Construction and Cost of Concrete Roads

Civil Engineer

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CONSTRUCTION AND COST OF CONCRETE ROADS

BY

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B. S. University of Illinois, 1909

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THESIS

Submitted in Partial Fulfillment of the Requirements for the

Degree of

CIVIL ENGINEER

IN

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OF THE

UNIVERSITY OF ILLINOIS

1915
I HEREBY RECOMMEND THAT THE THESIS PREPARED BY

Rodney Linton Bell

ENTITLED CONSTRUCTION AND COST OF CONCRETE ROADS

BE ACCEPTED AS FULFILLING THIS PART ON THE REQUIREMENTS FOR THE

PROFESSIONAL DEGREE OF Civil Engineer.

Ira O. Baker

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Recommendation concurred in:

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Committee
CONSTRUCTION AND COST OF CONCRETE ROADS.

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II COST OF CONCRETE ROADS.
INTRODUCTION.

The writer has been employed during the past six years by the Illinois Highway Commission on the construction of all types of roads. This work consisted of construction of gravel, water bound macadam, bituminous macadam, concrete and brick roads. During the past three years I have spent most of my time on concrete road work either as superintendent of construction or as division engineer. During the past year I have had charge of the construction of concrete roads amounting to $145,000 and brick roads amounting to $180,000. The methods described in this thesis have all been tried out under my personal supervision and have been found to be successful.
I CONSTRUCTION OF CONCRETE ROADS.

Excavation.

Whenever the traffic on a road justifies the expense of constructing a concrete roadway, a certain amount of grading will need to be done. The hills must be cut down and the low places filled, which will reduce grades and facilitate drainage.

It often happens that in excavating deep cuts seepy places are encountered. Many times they will be found at the very tops of the hills. If the flow is from one well defined area, a line of small drain tile can be laid from this place to the side ditch, thus removing the water as fast as it collects. A blind drain of coarse stone, broken tile or brick will often answer the same purpose. If the flow is distributed over a large portion of the roadway, it is often necessary to lay the line of drain tile just below the edge of the seep and run the blind drains into it, parallel to the line of the road. The tile drain should make an angle of about forty-five degrees with the center line of the road.

In cuts it is often necessary to lay a line of tile on one or both sides of the road; and if ground water seems prevalent over the entire cut, it may be advisable to use blind drains to get the water to the tile.

There are tight clay soils that are so nearly impervious to water that a tile will not drain more than three feet on each side, and in soils of this type it is almost useless to place tile drains without the blind drains to facilitate the water reaching them. In some cuts, all the water will come from one side of the road and in that case, one line of tile under the side ditch will
be sufficient to assure a dry subgrade.

It is just as essential to secure a dry subgrade in the cuts as at any other point of the road, and as a rule, under-drainage is the only effective method of removing ground water.

Many times, drainage is not needed and on soils that have a tendency to wash, side ditches are not even opened if the grade is as much as one percent. The dirt is given a slope away from the concrete of about one inch to the foot. This will collect the water at the sides of the embankment, where it will run off without wetting the subgrade.

For the average Illinois soils, the cuts should be left with a side slope of one and one-half horizontal to one vertical. Many soils will stand temporarily with a slope of one to one, but they will eventually assume a more gentle slope and it should be provided for from the first.

The best precaution that can possibly be taken to insure a well compacted fill, is to specify that the fill must be placed and allowed to go through one winter before the concrete is poured. If the season is dry, it is impossible to so compact a fill of two feet or more that it will not settle when the rains come.

If the roadway must be placed the same season that the fill is made, there are some things that can be done to insure a minimum amount of shrinkage. A common specification is to allow dirt to be placed in layers one foot thick. These layers should be carried continuously from one toe of the slope to the other. It is often specified that each layer must be thoroughly rolled with a ten-ton three-wheeled roller. This clause is worse than useless. It leaves the roadway smooth and the fill is made up of
layers, rather than one solid mass. If compaction is to be obtained by machinery, it would be much better to specify that the rolling be done by a traction engine. This would secure the same compression and leave the roadway roughened to facilitate the joining with the next layer.

A better specification would require the material to be placed in six inch layers and depend on the action of the horses' hoofs, wheels of the scrapers and wagons for compaction with no concrete to be placed on a fill over three feet in height the same season that the fill is made.

No stumps, planks, grass or other vegetable matter should be placed in a fill at any time. These materials will soon decay and cause the fill to settle.

Concrete is a rigid material and it must have a constant and uniform support, if it is to fulfill its mission as a road surface.

Subgrade.

A mistake is often made, by engineers inexperienced in road construction, in trying to lay the road metal before a proper foundation is secured. I do not know of any road surface where as much care should be used in the preparation of the subgrade as for a concrete road. With a road metal that can be easily repaired, some chances may be taken with the foundations; but with a concrete road, where repairs are difficult and expensive, every possible precaution should be taken to insure a solid, uniform subgrade.

