slip-form construction of highway appurtenances

Gordon K. Ray, Edwin C. Lokken, and E. G. Robbins
Portland Cement Association, Skokie, Illinois

This paper describes slip-form construction techniques for widening and resurfacing, curb and gutter building, single-lane concrete paving with integral curb, and concrete safety barrier. Formerly, most of this type of construction was done by using forms and hand tools. Labor requirements were high, and production rates were low. In recent years development of specialized slip-form equipment by contractors and equipment manufacturers has revolutionized this type of concrete construction. The authors describe some of the equipment available and the wide variety of equipment that provides for interchangeable mules or forms to shape concrete to almost any cross section. The paper presents some recommendations on suitable concrete mixes and finishing techniques for this type of work.

•When James Johnson of the Iowa State Highway Commission extruded his first concrete slab in the laboratories in Ames in 1947, it is doubtful that any of the engineers who were present could have imagined the ultimate development of slip-form pavers discussed in this paper. The Iowa engineers were looking forward to the development of a machine that could place a 10-ft-wide, 6-in.-thick slab. In 1949 such a machine was used to build a mile of a rural road in two 10-ft lanes. Other papers in this Special Report discuss some of the current projects using this sophisticated equipment. Today giant electronically controlled pavers are building concrete slabs up to 17 in. thick and 50 ft wide.

This paper deals with more prosaic paving. It describes the use of slip-form or extrusion equipment to build concrete safety barriers; to widen concrete shoulders, curb, and gutter; and to pave single lanes 10 to 16 ft wide with integral curb for ramps or city streets. Such construction has traditionally been done by hand methods. In many cases rather primitive wood forms and tools were used; production rates were low and labor costs high. Generally this type of work was subcontracted to specialty contractors, and unit costs were high. In some urban projects the total costs of miscellaneous paving work exceeded main-line paving costs.

Today the know-how and ingenuity of contractors and equipment manufacturers have provided slip-form equipment to build almost all concrete appurtenances without fixed forms and with a minimum of labor. This equipment, which has relatively high production rates, can be used with transit-mixed or centrally mixed concrete. The final quality of the work—of the concrete mix, alignment, finish, and texture—is usually superior to hand work, and the costs are lower.

Most equipment is now made so that different templates, molds, or mules can be interchanged quickly and easily on a single standard machine, to the user's specifications. Any curb style, any configuration of gutter, and various heights and shapes of walls can be built; longitudinal steel can be inserted through the front of the machine. Some provide built-in texturing brushes or brooms. Equipment has been developed to form a continuous key in footing and to leave marks to locate positioning of tie bars. Some can add devices that form and position keyways and shoot tie bars into the edges of slabs and gutters.

At least one curb and gutter machine has been made to shape the curb, gutter, and sidewalk simultaneously. Curb and gutter machines can trim the grade and slip form in a single operation, or grade trimming can be done separately.

Some machines have an "outrigger" hopper-conveyor that allows the concrete supply truck to transfer concrete to the slip-form machine without leaving the adjacent pavement slab or haul road. This unit is removable so that concrete can be dumped either into it or directly into the main hopper on the machine.

CONCRETE WIDENING AND SHOULDERS

In the late 1940s and 1950s many 18-, 20-, and 22-ft pavements were widened to 24 ft, which had become the new standard for a two-lane primary highway. In many cases the widening work also included overlay of the entire 24-ft width. For this reason surface tolerance and edge alignment were not considered so important as on new exposed pavement. These concrete widenings were usually built with a crude improvised slip form, consisting of little more than a hopper box equipped with a vibrator, which was usually pulled by a tractor or motor grader.

