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INSULATION FACILITATES WINTER CONCRETING

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No. 22

INSULATION FACILITATES WINTER CONCRETING

by
George B. Wallace
Canals Branch
Division of Design
Appropriate field information contributed by:
James T. Wynhoff, Concrete Engineer - Trenton Dam
Shirl A. Evans, Materials Engineer - Kirwin Dam
Mac. D. Newsom, Materials Engineer - Bostwick Division

Technical Information Branch
Denver Federal Center
Denver, Colorado

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INTRODUCTION

The practicality of using insulating materials on forms and on unformed surfaces to retain heat and moisture in concrete placed during freezing weather has been established from experience on several Bureau of Reclamation projects. Insulating materials successfully used include spun glass, rock wool bats and blankets and fiberboard.

The use of insulation for protection of concrete structures offers many advantages over methods previously used. Previous practice of covering concrete with tarpaulins and heating by various methods is expensive, inconvenient, and sometimes harmful to the concrete. Proper use of insulation increases the convenience and economy of winter concreting and assures better structures because of the elimination of some of the hazards.

Laboratory investigations and analytical studies initiated in 1951 demonstrated the feasibility of protecting fresh concrete by insulation. Field trials confirmed the laboratory and analytical studies. The results of these field trials are discussed in this monograph. Tables giving computed thicknesses of insulation for safe protection at various minimum air temperatures and the derivation of the formulae on which the tables are based are included in an appendix.

Bureau specifications have been revised to make winter concreting more practicable. The use of 1 percent calcium chloride, by weight of cement, is required when the mean daily temperature at the work site falls below 40° F. For concrete cured by sealing compound, protection is required at 50° F for only 72 hours if the protection is obtained by means of adequate insulation in contact with forms or concrete surfaces. If insulation is not used, protection against freezing is required for an additional 72 hours.

PROBLEMS OF WINTER CONCRETING

Protecting Concrete in Forms

The primary problem of successful winter concreting is to maintain newly placed concrete at a temperature that will result in the development of adequate strength and durability. The concrete must also be kept moist either by adding water or by sealing in the mixing water. Protection should be started as soon as a concrete surface is brought to grade and is finished. Flat work requiring a floated or troweled finish should be placed as dry as practicable to permit finishing as soon as grade is reached.

Results of some strength development tests of concrete specimens cured at 16° F, 33° F, and 75° F are shown in Figure 1. These data indicate that there is practically no strength development when concrete is cured at temperatures below freezing, and that there is very little strength development when the temperature is only slightly above freezing. However, it is interesting to note that when warmth and moisture are provided, even after 27-3/4 days of low temperature storage, the concrete rapidly develops strength.

Low curing temperatures with resulting low strength development delay the time at which forms can be safely removed. If forms are stripped before sufficient strength has been developed to support the weight of the structure and to resist forces imposed by stripping operations and subsequent loads from adjacent concrete or backfill placements, damage requiring costly repairs may result. Since early form removal is usually vital to economical construction operations, it is necessary to provide means for such early form removal by heating the concrete or by protecting the concrete against loss of the heat generated by hydration of the cement.

Figure 2 shows that 3 days of moist curing at 50° F, of air-entrained concrete containing 1 percent calcium chloride, will produce adequate strength and resistance to freezing and thawing to permit stripping of forms from walls, barrels, boxes, floors, beams, columns and similar structures.

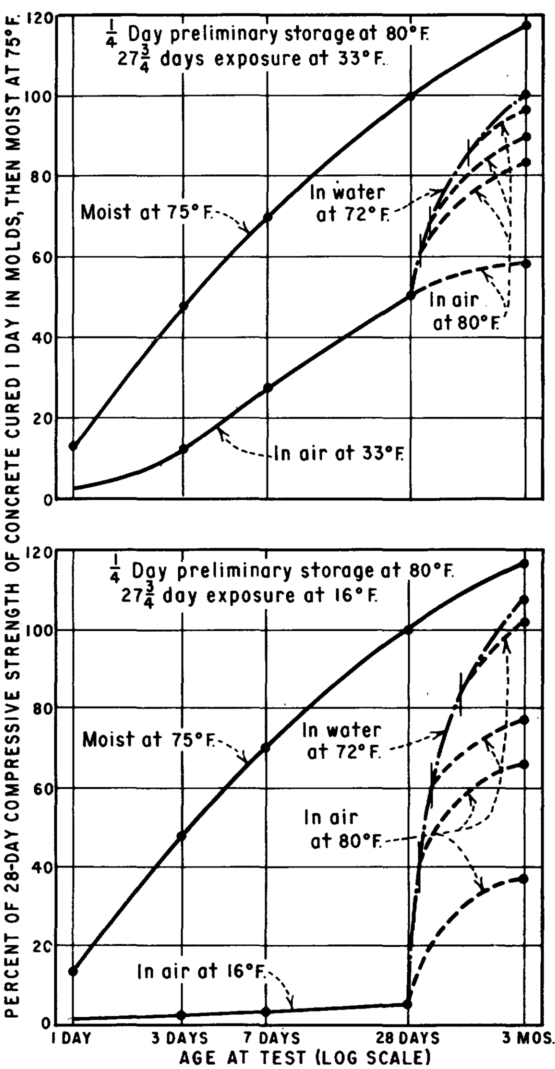
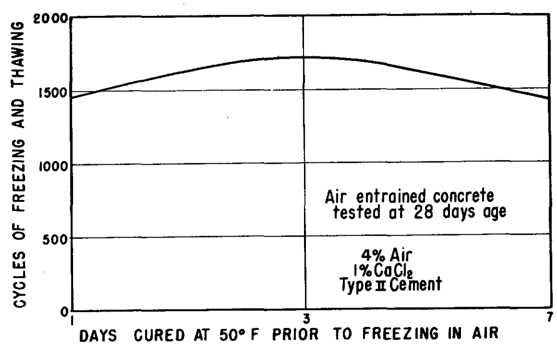
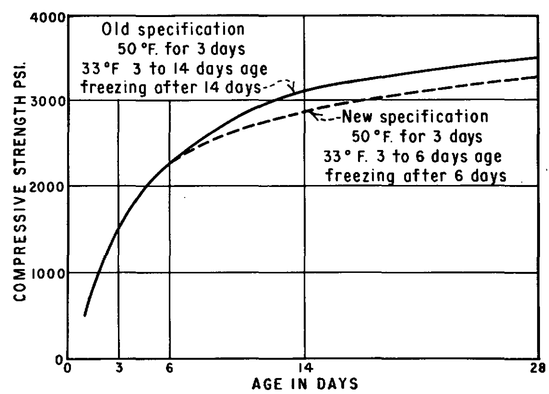


FIGURE 1 -- Relative strength of concrete as influenced by warming both in water and in air after exposure to temperatures of 16° and 33° F--normal cement. (From ACI Proceedings, "Recommended Practice for Winter Concreting Methods." v. 45, 1949, p. 9.)



Three days protection at 50° F gives maximum durability.



Shorter protection reduces 28-day strength only 7 percent; ultimate strengths are equal.

FIGURE 2 -- Effect of curing temperature on strength and durability of concrete containing 1 percent of calcium chloride by weight of cement. (From ACI Proceedings, v. 48 1952, p. 254.)

Methods previously used of covering the concrete with tarpaulins or other materials and heating by salamanders or by stoves of various types have usually proved to be expensive, inconvenient, and sometimes ineffective. These methods may be harmful to the concrete and are hazardous because of the danger of fire. Live steam released under a canvas or Sisalkraft housing, as shown in Figure 3, offers ideal protection and curing but is expensive. These handicaps have greatly curtailed the amount of concrete placed during winter weather.

FIGURE 3 -- Canvas or Sisalkraft housing and live steam offer ideal protection and curing but are more expensive than insulation blankets.

New methods proposed herein involve the use of insulation bats or board for formed surfaces and blankets for unformed surfaces to minimize loss of heat introduced at the time of mixing and also to control the loss of heat generated by hydration of the cement.

Figure 4 shows the temperature rise of mass concrete with Type II cement which was heavily insulated. No heat was lost from the concrete during the curing period, and none was added. The heat rise of the concrete was produced by the chemical reaction of the cement and water. The figure shows a perfect insulator is not necessary or even desirable for good curing. It is a well-known fact that concrete placed and cured at a comparatively low temperature will have less tendency to crack than concrete placed and cured at the high temperatures indicated in the figure.

Caution must be used not to overinsulate concrete. The ideal insulator for concrete placed at the optimum curing temperature would maintain the concrete at a relatively even temperature by permitting a balance between heat loss and heat released from the hydrating cement. However, good temperature control can be obtained by choosing an insulator which is adequate for the most severe weather conditions under which the work will be continued, and by cooling the concrete, when necessary, during less severe weather conditions by loosening forms or removing surface blankets. Figure 4 shows that the rate at which heat is released from the hydrating cement is very great during the first few days of curing but relatively small thereafter. For this reason, low-cost insulators will adequately retain the required heat during the early age of the concrete.

The number of days having mean daily temperatures below 32° F, 20° F, 10° F, and 0° F at selected points within the Bureau's work area are shown in Table I. This table was prepared by the United States Weather Bureau.

Subgrade Protection

When an earth subgrade is frozen, it may "heave" because of the formation of frost crystals between the soil particles. Upon thawing, a subgrade will subside. Obviously, a concrete structure placed on a frozen subgrade would be subject to undesirable stresses as the subgrade thaws and subsides. For this reason, Bureau specifications provide that earth foundations, upon or against which concrete is to be placed, shall be free from frost or ice.

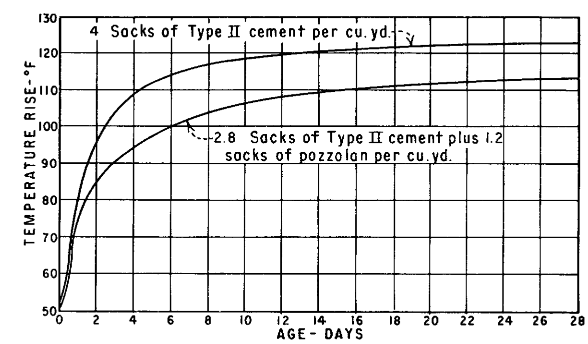


FIGURE 4 -- The temperature rise of perfectly insulated concrete is more than adequate for good curing.

It is usually much less expensive to prevent a subgrade from freezing than to thaw it out. Most subgrades are below adjacent ground lines and are thus protected from the wind. Also, since underlying soils are not frozen, these warmer soils tend to keep the exposed subgrade from freezing. When the elevation of the subgrade is below the frost line, freezing may be avoided simply by timing the excavation so that concrete placement can be made before the subgrade has cooled to the freezing point. When the excavation must be made a long time in advance of concrete placement, the subgrade may be protected by commercial insulation blankets, thick blankets of straw, or tarpaulins and heaters. Figure 5 shows how a shale foundation for Kirwin Dam spillway was protected. A watertight foundation was required, and it was necessary to protect the subgrade

TABLE I

COLD WEATHER CLIMATIC DATA

Location	Ground Elevation (Feet)	Temperature °F January Means		Mean No. of Days Per Year Minimum Temp is		Mean Yearly Snowfall
		Daily Max.	Daily Min.	32° F and Below	0° F and Below	
Region 1						
Medford, Oregon	1314	44.9	29.9	83	*	7.2
Yakima, Washington	1061	35.7	19.7	128	3	21.7
Kalispell, Montana	2965	28.7	15.0	163	12	49.4
Lewiston, Idaho	738	--	--	102	5	--
Boise, Idaho	2842	34.6	19.0	125	2	22.5
Pocatello, Idaho	4444	30.9	13.0	162	10	38.4
Region 2						
Red Bluff, California	341	52.4	34.6	26	0	3.1
Mount Shasta, California	3554	--	--	137	*	--
Sacramento, California	25	52.4	38.8	8	0	0.2
Region 3						
Flagstaff, Arizona	6895	--	--	198	9	--
Winslow, Arizona	4800	--	--	132	3	--
Region 4						
Reno, Nevada	4397	43.0	20.3	157	3	28.9
Salt Lake City, Utah	4260	36.5	21.8	106	1	55.3
Grand Junction, Colorado	4849	36.3	15.1	132	5	21.3
Region 5						
Alamosa, Colorado	7546	--	--	230	48	--
Albuquerque, New Mexico	5310	46.4	22.2	118	*	8.6
Roswell, New Mexico	3612	54.7	24.8	98	1	10.3
Region 6						
Helena, Montana	3893	28.4	11.4	157	23	54.6
Billings, Montana	3568	31.8	12.7	149	17	48.3
Lander, Wyoming	5563	31.6	5.6	191	28	72.0
Rapid City, South Dakota	3165	34.9	11.6	158	21	32.8
Region 7						
Denver, Colorado	5292	42.6	18.5	139	8	56.1
Scottsbluff, Nebraska	3880	--	--	179	16	--
North Platte, Nebraska	2779	36.0	11.8	158	15	25.3
Grand Island, Nebraska	1864	--	--	148	15	--
Concordia, Kansas	1375	36.9	17.7	119	7	20.3
Goodland, Kansas	3687	--	--	152	9	--

Data for this table based on records of the United States Weather Bureau through 1952.

*Less than 1 day

TABLE I (continued)

COLD WEATHER CLIMATIC DATA

Location	Number of days having daily mean temperature less than		
	20° F	10° F	0° F
Grand Island, Nebraska	26	9	3
Scottsbluff, Nebraska	26	8	2
Goodland, Kansas	20	5	1
Albuquerque, New Mexico	17	0	0
Alamosa, Colorado	43	13	2
Grand Junction, Colorado	12	2	0
Denver, Colorado	14	3	1
Rapid City, South Dakota	38	15	5
Lander, Wyoming	43	15	5
Billings, Montana	34	15	6
Helena, Montana	43	22	11
Salt Lake City, Utah	12	2	0
Pocatello, Idaho	24	8	2
Boise, Idaho	10	2	0
Lewiston, Idaho	7	2	1
Pendleton, Oregon	7	3	1
Yakima, Washington	9	1	0
Medford, Oregon	0	0	0
Reno, Nevada	7	1	0
Red Bluff, California	0	0	0
Average	20	6	2

Data for this table based on records of United States Weather Bureau for 1944 through 1954

from freezing because freezing would cause cracking with subsequent surface disintegration.

When subgrades are inadvertently frozen, they may be thawed by using heated enclosures or by burning straw or other combustible material which will smolder when covered with a layer of sand to hold the heat. A 4-foot layer of straw covered with 4 cubic yards of sand per 100 square feet has been successfully used.

Storing and Handling Materials

The initial temperature of the concrete is important in winter concreting. Snow, ice, and extremely cold aggregate must be removed from stockpiles used in batching to avoid a low initial concrete temperature and to maintain the required consistent production of uniform concrete.

On small jobs, it may be feasible to melt ice and snow in aggregates by heating the aggregate over a culvert pipe. Artificial heating of large aggregate stockpiles during cold weather is an expensive and often an unnecessary operation in most parts of the United States. If aggregate stockpiles are located

FIGURE 5 -- Baled straw has been used for many years to protect concrete from freezing, but new insulation blankets are much easier to handle. Straw shown protects shale foundation prior to placing concrete.

so that they are exposed to the rays of the sun and are protected from cold winds, the aggregate mass will usually be much warmer than the surrounding air temperatures. It is estimated that a stockpile about 15 feet high containing 40,000 cubic yards of coarse aggregate at a mean temperature of 40° F would have to be exposed to 0° F air temperature for several months before it would be cooled to a mean temperature of 20° F. Temperature records from Kirwin Dam show that on January 27, 1954, after 2-1/2 months of cold weather and immediately after 7 consecutive days with the minimum daily air temperature below zero, the temperature of aggregate at batching was 26° F. This was the lowest average aggregate temperature at batching measured during the entire season.

Batching aggregate from the bottom and center of a pile by conveyor belt will usually provide the batching plant with relatively warm material free from snow and ice.

The temperature of fresh mass concrete is equal to approximately 81 percent of the aggregate temperature plus 13 percent of the water temperature, plus 6 percent of the cement temperature. Since the temperature of the aggregates has such a pronounced influence on resulting temperature of fresh concrete, it is important to take advantage of any nonshading natural protection available and shaping stockpiles for minimum loss of heat.

Cement and pozzolan should be stored within an enclosure primarily to keep it dry. Some projects have reported that cold cement reacted with hot water to produce a flash set, whereas warmer cement stored within an enclosure did not produce a reaction.

Controlling Placing Temperature

Bureau specifications require that the temperature of concrete when placed shall have a temperature of not less than 50° F in freezing weather. In western and midwestern United States, the temperature of the fresh concrete can usually be maintained at 50° F by heating the mixing water.

At Kirwin Dam in January 1954, minimum daily air temperature was below zero for 7 consecutive days, and no difficulty was encountered in producing fresh concrete having a temperature of 50° F. Table II shows the temperature of concrete ingredients at batching and the resulting temperature of the fresh concrete taken from field records of the Courtland Canal and Kirwin Dam projects. The temperature of fresh concrete, as computed using the following formula, is also tabulated in the table:

$$t = \frac{s\,(t_a W_a + t_c W_c) + t_a W_f + t_w W_w}{s(W_a + W_c) + W_f + W_w}$$

where

t = temperature of fresh concrete, °F

s = specific heat of dry materials, assumed to be 0.22

t_a = temperature of aggregates, °F

W_a = weight of saturated surface dry aggregates, pounds

W_f = weight of free moisture in aggregates, pounds

t_w = temperature of mixing water, °F

W_w = weight of mixing water, pounds

t_c = temperature of cement, °F

W_c = weight of cement, pounds

Substituting 0.22 for s, in the equation and the values of W_a, W_f, W_w, and W_c shown at the bottom of Table I, yields equations with form:

$$t = C_w t_w + C_c t_c + C_a t_a$$

Where C_w, C_c, and C_a are constants for a given mix whose sum = unity, for 1-1/2-inch maximum size aggregates:

$$t = .22\ t_w + .11\ t_c + .66\ t_a$$

for 3-inch maximum size aggregates:

$$t = .15\ t_w + .08\ t_c + .77\ t_a$$

for 6-inch maximum size aggregates:

$$t = .13\ t_w + .06\ t_c + .81\ t_a$$

A graphical representation of the above equation is shown in Figure 6, in which the temperature of cement was assumed to be

TABLE II

COMPARISON OF CALCULATED AND MEASURED TEMPERATURE OF FRESH CONCRETE

No.	Temperature °F Water (t_w)	Temperature °F Cement (t_c)	Temperature °F Aggs. (t_a)	1 $C_w\ t_w$	2 $C_c\ t_c$	3 $C_a\ t_a$	Calculated concrete temp. °F	Measured concrete temp. °F
			1-1/2-inch maximum aggregates $C_w = .22,\ C_c = .11,\ C_a = .66$					
1	124	58	38	27.3	6.4	25.1	59	59
2	155	67	47	34.1	7.4	31.0	72	67
3	145	54	43	31.9	5.9	28.4	66	64
4	144	48	42	31.7	5.3	27.7	65	65
5	150	44	39	33.0	4.8	25.7	64	68
6	146	36	38	32.1	4.0	25.1	61	61
7	162	38	38	35.6	4.2	25.1	65	60
8	115	50	46	25.3	5.5	30.4	61	64
9	120	48	43	26.4	5.3	28.4	60	65
10	110	32	32	24.2	3.5	21.1	49	47
11	142	51	38	31.2	5.6	25.1	62	68
12	140	34	30	30.8	3.7	19.8	54	58
13	138	40	38	30.4	4.4	25.1	60	66
14	132	50	5	29.0	5.5	34.3	69	68
			3-inch maximum aggregates $C_w = .15,\ C_c = .08,\ C_a = .77$					
15	180	*	26	27.0	2.1	20.0	49	54
16	185	--	33	27.8	2.6	25.4	56	52
			6-inch maximum aggregates $C_w = .13,\ C_c = .06,\ C_a = .81$					
17	160	--	26	20.8	2.9	21.1	45	48
18	170	--	26	22.1	2.9	21.1	46	47
19	180	--	31	23.4	3.4	25.1	52	54

*t_c assumed equal to t_a where measured temperature is not shown.

