HOLTON

Roads for Motor Traffic

Civil Engineering

B. S.

1913
ROADS FOR MOTOR TRAFFIC

BY

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THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

1913
May 24, 1913.

I recommend that the thesis prepared under my supervision by CARYL AMES HOLTON entitled Roads for Motor Traffic be approved as fulfilling this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

[Signature]
Instructor in Civil Engineering.

Recommendation approved

[Ira O. Baker]
Head of Department of Civil Engineering.
ROADS FOR MOTOR TRAFFIC

CHAPTER I.

INTRODUCTION

Before the advent of the automobile the practice of road building had been practically standardized. The best kind of road for all different conditions had been determined, and the problem had been reduced to one of economics rather than one of engineering. The kind of road generally conceded to be the best was the water-bound macadam.

The water-bound macadam road was of uniform construction wherever used. It consisted of three courses. The first or foundation course was of broken stone varying in size from about 2 to 3 inches, the course having a thickness of 4 to 6 inches after having been thoroughly rolled. The next course was of stone varying from 1/2 to 2 inches in size rolled to a thickness of about 2 inches. The top course was from 3/8 inches to 1 inch in thickness and was composed of rock screenings. These screenings with the water which was sprinkled over the road at the proper time was usually the only binder used, although other materials as clay, loam, sand, and shale were sometimes used.

The telford road differed from the macadam in that the foundation was constructed of large flat stones which were laid together making the foundation itself a pavement. Owing to the difficulty of obtaining the larger rock, to the cost of laying it, and to the fact that the macadam was as good or better than the telford, the macadam came to be almost universally used.
As soon as any considerable amount of motor traffic came upon these roads, however, they began to show wear very noticeably. Among the first macadam roads built in the state of Connecticut was Ocean Avenue, New London. The road carried a heavy traffic of horse-drawn vehicles and for twelve or thirteen years it received no attention excepting an occasional cleaning. After twelve years, Mr. M.O.Eldridge of the U.S. Office of Public Roads pronounced it one of the best roads he had ever seen. Even the first automobile traffic did not affect it, because the machines were light and of slow speed. But after high-speed machines began to run upon it, the road became full of ruts and the bond was fully destroyed.

This is one of a very great number of similar cases. In fact wherever macadam roads became subjected to heavy motor traffic, the bond was destroyed and the road soon became full of injurious ruts.

The exact action of a motor car upon a road has been a matter of much discussion. At first the general theory was that the road was disintegrated by a suction produced by the tire. No doubt there is such an effect, but this effect alone could not possibly be great enough to produce the large ruts which do result from motor traffic. Horses' hoofs exert a backward thrust upon a road which tends to tear it up, but the wheels of the vehicle which the horse is drawing tend to roll the loose stones into place, thereby overcoming, at least partially, the effect of the horses' hoofs. The wheels of the horse-drawn vehicle have only the effect of compacting the road, as there is no backward thrust whatever on the wheels.

No doubt the greatest destructive force exerted by the
automobile is the backward thrust of the driving wheels upon the road in a direction parallel to the surface of the road. We need only to call to mind Newton's law of motion which states that "for every action there is an equal and opposite reaction," to understand the conditions. There must be an external force acting upon the automobile to give it an acceleration. It is easily seen that as the road is the only external body in contact with the machine, it must exert this necessary force.

Still another force, which is usually neglected in discussions of this subject, is to be reckoned with. It is the force exerted by the tire itself as it expands to its normal size after being compressed while in contact with the road.

The magnitude of the resultant of all these forces is more or less a matter of conjecture. An estimate of the value of this force of 100 pounds per inch of width is based upon a course of reasoning which is presented in the appendix to this thesis.

The problem then has been to find the best form of road construction that will withstand this severe wear. By "the best" is not necessarily meant the road which will wear the longest, but rather which wears well for the cost of construction and maintenance. However, the road which wears the longest and requires the least maintenance will usually prove to be the most economical road although the first cost is high.

There are several features which are common to all improved roads. Probably the most important of these is drainage. To quote Professor Baker; "Drainage is the most important feature to be considered in the construction of Earth roads since no road, whether earth or stone, can remain good without it. Drainage alone
will often change a bad earth road into a good one, while the best stone roadway may be destroyed by the absence of proper drainage."

The form of drainage ordinarily used for improved roads consists of shallow surface ditches at either side of the roadway and one or two lines of tile. When one line of tile is used it is placed along the side of the roadway — under the surface ditch. When two lines are used, one is placed at each side of the road under the surface ditches. When only one line is used it should be placed in such a way as to intercept the greatest amount of ground water possible which would otherwise come close to the surface of the road. The side ditches should contain, at certain intervals, basins by which the surface water can reach the tile.

Another part of road construction which is common to all forms of hard roads is the condition of the earth upon which the road is built. The form of the earth varies, of course, with the form of road to be built, some forms requiring excavation, and some being built upon the earth road as it stands. The amount which the soil is compacted, however, is common to all forms of improved roads. The earth should be compacted as much as is possible under the conditions. This is best done by the use of a steam roller as it is heavier than the horse-drawn roller and eliminates the action of the horses' hoofs in tearing up the subgrade. If the roller leaves any depressions they should be filled and re-rolled. With the final rolling, the roller should not leave any depressions.

The first work done toward building a road to withstand automobile traffic was done upon the macadam road. This was a natural consequence, because when the macadam roads were torn up by the traffic, a method of repair was sought which would withstand
the sort of traffic which was doing the damage. A very great
amount of the experimental work has been done on the old macadam
roads and has consisted in the experimenters trying to find some
binding material which will withstand the automobile traffic. It
seems that tar and asphaltic oils are the only binding materials
which have been considered as a solution to this problem and con-
sequently the experimental work has been pertaining to their use.
There are so many different kinds of tars and oils, however, and
so many different methods of applying the same material, that the
experiments have brought forth widely varying results, and eminent
engineers have and are disagreed as to the advisability of using
many of the methods which have been tried. In the "Good Roads Con-
gress" held in Belgium in 1910 the American and English engineers
seemed to think that the tar and asphalt oils furnished the sol-
ution of the problem; but the European engineers, especially the
German and the French, seemed to think that the tar and asphaltic
oil did not prove to be a good surfacing or binding material under
heavy motor traffic.

The first method of repairing the macadam roads by using
tar or oil, consisted in simply spreading it over the road. Some
times the tar was covered with stone screenings or fine gravel.
This method proved satisfactory for a short time, but to give com-
plete satisfaction the operation had to be repeated at least once
each year.

In an effort to get a more permanent surfacing, the idea
of incorporating the tar or oil with the top course of stone was
originated. In repairing old roads the surface of the road was
scarified, leveled, and rolled; and then a course of $1\frac{1}{2}$ inch stone
was applied. This last course was rolled and then covered with a coating of tar. The tar was spread upon the surface and left to flow into the voids by gravity. This method is known as the penetration method and is one of the two methods which have been developed for the incorporation of the binder with the surface stone. The tar was usually covered with stone screenings or fine gravel.