In the case of widening by a full lane, e.g., older four-lane Interstate highways upgraded to six or eight lanes, the self-propelled slip-form pavers came into use to build new exposed concrete. One track of the paver operates on the edge of the existing slab as single 24-ft lane slip-form machines build the additional lanes. In most cases this work is carried out on the inside lane of the divided highway with no interruption to traffic. One or two additional lanes can be added to existing concrete pavements in this manner with no difficulty. On those projects where tie bars are required between the old lanes and the widening, these can be quickly placed in the edge of the existing slabs through the use of self drilling or stud types of threaded anchors (5).

Concrete shoulders have been used on some urban freeways in several states for some time. Missouri uses red pigment to provide a color differentiation with the main-line pavements. Illinois was the first state to build concrete shoulders on a rural highway in 1965. In an experimental project Illinois used corrugations built in the plastic concrete to provide extra safety (1). The corrugation discourages drivers from using the shoulder as an extra driving lane and provides a rumble or warning to alert drowsy or inattentive drivers who stray from the main traffic lanes (2).

The first project and two subsequent experimental shoulder projects conducted in Illinois in 1966 and 1967 were all built by using a rather simple slip-form device designed by the contractor. The device was towed by a tractor and held against the old slab by a motor grader. Because of the excellent performance of these experimental concrete shoulders, the Federal Highway Administration established the National Experimental and Evaluation Project in 1970, and many states began to plan and build concrete shoulders (Table 1) (3).

Paving contractors began to apply to shoulder paving the same type of high production equipment and techniques that they were using in main-line paving (4). Special smaller slip-form models were employed. Some contractors blocked out full-size slip-form pavers to build a 10-ft-wide shoulder. These more sophisticated self-propelled pavers established production records of a mile of shoulder per day. With most of the slip-form equipment used for shouldering, line and grade were controlled by an electronic

Table 1. Details of concrete shoulder projects.

Present Condition	State	Year	Route	Length (miles)	Width (ft)	Thickness (in.)	Jointing (ft)	Remarks
Built	Ill.	1965	Ill-116	5	8, 4	6 P	50, 100	Described in Illinois R&D reports 24 and 27
		1966	I-74	0.83	10, 4	6 P	10 to 100	Described in Illinois R&D reports 24 and 27
		1967	I-80	1.9	10, 4	8 to 6 P	20	Described in Illinois R&D reports 24 and 27
		1971	Ill-72	7.5	10, 4	6 P	20	
		1972	E-W Tollway	69	11, 5	8½ to 6	Random	Partially built; to be completed in 1973
	Iowa	1971	I-80	1.25	10, 6	6 P	20	In connection with reconstruction project
	Md.	1969		3.6	3 to 8	7 R	40	
	Mich.	1971	I-69	1.5	9	9 to 6 P	17, 9 in.	
	Neb.	1970-71	Neb-36	10	8	5½ P	15	
	N.C.	1972	US-52	4.5		7	30	2-in. red colored concrete topping
	N.D.	1972	I-29	14.7	10, 3	8	CRCP	3-ft width slip formed with roadway pavement
	Pa.	1971	I-81	5.9	10, 4	6 P	15½	
	Tex.	1971	I-30	6.9	10	8	CRCP	Experimental textures
Awarded	Ala.		I-59	5	10, 4	8		Evaluate designs and delineation methods
	Ark.		I-430		10, 4	8	CRCP	
	Ky.		US-31W	3.7	10, 4	5, 6, 7	20 P, 50 R	
	N.M.		I-40	4.3	10, 4	8	13-19-18-12	Stage construction
	Pa.		US-220	23,000[a]		6 P	15½	
				21,000[a]		8 to 6 P	15½	
				2,500[a]		8 P	15½	
	W.Va.		I-77	30,200[a]		8	20	
			I-64	14,300[a]		8	20	
Planned	Ariz.		I-10		10, 5		Skewed and random	In planning stage
	Calif.		US-101					In planning stage
	Ga.		I-75	8	10	11 to 6		No subbase
	Idaho		I-90					In planning stage
	Minn.				10, 3			In planning stage
	Nev.		I-15	2.2	10, 4			Being designed
	Ohio		I-675	4.2	10			Being designed
	S.D.		I-29					Experimental, in planning stage
	Utah		I-15	1		9	Random	

[a]In square yards.

