not like. This is not a pleasure to the examiners, but the statutes place responsibilities upon us which we must meet, and we do meet them fairly and squarely. Regardless of the consequences, our reports must speak the truth and show the facts as they are found to exist.

The law places the same authority with the department as to examinations of state offices and departments that it does in the examination of county, township and other public offices.

An office or department in the State House is not entitled to any more privileges in an examination of its accounts and affairs than the smallest town or township in the state.

Our examinations will be made without fear or favor and we will carry out our duties as provided by law.

During my administration as State Examiner I have endeavored to make the department helpful to all public officials and I invite you to send your problems and questions to me. We extend to you our services in the spirit of co-operation and assistance to the end that we may all serve to the best of our abilities in the interest of efficient, economical and honest government.

THE RESURFACING OF BADLY WORN CITY PAVEMENTS

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The resurfacing of badly worn city pavements is a subject that is receiving considerable attention at the present time. The large increase in motor traffic has brought about a demand for smooth roadways, and many cities are attempting to transform their old pavements into boulevards by the use of some type of bituminous surface. Most of our highway engineers have also recognized the economy of salvaging whatever value there is in their old roads, and are resurfacing gravel and macadam roads with asphalt or other bituminous material. The increase in the construction of this type of pavement is no doubt due to the fact that the financing of a paving program, in most communities, is becoming a serious problem, and any saving that can be made in construction cost, which does not lower the value of the service rendered by a pavement, is certainly justified. In some cities this work is being done by the application of a thin layer of asphalt, having a thickness of one-half or three-quarters of an inch, and frequently this is feathered out to zero at the curb and
at the rail of a street railway track. Such construction is no
doubt justified as a temporary measure, but in this discussion I
will ask you to keep in mind that resurfacing means the laying
of a high type of asphalt surface on an old pavement, the latter
being considered as a foundation for the new surface.

Through the co-operative efforts of all agencies engaged in
the work, the science of road building has made greater strides
during the past quarter century than for many centuries past.
The industry is growing at a tremendous rate. We are now
spending a billion dollars a year on roads and pavements. We,
as engineers, have been so busy planning and supervising the
construction of this vast volume of work, that I wonder whether
we have taken enough time to investigate the work done, in the
past, with the idea of utilizing in our present day practice, the
experience gained from past performance.

Many cities in the United States have pavements that have
been in service for a quarter of a century, or more, and it seems
to me that if these pavements were studied with some care we
would be able to draw some conclusions that would help, mate­
rially, in the design and construction of roads and pavements. I
am not unmindful of the fact that many city pavements con­
structed in the past have illustrated how not to build rather than
how to build, so we can learn from our failures as well as from
our successes.

City pavements have not only been subjected to traffic but
to the heat and rain of many summers and the snow and ice of
many winters, and it is the action of traffic combined with these
destructive agencies that more often show up the defects in pave­
ments or cause failures in them than the traffic alone. While
many of our old city pavements were designed for traffic condi­
tions as they existed twenty-five or thirty years ago, it is a re­
markable fact that some of them are in good condition today and
are carrying a traffic never dreamed of at the time they were
built. From the experience gained during the past half century,
municipal engineers have generally recognized the three funda­
mental requirements of a properly constructed high class pave­
ment to be:

1st. A stable, well drained sub-base.

2nd. A firm foundation, strong enough to carry the loads
to which it will be subjected.

3rd. A smooth wearing surface to withstand the abrasion
of traffic and protect the base and sub-base from the action of
the elements.

It is pretty well recognized that the sub-base and foundation
of a street or road should be constructed in such a way as to be
a permanent investment but that the wearing surface of necessity
must be repaired from time to time, and may, ultimately, have to be entirely renewed.

In the resurfacing which I will describe to you these fundamentals were kept in mind, as resurfacing in Columbus has only been attempted when the condition of the old pavement fulfilled the requirements for base and sub-base.

