The Value of Insulated Forms for Winter Bridge Construction

H. B. BRITTON, Senior Structural Specifications Writer, New York State Department of Public Works

• SUFFICIENT literature is available to support the theory that winter-produced concrete can be adequately protected in its initial stage by the use of insulated forms. The purpose of this paper is to report the findings of the New York State Department of Public Works in its use of insulated forms for winter concreting on bridge construction for the period from 1957 to 1960.

Scurr (1) of the South Dakota State Highway Commission must be recognized for his responsible reporting of work done in this field at a time when the need was great and the answers were few. As with all original work, certain refinements may be made by others whose interests are only to add to the storehouse of knowledge by using the basic thesis objectively in gathering additional data.

In general, the temperature in New York State can be expected to be below 32 F for an average of 125 days a year. In South Dakota, the temperature can be expected to be below 32 F for an average of 163 days a year (Fig. 1).

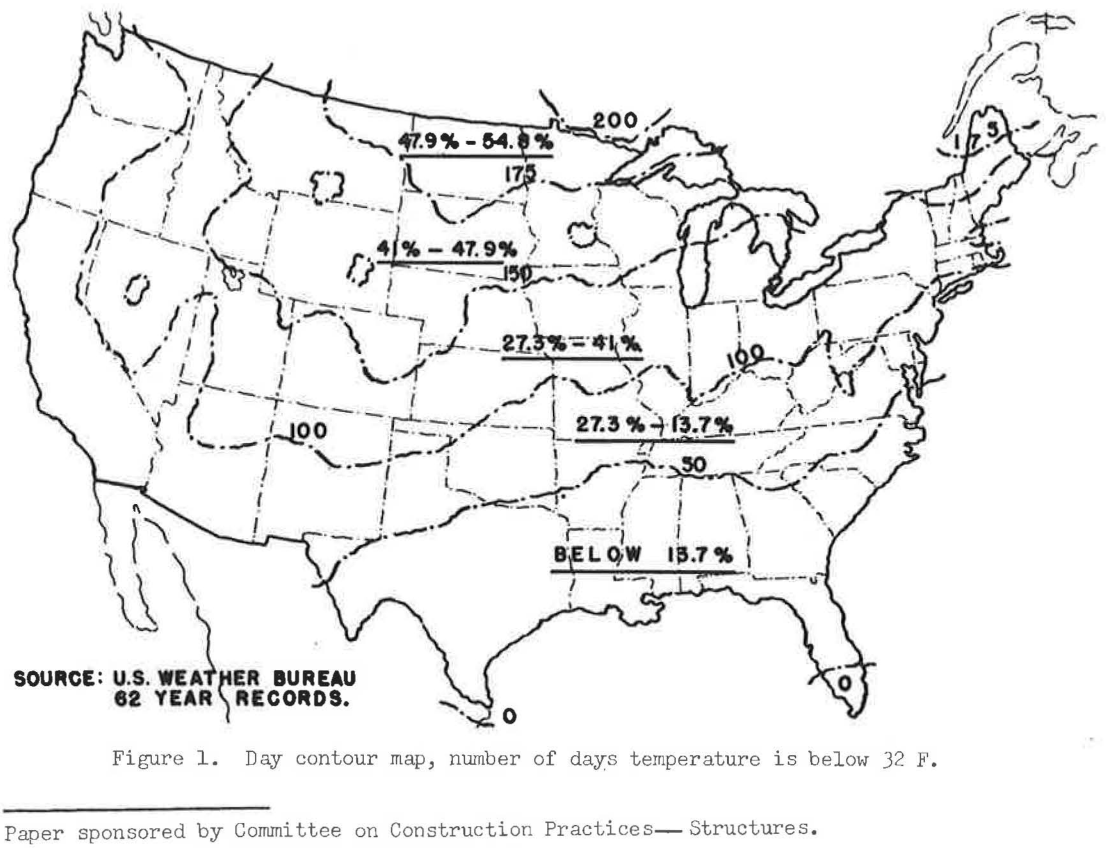

Figure 1. Day contour map, number of days temperature is below 32 F.

Paper sponsored by Committee on Construction Practices— Structures.

From the relationship of these two States it could be expected that the ambient air temperatures of South Dakota would be somewhat lower than those encountered in New York State. This could, in part, be responsible for the difference in the results reported by Scurr and those obtained in New York State.

The pros and cons of the required protection for winter-produced concrete are amply covered in Scurr's paper (1). One observation, however, might be made regarding the great amount of construction carried on in the metropolitan areas of New York State. In many instances the only space available to the contractor is actually the construction limits of his contract. The employment of housing and salamanders or heating elements would deny the contractor freedom of movement in his already confined area. The use of insulated forms releases to the contractor this much needed usable space.

New York State instituted its first program of using insulated forms for the protection of winter-produced concrete during the winter construction season of 1956-1957. This program was carried out on three contracts all in the Buffalo area. The specifications for control were limited, in that it was stipulated that 2-in. insulation be used, but in all other respects the concrete should be formulated in compliance with the current specifications for concreting in cold weather.

The pertinent requirements contained in the construction specifications for concreting in cold weather were predicated on the use of external heat:

> All water used for mixing concrete shall be heated to a temperature of at least 70 F but not over 150 F. Aggregates shall be heated either by steam or by dry heat to a temperature of at least 70 F but not over 150 F. The heating apparatus shall be such as to heat the mass uniformly and preclude the possibility of the occurrence of hot spots which will overheat the material.
>
> The temperature of the mixed concrete shall be not less than 60 F at the time of placing in the forms.
>
> In cases of extreme weather conditions the Engineer may, at his discretion, raise the lower limiting temperatures for water, aggregate and mixed concrete.

Figures 2 and 3 show the method of applying the insulating blankets. Figure 4 shows the location of thermometers and thermocouples.

