Construction Procedures of Slip-Form Pavement

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For purposes of discussion it is necessary to define the paver as the simple, basic slip-form unit first introduced to the construction industry in the early 1950's. Modifications have taken place since that time, but the machine is essentially the same. It travels over a deposit of fresh pre-mixed concrete, vibrating, tamping and forcing it through an orifce which gives dimension, shape and density to the concrete. Critical to these operations and the best functioning of the paver are: (a) the subgrade to be paved must be an accurate presentation of the plane of the finished concrete pavement; (b) the concrete itself must be of proper and uniform consistency and may be a specially designed mixture for best results with the slip-form machine; and (c) best over-all results will accrue to an operation so synchronized that the paver is fed at a constant rate and starting and stopping are reduced to a minimum. These phases of the paving operation are a joint engineer-contractor responsibility, best handled by team operation dedicated to both volume and quality.

The paver presents one of the greatest strides in the production of concrete paving for many years, and shows such a potential toward volume production at minimum cost as to bring about greater use of portland cement concrete paving, heretofore considered too costly by many highway construction agencies.

● THE SLIP-FORM UNIT with which this discussion is concerned is the basic unit first introduced to the construction industry in the early 1950's. It carries none of the electronic control devices that have occasionally been added nor does it involve special finishing equipment or floats that have been added by various contractors to meet specific conditions or requirements. Most slip-form pavers even today are basically the same as the early units. Actually it is a concrete lay-down machine and functions in a manner similar to the machine used to lay bituminous pavings.

As the paver moves forward straddling a deposit of freshly pre-mixed paving concrete, its forward thrusting ram strikes off the mixture in bulldozer fashion, to the approximate volume that will be required to produce the designed pavement width and thickness and begins confining the concrete to the traveling form. As the paver continues forward, a set of vibrators is forced through the mixture, followed by a tamping bar and vibrating screed. An orfice, or extrusion meter, through which the fresh concrete is then forced, gives it dimension, shape, and density while still confined in moving side-forms. The final machine operation belts off the surface and as the attached trailing forms are pulled forward, a burlap drag located on the final form bridge adds texture to the finished surface. As the trailing form slides along the pavement edges, the machine leaves a ribbon of finished concrete paving that is ready for the curing compound. This is the unit and the general operation to which the balance of this discussion is confined. Its most successful use will be contingent on certain basic construction procedures which are outlined briefly in the following discussion. These procedures are not new or unusual to any good concrete paving operation.

Probably the prime concern in using this machine is rideability and because the machine moves on crawler tracks that travel along the surface of the subbase, primary among construction procedures is the accuracy of that subbase. The foundation or base courses must be firm under the paver tracks. Should the tracks dig in, there will be a depression in the concrete as it is finally cast. Should the subgrade present a hump, the paver will follow the grade of this hump and most certainly produce an erratic final roadway surface. The wheel base of the tracks on the machine, being some 22 ft long, tends to produce a uniformly good riding surface, free from choppiness but will not take out inherent humps and hollows or long undulations in a poorly finished grade. The very nature of the paver's operation makes it absolutely necessary that the tracks be presented with a subbase that will be identical to the plane of the pavement surface expected. Thickness of the slab, crown, or other final surface shape is varied by adjustment of the screed.

Beginning with the subbase and continuing through all further courses of foundationing materials, each consecutive layer should be shaped and consolidated to accurate grade control stakes. On the final subgrade surface, such staking might well be set at 50-ft intervals on tangent grades and 25-ft intervals on vertical curves. As the subbase is brought within reasonable limits of elevation, it is occasionally better to relax further elevation controls in favor of the long wheel-based land planers or other leveling equipment. At this point interest lies in achieving a subbase free from long undulations as well as any choppiness.

The use of the best available base course aggregates or cement-treated bases will be of great value to the preparation of the subbase as well as the ultimate service life of the pavement. Such subbase treatment should be designed for sufficient width to accommodate the paver's tracks. If the final subbase has any tendency to displace under equipment traffic and especially in the area of the paver's tracks, consideration should be given to restricting or even denying use of that subbase to the hauling equipment. Uncontrolled movement of haulage equipment can also contribute to non-uniform subgrade density — a particular problem in areas of swelling soil.

Final subbase shape is often achieved by use of a track-mounted subgrade planer. This unit presents a template that can be varied to produce any given final surface shape — after the general plane of the subbase has been achieved. The planer operates from crawler tracks that travel the same area as the paver itself.