**Methods Used in Columbus**

We now proceed to describe the methods used in resurfacing old pavements in Columbus, Ohio; to tell you under what conditions resurfacing as a permanent improvement is justified; to give you the results obtained in terms of the cost of maintenance, and finally to compare these maintenance costs with that of the ordinary construction of high grade pavements using a concrete base.

There are four types of old pavements that have been resurfaced in Columbus, namely, brick, boulders, stone block and macadam. Of 195,110 square yards of this type of construction about 72 per cent of the work has been on brick, about 20 per cent on boulders and 8 per cent on macadam and stone block. In general it may be said that the results from stone block and brick have been uniformly successful and that in the case of the boulder pavements the results have been generally successful. The resurfacing over macadam has been of such recent date, the oldest pavement having been laid in 1922, that no general conclusion as to the merits of this work can, as yet, be stated.

The oldest paved roadway in the city of Columbus is Bryden Road, from Parsons Avenue to Twenty-second Street. It is a street with a forty foot roadway, and carries a large volume of traffic, from eight thousand to ten thousand vehicles daily. It is a sheet asphalt pavement laid in 1888 over boulders, and is, therefore, 36 years old. We have no record as to when the original boulder pavement was laid, but it consisted of a foundation of about eight or ten inches of crushed stone, the boulders being imbedded in sand on top of this base. At the time the asphalt resurface was placed on this roadway it was thought necessary to coat the boulders with a bituminous material so that the asphalt would adhere better to the surface. Therefore, cold tar pitch was sprinkled over the boulders before laying the asphalt. The asphalt was then laid without any binder, in the same manner as sheet asphalt is laid at the present time, it being dumped on the roadway and shoveled to place and raked to the proper thickness and then rolled. Two or three years later several other streets were laid in a similar manner, and, with one or two exceptions, the pavements are smooth and giving excellent service today. In 1912 another old pavement of this
type was resurfaced, but in this case a binder course was used and the pavement laid in the same manner as a sheet asphalt paving. One of the streets resurfaced over boulders in 1891 is on our program for reconstruction this year. The sub-base conditions on this street are not first class and the construction of a sewer, some years ago, added to the sub-base defects. Another pavement laid the same year has shown rather high maintenance, due, partially, to frost action. The pavement on Bryden Road, however, is in very good condition today as may be observed by Fig. 1.

Fig. 1. Bryden Road, a boulder pavement, resurfaced with asphalt in 1888.

**Resurfacing Old Brick Pavements**

The resurfacing over old brick pavements has been done in more recent years, and we have definite information as to the details of the work and the construction method. Practically all of these old brick pavements were originally constructed between the years 1888 and 1892. They were laid on a macadam base, averaging about ten inches in thickness, which consisted of crushed limestone, such as is available in Central Ohio, and water-bound with crushed stone screenings. After rolling, a two-inch cushion of sand was spread over this surface, on which the brick were laid and the joints filled, in most cases, with cold tar pitch. These old pavements have given good service, although there has been considerable repairs made on most of them and all had, for some years preceding resurfacing, a rough surface which did not meet the requirements of motor traffic.

All of the resurfacing over brick has been done only after a careful investigation of the sub-grade conditions, as evidenced by the condition of the paving and the curbing. In some cases
where there was some question about the condition of the foundation, or the sub-base, actual excavation was made to determine, definitely, these conditions. If it was found that the curbing had become displaced by frost action, or that the brick in the surface had, in places, become displaced, from a similar or other cause, we would naturally conclude that there was an unsatisfactory sub-base condition or a weakness in the foundation, or both, which, if extended over a considerable area of the improvement, would make resurfacing impracticable. The best time to discover a weakness in a pavement is in the spring when the frost is coming out of the ground, and it has been our practice, for some years past, to observe our old pavements at this season, so that we may know of any weakness in sub-surface conditions which would make resurfacing unjustifiable. We have, in Columbus, some brick pavements laid on macadam bases, in which ground water comes to the surface in the spring, and it is not unusual to see sections of these pavements utterly destroyed by traffic, at such time, the brick being actually thrown out of position or asphalt disintegrated and broken up by the traffic. Clearly, it would be a waste of money to attempt resurfacing under such conditions.