The penetration method has been much used in the building of new roads as well as in the repair of old ones. Nearly all of these roads have been built just like the water-bound macadam roads until the second course was laid. This course, as before stated, usually consists of 2 inches of rock varying in size from 1/2 to 2 inches. The oil or tar is spread over this surface and left to fill the voids. It must, of course, be in a very liquid state. It is usually necessary to heat the oil in order for it to be liquid enough to flow freely through the course.

The other method is considered the better and is the more expensive of the two. It is known as the mixing method. In this type of construction the binder is mixed with the stone of the top course before it is put in place. The mixing is done in a way similar to the mixing of cement concrete, either by hand or in a mechanical mixer. The bituminous material usually has to be heated, and must be mixed and placed before cooling. It is leveled with rakes, rolled, and covered with stone screenings or fine gravel. The mixing method requires about 20% less bitumen than does the penetration method, but the cost of laying is increased considerably.

Experiments with this form of construction have given greater satisfaction than those with the penetration method; and if bituminous macadam should prove to be the best solution to the road
problem this undoubtedly will be the form of construction which will be used.

There are two other road building materials which come into consideration as possible solutions to the motor-road problem, namely, Brick and Cement Concrete.

The use of brick as a paving material in cities has resulted in this type of pavement being practically standardized. At present authorities differ only on such things as the proper kind of filler and the use of expansion joints. Even with these differences there are but two or three methods of laying brick pavement which are now in vogue, so that in constructing a brick pavement, its exact performance can be prophesied.

Cement Concrete road building, however, is still in the experimental stage. Although a number of miles of these roads have been built within the last few years, exact prophesies as to what their performance will be, cannot be made. Nevertheless, enough is known of them that it can be safely said that they are bound to come forward for careful consideration as a possible solution to the motor road problem because of their durability and cost.

The purpose of this thesis will be to consider the use of Bituminous Macadam, Brick, and Cement Concrete, as materials for building roads to resist motor traffic. The discussion will be limited to these three materials because they are used almost entirely in the road building of to-day, and the solution of the problem of the best road for motor traffic seems to lie in the use of one of them.
CHAPTER II.

BITUMINOUS MACADAM ROADS

When automobiles came to form a noticeable percentage of the country road traffic, the first thing which came up before those concerned with road maintenance was the dust problem. The dust was so great in some localities that it became a menace to health and comfort, and property owners were forced to resort to the application of some kind of dust preventative at their own expense. This lead the road officials to search for a permanent dust preventative. The fact that the dust was a result of the deterioration of the roads did not present itself to those trying to find a remedy for the conditions.

Later it was seen that the motor cars were tearing up the roads and methods by which to repair them were sought. The two problems of preventing dust and of finding a surfacing material to withstand the wear of motors, helped to solve each other. This was due to the fact that the same materials were tried for both purposes. Highway engineers have about solved the dust problem on macadam roads by the surfacing of the roads for motor traffic with bituminous macadam.

Some form of bituminous material seems to have been the only thing which was considered as a permanent dust preventative or as a road preservative. Naturally the first method of applying the bitumen was by spreading it in a thin layer over the road. This method of application however, did not give permanent results. The automobiles soon wore through the thin layer of tar leaving the road in its original condition.
Very naturally the next method tried was that of incorporating the bituminous binder with the materials of the road. The first method used is illustrated in the work done upon an old macadam road at Morristown, N.J. The old macadam was scarified, graded and rolled. Then a three-inch course of 1\frac{1}{2}-inch stone was spread and rolled. Forty to fifty pounds of sand per square yard was spread on this filling the voids to within about one inch of the top. To this was applied .8 to 1.0 gal. of binder per sq. yd. at 175\degree, 75 lbs. per sq. yd. of 3/4\" stone was then spread and rolled and another application of the binder was made. The surface was finished with 1/2-inch stone and sand. This form of construction can be taken as a fairly good example of what has come to be known as the penetration method.

More simple methods were tried in the repair of old macadam. In some instances the old road was simply scarified and then the binder was applied. This method did not prove permanent, however, and the methods which have come into general use are the penetration and the mixing methods.

The mixing method is the method of construction in which the bitumen and the aggregate are mixed — either by hand or by mechanical mixers — before being spread upon the road. The method will be taken up in detail later.

Bituminous road materials may be classified as follows:

(1) petroleum products, including residual petroleum products, fluxes, oil asphalts, and fluxed or cut-back oil asphalts; (2) malthas; (3) asphalts and other solid native bitumens, and the asphaltic cement produced by fluxing them; (4) tars and tar products; (5) mixtures of tar with petroleum or asphalt products,
bituminous emulsions, and factitious asphalts; (6) bituminous aggregates, including rock asphalts or bituminous rocks, bituminous concrete and asphalt or other bituminous topping.

Messers. Prevost Hubbard and Charles S. Reeves - a chemist and assistant chemist respectively, of the U. S. office of Public Roads, have prepared a pamphlet which gives in detail the tests and methods by which they are made for each of these materials. This is entirely too extensive to be quoted here, but the specifications of the Massachusetts State Highway Commission will give a good idea concerning the properties of the bituminous materials which give the best results. These specifications are written to cover Asphaltic Oil, Oil Asphalt, and Refined Tar - the most common of the bituminous road building materials. These specifications are as follows:

For Asphaltic Oil.

The oil shall be of uniform color, appearance, general character and viscosity, must contain no bodies not naturally present in an asphaltic oil, and must fulfill the following requirements:

(a) It shall not contain more than 5% of adventitious mineral matter.

(b) It shall have a specific gravity of at least 0.97.

(c) It shall not contain more than 1% of matter insoluble in carbon bisulphide and should not contain more than 10% of matter insoluble in petroleum ether.

(d) It shall contain no body that distills at a lower temperature than 250°C. and shall not loose more than 55% by weight by distillation to 380°C.
(e) It shall be of such viscosity that 60 cc measured at 78°F. shall when at 100°C. be not less than 5 or more than 10 minutes in passing through a viscosimeter orifice 5/64 in. in diameter under head of 4½ inches.

(f) When 20 grams are heated in a flat bottom dish 3 inches in diameter for 21 hours in an oven kept at 100°C. it shall not lose more than 5% by weight.

(g) When 13½% by weight of material is mixed with 37½% by weight of sand, and briquettes made 3 in. square and 1/2 in. thick, these briquettes must keep their shape and show some binding together.

Oil Asphalt.

(a) The Asphalt shall be of uniform color, appearance and character, and shall contain no body not naturally present in an oil asphalt.

(b) It shall not contain more than 1% of dirt or of adventitious mineral matter.

(c) It shall have a specific gravity between 1.00 and 1.10

(d) It shall contain not more than 1% of matter insoluble in carbon bisulphide, and should not contain more than 30% of matter insoluble in petroleum ether.

