HIGHWAY RESEARCH BOARD

Bulletin 162

Concrete Pavement Construction and Winter Construction of Bridges

National Academy of Sciences—
National Research Council
publication 52

HIGHWAY RESEARCH BOARD

Officers and Members of the Executive Committee

1957

2101 Constitution Avenue   Washington 25, D. C.

HIGHWAY RESEARCH BOARD
Bulletin 162

Concrete Pavement Construction and Winter Construction of Bridges

PRESENTED AT THE
Thirty-Sixth Annual Meeting
January 7-11, 1957

1957
Washington, D. C.

Department of Materials and Construction

R. R. Litehiser, Chairman
Engineer of Tests, State Highway Testing Laboratory
Ohio State University

CONSTRUCTION DIVISION

Howard R. Craig, Chairman
Engineer of Construction
Ohio Department of Highways

COMMITTEE ON CONSTRUCTION PRACTICES—RIGID PAVEMENT

John H. Swanberg, Chairman
Chief Engineer, Minnesota Department of Highways

F. L. Ashbaucher, Engineer of Road Construction, State Highway Department of Indiana

J. F. Barbee, Assistant Engineer, Ohio State Testing Laboratory

Walter Van Buck, Division Engineer, Bureau of Public Roads, Kansas City, Missouri

Forrest Cooper, Deputy State Highway Engineer, Oregon State Highway Department

S. E. Hicks, Engineer of Construction, State Highway Commission of Wisconsin

J. W. Johnson, Laboratory Chief, Iowa State Highway Commission

Emmett H. Karrer, Professor of Highway Engineering, Ohio State University

R. L. Peyton, Research Engineer, State Highway Commission of Kansas

G. K. Ray, Portland Cement Association

Charles E. Shumate, Administrative Engineer, Colorado Department of Highways

R. H. Tittle, Engineer of Construction, Illinois Division of Highways

Contents

Criteria for Present Day Concrete Pavement Construction

R. L. PEYTON, State Highway Commission of Kansas

This paper presents in general terms the criteria which should be used in preparing plans and specifications for the control of modern concrete pavement construction. These criteria are developed from three basic concepts: (1) The objectives of the owner, represented by the engineer or inspector, and the contractor are, or should be, identical. (2) A concrete pavement construction operation is in reality an outdoor mass production assembly line and as such is subject to the same rules of operational procedure as any mass production assembly line. (3) An accurately adjusted and properly operated machine, designed to perform a specific operation in the line, will do a better job than a man or a group of men.

Each of these basic rules is analyzed in some detail with respect to their application in the preparation of plans and specifications for control of concrete pavement construction and the achievement of principal objectives of such construction work. Criteria are indicated for control of each of the four principal areas of operation in pavement construction: (a) assembly, batching and hauling materials, (b) subgrading and forming, (c) mixing and placing, and (d) finishing and curing.

● SUPERVISING construction of concrete pavement is an art, not easily acquired and ordinarily requiring years of practical experience for proficiency. Throughout some 30 years many techniques, methods of construction and devices for use on such construction have been developed. No doubt all of these were once considered either useful or desirable on a pavement construction job; however, many such practices have become outmoded or obsolete. It seems appropriate to review the methods of pavement construction with the objective of establishing criteria by which modern pavement construction practice can be governed.

Many experienced pavement construction engineers may consider this paper an unnecessary reiteration, but newcomers enter the field and their number will increase in the future. It is desirable to provide them with the knowledge derived from experience of others.

Pavement construction practices vary widely throughout the country and methods considered desirable in some areas are not always found acceptable in others. The ideas expressed here reflect experience acquired in the Midwest, and more particularly in Kansas.

Classification of pavement construction practices as good or poor may be premised on three general rules: (1) The objectives of the owner, represented by the engineer or inspector, and the contractor do not conflict but on the contrary are, or should be, identical. (2) Concrete pavement construction is in reality an outdoor mass production assembly line and, as such, is subject to the same rules of operational procedure as any mass production assembly line. (3) An accurately adjusted and properly operated machine, designed to perform a specific operation in the line, will do a better job than a man or group of men.

Acknowledgment and acceptance of the first basic concept will do much to eliminate a poor construction practice that is generally widespread and frequently encountered; that is, the "cops and robbers" attitude adopted by many engineers and inspectors in their relationships with contractors and their representatives. Also, contractors can help by recognizing that the owner's representatives are not present only to impede their progress, make impossible demands upon them, and generally foul up the job by their presence.

The objectives of both parties are the same. The owner desires to acquire a modern concrete pavement, properly designed for safety, and constructed with quality materials at a reasonable price; the contractor desires to provide the owner with just such a product and in so doing make a reasonable profit on the venture. Achievement of these objectives provides the owner with a needed facility, and with the tools and trained personnel required for subsequent work of the same character. It enhances the contractor's reputation and enables him to stay in business.

The contractor or the construction engineer is responsible for neither the design of the pavement nor the designation of the type and quality of the materials. Good and poor practices also exist in the fields of design and materials. An element of design either omitted from or incorporated into the pavement plans will often force upon the paving engineer and contractor a construction operation that is poor practice, over which they have no control. The same is true of materials specifications and quality control requirements particularly with regard to the time element involved in testing procedures. Since these problems should be resolved in advance of construction, it will be assumed for the purposes of this discussion that they do not exist.