**Rules Governing Resurfacing**

In general it may be said that any pavement that has retained its general shape and contour for a period of ten or twelve years shows evidence of a satisfactory sub-base and foundation and that such a pavement may be resurfaced with a reasonable expectation of securing satisfactory results.

In preparing plans for resurfacing of any pavement it has been our practice to take cross sections of same at frequent intervals, which are platted on cross section paper to any convenient scale. From these sections a new crown for the proposed surface is worked out which gives the required minimum thickness desired for the new surface, or 1½ inch binder, 1½ inch top. On account of the worn condition of the old pavement, these sections will usually disclose the fact that at certain points the old surface must be built up to form a satisfactory crown, and where this condition is such as to require a thickness of three or four inches of binder, it has been our practice to place the binder in two operations; that is the low sections of the street are first brought up, with binder, to a crown three inches below that desired for the finished work, and then the surface put on in the usual manner.

If the depth of the gutter in the old pavement cannot be reduced, safely, it has been our practice to take up a strip of the paving four or five feet in width, and either lay a concrete foundation at a lower grade, over which the asphalt surface may be laid,
or to lay a brick gutter that will give the proper depth at the curbing and a shoulder three inches deep against which to lay the asphalt. In this connection I might say that in sections of the city where there is considerable parking of automobiles, it is our practice, both in resurfacing and in the construction of new asphalt pavements, to lay a six foot strip of brick or granite block paving next to the curb, as a parking strip for automobiles. Fig. 2 shows a brick surface prepared to receive the asphalt top.

An extremely important feature in connection with resurfacing is the laying of drain tile along the curb on each side, and at other points if necessary, in order to insure a properly drained sub-base. We have used drain tile on all of our street construction in the past twenty-five years, and in resurfacing, where tile was not used, originally, we lay a four inch farm tile twenty-four inches below the surface of the paving, just in front of the curb line, with outlet at catch basins or sewer manhole.

In many cases we have found it desirable to reset and recut the curbing in connection with resurfacing, practically all of the curbing used in Columbus being Ohio sandstone. This is not absolutely necessary unless it has been forced out of position by frost action, but it improves the appearance of the improvement and the cost is only a small percentage of the total. Fig. 3 shows a typical section of this construction.

**Detailed Resurfacing Operations**

Our contracts for this kind of work are all let on a unit price basis, that is a square yard price for the surface, which includes 1½ inch binder and 1½ inch top, and a cubic yard price
for additional binder. The first step in the construction of such an improvement is to excavate for the strip along the curb, lay the drain tile, reset the curb, if necessary, and lay the foundation strip along the curb, including the brick surface, if brick is used. The old pavement is then thoroughly cleaned with the use of water from a fire hose and men follow along behind with push brooms, sweeping the surface thoroughly to insure the removal of all dirt and foreign substances from the surface of the brick and the joints. After the pavement is thoroughly cleaned and dry, it is then ready for an application of the extra binder to bring the surface to the proper crown. When this is done the regular binder course, and the top course is laid in the same manner as the laying of a regular sheet of asphalt surface.
At intersecting streets it is necessary to relay a portion of the pavement on such street in order to meet the grade of the new work. If this be an asphalt pavement a portion of the old surface can be heated and removed and new top added, building it up to meet the new crown. If it is a brick or block pavement it is best to relay a number of rows of the brick or block at the proper grade to form a shoulder for the asphalt. This detail is shown in Fig. 4.

The resurfacing over stone block is done about the same manner as over brick, the proper crown being mapped out and the surface laid as described above.