There has been a great deal of discussion regarding the crowned and flat subgrade for concrete roads, and a large majority
of the testimony has been in favor of the flat subgrade. In theory, it seems reasonable to suppose that a flat subgrade can be shaped more economically than the crowned subgrade. In practice, there is no difference in the cost. The only way to insure the required thickness of concrete is to dress up the subgrade with a template, after the side forms are placed, and just as much crowned subgrade can be finished in a given time as flat subgrade. At the present stage of concrete road construction, there is something to be said in favor of flat subgrade. According to present knowledge, we feel that a concrete road should be thicker in the center than on the edges. For a concrete road ten feet wide, on a flat subgrade, it is common practice to provide for seven inches of concrete at the center and six inches at the edges, giving the road a one-inch crown. On an eighteen foot road, the common practice is eight inches of concrete in the center and six inches on the edges, giving the road a crown of two inches. Most engineers agree that for a single-track road ten feet wide, a crown of one inch is sufficient; but with an eighteen foot road, many engineers insist on a greater crown and to do this economically, the subgrade must be crowned.

If the surface of the road follows the arc of a circle and the ten foot road has a crown of one inch, the eighteen foot road, using the same arc, should have a three and three-eighths inch crown. If the surface follows the arc of a parabola and the desirable crown of the ten foot road is one inch, the crown of the eighteen foot road would be three and twenty-four hundredths inches.
Where it is desirable to secure a greater crown than can be obtained by using different thicknesses of concrete at the center and edges, it can easily be secured by giving the subgrade a slight crown, without any additional labor cost.

Some have objected to the crowned subgrade, saying it interfered with the movement of the concrete, due to expansion and contraction, but the extra area in contact with the subgrade is negligible.

A large portion of any subgrade will be on soil that has not been disturbed, as most specifications require that the soil is not to be loosened below the level of the subgrade, except to remove soft pockets. Where this condition holds, the main function of the roller is to smooth up the subgrade and locate the soft places which must be dug out and replaced with dry earth. Rolling should be done with a ten-ton three-wheeled roller and should be continued as long as it makes any impression upon the subgrade.

The first requirement of a permanent road is good drainage. Any system that helps the road as a whole, is a direct benefit to the subgrade. Occasionally, special conditions arise that render tile drainage imperative. For the majority of concrete roads, however, well maintained side ditches with blind drains leading to them from the subgrade, wherever needed, will afford ample drainage.

The bottom of the side ditches should be at least eighteen inches below the level of the subgrade. These ditches should be of ample size to provide some little storage for water at times
when the rainfall is excessive and the outlet to the ditches is flooded. After providing for ample side ditches, the water courses should be kept open at all times. It is of no advantage to have water standing in the side ditches, for the entire road bed will soon become saturated.

Some of the water that falls on the concrete, will find its way to the subgrade through the cracks and expansion joints. If the ditches are properly constructed, this water will filter away and have no injurious effect on the subgrade or the road itself.

During the first year after the construction of a concrete road, considerable water will reach the subgrade by running down between the edges of the concrete and the earth shoulders. After the shoulders have become well compacted, this is reduced to a minimum. To facilitate the movement of this water to the side ditches, blind lateral drains are needed at certain parts of the road. The general rule is to place them at and near the bottom of slopes and places requiring special attention. Each road is a problem in itself and requires special consideration.

These drains should extend across the subgrade. A trench eight inches wide should be dug each way from the center of the subgrade to the side ditches, giving ample fall. About eight inches of coarse stone should be placed in this trench and covered with earth where it crosses the shoulders. The trench should be about nine inches deep across the subgrade. After the stone is placed, it should be covered with an inch of earth and tamped flush with the subgrade. This thin layer of earth prevents the
mortar from the road running into the laterals, which would not only prevent free access of the water to the drain, but weaken the road at this point.

Side forms set. Subgrade to be brought true to grade and rolled. The aggregate distributed along the sides.

Before placing the aggregate, the subgrade is thoroughly rolled and is generally left slightly higher than shown on the plans. In hauling the aggregate, a certain amount of damage will be done to the subgrade. When the mixing and placing of concrete starts, a template that rests on the side forms is used to test the subgrade, and with a well organized gang, it will take most of one man's time to dress up the subgrade, either just ahead or just behind the mixer. In this way, an absolutely true subgrade can be secured, and I have seen fourteen thousand feet of ten-foot concrete road placed where the average variation in the amount of cement used from the theoretical amount was less than one sack per hundred feet, or about seven-tenths of one percent.
Side forms set with aggregate placed directly on the subgrade.

Aggregate.

