Criteria for Present Day Concrete Pavement Construction

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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 non-uniform 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.