SLIP-FORM PAVING

AS DEVELOPED AND PIONEERED IN IOWA

By
L. M. Clauson
Chief Engineer, Iowa State Highway Commission

For Presentation at the Annual Highway Conference
Maine Section American Society of Civil Engineers, Bangor, Maine
November 3, 1961

In 1949, the first half-mile of slip-form paving was constructed in O'Brien County, Iowa. This was the first of some 600 miles of this new type of portland cement concrete pavement which has been constructed in Iowa and other states up to the year 1961. Nationally over 770 miles of this pavement have been constructed during the past five years.

In Iowa, post-war challenges of an immediate and urgent nature focused the attention of our engineers to this necessity for developing and using new and more economical construction methods.

The marketing of agricultural products from the low population densities associated with high agricultural production in Iowa demands an extensive highway system. The state ranks only 22nd in population and 25th in area among the 50 states, but it has the 6th largest road system in the nation, with a total of 111,670 miles. Over 90,000 miles are in the secondary system; the 34,000 mile farm to market system is the largest of its kind in the nation.

The changes in requirements and in types and amounts of traffic during the period following Work War II resulted in an acute need for more high-type roads. These roads were needed to reduce the cost of maintaining loose granular surfaces, to accommodate modern traffic safely and adequately, and to minimize the demand on diminishing aggregate sources. These same changes created the need for widening over 4,000 miles of 18 foot width primary pavement to meet modern standards.

Portland cement concrete paving methods were reviewed to find more economical ways to satisfy these needs. The specification of the Iowa Highway Commission with which the engineers were fairly well in agreement required that the placement of the concrete next to fixed forms was necessary to obtain god workmanship. But in 1949 some engineers advanced the idea that acceptable concrete could be placed with an extruding process, in which the forms would slip along a well prepared subgrade. The forms moved away from the freshly placed concrete after it had been consolidated and struck off to the desired cross section. An evaluation of the paving methods in use indicated that production costs could be reduced by eliminating the need for forming with its equipment and labor costs. Also, further reduction in costs could be offsetted by reducing the number of finishing machines and operations. An additional advantage would be gained in Iowa by the elimination of forming, because it would make paving operations on secondary roads more feasible. The average grade widths on most secondary roads are not adequate for the efficient operation of equipment necessary in the forming operations.

These narrower widths are the result of the policy of building higher grades within 80 foot to 100 foot width right of way. This had several affects on the economy of Iowa's county road progress. The higher grades and the streamlining of these grades allow for efficiency in snow removal and permit the wind to sweep the road surfaces clear of snow. In this design, the county does a large part of the snow removal during design and construction when a greater efficiency may be had from men and equipment. Although the highly graded roads were not looked upon with favor at first by some of the traveling public, their objections lessened after a heavy snow when those who lived upon a high graded road could travel after a heavy snow and those on the low grades had to wait for the road to be opened.

The high grade provides good drainage and helps reduce the cost of the future base when a dustless surface is planned. One county reports that from $3000 to $5000 is saved in base cost by building the high grade first. The wider right of way permits modern scrapers to operate effectively in wide side ditches and often accounts for lower unit prices for the excavation. It also aids the contractor in the building of the higher type surface and many times supplies the added borrow material needed for finishing shoulders after the base work is completed.

Development of Extrusion Methods

The Iowa Highway Commission engineers decided that the best way to meet the requirements of modern pavement construction was in the development of an extrusion method for paving. Exploratory work on extrusion methods was started in the summer of 1947. These activities were under the direction of James W. Johnson, Iowa Highway Commission Testing Engineer, working under the direction of the late Bert Myers, Iowa State Highway Commission Materials Engineer.

The first small scale working model was placed in operation on November 22, 1947. This model extruded a slab of consolidated and finished concrete 18 inches wide and 3 inches thick. The vibrating unit which is shown in the next picture *(pictures not included)* was actuated by a snytron hammer. The small motor on the rear of the machine drove a flat belt which produced the final finish on the slab. Forward motion was accomplished with winches.

The drawing above of the vibration unit are fairly self explanatory.

This rear view picture of the same machine shows a slight batter on the side forms. A 7 ½ degree batter on the forms was retained on all experimental models in anticipation of some problems with edge slump. Later experiences indicated that securing vertical edges on extruded concrete presented no real serious problem.

The results obtained with the first working model were so promising that a larger machine was constructed. This same model which extruded a slab 36 inches wide and 6 inches deep was placed in operation on February 13, 1948. This model was basically similar to the first model. A small vibrator such as commonly used for internal vibration of concrete was used to actuate the vibration unit.

One feature of his second model is that a considerable part of the force required to propel it is provided by the unbalanced reaction of the concrete against the machine.