Concrete paving operations are unique in the general area of concrete construction work. In pavement construction there is more surface area of concrete exposed outside the forms (per unit of volume) than in any other type of concrete work. This factor indicates the need for high speed operation from the point of placing the concrete to the final protection or curing of the slab. The equipment required must be mobile and move along the line as the job progresses, and the whole operation is susceptible to weather conditions. Since the unit cost of the product decreases with increase in volume, the capacity of the paving plant should be large and the various components in the line should be of great reliability with respect to continuous operation. All of these requirements lead to the concept of the outdoor assembly line technique; the essentials of high capacity, speed, and reliability point to the use of machine methods wherever possible. Therefore, design, specifications, and construction technique predicated upon these concepts is good construction practice. Any element in the design, specifications for materials and/or construction methods which tends to impede or obstruct the use of the assembly line technique and machine operation is poor construction practice.

The details of operation will be subject to such factors as the size of the job, the character of the terrain at the job site and anticipated weather conditions. There are, however, some elements of good construction practice common to all paving projects.

ASSEMBLY, BATCHING AND HAULING MATERIALS

The primary requirement for the plant site where these operations are concentrated is adequate space. The site should be large enough to provide for delivery and assembly of materials on the site and proportioning or batching of materials and hauling away from the site. These functions should be accommodated by arranging stockpiles, storage areas and maintenance areas so that cross traffic is minimized or eliminated between the delivery services and the batch hauling vehicles, and so that the assembly line principle of uniform straight line flow of materials can be utilized with minimum impedance from stops, turns and waiting for counter-flow traffic. Location of the site to minimize hauling distances and to provide access to other forms of bulk transportation is also an important criteron for consideration in establishing a paving plant.

A satisfactory arrangement of plant facilities will promote good construction practices in respect to the usual details of control found in many specifications such as bermed stockpiles for prevention of segregation and adequate storage for a specified period of operation, moisture control, etc. On the other hand, when space is limited and the plant facilities are crowded, such specifications are difficult, if not impossible, to enforce; traffic is confused and delayed; and the rate of production upon which the efficiency of the entire paving train depends is seriously curtailed.

SUBGRADING AND FORMING

The only element of construction or design that is discernible to the casual user after construction is the riding quality of the finished slab. It is basically good construction practice, therefore, to direct maximum effort toward the production of a smooth riding pavement. This effort should start with the subgrading operations and continue to be the paramount objective in the construction of the subbase and in setting form lines for concrete slab.

High density is a desirable and necessary condition in most pavement subgrades and in all subbases. But even more important with respect to the construction of smooth pavements is uniform density of the subgrade and subbase in both the longitudinal and transverse directions of the slab. Equally important is the continuity of the grade line and the smoothness of the finished surface in each stage of the construction.

Density control in the subgrade and subbase is usually specified as a minimum percentage of some standard density governed by stated conditions of compactive effort and moisture content. The enforcement of such specifications to the letter can easily result in conditions that will produce rough riding pavements if no attention is directed toward the uniform densification of the material throughout the area to be paved. Indeed it is believed that the uniformity of the compacted layers, subgrade, and subbase is far more important to the finished product than the degree of compaction in these components of the pavement structure. An excellent construction practice of recent development is to use a heavy pneumatic roller as a testing instrument to insure a uniform condition of support in the subgrade and subbase after all other construction operations in these phases have been completed.

The character of the surface of the finished subgrade and subbase can also be of considerable influence on the smoothness of the concrete slab. The usual precautions may be taken to insure that the form sections are straight and of adequate cross-section to support the load of passing equipment, and they may be accurately set to line and grade, properly locked together and pinned in place. But unless they are supported throughout their length by a subgrade or base that is constructed to the same line and grade and compacted uniformly to the degree that deflection under load will be at a uniform rate, rough pavement may result. The machines in a modern paving line are heavy, and nonuniform deflections in the form line will occur at any point not capable of supporting the load to the same degree as any other point along the line. Pavement roughness may also be produced in the interior of the slab when imperfections in the surface of the base are present or the density of the material is not uniform because of a varying rate of consolidation and shrinkage of the concrete in these areas.

Most plans and specifications require uniformity of compaction of subgrade and subbase, accurately cut line and grade, and surface smoothness of these layers, by inference only. Whether or not they are fully described in the specifications and plans, it is good construction practice to ensure their achievement; it is poor practice not to, as the probably result will be a rough pavement. There are many methods available to achieve the desired results; the details should be left to the project engineer and the contractor. The principal objectives of this section of operations, forming and subgrading, should be a smooth surface constructed accurately to line and grade, and compacted to a uniform density throughout. Assembly line techniques and continuity of operations, whatever the method or equipment used, are particularly well adapted to produce the desired results.

MIXING AND PLACING CONCRETE

On a modern concrete paving outfit the operations of mixing and placing are probably the easiest of any to accomplish physically. At the same time, they are the most important of all the phases of operation because the rate of production from the mixer governs the capacity required in all other phases, and the capacity of the mixing equipment is usually greater than that provided for batching and finishing.