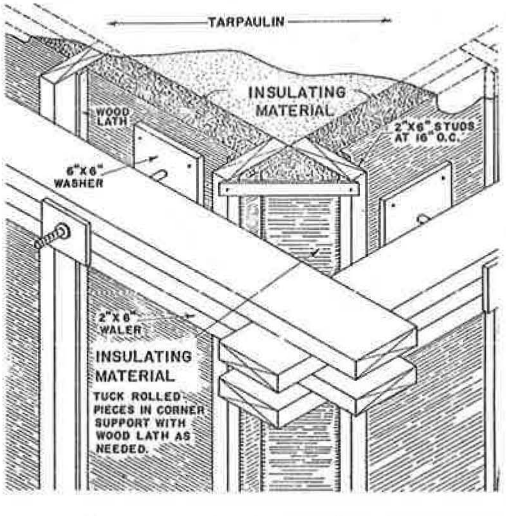

Figure 2. Method of applying insulating blankets, wood forms.

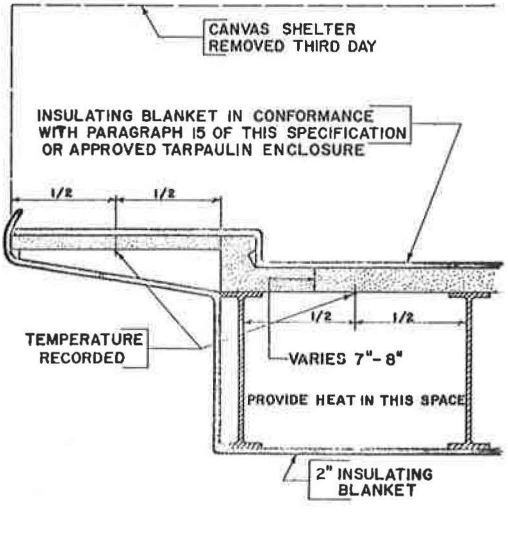

Figure 3. Method of applying insulating blankets, steel forms.

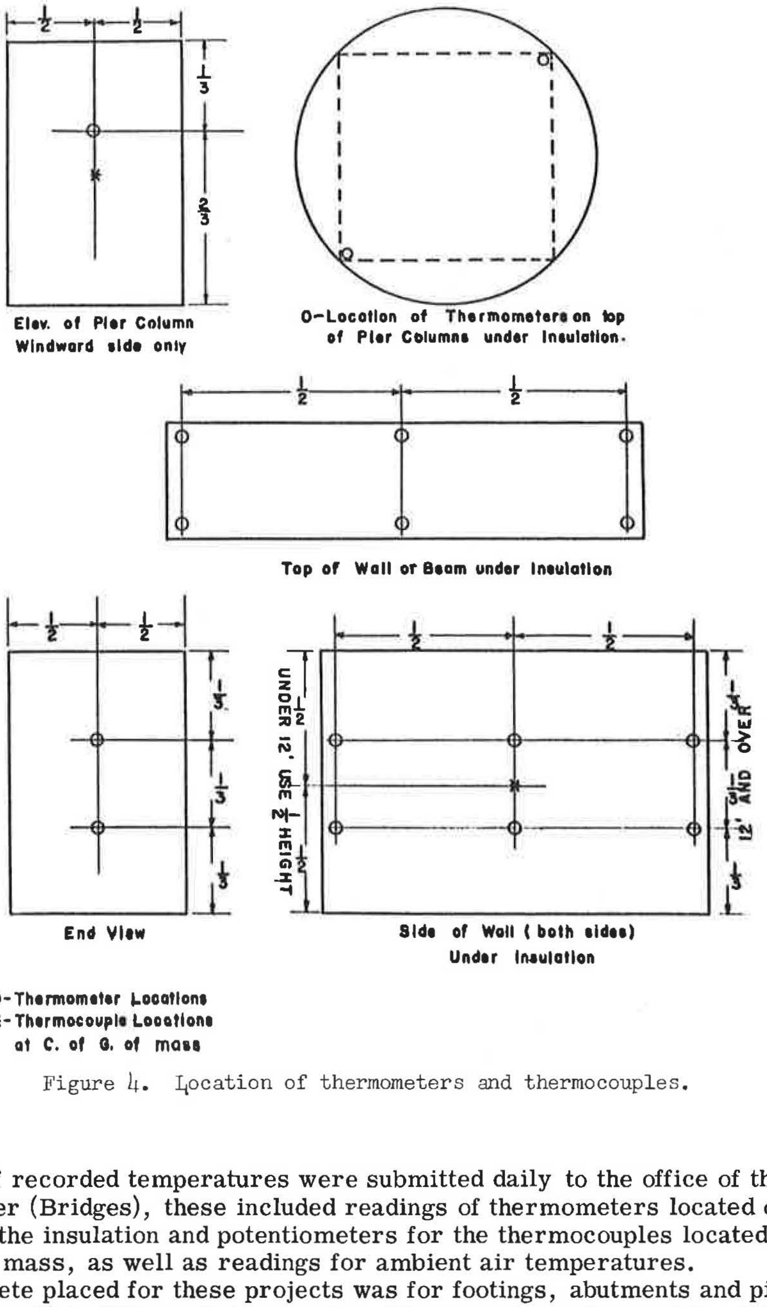

Figure 4. Location of thermometers and thermocouples.

Reports of recorded temperatures were submitted daily to the office of the Deputy Chief Engineer (Bridges), these included readings of thermometers located on the forms under the insulation and potentiometers for the thermocouples located at the center of the mass, as well as readings for ambient air temperatures.

The concrete placed for these projects was for footings, abutments and pier beams requiring from 50 to 130 cu yd of concrete. The cement requirement for this concrete was 6 bags per cu yd. The forms used were ¾-in. plywood, and the temperature of the concrete at time of placement was 75 F. The ambient air temperature at time of placing the concrete was 44 F and the average ambient air temperature for the 5 days of curing was 36 F.

Internal temperatures were reported as high as 158 F at approximately 32 hr after placement. Temperatures on the side of forms under the insulation were reported as high as 129 F at approximately 32 hr after placement. Temperatures on top of concrete under straw were reported as high as 98 F at approximately 24 hr after placement.

