

Ohio's First Experience with Slip-Form Paving

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The successful construction is described of approximately 8 mi of plain concrete pavement on the secondary highway system in Ohio using the slip-form technique. Design features, as well as construction experiences, are reported. The pavement was constructed on earth subgrade on fills and all cuts except for rock cuts where a 4-in. subbase was specified. The grade was prepared using an automatic subgrader. Concrete was produced in a central mix plant erected on the project and hauled to the paving site in trucks with dump bodies. A slip-form paver, without automatic controls, was used to extrude the concrete into a 24-ft by 7-in. concrete pavement.

• FOR SOME YEARS highway engineers in Ohio have followed with interest the development of slip-form paving techniques in such states as Iowa, Colorado and California. Six years ago, a project was planned in Ohio which called for 8-in. plain concrete pavement and permitted the contractor to place the pavement by conventional methods using forms or by the use of a slip-form paver. Since the project had a length of only 2 mi and involved placement of some variable width pavement, the successful bidder elected to use forms rather than procure the specialized equipment for slip-form work.

Several years later when plans were being developed for an 8.8-mi section of completely new construction on new line and grade on the Federal-Aid Secondary System in southeastern Ohio, the slip-form option was again considered. The plans called for elimination of a number of sharp curves, including one 66° hairpin turn, and reduction of the maximum grades from about 11 to 6 percent. The new alignment, having a 50-mph design speed, contained several 3° and 4° horizontal curves with only one curve at the maximum of 5°.

This project lies in the unglaciated Appalachian plateaus of southeastern Ohio. Local relief is on the order of 200 to 300 ft. Bedrock consists principally of shales, indurated clays, sandstone and occasional thin beds of limestone and coal. The rocks are essentially flat lying and belong to the Conemaugh formation of the Pennsylvanian system. The rock mantle is composed of residual silt clay and clay soils in the A-6 A-7-6 HRB classes. The area is generally subject to landslides and several small slides developed and were treated during the grading required for the project.

Traffic volume on this road is fairly light and relatively few heavy commercial vehicles use the road. The 1960 count ranged from 480 at the east end to 840 veh/day near Caldwell. The total commercial count was 60; however, as on many roads in this part of the state, opening of a coal mine in the vicinity may induce a large volume of heavily loaded coal trucks for a period of variable duration depending on the peculiarities of the particular mine in operation. Needless to say, these vehicles haul all that the law will allow.

The native rock and soil materials are not suitable for the development of the substantial quantities of aggregates required for major highway construction. The nearest large source of commercial gravel is approximately 50 mi away in the valley of the Muskingum River. Flexible pavements are normally selected for low traffic volume



Figure 1. Gurries automatic roadbuilder.

roads in Ohio; however, on this project, because of the scarcity of aggregate, a careful study was made of the economics of alternate flexible and rigid designs. The predominant soil type on the project was determined to be an A-6 silt clay with a group index of 9 and with estimated CBR and K values of 6 and 150, respectively. For these conditions, the following alternate pavements were considered to have equal load-carrying capacity.

1. Rigid: 7-in. plain concrete—A 4-in. granular subbase was added in rock and shale cuts to provide a cushion between the slab and underlying bedrock. There was about 1.7 mi of this kind of subgrade.
2. Flexible: 4 in. hot-mixed asphaltic concrete surface and leveling material placed in three separate courses.
3. 6 in. crushed aggregate base.
4. 6 in. granular subbase.

An economic analysis of the probable cost of these alternates indicated that initial cost of both types was about the same, i.e., \$60,000/two-lane mile. Our experience indicates that resurfacing will be required at a considerably earlier date and that routine annual maintenance costs will be somewhat higher for bituminous-surfaced pavement than for concrete. The 7-in. plain concrete design was, therefore, selected and the option of paving by the conventional method or by the slip-form method was made a part of the contract.

CONTRACT AND EQUIPMENT

The contractor for this 8.8-mi improvement of SR 78 in Noble County, Village of Caldwell, and Olive, Center and Stock townships elected to place the concrete pavement using the slip-form principle permitted by Proposal Note (see Appendix). Although the project was located on the Federal-Aid Secondary System, it was financed with state funds due to the size of the contract and to the need for Federal-aid funds elsewhere.

A new Johnson automatic batch plant with an 8-cu yd central mixer was erected on the project to produce the pavement concrete. The contractor rented a Rex slip-form machine for the paving. The subgrade, and the subbase in rock cuts, were prepared using a Gurries Automatic Roadbuilder.