The coarse aggregate used in a concrete road should be as nearly perfect in composition as it is possible to get, both in gradation, hardness and uniformity. The aggregate should vary uniformly in size, from one-fourth inch to one and one-half inches. If one hundred percent passes a one and one-half inch round mesh, and from fifty to seventy-five percent passes a three-fourths inch round mesh, and one hundred percent is retained on a one-fourth inch round mesh, it can be called a uniformly graded material.

Washed gravel and trap or granite rock are excellent for use in a concrete road. Limestone, unless exceptionally hard, should not be used. A French co-efficient of wear of not less than ten should be required. After one year's traffic on the road,
the travel will begin to wear on the coarse aggregate and where that aggregate is soft limestone or some other soft material, it will soon begin to pick out and give a pitted surface. The soft material in gravel should not exceed one percent by volume. Bog iron in gravel banks has caused the rejection of what was otherwise an excellent material.

Fine aggregate should be made up of clean quartz or hard silicious grains, and should not contain more than about two percent of clay, by weight. This material should pass one hundred percent through a one-fourth inch square mesh and from thirty percent to seventy-five percent through a one-sixteenth inch square mesh.

In using coarse and fine aggregate, each and every batch of concrete will be exactly the same. In using mixed aggregate, we know that our mixture will not be uniform. In loading mixed aggregate at the washing plants or crushers, the car is loaded from the two ends. The coarse aggregate tends to separate and run to the edges of the piles and the center of the cars. When this material is taken from the car, there will be a few yards of the material in the center that will not have enough fine aggregate to fill the voids. When the gravel is dumped on the road, the coarse aggregate tends to run to the edges. Some of the concrete will not have enough fine aggregate to fill the voids; some will have too much, which means that the cement will not fill the voids in the fine aggregate. It is a physical impossibility to secure a uniform mixture in a road when using mixed aggregate and for this reason, it should not be used.
Cement.

Any standard brand of Portland cement may be used. It should be bought to conform to the United States Specifications for Portland cement, as given in circular number thirty-three of the Bureau of Standards. Arrangements should be made to test all cement used and reject that which does not meet these specifications, not only as to physical but chemical test. It is an easy matter to grind ashes, cinders and unburned rock in with the cement and by adding gypsum, cause it to show enough strength to pass the seven-day test. The chemical analysis will detect this adulteration.

Setting Forms.

In setting forms for a concrete road, care is required to get them true to line and grade. Grade stakes are generally set every twenty-five feet, on each side of the road, to the nearest hundredth of a foot. These stakes are commonly set eighteen inches off the line. This enables the form setter to level over to the forms, using an ordinary carpenter's level. Vertical curves are used at breaks in grade and horizontal curves at changes in alignment. It is usually easier to get the forms set true to grade than it is to line; and yet, after the road is completed, anyone will notice a bend in the line while a very few will notice an irregularity in the grade. For this reason, it is essential that the forms be set true to line and sufficiently well braced to remain in line while the concrete is being placed.

Line stakes are generally set and tacked from one hundred to one hundred and fifty feet apart on each side of the road. An
engineer, with one helper, should be able to set from fifteen hundred to two thousand grade and line stakes in a ten hour day. Finished grade stakes should always be set true to grade, rather than depend on the form setter to measure up or down to get the proper elevation.

Mixing and Placing Concrete.

A good mix for a concrete road, and one much in use, is one part cement, two parts fine aggregate and three and one-half parts of coarse aggregate, all measured dry. In using these proportions, there will be an excess of mortar, which is absolutely essential in the construction of a one-course concrete road. The construction at this time is practically all one-course work.

The amount of water to be used varies with the different classes of material and with the weather. Damp aggregate will require less water than dry aggregate. Enough water should be used so that the resulting concrete, when dumped on the road, will flatten out, but will not be wet enough for the mortar to separate from the coarse aggregate.

The type of mixers in use today have one of two arrangements for the distribution of the concrete after it is mixed. One type uses a spout that can be swung from one side of the subgrade to the other. The other type uses a boom with a traveling bucket. Some of the advantages of the boom with the traveling bucket over the spout are: 1st, that concrete can be placed farther away from the mixer, thus leaving room between the mixer and the concrete to dress up the subgrade and set expansion joints; 2nd, that a
temptation to mix the concrete too wet is removed, for a mixture that flows freely in the spout is too wet for a concrete road; 3rd, that the coarse aggregate does not separate as is often the case when using the spout.

The bucket in general use today, and the one best adapted to this class of work, is so arranged that when the power which runs it along the boom is released, the doors, which form the bottom of the bucket, are opened. Another type of bucket is run by power along the boom to where it is desired, but must be dumped by hand. Still another type of bucket, which is more cumbersome than either of the others, is the one that is run along the boom by hand and is dumped by being tipped sidewise. Any type of bucket is preferable to the spout but the one first described comes nearer meeting all requirements than any of the others. The subgrade should be thoroughly wet before the concrete is placed.

