DESIGN OF LOW VOLUME CONCRETE ROADS

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The Bicentennial last year has made us all more aware of our heritage. It gave us pride in our country and state. We in Iowa are very proud that it was in Iowa and by an Iowan that the slipform method of paving had its origin.

This origin started back in 1946 while three employees of the Iowa State Highway Commission (now a division of Iowa DOT) were on a field trip to observe a demonstration of cement-treated base construction.

One of these men was James W. Johnson, a testing engineer, and since has been called the "father of the Slipform Paver". It was his idea that if more cement was put in the mixes and vibrated into place it might be possible to eliminate side forms.

After returning to Ames these men started to build a machine to test their idea. The first machine was a small skid-mounted box spreader to which they mounted a vibrator. It was a very crude apparatus but they were successful in placing a concrete slab 3 inches in thickness and 18 inches in width. It was a slip form sidewalk machine.

Due to the success of their first machine they started out to build a bigger one, this time a slab six feet in width was poured. The next model was a self-propelled machine that placed a slab six inches thick and a width of 10 feet. This slab was placed at the civil engineering lab on the Iowa State University Campus.

In September 1949 the first attempt to pave an actual county highway, with Mr. Johnson's machine, was done near Primghar in O'Brien County. This was done with county personel, a lot of determination, and a bit of luck. The project was about one-half mile in length, 6 inches in depth and twenty feet wide. Since the first machine only paved a ten foot width, two passes were necessary to complete the twenty foot width.

The cost of this project was 8,000 dollars - seems like a nice round figure - for the 5,432 sq. yards of pavement. This made a square yard cost of $1.47. The engineers estimate for the same project with forms was $12,718, thus a savings of over $4,000 or 33%.

Late in November of 1949 Mr. Johnson's paver was used again to place one mile of road 6 inches in thickness and 20 feet wide near Mason City, Iowa. This was done under contract by the Andrews Construction Company of Clear Lake for a bid price of $2.32 per square yard. This was the first slipform paving job completed under contract.

The results obtained from these two projects proved that the slipform method would work and could be done at a savings. The next big job was to convince the contractors that this was the coming way to pave. They could then throw their forms in the junk pile. This was not easy to accomplish and very little developed until 1954.

In 1954 another county engineer rented Mr. Johnson's machine and paved a two mile section of secondary road. This helped to prove anew the practicability of slipform paving.

Engineers and contractors from other states were watching the developments in Iowa, and early in 1955 a contractor from Illinois built his own machine. He used this machine to pave several miles of concrete base for the Illinois Division of Highways. Another Illinois contractor used an equipment manufacturer's early developmental machine to pave his equipment yard near Chicago.

Now that the equipment manufacturers were beginning to become interested in this machine things would develop at a much faster pace. A manufacturer could spend much more money developing a paving machine than any highway department. With profit to motovate them the manufacturer would do it much faster too.

In 1955 the Quad Cities Construction Company of Rock Island, Illinois produced a refined and much improved slipform paver and started paving using a new concept. This paver was designed using Mr. Johnson's principle but had three distinct differences; (1) Concrete was placed directly on the subgrade in front of the machine and not into a hopper. (2) The width was adjustable from 20 feet to 30 feet, enabling the full roadway width to be paved at one time. (3) The paver was propelled by long crawler track assemblies rather than wheels.

After the Quad Cities paver became available, use of slipform paving increased rapidly in Iowa and soon spread to other states. In 1955, 28 miles of 6 inch pavement 20 to 22 feet wide was constructed.

Progress improved each year after 1955 at a rapid pace - the paver was continually rebuilt and improved, more contractors went into the slipform paving operation and by 1970, 21 years after the first half mile was paved, over 300 miles of secondary roads varying in depth from 6 inches to 8 inches and widths from 22 to 24 feet were constructed in Iowa. The following table shows the miles of secondary roads paved from 1971-1976.