Paving contractors now commonly produce from ½ to ⁶⁄₁₀ mi. of 24-ft reinforced concrete pavement, 9 or 10 in. thick, per working day. An efficiently operated mixer can produce from 1 to 1½ cu yd of concrete every 45 seconds. At the rate of 1¼ cu yd per batch, a double mixer outfit may easily produce 3,000 lin ft of 24-ft pavement in a 10-hour day. Good construction practice requires plans and specifications which allow the contractor to make use of this high capacity mixing equipment. This requires him to provide adequate batching facilities to serve the mixers and ample spreading and finishing equipment to care for the mixed concrete. The production rate of the mixers on a job represents, to the contractor, the profit making rate of the job—creating a strong tendency on his part to keep the mixers running regardless of the effect on the quality of the other phases of operation, particularly finishing and curing. If specifications and standard construction practice provided ample facilities to operate at maximum mixer capacity, many of the difficulties which beset the project engineer and pavement inspector with respect to finishing and curing operations would be eliminated. Many current pavement specifications should be reviewed and revised in accordance with this concept.

Mixing and placing concrete on a paving job can be almost entirely a machine operation. The only remaining manual operation is installing the reinforcement in pavement. With the advent of sawed longitudinal joints, automatic machines have been developed to install tie bars; some enterprising contractor probably will develop a machine to lay paving mesh.

The actual operations of mixing and placing are fairly simple once the machines have been properly adjusted by competent operators. It is good practice to adjust, calibrate, and operate the equipment prior to the start of the work in order to avoid wasting time the first day of paving operations. This involves adjustment and calibration of the water measuring device, admixture dispensing units, mixing time unit, operating controls on the mixer, and the spreading devices and strike off on the spreader. Full power should be available from the driving motors.

The principal objective of good construction practice in this phase of operations is the production of a uniform material—plastic concrete. The details of mix design, consistency and finishing properties are the responsibility of the materials engineer on the job. Once these properties have been agreed upon the rate of production should be determined, based upon the capacity of the slowest unit in the line. This unit should be the mixer, or mixers; unfortunately it usually is not. Whatever the production rate, once it is set by this criterion and the machines are adjusted to peak operating efficiency, achievement of this objective is simple, and continuous operation is assured.

FINISHING AND CURING

These operations are the most difficult to accomplish in a concrete pavement production line. There are many different ways of performing these phases of the work. They are radically affected by weather conditions and also by all the other construction operations preceding them; such as, density and smoothness of base, mix design, uniformity of product and rate of production of the concrete. For these reasons it is difficult, if not impossible, to insure good construction practice by specifications and instruction manuals only. The engineer and the contractor must rely on experience and their knowledge of the presence and effect of these variables to direct the operations of finishing and curing in a manner that will produce the desired result.

Finishing

The objectives of good construction practice in finishing are to consolidate the plastic concrete (deposited on the grade and struck off in the mixing and placing operations) into a condition of uniformly high density without segregation of coarse aggregate and mortar and to smooth off the surface true to line, grade, and cross-section, properly jointed and with a continuity of line in the longitudinal direction that will provide a satisfactory riding surface. Machines are available which obtain these objectives with little or no manual methods, provided they are correctly adjusted before starting the work, maintained in that condition of adjustment, and operated in a proper timing sequence that takes into account the current weather factors, the rate of production, the character of the concrete mix and other elements. In the usual order the finishing operations include transverse strike-off and screeding with accompanying consolidation (vibrators or tampers), transverse strike-off and screeding without special consolidating equipment, longitudinal screeding, surface finish (brooming, belting or dragging). When formed joints are used some type of joint cutting equipment may be used between the second transverse screeding and the longitudinal screeding.

The first and most important element of good practice here is to assure the presence in the line of enough finishing equipment to handle the concrete at the established rate of production, within the time available as indicated by such factors as setting time, weather conditions and others. Insufficient equipment will result in poor practice on the production line since all other operations will be delayed.

The second important element is adjustment of the equipment. Modern machines can be adjusted to form almost any desired cross-section, as well as compact and smooth off the concrete. Adjustment of the equipment includes regulation of screed speed, forward speed of the machine, and check for adequate power—as well as setting the form of the screeds and their elevation above the surface. These adjustments and checks should be made before starting work, ample time should be allowed for this purpose, and a thorough job of adjustment at this point will insure good finishing practice. It is poor practice to leave the supervision of these adjustments to the contractor's operators and to find subsequently improper machine adjustment which requires continual readjustments. Correct adjustments in the machines should, of course, be maintained as the work proceeds.

The final element of good practice is timing the sequence of events from the initial compaction of the concrete to the final surface finish. This cannot be established by specification or regulation in advance of the work but must continually be supervised by the engineer and contractor and adjusted to conform to the governing conditions of mix characteristics, weather and production rate. The use of manual finishing operations is generally required to correct the mistakes or inadequacies of machine finishing due to improper timing sequences. Manual finishing is not necessary if the machines are timed properly and efficiently operated. However, most specifications recognize by inference that the objective of proper timing of the machines will not be achieved and compensate with required manual finishing.

Unfortunately, the value of a properly conceived timing sequence of finishing equipment in terms of quality of finished pavement is often not recognized. Often the timing sequence is regulated by attempts to develop maximum production from the mixer with inadequate finishing equipment and by the fear that a costly shutdown due to inclement weather or machine breakdown might occur. Finishing equipment adequate for the established rate of production, combined with standby replacement units and an efficient maintenance plan, will minimize such operations. Alert supervision can usually anticipate unfavorable weather conditions before the pavement is damaged. The timing sequence for a set of finishing equipment is variable and may be described only in terms of the principles used to establish such a sequence under a given set of working conditions. The initial compacting and screeding operation should follow the mixer as closely as possible; all subsequent operations should be delayed as long as feasible but allowing time for completion before the concrete becomes unworkable.