The first macadam pavement resurfacing was done in 1922 and the second in 1923, these two being the only pavements of this type resurfaced in Columbus. Both of these pavements had been built for twenty years, or more, with brick gutters along the curb, and the old curbing, brick gutters and macadam had shown evidence of satisfactory sub-grade conditions. The macadam had a thickness of fourteen inches. This surface was scarified to a depth of three inches and the material removed, after which the surface was rolled to a grade that would permit of the laying of three inches of asphalt and meet the shoulder of the brick gutter.

As stated before it is too early to form an opinion as to results of this work, as my experience shows that it takes from ten to twelve years of service to demonstrate whether or not a particular type of pavement is a success, and I will give you, later, some evidence in support of this conclusion.

**Streets Containing Car Tracks**

The problem of resurfacing a street containing car tracks is one that is rather difficult of solution, unless the tracks are reconstructed. We have attempted this on one street only, a main thoroughfare on which the maintenance cost had been very heavy for several years, and on which it was the desire to improve the surface without the expense of reconstruction. This work was done by city forces out of funds appropriated from maintenance, and if the new surface will last seven years, the cost of the work will not be in excess of seven years' ordinary maintenance.

In this case a strip of brick about twelve inches wide along the outer rails of the car tracks was relaid at such a grade as to give a shoulder against which to lay the asphalt, and at the curb the thickness of the resurfacing material was reduced to one inch in order to give a proper depth of gutter. Asphaltic concrete was used on this work except for a distance of about 2,000 feet on one side of the street where Kentucky rock asphalt was used in
order to try out this material for this character of work. As an experiment, there was also laid for a short distance a manufactured asphaltic material known as cold laid asphaltic concrete.

This material was all laid without a binder course, and to a depth of two inches, except at the rail and curb where it was reduced to one inch. The work was done during the fall of 1924 and while it has promise of giving satisfactory results it will take some years to demonstrate whether this cheaper type of construction is justified.

**Costs**

The cost of resurfacing will vary in different communities, depending on the cost of labor and material. In Columbus, when done by contract, the work costs, where binder is used, from $1.65 to 1.75 per square yard, and where the curb is not reset, or new gutter laid, it has been done for from 50 per cent to 60 per cent of what new construction costs, depending on the amount of additional binder required to provide a proper crown for the street. When new gutters are laid and the curbing reset, the cost amounts to from 65 per cent to 75 per cent of the cost of new work, depending on the type of paving used for the gutters.

The maintenance cost of city pavements is a subject that has not, in the past, been given as careful investigation as is warranted by its importance. However, it is now being recognized that the maintenance of city pavements is a very important part of city service and is receiving more consideration in the financial program of progressive cities. In Columbus we have been able, however, especially in later years, to secure funds enough to maintain our pavements in a fairly satisfactory manner, judging by the very few complaints relative to them registered by our citizens; so that we will not be making a violent assumption when we say that the pavement, on which maintenance costs are given herein, are in good condition today.

In preparing some maintenance data on our resurfaced work in connection with this discussion, I thought it would be of interest to give you a comparison of such costs with the maintenance cost on the ordinary type of sheet asphalt construction. Before doing so, however, it will be necessary to describe, briefly, how the repairs are made and cost data compiled. Prior to 1907 our asphalt repairs were done by contract on a unit price basis; the area of the surfaces repaired being carefully kept and payments made in accordance therewith. In 1907 the city installed an asphalt plant of 1,000 yard capacity, and since that time the repair work has been done by city forces. We have continued, however, to keep the same data as when the work was done by contract; viz: the repaired area and the cost. To arrive at the
cost we figure the entire cost of the season's work, including labor, material, supplies, a charge for use of plant, etc., and divide this by the total yardage of the repaired area, which gives a unit cost to be applied to each street.

During the past three years I have been compiling these figures for all of our pavements, some 6,000,000 square yards, and 1,300 improvements, with the idea of having a complete service record of each particular improvement, and we have just completed this work for our asphalt pavements, involving some 300 improvements and 1,770,000 square yards. In compiling these figures it has been my aim to show each year for each improvement:

1st. The area of the improvement.
2nd. The area repaired.
3rd. The cost of the repair.
4th. The cost per yard of total area.
5th. The average cost per yard per year.