The successful operation of this model proved that concrete pavement could be laid by an extrusion process, and that this method would result in a reduction of the total cost of concrete paving projects. This cost reduction would be effected by eliminating forming operations, by eliminating all but minor hand finishing, and by using a method which requires fewer pieces of equipment that those needed for conventional methods. In addition to these reductions in cost, the extrusion method of paving would be more satisfactory than conventional methods for paving secondary roads where narrower grades do not allow trucks to operate on the shoulder to pick up and haul the forms ahead and do other necessary work.

It is pertinent to note that the development of this working model resulted in the slip-form methods used for widening approximately 1600 miles of pavement in Iowa up to the year of 1961.

With the successful operation of this second model, sufficient data was secured to warrant a full-scale field experiment. Accordingly, a final motorized working model was developed. This model extruded a slab 20 feet wide by 6 inches thick.

Basically, this model was quite similar to the two previous models except for a saddle-yoke type of power unit which pulled the basic paver along the grade. Pulling connections were two short pieces of chain attached to the front end of the paver. This arrangement allowed the paver to react independently of the power unit, and any settlement of the wheels was not reflected in the pavement thickness. The paver could also be suspended from the power unit for transportation.

In 1949 this pilot machine was used to construct a half mile of experimental pavement. The project was located in O'Brien County. A second experimental project one mile in length was constructed later that year in Cerro Gordo County.

These two projects had adjacent 10 foot lanes. A 3 to 4 inch gap between the slabs was filled with asphaltic concrete. In spite of this unusual design required by the pilot machine, these two projects demonstrated conclusively the feasibility of the slip form paving method and acceptance of formless pavement by County and Iowa Highway Commission engineers was enthusiastic.

Though generally accepted, little progress was made in slip-form construction during the next five years. This can be attributed to the delay in development of a commercial paver. One Iowa County Engineer became impatient and secured permission to rent the pilot model for the construction of a two mile project in 1954. On this project, built by Greene County, a job trial was made at filling the 3 to 4 inch gap between the two lanes with portland cement concrete immediately following the construction of the second lane. The battered edge was used, and there was some objection to abutting the two slabs with other than a vertical joint. Several years of life on this pavement has not demonstrated that this feature was too objectionable.

Within this same period the Iowa Highway specifications required the use of air entrained concrete. For better than 20 years a longitudinal float has been required for the finishing process, and parting strips were required longitudinally and transversely in the paving slab.

The combination of the stickiness of air entrained concrete and the action of the longitudinal float made it difficult to hold these parting strips vertical.

Previously these parting strips had shown very little deviation from their designed position, now deviations much as three inches from their intended locations were experienced. The Commission engineers suggested that a machine be developed which would incorporate in the finishing operation a pan that would pass over the concrete in a longitudinal direction to give a better finish. Developments have been made along this line.

A commercial slip-form paver was finally available in 1955. This machine was designed on the same basic principles developed by the Iowa State Highway Commission with two major exceptions. In this commercial model the paving and power units were one integral machine, and the concrete was deposited directly on the grade instead of in a metering hopper.

The use of slip-form paving methods in Iowa increased rapidly when this machine became available. Approximately 28 miles of 6 inch pavement 20 to 22 feet wide was constructed in 1955.

On the primary road system 15 miles and on the secondary road system 48 miles was constructed in 1956.

Approximately 77 miles of 6 and 8 inch thickness pavement was constructed in 1957 on both primary and secondary roads.

Over 100 miles was built each year in 1958 and 1959. Construction in 1960 approached some 170 miles.

Approximately 550 miles of slip-form paving has been constructed in Iowa during the past 6 years. Some 31 per cent of this total was constructed in the primary road system.

Secondary projects in Polk County that would permit the use of this machine were prepared for letting.

The low bidder who was awarded these contracts elected to use slip-form paving methods for placing concrete pavement.

The specifications for these projects were so designed as to take advantage of the maximum possibilities of securing a low cost pavement suitable for secondary roads and low traffic primary roads.

On this type of secondary construction, the total average daily traffic is 155 vehicles per day with a maximum total ADT of 620, including a maximum truck ADT of 90.

With this in mind, the pavement was required to be constructed on a subgrade shaped to conform to the existing road profile. This shaping was accomplished by motor blade graders without the benefit of grade stakes or other controls. Pavement surface tolerances were 3/16 inch in 10 feet.

Contraction joints were generally accomplished by sawing; however, other methods were permitted.

Several methods of curing were permitted, but, white pigmented curing compound applied soon after the final finish was the method most generally used. This was because water trucks could not be used along the edge of the completed pavement. Also this type of curing does not break down the fresh pavement edge.