At this time all the normal consolidation due to the effects of initial working and the weight of the mass itself will have occurred; water gain or bleeding will be complete and nearly evaporated. Working the concrete under these conditions will minimize or eliminate shrinkage cracking of various types and surface irregularities due to subsidence. A timing sequence for finishing operations based on these principles will produce concrete pavement of the highest possible character with respect to riding quality, durability, and uniformity of product.

Curing

The merits of the various methods of curing for concrete pavements are somewhat controversial among their proponents. Whatever the method adopted by specification, it should be considered with respect to the requirements of good construction practice.

Curing may be defined as the process necessary to protect the concrete slab from the adverse actions of the elements and other physical forces, both external and internal, during the period in which the concrete is hardening and gaining strength sufficient to resist these forces without external support. Good practice requires a curing method that will protect the concrete during this period from:

1. The extremes of temperature—both high and low.
2. Adverse effects of driving rains and drying winds.
3. Premature loading and abrasion.
4. Excessive volume change due to high removal rates of excess mixing water.

Obviously, if any of these damaging elements are not present, it is not necessary to provide protection from them. This concept partially explains why some methods of curing are found to be satisfactory in some parts of the country and not so satisfactory in other areas.

Whatever the method adopted, based on the principles of good practice, it should be promptly applied upon completion of the finishing operations, and maintained in good condition throughout the required period of protection. The application of the curing cover, whatever it may be, should not be delayed for any reason. In the general concept of the assembly line technique of paving, facilities for application of the curing should be provided to accommodate any possible rate of production. If it is necessary to remove temporarily the curing cover or deface it for some construction operation such as joint sawing or sealing, a sequence of operations should be developed that will provide maximum protection and the shortest possible time in the unprotected state.

SUMMARY

Criteria for modern concrete pavement construction practice should be developed from these basic concepts: (a) the objectives of the owner and the contractor are identical, (b) a modern concrete pavement construction operation is a mass production line and should be operated as such in all phases of the work, and (c) machines properly adjusted and operated do a better job than a man or group of men.

Plans, specifications and construction methods should be prepared to take advantage of the high capacity of modern concrete paving equipment and, at the same time, insure the achievement of the principal objectives of the work.

A pavement constructed of high quality, durable concrete and finished to provide excellent riding qualities are the objectives of the construction forces. All phases of con struction, from the initial grading operation to the final curing of the finished slab, should be directed toward these objectives.

Discussion

WARNER HARWOOD, Portland Cement Association—This paper presents in a very logical manner the requirements which are essential to secure satisfactory concrete pavement construction.

If additional emphasis is needed on any one point, it is the question of uniformity. The importance of this factor in regard to the subgrade is stressed but the uniformity of the concrete itself and the operations of finishing are curing mentioned only casually.

Satisfactory pavement can be made from a variety of concrete mixes as long as each batch is the same in proportions and consistency. Conversely, it is difficult if not impossible to construct concrete pavement having acceptable riding qualities regardless of the mix proportions if the batches are not uniform.

Uniformity of each step in the finishing operations begins with even distribution of the concrete on the subgrade by the mixer operator in the proper amount to construct the pavement. The spreader operator should leave the correct amount for proper consolidation and finishing. Both of these operators should watch for changes in the amount of concrete left for the following machine and should adjust their operations to insure its uniformity.

This attention is necessary if the slab is to require only light floating by the longitudinal mechanical float to remove minor surface irregularities left by the transverse finisher.

To secure satisfactory riding concrete pavements, it is essential that concrete of uniform proportions and consistency be placed in a uniform manner by suitable mechanical equipment on a uniformly compacted subgrade.

The paper recommends that the second transverse screeding, longitudinal screeding, and surface finishing should be delayed as long as feasible to permit as much as possible of the normal consolidation to take place. This procedure is undoubtedly an aid in securing good riding pavements. But this delay naturally results in a drying of the surface, especially of air-entrained concrete which does not bleed as extensively as non-air-entrained.

Many finishers insist on adding water to the surface to permit easier operation of floats and to prevent tearing of the surface. If this is permitted, the method of application should be carefully controlled. Throwing water on the pavement from a bucket or flipping it from a brush should not be permitted. Either method results in very unequal distribution of the additional water with undesirable concentrations in certain areas.

If the addition of water is permitted, it should be applied in the form of fog from nozzles mounted on the carriage of the longitudinal float. The effect of this procedure on the durability and resistance of the concrete to freezing and thawing is one on which there is little or no accurate information. It is one which might well be the subject of research.

New Developments in Pavement Jointing

C. B. LAIRD, Michigan State Highway Department

● SINCE the word "new" is purely relative, this paper reviews briefly some more-or-less ancient history on concrete pavement construction in Michigan to show how past procedures have led to new developments which are presently in vogue. These, in turn, will later show some deficiencies which, through research, will result in the use of new materials and techniques for pavement joint construction in the road of tomorrow. For proper continuity, this discussion of pavement joints is broken down into three main categories; namely, past, present, and a brief glimpse of the possibilities of the future.

