BITUMINOUS PAVEMENTS

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(A) BITUMINOUS MACADAM

Bituminous macadam is a pavement built in a similar manner to the ordinary waterbound macadam, with the exception that the coarse crushed stone of the top course, spread and rolled in place, is penetrated with heated bitumen. This wearing course is then keyed, sealed and well rolled.

Considering the design of bituminous macadam as a flexible type of pavement, we are necessarily concerned with the subgrade as well as the surfacing materials The identification and means of stabilizing subgrades has been considered by another subcommittee It will be assumed that the results of that research work is available elsewhere in this report. This paper will be limited to a consideration of the factors affecting the design of the penetration or top course only of a bituminous pavement.

Practically no planned research work has been done to date to check up on the design of bituminous macadam pavements as they are now being built Design as used in various localities is mainly the result of observation and experience covering a period of some fifteen years. Some experimental work has been done by the United States Bureau of Public Roads on the action of pressures distributed through compacted sand, and an analogy may be drawn between these results and those produced by pressure applied to bituminous macadam pavements Improvements, based on the results of tests on other types of pavement, have been suggested, and two or three states are now experimenting with cross sections having thickened edges and stepped construction for the base and subbase.

A considerable amount of attention has been directed to this type of construction during the past few years, and numerous articles, giving the details of design and construction as practiced in various sections, have been written Mr I. W Patterson covered the fundamentals of successful design in Rhode Island in an article in Engineering News-Record in 1919. This has been amplified and brought up to date in a recent article by the writer An excellent theoretical discussion of the forces at work and the problems to be dealt with in building a bituminous macadam road was presented by Mr. A. T. Goldbeck at the Fifth Annual Asphalt Paving Conference in Washington, D. C, in 1926.

The following conclusions, or strong indications, are more the result of personal observation and the experience of others (as noted) than the result of extensive research:

Strong Indications. This type of surface being a flexible type of pavement requires a good subgrade support—this may mean the addition of subbase or foundation courses to adequately support the top course (1).*

No fixed standard design is applicable to all sections of the country, owing to differences in the character of materials reasonably available for constructing the pavement

A rough rule to follow in building a penetration top course, that has been checked many times in practice, is that the maximum size of stone (in inches), the depth of the course (in inches), and the amount of asphalt used (in gallons per square yard) is approximately the same. In other words, 2½-inch stone in a 2½-inch course will take approximately 2½ gallons of asphalt

With a hard, tough stone available, a uniform depth of from 2 inches to 2½ inches, with stone sizes limited between 1½ and 2½ inches, seems to give the best results for the surface course (7a) * With softer stones the depth of top course and size of stone should be increased A depth of 3 inches, involving the use of coarse stones of a size up to 3 inches and 3½ inches, has proved successful in certain localities

A French coefficient of less than 10 may usually be regarded as a soft stone, and, therefore, requires the larger sizes.

Uniform depth of the penetration course and ultimate good riding qualities of the surface can be ensured by thoroughly consolidating each subcourse and bringing it parallel to the finished grade and cross section (7a) * All soft spots in one course should be eliminated before the next course is added

Uniformity in size of aggregate is particularly desirable in the penetration course in order to obtain a uniform distribution of voids for penetration (9).*

The resistance of a bituminous macadam surface against waving is largely dependent on the uniformity of size and mechanical bond or interlocking effect of the crushed stone and quantity of bitumen It is important that thorough rolling be given to firmly lock the stone together.

The use of hard, tough stone in the surface course is highly desirable, even if softer stone is used in the base course (5).*

* See Bibliography.

A transverse slope of from $1/4$ inch to $3/8$ inch per foot is satisfactory under most conditions

The rolling of all stone courses from sides toward center is necessary to obtain a well-bound stone course of the desired contour

Before applying bitumen, the stone should be dry and clean.