The slip-form pavement was placed in the fall of 1963. A small quantity of pavement at the west end of the project was placed in the spring of 1964 using conventional



Figure 2. Subgrade approximately 1 in. above grade.

methods of construction. The conventionally placed concrete was used since a busy at-grade intersection with traffic maintained, and two closely spaced structures were grouped in this area with short stretches of pavement interspersed.

SUBGRADE PREPARATION

The Gurries was controlled by a tracer from a piano wire, preset parallel to the pavement grade for the first pass approximately 14 ft in width, as shown in Figure 1. The adjoining lane was controlled by a rubber-tired wheel operating from the adjacent finished lane. The subgrade for the pavement and the grade for the paver were prepared in the same operation with the two adjacent passes of the Gurries. The automatic subgrader, towed by a D-9 tractor, was operated over the entire project to bring the subgrade to approximately 1 in. above grade (Fig. 2). Normally two passes by the automatic subgrader were required to complete the subgrading. After the first pass, large stones at grade were removed by two laborers working behind the subgrader with picks. Next, material free from large stones was bladed back onto the grade and construction traffic as well as local traffic was permitted to use the roadbed. The Gurries returned to make a final pass just ahead of the paving operation to bring the subgrade within the specified tolerance.

Ohio was experiencing a drought during pavement construction, and it was necessary to water the subgrade to obtain maximum density as well as to prevent absorption of water from the concrete after it was placed. Since the concrete trucks were using the subgrade for a haul road, it was not desirable to sprinkle to the extent that the subgrade would be damaged by the hauling units, or that the paver would slip on its treads. Therefore, water was generally applied to an area of subgrade the evening before it was to be fine-graded and paved. In this manner, the water would penetrate during the night resulting in a uniform moisture content for several inches in depth. Maximum density was then readily obtained and the subgrade was near optimum moisture when the pavement was placed.

CONCRETE MIX

Class D concrete as specified was composed of 6.5 sk/cu yd, sand, and two sizes of coarse aggregate. The dry weights of the aggregates per sack of cement were sand,

TABLE 1
SIZES OF COARSE AGGREGATES

Standard Sizes	Total # Passing (square openings)														
	4 In.	3½ In.	3 In.	2½ In.	2 In.	1½ In.	1 In.	¾ In.	½ In.	⅜ In.	¼ In.	No. 4	No. 6	No. 8	No. 16
No. 1	100	90-100	35-70	0-15	-	-	-	-	-	-	-	-	-	-	-
No. 12	100	90-100	65-85	25-60	-	0-15	-	-	-	-	-	-	-	-	-
No. 2	-	-	100	90-100	35-70	0-15	-	-	-	-	-	-	-	-	-
No. 3	-	-	-	-	100	80-100	20-60	0-20	-	0-5	-	-	-	-	-
No. 34	-	-	-	-	100	90-100	-	30-65	-	0-20	-	0-5	-	-	-
No. 4	-	-	-	-	-	-	100	80-100	20-60	5-30	-	0-5	-	-	-
No. 46	-	-	-	-	-	-	100	95-100	65-90	35-65	-	0-15	-	-	-
No. 6	-	-	-	-	-	-	-	100	90-100	-	-	10-35	-	0-5	-
No. 6a	-	-	-	-	-	-	-	100	90-100	40-70	-	0-15	-	0-5	-
No. 6b ^a	-	-	-	-	-	-	-	-	100	75-100	-	0-15	-	0-5	-
No. 9	-	-	-	-	-	-	-	-	-	100	95-100	60-90	-	0-20	0-10
No. 9c ^a	-	-	-	-	-	-	-	-	-	100	90-100	0-50	0-10	0-5	-

^aNo. 6b and No. 9c are sizes having rigid void control.



Figure 3. Central mix plant.

170 lb; No. 3 coarse aggregate, 165 lb; and No. 4 coarse aggregate, 146 lb. Lime-stone was used for the No. 3 coarse aggregate and gravel for the No. 4 coarse aggregate (Table 1). Entrained air was maintained between 4 and 7 percent by use of air-entraining admixture, Darex.

MIXING AND PLACING CONCRETE

Concrete was produced in a central mix plant and discharged directly into dump trucks for transportation to the paving site (Fig. 3). On arrival at the slip-form paver the concrete was dumped into pull-type spreader boxes which spread the concrete uniformly on the subgrade. The concrete was then extruded into the final pavement, 24 ft wide and 7 in. thick, in a single pass operation by the slip-form machine.