In an attempt to counteract this high internal temperature, the engineers in the field were instructed to crack the forms after the second day. This proved expedient though at the same time a doubtful way to control temperatures of concrete when using this type of construction.

Concrete developing the temperatures indicated would be vulnerable to thermal shock should the forms be removed under normal construction procedures. There is also a possibility that the excessive internal temperatures could produce varying expansions and, on cooling, cause internal fractures that could destroy the homogeneity of the mass. This expansion could possibly result in a variation of the elevation of the top surfaces of the unit from that indicated on the plans.

During the summer of 1957 an intensive study was made on this subject, and in the fall of 1957 an alternate specification for concreting in cold weather was issued together with a letter of instruction, to the engineers in charge of projects. This specification, amended, and the letter of instruction are given in the Appendix.

The specification required that concrete units having a depth of 24 in. or less would require the 2-in. insulation on the forms, the concrete temperatures at placement should be not less than 50 F nor more than 60 F. Concrete sections having a depth greater than 24 in. would require 1-in. insulation on the forms and the temperature of the concrete at placement should be not less than 40 F nor more than 50 F. This specification also included a table of insulation requirements for concrete walls, piers, abutment, and floor slabs above ground. The data contained in that table can be found elsewhere (2, 3). There is, however, no reference made to indicate whether the form material is wood or steel. It has been determined that these data were predicated on the use of steel forms that have no insulating value. Because this fact has been established, it is possible to reduce the thickness of the insulation on wood forms.

During the 1957-1958 winter construction season, 40,000 cu yd of concrete were placed using insulated forms. Results obtained were significantly better than those of the 1956-1957 winter construction season. The greatest difficulty encountered was impressing on all parties the necessity of reducing the temperature of the concrete at time of placement.

Figure 5 shows the resulting temperatures for a pier beam. This unit was protected with 2 in. of insulation on wood forms. Temperature of concrete at time of placement was 74 F. Internal temperatures of 140 F were recorded 28 hr after placement. Temperatures of 112 F were recorded on sides of forms under insulation 48 hr after placement. Temperatures of 96 F were recorded on top of unit 52 hr after placement. The ambient air temperature at time concrete was placed was 50 F and did not go below 32 F until early on the fourth day. Internal heat loss started approximately 54 hr after placement at an average rate of 4 F per day for 3 days. On the last recorded day the internal heat loss was 24 F. Heat loss indicated from report of readings on sides averaged 9 F per day. Heat loss indicated from report of readings on top averaged 8 F per day. During this same period the ambient air temperature had dropped 20 F at a rate of approximately 4 F per day.

Figure 6 shows the resulting temperature for a wall stem. This unit was protected with 1 in. of insulation on wood forms. The temperature of the concrete at time of placement was 70 F. Internal temperatures of 112 F were recorded 48 hr after placement. Heat loss averaged 9 F per day. Temperature of 74 F was recorded on side of forms 24 hr after placement. There was a temperature loss of 19 F after 4 days in place followed by a rise in temperature of 14 F at the end of 6 days. Temperatures of 68 F were recorded on top of unit 48 hr after placement. Heat loss was 14 F in the next 24 hr, then retaining a constant temperature for the remaining 3 days. In this instance, the ambient air temperature was 40 F at the time the concrete was placed and at no time did it register below 36 F. The ambient air temperature rose an average of 10 F per day for the final 2 days or to 55 F. However, the differential in temperature from the ambient air to the internal is but 15 F at the end of the 6-day period.

When placement temperature of the concrete was reduced, there was a noticeable reduction in peak temperature. From the records this peak temperature was not attained until 72 hr after the concrete was placed.