Again in line with the intent of the special provision, a table of concrete proportions was designed by the Materials Department on a strength and quality basis which allowed the use of highly sanded mixes. Since these proportions allowed greater use of local materials, further cost reductions were possible. These proportions also allowed contractors to select design mixes ranging from 1-1/4 to 1-1/2 barrels of cement per cubic yard. Quality requirements for all materials were the same as required for all other concrete.

The completion of these and other early projects demonstrated that quality concrete pavement could be placed 20 to 24 feet wide without using fixed forms and that vertical instead of battered edge forms could be used. However, the paver and construction methods had some objectionable features.

It was demonstrated that some method should be provided for striking off the concrete before it starts through the paver. The paver as originally designed has no preliminary method of striking off the concrete before it passed under the pan of the concrete laying machine. This was objectionable because the machine had a tendency to climb onto the deposited piles of concrete. This lifting effect caused the machine to lose its traction and form an undesirable surface.

The specifications for this type of work were changed to require that the machine for placing the concrete should have some mechanical device for striking off the concrete to a uniform depth before it is fed under the pan of the paving machine. This was accomplished by added a bulldozer arrangement on the front of the machine operated by hydraulic rams.

Although the pavements on these early projects have a satisfactory surface tolerance as measured by the Bureau of Public Roads type of roughometer, the undulations in the grade line made them uncomfortable for high sped driving. To correct this the specifications were changed to require that the wheels, tracks, or skids of the laying machine should operate on surfaces prepared by a form grading machine. Also, it was required that that subgrade between these tracks be completed not less than 500 feet in advance of the operation of the placing concrete. Carefully and accurately set string lines for alignment and grade are now required to be maintained ahead of the paver for a distance of not less than 500 feet. The specification required a smooth subgrade which is true in grade to secure quality slip-form pavement.

In addition, an adequate supply of concrete of uniform consistency must be kept in front of the paver at all times. Continuous forward movement of the paver gives the maximum surface smoothness.

The possibilities of securing an excellent riding surface with slip-form paving methods was indicated in the results of a straight edge survey of the one mile project constructed with the pilot model in 1949. A total of 2,022 points were checked in both lanes with a 10 foot straight edge. Less than 12% of the total points measured showed a deviation of 1/8 inch and only 3.6% showed a deviation of ¼ inch.

Road roughness measurements on slip-form pavement as determined by the Bureau of Public Roads type of roughometer have consistently been less than those on conventional pavement. The weighted average road roughness for approximately 104 miles of pavement constructed by slip-form methods in 1960 was 64 inches per mile. This is 14 inches per mile less than that obtained on 193 miles of conventional pavement. The undulations in grade line on the earlier projects have been eliminated by improved construction procedures.

Average flexural strengths meet design requirements. The average of 195 specimens in 1959 was 606 pounds per square inch with an average w/c of 0.539 for mixes ranging form 470 to 523 pounds of cement per cubic yard. Sand contents ranged up to 60 per cent of the aggregate in some cases.

The 1960 average of flexural strengths for the same mixes was 594 pounds per square inch with a w/c of 0.559.

Corrected 28 day compressive strengths determined from cores approach an average of 4000 pounds per square inch.

Flexural and compressive strengths on concrete with higher cement content which have been constructed by slip-form methods are comparable with those from pavements constructed by conventional methods.

In summarizing Iowa's 14 years of experience in pioneering and developing slip-form paving methods probably the best indication of whether a cost reduction can be effected by using slip-form methods would be a evaluation of the contracts which gave the contractor a choice of paving by the slip-form method or by fixed forms methods. Less than 23 miles of approximately 524 miles in Iowa was constructed by conventional methods. Most of this 23 miles was constructed by one contractor. Now he is paving with slip-form methods. Five larger paving contractors now have slip-form paving equipment.

The range in prices on the 1960 secondary projects through June was $2.49 to $2.98 per square yard with an average price of $2.52 or $29,600 per mile for pavement 20 feet wide and 6 inches thick. The average price has varied from a low of $2.50 in 1959 to a high of $2.56 in 1960.

The range in square yard prices for 1961 was $2.54 to $2.84, except one short project which was $3.12.

These figures indicated a remarkable stability in the face of rising costs for labor and materials.

The motive power on the slip-form paver as developed in Iowa was independent of the paving unity. Settlement of the wheels or crawler tracks, due to subgrade conditions, would not reflect a decrease in pavement thickness.

While slip-from paving was developed in Iowa primarily for use on secondary and low traffic primary routes, other states have demonstrated that this type of construction could also be used on high type primary and interstate roads of greater widths and thicknesses.

Slip-form paving machines with a curb forming attachment, are being used on urban paving projects.

The following slides will illustrate the slip-form paving machine in operation. *(No slides included.)*