of all surfaces now existing and the insistent demand for economy, we as road builders would be betraying our trust if we did not give our most serious consideration to protecting and preserving the enormous original investment.

RESURFACING ROUGH PAVEMENTS WITH THIN LAYERS OF BITUMINOUS MIXTURES

By A. O. Hastings, District Engineer, Indiana State Highway Commission, Greenfield, Indiana

Because of the great increase in weight and volume of traffic over our highways within the past few years, some of our older, poorly designed pavements have become worn or broken down to such an extent that they demand the immediate attention of highway engineers.

Many of these pavements are in such condition that light maintenance repairs fail to keep up with the destructive forces of traffic and weather. Many still possess sufficient strength and value to render it uneconomical to tear them up and construct new ones. The problem of insuring such surfaces the proper smoothness and stability requires an entire resurfacing.

Initial investments in these pavements are so large as to make the conservation imperative. Many roads are in such condition that they no longer meet the needs of modern traffic. It would be a distinct economic waste to destroy or abandon them. Enormous savings can be effected by resurfacing. By this salvaging method, which I maintain is sound, many advantages are derived. First, the original investment in the old pavement is conserved. Secondly, resurfacing materials may be obtained at very nominal cost, particularly at present prices. Thirdly, the operation may be completed with little or no interruption to traffic. The above economical undertaking results in a pavement good for many years of satisfactory service at a reasonable cost.

Bituminous mixtures lend themselves readily to the patching and resurfacing, or modernizing, of old pavement. The bituminous mixtures adhere readily to the old pavement, waterproof it, add a certain value as a shock absorber between the load and the base, and furnish also a durable non-skid surface. Such resurfacing can usually be done at a cost far below that of complete new construction.

Where such pavements exist, with conditions as described above, the maintenance engineer should carefully study the problem before deciding on the exact amount and type of such resurfacing. He should ascertain the amount and kind of
traffic using the particular section in question and estimate as nearly as possible the probable increases in this traffic within the next few years. He should investigate the stability of the present pavement which is to be used as a foundation for the new surface. If weak places, indicating poor drainage, bad sub-soil, etc., are found, they should be corrected, thoroughly drained and patched out to the grade of the old pavement before any resurfacing is placed thereon. The whole surface should be stabilized until it presents a fairly equal and adequate resistance to the loads to which it will be subjected.

If the old pavement shows sufficient strength to carry the load, then a very light resurfacing may be used; but if it is weak, a thicker resurfacing course should be used, thereby adding the required bearing strength.

Irregularities in the old pavement should be patched out with a mixture of crushed aggregate and bituminous material, bringing the patched surface to the desired grade and cross section. The resurfacing course should be of approximately uniform thickness over the entire section to obtain the best results. This patching should be done by using crushed aggregate of a size comparable to the depth of the hole or depression to be patched. The aggregate should be mixed thoroughly with just sufficient tar or asphalt of the proper grade to insure the patch against ravel. Care should be taken not to use an excess of bituminous material, particularly combined with smaller aggregate, since this is very liable to cause pushing and shoving and, ultimately, a wavy surface.

In resurfacing an old pavement which has been stabilized and presents approximately the same bearing strength over the entire surface and yet needs reinforcing, the thickness of the resurfacing course should be determined by the amount of additional strength required. In other words, if there is no question about the strength and stability of the old pavement, then a rather thin resurfacing course may be used; while if the old pavement is weak, a thicker resurfacing course should be used to give the results desired.

In resurfacing with a bituminous mixture, the size of crushed aggregate used in the mixture should be varied and be comparable with the depth of the course. If the resurfacing course is so constructed, added strength to the pavement will be directly proportional to the depth of the resurfacing.