(e) It shall contain no body that will distill at a lower temperature than 225°C., and shall not lose more than 40% by weight by distilling to 360°C.

(f) When 20 grams are heated in a flat bottom dish 3 inches in diameter for 21 hours in an oven kept at a temperature of 100°C., the weight shall remain practically constant.
Refined Tar.

The tar must be uniform in color, character, appearance, and viscosity and must have the following qualities:

(a) Shall not contain more than 5\% of mineral matter or dust.

(b) Shall have a specific gravity between 1.18 and 1.25.

(c) Shall not contain more than 17\% by weight of free carbon.

(d) Shall contain no body that distills at a lower temperature than 225\(^\circ\)C.; not over 10\% by weight shall distill below 270\(^\circ\)C. and shall contain at least 65\% by weight of pitch or bituminous material, after all bodies up to 360\(^\circ\) have been distilled.

(e) When 20 grams are heated in a flat bottom dish 3 inches in diameter for 21 hours in an oven kept at 100\(^\circ\)C. the loss shall not exceed 10\% by weight.

(f) It shall be of such viscosity that 60 c.c. measured at room temperature shall when at 100\(^\circ\)C. be not less than 150 seconds nor more than 450 seconds in passing through a viscometer orifice 5/64 inches in diameter, when acting under a head of 4\(\frac{1}{2}\) inches.

(g) When 12\(\frac{1}{2}\)% by weight of the material is mixed with 87\(\frac{1}{2}\)% of sand of such a grade that all will pass through a sieve having 10 meshes to the linear inch, and practically none through a sieve having 190 meshes to the linear inch, and briquettes are made 3 inches square and 1/2 inch thick, such briquettes will so harden in seven days at ordinary room temperature, that when laid flat and held by their edges on two parallel knife edge bars, they shall not bend when a weight is suspended from a third knife edge or parallel bar placed across their center until its weight reaches
200 grams and shall not break at less than 250 grams, and the weight causing bending shall not be greater than 80% of the weight causing breaking.

The bitumen is always applied when hot, as it must be in a liquid state. In the mixing method the mixture is kept hot until it is spread. The degree of heat required varies, of course, with the different binders - those which are naturally the more liquid, requiring the smaller amount of heat.

In the construction of bituminous roads there are many kinds of aggregate used beside broken stone. Blast furnace slag and gravel are used to some extent. Stone however is used for the aggregate in by far the largest percentage of bituminous roads and will be the only one considered at all extensively in this thesis.

The details of the two methods also differ somewhat. Probably on no two pieces of work has the procedure been exactly the same. The general methods however are approaching a standard— and the general way in which these roads are constructed will be considered.

In the building of an improved road - as stated before - the drainage and the preparation of the subgrade, are of the utmost importance. After the drainage is assured, the subgrade should be shaped to the proper crown and rolled with a steam roller until it is thoroughly compacted.

"In general, stone of a quality suitable for ordinary macadam construction is adapted for bituminous work. The function of the aggregate in any type of road is to transmit the weight of traffic to the foundation and to take the wear. Much the same considerations govern the selection of stone as regards kind and quality, irrespective of the type of pavement it is to go into, except
in some particular cases where conditions warrant the use of a stone of what, for plain macadam work, would be an inferior quality. The sizes chosen will, of course depend upon the requirements of the individual cases."

Penetration Method

In the building of bituminous macadam roads by the penetration method a two course construction is usually employed. The first course consists of stone of a size generally between 1 in. and 3 in., the exact size or range of sizes depending upon local conditions or individual preferences. This course is laid on the subgrade to a depth of approximately 4 inches, slightly greater or lesser depth being used, as the occasion demands. A smaller stone may or may not be used as a filler. As a general rule no binder is used in this course. After this course is laid and spread evenly it is rolled with a steam roller until thoroughly compacted. The amount of rolling is likely to be slighted rather than over done. In a discussion of the subject in "Roads and Pavements" Professor Baker leaves the impression that as a rule there should be at least 100 passages of a 10 ton roller over the road.

The top course, which takes the wear, is usually about 2 inches in thickness and composed of stone from 1/2 inch to 1 1/2 inches and even 2 inches in the longest dimension. The stone is spread evenly and uniformly upon the lower course, and may or may not be filled with stone of a smaller size, before the binder is applied.

The binder is applied in different ways. One of the first forms of distributors was simply a modification of a street sprinkler, with the pipes and openings designed for the bitumen to
flow through them. The bitumen was heated before being put into the tank of the distributor. The orifices from which the bitumen flowed were only about 6 to 12 inches above the road.

This method of distribution proved unsatisfactory for two or three reasons. The orifices would become clogged and trouble was experienced in keeping all of them open. The bitumen was applied in "streaks" there being a portion of the macadam that was left uncovered by the binder. By this method the force of gravity was depended upon to cause sufficient penetration; but if the binder became a little cool, it did not penetrate the course but simply covered the top of the stone.

A more satisfactory method which was tried later was that of hand spreading. The bitumen was poured upon the road from hand sprinklers made for the purpose. They resembled ordinary lawn sprinklers with the exception of the nozzle which was made "fish-tail" shaped. The objection to this method is that unless the men exercise care they lap one layer of bitumen on another. This causes small ridges which do not appear until traffic passes over them when they soon become evident.

The method later devised — which is the most satisfactory yet tried—is that of applying the binder under pressure. The binder is placed—from the heater—into the distributor tank which is made air tight. The pressure is furnished either by steam or compressed air. If the bitumen must be applied at a temperature greater than 212°, air must be used as steam will cool it. The form of nozzle used varies. At first a "fish-tail" nozzle attached to a large hose from the distributor tank was used. The Illinois State Highway Commission (A. N. Johnson, Engineer) have adopted a much more satisfactory form. The nozzle is a round pipe — about
4 feet in length, bent at right angles at about the center. This nozzle connects to the large hose leading from the distributor tank. Inside this large pipe is a small pipe which ends just inside the end of the large nozzle. At the base of the large nozzle this smaller pipe is connected to a small hose leading to a boiler. Steam is forced through the smaller pipe as the bitumen is forced through the larger - the result being that the binder comes from the nozzle in the form of a fine spray which can be evenly applied and which forces its way into the voids.

After the application of the binder and of sand, chips or screenings as a filler, and after the rolling of the second course, a seal coat is usually applied. This is made by applying a small quantity of bituminous material and covering with a very thin layer of fine mineral matter. In some cases this course is omitted entirely, the top course being finished by the application of a thin coat of sand, chips of stone, or screenings.

The Mixing Method

For the construction of bituminous pavements by the mixing method, as by the penetration method, many methods differing in minor details are employed. In all, of course, the pavement consists of broken stone mixed with a suitable binder before being placed. The methods differ in the grading of the stone, in the kind of binder used, in the using of cold or heated stone, in the employment of hand or machine mixing, and in many other details.