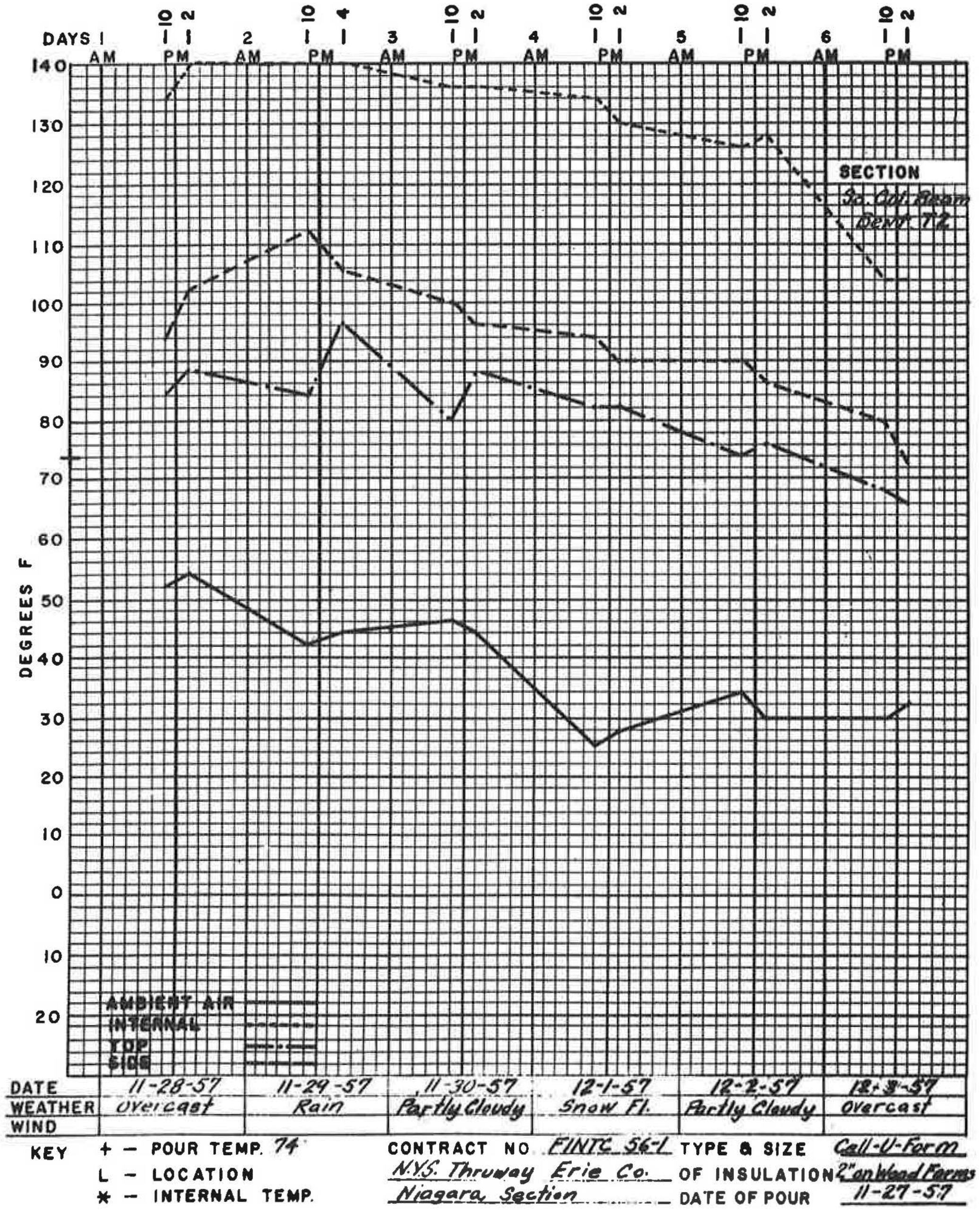

Figure 5. Pier beam temperatures.

Figure 6. Wall stem temperatures.

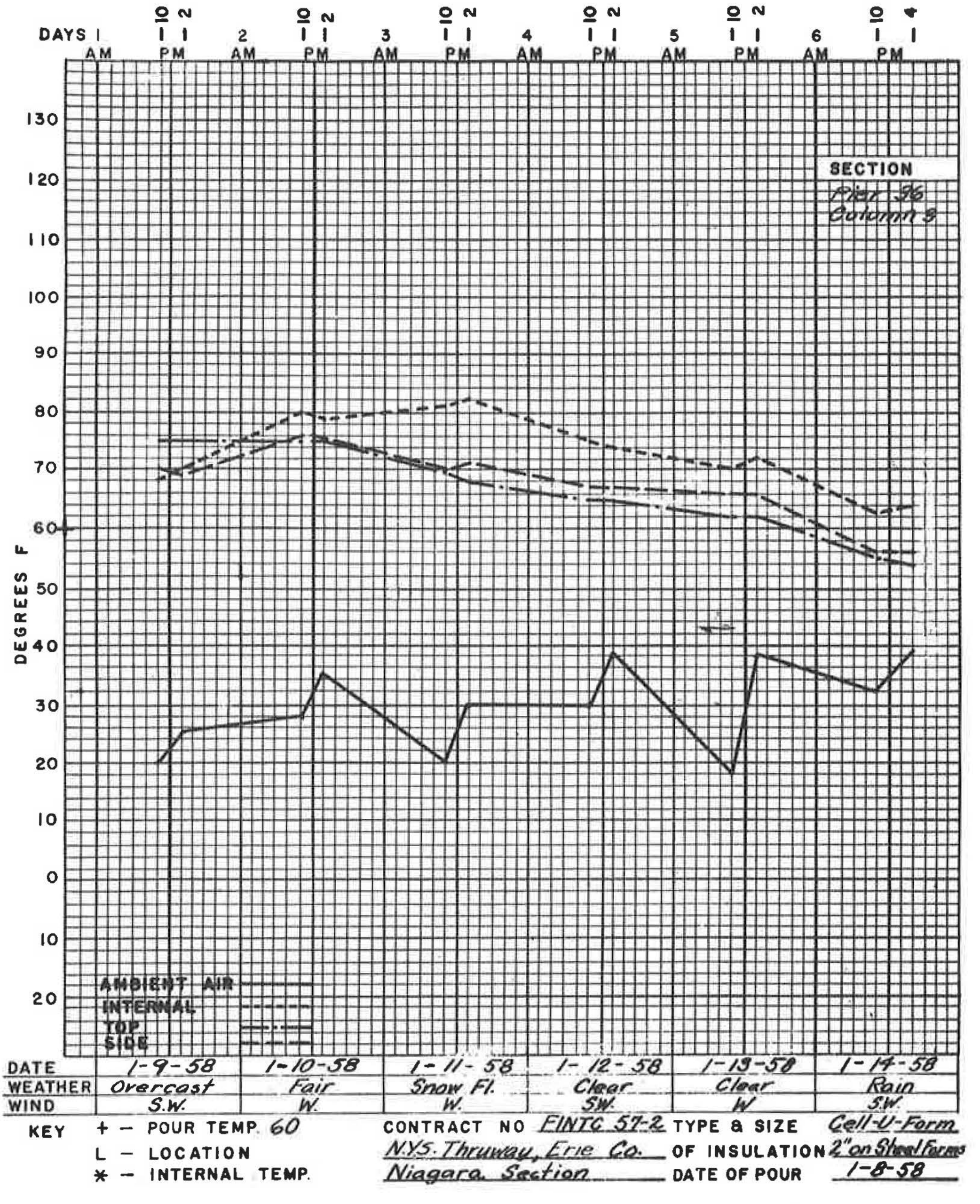

Figure 7. Heat evolvement from concrete placed at 60 F, with 2-in. insulation on steel forms.