The subbase to be paved must be a firm and accurate presentation of the desired plane of the finished pavement. Once this is accomplished, good rideability can be expected. Other procedures can improve the ride even further but they are not quite so essential.

For the machine to perform at its best, the consistency of the concrete mixture should be maintained as perfectly as possible. Mixtures too wet or inconsistent in either moisture content or aggregate ratios will give trouble both in edge slump and resulting rideability. Because aggregate ratios are readily controlled, the prime complication comes from moisture variation in the aggregate itself. Because it is impractical to run a moisture test and make proper adjustment of each concrete batch, it is necessary to stock-pile aggregates for such period of time as may be necessary to bring about reasonable equalization of moisture content throughout the stock piles. Uniformity of concrete mixture, however obtained, is of prime importance.

It has been the Department's practice to run paving concrete with a maximum 1½ in. slump. The slip-form paver, particularly one equipped with a battery of stinger-type vibrators, produces a final paving shape that tends to stand very nicely after the sliding forms have passed. Slumping at the edges, prevalent in wet or oversanded mixtures, has at most been a matter of ⅜ in. which will occur at the edge and taper out to zero within the first 12 in. from the pavement's edge. This has not been a prevalent condition due to the ease with which it can be handled and it is thought that vehicles traveling the very edge would not notice it perceptibly.

The type of vibrating equipment used with any given machine will probably require minor adjustment of the concrete mix or the vibratory cycle or both. High-speed vibration together with relatively high travel speed of the paver can produce a swell or surge in the concrete as it passes out of the orfice behind the machine. This will tend toward a choppiness in the pavement surface but it is readily detected in the hand straight-edging that normally follows. The straight-edging and any corrective hand finishing must be completed while the concrete is within the trailing forms.

Concrete mixtures dedicated to specific use with the slip-form paver have not been set up, but it is believed this will be done on future work. The following typical paving mixture producing 28-day minimum strength of 3,000 psi has been used with good results:

Class of concrete — Pavement
Air-entraining agent — Protex
Quantity of air-entraining agent — 2 oz
Cement (lb) — 94.0
Fine aggregate (lb) — 173.0
Coarse aggregate (lb) — 346.0
Water (lb) — 41.5
Slump (in.) — 1.75

The following mechanical operations are considered pertinent to good operation of the paver. Smoothest pavements are occurring when proper synchronization between the delivery of concrete and the travel speed of the machine is maintained. Starting and stopping of the paver should be held to a minimum. The start once more tends to produce a surge of concrete as it passes out of the orfice. As a further precaution against this problem, vibrators and tamper bar shall be stopped during any delay in forward movement of the paver. This is also advisable as a precaution against segregation of the aggregates immediately around the vibrators.

Care may well be taken in the manner of depositing concrete from the mixer directly in front of the strike-off ram. The ram, to function best, should be carrying a constant load, from side to side, keeping the ram as nearly uniformly loaded as possible.

Concrete spillage that may get under the tracks of the paver is to be avoided. Occasionally an overload at one corner of the ram will result in such spillage. The tracks, being the key to vertical control, will walk up over that spillage raising the orfice and creating a bump or roll in the final product.

Where hauling equipment is to be permitted on the finished subbase, constant care must be taken that all humps or depressions are smoothed out immediately in front of the paver. This is particularly necessary in the area that the paver tracks will follow. It is also of concern in maintaining a uniform slab thickness.

No comment has been made concerning the edge alignment of the pavement resulting from slip-form operation. Actually this is almost a negligible problem; first, because in running a single 24-ft paving width a deviation of as much as 1 in. from the straight line would be unnoticed; and second, the machine operator simply keeps a suspended plumb bob, on the front of the machine, traveling along a pre-set string line. Normal deviation should be very minor. Curvature up to 4 degrees is negotiated in the same manner and without difficulty.

As in any other concrete paving operation, use of the slip-form paver on level or near level grades will produce best results, however, the slip-form unit has been used on grades up to 5 percent and no serious problem in rideability or choppiness that would not be experienced in an ordinary formed paving operation, has been found. If it is a practical thing workwise, the operation of the paver upgrade will produce a smoother riding surface than will its operation downgrade. It is felt that grades up to 4 percent deserve little or no consideration as to direction of operation, however in excess of 4 percent grades, an attempt is made to operate that paver on the uphill approach. The mere fact that the machine demands uniformly stiffer concrete mixtures that will tend to stand rather than slump, actually reduces the problem. Further, the problem of edge slump is foremost in the contractor's mind. As a result, it receives more than normal attention, thus often achieving better riding concrete surfaces on the steeper grades than otherwise would result.