The first Standard Specifications on file at the Michigan State Highway Department were issued in February 1918. They specified a filler for expansion joints of an asphaltic or tar felt ¼ in. in thickness, of a width equal to the thickness of the pavement plus 1 in., and of a length equal to the width of the pavement. Spacing of the joints was to be as shown on the plans and at locations where unavoidable interruptions of the paving work occurred, with no section of the pavement less than 10 ft in length. Joint spacing, as shown on the plans, was generally at the end of the day's work. No mention was made of longitudinal joints. Variations of this design were made from 1919 until 1940 with a tongue-and-groove joint being specified in 1923. The tongue-and-groove feature was the first mention of any joint in Michigan with a load transfer function. One detail which would hardly receive approval now was a requirement that expansion joint filler be trimmed off ½ in. above the pavement surface.

The 1940 Standard Specifications reveal a number of forward steps to improve the riding quality and durability of concrete pavements. For the first time, load transfer devices of the dowel bar type or equal were specified. Another new requirement was the use of plane-of-weakness joints with load transfer, except when pavement reinforcement was carried through the joint.

The requirement for longitudinal joint in concrete pavements was first adopted as a Standard Specification in Michigan in 1923. The nomenclature for this innovation was "central joint." The specification provided for a triangular strip of 16-gauge metal punched for tie bars and staking pins and placed in a vertical position on the center line of the pavement. This provision was the first effort in this state to control longitudinal cracking, which had been a contributing factor to the too-rapid deterioration of concrete pavements.

Pre-moulded asphaltic board for longitudinal joints was first used in 1929. Such joints were constructed by cutting a groove in the surface of the fresh concrete, placing a strip of filler material on edge in the groove and then restoring the surface of the concrete by hand floating. Another variation of this type of longitudinal joint was one formed by a continuous ribbon of ⅛-in. thick asphaltic felt placed in the pavement surface in the same manner as previously mentioned. Lane tie bars were used in both of these joint designs. Such pre-moulded longitudinal joints, with minor changes, endured in Michigan as a Standard Specification requirement until 1954.

It is quite apparent that the changes in pavement joint construction incorporated in the 1940 Standard Specifications reflected conclusions reached from studies of the behavior under load and also the structural effectiveness of typical longitudinal and transverse joint designs which were conducted by the U. S. Bureau of Public Roads at the Arlington Experimental Farm in Virginia in the early 1930's. Prior to the time of this research, there was an almost complete lack of data concerning the structural behavior of the existing longitudinal and transverse joint designs. Recognition of this lack made such a study almost imperative. Information was also needed regarding the effect of dowel spacing and joint width on the structural action of joints. Test procedures are omitted here, but the conclusions reached as a result are touched on briefly to show their influence on the changes in the Standard Specifications for 1940 and later years. They are as follows:

1 oints are needed in concrete pavements for the purpose of minimizing the stresses r sulting from causes other than applied load in order that the natural stress resis-

tance of the pavement may be conserved to the greatest extent for carrying traffic loads.

2. A joint is potentially a point of structural weakness and may limit the load carrying capacity of the entire pavement.

3. Joints are classified by function as (a) those designed to provide space for unrestrained expansion, and (b) those designed for the relief or control of the direct tensile stresses induced by a restrained contraction.

4. Expansion joints should be provided at no greater intervals than about 100 ft to prevent excessive joint openings.

5. The permissible unit stress of the concrete should determine the spacing of contraction joints.

6. Doweled transverse joints were quite effective in relieving stresses caused by expansion and contraction.

7. Aggregate interlock cannot be depended on to control load stresses, thus the need for independent means for load transfer in plane-of-weakness joints.

Later study on the Michigan test road verified some of these conclusions and disproved others. One notable change is the finding of the Michigan State Highway Department's Research Section that satisfactory performance of long sections of pavements under full restraint is possible without expansion joints, except at structures where excessive compressive stresses induced by expansion forces are undesirable.

Such studies resulted in the development of the design standards at the end of World War II which made provision for doweled load transfer devices using 1-in. by 15-in. round dowels supported by a wire frame. Also provided was a metal base plate at the bottom of both expansion and contraction joints to prevent the infiltration of subgrade material into the joint opening.

Bonding of concrete to the dowel bars was to be prevented by a coating of red lead or cutback asphalt, with provision for an air space at one end of the bars for expansion joints by means of a metal cap. The steel shortage in the postwar years prevented use of the metal base plate and brought into use for this purpose a substitute fabricated from a hard asphaltic board. The steel shortage also necessitated the use of No. 5 wire for the wire frame work on baskets instead of No. 3 wire, specified on the standard plans.

Several types of dowel baskets, based on the standard, appeared on the Michigan scene between 1945 and 1952. Generally, the types approved for use were field assembled and depended on tension developed between two vertical wires or loops placed at each side of the basket to hold the dowel bars in alignment, both vertically and horizontally.

After this type of joint assembly had been in use for a few years, there was trouble. Surface spalling developed immediately adjacent to joint openings and progressed rapidly to the point where, in many instances, concrete was completely crushed. Study of the failed joints disclosed that the main responsibility for the failure rested on two or three of the following factors:

1. Misalignment of the dowel bars vertically or horizontally due to basket weakness.
2. Locking of joints because of improper coating of bars prior to placement.
3. Locking of joints caused by infiltration of water. This problem resulted from the failure of joint seals in adhesion, cohesion, or both. The subsequent corrosion increased friction to the point where movement was no longer possible.
4. Careless placement of the dowel assembly during construction.
5. Infiltration of soil into the joint opening at the sides and bottom of the slab due to the rupturing of the substitute base plate material.