Table 2. Constructed and planned concrete safety shape barriers (as of Dec. 31, 1972).

State	Miles	State	Miles
Alabama	1.0	Nebraska	1.7
Alaska	—	Nevada	12.1
Arizona	10.2	New Hampshire	—
Arkansas	15.3	New Jersey	218.0
California	182.0	New Mexico	8.3
Colorado	27.0	New York (Thruway)	1.0
Connecticut	2.0	New York City	34.0
Delaware	2.0	North Carolina	26.1
D.C.	6.0	North Dakota	—
Florida	6.0	Ohio	34.3
Georgia	11.7	Oklahoma	11.0
Hawaii	4.0	Oregon	62.5
Idaho	4.1	Pennsylvania	6.9
Illinois	3.0	Rhode Island	—
Indiana	6.4	South Carolina	4.6
Iowa	0.8	South Dakota	—
Kansas	1.0	Tennessee	10.6
Kentucky	15.7	Texas	45.0
Louisiana	17.0	Utah	20.0
Maine	—	Vermont	—
Maryland	47.0	Virginia	14.5
Massachusetts	1.0	Washington	49.5
Michigan	15.5	West Virginia	9.9
Minnesota	12.8	Wisconsin	32.0
Mississippi	3.0	Wyoming	—
Missouri	30.1	Total	1,032.4
Montana	5.8		

guidance system. Such a system usually operates against the edge of the main-line slab to keep the shoulder tight against the pavement. A string line may be established outside the shoulder to provide elevation control for the outside edge of the shoulder, or a skid can run on the pretrimmed subgrade. The inside edge of the paver for the shoulder takes its elevation from the already-built pavement.

In 1972, on a project on I-29, the North Dakota Highway Department allowed a contractor to build the 3-ft inside shoulder integrally with the 24-ft two-lane slab. A 27-ft paver was used, and, because the same design and thickness were specified, the shoulder paving presented no special problem. This method completely eliminated one separate paving operation. This year on the extension to the Illinois East-West Tollway a contractor will use a 41-ft-wide slip-form paver to place the 25-ft main-line slab, the 11-ft outside shoulder, and the 5-ft inside shoulder all in a single pass. The details of this project are covered by Stone and Grimes (13).

Corrugated rumble strips in the shoulders of the Illinois Tollway have also been formed by newly developed equipment. A power-driven roller was mounted on a self-propelled machine that straddled the shoulder. The rotating corrugated roller made several passes to completely form the 6-ft-wide rumble strip according to job specifications.

Whereas most early shoulder projects used transit-mixed concrete, the slip-form equipment used recently permits a wider variety of hauling equipment. Several paving contractors have used their regular central mix plants and dump trucks with or without agitators. This permits higher rates of production and reduced paving costs.

CURBS AND CURB AND GUTTER

For several years equipment that can build concrete curbs and curb and gutter sections without the use of side forms has been available. Early models were extrusion machines that required a special concrete mix having smaller coarse aggregate and low slump (6, 7). Generally these extrusion machines are smaller and less expensive than slip-form pavers, but their production rates are lower. Today there are at least seven equipment manufacturers who produce slip-form paving equipment capable of building a wide variety of curb and curb and gutter widths and shapes (8, 9).

All of these machines are electronically controlled and take both line and grade from preset string lines. They are all self-propelled. Many have provision for final trimming of subgrade to grade. Some of them have three crawler tracks and some two. Some machines straddle the curb with a track on each side, whereas others operate with the slip form outside of the tracks to permit construction of the curb close to fixed obstacles such as utility and light poles, fire hydrants, and traffic signs. Nearly all of the curb and gutter machines are designed to permit construction around curves of the type normally encountered at street intersections and at expressway ramps and cloverleafs. Whereas all of these pavers are equipped with some type of hopper to receive and hold the concrete, they are too small to receive an entire truckload of concrete directly from a dump truck. Hauling units must be equipped with a chute similar to those on transit-mix or agitator trucks.