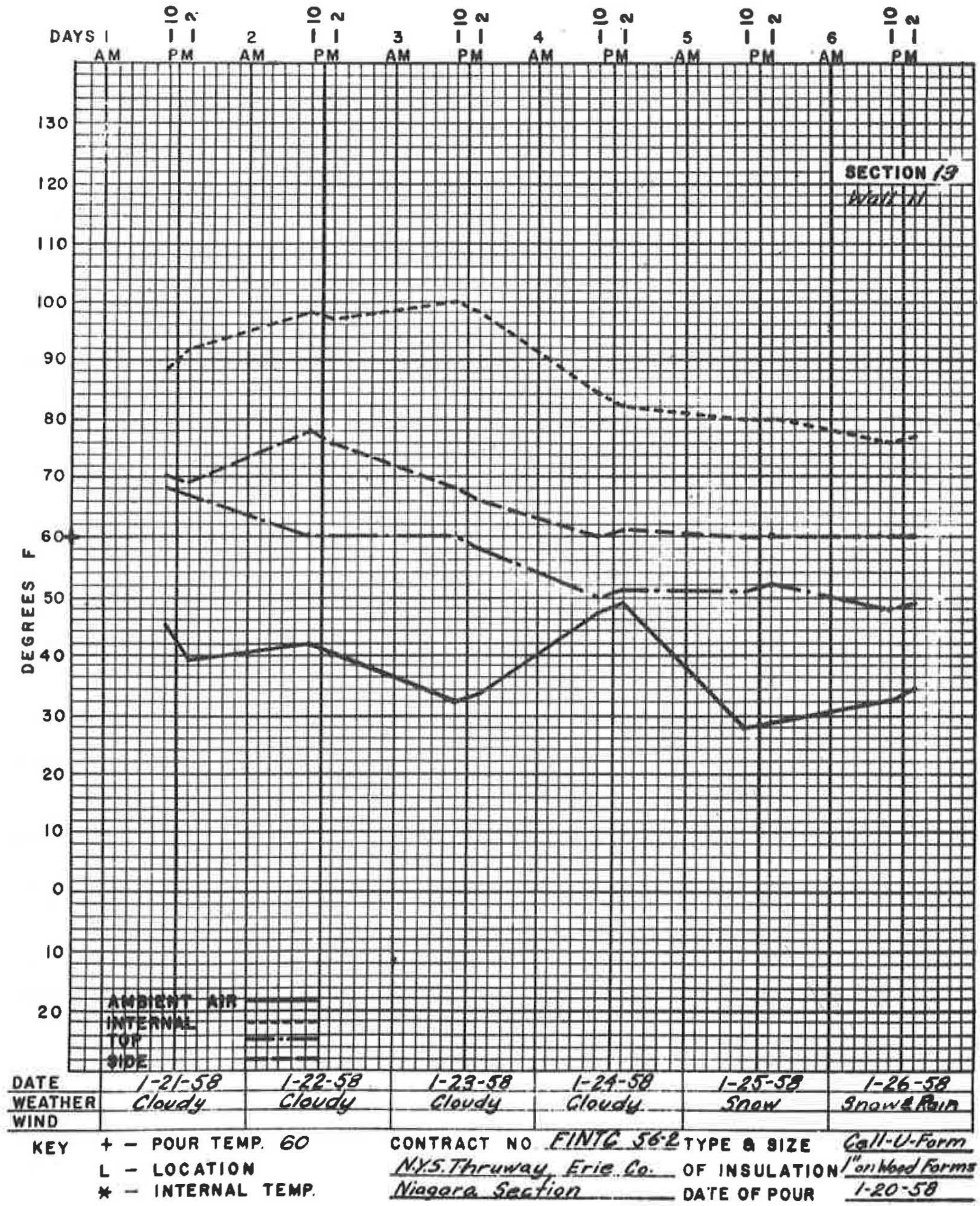

Figure 8. Heat evolvement from concrete placed at 60 F, with 1-in. insulation on wood forms.