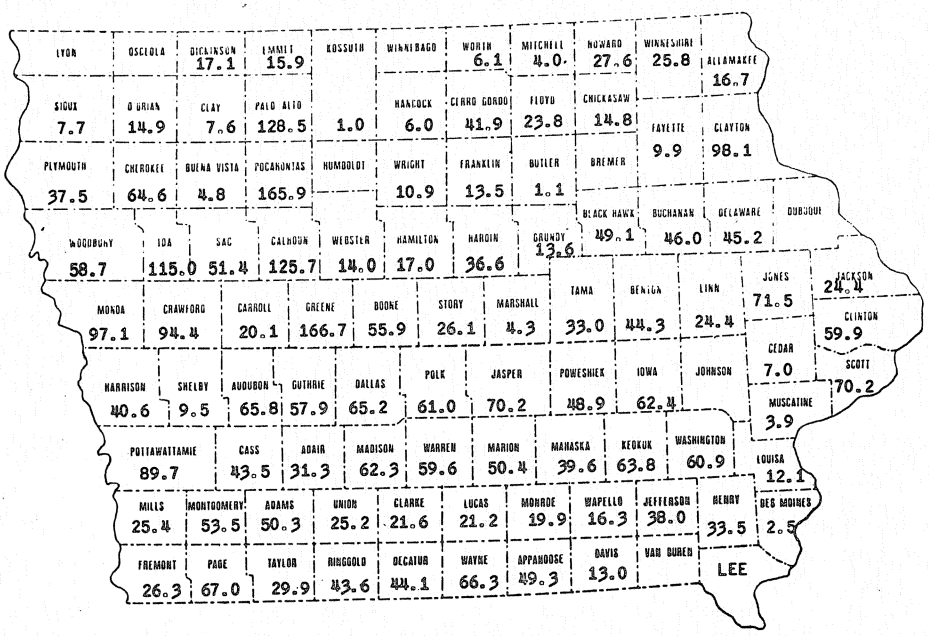
Year	Number Miles	Year	Number Miles
1971	318.60	1974	199.60
1972	239.80	1975	184.40
1973	194.60	1976	190.00

The decrease in the number of miles paved in recent years shows that the cost of road construction has increased faster than the money available and this has resulted in fewer miles paved each year.

Since 1958 several equipment companies have started to manufacturer slipform paving equipment. This has resulted in more improvements in the equipment which has been the major weapon in the fight against rising costs and has enabled the counties to continue paving as many miles as they do with little increase in the tax revenue. These new improved machines increased the one-half mile average of the early 1960's to the one mile average of today's paving with little increase in number of employees.

Equipment developed in the past few years that has enabled the 1 to 2 miles per day accomplishments are the C. M. I. subgrader and the central mix plant. These two machines have more than doubled the productive capacity of our contractors in Iowa.

Equipment and material costs have increased around 30% and the equipment cost over 300% but the square yards produced per day has also increased about 150% which helps temper the equipment and labor increases.



This map shows the counties and the number of miles per county with slipform paved secondary roads as of 6-1-76. There are only 10 counties with no paving and 5 counties with over 100 miles of slipform paving.

Washington County did their first slipform paving in 1962 which was 6 miles in length and was 6 inches in depth and 20 feet wide. This road also had four foot rock shoulders. We now are paving 6 inches in depth but 22 feet wide with 10 foot rock shoulders. Washington County has 61 miles of slipform paving.

Our first paving job was done dry batch with the mixer on the grade. The last paving project in 1974 was done with the central mix plant and we averaged one mile a day for the ten mile project.

We also had a 3/4 mile project 22 miles from the plant site so we used a retarder in the mix. That was one of the first projects in the state to use a retarder on a paving project. At the present time the Iowa DOT is writing a specification for the use of retarder on paving projects. This was funded with county money and not state funds; therefore we could use the retarder. Had this been a state funded project we would not have been permitted to use a retarder. This would have required the contractor to move his plant site closer to the project to meet the time requirements of 30 minutes from mixing time to the time the concrete is placed. This move would have cost $10,000. So far there has been no signs of defects in this paving and all the cylinders tested as high or higher than the concrete in which the retarder wasn't used.

The maintenance cost of the concrete paving in Washington County has been far below the state average of $20 per mile per year. This figure is for crack and joint sealing and mud pumping over culverts. Some counties have had paving for more than 20 years and that might be the reason our average is so much lower.

Most of the secondary roads in Iowa, that have been paved, carry between 200 and 2,000 vehicles per day. Ninety percent of these roads are 6 inches thick, 8.5 percent are 7 inches thick, and 1.5 percent are 8 inches thick.

The standard design for these pavements call for a uniform thickness.

One-half inch round tie bars are used across the sawed longitudinal center line joint at 4 foot centers. Transverse joints are sawed at 40 foot intervals. The 40 foot joint spacing is a matter of economy since Iowa aggregates have a normal crack interval of less than 20 feet. It might be advantageous to use a 20 foot transverse joint interval in the intermediate crack which sometimes forms during the first ten years of service. Washington County has practically no intermediate cracking. No mechanical load transfer devices or distributed steel reinforcing are used.

No special subbase or base course is used in the design. Most counties grade their roads one to two years prior to paving. By this method they have taken advantage of the natural compaction of the grade by traffic and weather. The counties also have time to find the trouble spots and correct them. Since these roads have been previously surfaced with either gravel or crushed limestone, some counties establish a grade line which will permit utilizing the existing granular surface in the subgrade. Other counties feel it is not worth the expense to save the existing granular surfacing. In Washington County when the crown is removed and reduced to 2 inches prior to paving we add additional crushed limestone.

