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The problem involved in constructing a pavement or resistant surface on the top of the ground which will withstand both the destructive effect of vehicles and the weather is not a simple one. It is hardly possible to set forth the essentials in a brief or simple manner. Opinions are necessarily colored by the experience of the writer in the field and in the laboratory, and some viewpoints may require modification as time passes. However, there are certain general principles which apply to all types of surfacing, and experience gained in one field should find application in related work.

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DESIGN OF BITUMINOUS PAVING MIXTURES

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The problem involved in constructing a pavement or resistant surface on the top of the ground which will withstand both the destructive effect of vehicles and the weather is not a simple one. It is hardly possible to set forth the essentials in a brief or simple manner. Opinions are necessarily colored by the experience of the writer in the field and in the laboratory, and some viewpoints may require modification as time passes. However, there are certain general principles which apply to all types of surfacing, and experience gained in one field should find application in related work.

Factors Influencing the Selection of Surfacing Type

Among the first considerations are the factors influencing the selection of the type of surfacing. This discussion will, of course, proceed on the assumption that costs or other factors have indicated a bituminous type. However, there are many varieties of bituminous pavements or wearing courses, and the selection of the particular type should be made with due consideration for the mineral aggregates available, weather conditions which will prevail throughout the construction and service periods, and also the type of construction equipment available.

The mineral aggregate may range from local top soil, sand, gravel, commercially produced crushed stone, or any combination of these various materials. The first step would be to study the available materials which might be used in construction and determine the cheapest source or combination. The selection of aggregate, however, cannot be made alone on the basis of cost delivered on the job. The local soil in place would doubtless be the cheaper, but might often require a quantity of oil and be so difficult to mix as to more than offset the cost of importing coarser aggregate.

Stormy weather conditions prevailing would definitely discourage mix-in-place type of construction, and would inevitably indicate plantmix as the only practicable means; but then, again, mixing plants are not always available.

Enumerating these points even in considerable detail does not add much to the original statement that the selection of the type of bituminous surfacing depends upon the funds available, the mineral aggregate, prevailing weather conditions, type of equipment, and may also be influenced by the character of the existing soil or foundation. Other things being equal, however, considerable economy will usually result from design aimed at utilizing the cheapest available aggregate, and the cheapest aggregate is most often that which requires the shortest haul to the site of the work. Mix-in-place is often a satisfactory type of construction, and may be utilized where the material on the ground is of suitable quality and where considerable periods of warm, dry weather are assured. If the aggregate must be transported to the road and/or weather conditions are unsatisfactory, the plantmix process of construction may be the most economical and certainly is generally the most satisfactory. It is invariably a far more uniform and assured method of construction.

In other words, it is possible to produce excellent surfaces by the mix-in-place or roadmix method, but the process is definitely uncertain, and taken over a period of time and on a number of projects, a considerable percentage of the work has always been more or less unsatisfactory. Plant construction, on the other hand, is much more positive and if properly designed and controlled, failures due to variation in the mixture can be almost entirely eliminated.

The question of the equipment available would seem to need little discussion. It is self-evident that if one does not have the equipment to do what he would like, it remains only to do the best possible with whatever is available. Broadly speaking, however, plantmix construction is preferable to the mix-in-place type at anything like a similar cost.

Principles Covering Mixture Design

There are many types of road surfacing in which the mineral aggregate is bound together by some type of bituminous material. The several types or variations have been given names, and in many cases sharp distinctions have been drawn, so that the layman and quite often the engineer is apt to feel that they have little in common. As a matter of fact, differences between the various types is largely only a matter of degree.

Most asphaltic binders are residues from the distillation of asphaltic base crudes and may vary in consistency from very fluid road oils and cutbacks to hard paving asphalts. However, all road asphalts are liquids which vary chiefly in degree of consistency or fluidity.

Mineral aggregates also vary. They may consist entirely of sand or fine particles, as in the case of sheet asphalt pavement, or may consist almost entirely of coarse particles, for macadam design. There are also numerous types of open and dense graded mixtures which include both coarse and fine aggregate.