Wheelbarrows containing aggregate are being dumped directly into the skip.
The newer types of mixers have loading skips so shaped that when they are lowered to the ground, the wheelbarrows loaded with aggregate can be run directly into the skip and dumped. When the mixture used is one-two-three and one-half, most machines will mix a two sack batch; that is, two parts cement, four parts fine aggregate, seven parts of coarse aggregate. This will require two wheelbarrows with fine aggregate and three with coarse aggregate. If the machine is being worked to its full capacity, these five wheelbarrows should be standing ready to be dumped the instant the skip is lowered. This will require ten men wheeling aggregate, two men to untie the sacks and empty the cement into the skip. With this sort of an organization, the skip should be loaded and ready to be raised in twenty to thirty seconds after it reaches the ground. The water should be turned into the drum just before the skip begins to discharge the aggregate and cement.

Loaded skip being hoisted.
Concrete is being conveyed by means of a spout directly from the mixer to the subgrade. Concrete much too wet for best results.

After being mixed thoroughly, the concrete is placed on the subgrade, either by a spout or a traveling bucket. Three men will be required to shovel the concrete into place and to manipulate the template. The concrete should be well spaded next to the side forms to prevent porous concrete. Any good batch mixer will mix concrete satisfactorily if it is properly managed. The drum should be run about twenty R.P.M., and at this speed twelve complete revolutions of the drum will usually be sufficient to give a uniform mixture. It only requires ordinary care on the part of the inspector to see that the concrete is being properly mixed, but it requires ceaseless vigilance after it is deposited on the road bed to insure a road of uniform density. Concrete must be worked after it is deposited on the road bed, and one of the best ways to insure this being done is to provide the men who handle it with gum boots and insist that, except when they are
using the template, they stay in the concrete. The walking back and forth and the shoveling required to get the concrete properly distributed will insure a well spaded dense concrete.

Another aid in securing a dense concrete is by the addition of hydrated lime. If hydrated lime, to the amount of 10% of the cement by weight, is added, a much denser concrete will be obtained. Concrete when hydrated lime is used is more plastic, denser and flows readily into place. It should not be used with the idea that less care be taken in the placing of the concrete, but rather as an added insurance that the road will be made up of a dense homogeneous concrete.
This picture shows a strip of road that has been struck off with the template but not floated.

The template should be made out of a two by ten inch board, cut to the crown of the road and shod with metal. It should have handles on both ends, and in striking off the surface of the concrete, should be worked back and forth across the road and gradually pushed ahead, rather than try to drag it forward. The template should be taken back and the road gone over the second time, and it may be necessary to repeat the operation the third time. When the template work is finished, the road should be true to crown; but it will be rough, requiring smoothing up with a wooden float. One man will do this work.

In floating a concrete road with a hand float, the float should be moved back and forth, parallel to the center line of the road. This reduces to a minimum the wavy surfaces caused by the template. Where a long-handled, patented float is used, a good concrete man can do good work by working crosswise of the road. But if the work is to be done by ordinary labor, the small hand float should be used.
This picture shows a type of bridge template and hand float in common use.

A strip of road that has just been finished but is not dry enough to be covered with the canvas.
Care must be taken that a perfect mortar-coat surface is obtained, no pebbles being left uncovered. If too much water is used, after the road has been floated small patches of pebbles may be found, caused by water carrying the mortar away. The finisher and the inspector must watch this part of the work closely and refinish these places, using a little sand and cement mortar.

In order to handle concrete economically, where an up-to-date mixer is used, the following men are required:

<table>
<thead>
<tr>
<th>Cost per day.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two men setting forms</td>
</tr>
<tr>
<td>Ten men wheeling aggregate</td>
</tr>
<tr>
<td>Two men emptying cement</td>
</tr>
<tr>
<td>One machine operator</td>
</tr>
<tr>
<td>One fireman</td>
</tr>
<tr>
<td>One man operating boom or spout</td>
</tr>
<tr>
<td>Three men spreading concrete and using template.</td>
</tr>
<tr>
<td>One man dressing subgrade</td>
</tr>
<tr>
<td>One finisher</td>
</tr>
<tr>
<td>One man operating water pump</td>
</tr>
<tr>
<td>Coal, oil, gasoline, etc.</td>
</tr>
<tr>
<td>One man tying cement sacks</td>
</tr>
<tr>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>

A gang of this size should average about six hundred square yards during a day of eight hours, at a cost of nine and one-tenth cents ($0.091) per square yard for mixing and placing concrete.

One contract of five miles was mixed and placed during the past summer for nine and two-tenths cents ($0.092) per square yard.

Covering and Curing Concrete.