Professor Blanchard divides bituminous concrete pavements into three classes, the division being according to the character of the mineral aggregate. In that classification the first class
consists of pavements in which one size crusher run stone is used; the second, of stone in which are used combinations of one size crusher run stone and finely divided mineral matter; and the third, those in which graded aggregates are used.

In a paper by Herbert C. Poore of the Massachusetts State Highway Commission, the author says: "The best results in Mass. have been obtained with broken trap rock 2\(\frac{1}{2}\) to 1/2" in size having 40% or less voids. Better results are obtained if the percent of voids is decreased by addition of small particles."

As a rule bituminous binder is employed only in the upper course or wearing surface of the road. This course is usually made 2 or 2\(\frac{1}{2}\) inches thick and may be laid upon any suitable foundation such as old macadam surface, new macadam or cement concrete foundations. The materials for the surface coat may be mixed at a central plant or at the road. In city work, where one location for the plant has a distinct advantage over another and where the hauling does not take so much time, the plan of a central plant is nearly always used. In country road work however the materials are nearly always mixed just where they are to be used. In the latter case, if the concrete is to be mixed by hand, the process is much the same as that of preparing cement concrete by hand mixing. The aggregate is brought to the work and dumped in piles at convenient points. The binder is brought in barrels or in tank wagons, transferred to the heaters, and carried from them to the mixing platform and poured over the stone. The stone may or may not have been heated previously by improvised heating devices or in heaters especially designed for such work. The aggregate and binder are then turned until mixed and taken to the road, usually in wheel-
barrows. Trouble has been met with in overheating the bitumen, which ruins it for use as a binder. It has been found well to keep a thermometer in the kettles, that the kettle man may regulate the heat. There is room for improvement in this equipment, especially in the burners used under the kettles.

Since the practice of building bituminous concrete roads has become so extensive, improved machinery has been designed for mixing the aggregate with the binder. The machines now available for this work vary from the ordinary concrete mixer to especially designed apparatus, comprising, in some instances, driers and heaters for the aggregate, heating devices for the binder, and measuring devices for both aggregate and binder, as well as mixing machines. From these machines the mixtures are taken to the road and spread, in the same manner as when prepared by hand.

A force of 10 men with one 2 or 3 yard concrete mixer can lay about 600 yards of bituminous concrete pavement per day.

The amount of binder used varies with the size of the stone, the percent of voids, and the consistency of the binder. A fair average of the amount of binder used is about 6% of the mixture.

After being placed upon the road the mixture is spread to the required depth and is rolled until thoroughly compacted, as in the case of pavements built by the penetration method, a seal coat may be applied to the surface, though this is not always done.

Cost

Below is given the cost per square yard of surfacing old macadam roads in the state of Massachusetts, with a course of
bituminous macadam. Different binders were used and the Penetration, Hand Mixing and Machine mixing methods were used.

Penetration Method

<table>
<thead>
<tr>
<th>Method</th>
<th>Cost per sq. yd.</th>
<th>Method</th>
<th>Cost per sq. yd.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tarvia (1)</td>
<td>Bitumen 2.14 gal.sq.yd</td>
<td>Tarvia (2)</td>
<td>Bitumen 1.36 gal.</td>
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<tr>
<td></td>
<td>Stone .111 ton</td>
<td></td>
<td>Stone .11 ton</td>
</tr>
<tr>
<td></td>
<td>Pea Stone .029 ton</td>
<td></td>
<td>Labor</td>
</tr>
<tr>
<td></td>
<td>Labor .176</td>
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</tr>
<tr>
<td></td>
<td>Total cost per sq. yd.</td>
<td>.508</td>
<td></td>
</tr>
</tbody>
</table>

| Tarite (3)   | Bitumen 1.25 gal.      | Tarite (4)   | Bitumen 1.83 gal.     |
|              | Stone .11 ton          |              | Stone .11 ton         |
|              | Labor .178             |              | Labor .178            |
|              | Total .500             |              | Total .600            |

Hand Mixing

(5) Tarvia coated stone painted with asphaltic oil

<table>
<thead>
<tr>
<th>Method</th>
<th>Cost per sq. yd.</th>
<th>Method</th>
<th>Cost per sq. yd.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tarvia</td>
<td>Bitumen 1.55 gal.</td>
<td>Tarvia</td>
<td>Bitumen 1.12 gal.</td>
</tr>
<tr>
<td></td>
<td>Stone .11 ton</td>
<td></td>
<td>Stone .101 ton</td>
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<td></td>
<td>Fuel etc. .045</td>
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<td>Labor</td>
</tr>
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<td></td>
<td>Labor .333</td>
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<td>Sealing Coat</td>
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<tr>
<td></td>
<td>Bitumen .55 gal.</td>
<td>Sealing Coat</td>
<td>Bitumen .62 gal.</td>
</tr>
<tr>
<td></td>
<td>Pea stone .019 ton</td>
<td></td>
<td>Sand .0012 yds.</td>
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<tr>
<td></td>
<td>Labor .011</td>
<td></td>
<td>Labor</td>
</tr>
<tr>
<td></td>
<td>Total .721</td>
<td></td>
<td>Total .403</td>
</tr>
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</table>

(6) Tarvia A with pitch

<table>
<thead>
<tr>
<th>Method</th>
<th>Cost per sq. yd.</th>
<th>Sealing Coat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tarvia A</td>
<td>Bitumen .64 gal.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pea stone .012</td>
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</tr>
<tr>
<td></td>
<td>Labor .016</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total .654</td>
<td></td>
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(7) Genasco

<table>
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<td>Genasco</td>
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<td>Stone .109</td>
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<tr>
<td></td>
<td>Labor .181</td>
</tr>
<tr>
<td></td>
<td>Heating and Rolling .035</td>
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<td></td>
<td>Total .507</td>
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</table>

Sealing Coat

<table>
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<th>Cost per sq. yd.</th>
</tr>
</thead>
<tbody>
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<td>Bitumen .083</td>
</tr>
<tr>
<td></td>
<td>Pea stone .012</td>
</tr>
<tr>
<td></td>
<td>Labor .052</td>
</tr>
<tr>
<td></td>
<td>Total .147</td>
</tr>
</tbody>
</table>
Machine Mixed

(8) Genasco  
Bitumen  1.25 gal.  .163  
Stone  .101 ton  .136  
Labor  .139  
Rolling  .019  
Supplies  .070  
Total  .517

Sealing Coat  
Bitumen  .55 gal.  .0615  
Pea stone  .0125 ton  .016  
Labor  .0115  
Fuel  .006  
Total  .095

As before stated these coats were for the top course only.