In November 1959, using the Bureau of Public Roads roughometer, a device for measuring roughness in terms of total vertical inches per mile of roadway, it was found that on a 20-mi project involving horizontal curvature of one degree and maximum 3 percent grades, the average roughness was 78 in. per mile. Variation in this measurement indicated that there were sections of roadway showing as little as 66 in. per mile and other sections running as high as 94 in. per mile. Here the slip-form paver was used to place a 24-ft ribbon of concrete 8 in. thick. This particular section carried no crown whatsoever but was sloped at 0.015 ft per foot from the median to the outside shoulder. The 24-ft width was placed in one pass and all contraction joints were sawn. Sawn joints have been used for the last eight years, formed joints being used only at the end of the day's operation or at a bridge approach where the new pavement is being brought into a structure approach slab.

To form joints in conjunction with the slip-form paver presents only this problem: that more hand finishing is necessary at each of the joints and of course this hand finishing must be done rapidly because the paving slab will only be within the area of the traveling form for a very short while unless it is desirable to shut the paver down while the joint is finished.

The 78 in. per mile of roughness measurement certainly is not a record nor is it particularly good but it is believed that no more roughness than this is not a critical thing. It might be well to consider that at the time the measurement was made the pavement had been in use for some three months. Also that this particular pavement slab was placed over several areas of swelling-type soil. Therefore, it might be expected that there is some contribution to this early roughness by reason of the action of that soil.

At this time it is very difficult to form a comparison directly between the roughometer figures or any other measure of roughness, resulting from the use of the slip-form paver as compared with conventional paving methods. The Department has many formed jobs but they are quite old and relatively few that would be comparable with the more recent paving work. After any section of concrete paving has been put to use for even a short period of time it is no longer comparable with another one in a totally different location and over a totally different subgrade soil. Thus it is felt that any comparison would lead only to erratic thinking in terms of slip-form results. Actually the slip-form paver has been used in projects where as little as 42 in. per mile of roughness has resulted. These projects have been placed over ideal subbases and up to this time are more the exception than the rule.

Being favorably impressed with the slip-form paver from Iowa operation, it was first used in Colorado in the summer of 1955 under special provisions of the Department's standard specifications. Being further impressed with the early results and the apparent economy, the specifications were revised to permit regular use of the machine. This revision was permissive but broad, saying, "Where a slip-form paver is employed, all reference in the preceding parts of this specification referring to forms shall be considered to be non-applicable and procedures shall be adopted which will result in a satisfactory end product". This revised specification presumed that an equal product would result.

The Department's experience, since permitting the slip-form method, has been surface smoothness that was equal to, and in most cases better than that obtained with conventional forms and the usual equipment train. Therefore, the Department is continuing to make this an acceptable method of construction. Specification for surface tolerance is the same — ⅛-in. from a 12-ft straight edge — regardless of the method the contractor chooses to use. In fact, with new developments in electronic controlling devices being introduced today, more accurate control of the slip-form operation becomes possible. This is still relatively new equipment and many further improvements can be expected. Even now, the equipment with some modification, has been used to lay a reinforced concrete pavement using woven wire reinforcing fabric.

It is no longer a speculative matter regarding the cost of pavement placed with the slip-form as compared with the conventional paving methods. Fifty cents or more per square yard of pavement can be saved. Greatest economy has yet to be realized by use of the slip-form machine. This is due in part to the limited number of the machines in use and the fact that those contracting agencies who have the slip-form paver find they do not have to squeeze their cost accounts too tightly to become a low bidder. Thus it is felt that they are not yet bidding at the most efficient level of operating cost plus reasonable profit. It is further believed that the maximum volume of which the unit is capable has not been reached in most contract operations. The machine is presently capable of producing up to 10 ft per minute of 8-in. concrete slab if properly fed and operated under reasonably good conditions. As a practical matter, however, no paving effort will feed the machine at such a rate. Usually production has been controlled by the capacity of a single dual-drum paving mixer. This operation produces 2,000 ft per day, or somewhat less than one-half the slip-form paver's capacity.

In the slip-form paving operation, as in any other, the equipment will perform in as satisfactory a manner as the contractor's organization and skill will permit. A poor job can be done; but just as surely, if there is effort and care put into the operation of that paving unit, an excellent product will result.