The central mix plant consisted of a Johnson automatic batch plant with an 8-cu yd mixer. Cement was transported by rail to a siding at Cumberland, Ohio, where it was transferred to trucks for the remaining 12 mi to the plant site. A 675-barrel cement silo was erected at the plant for temporary storage. Water was obtained from Caldwell and was stored in a 26,000-gal water tank maintained at the plant. Aggregates were stockpiled at the plant site in such a manner that the coarse aggregates could be



Figure 4. Uniform spread of concrete ahead of slip-form paver.



Figure 5. Hydraulic ram on front of slip-form machine striking off concrete.

sprinkled before use to meet the moisture requirements of the specifications. Coarse aggregates were moved by front-end loaders to hoppers where they were elevated to the bins by conveyor. The fine aggregate was dozed into the hopper and similarly conveyed to the plant bins. Batches were weighed automatically, charged into the mixer by conveyor belt, mixed for a minimum of 90 sec after all the ingredients were in the drum.

Some of the dump trucks used to transport the concrete had fillet plates welded into the corners of the dump bodies to prevent buildup and had gasket material around the tail gate to prevent loss of mortar. As additional trucks were used to increase production, the fillet plates and gasket material were omitted and little difference was noted in buildup or mortar loss. On arrival at the paving site the trucks backed in ahead of the paver and one of the two spreader boxes operating side by side was attached. The concrete was discharged into the spreader which moved forward, spreading concrete uniformly ahead of the slip-form paver (Fig. 4).



Figure 6. Finishers correcting surface and edging concrete along forms.



Figure 7. Burlap drag.

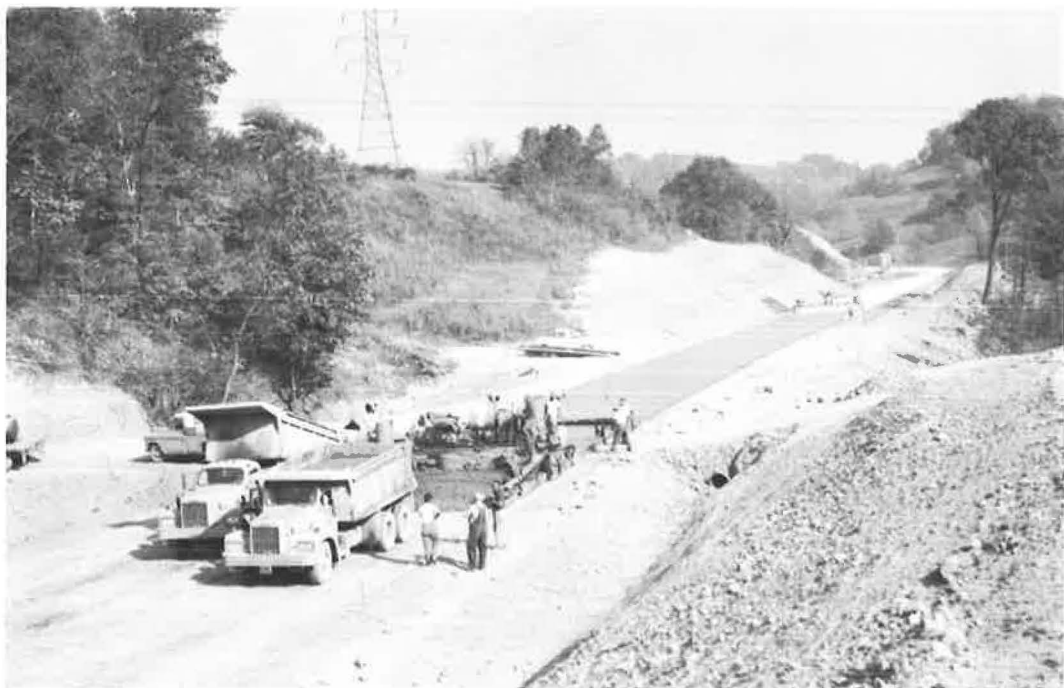


Figure 8. Application of membrane curing material.

The hydraulic ram on the front of the slip-form machine struck off the concrete, filling the voids left by the spreaders at the center and at the edges (Fig. 5). The concrete was vibrated by full-width pan vibrators before being further consolidated by mechanical tampers. The concrete then passed through the 42-in. extrusion meter where it was further compacted and shaped into the specified pavement dimensions. The initial surface finish was immediately applied by a rubber belt with a reciprocating lateral movement. The hydraulic ram, pan vibrators, mechanical tampers, extrusion meter, and reciprocating belt were all components of the paving machine.