A variety of slip-form pavers are being used to place curb and gutter sections. One machine also is being used to place a rolled curb and a hollywood type of sidewalk immediately behind the curb.

STREET PAVING WITH INTEGRAL CURBS

In many municipalities where concrete streets are used, contractors have built integral curbs to eliminate having to build a separate curb and gutter. Many times city streets are built only one lane or half a street wide at a time to permit through traffic access to abutting property. Several equipment manufacturers have met this need by producing narrower slip-form pavers. Generally these are capable of paving lanes from 6 to 20 ft wide. Some provide for power widening. Most are also capable of building an integral curb on at least one side.

The manufacturers have attempted to produce slip-form pavers for city street work that are smaller, lighter, and less expensive than equipment for main-line highway paving. Usually city jobs are smaller and more cut up by intersections, drainage structures, and general street layouts. This is particularly true in residential areas with many curved streets and cul-de-sacs. For these reasons flexibility, portability, and maneuverability are probably more important than high rates of production. Because slabs are thinner (frequently only 6 in.) and because most street pavements are unreinforced, pavers can be considerably lighter and have smaller power units. In most models the concrete is deposited in a hopper from a chute, so transit-mixed concrete is used on many street paving projects. Today some manufacturers are providing conveyor spreaders with belts to receive concrete from a conventional dump truck hauling centrally mixed concrete.

CONCRETE SAFETY BARRIERS

From construction of a curb and gutter with 16 or 18 in. back height it was only a small step to slip forming a 32-in.-high safety shape concrete barrier. Until 1971, all barriers were built in fixed forms or as precast sections. In 1971 two manufacturers of curb and gutter slip-form machines modified them to produce concrete barriers on projects in Maryland and Michigan (10). In less than a year at least five different machines were available, and barriers with a variety of designs and details had been built (Table 2).

In the Milwaukee area alone in 1972 two contractors used two different slip-form machines to build 29 miles of double barrier on each side of center-mounted lighting, traffic signs, and bridge piers in the median of an existing multilane Interstate freeway. Much of this work was done at night to minimize traffic delays, although all construction equipment including concrete trucks were confined to the inner lane adjacent to the median. Heavy truck traffic in adjacent lanes did not disturb the free-standing concrete barrier behind the slip form. On the Wisconsin project, where fixed obstacles were too close to the barrier to allow passage of the slip-form equipment, precast or cast-in-place barrier was substituted.

Slip-form machines have proved their versatility in placing concrete barriers. On some projects the concrete foundation for the barrier has been built by the same slip form, equipped with a different template, a day or two before barrier construction. Some contractors have successfully slipped the barrier integrally with the foundation in one pass. At least one machine is available that will slip a barrier on a superelevated curve section where the base of the barrier is at different elevations on the two sides. Another machine extrudes a barrier containing sheathed prestressing cables that are subsequently tensioned. The surface of barriers behind the slip form is excellent. Except for application of a light brush texture, no additional hand finishing should be necessary. Excessive floating or troweling may create an uneven surface that has less durability in a severe freezing and thawing environment than the surface immediately behind the slip form. Joints in slip-form barriers are formed most easily by sawing. With most aggregates a one-man portable saw can be used to cut surface grooves on both sides and over the top of the barrier at the specified intervals. Joints have been formed with hand tools, but this requires considerable manipulation of the free-standing barrier.

Curing of the barrier can be accomplished with polyethylene sheets, wet burlap, or white-pigmented curing membranes. Probably the latter method is most satisfactory and most economical. Care should be taken to ensure uniform application of the specified amount of membrane.