During the hot days of summer, it will be necessary to cover the concrete with canvas and keep the canvas damp. This will prevent the appearance of sun cracks, due to the too rapid
drying of the surface. The canvas should be placed on the road as soon as the concrete has set sufficiently. In midsummer, the canvas can be placed in from one to two hours after the concrete is poured. The canvas should be left on the road during the night, as it affords some protection to the surface against dogs or other animals that might walk over the soft concrete. This canvas should be at least one foot wider than the road and in thirty to fifty foot lengths.

The next morning after the concrete is placed, the canvas should be removed and the concrete covered with at least two inches of earth. The gang that works on the mixer should do this work before starting concreting. In this way, the concrete will all be covered in an hour or less. After it is covered, one man can be detailed to sprinkle this earth covering until it is thoroughly saturated. It should be kept in this condition for at least two weeks. Where only one or two men are detailed to cover the concrete with earth, there is danger of it developing sun cracks even on the second day. Of course, where concrete is placed late in the fall of the year, it is not necessary to use the canvas, and when the nights are cool, the concrete is not always set sufficiently the next morning to permit the covering with earth, but it should be done just as soon as the concrete will permit.

The earth should be left on the road thirty days, when it may be removed and the road opened to traffic. If any contraction cracks have developed in the road, they should be thoroughly cleaned out and filled with hot asphalt before the road is opened.
Expansion Joints.

The term "expansion joint" is a misnomer, as the purpose of the joint is not to take care of the expansion, but to prevent contraction cracks. It has been demonstrated that a monolithic pavement, such as cement grout filled brick or concrete, does not need joints to take up the expansion. The first roads that were constructed by the Illinois Highway Commission, in 1912, had expansion joints placed every fifty feet at sixty degrees with the center line of the road. This was to prevent the opposite wheels of vehicles from hitting the joint at the same time.

During the summer of 1912, two kinds of joints were tried out; the armored metal joint and the creosoted wood block. It is evident from the use of the wood block that the idea still prevailed that expansion must be provided for.

An armored metal joint in place.
The metal plates were bought cut to the crown of the road and were placed one-half inch apart and this space was filled, sometimes with asphalt or tar, but generally with a prepared tarred felt. The two sides of the joint and the felt were clamped together with small cast iron clamps and set in place, using iron pins on the side to hold them upright and wooden pegs underneath to keep the joint up to the crown of the road. When the concrete had been placed on each side of the joint and the surface struck off with the template, the pins were pulled out and the clamps removed.

In setting the creosoted block joint, a section of pavement, four inches in length, was left out. This was accomplished by having a form cut the crown of the subgrade on the bottom and the crown of the road on the top. These forms were placed wherever a joint was needed. The concrete was placed and finished on each side of these forms. After it had set the forms were removed.

To facilitate the removing of these forms, they were made in two pieces running across the road. The combined width of the two pieces for a four-inch joint was three inches. They were held one inch apart by wedges. When the wedges were taken out, the forms could be removed without disturbing the concrete. Just before the road was to be opened for travel, the creosoted wood blocks were placed. They were set to a driving fit on a bed of gravel thoroughly packed and left one-fourth inch above the edges of the concrete, the interstices being filled with hot asphalt.
These joints were subjected to travel only about two months, when they had to be taken up and replaced, the traffic having forced them down between the edges of the concrete. It has been found impossible to hold them in place with a gravel foundation. It is now the plan to set them in concrete and when this is done, I have no doubt but that they will give good service. Needless to say, these joints were used but one season and on only two roads.

Beginning in 1914, the distance between joints was increased to one hundred feet and the metal plates discarded.

The joint now used is a prepared tarred felt, one-fourth inch thick. This joint is cut to the crown of the road and is wide enough to rest on the subgrade. It is placed on the road bed in exact position, before any concrete is poured around it, and is held in place by pins on one side and by pins and a board to stiffen it on the other. After the concrete has been placed on both sides and struck off with the template, the pins and board are removed.

When expansion joints were placed fifty feet apart, transverse cracks developed about half way between the joints. Now that the joint distance has been lengthened to one hundred feet, transverse cracks are still found about half way between the joints.

At the present time, there has been no system of joints devised that will prevent cracks. That being the case, the logical method would seem to be to eliminate the expansion joints entirely, except perhaps at the end of a days work. This would cause fewer cracks than where joints are used, for an expansion
joint is nothing but a crack and must be maintained as such. If the joints are eliminated the stresses developed due to changes in temperature can be taken care of by the concrete. It has been proven that when a concrete column is put under compression its diameter increases and a concrete road will act the same way.

A finished road. Note expansion joint set at sixty degrees with the center line.
A finished road.

SUITABILITY OF CONCRETE FOR PAVING PURPOSES.