Thirty-two feet of trailing forms were used to protect the pavement edges while the surface was being straightened. Within the trailing forms, four finishers checked and corrected the surface and edged the concrete along the forms (Fig. 6). A burlap drag was fastened to the crossframe at the end of the trailing forms to texture the pavement surface (Fig. 7).

After the water sheen had disappeared from the surface, membrane curing material was applied by a spray machine riding on rubber tires and operating outside the edges of the pavement (Fig. 8).

Transverse contraction joints were usually sawed the same day the pavement was placed; however, when the nights became cool the concrete placed late in the day could not be sawed until the following day. The joints were sawed dry, using abrasive blades, to a minimum depth of $1\frac{1}{4}$ in. and a minimum width of $\frac{1}{4}$ in. Compressed air was used to clean out the joints before sealing with a hot-poured sealer. The longitudinal joint was required to be sawed within 3 days, and was generally sawed the following day.

CONSTRUCTION FEATURES AND CONCLUSIONS

An attempt was made to water the coarse aggregates on the conveyor belt as they were being charged into the plant bins. A spray bar was positioned at the bottom of the belt and appeared satisfactory for the low absorption aggregates during uniform production. However, when production varied, saturation varied correspondingly, resulting in variable slump concrete which was especially troublesome for slip-form paving. After a few days the watering on the conveyor was discontinued in favor of

sprinkling systems on the coarse aggregate stockpiles. Uniform saturation of the aggregates was accomplished and, therefore, uniform slump concrete was obtained.

After using the spreader boxes for several days, the contractor elected to dump the concrete directly on the subgrade to increase production. By tailgating, the concrete was easily spread ahead of the paver and production was increased. Also, a problem encountered with the boxes on subbase in the rock cuts was eliminated.

Concrete had a tendency to adhere to the truck beds even though the truck bodies were modified by fillet plates in the corners. Therefore, the contractor decided to hose out the trucks beds on return to the plant after each round.

If low-slump concrete (1 to 1½ in.) was used, the edges of the concrete pavement exhibited little or no slumping, but additional hand finishing was required to close the open-textured surface of the concrete. With high-slump concrete (2½ to 3 in.), little hand finishing was needed; however, there was noticeable slumping at the pavement edges. The ideal slump appeared to be about 2 in. since edge slumping and hand finishing were both minimized with concrete at that consistency.

While discussing the slumping at the pavement edges it should be pointed out that, at the outset, considerable difficulty was encountered with the alignment. The paver was steered manually and occasionally veered off line, resulting in kinks in the alignment. When alignment corrections were made abruptly, considerable handwork was required, especially at the end of the trailing forms. This excessive handwork had a pronounced effect on the edge slump. An additional person was used to operate the steering mechanism until the operator had acquired sufficient experience to manage all mechanisms.

Edge slump is also the result of excessive edge finishing and long lengths of trailing forms. The length of trailing forms should be the minimum needed to permit hand finishing of the surface and edge finishing should be held to a minimum. Forty-eight feet (3- to 16-ft sections) of trailing forms were used for the first few days until the finishers became acclimated to working within the trailing forms. Then one section of the forms was eliminated and the remainder of the paving was placed using 32 ft of forms. The long lengths of trailing forms particularly affected the pavement edges at transitions into and out of the many superelevated curves. Changes in cross-slope at the paver were transmitted by the forms to the edges, further complicating control of the edges. Despite all these difficulties, pavement edges were considered satisfactory, even though slight slumping generally occurred throughout the project.

Construction joints at the end of each day's production consisted of a bulkhead with holes for 1-in. by 18-in. dowels. The contractor used a steel bulkhead specially fabricated for this project with holes for staking pins as well as dowels. In the last 25 ft of pavement placed each day, ¾- by 7-in. boards were placed along the inside edges of the trailing forms to reduce the pavement width to facilitate positioning of the paver when paving was resumed.

A longitudinal key joint without tie bars was required at various locations where local intersecting roads were encountered. The contractor was unsuccessful in his attempts to extrude a key groove in the edge of the 7-in. slab and it was necessary to install wooden forms, with keyways attached, and to hand finish the surface adjacent to the edges. This hand method was permitted because there were only a few intersecting roads where longitudinal key joints were required, and because it was impractical to procure metal keyways for insertion at the side forms at the front of the paver.

Production varied from approximately 400 lin ft on the first day to a maximum of 4,217 lin ft. On several days the 4,000-ft goal was achieved; however, an average production was near 3,000 lin ft.