Mechanical distribution gives more uniform and better results than hand-pouring, provided the distributors are properly designed to heat the bitumen and to produce uniform pressure on varying grades (4) *

An excess of bituminous material is one of the known causes of lack of stability and one of the evils to be guarded against in bituminous macadam construction

There is a very definite trend toward the use of stiffer bitumen for penetration macadam work (11) * Asphalt of from 85 to 100 penetration appears to be widely used.

Key stone for binder course and the chips for the seal coat should be of such a size and so applied that they will wedge the top course tightly in place without building up a layer on top of the coarse stone An excess of stone in these key courses is undesirable.

Best results are obtained from this type of construction when the crushed stone in the surface course is exposed and allowed to take the wear, the binder and seal coats simply filling in the voids on the surface

Re-seal coats are not usually needed for a period of years unless signs of disintegration are distinctly evident (7a) *

The practice of extending base and subbase courses out sufficiently to properly support the penetration course is slowly being adopted (7d).* Thickened-edge designs have also been advocated for this same purpose

Building shoulders of selected material and oiling same is considered good practice to furnish lateral support to the edge of the penetration course(7a).*

Back-rolling after bitumen has been applied cannot be overdone(7a) * The best results are obtained from this back-rolling when the bitumen is warm

The cost of maintenance of this type of road when carefully designed and constructed compares very favorably with that for more expensive pavements(10).*

Maintenance methods giving most satisfactory results involve the use of materials and construction methods similar to those used in the

* See Bibliography

original construction This usually means a gang patrol system supplied with the proper equipment for this work

Experience shows that a properly constructed bituminous macadam on a firm subbase provides an agreeable road to ride upon and one which will stand up under heavy mixed motor-vehicle traffic for a long term of years Many bituminous macadams have been credited with failing when the real failure was in the subbase Bituminous macadams in service for twelve years or more on roads carrying as high as 15,000 maximum daily traffic show little or no surface wear

Research in Progress We are unaware of any research now in progress that has definite application to this type of pavement, unless the trial of new cross sections as adopted by Ohio and Indiana may be thought of in this light

Research Work Suggested Measurement of intensity and distribution of pressures produced by wheel loads acting through a penetration macadam top

Trial of various types of thickened-edge design.

Effect of size of stone on stability

Study of smoothness

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(B) PRE-MIXED TYPES

Under this heading comes all the bituminous mixed types of surfacing, except natural rock asphalt, ranging from coarse graded con cretes, with or without special grading and filler, to sand asphalts and the more highly developed sheet asphalt mixes The present design of most of these types is the result of experience and usage in various localities Sheet asphalt and the finer graded mixtures, however, have been subject to special research during the past few years.

A new school of asphalt paving has been developing Specifications and requirements dictated by the experience of a few pioneers in asphalt paving had been accepted because they seemed to work out fairly well Careful observers, however, had repeatedly noted that, where certain requirements had been violated, no bad results had followed and in some cases superior pavements had been developed. In 1926 in Chicago a new association was organized for the specific purpose of investigating and studying all phases of asphalt paving This organization is known as the "Association of Asphalt Paving Technologists" Their efforts have been confined mainly to studies of the finer mixes in an effort to find out the fundamental principles underlying the control of the stability or resistance to displacement of the completed mixtures as they are used in pavements

As a discussion of the facts or strong indications brought out by experience in the construction and use of all of the mixed-type pavements would be beyond the scope of this paper, we will limit ourselves to a statement of some of the strong indications brought out by active workers in the above association Messrs Hubbard and Field in an article on "Researches on Asphalt Paving Mixtures" have ably summed up most of the early work (7a).* The following conclusions give the result of more recent research

Strong Indications Experimental work has shown that sands which previously were refused as being too coarse or too fine may possibly be mixed with a greater amount of different fillers, within limits, and lesser amounts of asphalts, to give good stability results (7a).* It is becoming apparent that the problem is merely one of combining asphalt with the materials which are at hand in an intelligent way

Of two theories advanced for asphalt paving design—*i e.*, "surface area" and "voidage"—results obtained from shear strength of asphaltic mixtures seem to show that the "surface area" theory is untenable and that "voidage" relationship is a positive basis for mixture design (15b).*

An excess of bitumen in a high-filler mixture causes a sharp reduction in shear strength

* See Bibliography

Various fillers have a surprising difference in their effect on shear strength.

