Insulated Forms for Winter Construction Of Bridges

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This paper develops the thesis that concrete bridge construction in the North Temperate Zone states of the United States has been traditionally subject to the disadvantage of a short construction season, due to the cold weather conditions existing during five months of the year. The only alternative to the short construction season has been the expensive alternate of using external heat and housings over the mass of concrete to be poured.

Furthermore, recent improvement in types of insulating materials has operated to reduce the additional cost of winter construction with no adverse effects on the concrete structures produced and with an attendant elimination of hazard by fire.

The greatly expanded highway construction program emphasizing the Interstate System, with a disproportionately large number of structures, creates such a demand on the existing construction plant that the program cannot be accomplished in a short construction season and the available plant must be economically used for a full twelve months if interests of the states and of the contractors themselves are to be properly served.

The illustrations used are from projects initiated in South Dakota in 1952 and 1953 and are intended to show that proper use of modern insulation in connection with forms for bridge structures offers a solution which is sufficiently economical to justify year-round construction. The experience of this state indicates that low temperatures alone are not sufficient justification to suspend construction operations in the case of the majority of concrete structures of the girder or slab type and in the case of foundations for structures of any type.

● USE of insulated forms of various types for protection of fresh concrete poured in subfreezing temperatures is not new. However, the pressures of modern construction programs are such that a search for better insulating materials and better techniques for their economical use is of constantly increasing importance. It is of special importance in the northern third of the United States that methods be devised which will permit uninterrupted concrete construction to be carried on economically throughout the winter months and create a 12-month construction season instead of a 7-month season.

One of the methods by which this can be accomplished is by the use of heated enclosures. This method is satisfactory, but expensive, and introduces a hazard due to fires. Use of insulated forms that will hold the initial heat of the mixture plus the heat generated during the process of hydration offers the safest, most efficient, and most economical method for enabling concrete construction to be carried on through freezing weather at a maximum production rate combined with a minimum of added cost.

There are well authenticated records of the use of various types of insulating materials in the Scandinavian countries, Russia, Canada, and the northern United States during the period following World War I and by the German and Russian armies in the construction of some military works during World War I. Some similar construction was done in Alaska during these years by individuals, but none by governmental agencies.

These known early examples, however, usually were confined to isolated projects and were executed by a few imaginative builders, using such materials at hand as had some insulating qualities. Included in this category were earth, straw, hay, wood shavings, sawdust, manure, moss, or peat. The use of such methods was usually the result of an emergency caused by a sudden or unexpected drop in temperature, necessitating protection of freshly poured concrete or a requirement to complete a partially poured construction unit.

A few major European projects utilized insulated forms in a planned program to carry on continuous construction through the winter. In these instances, however, the insulation was not for prevention of freezing of the concrete before it was safely cured, but to prevent thawing and refreezing. The forms were left in place and additional forms were built for the next stage. Then in the spring all the forms were removed and the normal curing cycle proceeded.

Use of heated enclosures was and is common, but the added expense and fire hazard is so great that this method must still be regarded as an expedient to meet a completion date or to accomplish a "crash program." With only this method of protecting concrete available, the ordinary, general purpose construction season cannot be considered to be effectively or economically lengthened to a 12-month season.

Following World War II the demands on the construction industry to build the backlog of projects resulting from the suspension of normal construction during the war years brought a sharp realization to these Northern builders that the shorter construction season in which they could work economically was creating an adverse situation for them and their organizations. Their equipment must be idle and their personnel on retainer pay in order to hold an operating force together. Of even greater importance, satisfactory progress in retiring the backlog could not be made.

The greatly accelerated Interstate Highway Program presents further demands on the existing construction organizations. With the heavy emphasis on controlled access and the multitude of interchange and separation structures by which this control must be accomplished, the program cannot be completed unless the personnel and equipment and construction "know how" can be kept employed 12 months each year instead of the average 7-month season generally prevailing in the extreme Northern states. Fortunately, modern research has met the situation, and techniques and materials have been made available which will enable the industry to operate on a year-round basis and to use its machines and personnel with year-round efficiency and reasonable economy.

The phenomena of internal heat generated during the setting-up processes in concrete have long been common knowledge, but the techniques of capturing and retaining this heat were not developed until special insulating materials became available which made use of insulated forms both efficient and economical. The most adaptable of these improved materials is the blanket type formed by encasing balsam wool, rock wool, or glass fibers between two tough Sisal-kraft covers with edge strips for nailing to or between studding.