Cores, removed to check thickness requirements, indicate that the concrete was uniform in depth and had satisfactory compressive strength. The average thickness for all cores removed was 7.3 in. Only one core was less than the 7 in. specified; it was 6.9 in.

As this was the first sizeable job in recent years with plain concrete pavement without load transfer devices, a 2-mi test section of skewed joints was specified by Plan Note (see Appendix) to compare their merits with the joints constructed normal to the centerline of the pavement. The Plan Note required that the skewed joints be con-

structed diagonally across the full width of the pavement so that the right edge of the joint is 4 ft ahead of the left. Observations will be made periodically and a Chloe or a roughometer will be used in the future to determine the merits of these joints.

In Ohio, a device is towed over newly constructed pavements which indicates when the pavement is outside the surface tolerance of $\frac{1}{8}$ in. in 10 ft. The apparatus makes two passes in each 12-ft lane; each time tolerance is exceeded, the pavement is sprayed with diluted paint to denote areas to be corrected. The number of paint marks per profilometer mile is then determined. This slip-form pavement had 16 marks per profilometer mile, which compares favorably with conventionally built pavements on the primary system.

Based on the satisfactory results obtained in its first venture in slip-form paving, Ohio is looking forward to slip-forming reinforced concrete pavements on the Primary and Interstate Systems. A project on the Primary System has already been selected for use of the slip-form option and is to be awarded early in 1965.

Appendix

PROPOSAL NOTE

T-70, Portland Cement Concrete Pavement, as Per Plan

This item shall be placed either as described in Item T-70 using regular forming and placing procedures, or by the use of a slip-form paver. For either type of placement the pavement shall have a standard longitudinal joint located at the center of the slab and shall have sawed or impressed contraction joints without load transfer devices spaced at intervals of 17 ft. If the contractor elects to use a slip-form paver, the following provisions shall apply:

1. Preparation of Subbase—The area which will support the slip-form paver and subgrade machine shall be cut in the compacted subbase to the proper elevation, using a properly designed and operated machine. The subbase shall then be finished to required cross-section and grade by means of a self-propelled subgrade machine.
2. Concrete Consistency—The concrete shall be of uniform consistency such that there will be no slumping at the edge of the pavement after forms have passed. Slump of the concrete tested in accordance with ASTM Designation: C-143 shall be not greater than $2\frac{1}{2}$ in. nor less than 1 in.
3. Slip-Form Paver—In lieu of the procedures outlined in Sec. T-71.21 for placing and finishing concrete, the concrete shall be placed and finished by the use of a slip-form paver of the self-propelled type equipped with crawler-type tracks not less than 22 ft in length. The paver shall be equipped with a mechanically operated primary strike-off which meters the concrete to the vibratory mechanism. It shall also be equipped with a vibrator and temping bar extending over the full width of the pavement and an extrusion plate not less than 42 in. in length (measured longitudinally with the pavement) extending for the full width of the pavement, set with its leading bullnosed edge approximately $\frac{1}{2}$ in. higher than the trailing edge so that the concrete is pressed down and squeezed out, under load, behind the plate. It shall be further equipped with a 24-in. rubber belt set behind the extrusion plate mechanically operated with a lateral movement of 4 to 8 in.
4. Paver Operation—The paver shall be operated with a continuous forward movement and all operations of mixing, placing, and spreading shall be so coordinated as to provide a uniform forward progress with stopping and starting of the paver held to a minimum. If for any reason the forward progress is stopped, the vibrating and tamping element shall be stopped immediately.
5. Slip Forms—The slip forms shall be held together laterally by cross-frame mounted above the pavement and shall trail behind the paver for such a distance that no slumping of the concrete will occur, but in no case less than 32 ft.
6. Final Finish—Final finish shall be in accordance with Section T-71.214 Method B (drag finish).

All other pertinent sections of Item T-70 shall apply to the pavement placed by the slip-form method. Under either method, the unit price bid for this item shall constitute full compensation for performing all the requirements of the item.

PLAN NOTES

Contraction Joints

Contraction joints shall be constructed according to Item T-71.28 of the specifications, except that load transfer devices will not be required and except from Station 442+00 to Station 547+00 where contraction joints shall be constructed diagonally across the full width of the pavement so that the right edge of the joint will be 4 ft ahead of the left.

Construction Joints

Construction joints shall be constructed according to Item T-71.27 of the Ohio Department of Highways Construction and Materials Specifications and the standard joint drawings, except that construction joints shall not be placed closer than 5 ft to another transverse joint.