CONCRETE MIXES AND CURING

The concrete mix used in slip forming highway appurtenances is not greatly different from that used in the same type of project built with forms. However, more uniform concrete with lower slumps will produce better results. Generally in street and shoulder paving, one size of coarse aggregate with a maximum of 1 to 1½ in. is recommended (11). For curb and gutter and barrier a coarse aggregate with a maximum size of ¾ or 1 in. will probably give better results. The ratio of fine to coarse aggregate will, of course, vary depending on aggregate type and gradation. Best results with slip forming are obtained when the fine fraction minus 100 mesh is high to produce concrete that will stand well when unsupported.

The slump of such concrete should generally be less than 1½ in. Most contractors report good results with slumps from ¾ to 1 in. Slip-form equipment works best with air-entrained concrete, inasmuch as it provides better consistency and workability. Air entrainment is also necessary to prevent segregation during hauling from a central mixing plant. Because all of the highway appurtenances discussed—shoulders, widening, curb and gutter, streets, and barriers—are subjected to heavy concentrations of de-icing materials in states where snow and ice are present, the concrete must have excellent durability. Air contents should be in the range of 5 to 8 percent, cement contents should be a minimum of 564 lb/yd^3, and water-cement ratios should be a maximum of 0.49 (12).

Recommended air contents for various maximum aggregate sizes are as follows:

Maximum Aggregate Size, in.	Percentage of Entrained Air
1½	5 ± 1
¾, 1	6 ± 1
⅜, ½	7½ ± 1

Adequate curing and a sufficient period of air drying are necessary before de-icing materials are applied. Laboratory studies have shown that curing periods of 7 days are necessary to ensure adequate strength and durable scale-resistant concrete. In periods of below-normal temperatures 14 days' curing must be allowed for types I and II cements. The use of type III cement or acceleration will permit the use of a shorter (7 day) curing period when temperatures fall to near 40 degrees. With slip-formed construction, this curing can best be obtained through the use of white-pigmented curing membrane. Field experience substantiates laboratory studies that a period of air drying after curing greatly increases the resistance of air-entrained concrete to de-icers. Pavements may be opened to traffic during the air-drying period provided that no de-icing chemicals are used during this period. Thirty days beyond the regular curing period is recommended for air drying before de-icers are used.

In areas of unusually severe exposure, e.g., urban areas where large quantities of de-icing materials are normally used, special surface treatments may be considered for added insurance against scaling. This is particularly important on projects completed late in the fall. Linseed oil treatments may be beneficial on shoulders, curb and gutter, and street pavements. But these treatments are not recommended on barriers because they darken the concrete and reduce its visibility at night. For this reason a clear or light-colored sealer of the type used on architectural concrete may be preferred if a sealer is considered necessary.

CONCLUSIONS

Because of the need for uniformity of concrete—consistency and workability—contractors have learned that quality control at the plant is important. Extra care is taken at central mix plants or in transit-mix operations to ensure uniform slump, air content, and thorough mixing. Concrete placed by slip-form or extrusion methods has generally been of a higher quality than that used in formed work.

Most of the highway appurtenances discussed are not subjected to high-speed traffic as is the main-line pavement. For this reason specifications should provide practical tolerances on line and grade. Too much attention to minute details or unrealistic tolerances are not justified and will preclude the use of modern high production equipment or will add unnecessarily to the construction cost.

Slip-form equipment has proved its versatility and suitability for building all sorts of highway facilities. Wherever a street, highway, or barrier project is fairly long without frequent interruptions, the slip-form method of construction will generally be the most economical. Slip-form construction eliminates the need for form stripping and subsequent cleanup, thus minimizing delays or interruptions to traffic and permitting earlier opening to traffic.

Slip-form paving and construction have revolutionized concrete construction of transportation facilities. Contractors, engineers, and equipment manufacturers continue to demonstrate their ability to find better, more economical ways to build with concrete. Designs and specifications must be flexible enough to permit use of these new methods to obtain the greatest benefit from our limited transportation funds.

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