as produce carbon monoxide. Infrared lamps have been used to keep fresh concrete from freezing. The lamps can be easily positioned and when arranged in a reflector in banks of three to five bulbs can protect a considerable area. With any type of warm air or radiant heating system it is especially important that proper moisture and humidity conditions be maintained at the surface of the concrete and that the concrete not be overheated. Electricity can also be used to

protect concrete by comparatively low temperature heating grids within the insulated form or by the direct burial of heating cables within the concrete. The cables are cut off after the concrete has cured. Heating tapes controlled by a rheostat are particularly useful at exposed corners, tops of walls and other thin sections which are susceptible to rapid cooling.

(3) Ordinary light bulbs are often utilized to provide some heat in addition to their prime use as a source of light. Since both safety and worker efficiency are directly related to illumination, it is imperative that sufficient lighting be provided. This is especially true in winter when sunshine is at a minimum and if the enclosure further reduces any natural lighting. On small construction jobs five to ten 100-watt bulbs are sufficient illumination for 1000 ft^2 of area.

d. Fire hazards. Fire is a major hazard in arctic and subarctic construction. The use of temporary heaters within an often-confined work area enclosed with or containing many combustible materials can be a potential fire danger. Heating equipment should be maintained and continually inspected to ensure proper functioning. Heating units should be carefully positioned away from formwork, tarpaulins and other combustibles and securely mounted or placed. Electrical heating is often advantageous on small jobs because of easy automated control and greater fire safety, even though cost may be greater. Non-combustible materials should be selected where feasible. Tarpaulins should be flame-proofed and secured from heavy winds. Firefighting equipment should be strategically placed both inside and outside of the enclosure and building at all times for quick access. When insulation can be used to avoid or reduce heating requirements, it may be possible to reduce risk of fire.

e. Protection of fills, backfill and embankments. Winter protection of fills, backfills and embankments is usually only justified for such purposes as (a) temporary prevention of freezing pending foundation or other emplacement or (b) protection of underlying construction such as utility pipes when construction is incomplete. A covering of peat or loose earth is ordinarily the best means of protecting the backfill from freezing. Loose rock backfill is ordinarily too porous to provide much protection against freezing. If loose earth is used, building paper, straw, or some other easily identifiable material can be placed on top of the compacted backfill so that the limits of the temporary fill can readily be determined at the time of removal. Careful records should be kept of all such temporary fills which must be removed before backfilling operations are resumed. A checklist should be maintained to insure that all temporary fills are removed at the beginning of the following construction sequence. After such insulating temporary fills are removed, the density of the underlying compacted fill should be checked carefully before backfilling operations are resumed. Any previously compacted backfill which has lost its specified density due to freezing should be removed or recompacted.

f. Foundation protection. The need to protect the foundation against frost heave or thaw settlement during construction is sometimes overlooked'''. When frost-susceptible soils are present, it is essential that the foundation be protected until the backfill is in place and, if heat in the structure is depended upon to prevent frost action, until heat is available. Methods which may be used to provide protection of foundations against frost heave in seasonal frost areas include the following, individually or in combinations, as appropriate:

Cover of earth, hay, sawdust, peat or other indigenous material.

Directly applied bat, blanket or foam insulation.

Insulated structural enclosure or tentage.

Cover of polyethylene sheeting or special fabric inflated by hot air blower.

Saturation of foundation soils with salt solution to prevent freezing.

Flooding of foundation with water to a depth of a foot or more greater than the normal ice thickness for the area.

Hot air, steam, or electrical heat.

Methods to prevent or minimize degradation of permafrost have been discussed in previous sections and include: Scheduling work in periods of below freezing air temperatures.

Covering permafrost with protective fill or backfill.

Shading or enclosure.

Insulation.

Artificial refrigeration.