Our experience has been that most of the old pavements to be resurfaced were not quite stout enough to carry the load, and that it was necessary for us to add strength to the pavement by thickening the resurfacing course. We have resurfaced some small stretches with a very thin course, say $\frac{3}{4}$ inch to 1 inch thick, but generally such resurfacing has not been very successful. In my experience, resurfacing 2 inches or more in thickness has proved more satisfactory.
SOME EARLIER EXAMPLES

During the past ten years, we have resurfaced stretches of old cement concrete, old brick laid on a compacted gravel foundation, old brick laid on a cement concrete foundation, old bituminous macadam, and old treated stone roads. We have used several types of bituminous mixtures in such resurfacing. In 1926, we resurfaced a portion of State Road 67 near Fort Benjamin Harrison and used several types of bituminous mixtures as an experiment. The part to be resurfaced was old cement concrete reinforced. This old pavement had broken down in many places, partially because of faulty construction and partially because of excessive loads. All badly broken places in the old concrete were removed and replaced with new cement concrete.

The first section was resurfaced with an emulsified asphalt mixture using crushed stone as aggregate for part and gravel aggregate for part. This resurfacing pushed and shoved and was not altogether satisfactory. However, I believe that if we had used a smaller percentage of bitumen in the mixture, we would have secured better results. Other roads have been resurfaced since then with emulsified asphalt mixture using a smaller percentage of bitumen, and they have stood up well.

The next section was resurfaced with bituminous concrete (hot mix laid hot). The surface was given a light prime coat of emulsified asphalt. The bituminous concrete was spread on the road, raked, and rolled while hot. The average thickness of this course was 1 1/2 inches. The surface was then given a squeegee coat of asphalt cement, and sand. This hot mix was very similar to the old Topeka mix specifications. Because of unusual irregularities in the old pavement and the fact that the mix could only be worked while hot, we were unable to get as smooth a riding surface as desired. This course did not add quite sufficient strength to the old pavement, and some trouble due to base failures occurred. However, a part of this section still presents a fair surface.

The next section of this road was resurfaced with Amesite mixture (hot mix laid cold). The old concrete surface was given a light prime coat of emulsified asphalt, and the Amesite mixture was spread on the road approximately 1 3/4 inches in depth, raked, rolled, and opened to traffic. The resurfacing ravelled and peeled off the old concrete shortly after opening the road to traffic. The company selling the Amesite claimed we should not have placed a prime coat on the old pavement. Therefore, at their expense, they removed the entire resurfacing course, cleaned the pavement thoroughly, furnished and spread new Amesite approximately 2 inches in depth. This final course of Amesite has lasted well and is in very good shape after six years of hard service with very little maintenance.
The next section of this road was resurfaced with a 3-inch course of bituminous macadam (penetration method). The old concrete surface was given a surface treatment with cut-back asphalt and a light amount of stone chips scattered over the freshly applied treatment. No. 2 stone with the smaller sizes removed was then spread over the surface approximately 3½ inches in loose depth. Penetration asphalt was then applied to the stone and the course rolled. A small amount of key stone was added during the rolling. The surface was then given a treatment of liquid asphalt CB in the amount of approximately 0.3 gallon per square yard. Covering material, No. 4 crushed aggregate, was evenly spread over the surface in the amount of approximately 15 lbs. per square yard. The surface was again rolled and opened to traffic. This section is wearing unusually well to date.

The next stretch of road was resurfaced with a 3-inch penetration macadam with a ½-inch rock asphalt wearing course. The bituminous macadam was built very similarly to that just described, except that the surface treatment was omitted and the rock asphalt used instead. This course has worn very well except that, in the writer's opinion, it would have been much better had we used a ¾-inch instead of a ½-inch rock asphalt wearing course and had the surface of the bituminous macadam been closed tighter before the application of the rock asphalt.

The next stretch of road was resurfaced with rock asphalt 1 inch in thickness laid directly on the old concrete after it had been given a light prime coat of bituminous material. On this stretch we have experienced considerable difficulty due to base failures. The resurfacing course did not add much strength to the old pavement.

In 1929, the stretch resurfaced with emulsified asphalt and part of the stretch resurfaced with bituminous concrete was again resurfaced with our standard retread placed on top of the old resurfacing. This retread was laid approximately 2½ inches in thickness, using No. 2 stone and applying liquid asphalt CB by the mixed-in-place method. This stretch so resurfaced is in very good shape at present.