South Dakota is located in the region handicapped by a short construction season during which unprotected concrete may be placed. It is natural, therefore, that it has had more than a casual interest in exploring methods by which concreting operations can be carried on without interruption and with a satisfactory degree of economy. The solution arrived at is deemed so satisfactory that the specifications have been changed to provide that low temperatures alone will not be considered as a reason to suspend work on a "weather-working-day" contract. It is not contended that there is no extra cost of winter work using these techniques; however, proved experience records indicate that the added cost of winter concreting by these methods is less than 25 percent of the added costs resulting from the heretofore conventional methods of using heated enclosures.

This method uses concrete introduced into forms insulated by double balsam or equivalent blankets at a temperature of about 65 F. The original temperature is obtained by means of heating water and/or aggregates in conformity with the provisions of "Recommended Practice for Winter Concreting," ACI Standard (604-56). This Standard also makes specific recommendations (Table 1) as to the values of various insulating material, which confirm the South Dakota practices during the winter of 1952-3.

The specific examples which follow are entirely from the South Dakota bridge projects of which the author has personal knowledge. No doubt other more striking examples on more important works are currently available.

USE ON BRIDGE PIERS

The first major project upon which the balsam wool blanket insulated forms were used by South Dakota offered an unusually favorable situation for comparison and verification of costs. The state had awarded a foundation contract of $1,250,000 for the substructure of a highway bridge at Chamberlain, S. Dak. About one-half mile downstream another

TABLE 1

INSULATION EQUIVALENTS

Insulating Material (1-in. Thickness)	Equivalent Thickness, in.
Commercial blanket or bat insulation	1.000
Loose fill of fibrous type	1.000
Insulating board	0.758
Sawdust	0.610
Lumber (nominal dim.)	0.333
Dead-air space (vertical)	0.234
Damp sand	0.023

agency had awarded a foundation contract for a railroad bridge with piers of the same height but greater mass. The same contractor, Guy James-Condon Conningham, was the successful bidder on both contracts and construction proceeded concurrently during the winter of 1952-3. On the first state pier conventional heated enclosure was used. Later the contractor elected to take advantage of the state's favorable attitude toward the use of insulated forms, but was required by the supervising authority on the adjacent similar project to continue to utilize heated enclosures. Costs on both projects were available and both projects involved work of similar magnitude.

The cost of constructing the enclosure alone for the housed and heated pier was approximately 20 percent higher than the cost of insulating the original forms for the similar insulated pier. To this original cost of enclosure must be added the cost of fuel, equipment, and watchmen to maintain required temperatures and moisture conditions, none of these costs being applicable to the work accomplished by the use of insulated forms. The salvage and re-use values of the insulating material was much higher than