MIX QUANTITIES USED IN CALCULATING CONCRETE TEMPERATURE

Max. agg. size (inches)	Quantities (pounds/cubic yard) Water	Cement	Aggregate	Percent sand	Percent moisture in sand	Percent air
1-1/2	269	554	3050	38	3	4.5
3	182	349	3404	31	3	5.2
6	151	274	3561	24	3	4.9

Temperature concrete = $C_w\ t_w + C_c\ t_c + C_a\ t_a$
See text for derivation of constants C_w, C_c, and C_a.

the same as the temperature of the aggregate. Figure 6 may be used to estimate the temperature of the mixing water necessary to produce a desired temperature in the fresh concrete for concrete mixes similar to those shown in Table II.

To avoid a flash set, water heated to a temperature of over 160° F should not come in direct contact with cement. Some air-entraining agents are also adversely affected by extremely hot water. However, water heated to the boiling point may be used if it is mixed with a portion of the aggregates before the cement is added to the mixer, and

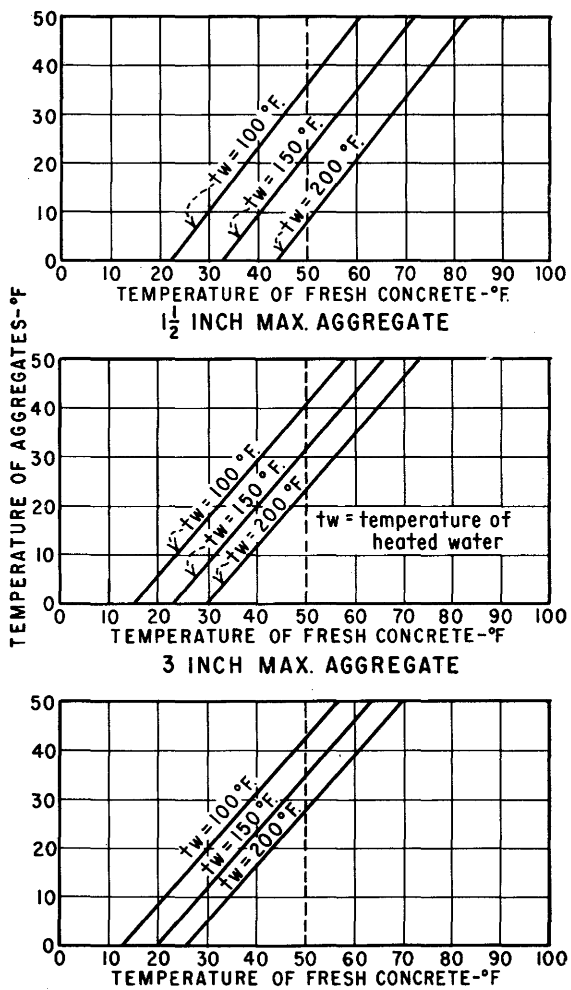


FIGURE 6 -- Showing the theoretical effect of aggregate and water temperature at batching on the resulting temperature of fresh concrete. Based on mix quantities shown in Table II.

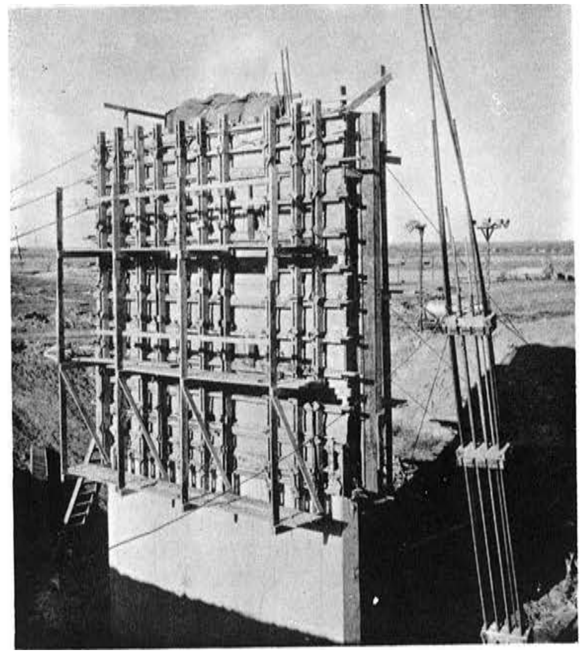


FIGURE 7 -- Wall form with spun glass insulation attached to outside of sheathing. This form had eight openings for vibrators that permitted rapid placement and consolidation of concrete and prevented unnecessary loss of heat from materials.

if it does not destroy the effectiveness of the particular air-entraining agent being used.

The effort of properly storing and preparing materials for batching and of heating the mixing water to produce fresh concrete with a temperature of 50° F or higher can be lost unless a few simple, inexpensive precautions are taken to avoid loss of heat during mixing, transporting, and placing. Construction of a shelter around the mixer and covering the open discharge end of the mixer will reduce temperature losses during mixing operations.

The mixer should be located as close as is practicable to the concrete placement to avoid loss of heat during transportation from the mixer to the point of placement. If concrete is hauled in buckets on flat trucks or in open dump units, it should be covered with a tarpaulin or insulation blanket to conserve heat. A large concrete surface is exposed to cold air as the concrete is dumped, vibrated, and finished before it can be protected. For quick and satisfactory place-

FIGURE 8 -- Cross section of spun glass insulation mats. Tough water-resistant Sisalkraft encasement makes blanket very durable. Blanket weight 0.24 pound per square foot.

ment of concrete to prevent objectionable heat loss, a sufficient number of form openings and vibrators should be provided. The wall form shown in Figure 7 had 8 openings for vibration and four 2-1/2-inch vibrators were used to consolidate the concrete quickly.

DESCRIPTION OF INSULATION MATERIALS

A description of the insulation materials successfully used on Bureau and other projects in recent years and the performance records of these materials are hereinafter presented.

Spun Glass Blankets

Spun glass blankets were used by the Texas Construction Company to protect concrete in Kirwin Dam and appurtenant structures during the Winter of 1953-54. The blankets were purchased at a unit cost of $0.1147 per square foot. They were 10 feet wide, 25 feet long, 1 inch thick, and weighed 60 pounds per blanket. Figure 8 shows the composition of the blankets to be a 1-inch layer of spun glass encased between durable, weather resistant, reinforced Sisalkraft paper. The light weight of the rolls makes handling convenient. One workman can carry a roll to a concrete placement and cover the top as placing operations proceed. Figure 9 shows a typical roll of insulation as received on the project. The blankets were applied to walls and massive blocks.

When applied to forms, the blankets were cut to the stud spacing and secured between the studs to the outside sheathing with 1- by 2-inch wood strips placed along the edges of the insulation and nailed to the forms. Figure 10 shows typical applications of spun glass insulation to wall forms. The tops of walls were protected by placing a strip of blanket over the concrete surface and securing the strip to the sides of the forms either by tacking or weighting down with boards. Figure 11 shows a recommended application of spun glass insulation to a curved wall form.

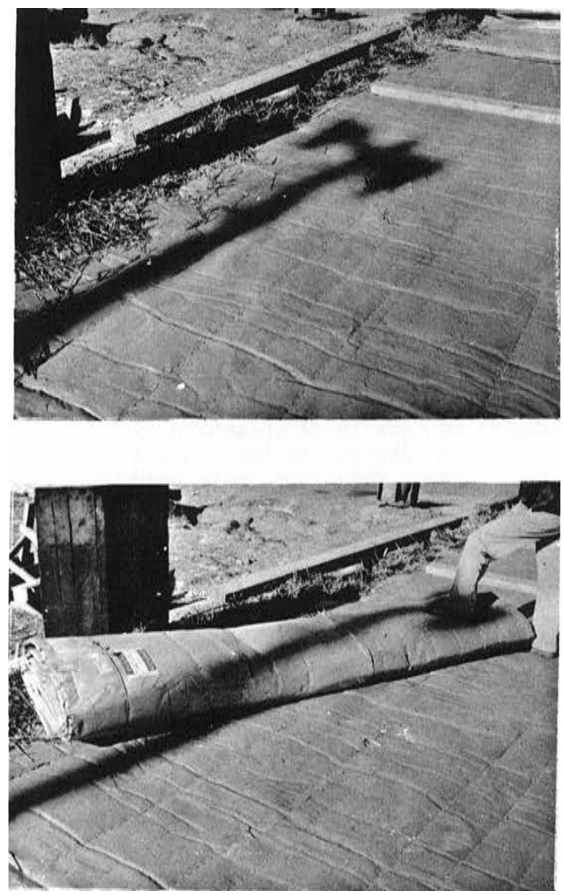
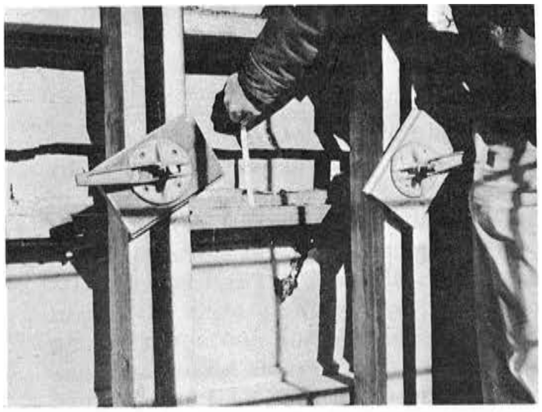


FIGURE 9 -- Spun glass insulation blankets placed directly on unformed concrete surfaces at Kirwin Dam. Rolls are 10'x25'x1". Note loose straw covering concrete between keyways along contraction joint. Heavy planks hold mats in place.



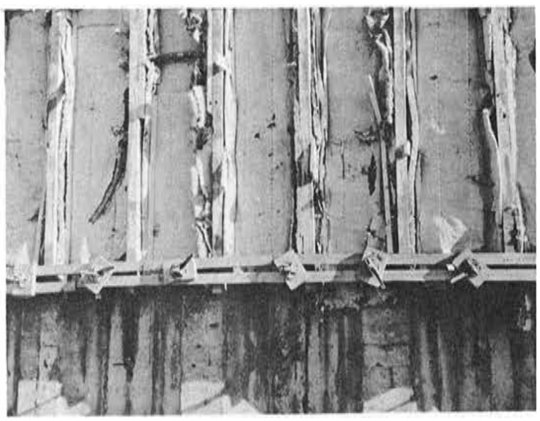


FIGURE 10 -- Spun glass insulation blankets cut to stud spacing and fastened to outside of sheathing by 1"x2" wood strips nailed to the forms. Lower form had been used seven times when picture was taken.

The blankets should be in direct contact with the top concrete surface. If reinforcing or dowel steel extends through the top of a wall placement, it may be punched through the blanket, or the blanket may be slotted and fitted snugly around the bars. When an air space exists between the blanket and the concrete surface, small holes in the insulation permit cold, dry air to enter below the insulation which seriously detracts from the beneficial effect of the blanket.

Spun glass blankets were placed in direct contact with unformed concrete surfaces to avoid any flow of air beneath the blankets which would lower their effectiveness to retain heat and moisture. Figure 9 shows the method used to protect horizontal surfaces. Note the straw placed along the edges between the construction joint keyways and the heavy planks which hold the blanket in place. The blankets are easily cut to fit special shapes such as the sluice pier shown in Figure 12. The spun glass blankets with Sisalkraft paper encasement were very durable. The blankets applied to forms at Kirwin Dam lasted the entire winter season. Some of the blankets applied to unformed surfaces were damaged by curing water, but approximately 80 percent of all the materials purchased were in usable condition at the end of the winter season.

Rock-wool Bats--Factory Made

Factory-made rock-wool bats were used by the Vinnell-United-Bell Construction Company to protect concrete in Trenton Dam and appurtenant structures during winter months of 1951 and 1952. The bats were 2 inches thick with black building paper encasement. Current price of these bats is approximately $0.044 per square foot. Rock-wool bats may also be obtained in 1-1/2- and 4-inch thickness and with special reflective encasements.

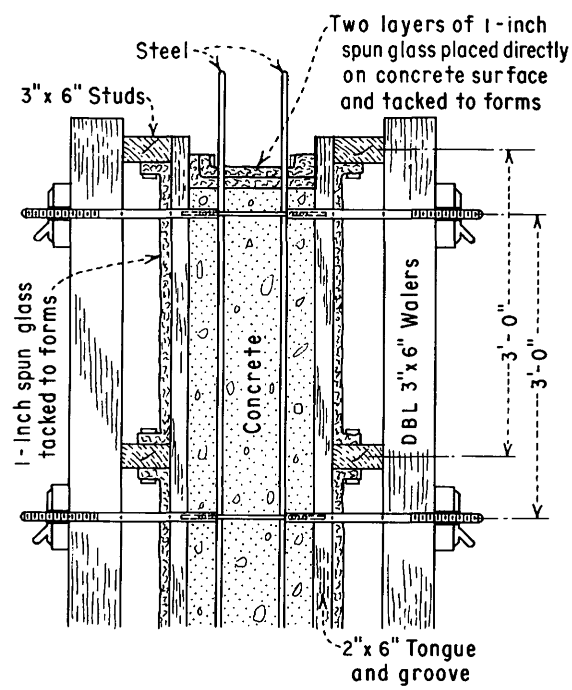


FIGURE 11 -- Spun glass insulation applied to curved wall forms. Top surface should be in direct contact with concrete to avoid flow of air under insulation.

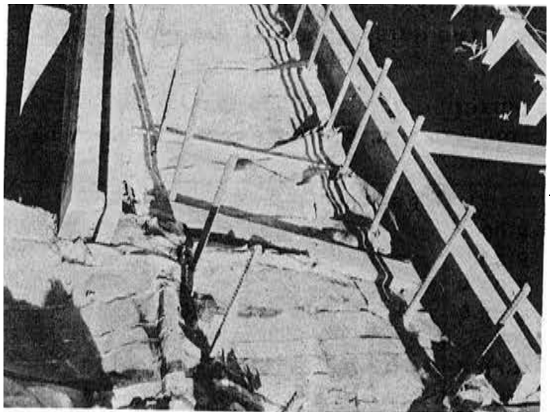


FIGURE 12 -- Spun glass insulation blankets are easily cut to fit special shapes such as this sluice pier at Kirwin Dam. Reinforcement steel was punched through blankets which fit snugly around bars.

The 2-inch thick bats used on the Trenton Project were placed between studs spaced 18 inches on centers. The bats were fastened to the outside of the form sheathing by battens along the edges, as shown in Figure 13. The forms were of extra sturdy construction designed for numerous reuses. Sheathing consisted of 1- by 4-inch tongue-and-groove flooring running vertically, and 2- by 6-inch tongue-and-groove flooring running diagonally. Studs consisted of alternate 4- by 6-inch and 2- by 6-inch timbers spaced 18 inches apart. Walers were pairs of 4- by 6-inch timbers placed on 3-1/2-foot centers. The tops of the walls were protected by two blankets. Each blanket was composed of 2 inches of rock wool held together with a burlap covering. The rock-wool bats covered with building paper were less durable than blankets covered with Sisalkraft paper. The paper covering deteriorated quite rapidly when exposed to wet weather, and project engineers recommended covering the bats with chicken wire or water-resistant paper for prolonged use. The rock-wool bats were used for 6 weeks while each set of forms was used to place 9 wall panels.

Rock-wool Blankets--Job Made

Job-made rock-wool blankets were used during the winter of 1952-1953 by the J. A. Terteling and Sons Construction Company to protect concrete in siphon barrels for the Courtland Canal near Superior, Nebraska. The blankets were constructed by the local construction forces at a cost of $0.30 per square foot. A 13- by 17-foot piece of canvas was laid out on sawdust on a wood platform and mopped with hot tar. A 2-inch layer of rock-wool insulation was placed on the canvas while the tar was still hot. Following this operation, more hot tar was mopped on the rock wool and a layer of burlap laid on top. The canvas was lapped 6 inches around the edges and mopped onto the burlap with tar. The resulting blanket was 12 feet wide, 16 feet long, and nearly 2 inches thick. However, the rock wool soon consolidated to a thickness slightly less than 1 inch.

The blankets were used to protect the concrete before and after forms were stripped, as shown in Figure 14, and to protect the subgrade of future placements. Forms were of steel construction and were of no help to the blankets in protecting the concrete. During extremely cold weather, small butane burners inside the barrel provided supplementary heat prior to stripping forms. Also, subgrades were protected by placing the burners under the insulation while it was draped over steel cages. As soon as forms were stripped, blankets were placed in direct contact with the outside concrete surface of the siphon barrel and weighted down, when necessary, to prevent circulation of air under the blankets. Blankets were moved forward with backfilling operations, or when the required protection period was completed. The

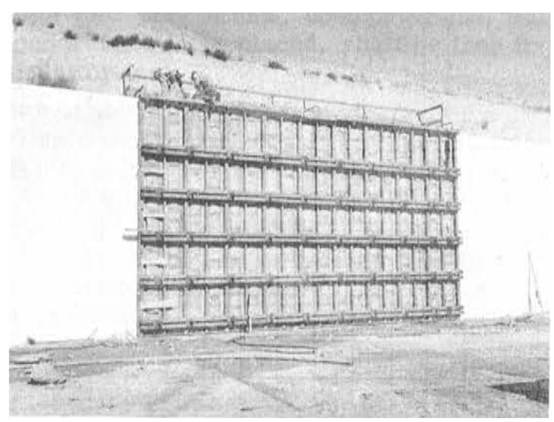


FIGURE 13 -- Rock wool insulation bats fastened to outside of form sheathing with battens along edges. These forms were used to construct nine wall panels.