The first concrete pavement in the United States was laid at Bellefontaine, Ohio, in 1893. The streets selected for this experiment were those surrounding the Court House block. Two of these streets were completed in 1893 and the other two in 1894. The city engineer wrote the specifications and was in charge of the work. The pavement was laid in two layers. The base was four inches thick and was mixed one part cement to four parts gravel. The wearing surface was mixed one part cement to one part sand. Both the base and wearing surface were mixed quite dry and tamped in place. The wearing surface was placed directly after the base had been tamped; and after tamping the wearing surface, it was sprinkled and finished with a steel trowel.

The work was started at one curb and carried across the street in strips five feet wide. These strips were afterwards
cut into blocks five feet square.

On two of the streets, the surface was marked into small square blocks by V shaped grooves, about one-fourth inch wide and one-half inch deep. The surface on the other two streets was pitted with a toothed roller, to afford better footing for horses. About four thousand square yards of pavement was laid at a cost of $2.25 per square yard, including curbs and drains.

This pavement has given fairly good satisfaction, considering some defects in construction. Excessive wear has developed, as would be expected, along the longitudinal joints. While this was the first pavement in the United States, it does not follow that it was poor concrete. In fact, samples taken from this pavement and exhibited at different road meetings, show it to be of the very best of concrete.

I believe that no other concrete has been laid in Bellefontaine, possibly because the city council passed an ordinance against concrete, unless the contractor would guarantee it to be equal or superior to brick.

In 1896, Richmond, Indiana, paved a short alley with concrete. The method of construction followed closely that used on the Bellefontaine work. In 1901, three additional alleys were paved in Richmond. The cost of the first work was $1.62 per square yard. Concrete is extensively used there as a pavement for alleys but has not been used for streets.

In 1904, a small amount of concrete pavement was laid at La Mars, Iowa. It was laid in two courses, the base being five inches thick, mixed one part cement to six parts gravel, with a wearing surface of one part cement to two parts coarse
sand, which was one and one-half inches thick. This pavement cost $1.25 per square yard.

While the pavements noted above had been in use a number of years and were giving reasonably good service, it was not until 1909 that concrete was ever considered as material for any comprehensive system of paving. It was in this year, that Wayne County, Michigan, began the first concrete road in that County and more have been constructed each year since that time.

The first roads were laid in two courses. The bottom course was a 1; 2-1/2; 5 mix of limestone, four inches deep. The wearing surface was 1; 2; 3 1/2 mix of crushed cobble stones, two and one-half inches deep, with expansion joints twenty-five feet apart. This type of construction has now been abandoned and nothing except one-course pavement is being built at the present.

The Wayne County roads have been inspected by road engineers from all over the United States and have been the means of bringing concrete to the front as a paving material. At the present time, these inspection tours are being directed towards Sheboygan, Wisconsin, as these concrete roads are said to be superior to the Wayne county roads. Doubtless the fact that the Wayne county roads are beginning to show the effect of wear, has had something to do with the cement interest withdrawing them from the limelight.

Despite the testimony of interested witnesses with cement to sell, I believe that concrete roads are still an experiment and everything tends to show that they have reached the top of their popularity and are now descending. The reason for this is plain.
They have been over-exploited by the cement interests and now that some roads have been constructed long enough to begin to give some idea of the effect of traffic, many engineers that have advocated concrete are revising their estimates of its usefulness.

Concrete has been recommended as the panacea for all road evils. It was advertised as the perfect pavement, moderate first cost, low friction resistance to moving loads, dustless and practically no maintenance. Part of these claims are true. It does furnish a dustless pavement over which large loads can be hauled, and its first cost is reasonable; but for a road to have a low maintenance cost it must resist the wear of the traffic through a long period of years. This concrete will not do.

A good concrete road, when first completed, cannot be excelled by any other pavement; but the fault is, it doesn't last. Under ordinary traffic, concrete will wear to an extent unbelievable, unless seen; but the wear would not be so serious if it were not for the appearance of the cracks. The large majority of cracks that appear in a well constructed concrete road are transverse cracks, but some few longitudinal cracks will appear, regardless of how well the road is constructed.

When cracks appear in a concrete road, the edges quickly become rounded under the action of the traffic. After these miniature ruts are formed, each wheel that passes over them increases the size, not only by the ordinary abrasion, but by the impact as well.

When we consider that concrete roads, after two or three years traffic, have these cracks developed so that they can be
detected from the seat of a buggy when driving over the road, it is folly to say that maintenance is not required. Neither is it, I believe, too much to say that concrete will need to be re-surfaced in less than fifteen years.

As a matter of fact, a concrete road requires maintenance from the first day. Before it is opened to traffic, there will be cracks develop that should be cleaned and filled with tar or asphalt. This operation will need to be repeated at least twice a year.

From a construction point of view, concrete is an ideal paving material. The entire road can be completed at one operation, which gives it a considerable advantage in cost over pavements that require two or more operations before completion. Then if the work is protected twelve hours, the danger of marring the surface is past, although it must be protected from the traffic.