Drastic changes in transverse joint design were necessary at once to remedy the problem. During the winter of 1952 a dowel basket assembly, fabricated in accordan with a modification of an assembly supplied by the Bethlehem Steel Company, was approved. The new design was superior in many respects to the one previously used. The base of the new basket was 6 in. wider than the 1945 model, providing greatly increased stability. Dowel length was increased to 18 in., with bars of $1\frac{1}{4}$-in. diameter, in accor ance with recommendations of the Research Section. The basket was also constructe 0-gage wire instead of the No. 5 wire previously used. To quickly implement use o the new basket, the Department made direct purchase of the assemblies for a number of projects constructed during 1953.

Easing of the steel shortage released material for a durable base plate to prevent infiltration of earth into the bottom of transverse joint openings. Here again, during the first season the improved device was used, the Department supplied the item by direct purchase. The Bethlehem basket design made provision for the center wires of the basket to straddle the base plate parting strip and hold it in proper position during concrete placement.

This combination has proven far superior to the joint assembly previously used. Dowel alignment has been greatly improved and delays in paving operations to permit correction of improperly placed basket assemblies are negligible.

Since 1953 the Research Section of the Testing and Research Division has developed test procedures to determine whether or not baskets of various designs meet minimum requirements. Recently, baskets fabricated by five different manufacturers have been approved for use.

Since 1953, longitudinal joint design and construction procedures have been subjected to scrutiny and drastic changes have been initiated. One change involved elimination of the use of bent tie bars at formed joints. Instead, hook bolts consisting of two pieces of $\frac{9}{16}$-in. steel, each threaded at one end and fastened together by a coupling, are now specified for this purpose. This change has resulted in positive placement of lane ties and has completely eliminated breakage of tie bars while straightening them out prior to pouring the second lane.

Another design change substituted sawed longitudinal joint construction in place of the pre-moulded type long used. It had long been realized that the placement of pre-moulded joint material involved working concrete back into the groove, which had attained initial set. This practice induced spalling and also resulted in rough surface areas adjacent to the joint. Sawing of center joints was tried experimentally on a few projects during the 1954 construction season, with results so gratifying it was made standard in 1955.

It has been apparent for some time that sealing of transverse joints with rubber asphalt compounds has resulted eventually in almost complete failure of the seal, either in adhesion to the concrete, cohesion within the seal itself, or a combination of the two.

A meeting attended by representatives of the Research Section, the Construction Division, and by individuals employed by all concerns supplying rubber asphalt sealing compounds for use in Michigan, explored ways and means of overcoming joint seal failures. One fact developed during the discussion was that the character of materials used in manufacturing the rubber asphalt had changed due to the development of synthetic rubber and the nearly complete disappearance of natural rubber from the reclaimed rubber supply. It was felt that this factor might be significant, because rubber asphalt compounded with natural rubber and used for pavement joint sealing on the Michigan test road in 1940 was still in excellent condition in 1950.

Thus, it seemed that a research project for joint sealing might possibly provide the answers for the problem at hand. Deputy Commissioner-Chief Engineer C. A. Weber promptly approved a recommendation for a test section of new concrete pavement to permit the study and evaluation of the performance of rubber asphalt joint sealing compounds. The project chosen for the test was a 10-mile section of four-lane divided highway on US 27 and M 78 between Lansing and Charlotte, conveniently located both to the Lansing office and the research laboratory. Supplemental specifications covering the joint sealing test sections were included in the bidding proposal. One roadway of the project was completed during 1956 and the second roadway is to be completed prior to July 1, 1957. Studies are now underway on the sealing completed during 1956, but to-date results have not been tabulated.

Five series of materials were used for the test sections. Included in this group is a newly developed hot-poured rubber asphalt which pours at temperatures 25 to 30 F lower than that now specified. Second, material conforming to Federal Specification SS-S-164 was introduced for control purposes. The third series included so-called hot-poured type compounds costing considerably more than materials currently used. If successful, however, the increased costs can easily be justified. The fourth series included cold applied joint sealing compounds meeting current Michigan specifications. Previous attempts to use this type of sealing compound for transverse joints have met with only mediocre success. The fifth type included two-component, jet fuel resistant, cold applied seals, and also a hot-poured material with which a primer was required. Test results should prove most useful in providing answers to problems in regard to sealing transverse joints.

Another innovation during the 1955 season was the use of jute to caulk the formed joint groove. This was placed the day after the pavement was poured. The purpose of the jute was twofold: (a) preventing the infiltration of small stones and dirt into the contraction crack below the joint groove, and (b) permitting delay in sealing joints until all earth moving and shouldering operations adjacent to the pavement had been completed. This procedure tends to prevent the formation of small areas in the joint crack where intense pressures might develop with damage to the concrete, and also reduces contamination of the sealing compounds while the material is curing. Later developments in forming joints have practically eliminated the use of jute for this purpose.

Experimental sawing of a ½-in. by 2-in. groove for contraction joints was also tried during the 1955 season. Excellent results were obtained, with no random cracking developing in the slabs in the test section. The sawing was accomplished with a standard self-propelled concrete saw using two diamond blades of ⅛-in. and ¼-in. thickness with a spacer between the blades.

Two obstacles appear to prevent adoption of this method for grooving joints. One is the cost of approximately $0.50 per lineal foot of joint; the other, the danger of uncontrolled cracking, especially critical in the 99-ft slab length used in Michigan.