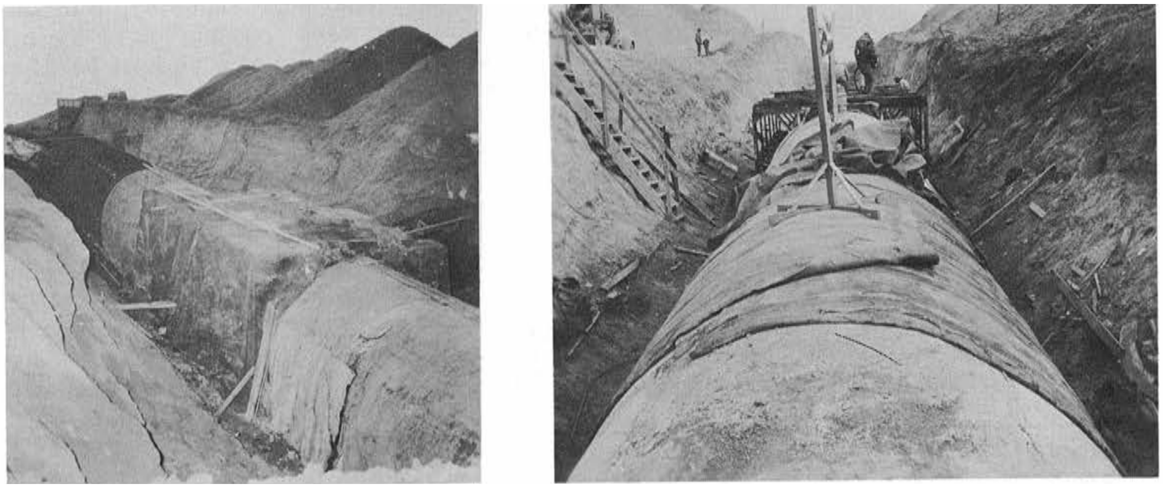


FIGURE 14 -- Rock wool insulation blankets were placed directly on exterior concrete surface of Courtland Canal siphon barrels. Metal slip forms were covered for 12 hours prior to stripping while concrete hardened. Note insulation blankets over steel cage ahead of forms to protect subgrade that is ready for concrete placement.

job-made rock-wool blankets were very durable and with proper care and handling should last for 2 seasons. Their biggest disadvantage was the rapid consolidation from 2-inch to approximately 1-inch thickness and the accompanying loss of efficiency.

Insulating Board

Fiber insulating board was used by the Winston Brothers Construction Company in January 1952 to protect formed concrete surfaces in the overflow section of the Flatiron Afterbay Dam on the Colorado-Big Thompson Project. Panels of 1/2-inch fiberboard were fitted between the form studding and separated from the sheathing by 1-inch furring strips, thus forming a 3/4-inch dead air space. A variety of insulating boards in various panel sizes is available from building materials suppliers. Current price of 1/2-inch fiber board is approximately $0.0510 per square foot, when bought in carload lots. Asphalt impregnated or coated fiberboard is also available. Fiberboard insulation was used only a short time and, therefore, its durability was not evaluated. It is generally known that uncoated fiberboard is not designed for outdoor use. However, asphalt-coated and asphalt-impregnated boards are available which are weather resistant. Current price of coated or impregnated 1/2-inch board is approximately $0.054 per square foot in carload lots.

Balsam Wool Bats

Balsam-wool insulation bats were used to protect concrete in bridge piers in a highway bridge across the Missouri River at Chamberlain, South Dakota. The work was performed in January and February 1953, by the James and Cunningham Construction Company under supervision of the South Dakota State Highway Commission. The balsam-wool bats currently sell for approximately $0.09 per square foot for double bats 2 inches thick, and $0.06 per square foot for standard bats 1 inch thick. The double bats were used on the Chamberlain job by fastening them to the outside of the sheathing with battens along the edges of the bats nailed to the studding.

EFFECTIVENESS OF INSULATING MATERIALS

The effectiveness of the insulating materials described herein was observed and evaluated. Temperature measurements of the concrete during the protection period were made and compared with the maximum and minimum daily air temperatures. In some cases, intermediate air temperature was obtained simultaneously with the concrete temperature.

The methods used in measuring the concrete temperature were much the same on

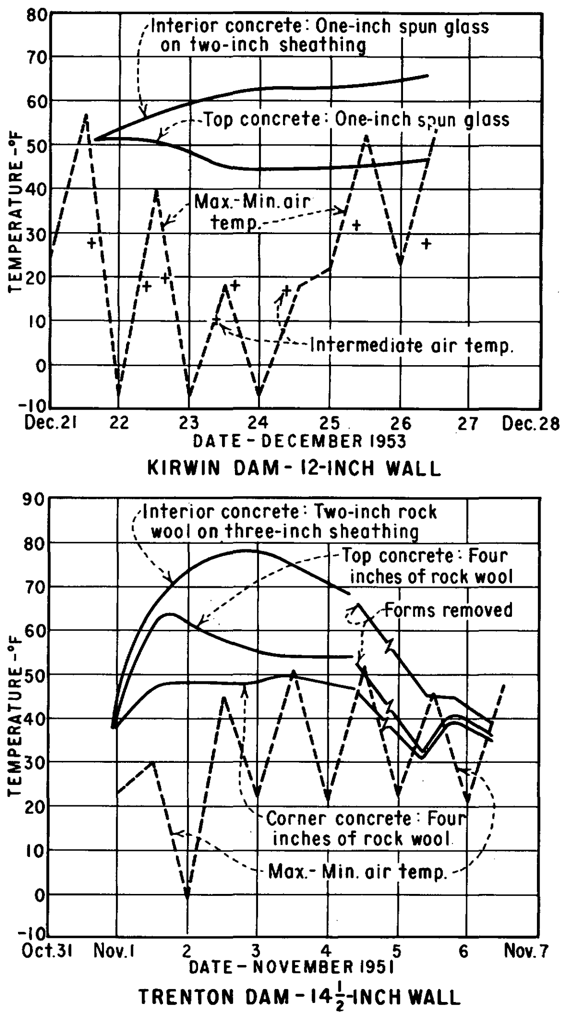


FIGURE 15 -- The temperature of concrete in walls approximately 12 and 14 inches thick was maintained well above freezing despite sub-zero air temperatures. Two-inch rock wool on three-inch sheathing is more than sufficient protection for the temperature conditions shown above.

The data for evaluating the performance of the insulators in maintaining required curing temperature during freezing weather are tabulated in Table II through Table IX, and select data are shown graphically in Figures 15 through 24. The tables and figures show that all of the materials maintained the temperature of the concrete adequately above freezing.

Concrete in Walls

Tables III and IV and Figures 15, 16, and 17 give the interior and surface temperatures of concrete in walls of various thickness, from time of placement through the required protection period. Spun glass and rock-wool all of the projects. Interior concrete temperatures were measured in form tie holes, or special holes located at the center of each formed surface and penetrating into the concrete 3 to 6 inches. After inserting a thermometer into a hole, the hole was sealed with insulation and readings were obtained after the temperature in the hole became stabilized. Surface temperature of concrete was measured by placing a thermometer in direct contact with the concrete and covering the thermometer with insulation. Readings were obtained after the temperature became stabilized.

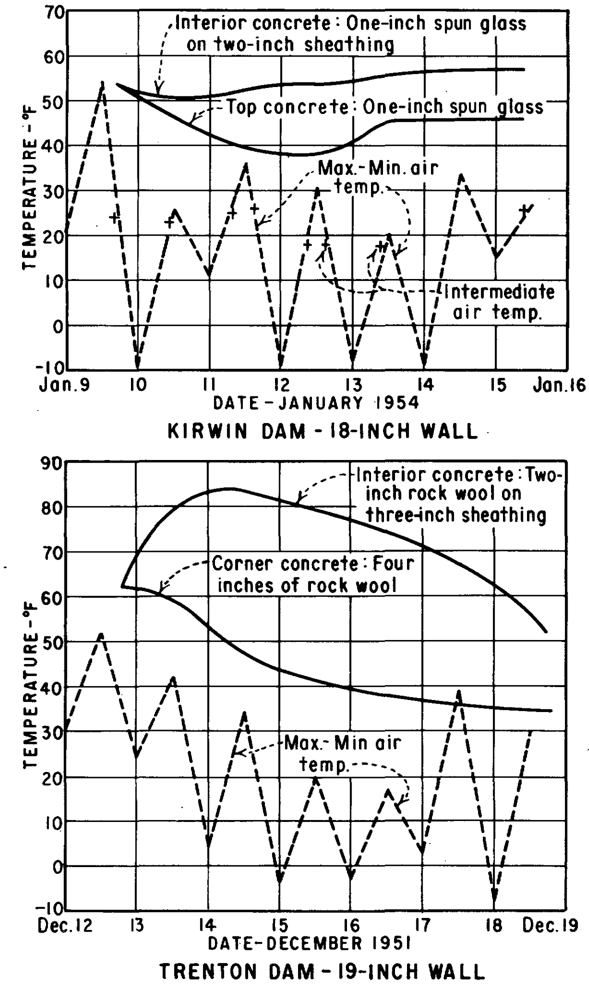


FIGURE 16 -- The temperature of concrete in walls approximately 18 inches thick was maintained well above freezing and uniform, despite sub-zero air temperature and large variations between maximum and minimum air temperature.

TABLE III

COLD WEATHER CONCRETING--KIRWIN DAM
TEMPERATURE RECORD 1953-54

CONCRETE IN WALLS
Average Mix Quantities for Winter Season

Aggregate Grading (%)					Water	Cement		Air	Slump
Sand	#4-3/4	3/4-1-1/2	1-1/2-3	3-6	lbs/cy	lbs/cy	W/C	(%)	In
31	18	23	26	2	182	349	52	5.2	2-3/4

Temperature of fresh concrete controlled by heating mix water.
One-inch spun glass attached to outside of two-inch sheathing.

PLACEMENT DATA		PROTECTION DATA						
	Pertinent conditions during concrete placement	Time of temp. measurements		Temp. °F			Daily air temp. °F	
				Concrete in place		Air		
No.		Date	Hour	Top	Interior	*	Max.	Min.
1	Time: Nov. 28, 8:45 a to 2:25 p	Nov. 28	10:00 p	--	56	32	55	32
	Avg. temp. of concrete: 54° F	Nov. 29	9:30 a	--	58	50	59	27
	Avg. temp. of air: 55° F	Nov. 29	3:00 p	--	58	58	59	27
	Avg. thickness of wall: 15-3/4"	Nov. 30	9:20 a	--	64	26	55	26
	Ca Cl_2: None							
2	Time: Nov. 30, 9:00 a to 3:30 p	Dec. 1	10:00 a	61	--	52	53	26
	Avg. temp. of concrete: 50° F	Dec. 2	8:30 a	68	--	41	63	33
	Avg. temp. of air: 53° F	Dec. 2	3:30 p	66	--	38	63	33
	Avg. thickness of wall: 16-1/2"	Dec. 3	9:00 a	57	--	32	39	32
	Ca Cl_2: None	Dec. 3	3:30 p	58	--	30	39	32
	Quantity placed: 30 cy	Dec. 4	9:00 a	58		24	32	20
		Dec. 4	4:00 p	58		34	32	20
3	Time: Dec. 5, 10:20 a to 1:20 p	Dec. 5	10:00 p	48	--	27	37	20
	Avg. temp. of concrete: 40° F	Dec. 6	9:00 a	48	--	34	36	21
	Avg. temp. of air: 36° F	Dec. 6	4:00 p	49	--	35	36	21
	Avg. thickness of wall: 12"	Dec. 7	9:30 a	48	--	40	45	21
	Ca Cl_2: 1%	Dec. 7	3:30 p	50	--	52	45	21
	Quantity placed: 20 cy	Dec. 8	8:30 a	48	--	34	48	26
		Dec. 8	4:00 p	48	--	32	48	26
		Dec. 9	9:30 a	44	--	22	33	19
		Dec. 9	3:00 p	46	--	21	33	19
4	Time: Dec. 10, 1:00 p to 5:30 p	Dec. 11	9:00 a	62	65	40	50	22
	Avg. temp. of concrete: 52° F	Dec. 11	4:00 p	63	70	40	50	22
	Avg. temp. of air:	Dec. 12	9:00 a	63	66	34	37	17
	Avg. thickness of wall: 12"	Dec. 12	4:00 p	62	65	40	37	17
	Ca Cl_2: 1%	Dec. 13	9:00 a	60	58	32	47	20
	Quantity placed: 20 cy	Dec. 13	4:00 p	59	62	42	47	20
5	Time: Dec. 11, 10:30 a to 2:00 p	Dec. 12	9:00 a	40	55	34	37	17
	Avg. temp. of concrete: 54° F	Dec. 12	3:30 p	44	65	36	37	17
	Avg. temp. of air: 38° F	Dec. 13	9:30 a	46	63	32	47	20
	Avg. thickness of wall: 15"	Dec. 13	4:30 p	48	64	42	47	20
	Ca Cl_2: 1%							
	Quantity placed: 26 cy							
6	Time: Dec. 16, 9:50 a to 3:30 p	Dec. 17	9:00 a	52	64	28	54	18
	Avg. temp. of concrete: 54° F	Dec. 17	4:00 p	53	64	33	54	18
	Avg. temp. of air: 36° F	Dec. 18	8:30 a	54	65	23	54	18
	Avg. thickness of wall: 17"	Dec. 18	4:00 p	51	65	48	54	18
	Ca Cl_2: 1%							
	Quantity placed: 59 cy							

TABLE III (continued)

No.	PLACEMENT DATA: Pertinent conditions during concrete placement	PROTECTION DATA: Time of temp. measurements: Date	Hour	Temp. °F: Concrete in place: Top	Interior	Air *	Daily air Temp. °F: Max.	Min.
7	Time: Dec. 19, 10:35 a to 10:45	Dec. 20	8:20 a	48	52	23	55	22
	Avg. temp. of concrete: 55° F	Dec. 21	8:45 a	50	54	23	57	24
	Avg. temp. of air: 30° F	Dec. 22	8:30 a	51	58	18	40	-07
	Avg. thickness of wall: 36+"	Dec. 22	3:30 p	52	62	20	40	-07
	Ca Cl_2: 1%	Dec. 23	8:30 a	47	57	11	18	-07
	Quantity placed: 286 cy	Dec. 23	4:00 p	48	57	18	18	-07
		Dec. 24	8:30 a	50	58	20	41	-07
		Dec. 25	9:30 a	52	56	32	52	22
		Dec. 25	4:00 p	50	58	45	52	22
		Dec. 26	9:00 a	48	50	30	54	23
		Dec. 26	4:00 p	51	54	40	54	23
		Dec. 27	10:30 a	50	55	34	51	23
8	Time: Dec. 21, 12:05 p to 2:30 p	Dec. 22	9:00 a	50	58	18	40	-07
	Avg. temp. of concrete: 51° F	Dec. 22	4:00 p	52	59	20	40	-07
	Avg. temp. of air: 28° F	Dec. 23	8:30 a	45	59	11	18	-07
	Avg. thickness of wall: 12"	Dec. 23	4:00 p	44	62	18	18	-07
	Ca Cl_2: 1%	Dec. 24	9:00 a	48	63	17	18	-07
	Quantity placed: 23 cy	Dec. 25	9:00 a	46	64	32	52	22
		Dec. 25	4:00 p	46	64	45	52	22
		Dec. 26	9:30 a	47	66	28	54	23
9	Time: Jan. 9, 10:45 a to 4:30 p	Jan. 10	10:30 a	44	51	23	26	-09
	Avg. temp. of concrete: 54° F	Jan. 11	8:00 a	41	52	25	36	11
	Avg. temp. of air: 24° F	Jan. 11	3:00 p	42	53	26	36	11
	Avg. thickness of wall: 18"	Jan. 12	9:00 a	38	54	18	31	-09
	Ca Cl_2: 1%	Jan. 12	3:00 p	38	54	18	31	-09
	Quantity placed: 91 cy	Jan. 13	9:00 a	46	56	18	20	-08
	Temp. of water: 180° F	Jan. 15	9:15 a	46	57	26	27	15
	Temp. of aggregates: 26° F							
10	Time: Jan. 23, 9:15 a to 11:30 p	Jan. 24	9:00 a	56	74	10	32	-08
	Avg. temp. of concrete: 52° F	Jan. 24	11:00 a	58	72	10	32	-08
	Avg. temp. of air: 26° F	Jan. 24	1:00 p	58	76	10	32	-08
	Avg. thickness of wall: 30"	Jan. 24	3:00 p	60	78	10	32	-08
	Ca Cl_2: 1%	Jan. 24	4:00 p	60	78	0	32	-08
	Quantity placed: 187 cy	Jan. 25	9:00 a	52	77	10	20	-08
	Temp. of water: 185° F	Jan. 25	9:00 p	50	74	6	20	-08
	Temp. of aggregates: 33° F	Jan. 25	11:00 p	54	74		20	-08
		Jan. 26	1:30 a	54	74	6	19	-01
		Jan. 26	3:30 a	52	74	2	19	-01
		Jan. 26	8:30 a	50	70	2	19	-01
		Jan. 26	10:30 a	50	70	0	19	-01
		Jan. 26	12:30 p	50	70	0	19	-01
		Jan. 26	2:30 p	50	70	-01	19	-01
		Jan. 26	4:00 p	50	70	-01	19	-01

*Temperature of air measured simultaneously with concrete temperature

insulators were used to protect these walls. The maximum and minimum daily air temperatures, and in some cases, intermediate air temperatures, indicate the severity of the exposure. The figures show that both 1-inch spun glass attached to 2-inch sheathing, and 2-inch rock wool attached to 3-inch sheathing satisfactorily retained the heat in the concrete even under prolonged subzero temperature. However, 1 inch of spun glass on top of the walls did not maintain the top surface temperature at 50° F. This deficiency can probably be avoided in future work by covering the top surfaces with 2 inches of spun glass, as shown in Figure 11. Although the top surface temperature dropped below 50° F, it remained above freezing and the concrete was apparently not damaged in any way. Figure 15 also shows that 4 inches of rock wool did not maintain concrete temperature at 50° F in corners, although the temperature was above freezing and the concrete apparently was not damaged in any way. Note that the corner temperature dropped as much as 30° F below the temperature of the main body of concrete.

