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Any attempt to discuss fundamentals or basic factors seems to lead sooner or later to a definition of terms and a consideration of nomenclature. One of the necessary steps in the process of Analysis is the grouping together of related phenomena or observations. Many observations and much valuable data have not been correlated because they seem to apply to unrelated fields. It is here that the question of nomenclature requires scrutiny, as it is a fairly common habit to accept without questioning an object or phenomenon which has been accorded a name. The engineer is as guilty as the layman in assuming that he knows a great deal about a matter because he knows what to call it.

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SOME BASIC FACTORS AND THEIR EFFECT ON THE DESIGN OF BITUMINOUS MIXTURES

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Any attempt to discuss fundamentals or basic factors seems to lead sooner or later to a definition of terms and a consideration of nomenclature. One of the necessary steps in the process of Analysis is the grouping together of related phenomena or observations. Many observations and much valuable data have not been correlated because they seem to apply to unrelated fields. It is here that the question of nomenclature requires scrutiny, as it is a fairly common habit to accept without question an object or phenomenon which has been accorded a name. The engineer is as guilty as the layman in assuming that he knows a great deal about a matter because he knows what to call it.

If all pavements composed of mineral aggregate bound together with some asphaltic product were considered under the one heading of bituminous mixtures, I do not doubt that we would have fewer differences of opinion as to what constitutes fundamentals. In a condition, however, where we have distinctive names, each of which conveys a somewhat different impression and covers a different group of experiences, we have wide divergences of ideas and much evidence that appears to be contradictory. Asphalt paving technology has been developed by a group of men who are individually acquainted with asphalt macadam, sheet asphalt, Topeka, asphalt concrete, rock asphalt, Bitulithic, Warrenite, Willite, and other patented types too numerous to mention, to say nothing of the more

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recent oil mixes, plant and road mix type, armor coat, multiple lift, retread, etc. These various names do have their useful purpose, but they also tend to leave our knowledge in separate pigeon holes. If all the known data are assembled and correlated, it is possible to detect any general principles which apply to all types. For example, one generalization common to all bituminous pavements is that they are composed of two essential ingredients - one of granular mineral aggregate and the other a liquid bituminous product of variable viscosity. The second universal condition is that all of these pavements, regardless of composition, must carry similar moving loads in the form of motor traffic on rubber tired wheels. The fact that bituminous pavements coming under any one of the above classifications can be constructed to carry considerable traffic without distortion indicates that the fundamental requisites for stability are sufficiently realized in every stable bituminous road surface regardless of type or designation.

By this simple process, it is then possible to decide which properties or factors are of fundamental importance and which are not. This approach immediately eliminates any particular gradation of aggregates as being essential to stability. It also indicates that the viscosity of the bituminous binder may vary greatly without losing the necessary stability. By considering all types to determine those requirements which are absolutely necessary, we can eliminate from consideration any particular aggregate grading, consistency of the bituminous binder, necessity for dense mixtures, the need for filler dust, hardness of aggregates, and any other condition or ingredient which is peculiar to some one type of bituminous pavement and does not exist in others.

It is realized, of course, that each of the various types of asphalt pavement have their individual advantages and disadvantages, and beyond doubt we will continue to see asphaltic materials used in many different types of pavement construction, and for sound engineering reasons. For example, sheet asphalt pavements have the advantage in construction for securing smooth riding qualities, but frequently develop a dangerous skid hazard. Macadam construction, on the other hand, is nearly always safe when wet, but smooth riding qualities are difficult to attain. There are many such pros and cons which might be enumerated at great length for the various types, and there is relative economy always to be considered.

In this light, it appears that a so-called fundamental, i.e. a basic essential requirement, is restricted to a particular property of the finished pavement. In other words, a fundamental requirement for stability may not be a fundamental requirement for impermeability. Steps to provide a workable mixture will not necessarily enhance the stability, and so on. Therefore, each esteemed property of the pavement must be secured by attention to its peculiar fundamentals. These various basic considerations are sometimes in direct conflict.

As an illustration of the application of fundamentals to a particular problem, the matter of stability will be discussed in some detail.