Another experiment tried on the same project was the use of strips of ½-in. by 2-in. Styrofoam and ½-in. by 2-in. corrugated paper board to form contraction joint grooves. The results attained indicated that the method had possibilities for improving joint construction. The objective of the experiment was to find a substitute for sawed transverse joints at a reasonable cost and without the risk of random cracking. The Styrofoam method appeared to achieve both aims.

The materials were placed in the pavement surface in a groove formed by a T-shaped bar having a 2½-in. vertical leg. The joint material was placed immediately in back of the longitudinal float and ahead of hand-finishing operations. After placement, the surface of the concrete adjacent to the joint was restored to a smooth condition by the use of 5-ft floats and 10-ft straight edges.

Concrete saws were used on the experimental joints to remove both Styrofoam and corrugated paper, but it was discovered that the Styrofoam could easily be removed with hand tools in much less time than required for sawing. Corrugated paper was more difficult to cope with, both with saws and hand tools.

The consensus of departmental observers was that the Styrofoam method appeared to warrant additional installations. Data on riding quality, obtained by the Research Section, furthered this belief. Comparisons made of profilometer readings taken on joints formed in the normal manner, sawed ½-in. transverse joints, joints formed with Styrofoam, and those formed with corrugated paper, were as follows:

Type of Joint	Average Profilometer Reading
Normal	5.17
Sawed	1.56
Corrugated paper	3.95
Styrofoam	1.67

The readings given are weighted, with ¹⁄₁₆ in. counted as 1; ⅛ in. as 4, and ¼ in. as 16.

Some 150 miles of concrete pavement have been constructed during the 1956 season using Styrofoam for forming joints. Results have varied somewhat from job to job, but in general have shown a two to one improvement in joint riding quality over those formed with a steel mandrel.

Some objectionable features have also developed and must be overcome. One is spalling, which occurs on some projects on the side of the joint away from the direction of paving. This trouble appears to arise from the deposit of mortar by the burlap drag as it is moved across the joint surface. Placement of Styrofoam with the upper edge not less than ⅛ in. below the pavement surface seems to be the answer to this problem and also minimizes the possibility of tipped joints. Concrete consistency must be maintained at between 1½- and 2½ in. slump to overcome the tendency of the material to float. Refinements in installing devices currently underway should also assist in overcoming these problems.

Another problem in joint construction currently being given increased attention is the "freezing" of joints due to bond between the concrete and load transfer bars. Michigan is experimenting with bars coated with various materials to decrease friction between bars and concrete. These materials range from lubricants to stainless steel sheaths, but no conclusive test results are yet available.

Erosion of concrete around the load transfer bar is another problem undergoing scrutiny, with no cure presently in sight.

The perfect transverse joint is a goal still unattained, but the challenge to develop such a device is great. The "Model T" age still prevails in pavement joint construction.

Insulated Forms for Winter Construction Of Bridges

K. R. SCURR, South Dakota State Highway Commission

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

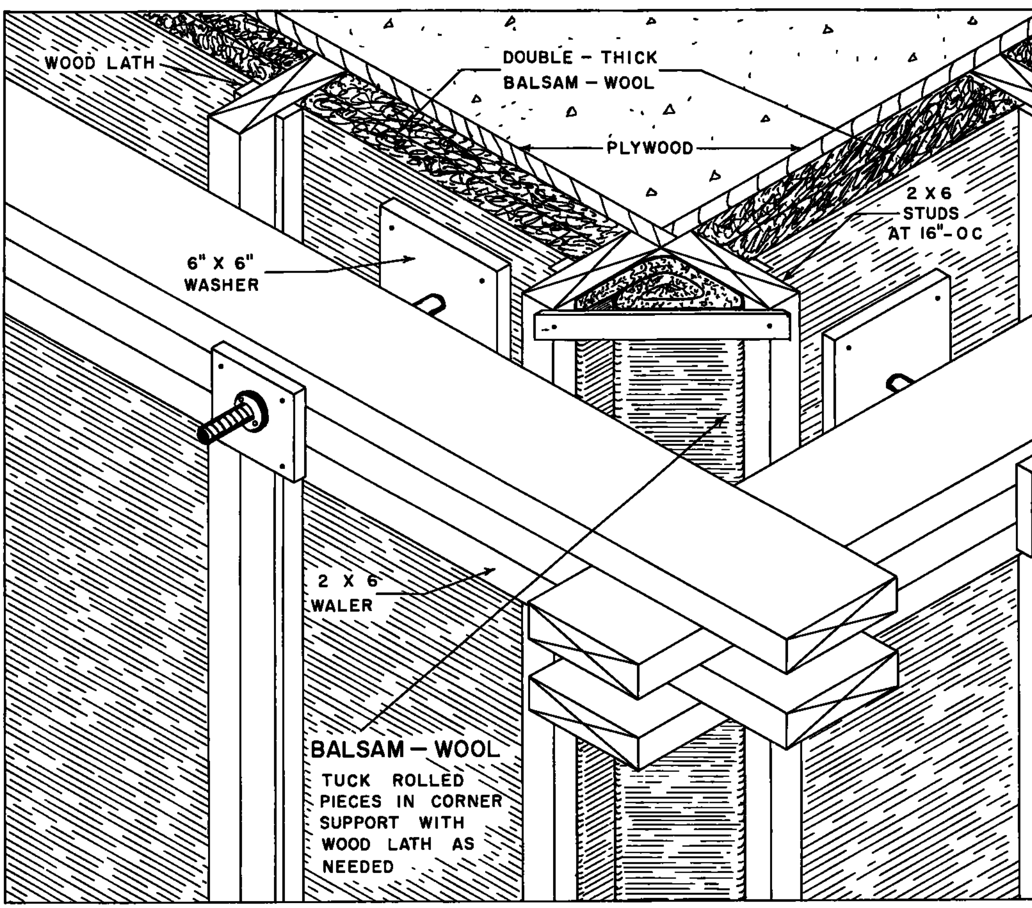

Figure 1. Method of applying insulation to mass concrete forms.