The amount of heat loss from a given volume of concrete varies directly with the exposed surface area. Concrete located near the top of walls, especially within 1 or 2 inches of edges and corners, has more cooling surface than an equal volume of concrete elsewhere in the wall and, therefore, requires more insulation for equal protection. Since concrete near edges and corners is also most vulnerable to damage during form-stripping operations, adequate protection of such surfaces plus liberal use of chamfer strips will minimize the number of difficult and expensive wintertime repair jobs.

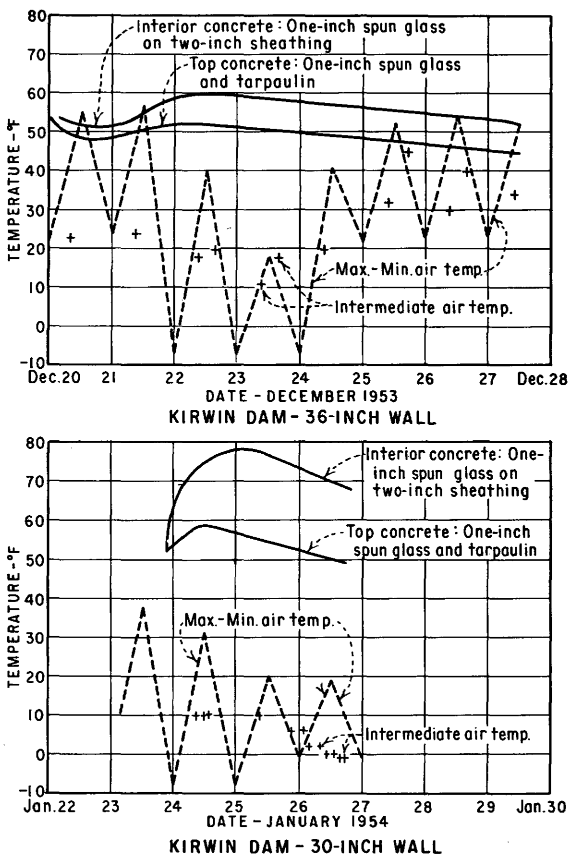


FIGURE 17 — The temperature in walls approximately 30 and 36 inches thick was easily maintained well above freezing. Care should be taken not to over-insulate formed surfaces and not to under-insulate top surfaces, corners, and edges.

Under equal protection and exposure conditions, thin walls will have a lower curing temperature than thick walls because of the higher ratio of surface area to volume. It is doubtful that walls 5 or 6 inches thick, such as those found in small canal and lateral structures, can be protected economically from long periods of continuous subzero air temperature by insulation. However, insulation undoubtedly can be used economically to protect such thin walls when air temperatures are considerably below freezing during the nights but above freezing during the day.

The temperature measurements recorded in Table IV, Placement No. 4, show that on the second day of curing the interior concrete reached a temperature of 98° F. During the moderate air temperature that existed throughout this curing period, the 2-inch rock wool on 3-inch sheathing retained more heat than was desired for good curing. To remedy this condition, the forms were loosened during the second day of curing and the interior concrete temperature dropped 14 degrees in the next 14 hours.

The above data show that both spun glass and rock-wool insulation will successfully protect concrete in walls 12 inches or more thick from freezing and will maintain adequate curing temperature even when exposed to prolonged subzero air temperature. Caution must be exercised not to overinsulate surfaces of massive placements nor to under-insulate top surfaces, edges, and corners.

Siphon Barrels

Temperature measurements of concrete in siphon barrels after 72 hours of protection with job-made rock-wool blankets are tabulated in Table V and shown graphically in Figure 18. Concrete temperature was measured near both inside and outside surfaces by inserting a thermometer in form tie holes. Outside concrete temperatures averaged 2° to 3° F lower than those of the inside, and were used in the time-tempera-

TABLE IV

COLD WEATHER CONCRETING--TRENTON DAM
TEMPERATURE RECORD 1951

CONCRETE IN WALLS
Average Mix Quantities for Winter Season

Aggregate Grading (%)				Water lbs/cy	Cement lbs/cy	W/C	Air (%)	Slump In.
Sand	#4-3/4	3/4-1-1/2	1-1/2-3					
30	23	24	23	241	473	.53	4 to 5	2-3/4

Temperature of fresh concrete controlled by heating mix water.
Two inches of rock-wool batts attached to outside of 3-inch sheathing.

No.	PLACEMENT DATA: Pertinent conditions during concrete placement	PROTECTION DATA: Time of temp. measurements: Date	Hour	Concrete temperature degree F: Top	Interior	Corner	Daily air temp. °F: Max.	Min.
1	Time: Oct. 31, finished 11:00 p	Nov. 1	3:00 p	64	68	48	30	23
	Avg. temp. of concrete: 37° F	Nov. 2	8:00 a	58	78	48	45	-1
	Avg. temp. of air: 38° F	Nov. 2	6:00 p	58	76	48	45	-1
	Avg. thickness of wall: 14½"	Nov. 3	7:30 a	54	76	50	51	22
	Ca Cl_2: 1%	Nov. 4	7:30 a	54	68	47	52	21
		Nov. 4	10:00 a	Forms removed			52	21
		Nov. 5	8:00 a	32	46	32	46	22
		Nov. 5	5:30 p	45	41	40	46	22
		Nov. 6	8:00 a	36	39	36	48	21
2	Time: Nov. 6, finished 6:30 p	Nov. 7	8:30 a	62	67	48	56	25
	Avg. temp. of concrete: 48° F	Nov. 7	5:30 p	70	74	64	56	25
	Avg. temp. of air: 44° F	Nov. 8	8:00 a	70	76	52	70	28
	Avg. thickness of wall: 14½"	Nov. 8	5:30 p	67	74	65	70	28
	Ca Cl_2: 1%	Nov. 9	8:00 a	74	82	56	68	30
		Nov. 9	2:00 p	Forms removed			68	30
		Nov. 9	6:30 p	64	70	60	68	30
		Nov. 10	8:00 a	38	54	34	72	32
		Nov. 10	5:30 p	62	60	59	72	32
		Nov. 11	--	--	--	--	65	31
		Nov. 12	8:00 a	38	45	36	70	35
		Nov. 12	5:00 p	59	56	58	70	35
3	Time: Nov. 23, finished 6:30 p	Nov. 24	8:00 a	56	65	47	40	26
	Avg. temp. of concrete: 60° F	Nov. 25	8:15 a	68	76	52	52	20
	Avg. temp. of air: 44° F	Nov. 25	5:30 p	70	82	52	52	20
	Avg. thickness of wall: 14½"	Nov. 26	8:00 a	66	85	50	62	26
	Ca Cl_2: 1%			Forms removed			62	26
		Nov. 26	5:00 p	60	64	54	62	26
		Nov. 27	8:00 a	36	46	32	58	25
4	Time: Nov. 27, finished 8:00 p	Nov. 28	8:00 a	72	96	66	62	29
	Avg. temp. of concrete: 66° F	Nov. 28	5:30 p	74	92	70	62	29
	Avg. temp. of air: 57° F	Nov. 29	8:00 a	73	95	67	62	30
	Avg. thickness of wall: 14½"	Nov. 29	5:30 p	73	98	68	62	30
	Ca Cl_2: 1%		Forms loosened to cool concrete					
		Nov. 30	8:00 a	69	84	63	63	21
				Forms removed				
		Dec. 1	8:00 a	48	56	46	41	37

TABLE IV (continued)

PLACEMENT DATA		PROTECTION DATA						
No.	Pertinent conditions during concrete placement	Time of temp. measurements: Date	Hour	Concrete temperature degree F: Top	In terior	Corner	Daily air temp. °F: Max.	Min.
5	Time: Dec. 5, finished 8:30 p	Dec. 6	8:00 a	56	66	52	38	22
	Avg. temp. of concrete: 52° F	Dec. 6	6:00 p	58	70	50	38	22
	Avg. temp. of air: 48° F	Dec. 7	8:00 a	60	74	52	48	26
	Avg. thickness of wall: 14½"	Dec. 7	5:30 p	56	74	54	48	26
	Ca Cl_2: 1%	Dec. 8	8:00 a	56	74	44	48	32
		Dec. 8	5:30 p	50	76	52	48	32
		Dec. 9	10:00 a	44	66	34	31	10
				Forms removed				
		Dec. 10	8:00 a	38	44	36	40	14
		Dec. 11	8:00 a	30	32	27	40	22
		Dec. 12	8:00 a	43	40	42	52	30
6	Time: Dec. 12, finished 7:00 p	Dec. 13	8:00 a	66	--	60	42	24
	Avg. temp. of concrete: 62° F	Dec. 13	4:00 p	70	85	58	42	24
	Avg. temp. of air: 42° F	Dec. 14	8:00 a	--	84	48	34	4
	Avg. thickness of wall: 19"	Dec. 14	5:00 p	--	78	46	34	4
	Ca Cl_2: 1%	Dec. 15	8:00 a	--	77	42	20	-4
		Dec. 16	--	--	--	--	17	-3
		Dec. 17	8:00 a	--	66	36	39	3
		Dec. 17	4:00 p	--	67	34	39	3
		Dec. 18	8:00 a	--	58	36	30	2
		Dec. 18	5:00 p	--	52	34	30	2
				Forms removed				

ture plot of Figure 18. Permanent temperature records were not maintained on all of the concrete placed throughout the time span shown on the figure, making the graph discontinuous. A total of approximately 3,220 cubic yards of concrete was protected by the blankets during the season.

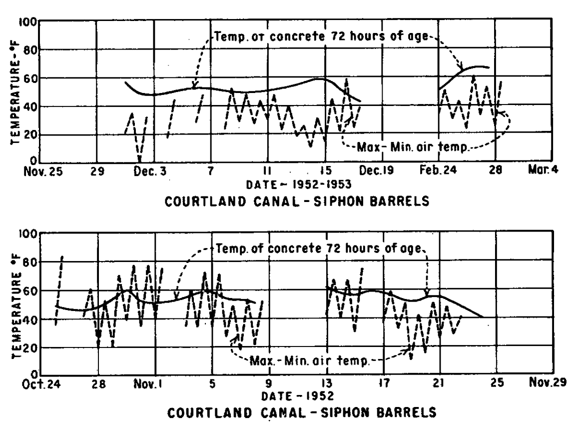


FIGURE 18 -- The temperature of concrete in monolithic siphons was maintained well above freezing and uniform, using rock wool insulation blankets approximately 1 inch thick. The siphons were 10.5 feet diameter with walls 10½ to 14½ inches thick.

The data show that the job-made rock-wool blankets maintained the temperature of concrete in the barrels comparatively uniform and well above freezing; and in a great majority of barrels, the specified temperature of 50° F was continuously maintained. No difficulty was experienced in stripping the forms 12 hours after placement, but several barrels were damaged when the steel forms were reset for adjacent placements. The damage was avoided by waiting 24 hours before resetting the forms.

Approximately 96 percent of the concrete temperature measurements made near the inside of the barrels and 82 percent of the readings obtained near the outside of the barrels were 50° F or above. Only one temperature of 40° F was observed, the next lowest was 46° F. From these results, it appears that the approximate 1-inch thick rock-wool blankets are generally sufficient to protect siphons from freezing temperatures, but that caution must be used in applying form pres-

TABLE V

COLD WEATHER CONCRETING--COURTLAND CANAL
TEMPERATURE RECORD 1952-53

CONCRETE IN SIPHON BARRELS

Barrels 10-1/2 foot diameter. Thickness of barrels varied from 10-1/2 to 14-1/2 inches

Average Mix Quantities							
Aggregate Grading (%)			Water	Cement		Air	Slump
Sand	#4-3/4	3/4-1-1/2	lbs/cy	lbs/cy	W/C	(%)	In.
38	31	31	269	554	.49	4 to 5	3

Temperature of fresh concrete controlled by heating mix water. One inch thick rock-wool mats placed over siphon barrels. During extremely cold weather butane burners provided supplementary heat prior to stripping forms.

	Avg. concrete temp. °F			Air temp. °F		
		72 hours of age		At	Daily	
Date	Fresh	Inside	Outside	Placement	Max.	Min.
Oct. 25	75	53	49	70	84	35
Oct. 27	67	49	46	61	61	42
Oct. 28	60	52	48	43	52	21
Oct. 29	65	58	54	63	70	20
Oct. 30	65	63	60	72	77	39
Oct. 31	75	55	52	70	77	35
Nov. 1	70	53	51	65	75	40
Nov. 3a	55	55	55	50	59	18
Nov. 3p	65	65	51	65	59	18
Nov. 4a	60	61	58	65	72	34
Nov. 4p	70	66	60	72	72	34
Nov. 5a	60	60	58	68	70	35
Nov. 5p	67	62	56	65	70	35
Nov. 6	50	56	53	48	51	27
Nov. 7	53	56	54	53	53	18
Nov. 8	48	52	51	50	51	22
Nov. 13a	60	62	62	55	67	42
Nov. 13p	66	60	59	60	67	42
Nov. 14a	60	58	57	60	66	39
Nov. 14p	63	59	56	60	66	39
Nov. 15a	60	58	56	63	75	30
Nov. 15p	77	61	59	70	75	30
Nov. 17	56	59	57	52	58	37
Nov. 18a	64	57	55	42	49	33
Nov. 18p	65	55	50	46	49	33
Nov. 19a	60	55	52	40	42	6
Nov. 19p	55	55	50	42	42	6
Nov. 20a	68	60	57	48	53	17
Nov. 20p	62	58	54	49	53	17
Nov. 21	63	62	56	44	48	24
Nov. 22	63	53	50	41	41	29
Nov. 24	58	47	40	33	34	29
Dec. 1	58	56	56	35	35	21
Dec. 2	56	51	48	32	32	1
Dec. 4	60	51	49	42	45	18

TABLE V (continued)

Date	Avg. concrete temp. °F			Air temp. °F		
		72 hours of age		At	Daily	
	Fresh	Inside	Outside	Placement	Max.	Min.
Dec. 6	60	57	52	46	48	28
Dec. 8	68	52	50	52	52	23
Dec. 9	68	-	-	53	48	29
Dec. 10	65	52	49	43	43	27
Dec. 11	68	57	57		48	30
Dec. 12	66	52	49	43	43	23
Dec. 13	60	57	55	26	26	18
Dec. 15	66	60	58	-	46	14
Dec. 16	70	52	48	50	61	21
Dec. 17	58	52	46	42	40	24
Feb. 24	60	54	50	35	50	33
Feb. 25	62	60	-	46	44	30
Feb. 26	68	64	66	58	60	23
Feb. 27	66	60	66	48	55	33

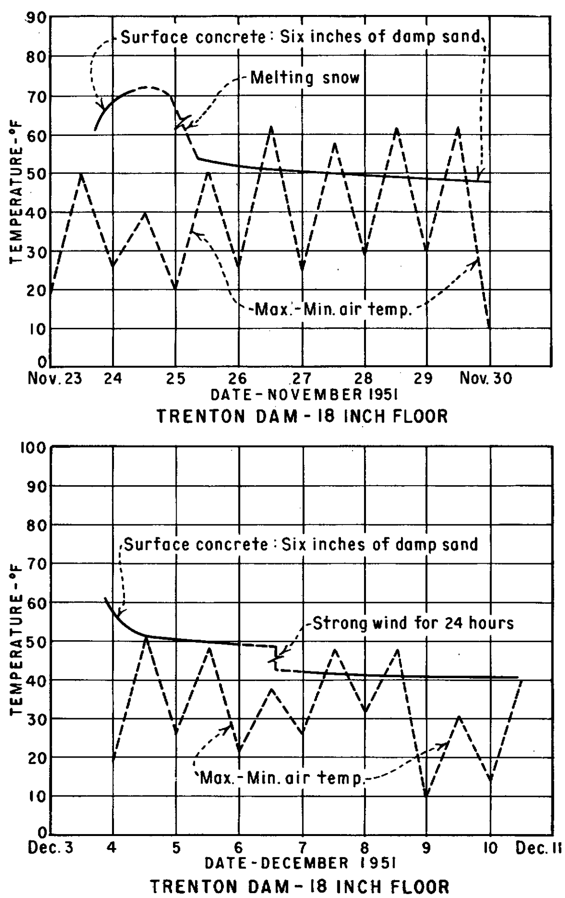


FIGURE 19 -- Protecting floor slabs from low temperature with a 6-inch cover of sand prevented freezing the concrete, but the surface temperature of the concrete was noticeably affected by strong wind and melting snow.

sures to concrete cured at approximately 50° F for less than 3 days.

The fact that siphons are usually constructed below surrounding ground levels, protected from winds, makes them especially suited for protection with insulation. It is very doubtful that the 1-inch rock-wool blankets would provide adequate protection for similar structures exposed to winter winds.

Floor Slabs

Floor panels for Trenton Dam spillway were protected from freezing with a blanket of damp sand. Placing of floor panels was not started until afternoon to permit thawing of frost in the pervious foundation blanket. Sealing compound was applied immediately after the concrete was finished and a prefabricated canvas shelter set in place over the panel. Airplane heaters were used to maintain the required temperature until the concrete hardened. The shelter was then removed and a 6-inch blanket of sand was placed on the concrete surface. Table VI and Figure 19 show that the sand blanket maintained the concrete temperature well above freezing but permitted a rapid drop of temperature when exposed to melting snow and strong winds.

There are little data available on the use of commercial insulation blankets on floor slabs, but it is believed that a durable mat or spun glass or rock wool, protected from foot traffic and weather by a canvas or duck

TABLE VI

COLD WEATHER CONCRETING--TRENTON DAM
TEMPERATURE RECORD 1951

CONCRETE IN FLOORS
Slab Size: 18" x 30' x 35'

Average Mix Quantities for Winter Season								
Aggregate Grading (%)				Water	Cement		Air	Slump
Sand	#4-3/4	3/4-1-1/2	1-1/2-3	lbs/cy	lbs/cy	W/C	(%)	In.
30	23	24	23	241	473	.53	4 to 5	2

Temperature of fresh concrete controlled by heating mix water.
Canvas shelter and airplane heaters protected concrete until final set.
Then a 6" layer of sand was placed on the concrete surface.