One property possessed by all masses of granular materials, regardless of size or shape, is some degree of internal friction which tends to resist movement or deformation of the total mass. The frictional resistance of solid particles under a given condition varies directly with the pressure to which they are subjected, is relatively independent of the speed of action, and independent of the area in contact. The observation that bituminous mixtures may develop stability regardless of variations in grading of the mineral aggregate is entirely compatible with this principle.

From this law it could have been deduced that bituminous pavements would be benefited by an increase in consolidation. The more effective the consolidation that is developed in the pavement, the greater will be the resistance to distortion. Experimental evidence and actual experience confirms this assumption.

Frictional resistance between two solid bodies may be lessened by separating them with a film of viscous liquid. Viscosity is a highly important quality of all lubricating oils. If the solid particles are completely separated by viscous liquid, any resistance to movement is then due only to the flow characteristics of the liquid, in this case the asphalt, and the law of liquid friction states that the resistance to movement of a viscous liquid between two parallel plates is relatively independent of the pressure, but varies directly with the speed of action and directly with the areas in contact. Examination of all types of bituminous mixtures offers no contradiction of this statement. However, a mixture of mineral aggregate and asphaltic binder forms a mass whose deformation characteristics will follow neither set of laws exactly, inasmuch as the surfaces in contact are neither wholly dry nor completely lubricated, and the difference between instability and stability of asphaltic pavements is almost without exception the difference between lubricated and unlubricated surfaces. Lubrication of pavement may be brought about by a sufficient amount of asphalt, oil, water, or a combination of two or more liquids, and is frequently enhanced by an excess of filler having unctuous characteristics.

From a consideration of this one quality of stability, it can now be concluded that bituminous mixtures possess only two fundamental properties which combine to produce stability of the mixture. One property is fractional resistance between the solid particles of mineral aggregate, and the other is frictional resistance in the films of bituminous binder. Liquid friction contributed by the asphalt may be variously designated as viscosity, cohesion, or tensile strength.

Both liquid and solid friction are variable, and in a pavement mixture may vary independently of each other, as the conditions which affect one may affect the other in an unrelated manner. For example, frictional resistance between the rock particles is enhanced by rough surface and angularity and by the degree of consolidation. It is not greatly affected by changes in grading or by density of the mass. Cohesion due to the asphalt is to some extent influenced by the character of particle surfaces, increases generally with increased surface area, and reaches its maximum for a given asphalt at the point of maximum density of the mixture. In bituminous pavements, the cohesion varies in a wide range with the temperature, with the consistency of the asphalt, and with the presence or absence of fine dust or filler.

Unfortunately, these two basic factors, which will henceforth be called simply friction and cohesion, do not contribute to stability either in equal degree or in kind, and it becomes necessary to decide whether to aim at increasing the friction or the cohesion or a combination of both, when designing the bituminous pavement.

High frictional resistance is obtained by selecting aggregates having a sandpaper-like surface texture, and with the quantity of asphalt maintained definitely below the total void volume. The percentage of voids which may be filled with asphalt is positively a variable, and differs for each type of grading and asphalt used. In other words, knowing only the voids in a mixture and with no other information it is not possible to determine the quantity of asphalt binder which will give the best results.

High cohesional strength can be obtained by use of low penetration asphalts and by increasing the quantity of fine sand and filler dust. Sheet asphalt mixtures, for example, develop very much higher cohesion than is the case with asphalt concrete. Asphalt concrete surface mixtures containing filler dust show much higher tensile strength than do base and leveling course mixtures without filler.

In order to decide how much of these two properties to incorporate in the design of a pavement, it is necessary to form some idea of their relative importance. For this purpose, the California

Laboratory used two separate instruments. The Stabilometer* is sensitive primarily to internal friction of the mixture and is affected to only a small degree by the cohesion. The other instrument, the Cohesiometer*, measures primarily the cohesion of a compact specimen, and is affected not at all by the frictional resistance of the aggregate. For example, a sample of sheet asphalt mixture compacted equivalent to pavement density has shown no difference in the Stabilometer value when tested at any temperature between 70° and 140°F. The same specimen in the Cohesiometer, however, showed a great increase in cohesion at colder temperatures.

These two instruments have been used to test samples taken from existing pavements representing practically every type of bituminous surface, with the exception of asphalt macadam using very large aggregate. The conclusion is inescapable that cohesion tests alone cannot be correlated with pavement performance under traffic. Samples of fuel oil mixtures that have withstood traffic for 10 years without any sign of deformation or instability, when tested in the Cohesiometer at 140°F show values so low as to be barely measurable.