Each of the above types have their advantages and disadvantages, and all have their loyal exponents. There are large areas, whole states in fact, where the prevailing construction is of the macadam type. Macadam type of construction utilizes coarse rock, usually crushed particles, which is spread upon a prepared subgrade and the layer of stone impregnated with asphalt by the penetration method. Such construction produces a pavement with large void spaces and a relatively small number of points of contact between the particles of aggregate. The percentage of asphalt by weight is usually not high, probably ranging between three and four per cent by weight of the average. Due to the low surface area of the coarse aggregate, the film thickness, or coating of asphalt, is quite heavy. One advantage of the macadam type of construction is the possibility of using coarse rock, and when aggregate is produced from crushing ledge rock, this fact is an economic advantage. The heavy film thickness of asphalt tends to resist weather action. The large rock with few points of contact and large void spaces makes a pavement type that is not critical. The disadvantages are that such construction is difficult to place to a smooth riding surface, the large voids provide easy entrance of water, and it is usually necessary to apply a heavy seal coat treatment at intervals in order to prevent the entrance of water. <u>If the foundation material is clay-like or has any tendency to become soft and plastic, it will work up into a macadam pavement and destroy the stability.</u> It should only be placed on a firm subgrade which is unlikely to become soft and plastic. This type of surfacing, however, has greater flexibility and will deflect to a greater degree without cracking than will the fine graded mixtures.

The most widespread type of pavement, throughout the Western States at least, is the dense graded mixed type. This pavement may utilize any type of bituminous product from road oil to hard asphalt, but for greatest economy and adaptability to local conditions is probably best represented by the type using road oils or liquid asphalt as a binder with local dense graded aggregate.

The grading of the aggregate may vary considerably and still provide a satisfactory surface. It is difficult to set forth the principles which cover particle gradation in simple terms inasmuch as they are variable and depend on a number of considerations. The simplest way to make the matter clear is to enumerate the most important qualities which a satisfactory mixture should have. It is then possible to describe the factors which affect these qualities. The mixture should produce a stable pavement; in other words, it should not groove, wave or otherwise deform under the action of rolling vehicles. High stability results from a mineral aggregate in which the rock particles are relatively rough and which possess a high degree of friction to resist sliding between adjacent particles. This friction must not be reduced by adding too great a quantity of lubricant to the aggregate; in other words, an excess of oil or water or both will lubricate the mixture and particles will move about with considerable facility, the result being an unstable pavement. The effect of lubricants, i.e. oil or water, is greater when the particles are small and the points of contact numerous than when the particles are coarse. In actual practice, then, stability is secured by adjusting the amount of asphaltic binder to the particular aggregate and by reducing the moisture content as low as possible, preferably below 1½% by weight.

It is also good practice to avoid an excess of fine dust, as such mixtures are critical and instability most frequently occurs in mixtures with a high dust content. This is not to say that very fine mixtures cannot be made to give satisfactory results, only that it is much more difficult to produce a stable product.

A satisfactory surface should not ravel or fail from abrasion. Raveling is due to a deficiency in binder and is always curable by increasing the amount of oil. With these two items, then, the amount of oil or asphalt for proper design lies between the excess which will produce instability and the deficiency which will result in raveling.

Permeability Considerations

Another important consideration in pavement design involves the passage of water through the pavement. This matter is not nearly as simple as it was once thought to be. A great many failures have occurred because rain water or melting snow percolated through a porous pavement, saturating the foundation soil to such an extent that bearing power was greatly reduced. The widespread belief in the necessity for seal coats originated largely from these experiences.

However, while there is a great deal of evidence to show that porous pavements have been the cause of failures, it is now being recognized that natural soils and subgrades will have good bearing value and support considerable loads so long as the moisture content is maintained at some equilibrium, and this equilibrium is often realized only when evaporation of ground water takes place. In other words, the water rises upward through the soil slowly and evaporates from the ground surface. Evaporation proceeds rapidly enough in many cases so that water does not become concentrated in the upper layers and the soil has considerable supporting power. If this soil is covered by an impervious pavement, however, so that evaporation is prevented, water will slowly accumulate until the liquid limit is reached, and if the subgrade is a plastic type, the supporting power will be destroyed.