No.	PLACEMENT DATA: Pertinent conditions during concrete placement	PROTECTION DATA: Time of temp. measurements: Date	Hour	Temp. °F Concrete in place Surface	Daily air temp. °F Max.	Min.
1	Time: Nov. 20, finished 6:00 p	Nov. 21	8:00 a	51	66	20
	Avg. temp. of concrete: 60° F	Nov. 22	--	--	44	30
	Avg. temp. of air: 42° F	Nov. 23	8:00 a	54	50	19
	Ca Cl_2: 1%	Nov. 24	10:00 a	56	40	26
2	Time: Nov. 23, finished 5:00 p	Nov. 24	8:00 a	72	40	26
	Avg. temp. of concrete: 62° F	Nov. 25	8:15 a	52	52	20
	Avg. temp. of air: 40° F	Snowed 2" Nov. 24, melted Nov. 25				
	Ca Cl_2: 1%	Nov. 25	5:30 p	54	52	20
		Nov. 26	5:30 p	52	62	26
		Nov. 27	6:00 p	50	58	25
		Nov. 28	8:00 a	44	62	29
		Nov. 28	5:30 p	54	62	29
		Nov. 29	8:00 a	45	62	30
		Nov. 29	5:30 p	48	62	30
		Nov. 30 – Dec. 10	--	36	63	10
3	Time: Dec. 3, finished 8:30 p	Dec. 4	8:00 a	50	51	19
	Avg. temp. of concrete: 61° F	Dec. 5	8:00 a	49	48	26
	Avg. temp. of air: 48° F	Dec. 5	7:00 p	52	48	26
	Ca Cl_2: 1%	Dec. 6	8:00 a	50	38	22
		Strong wind for 24 hours				
		Dec. 7	8:00 a	42	48	26
		Dec. 7	5:30 p	40	48	26
		Dec. 8	8:00 a	42	48	32
		Dec. 9	10:00 a	40	31	10
		Dec. 10	8:00 a	42	40	14
4	Time: Dec. 7, finished 5:00 p	Dec. 8	8:00 a	34	48	32
	Avg. temp. of concrete: 52° F	Heater broke down during night				
	Avg. temp. of air: 46° F	Dec. 8	5:30 p	48	48	32
	Ca Cl_2: 1%	Dec. 9	10:00 a	47	31	10
		Dec. 10	8:00 a	42	40	14
		Dec. 10	5:30 p	46	40	14
		Dec. 11	--	--	40	22
		Dec. 12	8:00 a	46	52	30
		Dec. 12	5:30 p	51	52	30
		Dec. 13	8:00 a	47	42	24
		Dec. 14	8:00 a	43	34	4

TABLE VII

COLD WEATHER CONCRETING--KIRWIN DAM
TEMPERATURE RECORD 1953-54

MASS CONCRETE IN CREST

Average Mix Quantities Throughout Season									
Aggregate Grading (%)					Water	Cement		Slump	Air
Sand	#4-3/4	3/4-1-1/2	1-1/2-3	3-6	lbs/cy	lbs/cy	W/C	In.	(%)
24	15	20	20	21	151	274	.55	2-1/2	4.9

Temperature of fresh concrete controlled by heating mix water.
One inch spun glass attached to 2 inches of sheathing covering formed surfaces.
One inch spun glass blankets covering unformed surfaces.

	PLACEMENT DATA	PROTECTION DATA						
	Pertinent conditions during concrete placement	Time of temp. measurements		Temp. °F Concrete in place		Air	Daily air temp. °F	
No.		Date	Hour	Top	Interior	*	Max.	Min.
1	Time: Dec. 22 and Dec. 23	Dec. 23					18	-07
	10:00 a to 11:30 p	Dec. 24	9:30 a	50		18	18	-07
	Avg. temp. of concrete: 50° F	Dec. 24	4:00 p	50		18	18	-07
	Avg. temp. of air: 10° F	Dec. 25	9:30 a	50		32	52	22
	Height of lift: 6 ft.	Dec. 25	4:00 p	54		45	52	22
	Quantity placed: 644 cy	Dec. 26	9:00 a	50		28	54	23
	Ca Cl_2: 1%	Dec. 26	4:00 p	58		40	54	23
		Dec. 27	10:00 a	50		36	51	23
2	Time: Dec. 29, 1:30 p to 5:00 a	Dec. 29					47	16
	Avg. temp. of concrete: 50° F	Dec. 30	8:30 a	48		24	39	11
	Avg. temp. of air: 24° F	Dec. 30	3:30 p	51		30		11
	Height of lift: 2.5 ft.	Dec. 31	8:30 a	58		31		15
	Quantity placed: 655 cy							
	Ca Cl_2: 1%							
3	Time: Jan. 12, 11:15 a to 5:00 p	Jan. 12					31	-09
	Avg. temp. of concrete: 48° F	Jan. 13	8:30 a	48	50	18	20	-08
	Avg. temp. of air: 18° F	Jan. 13	4:00 p	48	51	18	20	-08
	Height of lift: 5 ft.	Jan. 14	8:45 a	48	53	28	34	-09
	Quantity placed: 87 cy	Jan. 15	9:00 a	50	55	26	27	15
	Ca Cl_2: 1%	Jan. 15	3:00 p	52	54	24	27	15
	Temp. of water: 160° F							
	Temp. of aggregates: 26° F							
4	Time: Jan. 15, 10:00 a to 12:35 p	Jan. 15	11:30 a	45	60	16	27	15
	Avg. temp. of concrete: 47° F	Jan. 16	8:30 a	38	62	3	28	-03
	Avg. temp. of air: 30° F	Jan. 16	4:30 p	42	60	10	28	-03
	Height of lift: 5 ft.	Jan. 17	8:30 a	38	58	30	21	-01
	Quantity placed: 33 cy	Jan. 17	3:20 p	44	61	37	21	-01
	Ca Cl_2: 1%							
	Temp. of water: 170° F							
	Temp. of aggregates: 26° F							
5	Time: Jan. 19, 12:15 p to 3:25 a	Jan. 19					30	12
	Avg. temp. of concrete: 54° F	Jan. 20	8:10 a	43	46	5	33	-04
	Avg. temp. of air: 34° F	Jan. 20	1:00 p	42	46	9	33	-04
	Height of lift: 4 ft.	Jan. 20	3:30 p	44	46	6	33	-04
	Quantity placed: 338 cy	Jan. 20	8:30 p	44	48	0	33	-04
	Ca Cl_2: 1%	Jan. 20	10:30 p	44	50	-03	33	-04
	Temp. of water: 180° F	Jan. 21	12:30 a	46	50	-04	7	-06
	Temp. of aggregates: 31° F	Jan. 21	2:30 a	44	50	-04	7	-06
		Jan. 21	4:00 a	40	50	-06	7	-06
		Jan. 21	8:30 a	50	51	6	7	-06
		Jan. 21	3:30 p	47	55	16	7	-06
		Jan. 21	8:30 p	46	55	18	7	-06
		Jan. 21	10:30 p	44	52	6	7	-06
		Jan. 22	12:30 a	42	50	4	18	-04
		Jan. 22	2:00 a	40	50	-02	18	-04
		Jan. 22	4:00 a	40	50	-03	18	-04

TABLE VII (continued)

PLACEMENT DATA		PROTECTION DATA						
No.	Pertinent conditions during concrete placement	Time of temp. measurements: Date	Hour	Temp. °F Concrete in place: Top	Interior	Air *	Daily air temp. °F: Max.	Min.
		Jan. 22	9:00 a	54	53	10	18	-04
		Jan. 22	3:30 p	54	55	11	18	-04
		Jan. 22	8:30 p	50	52	16	18	-04
		Jan. 22	10:30 p	50	52	--	18	-04
		Jan. 23	12:30 a	50	52	--	38	-02
		Jan. 23	2:30 a	50	52	--	38	-02
		Jan. 23	4:00 p	50	52	--	38	-02
		Jan. 24	12:30 a	54	54	--	32	-08
		Jan. 24	8:30 a	55	55	10	32	-08
		Jan. 24	10:30 a	55	55	10	32	-08
		Jan. 24	1:00 p	55	55	10	32	-08
		Jan. 24	3:00 p	54	54	10	32	-08
		Jan. 24	4:00 p	54	54	10	32	-08
		Jan. 24	9:00 p	50	51	8	32	-08
		Jan. 24	11:00 p	50	50	8	32	-08
		Jan. 25	1:30 a	50	52	6	20	-08
		Jan. 25	3:30 a	50	53	6	20	-08
		Jan. 25	9:00 a	50	52	2	20	-08
		Jan. 25	11:00 a	50	53	2	20	-08
		Jan. 25	1:00 p	50	53	0	20	-08
		Jan. 25	3:30 p	50	52	0	20	-08
6	Time: Jan. 27 and Jan. 28	Jan. 27					17	-01
	2:15 p to 11:00 p	Jan. 28					48	2
	Avg. temp. of concrete: 60° F	Jan. 29	1:00 a	55	58	27	60	24
	Avg. temp. of air: 30° F	Jan. 29	3:00 a	54	58	26	60	24
	Height of lift: 3 ft.	Jan. 29	5:00 a	55	63	25	60	24
	Quantity placed: 921 cy	Jan. 29	8:00 a	52	60	32	60	24
	$CaCl_2$: 1%	Jan. 29	2:30 p	52	62	32	60	24
	Temp. of water: 130° F	Jan. 30	1:00 a	52	66	30	65	28
	Temp. of aggregates: 26° F	Jan. 30	3:00 a	53	67	29	65	28
		Jan. 30	5:00 a	54	67	28	65	28

*Temperature of air measured simultaneously with temperature of concrete.

cloth, would be superior to earth blankets, both for protection and for ease of handling. Also, it could be placed much sooner than earth blankets without marring the fresh concrete surface.

Massive Concrete Structures

All insulation materials for which temperature observations were made satisfactorily maintained the temperature of concrete well above freezing. The lower graph in Figure 20 shows the effect of low night subzero air temperature on the fresh concrete at Kirwin Dam before protection was applied. The placement started at 12:15 p.m., January 19, and was not completed until 3:25 a.m., January 20, 1954.

The temperature of mass concrete in Kirwin Dam spillway, protected by 1-inch spun glass, was strikingly uniform despite wide variations in air temperature, and its lower range of curing temperature, shown in Figure 20 and Table VII, is an asset because such concrete will have less tendency to crack when subjected to low temperatures after protection is removed. The early strength requirements of mass concrete are small compared to that of thin sections.

Rock wool satisfactorily protected both formed and unformed surfaces of massive bridge piers and columns at Trenton Dam, shown in Figure 21. Temperature of concrete was checked as the work progressed, but a permanent record was not maintained.

Figure 22 and Table VIII show that 1/2-inch fiberboard with a 3/4-inch dead air space was more than adequate protection for formed surfaces of mass concrete of the Flatiron

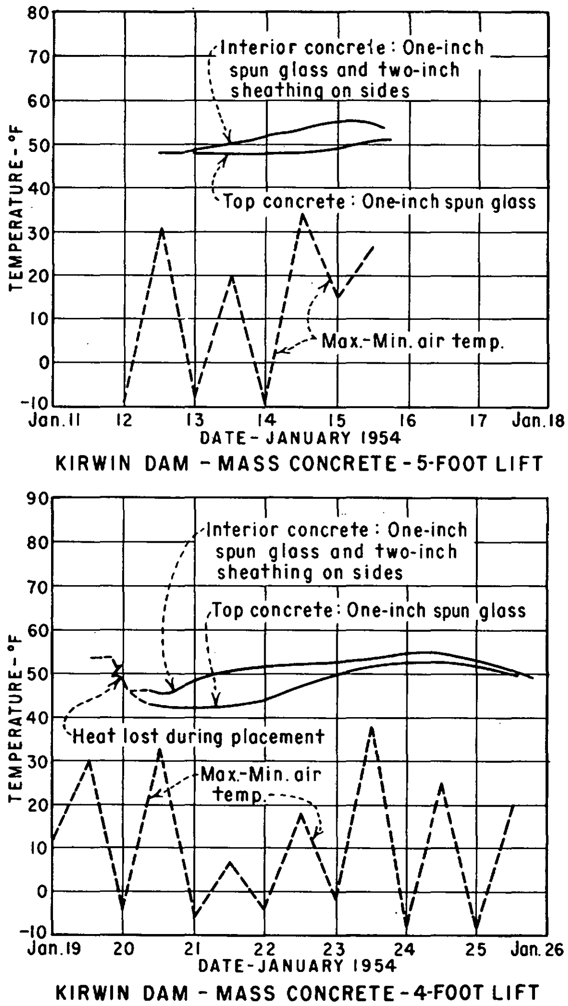


FIGURE 20 -- The temperature of concrete in massive spillway blocks was uniformly maintained well above freezing despite sub-zero air temperature by use of spun glass insulation, Note heat lost during long cold night placement on January 19, 1954.

Afterbay Dam under comparatively mild air temperatures. The high surface temperature shown in the figure may be avoided by loosening forms. Note also that the temperature of concrete near corners and edges was considerably less than that of interior face concrete.

The performance of balsam wool in protecting concrete in massive bridge piers is shown in Figure 23. This figure was compiled from data furnished by the South Dakota State Highway Commission. It shows that ample curing temperatures were obtained. The high temperatures developed near the fourth day are not objectionable considering the fact that the forms were left in place for 15 days and the concrete cooled at a very conservative rate.

Sisalkraft paper covered with 6 inches of straw and a tarpaulin successfully protected unformed surfaces of Flatiron Afterbay Dam. Temperature of concrete was checked as the work progressed, but a permanent record was not maintained.

Wood shavings successfully protected both formed and unformed surfaces of Hungry Horse Dam. Temperature data are presented in the 1952 Proceedings of the American Concrete Institute, page 256.

The performance of damp sand and silt blankets in protecting horizontal mass con-

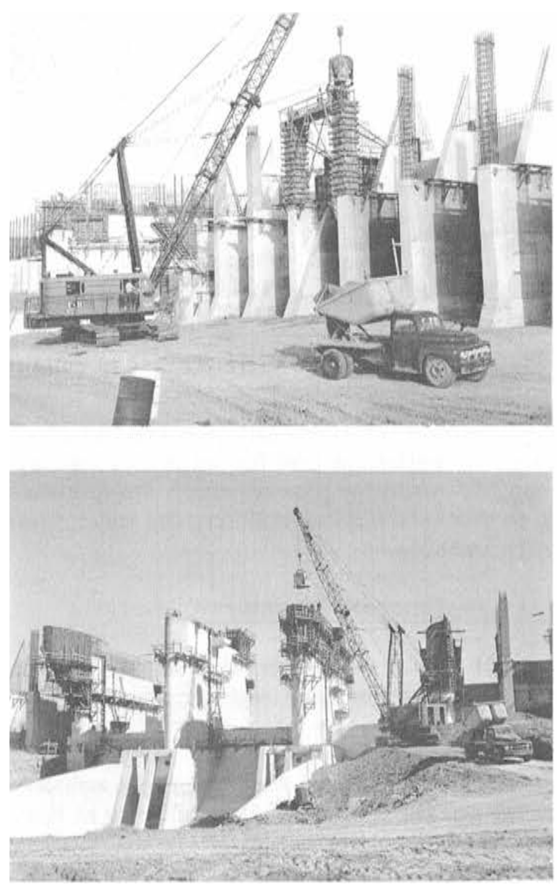


FIGURE 21 -- Rock wool insulation bats fastened to the outside of the form sheathing were successfully used to protect these massive bridge columns and piers from freezing temperature.

TABLE VIII

COLD WEATHER CONCRETING--COLORADO-BIG THOMPSON PROJECT JANUARY 1952

CONCRETE IN SPILLWAY

Average Mix Quantities

Aggregate Grading (%)				Water	Cement		Slump	Air
Sand	#4-3/4	3/4-1-1/2	1-1/2-3	lbs/cy	lbs/cy	W/C	In.	(%)
34	20	23	23	255	556	.46	2	4.0

One-half inch fiber board, with 3/4-inch dead air space next to form.

PLACEMENT DATA	PROTECTION DATA						
Pertinent conditions during concrete placement	Date temp. measured	Age of concrete	Temperature °F of concrete			Daily air temp. °F	
			Interior	Edge	Corner	Max.	Min.
Date: Jan. 8, 1952	Jan. 9	1	66	62	62	31	6
Avg. temp. of concrete: 50° F	Jan. 10	2	78	64	62	48	8
Height of lift: 10.9 ft.	Jan. 11	3	100	78	64	52	22
Quantity placed: 100 cy	Jan. 12	4	98	78	64	52	24
$CaCl_2$: 1%	Jan. 13	5	90	70	60	56	36
	Jan. 14	6	84	64	58	42	26

Weather notes: Skies clear all 6 days.
Windy on Jan. 9 and Jan. 14.
Calm Jan. 10 through Jan. 13.

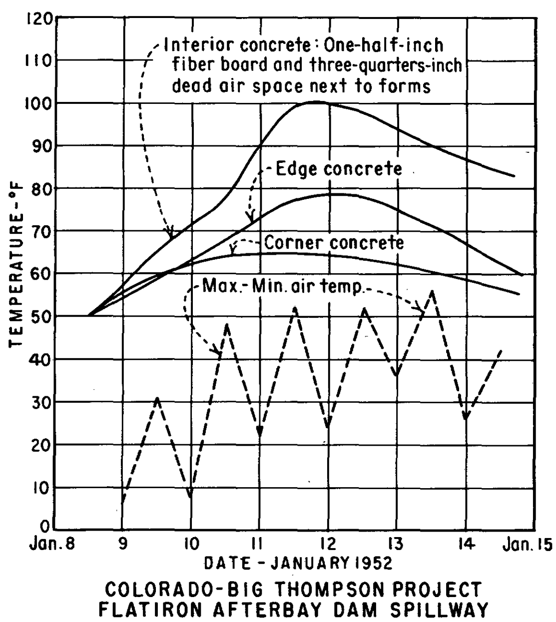


FIGURE 22 -- The temperature of massive concrete adjacent to forms insulated with 1/2-inch fiber board and a 3/4-inch dead air space was higher than desired under the air temperatures shown above. Unformed surface of overflow protected with Sisalkraft paper, 6 inches of straw, and a tarpaulin.