In the Borough of the Bronx, New York City, have recently been constructed several experimental roadways. The surfacing material in all of these was bituminous concrete, differing only in the kind of bitumen used. Two kinds of foundations were used, namely, cement concrete and plain macadam. The cement concrete foundation, however, was not constructed in the usual way. In its construction 1½ inch stone was spread to a depth of 6 inches. On this a dry mixture composed of three parts screenings and one part cement was spread, rolled with an 18 ton roller and sprinkled with water. This operation was continued until the voids were filled.

The total cost of the bituminous concrete pavement with this foundation was $1.492 per square yard. The total cost of the pavement with the plain macadam foundations varied from $1.032 per sq. yd. to $1.63 - the average cost for 7 pieces of road being $1.31. The cost of constructing 4 pieces of road by the penetration method, varied between $.853 per sq. yd. and $1.071 per sq. yd. the average being $.97 per square yard.

Since these pieces of road were none of them greater than 700 sq. yards in area, these costs could no doubt be greatly reduced where one kind of material and one form of construction
would be used over a large mileage of road.

Engineers differ as to the advisability of using one or the other of these forms of construction. Theoretically the mixing method should give the better road because of the more thorough coating and consequently the better binding of the aggregate. In some States, the penetration method has proved very satisfactory while in others the results have not been so pleasing.

In New Jersey old roads have been re-surfaced and new roads constructed by the penetration method with unsatisfactory results. Much better results have been obtained by using the mixing method. The final practice of the engineers, however, is to build the plain water-bound macadam roads and then apply a light surfacing at the right time to lay the dust. This has proved to be the most satisfactory road for the least money although it has raised the cost of maintenance from 3 cents to 7 cents per square yard. In 1911 New Jersey constructed 27.5 miles of water-bound macadam roads, 27.5 miles of bituminous treated macadam roads, and 19.5 miles of gravel roads. The macadam roads cost $9500 per mile, the bituminous treated $9100 and the gravel $5800.

In Massachusetts different conclusions have been reached. The best results have been obtained by the use of the penetration and the mixing method. Of 54\(\frac{1}{2}\) miles of road constructed in Massachusetts in 1910, 30 miles were built by the penetration or the mixing methods. In addition there were 308 miles surfaced with 1/4 to 1/2 gallon of oil per square yard. In speaking of the work in Massachusetts President Parker of The American Road Builders Association said before that body in their 1911 convention: "We have restored our old macadam roads by patching, and then by apply-
ing a coat of asphalt and oil applied on the road under a pressure of 70 lbs. put on in thin layers. They are immediately covered with stone chips and rolled down with a light roller. As many of those applications are put on as are necessary, and it has produced a road which will wear three years without being touched, even when the traffic is heavy. That has reduced the cost of maintaining roads under the fierce attack of automobiles to less than it was for the old macadam road before the coming of the automobile."

After four years of experimenting with bituminous materials used in road building the conclusions reached by the Massachusetts State Highway Commission are: (1) That no surface treatment of a road will prove satisfactory unless the dust and fine particles are removed before the application of the oil; (2) that one half gallon of oil per square yard is sufficient for one season and that it is preferable that the oil be applied in two applications; (3) after the road has been oiled it must be covered with a thin coating of pea gravel or course sand; (4) that the use of heavy asphaltic oils is not advisable where the predominating traffic is of horse-drawn vehicles with iron tires; (5) that the distribution of the bituminous material under pressure is preferable to its distribution by gravity, as in the former method more uniform distribution is secured. The use of pressure does not appreciably increase the penetration however; (6) that the road surface should be moist rather than very dry, when the oil is applied. The cost of applying 1/2 gal. of oil per sq. yard is 8 cents and the average annual cost of maintaining a mile of road in this way is about $1.60.

Connecticut has done but little experimental work, rather spending the appropriations in constructing good water-bound
macadam and gravel roads and improving the alignment and grades of those already built. They have had less trouble with their roads than any of the Eastern States. Whether this is due to better construction or lighter traffic, or a combination of the two, is not known but it is true that there are some trap macadam in the state which were built 13 years ago which have never required resurfacing. Since 1910 the Connecticut Highway Commission has been using light oils for surfacing their roads - and have built some roads by the penetration and mixing methods.

Other states which have lead in experimental work of this kind are New York, New Jersey, Pennsylvania, Maryland, New Hampshire and Maine. Most all of the experimental work has been concerning the use of oils in surfacing roads of different kinds - for the most part macadam. Some of the middle western states, notably Illinois, Indiana, Wisconsin and Michigan, are carrying on some experimental work as are the far western states of California and Washington.

Nothing has been published as yet concerning the experimental work in Illinois; but in a lecture by Mr. A. N. Johnson in January 1913 he stated, concerning a bituminous macadam road built by the penetration method two years ago, that ruts were beginning to show and that another coat of tar and small stone should be added.

Bituminous macadam roads at least deserve very deliberate consideration as a possible solution for the motor road problem. And in the building of these roads, more perhaps than in any other type, the details of construction are very important.
CHAPTER III.

BRICK PAVEMENTS

The construction of brick pavements is more nearly standardized than the construction of pavements of any other material. Although the introduction of brick as a material for country road construction is comparatively recent, the construction is virtually the same as for city streets.

The National Paving Brick Manufacturers Association has done much towards standardizing the construction of these pavements. They have determined what they think is the very best method for building these pavements and their specifications are followed by many engineers.

The preparation of the sub-grade for brick roads is essentially the same as for any other pavement. It should, of course be thoroughly drained and rolled. The earth should be removed with plow, scraper or other device to within two (2) inches of sub-grade and then brought to the true grade with the roller, the weight of which should not be less than five (5) tons nor more than eight tons.

In "fills" the earth must be applied in layers of eight inches in thickness and each layer thoroughly rolled, and in both excavation and embankment the subgrade must have uniform density.

When concrete curbing is used it should be placed before the sub-grade is finished. The form of curbing used is probably the only noticeably difference between the city and country road construction. This difference is readily explained.

Owing to the expense of construction, brick roads are often built just wide enough for one vehicle — and never wide enough
for more than two. The maximum width is then about 16 feet. It is customary to provide an earth road-way at the side of the brick road and about on a level with it. When a very narrow, say a 9-foot, road-way is built, two such tracks are often provided,—one on each side of the brick. It can be seen that it is necessary that the top of the curbing be just level with the top of the brick. The usual form is shown in cross section in the accompanying figure.

![Diagram of curb construction]

This curb is constructed of 1:2:4 parts of cement, sand and stone or of 1:6 parts of cement and gravel.

The foundation should be of good concrete varying in thickness from 4 to 6 inches with the kind and amount of traffic it is to carry. A thickness of 5 inches would probably be advisable for most roads although 4-inch foundations are very common.

The stone for the concrete should be of very hard quality, free from all refuse and foreign matter, with no fragment which in its largest dimension will pass through a two inch ring. The sand should be clean, sharp and dry and some approved kind of Portland cement should be used.
The foundation should be laid to the required thickness with its surface exactly parallel to the proposed surface of the finished pavement.