Therefore, it becomes necessary to know in advance whether or not it is safe to place an impervious blanket over an existing roadbed soil.

This condition may be met in several ways. The natural plastic soil might be covered with a layer of harsh, granular material which is not readily lubricated by water and which will retain its stability even though the moisture content is quite high. Another method which is being considered in several areas utilizes the construction of a relatively dense graded pavement in which the pores or voids are small enough to prevent the entrance of any quantity of rain water, but which will permit the suspiration of water vapors from the subgrade. Such a design is quite within the bounds of practicability and would seem to offer a solution to the problem at the lowest cost. It may be, however, one of those expedients often described as, "a good trick if you can do it."

As said before, almost any gradation of aggregate may be used for the mixed type of construction, although the coarser dense graded types without excess dust are preferable.

Resistance to Water Action

There is another property of mineral aggregates, however, which must be recognized if the pavement is to be durable and resist the action of weather. All types of rock or gravel are not equally suitable for combination with asphalt.

Asphalt will wet and adhere to some rock surfaces very strongly and cannot be readily displaced. There are other types, however, in which the asphalt is readily washed off by water. This whole effect is due to selective or preferential adsorption and there are a great many variations and ramifications of the phenomenon. Generally speaking, asphalt will adhere strongly to limestone and trap rock, and does not adhere well to siliceous material such as quartz, chert, etc. Mineral aggregates are classified in this regard as hydrophilic (water-loving) or hydrophobic (water-fearing). The hydrophobic types are much to be preferred for bituminous construction. All aggregates should be tested to determine their relative affinities for water and for asphalt. A strongly hydrophilic aggregate should not be used unless adequately protected.

Selection of the Asphaltic Material

Selection of the asphalt material depends largely on the type of construction; in other words, it is impossible to use hard asphalt in roadmix work, hence roadmix operations require a fluid product which can be handled under the prevailing conditions. Very fine mineral aggregate requires a light oil of low viscosity, whereas a macadam type inevitably demands a much heavier binder. There is nevertheless a considerable range of asphaltic products which can be utilized in the various types of construction and the choice must depend somewhat on weather conditions and largely on the degree of hardness - rigidity or freedom from brittleness which is desired in the completed pavement.

Determination of Proportions of Asphalt and Aggregate

The determination of proportions of asphalt and aggregate is affected to some extent by the conditions of service, but most definitely by the character and grading of the aggregate. It has been demonstrated that it is possible to produce stable surfacing layers with almost any grading of mineral aggregate with a wide variety of mineralogical types ranging from very soft to very hard particles. These successful surfaces, however, must in each case have the bitumen content proportioned to suit the individual requirements. A number of formulae and methods have been proposed and many are still in use for making this determination. In California, we proceed on the assumption that the amount of asphaltic binder is directly affected by the amount of superficial surface presented by the aggregate. In other words, each grading and type of mineral aggregate requires that a certain film thickness be spread over the particle surfaces, and this thickness of film must vary depending on the fineness of the grading, character of the particles and the grade of asphalt. In California highway practice the amount of asphalt is estimated from surface area analysis or the Centrifuge Kerosene Equivalent Test. The calculated results are checked by means of Stabilometer Tests.

Almost all of the desirable properties of a bituminous pavement encourage the use of a high percentage of bitumen. For example, resistance to weather attack, resistance to abrasion, self-healing of cracks, latitude for reworking, etc., are all considerations which are benefited by a comparatively rich mixture. Stability, however, is always reduced if the bitumen content is too high, and in many cases non-skid qualities are reduced by too much asphalt.

To sum up the situation, then, the bituminous pavement must have several distinct and separate properties in order to meet the multiple demands which are made on the pavement.

Stability

The pavement must be sufficiently stable in order that it shall not become rough or corrugated under the action of rolling loads or under the drag of brakes. Many types of apparatus have been devised for testing this property in the laboratory. Following is a partial list: An impact test by Besson; rod penetration by McNaughton; ball penetration by Howe; compression and radial fracture determination by Taylor; compression test by Ulman and Milburn; shear tests by Skidmore and Abson, and by Stokes and Zapata; and a complex shear by Hubbard and Field. In California, we have our own stability test, the Stabilometer.