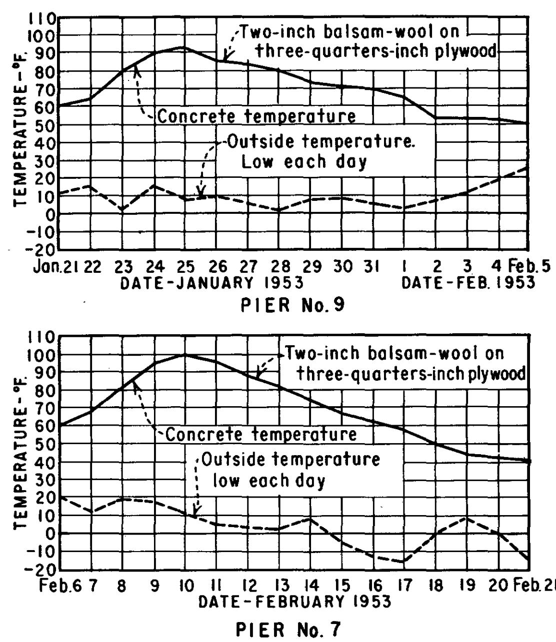


FIGURE 23 -- The concrete temperature in massive piers was maintained well above freezing for 15 days by use of 2-inch balsam wool insulation on 3/4-inch plywood.
(Substructure Missouri River Bridge, Chamberlain, So. Dak., courtesy So. Dakota State Highway Commission.)

TABLE IX

COLD WEATHER CONCRETING--TRENTON DAM
TEMPERATURE RECORD 1951

MASS CONCRETE IN GATE STRUCTURE
Average Mix Quantities for Winter Season

Aggregate Grading (%)				Water	Cement		Air	Slump
Sand	#4-3/4	3/4-1-1/2	1-1/2-3	lbs/cy	lbs/cy	W/C	(%)	In.
29	23	25	23	241	446	.54	4 to 5	2

Temperature of fresh concrete controlled by heating mix water.
Formed sides of panels protected by canvas and heaters.
Protection for tops of panels noted below.

PLACEMENT DATA		PROTECTION DATA				
	Pertinent conditions during concrete placement	Time of temp. measurements		Temp. °F Concrete in place	Daily air temp. °F	
No.		Date	Hour	Surface	Max.	Min.
1	Time: Nov. 19, finished 12:30 p	Nov. 20	8:00 a	56	64	26
	Avg. temp. of concrete: 58° F	Nov. 21	8:00 a	61	66	20
	Avg. temp. of air: 46° F	Nov. 22	--	--	44	30
	Panel size: 3' x 37-1/2' x 66'	Nov. 23	8:00 a	76	50	19
	Ca Cl_2: None	Nov. 24	8:00 a	72	40	26
		Nov. 25	8:15 a	72	52	20
Panel covered with 10 inches of loose impervious soil 1-1/2 hours after finishing.						
2	Time: Nov. 21, finished 9:35 p	Nov. 23	8:30 a	70	50	19
	Avg. temp. of concrete: 56° F	Nov. 24	8:00 a	60	40	26
	Avg. temp. of air: 51° F	Snowed 2" Nov. 24, metled Nov. 25				
	Panel height: 5'	Nov. 25	8:00 a	54	52	20
	Ca Cl_2: None	Nov. 26	8:00 a	50	62	26
		Nov. 27 – Dec. 10	--	63	42	10
Panel protected with canvas shelter and heaters for 40 hours, then covered with 6 inches of damp sand.						
3	Time: Nov. 30, finished 1:30 a	Dec. 1	6:00 a	54	41	37
	Avg. temp. of concrete: 48° F	Dec. 1	5:00 p	60	41	37
	Avg. temp. of air: 41° F	Dec. 2	8:00 a	62	50	20
	Panel height: 5'	Dec. 2	5:30 p	65	50	20
	Ca Cl_2: None	Dec. 3	8:00 a	62	50	20
		Dec. 4	8:00 a	56	51	19
		Dec. 5	8:00 a	58	48	26
		Dec. 6	8:00 a	56	38	22
		Dec. 7	8:00 a	50	48	26
		Dec. 8	5:30 p	52	48	32
		Dec. 9	10:00 a	52	31	10
		Dec. 10	8:00 a	44	40	14
		Dec. 11	--	--	40	22
		Dec. 12	8:00 a	46	52	30
		Dec. 13	8:00 a	47	42	24
		Dec. 14	8:00 a	38	34	4
		Dec. 15	8:00 a	32	20	-4
Panel covered with 6-inch layer of damp sand, 6 hours after finishing.						
4	Time: Dec. 10, finished 3:00 a	Dec. 11	5:30 p	50	40	22
	Avg. temp. of concrete: 44° F	Dec. 12	8:00 a	46	52	30
	Avg. temp. of air: 33° F	Dec. 12	5:30 p	62	52	30
	Panel height: 5'	Dec. 13	8:00 a	58	42	24
	Ca Cl_2: None	Dec. 14	8:00 a	54	34	4
		Dec. 15	8:00 a	53	20	-4
		Dec. 16	--	--	17	-3
		Dec. 17	8:00 a	40	39	3
		Dec. 18	8:00 a	42	30	2
Panel protected by canvas and heaters for 11 hours, then covered with 6-inch layer of damp sand.						

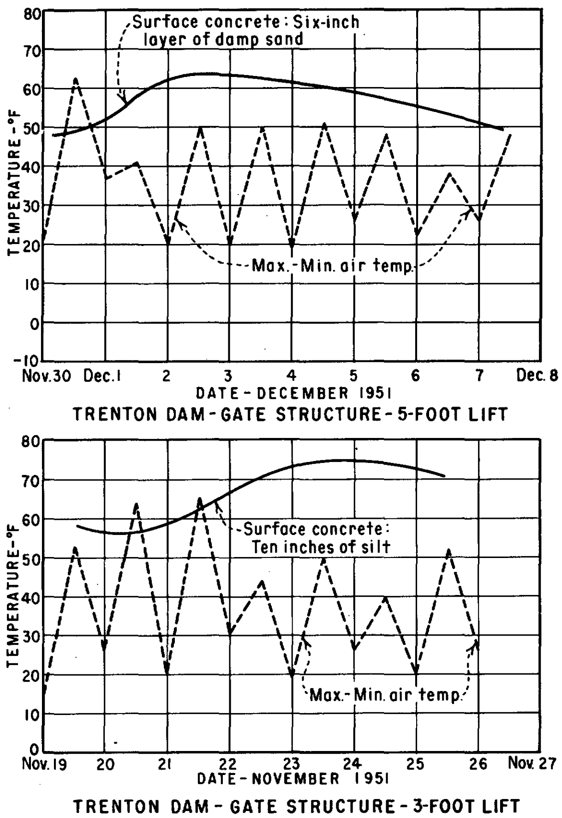


FIGURE 24 -- The surface concrete of a massive gate structure was satisfactorily protected by sand blanket and by silt blanket. The silt probably provides better protection from strong winds and melting snow.

crete surfaces is shown in Figure 24 and tabulated in Table IX. Both were satisfactory. The silt provides better resistance to strong winds and melting snow, but its use in most cases would be limited to concrete surface to be backfilled with impervious material.

CURING CONCRETE PROTECTED BY INSULATION

The use of insulation to protect concrete surfaces to be cured by painting with sealing compound posed no particular problem. When insulated forms were stripped immediately after the required protection period, the concrete surfaces appeared damp, indicating that adequate moisture for curing had been retained during the protection period. After forms were stripped, concrete surfaces were immediately painted with white pigmented sealing compound. Unformed surfaces were sprayed with sealing compound prior to covering with insulation if weather conditions were such that the concrete was not objectionably cooled. During severe freezing weather, the concrete was covered immediately following placement and the sealing compound applied later. The Sisalkraft paper encasement of the spun glass blankets, when in contact with the concrete, kept evaporation of surface moisture to a minimum.

Continuous applications of water to concrete surfaces protected by insulation blankets proved difficult and were usually unnecessary. On the first large mass placement for Kirwin Dam spillway, water was pumped underneath the spun glass blankets. This procedure soon damaged the blankets and caused water and ice to build up in the areas adjacent to the placement. The most satisfactory method used to water-cure was to roll the insulation back in panels and spray the concrete with water and then replace the insulation. Usually one wetting a day would keep the unformed surfaces damp. Wet sand-blasting construction joints proved to be impractical during freezing weather and dry sand-blasting was permitted.

SUMMARY AND CONCLUSIONS

1. Concrete may be satisfactorily protected from freezing temperatures and dry winter winds, in accordance with requirements of current Bureau specifications, by the use of insulated forms and surface blankets. This type of protection is considerably less expensive and is more uniform and reliable than utilizing heated enclosures.

2. The thickness of insulation necessary to maintain the required temperature of concrete depends primarily on:

a. Air temperature and wind velocity

b. Amount of heat generated by cement in setting

c. Surface modulus or ratio of the exposed surface for any part of a structure to its volume

It is not feasible to maintain a variety of insulation types and sizes to accommodate numerous changes in the above factors; but a recognition of these factors will aid in selecting adequate protection at minimum cost.

3. A comparison of the temperatures in Table I with the exposure temperatures that were successfully resisted by the insulation materials, shown in Figures 15 through 24, indicates that in much of the Bureau work area, concrete placed throughout the winter season can be protected economically by insulating the forms and exposed surfaces.

4. The performance records of the insulating materials described above show that top surfaces, edges, and corners of walls are critical points and that considerably more insulation should be provided at these points than for adjacent surfaces.

5. Indications are that for locations with climates similar to that of southern Nebraska or northern Kansas, 1 inch of commercial insulation blanket or bat on 2-inch sheathing or its equivalent will usually be adequate for protecting formed surfaces of walls 12 inches or more thick; 2 inches of commercial insulation blanket or bat or its equivalent will usually be adequate for tops of walls or floor slabs; and 1 inch of commercial insulation blanket or bat or its equivalent will usually be adequate to protect unformed surfaces of mass concrete.

Tables giving computed thickness of insulation for safe protection at various minimum air temperatures are included in the appendix. The derivation of the formulas on which the tables are based is also included.

6. The large number of continually changing conditions that affect the generation and retention of heat in concrete make it advisable to check the temperature of the concrete at regular intervals during the first 3 days after placing. One important advantage of insulating the concrete is that the residual heat does not dissipate rapidly. If the temperature of the concrete is measured twice daily, there is little danger that the temperature will drop to the critical point without ample time to secure additional protection.

7. Contractors' personnel that cooperated in testing various insulating material on the job were unanimous in their preference for the insulation method over heating with enclosures. Kirwin Dam cost data indicated that the cost of using insulation to protect concrete from freezing was only about one-half as much as for providing heated enclosures.

APPENDIX

(Reprinted from Proceedings of the American Concrete Institute, V. 48, 1952.)

The following is a portion of a paper by L. H. Tuthill, R. E. Glover, C. H. Spencer, and W. B. Bierce, "Insulation for Protection of New Concrete in Winter," presented at ACI 48th Annual Convention, 1952.

CALCULATION OF CONCRETE TEMPERATURES

Where plans are made beforehand to use insulation for the protection of concrete to be placed in cold weather, some means of estimating the temperatures which will be maintained in the concrete under the anticipated weather conditions are needed. The graphs of Fig. 27, 28, and 29 have been prepared to supply this need. Before proceeding to a description of these graphs, it will be advisable to explain some of the reasons why

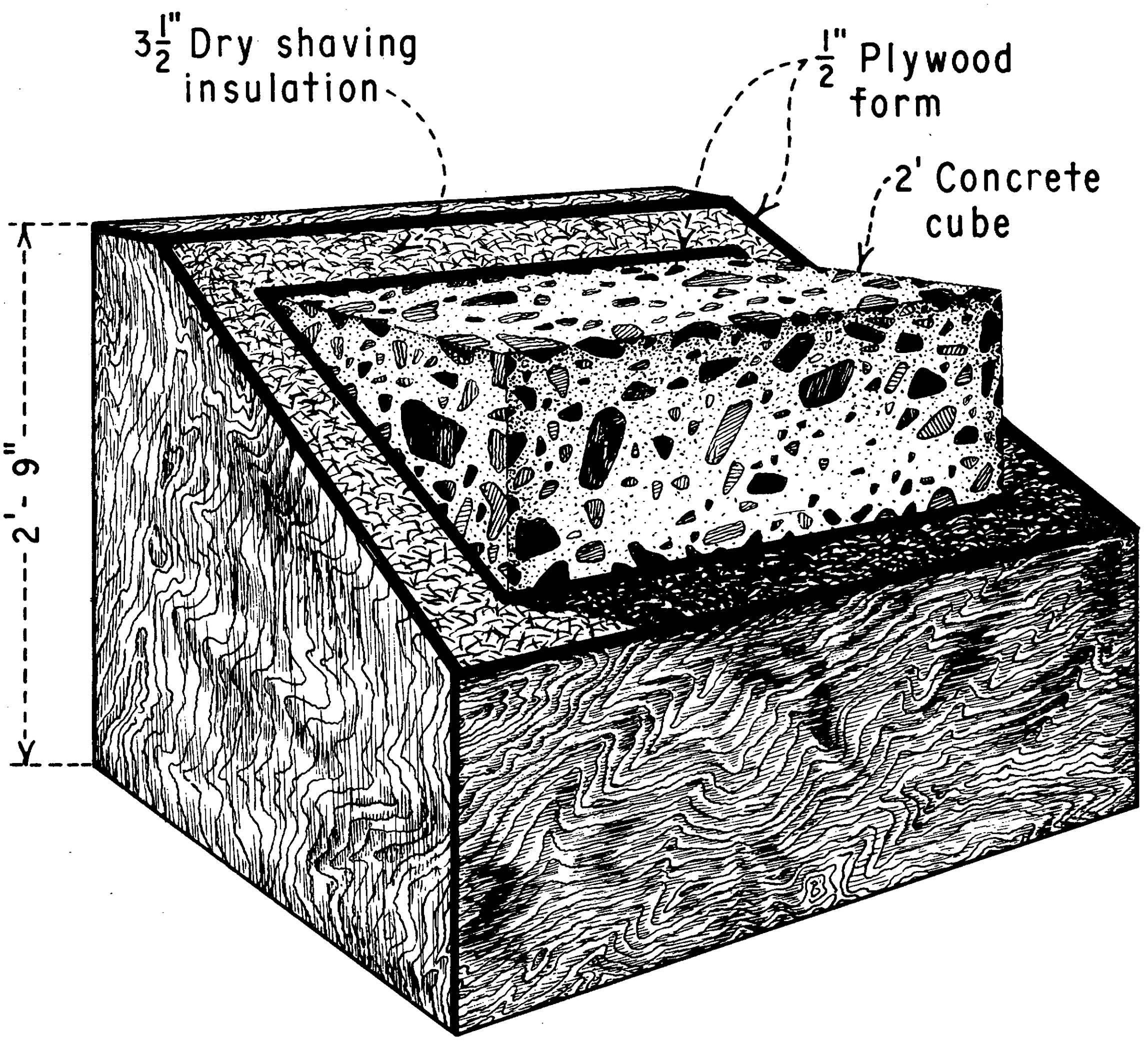


FIGURE 25 -- Cutaway section showing construction of 2-foot block and insulated form tested in laboratory for temperature control. See Fig. 26.

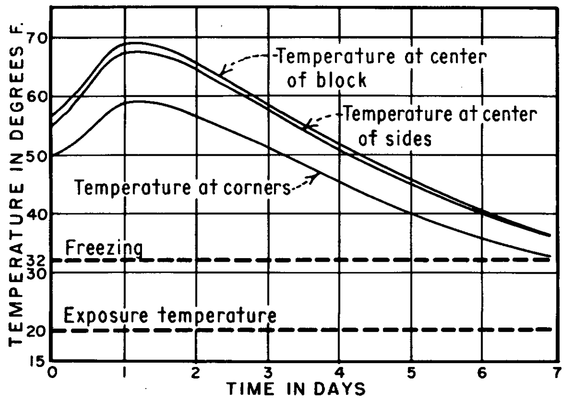


FIGURE 26 -- Insulated form keeps corners of a 2-foot cube above 50° F for 3 days and above freezing for 7 days. Placing temperature 55° F, air temperature 20° F, cement content 6 sacks per cu. yd., form insulation $3\frac{1}{2}$ inches dry shavings. See Fig. 25.

the forms shown were chosen.

The problem of computing temperatures in a solid body involves an unusually large number of variables. These are three dimensions, three coordinate positions, initial, external, and transient concrete temperatures, time, three thermal properties of the concrete, the surface emissivity and, in our case, heat generation within the body. Although mathematical expressions can be obtained which account for nearly all these factors, they are too cumbersome to be attractive for computation purposes. If an attempt is made to graph these expressions, it will be found that the number of variables is so large that none of the common forms for presenting data are adequate. These difficulties have been overcome in the present case by use of a product law. By using this device, graphs for the one-dimensional case can be used for two- and three-dimensional cases by multiplying together values obtained from the graphs. In this way, the number of variables can be reduced so that charts can be prepared provided that the other variables are combined in certain ways. These combinations will be identified in the following descriptions.

Fig. 27 is a graph prepared for a wall of thickness L exposed on both sides. The notation used is as follows:

C = Specific heat of the concrete (Btu per lb per deg F)

E = Surface emissivity. This figure represents the heat loss per unit of area per unit of time per unit of temperature differential between the surface of the concrete and its surroundings (Btu per sq ft per hour per deg F)

$h^2 = \frac{K}{Cp}$ = "Diffusion constant" for the concrete (sq ft per hour)

K = Conductivity of concrete (Btu per ft per hour per deg F)

L = Thickness of the wall (ft)

t = Time (hours)

$U = \frac{\theta}{\theta_o}$ = Ratio of the temperature differential at time t at the point indicated to the original temperature differential. These differentials are the differences between the temperatures at the points indicated and the external temperature. (Dimensionless)

θ_o = Temperature differential at time zero. It is assumed that the temperature is uniform throughout the mass at this time which will, in many cases, be the time of placing the concrete (deg F)

θ = Temperature differential at the time t (deg F)

p = The density of the concrete (lb per cu ft)

In Fig. 27 the variables have been grouped into the combinations h^2t/L^2, EL/K and θ/θ_o or U. If values of the first two of these are at hand for a specific case, we may start on the abscissa with the value h^2t/L^2, follow up the vertical lines until the curve for EL/K is reached, and then go to the left to read U on the ordinate. The value of U so obtained represents the ratio θ/θ_o, where in this case, the temperature θ is surface temperature at time t. Fig. 28 is similar except that the temperature differential θ is at the center of the slab. Fig. 29 gives, in a somewhat similar way, the temperatures at the surface of a mass of great depth. In each case, the solution represents the decay of an initially existing temperature differential toward an external exposure temperature. Temperature differentials are, of course, computed from the relation $\theta = U\theta_o$.