Above the concrete foundation is placed a two-inch sand cushion the object of which is to afford a uniform support to the monolithic wearing surface—an equilibrium to the vibrations of the impact, yet a relief so slight that the cement bond will not be shattered.

The sand should be practically free from foreign or loamy matter. It need not necessarily be sharp. The cushion should be two inches thick, thoroughly and uniformly compressed before the brick are placed upon it.

The sand should be sufficiently fine to pass through a 1/4-inch mesh. The compressing should be done with a hand roller weighing 300-400 pounds.

The proper location of expansion cushions in brick pavements is a matter which has undergone much discussion. There is no doubt that expansion joints are necessary, especially in cement grout-filled pavements. Professor Baker in his "Roads and Pavements" gives quite a lengthy and thorough discussion of the effect of temperature changes upon a brick pavement. He shows that a total rise of 50°F will lift the crown of a 40-foot pavement approximately 1 inch from the foundation, provided the curbs are immovable.

All engineers agree that longitudinal expansion joints should be provided. An expansion cushion must be provided for parallel with and next to the curb. It should be one (1) inch in width for streets 30 feet and less in width and 1 1/2 inches in width for streets wider than 30 feet. The National Paving Brick Manufacturers
Association specifications say nothing concerning the use of transverse expansion joints but many engineers insist upon their use. Experience, however, seems to show that the longitudinal expansion cushions are sufficient to provide for all expansion.

Expansion joints are constructed by placing boards of the thickness which the joints are to have, along the curb. The brick are laid and the filler applied—in fact the pavement is completed except for the expansion cushions, before these boards are removed. After they are removed the joint is filled with some preparation suitable for the purpose—usually some preparation of tar or asphalt.

The brick should be first class and thoroughly vitrified, showing at least one fairly straight face, upon which slight kiln marks are allowed. They should be free from cracks with but slight laminations. They are to be made expressly for paving purposes.

In size they should not be less than $2\frac{1}{2}\times4\times8$ nor more than $3\frac{3}{4}\times4\times9$ inches. If the edges are rounded the radius should not be greater than $3/16$ of an inch. They shall not vary more than $1/4$ inch in width $1/4$ inch in depth nor more than $1/2$ inch in length.

The brick should be hauled and neatly piled along the curb before the grading is finished. They should not be dumped or thrown in loading or unloading. They should either be carried to the brick setters by hand on pallets or conveyed on a gravity carrier. There should be no wheeling in barrows on the brick surface.

After the brick are laid and inspected they should be swept clean and thoroughly rolled with a roller weighing not less than three (3) nor more than five (5) tons. They should be rolled twice, once longitudinally and once transversely until each brick is firmly imbedded in the sand cushion and they are all brought to an even surface.
The question of filler for brick pavements is another which has caused much discussion. At present there are three kinds of filler used,—sand, tar and cement grout. Sand filler was the first used and has certain advantages over any other.

"(1) It is cheap its cost being about 2 cents per square yard.

(2) The pavement may be thrown open to traffic as soon as the bricks are laid.

(3) The pavement may be taken up easily and without breakage of the brick.

(4) It is practically water-tight particularly after being in service a short time." *

The disadvantages of a sand filler are:

(1) It does not protect the brick from chipping. It is not unusual to see sand-filled brick pavements which have been in use for a few years in which the bricks are chipped off until they resemble cobblestones.

(2) Heavy rains tend to wash the sand away from between the bricks.

(3) Street sweepers remove the sand from the top of the joints.

The advantages of tar filler are:

(1) It makes an absolutely impervious pavement.

(2) It tends to deaden the sound making a brick pavement quieter than a cement or sand filler.

The disadvantages of a tar filler are:

(1) It costs from 10 to 12 cents per square yard of pave- 

* From Baker's "Roads and Pavements." Page 507.
ment.

(2) It is very apt to become sticky and soft in summer and to run out of the joints, while in the winter it often becomes brittle and breaks off.

(3) When it becomes worn down, it does not protect the edges of the brick.

The advantages of the cement grout filler are:

(1) It makes of a brick pavement an absolute monolith.

(2) In protecting the edges of the bricks from chipping it insures a smooth pavement.

(3) In protecting the bricks it adds materially to the durability of a brick pavement.

The disadvantages are:

(1) It does not take up the expansion, which must be provided for by the use of expansion joints.

(2) It is hard to take up the brick for making repairs.

When we consider that expansion can be easily and cheaply provided for in expansion joints and that the necessity of tearing up a country road would arise seldom if ever, we can see that the cement filler is undoubtedly the best of the three.

The mixture used for this filler should be composed of one part each of clean sharp, fine sand and Portland cement. The mixture should be placed in a box and mixed dry. Water should then be added forming a liquid mixture of the consistency of thin cream. The sides and edges of the brick should be thoroughly wet by sprinkling before the filler is applied in order that they will not absorb the water from the grout. The mixture should be kept in constant motion from the time the water is applied until the last drop is removed and floated into the joints of the pavement. This grout
should be applied by sweeping into the joints, in two courses, the second being applied a few minutes after the first. The second mixture should be slightly thicker than the first. The grout should come just flush with the surface of the brick. Very often a very thin layer is swept over the bricks but is soon chipped off by traffic.

The cost of grout filler is from 8 to 12 cents per square yard—usually between 8 and 10 cents.

A road which has been built to conform (with a few exceptions) to these specifications is that at Newman, Illinois, which was built some three years ago. The road consists of a 9-foot brick road-way with a 6-inch concrete curbing making a width of 10 feet over all. The pavement is built at one side of the road leaving room for a 12-foot earth road parallel to it. The outside of the curbing is at the center of the road and the pavement is built flat with a slope of 2 inches in the 10 feet of width. The earth road is sloped 4 inches in 12 feet. A cross section of the road is shown in the accompanying figure.

One peculiarity of this piece of work is that the base and curbing were built together making a monolith of them. This road has given entire satisfaction. There has been no maintenance
charges nor will there be any for years to come. The motor traffic over this road is no more than that over any road leading to a country town of about 2000 population, but it forms probably one half of the total traffic on the road. The pavement is kept clean by the dirt being swept loose by automobiles and washed off by the rains. The fact that the earth road is not travelled at all when it is soft accounts for the maintenance charges on it being a minimum.

The cost of this particular pavement was "$1.62 per running foot or $8563 per mile" - this is a cost of about $1.62 per square yard. It seems that it falls slightly below the "$1000 per mile per foot of width" rule. The price quoted was the contract price which included all the excavating and grading as well as the construction proper.

The locality has a great deal to do with the cost of brick roads because of the cost of transportation. Professor Baker states that the cost of brick pavements varies from $1.20 to $1.70 per square yard. This is for city work and the extra haulage would make road work more expensive. Labor costs have increased also since this price was quoted so it is probable that a cost of $1.20 could not be reached under the most favorable conditions.
Concrete has been used in the construction of pavements for several years but its use has almost invariably been in combination with some other paving material as brick or asphalt. In these pavements it serves as a foundation and is universally used in their construction.