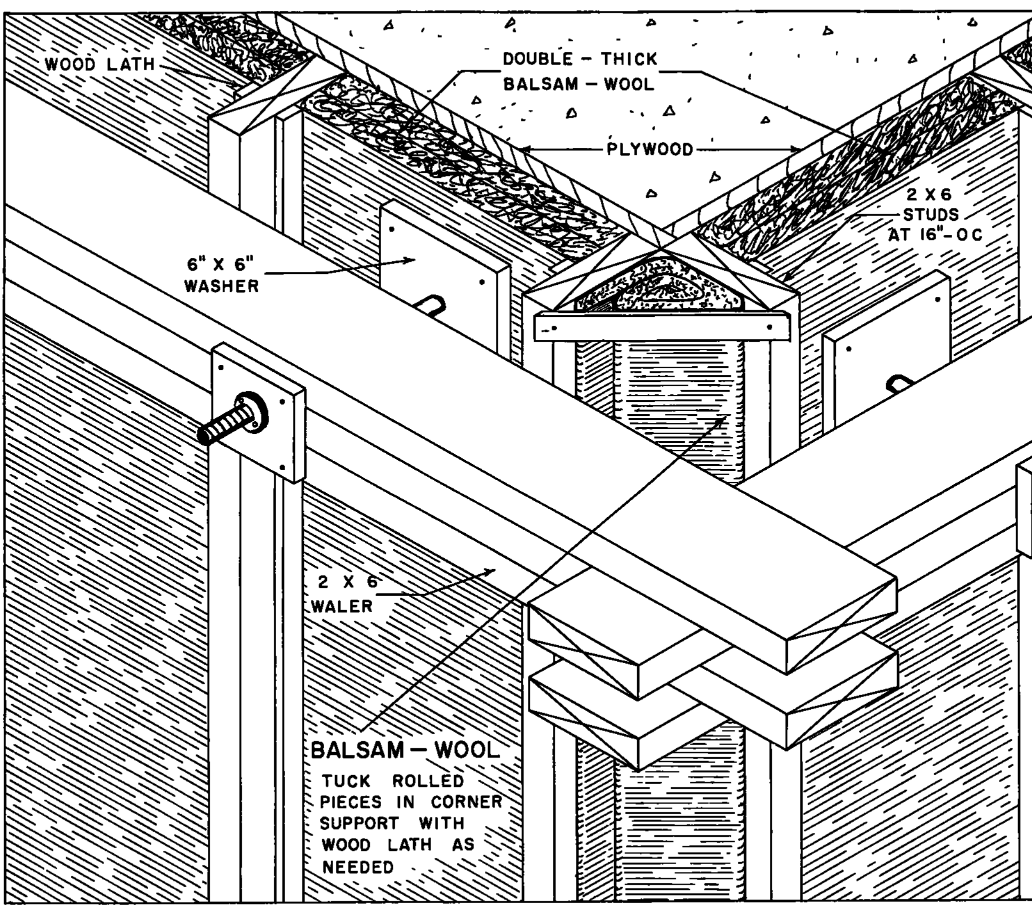

Figure 1. Method of applying insulation to mass concrete forms.

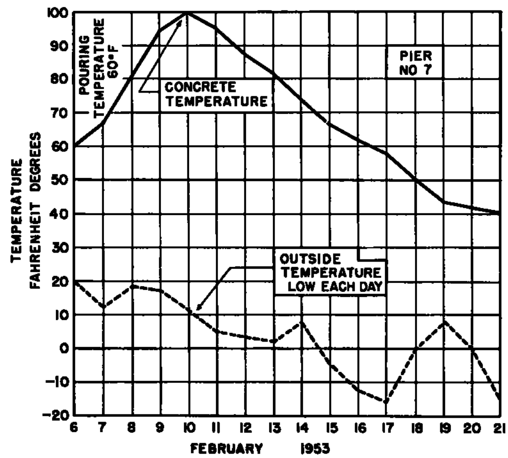

Figure 2. Typical temperature curve for all pours of Pier 7, bridge at Chamberlain, South Dakota.

for the enclosure. The average cost of insulating the forms for these piers was approximately $3 per cubic yard of concrete protected for the first set of forms. Most of the form panels were re-used three times without removal of the insulation from them. The over-all cost was about $2 per cubic yard of concrete protected by insulation, as compared with approximately $8 per cubic yard for concrete protected by enclosure and heating. This rather high unit cost is attributed to the height of the pier, which did not affect the cost of insulation to the same extent. The monetary saving is not the only measure of the advantage of this method over those involving use of external heat introduced by burners or steam. On the railroad structure project, built concurrently with the highway structure by the same contractor, the heated enclosure method resulted in two fires that destroyed enclosures and forms and may have caused some surface damage to the concrete itself. One man was killed in attempting to bring the enclosure fire, at a height of 65 ft, under control.

Figure 1 illustrates the method of applying the insulating blankets. In each case a 1-in. bolt was introduced through the form into each pour of concrete. This bolt was removed after initial set had occurred and the aperture left by its removal was used for insertion of a thermometer to record the heat changes. Access to the thermometer was through a flap-covered slit in the blankets. Temperatures were taken about 2 in. inside the forms. Check temperatures, taken inside the insulation but outside the form, were 6 to 8 F lower than the inside temperatures, which are considered the more significant because the form itself has a good insulating value.

Each successive lift was poured on a previous lift or base which had attained outside temperatures. A flap of 12 in. of blanket overlapped the construction joint to minimize heat loss, but no attempt was made to preheat the surface. An enclosure for protection of workmen was supported on the dowel bars projecting into the next lift. Heat from a propane heater was blown into the enclosure while the concrete was being placed and finished. This was the only artificial heat used.

Figure 2 shows the typical temperature curve for all pours for Pier 7, in January and February 1953, during weather that approached or was below zero. The concrete was S. D. Standard, Class A, 4,000-psi, using six bags of cement per cubic yard with no additives.