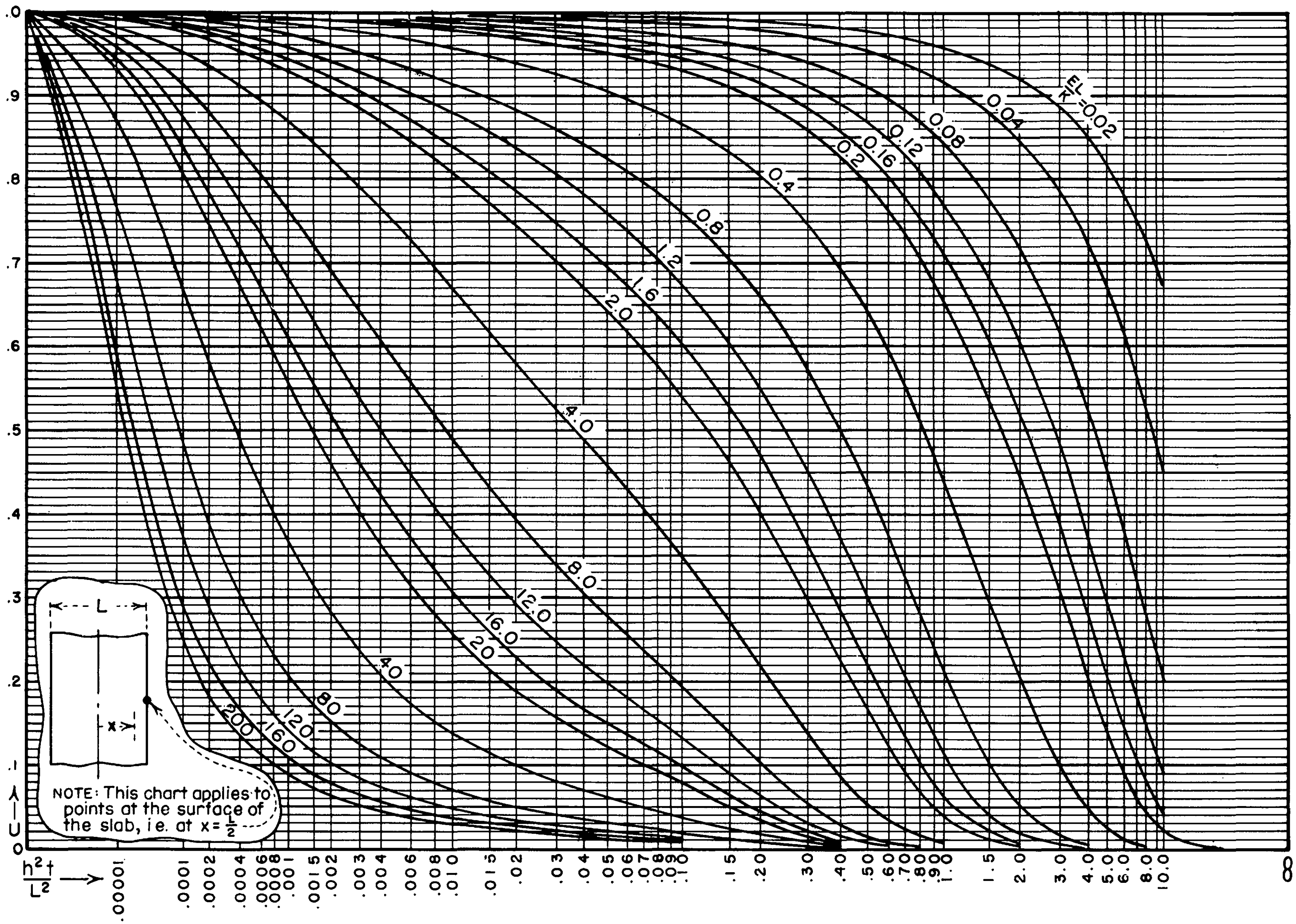


FIGURE 27 -- Plot of U versus h^2t/L^2 for points at the surface of a slab.

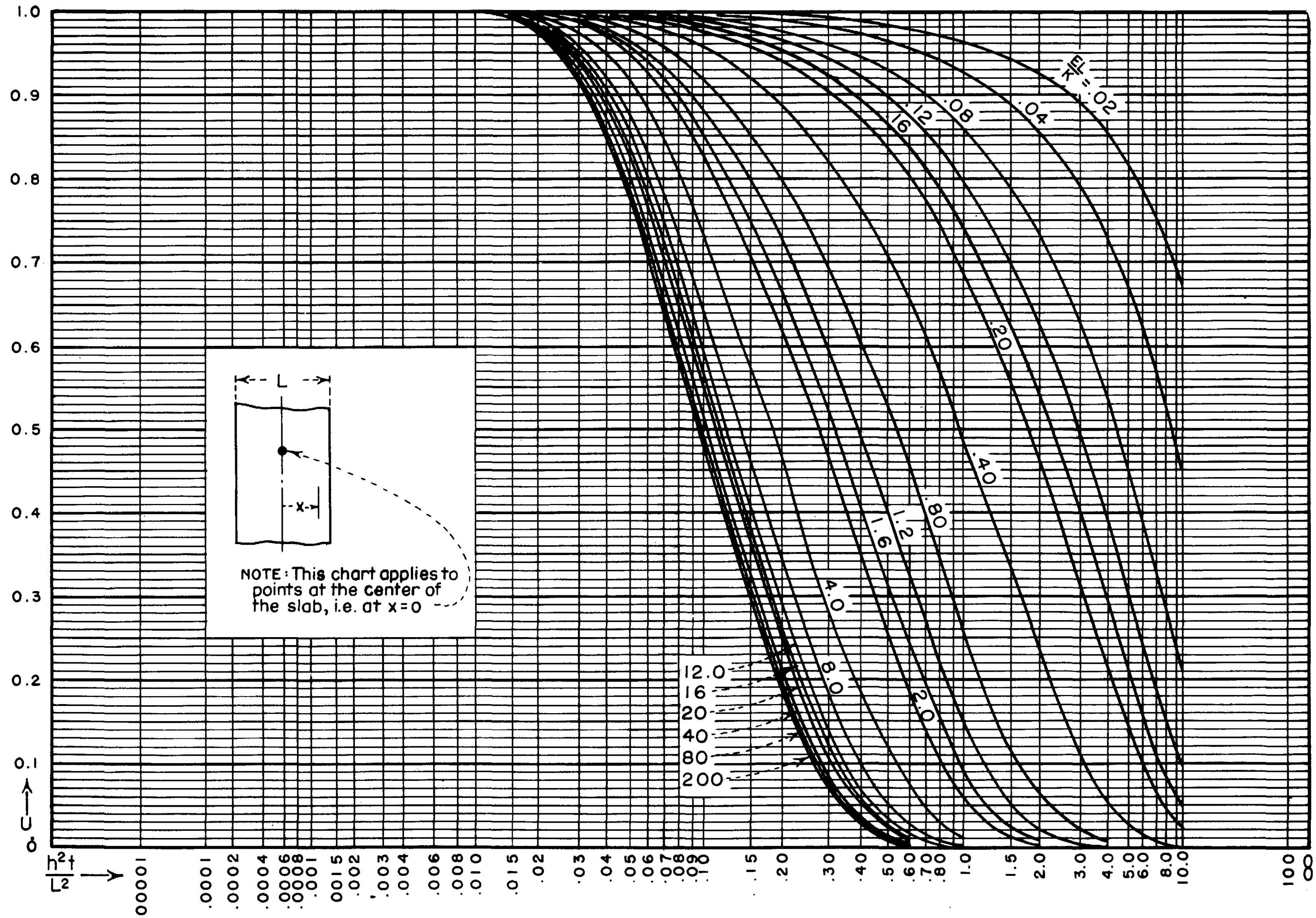


FIGURE 28 -- Plot of U versus h^2t/L^2 for points at the center of a slab.

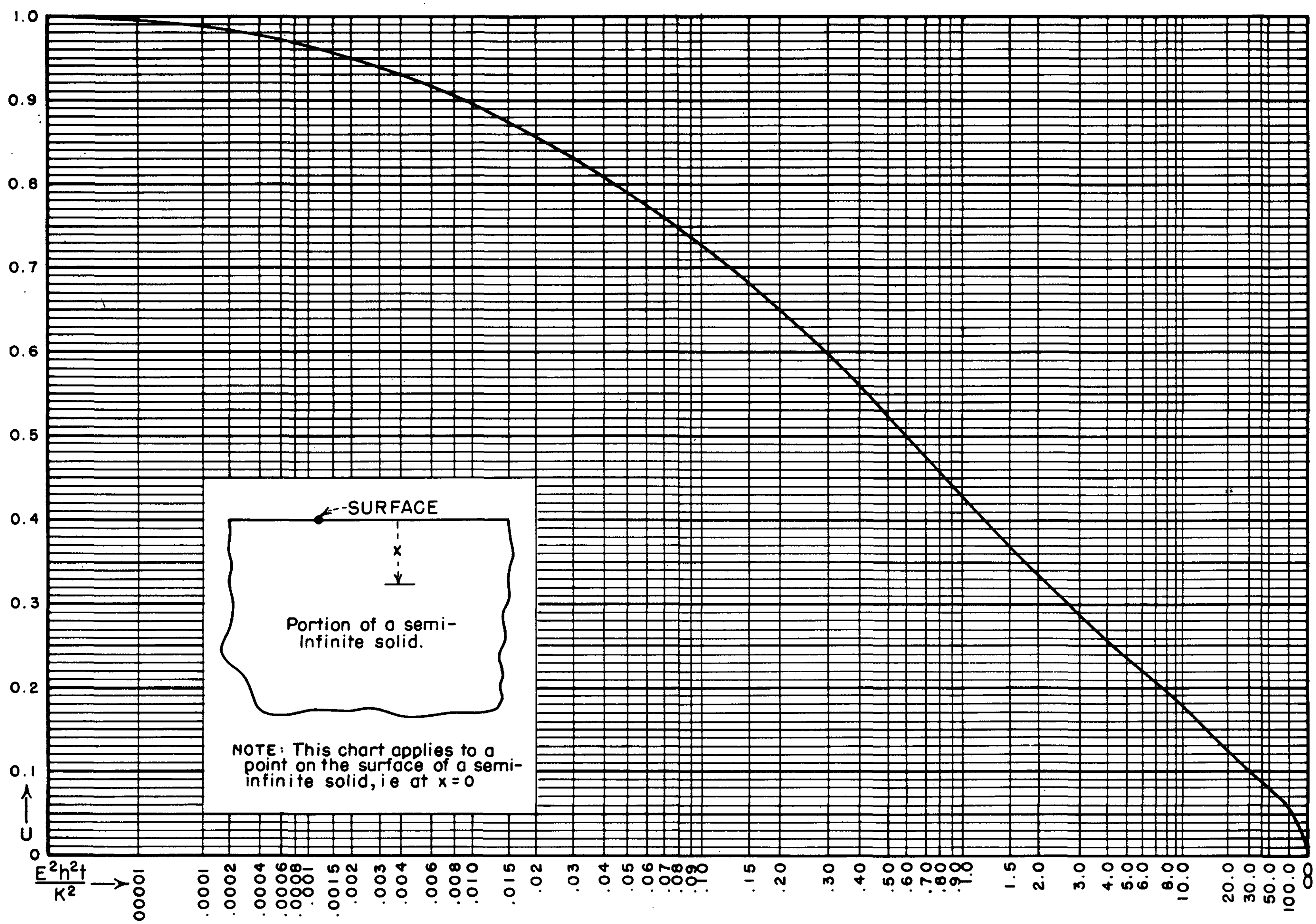


FIGURE 29 -- Plot of U versus E^2h^2t/K^2 for points at the surface of a semi-infinite solid.

The extension to a prismatic body is made by use of the product law in the following way. Suppose the body has the dimensions L_1 and L_2. Use the two values of L in succession to get corresponding values of U. Call these U_1 and U_2. If the U values were obtained from Fig. 27, the product U_1U_2 represents the U value for an edge. If U_1 came from Fig. 27 and U_2 came from Fig. 28, then the product U_1U_2 represents the U value for the middle of the side whose dimension is L_2. If U_1 came from Fig. 28 and U_2 came from Fig. 27, then the product U_1U_2 gives the U value for the middle of the side whose dimension is L_1. If both come from Fig. 28, then the product U_1U_2 is the U value for the center of the prism.

In case the body has the form of a rectangular parallelepiped with dimensions L_1, L_2, and L_3 and each length is used in turn to obtain a U value, then the U value for a corner is obtained by forming the product $U_1U_2U_3$ where all the U values are obtained from Fig. 27. If two U values came from Fig. 27 and one comes from Fig. 28, the product $U_1U_2U_3$ gives the U value for the mid-point of an edge. If one U value comes from Fig. 27 and two come from Fig. 28, the product $U_1U_2U_3$ gives the U value for the middle of a side. If all three U values come from Fig. 28, the U value obtained applies to the center of the solid. These relations are all exact and remain so even if the E values corresponding to the dimensions L_1, L_2, and L_3 are all different.

These processes relate only to the decay of an initial temperature toward an assumed constantly maintained external temperature. How, then is one to deal with the effect of heat generation and of changing external temperatures, such as might be provided, for example, by a cold wave? The answer is that these solutions obey the law of superposition. The effect of heat generation is accounted for by substituting a stepped curve for the smooth curve of temperature rise obtained from an adiabatic calorimeter test on the concrete, applying the procedure described to each step and adding the results. This is not as formidable an undertaking as it sounds because the steps may be made larger for the longer time periods. Thus, if temperatures are to be computed at the end of 24 hours, 4-hour increments may be short enough. If the computation is to be made at the end of a week, then 1-day increments should give a close enough approximation for engineering purposes. This process is approximate, of course, and the greater the number of increments taken, the nearer will the result approach analytical perfection.

Temperature changes are taken care of in much the same way. The principle of assuming that a temperature differential, once applied, remains forever is followed. Thus, a cold wave lasting for 3 days would be computed by applying the appropriate differential at the time the cold wave begins. At the end of the cold period, the original differential is not removed, but the external temperature is restored by adding a new differential equal in magnitude, but opposite in sign, from the first. It may be noted that in all cases the temperatures computed refer to the last external temperature change applied, but that in computing the θ value from the relation $\theta = U\theta_o$, the θ_o values remain unchanged, Fig. 29 is used where the thicknesses are so great that Fig. 27 cannot be used. The insulation applied affects the E values.

Experience with these methods has shown that accurate data must be used if close correlation is to be obtained. The reason is that, if the insulation is skillfully chosen, the temperature rise due to heat generation will nearly offset the natural cooling. Thus, at the end of 3 days each of these factors may be about 30^o F but the net temperature change may be near zero. It is easy to see, therefore, how an error in computing one of the factors can make a relatively large error in the final result. This possibility should be kept in mind when using these methods.

Example 1

A computation of temperatures in the 2-ft cubical test block of Fig. 26 illustrates the use of the charts and of the product law. Temperatures at the corners, at the midpoint of the sides, and at the center of the block, 3 days after placing, will be computed. The following data are required:

Thermal properties of concrete:

Specific heat	C = 0.230 Btu per lb per deg F
Conductivity	K = 1.56 Btu per ft per hour per deg F

TABLE X--COMPUTATION OF TEMPERATURES IN 2-FT CUBE TEST BLOCK

1	2	3	4	5	6	7	8	9	10	11	12	13
Time hr	Temp. rise ^oF	Incre-ments, ^oF	Life at 72 hr	$\frac{h^2 t}{L^2}$	U_1	$U_2 = U_3$	$U_1U_1U_1$	$U_1U_2U_3$	$U_3U_3U_3$	^oF $U_1U_1U_1$	^oF $U_1U_2U_3$	^oF $U_3U_3U_3$
0	0	10.2	72	0.799	.720	.755	.373	.410	.430	3.80	4.18	4.39
6	10.2	8.5	66	0.733	.735	.778	.397	.445	.471	3.37	3.78	4.00
12	18.7	4.8	60	0.666	.750	.792	.422	.470	.497	2.02	2.26	2.39
18	23.5	3.5	54	0.599	.774	.815	.464	.514	.541	1.62	1.80	1.89
24	27.0	3.1	48	0.532	.796	.835	.504	.555	.582	1.56	1.72	1.80
30	30.1	2.6	42	0.466	.812	.854	.535	.592	.623	1.39	1.54	1.62
36	32.7	2.4	36	0.400	.835	.878	.582	.644	.677	1.40	1.54	1.62
42	35.1	2.2	30	0.333	.855	.900	.625	.692	.729	1.38	1.52	1.60
48	37.3	2.0	24	0.266	.875	.922	.670	.744	.784	1.34	1.49	1.57
54	39.3	1.8	18	0.200	.898	.943	.724	.798	.838	1.30	1.44	1.51
60	41.1	1.7	12	0.133	.917	.964	.771	.852	.896	1.31	1.45	1.52
66	42.8	1.7	6	0.067	.948	.990	.899	.929	.970	1.53	1.58	1.65
72	44.5	--	0	0	1.000	1.000	1.000	1.000	1.000	--	--	--
										22.02	24.30	25.56

Placing temperature = 55° F External temperature = 20° F
Temperature at corner = (55°-20°) $U_1U_1U_1$ + 22.02° = 55.08°
Temperature at middle of side = (55°-20°) $U_1U_2U_3$ + 24.30° + 20° = 58.65°
Temperature at center of block = (55°-20°) $U_3U_3U_3$ + 25.56° + 20° = 60.61°
EL/K = (0.15) (2) / 1.56 = 0.192
h^2/L^2 = 0.0444/4 = 0.0111

Density	ρ = 152.9 lb per cu ft
Diffusivity	$h^2 = K/C\rho$ = 0.0444 sq ft per hour
Placing temperature	55° F
External temperature	20° F
Emissivity	0.15 Btu per sq ft per hour per deg F

The detail of the computations is as follows: Column 1 (Table X) contains the time after placing, while column 2 contains the temperature rise which would be produced in the specimen if the setting heat were not allowed to escape. Column 3 contains the differences of the quantities in column 2. These differences represent the adiabatic rise in each 6-hour interval. These changes can be assumed to occur at either the beginning or end of the interval. In this case they have been assigned to the beginning. The time interval should be chosen short enough so that it will not make much difference which choice is made. Column 4 contains the lengths of time each of the corresponding increments is assumed to have been in existence at the end of the 3-day period. The values in column 5 are computed from the figures in column 4 and the U values for the surface and the center of the cube are found from Fig. 27 and 28 and entered in columns 6 and 7, respectively. The values for U_2 and U_3 are the same because the lengths and insulation are the same. Columns 8, 9, and 10 contain products of U values from columns 6 and 7. These three columns contain the appropriate U values for a corner, the middle of a side, and the center of the cube, respectively. Columns 11, 12, and 13 contain the products of the increments in column 3 with the U values in columns 8, 9, and 10, respectively. The sums of the quantities in columns 11, 12, and 13 represent the temperature rise above the placing temperature, produced by setting heat alone, at the end of the 3-day period.