Stability of a given mixture is almost directly proportional to its degree of compaction (15c) *

It is extremely desirable to secure maximum density and uniform stability during the construction of a pavement

Dense modern mixtures can best be obtained by the use of a heavy roller for initial compression.

As measured by their "stability tests," higher values of stability than those ordinarily obtained may be necessary in a pavement which has to meet severe traffic strains such as sudden stopping and starting

The "stability test" properly used and interpreted may be of considerable value as a means of analyzing the past performance of existing pavements and the probable future behavior of new pavements under various traffic conditions

Reduction of voids by compression of the mineral aggregates exerts a much greater stabilizing effect than the mere reduction of voids in the entire mixture (14) *

Any attempt to proportion asphalt in a mixture with the idea of filling the voids completely may result in the use of too much asphalt with a marked reduction in stability.

From the standpoint of stability, mixtures should be designed so as not to be completely voidless even after thorough compression during construction.

To secure maximum stability the percentage of asphalt may be controlled within much narrower limits for high-filler, low-void aggregates than for low-filler, high-void aggregates

Of all the physical characteristics of asphalt which are usually determined, penetration at 77° F appears to exert the most direct and definite effect upon the stability of the mixture at all temperatures, and a general increase in stability, produced with a given mineral aggregate, accompanies decreases in the penetration of the asphalt.

Next to the closeness of packing of the mineral aggregate, the percentage of filler appears to be the greatest stabilizing factor and, provided the proper proportion of asphalt is used, increased stability is invariably produced by increase in filler up to a certain maximum after which further increase of filler causes a falling off in strength

The stability of a given compressed mixture appears to be directly proportionate to its temperature, increasing as the temperature decreases.

* See Bibliography

Sharpness of sand grains has a marked influence on the stability of asphalt mixtures (15d).*

This influence persists even after the addition of limestone dust

Relative stability is not dependent upon the density of the mixture

It has been definitely established that increasing the percentage of filler, decreasing the percentage of asphalt and hardening the asphalt will produce a more stable pavement, but it is not as yet determined just how far construction methods should proceed along these individual lines (13) * Using the stability test as developed, it is hoped that in the near future the influence of various climatic and traffic conditions will be evaluated properly with relation to stability at a high temperature and resistance to cracking at a low one Until this work is advanced further it is particularly dangerous to proceed to extremes in hardening the asphalt cement or in reducing greatly the percentage in the paving mixtures, as it is believed that the longest serviceable life and greatest resistance to cracking will be obtained from mixtures carrying the largest percentage of a moderately soft asphalt, producing the degree of stability required by the traffic and climatic conditions which it will have to meet

In some tests made by Leon Archibald, B Sc., (11)* in the experimental engineering laboratories of the University of Minnesota, concerning the effect that various kinds and quantities of mineral dust filler had on an asphaltic concrete pavement, the following conclusions were reached:

"The quality of the different fillers in this investigation was somewhat incidental, each one gave results which might be characterized as good; their individual use seems to be determined by local conditions. From the results obtained, it is apparent that the ideal amount of mineral dust filler in asphaltic concrete approaches very closely to 16 per cent by weight."

Tests measuring the internal temperatures of asphaltic pavements, as conducted by the Bureau of Public Roads, showed that pavement temperatures are higher than air temperatures and that certain asphaltic paving mixtures, notably those containing excessively high percentages of bitumen for the accompanying aggregates, are susceptible to displacement under traffic (12) * Such weakness is particularly manifest during warmer seasons Pavement behavior, frequently explained on the basis of traffic only, should be analyzed also with regard to the prevailing climatic conditions at the time such traffic is imposed

* See Bibliography

The deteriorating effect of dripping gasoline is low when the mixture has well-balanced percentages of bitumen, stone and sand filler (15g).* It is also low when a slight excess of bitumen, from the standpoint of the "stain test," is present.