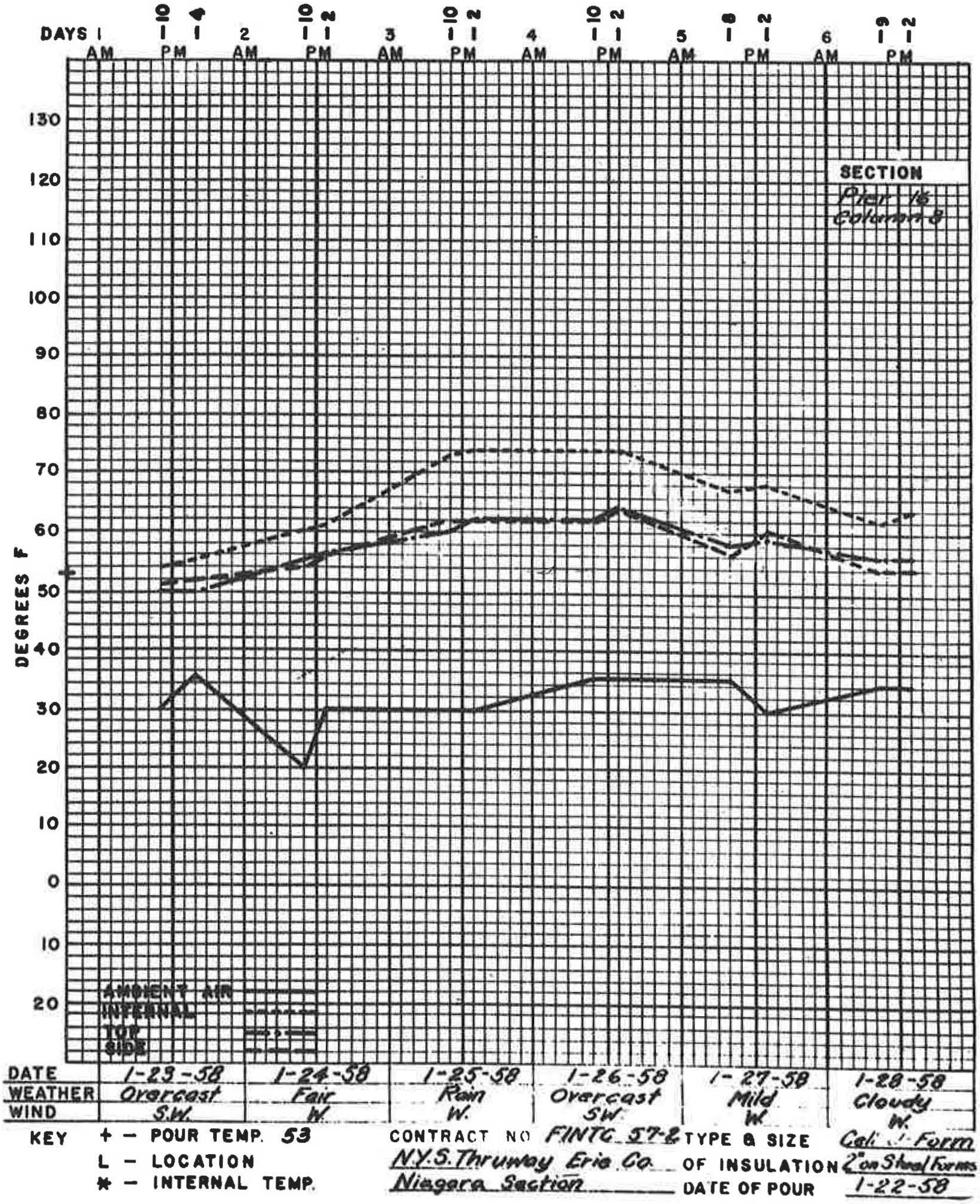

Figure 9. Heat evolvement from concrete placed at about 50 F, with 2-in. insulation on steel forms.

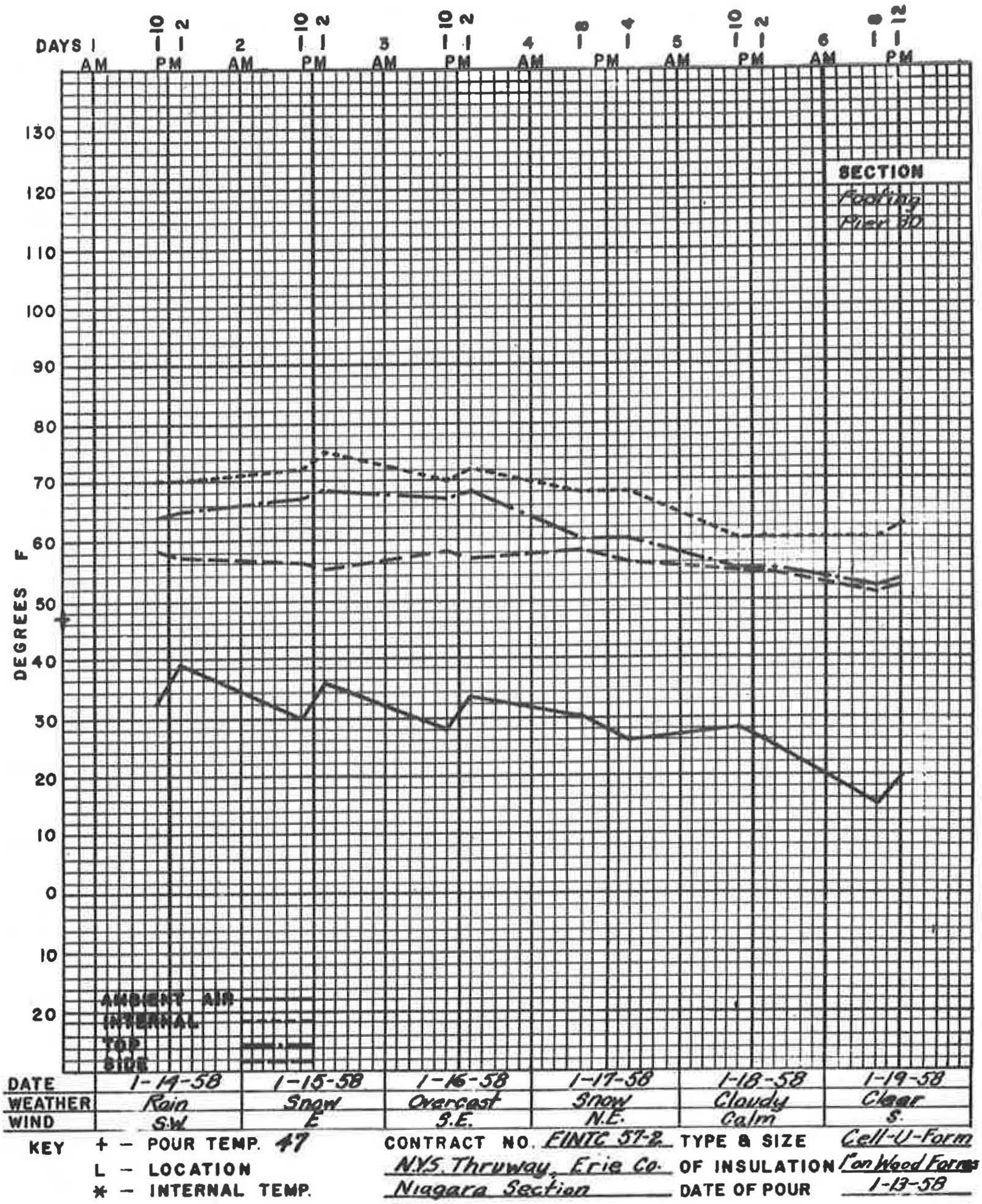

Figure 10. Heat evolvement from concrete placed at about 50 F, with 1-in. insulation on wood forms.

Figures 7 and 8 show heat evolvement when concrete is placed at 60 F. Figure 7 shows the use of 2-in. insulation on steel forms, and Figure 8 shows the use of 1-in. insulation on wood forms. Ambient air temperatures for these two conditions have an entirely different pattern, and it must be assumed that this, in part, is responsible for the temperature gradients attained for the concrete within the forms.

Figures 9 and 10 show heat evolvement when concrete is placed at approximately 50 F. Figure 9 shows the use of 2-in. insulation on steel forms, and Figure 10 shows the use of 1-in. insulation on wood forms. The average ambient air temperature for these two conditions was almost identical, and the temperature gradient patterns of the internal, top and side of the concrete within the forms were closely grouped.

The information contained in Figures 5 through 10 though specific in nature were chosen from some 1,500 reports as representative of the results obtained in four winter construction seasons. Test cylinder results on this concrete indicated an average strength of 5,200 psi.