From this curve it can be seen that the concrete was introduced into the forms at an average temperature of 60 F with outside temperatures of 20 F. The heat generated during the process raised the temperatures at the thermometer apertures inside the forms to approximately 100 F on the fourth day and thereafter a practically uniform loss of 5½ F per day continued for 11 days with outside temperatures varying between 20 and -16 F. At the end of 16 days the temperature inside the forms was still 40 F. No further record was maintained, as the forms were then removed for re-use. It would have been considered entirely safe to remove the forms on the eighth day if the schedule of operations had made it desirable. Test cylinders cured inside the insulation next to the forms followed normal strength curves.

Inasmuch as no fine finishing is required on work of this type (except on the top surface, which was finished as it was poured), and final dressing of the vertical surfaces must be done after a pier is entirely completed, the method had no real effect on the cost or quality of finishing.

The maximum temperatures attained in the forms and the rate of loss after passing the peak temperature are both functions of the mass of the protected concrete. The sec-

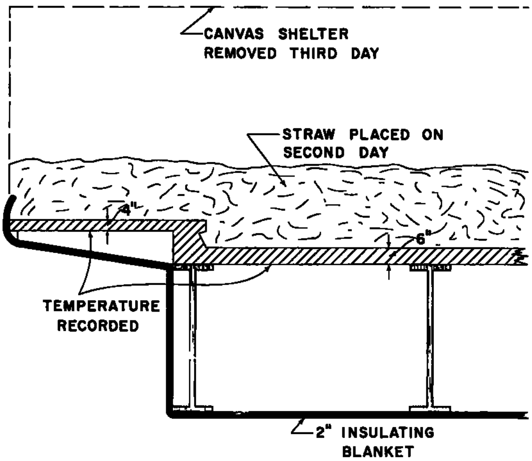

Figure 3. Method of insulating concrete slab poured on steel girders; Bad River bridge, Ft. Pierre, South Dakota.

tions referred to were columns of approximately 6-ft rectangular section. The same technique has been used with light structural frames of 2-ft rectangular section. In such structures a maximum temperature of approximately 90 F was attained on the third day after which there was a uniform loss of about 7 F per day. In no case did the concrete in the insulated forms fail to meet the most rigid strength requirements.

USE ON SLAB-AND-GIRDER CONSTRUCTION

The preceding typical instances deal only with insulation to capture and utilize the heat of hydration. Insulation of forms has another application that is almost equally important. This is in connection with the construction of thin slabs on structural steel girders. In such a case, however, complete reliance has not been placed on utilizing heat of hydration, due to the larger exposed areas, the thin section formed on one side only, and the fact that the steel girder conducts cold to the slab, thus creating undesirable low temperatures above the girder flange. In such instances insulation has been used in conjunction with external heat. Figure 3 illustrates this combined technique as applied to the Bad River bridge at Fort Pierre, S. Dak.

In this instance the insulation retained the inadequate internal heat and minimized the requirement for introduction of external heat by preventing its loss. A substantial economy resulted from this type of operation as opposed to formerly used conventional housing and heating methods. The canvas working enclosure provided to protect the slab and personnel during placing and finishing operations was removed on the third day, when straw insulation was provided over the entire top surface. The external heat was introduced through the ducts formed between the girders by the insulation to preheat the cold girders and was transferred to the enclosure above when placement of concrete commenced. No direct heat was applied under the sidewalk. Figure 4, the temperature record at the underside of the sidewalk slab and the floor slab, shows that the maximum temperature was attained on the first day, with a drop to approximately 35 F at the sixth day. Since no external heat could reach this slab directly, it indicates that no external heat need be supplied to protect such a slab as thin as 5 in. if other means could be provided to prevent cold conductance through the steel girders.

In the case of concrete box culverts the thin walls and slabs can be adequately protected by use of insulated outside forms with closures at each end. A minimum amount of heat is introduced through the closure into the barrel for one day to counteract the effect of the cold bottom slab, which is poured at an earlier date under conventional protection conditions. The top slab, after finishing under a heated enclosure, is protected by straw or balsam blanket cover as in the case of the

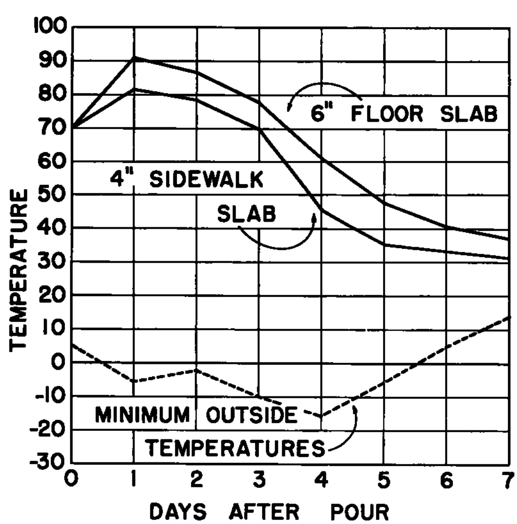

Figure 4. Temperature chart, Ft. Pierre bridge; typical of five pours.

floor slab of the Fort Pierre Bridge. Figure 5 illustrates this method.