Research in Progress. The "strong indications" noted above should be considered as progress reports because most of the investigators realize that they have not solved all their problems in connection with the behavior of the combined aggregates as they are used in the road.

Suggestions for Further Research The following items appear to need further investigation:

Determination of the limits of the physical properties of aggregates rendering satisfactory service in bituminous mixed type pavements; i e., abrasion and toughness of stone, etc , etc.

Development of apparatus for determining stability of mixtures containing larger sizes of aggregates than those used in the finer graded mixes

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(C) BASES AND SUBBASES

Bases and subbases designed as a support for bituminous pavements have usually been prescribed to fit particular local conditions Changes in the character of subsoil at frequent intervals are common in many parts of the country. No one design is, therefore, economically available as an efficient cure for all cases Considerable research has been done in an effort to identify dangerous subsoils and to provide simple field tests for warning engineers of their presence Reference to the report of the Subcommittee on Subgrades will give the present status of these studies To date an intimate knowledge of the behavior of soils in a given locality, combined with inspection during winter and spring thaws, has enabled many designers to recognize conditions needing correction The details of this procedure are undoubtedly covered in the report just mentioned

Experience has brought out the following strong indications with regard to the construction of bases and subbases

Strong Indications On light, well-drained and well-compacted subsoils a subbase is usually not needed

When tight, unstable soils are encountered, recourse may be had to special treatments to remedy conditions as found.

Foundations and drainage are frequently used to cure these poor conditions and provide a foundation for the base and top courses of bituminous pavements that will give uniform support under all conditions of temperature and moisture

Common practice today in northern states where stone and gravel is common is to remove the unstable subsoil and use gravel or stone foundations in its place Conclusions reached as the result of this practice are as follows:

Stone Subbases Stone foundations or subbases have been found particularly advantageous in ledge cuts for draining low pockets and taking considerable amounts of free water from seams and springs to low points where it may be conveniently tapped

In the use of stone foundations on subsoils which may have a tendency to become very unstable and even reach a liquid consistency during spring thaws, it is well to provide a mat of 2 inches to 6 inches of well-graded sand or other fine granular material over the subgrade before the stone foundation is placed

Filling interstices of a stone foundation should be done with a coarse, light gravel or sand that will allow free drainage of water to points of spill

Stone should ordinarily be laid flat and should break joints This provides a maximum bearing surface for all stones and gives maximum support for loads applied on surface. The practice also helps to prevent the intrusion of subsoil into the stone base courses, especially when a sand mat has not been provided

Taps or weep holes of liberal dimensions should be provided at frequent intervals to release the water as soon as possible to proper drainage structures

Gravel Subbases Coarse, heavy gravel is usually specified for gravel foundations A minimum of 40 per cent of the gravel retained on a 1-inch screen is desirable. This not only provides good stability for the trucks placing material, but also prevents a considerable loss of crushed stone applied on the base course

Sand passing ½ inch mesh should not have more than 25 per cent passing a 40-mesh screen, and should be reasonably free from clay, silt and loam Silt removable by elutriation should not exceed 7 per cent. These requirements ordinarily provide for a coarse, free sand that will not readily retain any great amount of water. Taps should be provided at frequent intervals.

The degree of stability which a gravel will attain in a foundation course and its ability to get rid of free water is usually evidenced by the way it acts in the floor of the gravel pit from which it is taken.

Ordinarily no quality conditions other than size and silt content have been used to date as a gauge for the suitability of gravel for use in gravel foundations

In southern New England a layer of gravel 12 inches deep will usually cure the worst subsoils encountered, while layers from 6 inches to 9 inches deep are frequently used.

Extension of foundations beyond the width of top courses and occasionally through the shoulder to the ditch line is coming more and more into use. A design which carries the gravel up into the shoulder for one or two feet adjacent to edge of pavement has also been successfully used and provides better lateral support for the wearing courses than the usual soft shoulder.