Not until within the last few years, however, has concrete come forward for consideration as a road making material in itself.

In 1893 in Bellefontaine, Ohio, was laid what was probably the first concrete pavement in this country. This pavement was not very extensive but received the heaviest traffic in the town, as it was laid around the court house square. It was laid in two courses. The first was a 4-inch course of 1:4 gravel concrete and the second was a 2-inch course of 1:1 cement and sand mortar. The pavement was laid in blocks 5 feet square having expansion joints both parallel and perpendicular to the axis of the street. It is said that after 19 years of service this pavement is in very good condition. The mistake made of placing longitudinal expansion joints in the middle of the street has resulted in slight ruts being worn along these joints. Another objection raised against this pavement is that it is very slick in wet weather. This is probably due in part to the method of finishing and to the rich mixture used for the wearing surface.

The only other concrete pavement laid before 1900 was that laid at Richmond, Indiana, in 1896 where a short narrow alley was paved. The construction was practically the same as that used
in Bellefontaine. This pavement shows practically no wear, but the traffic on it is not as heavy as that on a main thoroughfare.

There are two general methods of constructing concrete pavements, namely: the one course and the two course methods. The two-course method is the one which is used most - and which seems the logical one to use. In this method a course of 1:3:6 concrete about 4 inches thick is laid and finished with a 2-inch course of richer concrete, like a 1:2:4 mixture, or a rich mortar is sometimes used.

When but a single course is used, the mortar for finishing is flushed to the top by tamping. This calls for a richer mixture than is used for the first course of the two-course pavement.

Wayne County, Michigan has carried on more concrete road construction than any county or state in this country. They began building concrete roads about four years ago and have built more than 30 miles.

The first of these roads were built in two courses, the lower being a 4-inch course of 1:2\frac{1}{2}:5 concrete and the top a 1:2:3 mixture 2\frac{1}{2} inches thick. The second course was laid within 20 minutes after the first course, in order to secure a good bond between the two courses.

The second experimental road was of one course 6 inches in depth and made of a 1:2:4 concrete.

Since these first roads were built considerable improvement has been made in the methods of construction, and, according to Mr. Hines of the Board of County Road Commissioners of Wayne County, the roads that are being built to-day are 25% better than those built at first. A single course pavement has been adopted and a richer mixture used than at first; the proportions now used
are 1:1\(\frac{1}{2}\):3. The minimum depth in the newer roads has been changed from 6 inches to 9 inches.

In the construction of concrete roads the subgrade is prepared as for any other road. The aggregate is piled on the subgrade in the proper quantities so that it will just be used up in the construction. In this way no hauling is required when the work is being carried on except for the cement which must be kept under cover until it is used. The mixer used is equipped with a delivery boom and bucket by which the concrete is deposited in place. Side rails 2" x 7" and protected on top by a 2" angle iron are used. After the concrete is thoroughly tamped it is struck off by a plank trimmed to the curvature of the road and bound with iron on the edges which rides on the iron edges of the side rails. Little floating is required after the concrete is struck off. The floaters work on a bridge which rests on the side rails so that it is never necessary for them to go on the new concrete. The concrete is covered with loose dirt as soon as it has set slightly and is sprinkled several times a day for eight days. The road is not opened to traffic until at least two weeks after the concrete is placed.

The feature relative to concrete road construction which seems to cause the most trouble, is the form and location of expansion joints. That they are needed is conceded by all but just how and where to build them is a question. Expansion joints filled with wood and tar have been tried but the unprotected edges of the concrete chip off. It has been found necessary to protect these edges in some way. In the Wayne County roads the joint now used consists of a soft steel plate 3 inches wide and 1/2 inch thick,
provided with shear members which tie it securely to the concrete base and wearing surface. These plates are clamped to a dividing board, shaped at the top to conform to the crown of the finished pavement, and two thicknesses of 3-ply asphalted felt extending the entire depth of the concrete, are inserted between the plates. Mr. Hines states that by the use of this they have succeeded in materially strengthening the weakest part of the road, as the plate largely removes the possibility of wear at the joints and results in an even and uniform surface.

Another problem that arises in this kind of construction is that of how to avoid the longitudinal cracks which almost invariably appear. In Wayne County the 1912 roads were built with a longitudinal expansion joint down the center of the road. Mr. Johnson, of the Illinois State Highway Commission, working on the theory that longitudinal cracks were produced by the arch action over the center of the road bed, devised the plan of constructing a shallow ditch or rather filling in along either side with some hard porous material that would not settle.

The Department of Agriculture is at present carrying on some experimental work by which they hope to learn the best method of placing expansion joints.

Longitudinal joints placed in the center of the road are surely to be avoided because of the wear they will receive, especially from the horse drawn traffic of narrow-tired vehicles. The transverse joints are ordinarily placed about every 25 feet.

Cost

Below is shown some data concerning concrete pavements in city work. These figures probably would not differ greatly from
the cost of roads of the same description in the same locality. The cost of the road might be lessened, however, by using a lighter and consequently cheaper construction.

<table>
<thead>
<tr>
<th>City</th>
<th>Date</th>
<th>Description</th>
<th>Cost per sq. yd.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windsor, Ontario</td>
<td>1908</td>
<td>Base 4&quot; of 1:3:7 Top 2&quot; of 1:2:4</td>
<td>$1.23 - $1.40</td>
</tr>
<tr>
<td>Ann Arbor</td>
<td>1910</td>
<td>6&quot; Concrete base - bitumen and sand surface (excluding grading)</td>
<td>.71 - .88</td>
</tr>
<tr>
<td>Toronto</td>
<td>1903</td>
<td>4&quot; base 1:3:7 - 2½&quot; top 1:1:3</td>
<td>1.74</td>
</tr>
<tr>
<td>Le Mars, Iowa</td>
<td>1904</td>
<td>5&quot; base 1:6 - 1½ top 1:2</td>
<td>1.25</td>
</tr>
<tr>
<td>Denver</td>
<td>1907</td>
<td>4&quot; base 1:3:6 2&quot; top 1:2:4</td>
<td>1.08 - 1.37</td>
</tr>
<tr>
<td>Bozeman, Mont.</td>
<td>1908</td>
<td>5½&quot; base 1:6 1½&quot; top 1:1:1</td>
<td>2.28</td>
</tr>
<tr>
<td>Chicago</td>
<td>1905</td>
<td></td>
<td>1.80 - 2.20</td>
</tr>
<tr>
<td>Gary, Ind.</td>
<td>1906-7</td>
<td>5&quot; base 1:2:4 2&quot; top 5:7</td>
<td>1.70</td>
</tr>
<tr>
<td>Ada County, Idaho</td>
<td>1912</td>
<td>7&quot; 1:2½:4</td>
<td>.69</td>
</tr>
</tbody>
</table>

The cost of the Wayne County roads has been from $1.04 to $1.75 per square yard varying with the amount of cut or fill and the length of haul.