This last figure is really the service test of a pavement. It gives the average yearly cost over any period of years. As a pavement becomes older it will cost more per year to maintain it, and unless we know the age the maintenance cost does not mean much. The average cost per yard, per year, is obtained by dividing the total cost of repairs up to a given date by the total area of the improvement in yards and this quotient divided by the age of the improvement. Thus an improvement having an area of 10,000 square yards and being 20 years old, on which the total maintenance cost during the entire 20 year period was $5,000, would have an average maintenance cost per yard per year of $2.5 cents. The maintenance on the resurfaced work over the old boulder pavements, the oldest of which was paved in 1888, averages a little over 3 cents per yard per year for the 36 year period. The resurfacing over the brick pavements, of which there are 24 improvements, has been done since 1912, the aggregate yardage of this work being 149,889 yards. The average age of these pavements is 5.6 years, the oldest being 12 years. The total maintenance on these 24 improvements, since they were constructed, amounts to $719 or .00086 cents per yard per year. In other words, if the combined yardage of these pavements was considered as a highway 18 feet in width this highway would be 14.2 miles in length and would have cost about $8 per mile per year for maintenance.

Critical Period in Life of Pavement

Fig. 5 gives, graphically, the maintenance figures for asphalt pavements, the age being shown by the horizontal ordinate and the cost in cents per yard per year by the vertical. The heavy
Fig. 5. Maintenance costs on asphalt pavements.

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<th>Age (years)</th>
<th>Total Yardage</th>
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Legend:
1. Oldest sheet asphalt on concrete base
2. Resurfaced pavement requiring heaviest maintenance
3. All resurfaced pavements
4. All sheet asphalt pavements
5. Oldest resurfaced pavements

The dash line shows the aggregate of all resurfaced pavements at the various ages. These figures have been obtained by adding together the maintenance cost for each improvement at a certain age, regardless, of course, as to when the improvement was made, the points for the curve being obtained by dividing the total cost up to a given year by the total yardage of pavements that were in service on that year and then this quotient divided by the number of years. The heavy dotted line shows the expenditure for all sheet asphalt pavements. The solid fine line shows our oldest resurfaced pavement which as you will note has a remarkable record. In order to make a comparison I have shown a broken line showing the oldest sheet asphalt pavement on a concrete base. The resurfaced pavement which has required the most maintenance is shown as a broken line above all other curves, and I have shown this in order to give you an idea of the range in maintenance cost as well as the average. From this chart a line could easily be plotted from which the maintenance cost for asphalt pavements could be estimated at any age. You will note that these curves all take a decided rise somewhere between the 10th and 12th year, indicating a comparatively heavy maintenance cost at this time. Most of them flatten out after that period and in case of some of them the cost during the next few succeeding years is less than at that period. This fact seemed rather startling to me, and in order to determine, if possible, the reason for heavy maintenance at this age period, I made some studies of several pavements of various types. Our earlier asphalt pavements were constructed under a ten year guarantee, and the records seemed to show that a few of them had been neglected for two years or more prior to the expiration of this guarantee, which would naturally increase the cost at that time; but for the past 15 years our guarantee period has been 5 years, so that the heavy maintenance on all of the pavements can not be attributed to neglect immediately prior to the expiration of the guarantee. In fact we have a large yardage that has passed the 10th year without requiring any main-
tenance. On the other hand I found that we have a number of pavements carrying heavy traffic on which the records seem to confirm the theory that the period of heavy maintenance is when they are from 10 to 12 years of age. To illustrate, an important street leading to the north was paved with asphalt in 1911. The present traffic on this street is about 12,000 vehicles daily. It passed the five year guarantee period without requiring maintenance. At the age of 8 years the cost per yard per year was $.008; at 10 years, $.045; at 12 years, $.07.