Bases. Bases used for bituminous pavements have been of many different kinds (1 and 12).* The chief requirement is stability under all conditions of weather and traffic Based upon this requirement, we find that old pavements, having no inherent weakness, may be used for bases. Wide experience has shown this to be practicable Care should be taken in widening the old surfaces, however, to provide equal stability in the sections added.

A correction of crown on the old pavement to agree with the new contour and the elimination of weak areas is the principal requisite in adapting these old pavements for use as bases (2c).* This work is usually accomplished by the use of various hot mix types called "black base," and also by penetration courses

Good gravel roads have been used for bases in "stage" construction (5)* Gravel containing a high percentage of clay cannot be depended on to carry heavy loads during the spring thaws in the frost belt or in localities where the subgrade is likely to be wet for considerable periods (5)* Careful maintenance of gravel roads previous to time of application of the top course with the idea of eliminating all soft spots and bringing the surface of base course truly parallel to the finished surface has been extensively used

In areas where gravel and stone is scarce and sand plentiful, there has been developed a "sand-asphalt" base course (6).* This has been successfully used in North Carolina and does not call for the use of filler. Analyses show approximately 91 to 94 per cent sand and 6 to 9 per cent bitumen in the 3-inch base course, with 89 per cent sand and 11 per cent asphalt in the 1½-inch top

"Black base" has been widely used for base courses (2b, 7b, and 10b).* This term applies to a coarse hot-mix bituminous concrete generally designed for use under a more carefully graded top course. Typical analyses show 53 to 70 per cent coarse aggregate from

* See Bibliography

2½-inch to ¼-inch size, 25 to 40 per cent sand or stone dust passing ¼-inch, and from 4 to 7 per cent bitumen Sound crushed stone or gravel is usually acceptable as a coarse aggregate. Little or no fine filler has to be added The thickness of this base seldom exceeds 4 inches on new work. It is often used for evening up or strengthening old pavements before a new top is applied.

Where reasonably good stone is available, crushed stone base courses from 4 to 6 inches thick with stone from 1-inch to 4-inch size are used (7c).* These are thoroughly rolled and then filled with either sand filler, stone dust or bitumen When a stone foundation course is in place, the thickness of this stone base course is usually reduced to an approximate depth of 2½ inches and used merely to even up the rough subbase course

Cement concrete in a 5- to 6-inch layer is extensively used for supporting bituminous pavements (11) *

As can be seen from the description of the various bases, most of these are of a flexible type and depend entirely upon the support given them by the subbase or natural foundations for their maintenance of line and grade. In finishing the surface of these bases, the usual procedure is to leave a fairly rough open texture to help the bond with the wearing course A vital requirement is that the surface of the base should also be finished truly parallel to the finished grade and cross section, so that when the surface mixtures are spread out they will compact to a uniform depth and give and maintain good riding qualities so readily obtained with bituminous pavements. The construction of wider base courses to properly support the edges of the wearing surface is coming slowly into use and has been adopted as standard practice by one or two states (5 and 12).*

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RESEARCH IN PORTLAND CEMENT CONCRETE PAVEMENTS

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As one reviews the progress in the development of a rational method for the design of concrete pavements during the last decade, two facts are apparent. First, that there has been really remarkable progress, and second, that there are still matters which need study and investigation

We are, today, in a position to more nearly design such pavements in a rational manner than ever before and, whatever information may still be lacking, many of the findings of the intensive research of this period have been accepted and are being generally applied This is a definite indication of progress

That there are still questions pertaining to concrete pavement design which must be answered by further research is evident when one considers the variety of practices among the various states concerning certain features of design. That this difference of opinion exists does not necessarily mean lack of progress in this field or that research has failed to supply data on the point in question Rather, it should be taken to mean either that there are factors whose existence is acknowledged but whose influence on the behavior of concrete pavements is not yet fully understood, or that the difference of opinion concerns details rather than principles and that there is need for more information regarding the details