Some road-builders seem to think that concrete roads undoubtedly are the solution of the good-roads problem. Wayne County Michigan has shown its faith in them by planning to spend nearly all of a $2 000 000 bond issue for this kind of roads. There are some questions, however, which must be met before concrete will be accepted as the material for the ideal road. Chief among these is that of how to eliminate the temperature cracks. In all of the concrete roads yet constructed cracks have appeared, which although
not necessarily detrimental are at least unsightly. Expansion joints must be placed and constructed so that they will take up all the expansion and not be detrimental to the pavement.
CHAPTER V.

CONCLUSION

In a comparison of the three kinds of roads which have been described, we should consider the advantages and disadvantages of each.

Bituminous Macadam

The advantages of bituminous macadam for road building are:

(1) It is cheap in first cost as compared with brick. In Illinois these roads cost from $1.00 to $1.15 per square yard and elsewhere the cost varies from $.75 to $1.50 per square yard.

(2) It furnishes a good foothold for horses at the same time having a low tractive resistance for both horse-drawn and motor traffic.

(3) It is quiet, resembling asphalt in this respect.

(4) It can be utilized in repairing old water-bound macadam roads by simply leveling the old road and applying a bituminous macadam surface.

Its disadvantages are:

(1) Its cost of upkeep. Although this is less than for the old water-bound macadam road, never the less any bituminous macadam road has to be resurfaced every two or three years at least, and in some states a light coat of oil is applied every year. This cost of maintenance varies between very wide limits—from 2 cents per square yard for sprinkling with a light oil to as much as 25 cents for applying a new sealing coat.

(2) The whole width of road must be paved when the material is used. Otherwise, vehicles will carry mud on to the road and the binder will be destroyed.
(3) Skill is required in heating the bitumen to the proper temperature. If it is under-heated or over-heated the binding power will be diminished or destroyed entirely. Such a result is very apt to be the case in the construction of these roads.

Brick

The advantages of brick pavements are:

(1) They are permanent and require practically no maintenance. With the manufacture of paving brick at the present advanced stage and the severe rattler tests standardized, a well constructed brick pavement should last a generation or more.

(2) They furnish an ideal roadway for motor traffic with a minimum tractive resistance.

(3) Their performance can be depended upon absolutely from the performance of other pavements similarly constructed.

(4) They can be made just wide enough for the traffic without danger from any earth that may be carried on to them.

The disadvantages of brick pavements are:

(1) They are expensive in first cost as compared with other roads. A good brick road costs from about $1.40 to $2.00 per square yard.

(2) Brick roads are very hard. Some people think that they are injurious to horses.

(3) They are noisy when used by horse drawn traffic. This, however, could hardly be rated as an objection to their use for country roads where noise would make little, if any, difference.

Concrete Roads

The advantages of concrete roads are:

(1) They are cheaper than brick costing from $0.70 to $2.00 per square yard. The average cost in this section of the country
being about $1.25 per square yard.

(2) They can be built just wide enough for the traffic.

(3) They seem to be permanent with a low cost of maintenance, although enough is not known about these roads to say how long they will last.

(4) Their tractive resistance is low.

The disadvantages of concrete pavements are:

(1) They crack because of temperature changes. Expansion joints have not yet been placed so as to avoid these cracks entirely.

(2) They are even less elastic than brick pavements because there is no "give" to them whatever.

(3) It is almost impossible to repair them because new concrete will not adhere to old.

(4) Owing to the fact that they are still the subject of experiments, the best method of construction is not known.

When these advantages and disadvantages are compared the one disadvantage standing out against the brick road is the cost. When it is considered, however, that the first cost is the only cost, this disadvantage is lessened. Considering that brick pavement costs 50 cents per square yard more than any cheaper pavement (and this is an average difference) and that it will last 25 years without maintenance charges; also that money draws 4% interest; we find that $.012 invested annually will amount to $.50 at the end of 25 years. That is, it is cheaper to build the brick pavement than to build a pavement costing $.50 less per square yard and spend more than $.012 annually in maintenance.

The solution of the road problem lies in the building of roads which require little or no maintenance. This eliminates bitum-
inous macadam roads for most localities. Concrete roads have not yet proved to be entirely dependable. Many road builders, among them Mr. A. N. Johnson of the Illinois State Highway Commission think that in concrete roads will be found the solution to the problem. The fact that they are cheap is the greatest thing in their favor.

The people who put their money into roads,—and these people are mostly the farmers—want roads that are reliable. In that they are known from past performance to be absolutely reliable, that they are permanent, requiring no maintenance, and that their cost is not high, considered economically, brick roads appear to approach most nearly the ideal in roads for motor traffic.
APPENDIX

In the equation $F = Ma$ where $F =$ force, $M =$ mass, and $a =$ acceleration, the acceleration curve is assumed to be a straight line, i.e., the acceleration is assumed to be uniform. That this is not the case is certain, but just what kind of a curve the acceleration curve is is only a matter of conjecture. It seems to the writer - after having been suggested to him by Professor Moore of the Engineering Experiment Station - that it is not unreasonable to assume the acceleration curve to be a parabola. Working upon this assumption the following results have been obtained.

Assuming the average case of a 4000 pound machine gaining a speed of 30 miles per hour (44 feet per second) in 30 seconds, the usual form of the acceleration curve would be as shown in Fig. 1. To facilitate the work, however, the coordinates are shifted as shown in Fig. 2 making the origin of the parabola at 0,0.

Solving for the equation of the parabola from

$$y^2 = 2px$$

we have $y = 30$, $x = 44$, then $p = 10.22$. 
\[ y^2 = 20.44 \times \]
\[ y = 4.51 \times \]

Solving for the tangent at point \( x, y \).
\[ y - y_1 = f(x_1)(x - x_1) \]
\[ y - 30 = \frac{3.25(x - 44)}{x_1} \]

or \[ y = 0.339x + 16.4 \]

Then slope of tangent \( 0.3395 \)

Again changing the coordinates to the original form we have
\[ a = \frac{1}{0.3395} = 2.95 \text{ ft. per sec.} \]

Then from \( F = Ma \)
\[ F = \frac{4000}{32.2} \times 2.95 = 372 \text{ lbs.} \]

This shows a force of 372 pounds exerted upon both wheels or \( \frac{372}{2} = 186 \) pounds upon one wheel.

When a 5-inch tire 36 inches in diameter is loaded with an average load it is compressed to at least 3/4 its normal size, as shown in Fig. 3. Just as the tire leaves the road there will be a considerable tangential force exerted by the stress thus produced in the tire itself. This stress is also a matter of conjecture.

Summing up this discussion it seems reasonable to place the force exerted by an average machine at about 300 pounds per wheel or 100 pounds per inch of width.