We have another main thoroughfare leading to the north in Columbus that was constructed in 1908. This was a brick pavement on a concrete base with a tar filler. It receives very heavy traffic, a count indicating that a traffic of approximately 16,000 vehicles use this roadway per day. During the years 1921, 22 and 23 this pavement was entirely resurfaced because the brick were so badly worn and broken as to make the street unfit for modern traffic conditions.

Another street 50 feet in width, carrying approximately the same amount of traffic, was constructed in 1911 of brick with a grout filler. This street was in excellent condition for a 10 year period but during the last 2 or 3 years we have been obliged to give it considerable maintenance, and the maintenance cost up to date has averaged about 4½ cents per yard per year, practically all of which has been done within the last three years.

Probably the most striking example is afforded by a sheet asphalt pavement laid on a portion of a thoroughfare leading to the east, a street which carries about 12,000 vehicles daily at the present time. This was constructed in 1890. In 1901 this roadway was resurfaced and in 1913 it was resurfaced for the second time. In 1924 we were obliged to reconstruct this pavement due to the fact that during the spring of 1924 ground water came to the surface and destroyed such large areas that it was not considered wise to attempt any repairs. This failure was due to an improperly drained sub-base and a weak foundation, but the point to which I wish to call your attention is the fact that in spite of this bad condition this pavement gave satisfactory service from 11 to 12 years after each repair.

In addition to the above examples as bearing on this heavy maintenance period, I wish to call your attention to an article by Professor French, of Mt. Gill University, published about 2 years ago, giving the results of an inspection of about 340 miles of concrete roads in northern United States and Canada. Without going into details I will say that his conclusions were that on heavy traffic roads the condition of these concrete pavements was such as to need resurfacing at the age of 9 years and on the light traffic roads at the age of 13 years.
Based on our records there seems to be ample evidence to show that when a pavement has required heavy maintenance it has been during the 10th to 12th year period after construction, but I do not wish to be understood that such conditions are common to all pavements.

For instance, of the total yardage of our asphalt streets that are 10 years old, or more, 60 per cent of their area or 396,293 square yards have reached that age without requiring any maintenance, 40 per cent have reached the age of 12 years without maintenance, 16 per cent 15 years, and we have four streets with a total area of 11,443 yards which have been in service 18 years without maintenance expense. However, as a result of these studies and supported somewhat by Professor French's investigation, it would appear that there is a critical period in the life of all pavements, and that this period is from the 10th to the 12th year after construction. Pavements may pass this period successfully by reason of favorable traffic and other conditions, and they may develop a weakness before this time by reason of abnormal conditions, but the evidence seems to show that serious defects, either in sub-base, foundation, or wearing surface, do not necessarily develop until this critical period, and we should hesitate, therefore, to draw any definite conclusion as to the merits of a pavement until such pavement, after 12 years' service, with moderate maintenance, is found to be in satisfactory condition.

While the diagram indicates that from the 10th to the 20th year after construction, the maintenance on resurfaced work has been greater than for asphalt pavements on a concrete base, beyond the 20th year the maintenance is substantially the same, and we can, therefore, conclude that the results from the resurfaced work as measured by maintenance cost, are nearly equal, if not entirely so, to the results obtained from other construction. In fact a comparison of the resurfacing over old brick pavements which were completed 12 years ago, are now in as satisfactory a condition and have received no greater maintenance than other work constructed at the same time.

These results are due, largely, to the care used in selecting for resurfacing only those streets which, after long service, have shown evidence of satisfactory sub-base conditions, and it is only by a study of these conditions, and correcting them if unfavorable, that a successful pavement of any type can be constructed.

In conclusion let me suggest that the pioneer days of constructing modern pavements is past, and in the future the problem will be studied in the light of experience gained from past performance. For I believe that from a study of the behavior of our pavements under actual traffic and climatic conditions, much can be gained to aid us in solving our paving problem.