A gain of about 25 F can be expected on the second day if concrete is introduced into the forms at 60 to 65 F. Thereafter, loss at the rate of about 9 F per day can be expected. This behavior is approximately the same for all sizes of culverts. The larger culverts have greater exposed areas contributing to the loss of heat, but this is offset by the thicker slabs with greater capacity for generating and holding heat.

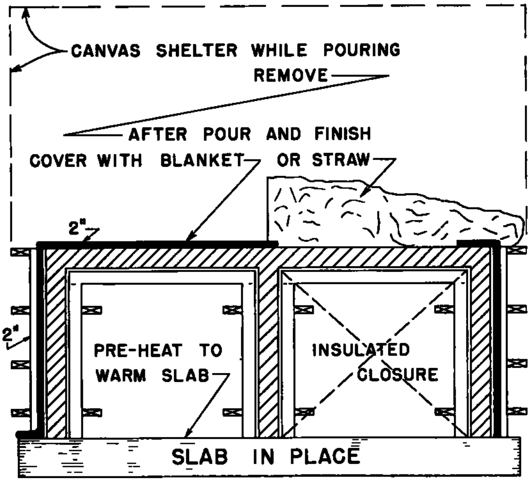

Figure 5. Method of protecting new concrete in concrete box culvert from freezing outside temperatures.

It is true that the cost per cubic yard of protecting thin slabs or small columns is greater than for more massive construction. However, the same differential in favor of the insulated forms as compared to heated enclosures continues to be evident, as the unit cost of housing and heating small volumes of concrete increases even more rapidly than the cost of insulating forms.

In every case test cylinders cured under the same conditions as the protected concrete showed no departure from a normal curve of strength attainment during the periods of protection.

The insulating material currently available seems to be sufficiently adaptable to lend itself to the solution of almost any form problem. Steel forms were insulated by one builder by fastening directly to the forms with an adhesive; another welded clips to the forms to hold nailing strips, to which the insulation was fastened. Still another large builder secured the insulation to plywood panels and created compartments around the forms but separate from them. Another problem involves the handling of reinforcing bars passing out of a construction joint. It appears to be adequate to cover these bars with protective wrapping or to enclose them in a protective but not necessarily insulated shelter. The usual percentages of reinforcing steel do not appear to carry off heat at a rate which affects the normal behavior of the mass of concrete if the steel and joint is not entirely exposed to the elements.

Another question has been raised as to the behavior of very large masses of concrete in insulated forms. Although South Dakota has not encountered this problem, it would appear that the criterion is self-evident. If the mass of concrete is such that internal heat must be dissipated or drawn off under summer construction conditions, the same provisions must be made if insulated forms are used. In such cases the use or non-use of insulated forms would not be the governing factor. Some of the internal heat can be dissipated to the forms and serve a useful purpose. Certainly the use of insulated forms confining the heat should reduce the differential between the heat at the center of the mass and at its surface. This should tend to minimize resulting distortions. It is even conceivable that insulated forms in non-freezing weather might serve a useful purpose on very massive sections by reducing the differential between interior and exterior parts of the work. It would seem that, where harmfully high interior temperatures might be generated, this heat should be dissipated through conventional circulatory systems rather than to rely on the questionable expedient of loosening forms or insulation.

As a result of experience between 1952 and 1957, the Bridge Division of the South Dakota Highway Department is sufficiently convinced of the practicability of economical winter construction by use of insulated forms that weather-working day contracts are not suspended for reasons of low temperature alone. Contractors do not hesitate to bid work that might involve winter operation. In fact, there are indications that the advantages of year-round operations now tend to offset the additional costs and hazards of cold weather operation.

All evidence points toward the conclusion that improved insulating materials and techniques provide the means for production of quality concrete any month in the year, at any temperature, without a prohibitive price penalty. This will permit the contractor to approach 12-month efficient employment of his plant and personnel. If all other obstacles to unimpeded progress in the highway construction field can be as successfully reduced as this one, the potential construction plant of the nation will be capable of meeting the challenge of the multibillion dollar program of the next ten years.