The old concrete surface on Road 9, north and south of Alexandria, was failing very badly. In the fall of 1927, we resurfaced some 2½ miles north and 4½ miles south of Alexandria with a 3-inch bituminous macadam course and a ¾-inch rock asphalt wearing course. Where the old concrete had broken badly, it was patched with cement concrete before placing the resurfacing course. This resurfacing was constructed in the same manner as described above in the bituminous macadam with rock asphalt wearing course. This resurfacing has stood up very well, and the maintenance cost of the surface has been very low to date.
SOME 1932 EXAMPLES

During the past season, we resurfaced some stretches of old brick and old bituminous macadam. On the brick section and parts of the macadam section, bituminous-coated aggregate with a rock asphalt wearing course was used. The old surface was given a treatment of emulsified bitumen in the amount of approximately 0.15 gallon per square yard, and bituminous-coated aggregate (pre-cote method) was then spread on the surface to an approximate depth of 2 inches. This bituminous-coated aggregate was delivered to the old surface through stone spreader boxes to gauge the amount used and was leveled mechanically by use of a planer drawn by a tractor, or by use of a Gledhill attachment on a 12-foot blade grader. Later the bituminous-coated aggregate was thoroughly rolled, and a rock asphalt wearing course in the amount of approximately 70 pounds per square yard was placed thereon. This rock asphalt was shoveled onto the road between metal strips which gauged the exact depth of the course. The surface was thoroughly luted and smoothed and then rolled once over with a 5-ton roller. The surface was then thoroughly leveled mechanically with a long base planer, and then rolled and opened to traffic. This resurfacing not only smoothed up an old surface that had become very rough and objectionable to traffic, but it also added considerable strength and, in my opinion, presents a surface that will show very little maintenance cost for some time to come.

Some of the old bituminous macadam stretches were resurfaced in accordance with our specifications AHMC (hot mix laid cold) spread to an approximate depth of 2 to 2½ inches and with a ¾-inch rock asphalt wearing course. In this bituminous-coated aggregate, we used No. 34 stone for coarse aggregate and penetration asphalt as a bituminous material. This AHMC mixture was placed on the old surface without a prime coat. The mixture was delivered onto the surface from end dump trucks, the end-gate being chained to gauge the amount put on. This course was then leveled with a 12-foot blade grader with a Gledhill attachment. A very smooth and uniform surface was produced. The AHMC was then thoroughly rolled and a rock asphalt wearing course placed thereon, by methods previously described. This method of resurfacing was very satisfactory. We leveled up the old base, added considerable strength to the old surface, and presented a smooth, non-skid surface for traffic. The cost of maintenance on this stretch of road should be very small for some time to come.

We resurfaced another stretch of bituminous macadam where it was necessary to reduce the crown (Fig. 1) and level up an old base that was adequate in strength but very rough. We used in this resurfacing bituminous concrete AHMC. In the binder course No. 36 aggregate was used in
Building curbs to new grade line as forerunner to elimination of high crown on a bituminous resurfacing job, U. S. Highway 40 west of Richmond.

The mixture. This binder course was spread thick on the edges and thinner towards the center of the roadway, reducing the crown and patching out the depressions. This binder course varied from $3\frac{1}{2}$ inches to 1 inch in thickness. We used No. 6 aggregate in the mixture for a top course. This top course was spread with a 12-foot blade grader with a Gledhill attachment and varied in thickness from practically nothing to $\frac{3}{4}$ of an inch, thus patching out many of the smaller depressions not taken care of by the binder course.

A prime coat is not necessary when using bituminous concrete AHMC. This last stretch described had ample strength in the old surface, but was very rough and was resurfaced primarily to smooth the surface rather than to add bearing strength. This work was all done under traffic, the traffic using one side of the road while resurfacing material was placed on the other. Traffic may be permitted on bituminous concrete AHMC immediately after it is rolled without damaging it perceptibly.