A special mix with lower cement quantities is used for county work. This is a Type B concrete from our standard specifications of the Iowa DOT Highway Division. The approximate quantity of dry materials per cubic yard of concrete is as follows:

Mix No.	Cement		Fine Aggregate Tons	Coarse Aggregate Tons
	Bbls.	Lbs.		
B-2	1.239	466	0.6288	0.9432
B-3	1.274	479	.7006	.8563
B-4	1.311	493	.7703	.7703
B-5	1.351	508	.8375	.6852
B-6	1.391	523	.9028	.6019
B-7	1.436	540	.9651	.5197
B-8	1.484	558	1.0250	.4393

The total quantity of water in the concrete including that in the aggregate shall not exceed 6.77 gallons per bag of cement (0.600 pound of water per pound of cement). These quantities are based on the following assumptions: Specific gravity of cement, 3.14; Specific gravity of aggregate, 2.65; Water-cement ratio, 6.04 gallons per bag of cement (0.536 pound of water per pound of cement); Air voids, 6.0 percent; Weight of one cubic foot of water, 62.4 pounds.

The contractor has his own option of using the mix design he feels is most economical. There is one size of coarse aggregate. The cure normally used is white pigmented liquid membrane-forming compound. The specifications call for a 14-day waiting period before opening pavement to traffic.

The future for slipform paving is brighter than before. I would predict that within ten years or less it would be a rare occasion for a paving job not to be done by the slipform method.

New subgrade equipment is now on the market that will remove asphalt and concrete from an old road surface to within ½ inch prior to resurfacing. This machine will prepare the surface of old paving so that a new surface of concrete can be applied with the slipform machine.

In conclusion there are 3 points that Iowa does differently in its design of low volume roads that other states do not - which are:

1. Lower cement content per cubic yard.
2. Twenty two foot width pavement.
3. Uniform cutting of subgrade.

This lower cement content has proven to be adequate for these low volume roads. In Washington County we first used this type of paving in 1962 and this section of road shows very little signs of deterioration. The type "B" mixes vary from 466 pounds of cement per cubic yard to 558 pounds of cement per cubic yard. This variance in cement depends upon the aggregate available for the mix throughout the state. We usually use 493 to 509 pounds of cement per cubic yard in Washington County. With this lower cement content traffic is kept off the slab for a minimum of 14 days or until the modulus of rupture is 500 pounds per square inch. At 28 days the P. S. I. will range from 4500 to 5500. The table below shows the roads paved and cost per square yard:

Date	Miles	Width	Price
1962	6.553	6"20'	2.44
1963	9.291	6"20'	2.57
1964	8.222	6"20'	2.81
1966	4.006	6"22'	2.67
1967	2.942	6"22'	2.63
1967	7.542	6"22'	2.72
1971	9.230	6"22'	3.10
1971	1.000	6"24'	5.75
1973	9,046	6"22'	3.19
1973	1.811	6"22'	3.28
1973	0.899	6"22'	3.93
1973	0.506	6"22'	3.63

A twenty two foot minimum width is required by the State with a four foot shoulder. We still pave only twenty two feet wide but have increased our shoulder width to ten feet because of the increased size of farm equipment.

Since most of these roads have been graded and resurfaced with stone surfacing for at least two years the crown in the road will vary from eight inches to one foot depending upon the width of the roadway. With this excessive crown in the subgrade it requires us to scarify the roadbed and removed the crown. Most counties will scarify the roadbed from shoulder to shoulder and relay the surfacing material with a two inch crown. In Washington County we have found out that the entire roadbed needs to be relaid to prevent quarter line cracking.

After the roadbed is relaid we let the traffic on the road from two weeks to maybe a month or so before the paving starts. When the paver moves in to do the fine grading we keep the subgrader in about one tenth of a foot cut throughout the entire roadbed. The surfacing material removed from the road is then used on the shoulders. Keeping the subgrader in cut makes the subgrade uniform and there are not hard or soft spots in the subgrade. This reduces the quarter line cracking substantially.

The material deposited on the shoulders is then smoothed and the shoulder surfaced with crushed limestone.

At the end of each days work a header is placed with dowel bars. These dowell bars are placed to transfer the load from one slab to the other.

Washington County is contemplating resurfacing a nine mile stretch of asphalt paving with 6 inches of slipform concrete. The A. C. paving was placed in 1958. It has been resealed several times since then but it is now in need of a new surface and we plan to pave right over the old asphalt surface.

As contractors are discarding their forms in increasing numbers it is proof that slipform paving is here to stay.