We have yet to account for the effect of the 35° F temperature differential between the placing temperature and the external temperature. This differential has existed for the entire 72-hour period and its effect may be computed by using the U values at the top of columns 8, 9, and 10 as appropriate. For the corner, the appropriate value comes from column 8. This computation then proceeds as follows:

External temperature	20° F
Parts remaining of the 35° F difference between the placing temperature and the external temperature 35° $U_1U_1U_1$ = (35°) (0.373°) =	13.0°
Parts remaining of the setting heat increments, from column 11	22.0°
Total	55.0° F

This is the computed temperature at the corners at the end of 3 days. The corresponding computations for the middle of a side and for the center of the cube are shown at the bottom of Table X. The computations can be referred to the placing temperature by multiplying the external temperature differential by (1 - U) thus:

Placing temperature	$+ 55^{o}$ F
$- 35^{o} (1 - 0.373^{o}) =$	$- 21.9^{o}$
Setting heat	$+ 22.0^{o}$
Total	55.1^{o} F

When the computation is made in this way, it brings out the point that, in this case, the two factors of loss of heat through the insulation and heat gain from chemical action counterbalance each other within 0.1^{o} F while each factor is about 22^{o} F. The results of the computations are therefore obtained as a small difference between relatively large numbers and the outcome of the computation becomes sensitive to variations in the assumed data. In this case, for example, the use of E = 0.10 instead of E = 0.15 will increase the computed temperature 10^{o} F.

Since a close balance between heat loss and heat gain will be the result of a skillfully chosen insulation in any field application, the importance of avoiding an overestimate of the effectiveness of the insulation will be appreciated. Another factor which will bear watching is the data on adiabatic heat rise. Such data are often obtained from an adiabatic calorimeter test started at 70^{o} F. The speed of the chemical reaction is, however, strongly influenced by temperature* and, therefore, care should be taken to use data appropriate for the temperature level anticipated.

This difficulty is inherent and it is therefore advisable to check the computations against field performance at every opportunity to obtain data for correcting the assumptions used.

*See, for example, Fig. 3-1 and 3-2, pp. 792 and 793, "Long Time Study of Cement Performance in Concrete," by William Lerch and C. L. Ford, ACI JOURNAL, Apr. 1948.

Canal linings

Some modification of the computation procedures described previously must be made in the case of canal linings because the thermal properties of the soils on which they are placed exert such a profound influence. The heat-storage capacity of the lining will generally be small compared to that of the earth beneath it, and it will, therefore, be permissible, as an approximation, to assimilate the lining to an equivalent thickness of soil and to treat the combination of lining and soil as a semi-infinite solid of soil. Fig. 29 will serve for computation of the effects of external temperature changes as well as before but the computation for the effects of heat generation and of initial temperatures of the concrete must be modified because the soil is inert. The semi-infinite solid idealization can be extended to cover these effects also if it is assumed that the heat coming from a placing temperature above that of the surroundings and from chemical action is applied to the surface of the solid beneath the insulation. Fig. 30 was prepared to assist this part of the computation. It was plotted from formulas derived* for the case of a semi-infinite solid which radiates to a temperature zero but which receives at the same time a heat supply of R Btu per hour per square foot at its surface. The ultimate temperature rise in such a solid will be R/E. Whereas, before, the effect of setting heat was accounted for by a stepwise approximation based on increments of temperature rise, these effects in the present case will be accounted for by a similar stepwise computation based on rates. These rates are connected with the temperature rise increments used previously in a manner which will be made clear in the following example. The purpose of the computation is to obtain temperature values at the surface of the concrete.

Example 2

As an example of the use of the charts for estimating the temperature of a canal lining, the temperature of the concrete at age 3 days will be computed. The required data are:

*See Par. 23 and 24, Bulletin 3, Part VII of the Boulder Canyon Project Final Reports, "Cooling of Concrete Dams."

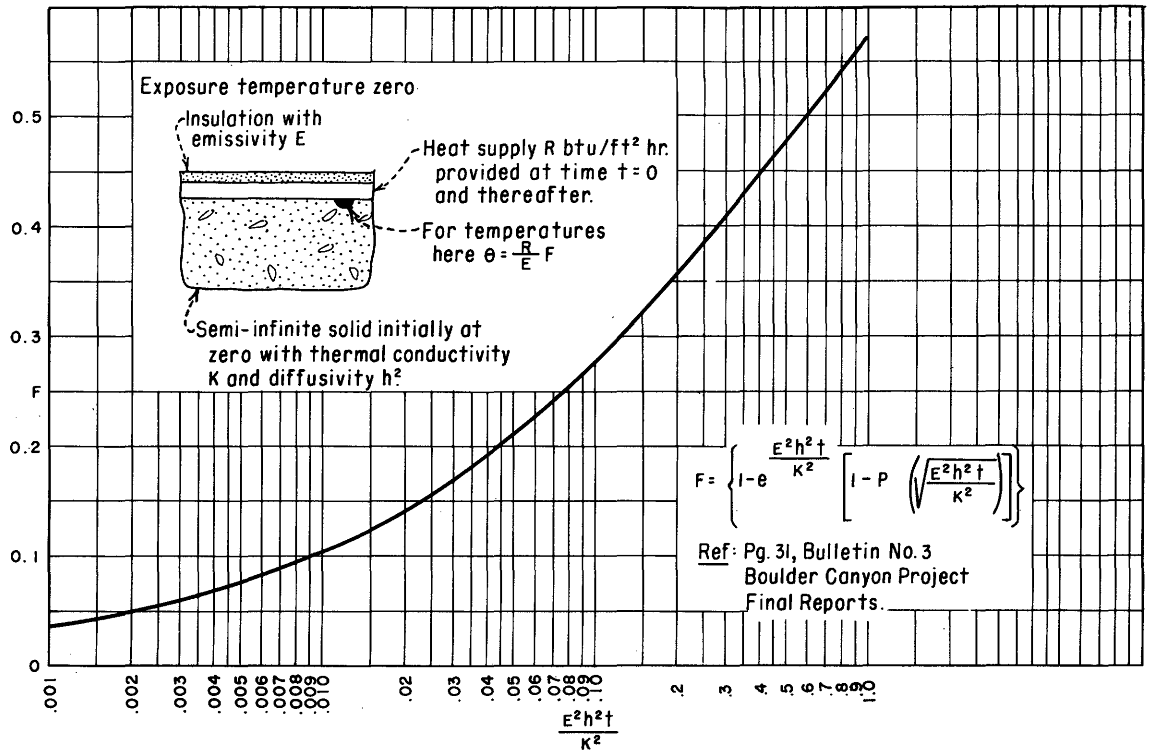


FIGURE 30 -- Radiating semi-infinite solid with heat supply.

Placing temperature of concrete (assumed)	50^{o} F	Thickness of concrete lining	0.25 ft
Soil surface temperature at time of placing (assumed)	32^{o} F	Insulation: Rock wool mat between Sisal-kraft paper facings.	

TABLE XI--COMPUTATION OF CANAL LINING TEMPERATURES 3 DAYS AFTER PLACING

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Time, hr	Assumed adiabatic temp. rise, °F	Increment of rise, °F	Rate* from setting heat	Rate* from initial temp. diff.	Rate from ground gradient	Total rate, R, Btu per sq ft per hr	R	Life of increment at 72 hr	$\frac{E^2h^2t}{K^2}$	F†	$\frac{F - \Delta R}{E}$	Mean daily air temp., °F	Differences,‡ T	Life at 72 hr	$\frac{E^2h^2t}{K^2}$	U§	TU
0	0	4.4	6.45	26.4	3.60	36.45	+36.45	72	0.1110	0.286	+41.70	38.5	+6.5	72	0.1110	0.720	+4.7
6	4.4	3.9	5.72	0	3.60	9.32	-27.13	66	0.1018	0.278	-30.17	38.5					
12	8.3	3.5	5.13	0	3.60	8.73	-0.59	60	0.0926	0.267	-0.63	38.5	+4.5	60	0.1926	0.735	+3.3
												34.0					
18	11.8	3.1	4.54	0	3.60	8.14	-0.59	54	0.0833	0.256	-0.60	34.0					
24	14.9	2.7	3.96	0	3.60	7.56	-0.58	48	0.0741	0.245	-0.57	34.0					
30	17.6	2.5	3.66	0	3.60	7.26	-0.30	42	0.0648	0.231	-0.28	34.0					
36	20.1	2.2	3.22	0	3.60	6.82	-0.44	36	0.0555	0.218	-0.38	34.0	+20.0	36	0.0555	0.780	+15.6
												14.0					
42	22.3	2.0	2.93	0	3.60	6.53	-0.29	30	0.0463	0.201	-0.23	14.0					
48	24.3	1.8	2.64	0	3.60	6.24	-0.29	24	0.0370	0.185	-0.21	14.0					
54	26.1	1.6	2.34	0	3.60	5.94	-0.30	18	0.0278	0.162	-0.19	14.0					
60	27.7	1.5	2.20	0	3.60	5.80	-0.14	12	0.0185	0.136	-0.08	14.0	-3.0	12	0.0185	0.860	-2.6
												17.0					
66	29.2	1.3	1.91	0	3.60	5.51	-0.29	6	0.0093	0.100	-0.12	17.0					
72	30.5							--	--	--	--	17.0					
											+8.24						+21.0

Computed temperature of the surface of the concrete at 72 hours after placing = 17.0 + 8.24 + 21.0 = 46.2° F

***Rate = $C_c \rho_c(0.25)$ °F/6**

†From Fig. 30

‡The first difference is with respect to the 32° F assumed ground temperature.

§ From Fig. 29

(Conductance 0.25 Btu per sq ft per hr per deg F

Cement content of concrete: 4 sacks per cu yd

Calcium chloride content: 1 percent of cement by weight

Thermal properties of concrete (assumed):

Specific heat	C_c	= 0.230 Btu per lb per deg F
Conductivity	K_c	= 1.56 Btu per ft per hour per deg F
Density	ρ_c	= 153 lb per cu ft
Diffusivity	$K_c/C_c\rho_c$	= 0.0444 sq ft per hour

Thermal properties of soil (assumed):

Specific heat	C	= 0.45
Conductivity	K	= 0.90 Btu per ft per hour per deg F
Density	ρ	= 100 lb per cu ft
Diffusivity	$K/C\rho$	= 0.020 sq ft per hour

Emissivity, with insulating blanket	E	= 0.25 Btu per sq ft per hour per deg F

We will take account of the placing temperature, the soil temperature, the setting heat, the temperature gradient in the ground, and the effect of the external air temperature changes. As stated previously, the temperatures will be computed on the basis that they occur in soil. The thermal properties of concrete will therefore find use only for making estimates of the heat contributed by the concrete. As before, a 6-hour time increment will be chosen. On this basis the rate of heat supply to account for the (50 - 32) = 18^{o} F difference between the concrete and ground temperatures at the time of placing will be computed as $C_c\rho_c$ x 0.25 x 18/6 = 26.4 Btu per sq ft per hr. And this rate will be assumed to be present during the first 6 hours.

The rate of heat supply due to a ground temperature gradient of 4^{o} F per foot is (4.0) K = 3.60 Btu per sq ft per hour. The detail of this computation is shown in Table XI. The first column shows the number of hours after placing the lining. The "adiabatic temperature rise" in column 2 is the temperature increase which the concrete would show if cured in an adiabatic calorimeter. These quantities are greatly influenced by the temperature*. Column 3 contains the differences of the quantities in column 2, and column 4 contains the equivalent heat supply computed from the entries in column 3. The formula used is shown at the bottom of the tabulation. The rate from initial temperature difference shown in column 5 is sufficient to accumulate the initial temperature excess of concrete over soil in the first 6-hour time interval. The purpose of this conversion is to permit computation of the effect of placing temperatures by use of Fig. 30. The rate from ground gradient in column 6 accounts for the heat coming up through the ground. In the winter this gradient averages about 4^{o} F per ft at the ground surface and the heat brought upward amounts to about 3.6 Btu per sq ft per hour. Column 7 contains the totals of the items in columns 4, 5, and 6. Column 8 contains the differences of the figures in column 7. The first figure represents the starting rate and is plus because the factors of columns 4, 5, and 6 all tend to cause a temperature rise. The succeeding figures are negative because they indicate a decrease in rate. Column 9 shows the time the items in column 8 have been in existence at the end of the 3-day period. The quantities in column 10 are computed from the items in column 9 and used to read the items in column 11 from Fig. 30. The figures in column 12 are computed from the items in columns 8 and 11 and represent the temperature changes produced at the end of the 3-day (72-hour) period by the heat supply rates of column 7. The concrete is assumed to have been placed at noon and the mean daily air temperature to prevail over the whole 24-hour period of each day. Column 14 contains the differences of the quantities of column 13. The first difference is taken with respect to the assumed ground temperature. The remaining differences are plus if the temperature is dropping. Columns 15 and 16 are similar to columns 9 and 10. The figures in column 17 are obtained from those of column 16 by use of Fig. 29.

*Lerch, William and Ford, C. L., "Long-Time Study of Cement Performance in Concrete, Chapter 3--Chemical and Physical Tests of the Cements," ACI Journal, Apr. 1948, Proc. V. 44, p. 745.

Column 18 contains the products of figures in columns 14 and 17. Figures in column 18 represent the parts remaining of the differences of column 14 at the end of the 3-day period. Thus, of the 20.0° F differential occurring because of a drop of air temperature 36 hours after placement, 16.0° F remains at the end of the 3-day period. In other words, the 20° F temperature drop at 36 hours only succeeds in causing a temperature drop of 20 - 16.6 = 4.4° F in the concrete at the end of the 3-day period. The computed concrete temperature at the end of this period is the sum of the prevailing temperature and the items in columns 12 and 18. The computed temperature is thus 17.0 + 8.2 + 21.0 = 46.2° F.

A computation of the effect of daily air temperature changes between day and night indicates that they should normally produce about a 1° F amplitude change under this blanket.

ACKNOWLEDGMENTS

Fig. 27, 28, 29, and 30 were prepared by Q. L. Florey and checked by G. G. Balmer. The experimental data for the 2-ft cube were obtained by L. J. Mitchell.

ADDENDUM*

DISC. 48-18

INSULATION FOR NEW CONCRETE IN WINTER

The following tables of insulation requirements for protection of concrete placed in cold weather were prepared by Q. L. Florey and G. G. Balmer from the charts published in the original paper.

TABLE A--INSULATION REQUIREMENTS FOR CONCRETE WALLS
Concrete placed at 50° F

Wall thickness, ft	Minimum air temperature allowable for these thicknesses of commercial blanket or bat insulation, degrees F			
	0.5 in.	1.0 in.	1.5 in.	2.0 in.
Cement content--300 lb per cu yd				
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 lb per cu yd				
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	

*ACI JOURNAL, Nov. 1951, Proc. V. 48, p. 253. Disc. 48-18 is a part of copyrighted JOURNAL OF THE AMERICAN CONCRETE INSTITUTE, V. 24, No. 4, Dec. 1952, Part 2, Proceedings V. 48.

TABLE A (Continued)

Wall thickness, ft	Minimum air temperature allowable for these thicknesses of commercial blanket or bat insulation, degrees F			
	0.5 in.	1.0 in.	1.5 in.	2.0 in.
	Cement content--500 lb per cu yd			
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 lb per cu yd			
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		

TABLE B--INSULATION REQUIREMENTS FOR CONCRETE SLABS AND CANAL LININGS PLACED ON THE GROUND

Concrete at 50° F placed on ground at 35° F; no ground temperature gradient assumed

Slab thickness, ft	Minimum air temperature allowable for these thicknesses of commercial blanket or bat insulation, degrees F			
	0.5 in.	1.0 in.	1.5 in.	2.0 in.
	Cement content--300 lb per cu yd			
0.333	*	*	*	*
0.667	*	*	*	*
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 lb per cu yd			
0.333	*	*	*	*
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		

TABLE B (Continued)

Slab thickness, ft	Minimum air temperature allowable for these thicknesses of commercial blanket or bat insulation, degrees F			
	0.5 in.	1.0 in.	1.5 in.	2.0 in.
	Cement content--500 lb per cu yd			
0.333	*	*	*	*
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 lb per cu yd			
0.333	*	*	*	*
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			

*Due to influence of cold subgrade on these thin slabs, insulation alone will not maintain their temperature at the required 50° F in cold weather. In such cases the additional heat supply necessary to maintain required temperatures in the concrete must be provided by using higher placing temperatures, preheating of the ground, electric resistance wire under the insulation, or by other means depending on the severity of prevailing weather.

Notes: The tables are calculated for the stated thicknesses of blanket-type insulation with an assumed conductivity of 0.25 Btu per hr per sq ft for a thermal gradient of 1 deg F per in. The values given are for still air conditions and will not be realized where air infiltration due to wind occurs. Close-packed straw under canvas may be considered a loose-fill type if wind is kept out of the straw. The insulating value of a dead-air space greater than about 1/2 in. thick does not change greatly with increasing thickness. Textbooks or manufacturers' test data should be consulted for more detailed data on insulations. See insulation equivalents, Table D.

TABLE C--INSULATION REQUIREMENTS FOR CONCRETE SLABS AND CANAL LININGS PLACED ON THE GROUND

Concrete at 50° F placed on ground at 40° F; no ground temperature gradient assumed

Slab thickness, ft	Minimum air temperature allowable for these thicknesses of commercial blanket or bat insulation, degrees F			
	0.5 in.	1.0 in.	1.5 in.	2.0 in.
	Cement content--300 lb per cu yd			
0.333	*	*	*	*
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		

TABLE C (Continued)

Slab thickness, ft	Minimum air temperature allowable for these thicknesses of commercial blanket or bat insulation, degrees F			
	0.5 in.	1.0 in.	1.5 in.	2.0 in.
	Cement content--400 lb per cu yd			
0.333	*	*	*	*
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 lb per cu yd			
0.333	*	*	*	*
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 lb per cu yd			
0.333	*	*	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			

*See footnote, Table B.

TABLE D--INSULATION EQUIVALENTS†

Insulating material	Equivalent thickness, in.
1 in. of commercial blanket or bat insulation	1.000
1 in. of loose fill insulation of fibrous type	1.000
1 in. of insulating board	0.758
1 in. of sawdust	0.610
1 in. (nominal) of lumber	0.333
1 in. of dead-air space (vertical)	0.234
1 in. of damp sand	0.023

†See notes, Table B.