An old stretch of badly worn cement concrete was resurfaced with bituminous-coated aggregate (Pre-cote method). This resurfacing was approximately 2$\frac{1}{2}$ inches in thickness laid as follows: The old concrete surface was given a prime coat of emulsified bitumen in the amount of approximately 0.15 gallon per square yard. The binder course, using No. 34 crushed aggregate in the mixture, was then spread at an average depth of about $1\frac{1}{2}$ inches. This binder course was leveled by use of a Gledhill attachment on a 12-foot blade grader and by a roller. We then placed a wearing course of bituminous-coated aggregate, using No. 6 aggregate in the
mixture at the approximate depth of 1 inch. This course was leveled by use of a Gledhill attachment and thoroughly compacted by rolling. A surface treatment was then applied, consisting of emulsified bitumen in the amount of about 0.25 gallon per square yard and coarse sand covering spread evenly over the surface. Tests of the bituminous-coated aggregate used in the binder course show approximately 3 1/2 per cent bitumen and in the wearing course 4 1/2 to 5 per cent bitumen. We experienced some slight ravel in this section, but, as a whole, it presents a very good surface that should not cost excessively for continued maintenance.

Some three or four years ago an old brick section was resurfaced and widened with our standard retread approximately 2 inches in depth. The old brick surface was very rough and showed signs of weakness at many points. Furthermore, the old road was high crowned, and it was necessary to vary the thickness of the retread to bring the finished surface to the proper cross section. This retread surface, because of variance in thickness, etc., was none too smooth, and during the past season this portion of road was again resurfaced, using approximately 110 pounds per square yard of bituminous-coated aggregate finished with a very light application of rock asphalt as a wearing course. Crushed stone, size No. 46, was used in the bituminous-coated aggregate. After the bituminous-coated aggregate had been leveled, planed, and rolled, a thin coat of rock asphalt was spread evenly over the surface in the amount of about 12 to 15 pounds per square yard and then again rolled. This rock asphalt did not entirely cover the surface, many of the stones in the bituminous-coated aggregate still showing. However, the rock asphalt served as a seal coat and helped to smooth the surface and to provide a wear-resisting, non-skid surface that should require very little maintenance for several years. While this particular surface has not been in service long enough to give definite conclusions, it is apparent that the addition of the small amount of rock asphalt makes a very good seal and, in all probability, will eliminate the necessity of subsequent surface treatments ordinarily required on retread or bituminous mix surfaces.

COST DATA

Resurfacing approximately 2 inches in depth, using bituminous-coated aggregate (Pre-cote method) finished with a seal coat of emulsified asphalt and fine chips or sand, costs approximately 40 cents per square yard. The cost of resurfacing old brick and bituminous macadam, as described above, with a 2-inch binder course of bituminous-coated aggregate or bituminous concrete and a 3/4-inch rock asphalt wearing course is approximately 30 to 35 cents per square yard for
the binder course and 35 to 45 cents per square yard for the wearing course, or a total of 65 to 80 cents per square yard. These costs vary somewhat in different localities, because of the proximity of local materials or variance in freight rates. For the resurfacing described above, where only 100 to 110 pounds per square yard of bituminous-coated aggregate were used as a binder course and 12 to 15 pounds per square yard of rock asphalt were used as a wearing course, the cost for the total resurfacing was a little under 30 cents per square yard.

In this paper, I have described several methods which have been used in resurfacing state highways within the past few years; and from our experience with such resurfacing, I wish to emphasize some of the main points that I believe should be carefully considered.

1. Consider the amount and kind of traffic that is to use the road.
2. Consider carefully the strength of the old pavement to be resurfaced.
3. Look into the availability and cost of possible resurfacing materials.

With these data at hand one can better design the proper section to be used in such resurfacing.

Many miles of pavement have been constructed within the past few years. When these pavements have worn to such an extent that maintenance costs begin to mount, it is economy to resurface them. Bituminous mixtures lend themselves very readily to that work and present probably the most economical method of handling the problem.

RESURFACING ROUGH PAVEMENTS WITH THIN LAYERS OF BITUMINOUS MIXTURES

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The resurfacing of rough pavements with thin layers of bituminous mixtures is a subject of increasing importance as our older pavements begin to show signs of failure, wear, or disarrangement as result of increasing loads and action of the elements. This is of greater concern to the city official, responsible for the maintenance of streets, than it is to county and state highway officials.

Resurfacing of rough pavements has a further appeal at this particular time because of the strained financial condition of the country at large and the resulting inability of the tax-paying public to finance reconstruction. In other words, the