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.

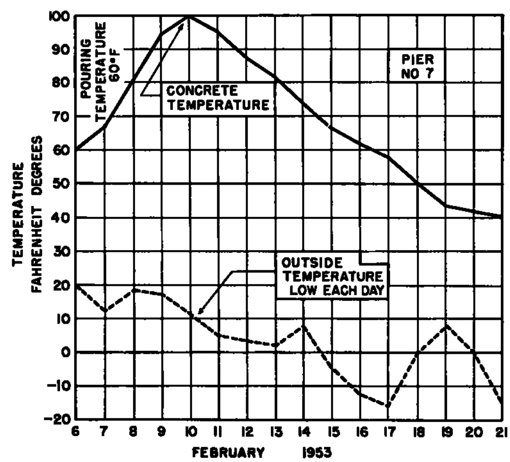

Figure 2. Typical temperature curve for all pours of Pier 7, bridge at Chamberlain, South Dakota.

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-

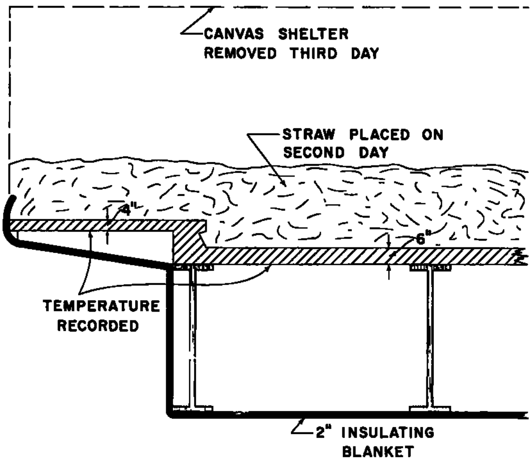

Figure 3. Method of insulating concrete slab poured on steel girders; Bad River bridge, Ft. Pierre, South Dakota.

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

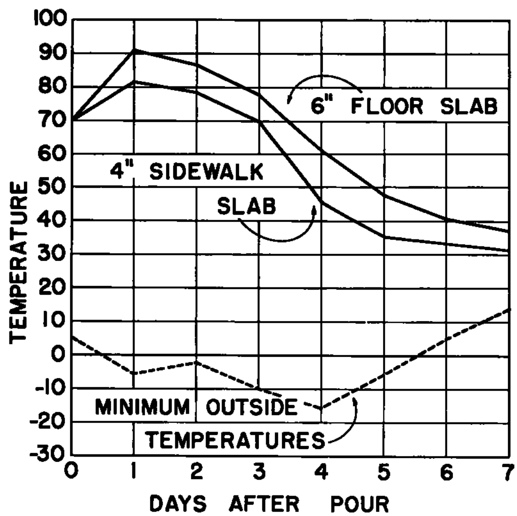

Figure 4. Temperature chart, Ft. Pierre bridge; typical of five pours.

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.

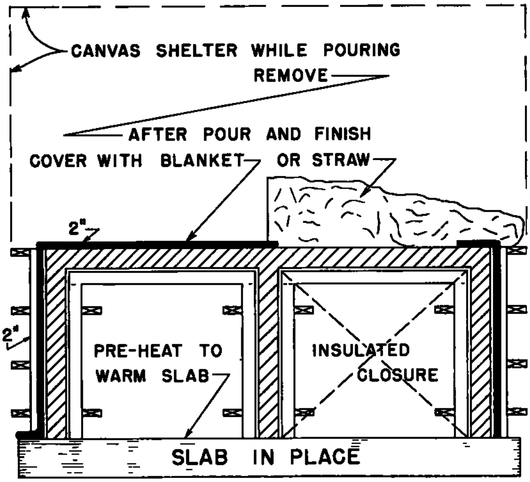

Figure 5. Method of protecting new concrete in concrete box culvert from freezing outside temperatures.

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 concret 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 form 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 part 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 col 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.

HRB OR-93

THE NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare. The ACADEMY itself was established in 1863 under a congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the federal government in scientific matters. This provision accounts for the close ties that have always existed between the ACADEMY and the government, although the ACADEMY is not a governmental agency.

The NATIONAL RESEARCH COUNCIL was established by the ACADEMY in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the ACADEMY in service to the nation, to society, and to science at home and abroad. Members of the NATIONAL RESEARCH COUNCIL receive their appointments from the president of the ACADEMY. They include representatives nominated by the major scientific and technical societies, representatives of the federal government, and a number of members at large. In addition, several thousand scientists and engineers take part in the activities of the research council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the ACADEMY and its RESEARCH COUNCIL thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the government, and to further the general interests of science.

The HIGHWAY RESEARCH BOARD was organized November 11, 1920, as an agency of the Division of Engineering and Industrial Research, one of the eight functional divisions of the NATIONAL RESEARCH COUNCIL. The BOARD is a cooperative organization of the highway technologists of America operating under the auspices of the ACADEMY–COUNCIL and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the BOARD are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.