The difficulty of repairing any serious defect in a concrete road is one of the main reasons against its use as a wearing surface. Whenever a road gets to the point that it cannot be repaired by some bituminous product and sand or small gravel, it means a complete re-surfacing with some material other than concrete.

As a foundation material, concrete is unequalled, but the qualities that make it a good foundation material render it unfit for a wearing surface. It is rigid and will take but little tension stress before cracking.

There is no concrete pavement that has been laid two years that has not developed contraction cracks.
Where traffic is heavy enough to justify the expense of a concrete road, it is heavy enough to cause rapid wear once the cracks appear. The logical and economical solution would seem to be to use concrete only as a base, with a brick wearing surface for all ordinary traffic roads and a sheet asphalt wearing surface on roads and streets devoted solely to pleasure driving.
II COST OF CONCRETE ROADS.

In Table 1 is given the detailed cost of the eight pieces of experimental concrete roads that have been constructed by the Illinois Highway Commission. An engineer from this department was superintendent of construction on each of these roads, and was not only responsible for the inspection, but the progress and the cost of the work as well. The tables for the most part are self-explanatory. Under the item of "Mixing and Placing Concrete," was listed not only the actual mixing and placing, but the setting of forms, the pumping of water and the removing of forms. Under the item "Forms and Other Lumber," nothing but the actual cost of the lumber is listed minus what salvage value it possessed at the end of the work.

In Table 2 are the detailed cost of four State aid roads completed during the summer of 1914. Two of these roads were constructed under my supervision, and the two others were taken from a different part of the State for comparative purposes.

These roads in Table 2 are referred to by number only, as it would be manifestly unfair to the contractor to publish it even in a thesis of this kind. It is collected purely for the guidance in the making of estimates, and most contractors are glad to give us access to their payrolls, knowing it will not be published, or if it is, it will be in such a way as not to be recognized by competitors.

The items of cost are the same in the two tables, except the cost of coal and oil in No. 1 was replaced by the cost of water pipe in No. 2. It was almost impossible to obtain the cost of coal
and oil from the contractor, and the price of pipe could be obtained. The price in the table is the cost of new pipe, minus a fair salvage. These items in both tables are actual cost prices.

In Table 2, the totals will vary from the actual money spent by the contractor, by a very small margin, for items such as traveling expenses, office and overhead cannot be obtained. They are not necessary for estimating purposes, as each road is a problem in itself and a proper allowance must be made for them, the same as for profit.
Table 1.

EXPERIMENTAL CONCRETE ROADS.

<table>
<thead>
<tr>
<th>Name of McLean: DeKalb: Springfield: Carlinville</th>
</tr>
</thead>
<tbody>
<tr>
<td>GENERAL DATA.</td>
</tr>
</tbody>
</table>

| Amount of pavement laid in square yards .......... | 5000 | 7334 | 5594 | 7111 |
| Thickness of pavement in inches ................. | 6    | 6½   | 7    | 6½  |
| Width of pavement in feet .. | 45   | 12   | 18   | 16  |
| Length of haul in miles .... | 1/8  | 1/2  | 1/8  | 1   |
| Cost of cement per bbl....... | $1.05 | $0.55 | $1.025 | $0.98 |
| Barrels of cement per sq. yd. of pavement ...... | 29   | .31  | .29  | .33  |
| Price of labor per hour, men and teams .......... | 20¢ & 40¢ | 25¢ & 45¢ | 20¢ & 40¢ |

Cost per Square Yard.

| Superintendence .......... | $0.028 | $0.027 | $0.036 | $0.022 |
| Excavation, shaping sub-grade and shoulders..... | 0.061 | .142  | .079  | .099  |
| Hauling sand, stone and cement .................. | 0.053 | .081  | .108  | .112  |
| Mixing and placing concrete....................... | 0.083 | .102  | .115  | .099  |
| Covering and seasoning............................ | 0.020 | .014  | .020  | .010  |
| Watchman and miscellaneous ....................... | 0.012 | .012  | .048  | .008  |
| Cost of sand and stone...................... | 0.204 | .228  | .290  | .105  |
| Cost of cement................................. | 0.309 | .170  | .277  | .325  |
| Expansion joints ............................... | 0.010 | .022  | .037  | .016  |
| Coal and oil for mixer.......................... | 0.006 | .005  | .022  | .003  |
| Forms and other lumber.......................... | 0.007 | .016  | .003  | .005  |