With the many variables involved, it is difficult to resolve the requirements that satisfy all conditions encountered at time of construction. It is therefore necessary to draft a specification that will allow the engineer to interpret the requirements intelligently so that the best end results can be obtained.

Insulating materials and their coatings have been improved since the time of Scurr's initial work in this field. These improvements are indicated in the attached copies of the New York State Specifications.

Some 100 contracts will be progressed through the winter construction season of 1962-1963 by New York State, using insulated forms to protect the concrete produced. This has become a normal construction practice which has allowed the State of New York to keep current with the ever-expanding highway program.

ACKNOWLEDGMENTS

The writer is indebted to Gordon A. Erickson of the Wood Conversion Company for his technical assistance throughout the entire investigational period, to all the engineers and contractors for their cooperation and collection of all data pertinent to this program, and to William Scrom of the New York State Department of Public Works (Bridges) for compiling the reported data and preparing the graphs.

REFERENCES

1. Scurr, K. R., "Insulated Forms for Winter Construction of Bridges." HRB Bull. 162, 13-19 (1957).
2. Wallace, G. B., "Insulation Facilitates Winter Concreting." Bureau of Reclamation, Engineering Monograph 22.
3. "Recommended Practice for Winter Concreting." American Concrete Institute, ACI 604 (1956).

Appendix

ALTERNATE SPECIFICATION FOR CONCRETING IN COLD WEATHER

The following specification shall become a part of the contract document whenever concrete construction work is done under outside temperatures at below 40 F.

Protection of concrete by use of insulated forms or insulation laid on horizontal slabs is permitted under the following conditions:

Product

1. The insulating blanket shall be Cell-U-Forms as manufactured by Wood Conversion Company, Saint Paul, Minnesota, or approved equal.

The approval of any product as equal shall be determined by the Deputy Chief Engineer (Bridges).

2. The thermal conductivity (k) of the insulating blanket shall not exceed .27 Btu per sq. ft. per hour, per degree F. temperature difference between the two surfaces.

3. a) The 1" and 2" insulating blankets used on vertical forms shall have, on the side exposed to the weather, a 90 lb. double creped kraft liner or a polyethylene plastic liner, minimum thickness .004" or approved equal. The ⅝" insulating blanket shall have a minimum 50 lb. asphalt coated and creped kraft liner or a polyethylene plastic liner, minimum thickness .004" or approved equal. The interior liner completing the total enclosure of the blankets shall be a minimum 40 lb. kraft liner. The liners shall be asphalt bonded to both sides of the insulating mat. The liners shall have an extension on each side to form a flange so the blanket can be applied to the frame work of the forms.

3. b) Insulation used on horizontal concrete slabs shall have a polyethylene plastic liner, minimum thickness .004" or approved equal on both faces. The liner shall be asphalt bonded to both sides of the insulating mat. All edges shall be sealed.

Application of Insulation

4. a) The blanket insulation shall be applied tight against the wood form with the nailing flanges extending out from the blanket so they can be stapled or battened to the sides of the framing, which are either horizontal or vertical and spaced 12" to 16" o. c. The ends of the blanket shall also be sealed by removing a portion of the mat in order to bring the lines together and stapled or battened down to headers so as to exclude air and moisture. The corners or angles should be well insulated and held in place. See Figure 2.

4. b) In the case of steel forms the insulating blanket shall be applied tight against the form and held in an approved secure manner with ends sealed to exclude air and moisture.

5. Where practicable, the insulation (or insulated form) shall overlay any previously placed (cold) concrete by at least one foot.

6. Insulation of slabs on steel members shall be as indicated in Figure 3.

7. Any tears in the liner shall be patched or covered with a tacky waterproof tape or a piece of vapor barrier asphalted in place.

8. Where tie rods extend through the insulated form a plywood washer (¾" × 6" × 6" approx.) shall be placed on top of the insulation blanket and secured in a manner to provide adequate protection satisfactory to the Engineer.

9. The tops of all pours (horizontal and vertical) shall be covered with insulating blanket (Sect. 15) except for inaccessible areas around protruding reinforcement bars which may be insulated with salt hay or wrapped with approved insulation. Tarpaulins shall be used to cover the top of such pours as directed by the Engineer.

General Requirements

10. Outside temperatures at which concrete walls, piers, abutments or floor slabs above ground may be protected with insulation under various conditions as shown in Table 1.

11. a) Wood forms shall be insulated with an approved ⅝" or 1" insulation blanket as directed by the Engineer, on all sections more than 24" in thickness when concrete mixture is made with 5-½ bags or more of cement per cubic yard. On sections more than 48" in thickness a ⅝" insulating blanket shall be used. All sections 24" or less in thickness shall have forms insulated with an approved 2" insulation blanket.

11. b) Steel forms shall have an approved 1" insulation blanket on all sections more than 24" in thickness when concrete mixed is made with 5-½ bags or more of cement per cubic yard. All sections 24" or less in thickness shall have steel forms insulated with an approved 2" insulation blanket.

11. c) Insulation used to protect top of slabs shall be approved types of blankets 1", 1-½" or 2" as directed by the Engineer.

12. When insulated forms are used the temperature of the concrete mixture (5½ bags of cement or more per cu. yd.) shall unless otherwise directed have a temperature of not less than 50 F. or more than 60 F. for concrete sections having a thickness dimension of 24" or less, and not less than 40 F. or more than 50 F. in sections greater than 24" in thickness. When concrete is to be placed in contact with previously placed

(cold) concrete or in contact with an excessive amount of cold reinforcing bars or other steel members, the temperature inside of the insulated form shall be raised, as directed by the Engineer, to bring the temperature of the steel members to approximately 50 F.