According to the viewpoint expressed here, the stability of the pavement is due to a combination of two qualities which are possessed to some degree by all bituminous mixtures and by most natural soils or granular materials. The resistance to distortion is apparently determined by the amount of friction between the particles of aggregate, aided by the cohesion developed by the binder. It is possible to test either of these qualities separately, and it appears that the stability under traffic is more significantly related to the friction than to cohesion, although cohesion can and does play a considerable part in certain cases.

Cohesion

One important factor which is often overlooked is that any steps taken to increase the cohesion resulting in greater density of the mixture and a high percentage of asphalt will often reduce the friction at the same time, and what may appear to be a gain in one direction is overbalanced by a greater loss in another. Nevertheless, some amount of cohesion is necessary for a successful pavement. As an offhand opinion, it would seem that an enriched surface using comparatively soft, pliable asphalt would be the most successful means. A soft ductile liquid such as 200-300 penetration asphalt can develop a tremendous resistance to high speed abrasive action. A relatively rich wearing surface is generally beneficial in promoting the life of the pavement.

Durability

It has long been known that asphaltic pavements require a certain amount of traffic or kneading to preserve their life and prevent them from going "dead." Recent studies on the characteristics of asphalt appear to offer an explanation for this often observed phenomenon. It appears that asphaltic materials when spread out in thin films over hard surfaces tend to alter in a manner which might be loosely described as crystallization or segregation; more precisely, there is a tendency for the colloidal material to flocculate under the influence of time, high temperature and sunlight. It is probable that the continuous kneading and working of the surface tends to remix or keep these materials in their original state. Whether or not this is the true mechanism, there is little doubt in the mind of anyone that richer mixtures have longer life and are much more durable. All of these considerations have led to our following one simple principle in mixture design - which is, use the greatest amount of asphalt which can be utilized without developing instability. But it should be borne in mind that in many cases the greatest amount is not necessarily a large amount.

To summarize then, in order to construct a satisfactory bituminous mixture, the first and most important essential is a good base and the type of gravel-clay mixtures that make the best type of gravel road usually make the poorest type of base for a bituminous surface. A crushed stone or gravel base should not contain more than eight per cent of material passing a No. 200 mesh sieve by wash analysis and should not have a sand equivalent value less than 30. The engineer should be given the information obtainable only from testing the aggregates intended for use in the bituminous mixture. It is not possible to estimate the amount of asphalt by the appearance of the mixture and such factors as the specific gravity of the stone, the degree of porosity, the sieve analysis and the roughness of the stone particles should all be evaluated by laboratory tests in order to know the amount of asphalt which should be included. Use of the sieve analysis and the Centrifuge Kerosene Equivalent method usually serve to give a very accurate indication of the amount of asphalt that should be used. All test procedures and design techniques are useless, however, unless the construction operations are carefully controlled. It is the primary function of the resident engineer and his assistants to establish and maintain uniformity and this is especially important in controlling the amount of asphalt. A wide variety in types and gradation of aggregate may be utilized but control and uniformity are essential in all cases.

SUPPLEMENTAL PAPERS

on

PAVEMENT DESIGN AND MATERIALS CONTROL

1. "Use of Stabilometer Data in the Design of Flexible Road Surfaces," Proceedings, American Road Builders' Association, March 1939, pp. 167-172.

2. "Gradation of Mineral Aggregates in Dense Graded Mixtures," American Road Builders' Association, March 1940, California Highways and Public Works, Vol. 19, No. 6, June 1941.

3. "The Centrifuge Kerosene Equivalent as Used in Establishing the Oil Content for Dense Graded Bituminous Mixtures," Proceedings, The Association of Asphalt Paving Technologists, January 1942, California Highways and Public Works, October 1946.

4. "The Design of Seal Coats and Surface Treatment," (Joint Author with W. R. Lovering and George B. Sherman) California Highways and Public Works, Vol. 28, Nos. 7, 8, July-August 1949.

5. "Density Versus Stability," (Joint Author with B. A. Vallerga)(Prepared for presentation at the Annual Meeting of A.A.P.T., Cincinnati, Ohio, January 28-30, 1952).