Total.... $0.793 : $0.319 : $1.035 : $0.804
**Table 1—Cont’d.**

**EXPERIMENTAL CONCRETE ROADS.**

<table>
<thead>
<tr>
<th>Name of Road</th>
<th>Jacksonville</th>
<th>LaSalle</th>
<th>Springfield</th>
<th>Highland</th>
</tr>
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<tr>
<td><strong>GENERAL DATA.</strong></td>
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<td></td>
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<td>Amount of pavement laid in square yards</td>
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<td>10663</td>
<td>8566</td>
<td>6680</td>
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<tr>
<td>Thickness of pavement in inches</td>
<td>6</td>
<td>6 1/2</td>
<td>6 1/2</td>
<td>6</td>
</tr>
<tr>
<td>Width of pavement in feet</td>
<td>18</td>
<td>20</td>
<td>9 &amp; 18</td>
<td>9</td>
</tr>
<tr>
<td>Length of haul in miles</td>
<td>1 1/2</td>
<td>3/4</td>
<td>3/8</td>
<td>4</td>
</tr>
<tr>
<td>Cost of cement per barrel</td>
<td>$1.285</td>
<td>$1.06</td>
<td>$1.025</td>
<td>$1.40</td>
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<tr>
<td>Barrels of cement per sq. yd. of pavement</td>
<td>.28</td>
<td>.29</td>
<td>.30</td>
<td>.29</td>
</tr>
<tr>
<td>Price of labor per hour, men and teams</td>
<td>22 1/4 &amp; 44 5/8</td>
<td>35¢</td>
<td>25¢ &amp; 50¢</td>
<td>20¢ &amp; 40¢</td>
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</table>

**Cost per Square Yard.**

<table>
<thead>
<tr>
<th>Item</th>
<th>Jacksonville</th>
<th>LaSalle</th>
<th>Springfield</th>
<th>Highland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superintendence</td>
<td>$ .040</td>
<td>$ .023</td>
<td>$ .047</td>
<td>$ .030</td>
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<tr>
<td>Excavation, shaping sub-grade and shoulders</td>
<td>.108</td>
<td>.158</td>
<td>.291</td>
<td>.214</td>
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<tr>
<td>Hauling sand, stone and cement</td>
<td>.107</td>
<td>.169</td>
<td>.173</td>
<td>.222</td>
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<tr>
<td>Mixing and placing concrete</td>
<td>.108</td>
<td>.133</td>
<td>.145</td>
<td>.098</td>
</tr>
<tr>
<td>Covering and seasoning</td>
<td>.022</td>
<td>.024</td>
<td>.024</td>
<td>.007</td>
</tr>
<tr>
<td>Watchman and miscellaneous</td>
<td>.030</td>
<td>.092</td>
<td>.042</td>
<td>.035</td>
</tr>
<tr>
<td>Cost of sand and stone</td>
<td>.269</td>
<td>.314</td>
<td>.301</td>
<td>.326</td>
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<tr>
<td>Cost of cement</td>
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<td>.418</td>
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<tr>
<td>Expansion joints</td>
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<td>.028</td>
<td>.030</td>
<td>.037</td>
</tr>
<tr>
<td>Coal and oil for mixer</td>
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<td>.021</td>
<td>.012</td>
<td>.015</td>
</tr>
<tr>
<td>Forms and other lumber</td>
<td>.008</td>
<td>.008</td>
<td>.007</td>
<td>.006</td>
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</table>

**Total** | $1.102 | $1.28 | $1.429 | $1.408 |
# Table 2.

## STATE AID CONCRETE ROADS.

<table>
<thead>
<tr>
<th>Number of</th>
<th>1</th>
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<tr>
<td><strong>GENERAL DATA.</strong></td>
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<tr>
<td>Amount of pavement laid in square yards</td>
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<td>14784</td>
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<td>38908</td>
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<tr>
<td>Thickness of pavement in inches</td>
<td>6(\frac{1}{2})</td>
<td>6(\frac{1}{2})</td>
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<tr>
<td>Width of pavement in feet</td>
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<td>10</td>
<td>18</td>
<td>18</td>
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<tr>
<td>Length of haul in miles</td>
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<td>4(\frac{1}{4})</td>
<td>2(\frac{1}{4})</td>
<td>2(\frac{1}{4})</td>
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<td>Cost of cement per barrel</td>
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<td>Barrels of cement per sq.yd. of pavement</td>
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<td>.34</td>
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<tr>
<td>Price of labor per hour, men and teams</td>
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<td>20¢ &amp; 40¢</td>
<td>25¢ &amp; 50¢</td>
<td>25¢ &amp; 50¢</td>
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## Cost per Square Yard.

<table>
<thead>
<tr>
<th></th>
<th>$0.029</th>
<th>$0.021</th>
<th>$0.013</th>
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<tr>
<td>Superintendence</td>
<td>Excavation, shaping sub-grade and shoulders</td>
<td>Hauling sand, stone and cement</td>
<td>Mixing and placing concrete</td>
<td>Covering and seasoning</td>
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<td>.055</td>
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</tr>
<tr>
<td></td>
<td>.006</td>
<td>.006</td>
<td>.007</td>
<td>.006</td>
</tr>
</tbody>
</table>

| Total | $1.386 | $1.294 | $1.317 | $1.331 |