TABLE 1

INSULATION REQUIREMENTS FOR CONCRETE WALLS, PIERS, ABUTMENTS AND FLOOR SLABS ABOVE GROUND

Cement Content lb. per cu. yd.	Wall Thickness (feet)	Minimum Allowable Air Temperature (Degree F.) for 1" Insul. Blkt.*	for 2" Insul. Blkt.*
400	.5	38	21
	1.0	22	-11
	1.5	8	-39
	2.0	2	-53
	3.0	- 6	
	4.0	- 8	
	5.0	-10	
500	.5	35	14
	1.0	15	-26
	1.5	- 3	-65
	2.0	-10	
	3.0	-20	
	4.0	-23	
	5.0	-25	
600	.5	32	6
	1.0	8	-41
	1.5	-14	-89
	2.0	-22	
	3.0	-34	
	4.0	-38	
	5.0	-40	

*The table is calculated for the stated thickness of blanket type insulation with a thermal conductivity of 0.25 Btu per hour per sq. ft. for a thermal gradient of 1 degree F. per in. Thermal resistance of the forms was not included, therefore, temperatures more accurately apply to concrete in steel forms. Use of wood forms would permit somewhat lower outside temperatures.

13. The Contractor shall provide thermometers to check the temperatures of the concrete as indicated in Figure 4.

14. Unless otherwise directed by the Engineer, the forms shall not be removed when the outside air temperature is 0 F. or below or when the weather forecast for the next 24 hours is for a temperature of 0 F. or below. They may be removed when outside temperature is below 32 F. providing the temperature difference between the air and the concrete surface is no more than 30 F. If possible forms shall be removed about the middle of the day to take advantage of the generally higher afternoon temperatures and radiant heat from the sun. However, in no case shall the forms be removed before the end of six (6) full days after the final placement of concrete in an individual unit.

15. Stand-by heat shall be provided if ordered by the Engineer. The application of exterior heat will only be necessary when thin slabs formed on one side only and in contact with structural steel are protected as indicated in Figure 3 or where the Engineer may direct in heavily reinforced sections, in lieu of altering the temperature of the concrete mix. When slabs are constructed and protected in conformance with Figure 3 external heat shall be introduced through the ducts formed by the enclosure, between the structural steel members prior to pouring the concrete, in order to preheat those members as directed by the Engineer. A uniform temperature of 50 F - 70 F. shall be maintained during the curing period. Transfer the external heat to the enclosure above the slab before the placement of the concrete, as directed by the Engi-

neer. The canvas enclosure shall provide protection for the slab and personnel during placing and finishing operation and shall be removed at the direction of the Engineer. Insulating blankets shall be placed on the surface of the slab as soon as the concrete has set so the surface will not be marred. The blankets shall be tightly butted together with the top of joints covered and edges held down with planks to prevent the wind from penetrating under it.

16. Permission to use this method does not relieve the Contractor of any of his responsibility under the contract nor does it change or modify any of the requirements of the specifications regarding concreting in cold weather except as stated herein.

ADDENDUM

Approved products for form insulation are:

1.) Celluform - as manufactured by Wood Conversion Company, St. Paul, Minn.

2.) Fiber glass curing blanket with fiber glass AF-15 filler - as manufactured by Owens-Corning Fiberglas Corp., Toledo, Ohio.

3.) Thermo-form and Thermo-slab - as manufactured by the National Gypsum Company, Buffalo, N. Y.

4.) Ultralite Glass Fiber Concrete Curing Blanket - as manufactured by Gustin-Bacon Manufacturing Co., 230 Park Ave., New York 17, N. Y.

5.) Ma Ka "Locked In" Insulated Blanket - as manufactured by Max Katz Bag Co., Inc., 316 So. New Jersey St., Indianapolis 4, Indiana.

October 22, 1958

Items 4 and 5 added
January 30, 1963

LETTER OF INSTRUCTION

Implementing Alternate Specification for Concreting in Cold Weather

TEMPERATURE OF CONCRETE PLACED - HEATING OF MATERIALS

The temperature of concrete when placed shall not be less than shown in the Alternate Specification for the class and type of construction indicated. Nor shall the temperature of the concrete when placed exceed that called for. The importance of proper pour temperature cannot be overemphasized. Concrete placed at low temperatures above freezing develops higher ultimate strength and greater durability than concrete placed at higher temperatures. High temperatures of freshly mixed concrete are always objectionable. Furthermore, higher temperatures require more mixing water, cause slump loss and sometimes quick setting, and increase thermal shrinkage. Rapid moisture loss from hot exposed concrete surfaces may cause plastic shrinkage cracks.

For air temperatures above 30 F with aggregates which are free of ice and frozen lumps, the desired temperatures of concrete can be obtained by heating the mixing water only. For air temperatures below 30 F, it is usually necessary to heat the aggregates to no more than temperatures of 35 to 40 F when the temperature of the mixing water is at 140 F. If the rock is dry and free of ice and lumps, adequate temperatures of fresh concrete can be obtained by only increasing the temperature of the sand which will seldom have to be higher than 100 F when the mixing water is 140 F.

Mixing water should be heated under such control and in sufficient quantity to avoid appreciable fluctuations from batch to batch. To avoid the possibility of flash set when water is heated to a temperature in excess of 100 F, water and aggregate should come together first in the mixer in such a way that the high temperature of one or the other is reduced before cement is admitted. Loss of potency of air-entraining agent is a possibility in the presence of hot water. Therefore, the agent must be placed in the batch after water temperature has been reduced.

TEMPERATURE RECORDS

Inspectors shall keep a record of the date, hour, outside air temperature (AM and PM), weather (calm, windy, clear, cloudy, etc.) and wind velocity and direction. The record shall include temperatures at all points indicated in Figure 4 of the Alternate Specification. It shall also include temperatures of the aggregates and water, the temperature of the concrete when placed, and thermometer reading shall be recorded giving the hour and dates of the reading for a minimum period of six days, with two readings per day, one in the morning and one in the afternoon.

The type of mix used (1-2-3½, 1-2-4) shall also be indicated.

TEST CYLINDERS

The test cylinders for this type of construction shall be job-cured consistent with the curing of the concrete in the structure insofar as it is practicable.

SELECTION OF INSULATION BLANKET - WOOD FORMS

When using wood forms for pours between 24" and 48" in thickness, the Engineer should base his selection of ⅝" or 1" insulation on the changeable climatic conditions consistent with the geographical location involved.

October 23, 1958