In our scale for measuring cohesion, the highest obtainable values are approximately 1000. In this scale, many stable fuel oil mixes commonly range from 50 to 100, whereas asphalt concrete and sheet asphalt specimens ranging as high as 500 have been taken from pavements that had distorted badly under traffic. It is true, however, that when cohesion values are below 50, there is a tendency for the surface to scuff or tear under traffic.

On the other hand, there is a distinct relationship between low Stabilometer values and unstable pavements. It, therefore, appears that the most important basic factor in securing the stability of a bituminous mixture is to maintain the frictional resistance between the aggregate particles sufficiently high.

Thus far in the discussion we have been dealing primarily with the property of stability, and I may say here that I agree that there has been a tendency to exaggerate the importance of stability at the expense of other necessary properties of the pavement. I believe that this tendency always occurs when we have means of measuring and expressing some particular quality, and lack means of assigning a numerical value to others.

Everyone dealing with the design of pavements should realize that the best design is not simply a matter of getting the greatest stability, or considering any one quality to the exclusion of others. The pavement should be regarded as a structure, and when planning a structure the engineer usually has more than one property to be incorporated, and must include all the essential needs as economically and as efficiently as possible. A good pavement should satisfy many requirements, some of which might be enumerated here. For the bituminous pavement, sufficient stability and freedom from raveling; resistance to weather action, including moisture, heat and cold, oxidation; a non-skid surface to eliminate driving hazards; a tight impermeable surface to protect the subgrade when necessary; or sufficient porosity to permit suspiration of ground water when that is necessary. The pavement should utilize economically the most available aggregates and lend itself readily to construction of a smooth riding surface with the available equipment.

In order to incorporate all of these desirable properties in one simple mixture, it is necessary for the designer to know something about the basic factors and how each particular effect can be achieved, and most important, to what extent he might compromise the several considerations. For example, in order to resist weather action, a relatively rich mixture is desirable. The heavier the film coating on the particles of aggregate, the greater will be the resistance to aging and deterioration of the asphalt. However, if this consideration is allowed to dominate the design, there is considerable danger that an unstable mix will be developed. Resistance to abrasion, raveling, and impact also increases as the quantity of asphalt is increased. But unfortunately, while we are improving the mixture to increase cohesion and "malleability" which are in themselves desirable, increasing the thickness of lubricating films beyond a certain point will simultaneously reduce the friction on which stability so largely depends.

When we approach the subject of durability and weather resistance, we are entering a large and complex field which merits the attention of a specialist in this line. It is no longer simply a matter of mechanics and fixed proportions; it is necessary to consider obscure properties of both the mineral aggregate and the asphalt. Sad to relate, all asphalts do not have equal ability to resist detrimental change and all mineral aggregates do not have the capacity to retain a coating of asphalt in the presence of water.

It is hardly within the scope of this paper to enter into a discussion of the ramifications of hydrophilic and hydrophobic aggregates, as a great deal has already been written, and much work remains to be done on this subject. This is also true of the important properties of the various oils and asphalts. Whether an asphalt should be heterogeneous or homogeneous, and whether ductility at 77°F. is or is not important, are matters which may ultimately be thrashed out.

The weathering of asphalts and their susceptibility to hardening during the mixing process and after being incorporated in the pavement is a subject now receiving considerable attention, and its importance can hardly be over-estimated. It appears, however, that separate tests on the various ingredients of a mixture can easily be misleading. I think that this has been well demonstrated throughout the history of asphalt tests, and it seems that after many years of applying the standard identification tests we are still not sure whether a given asphaltic product will make a good road or not.

I am tempted to venture into the hazardous field of prophecy, and express the opinion that in all likelihood the only satisfactory tests for either asphalts or aggregates will be performed after mixing the two materials in approximately the same proportions as are used in actual practice. It should thus be possible to detect the tendency of an asphalt toward premature aging and brittleness, and it is already possible to detect hydrophilic tendencies of aggregates with a fair degree of assurance by means of tests on the complete mixture, although procedures for this purpose no doubt will be improved.

If the pavement mixture is to be rendered tight or impermeable so that moisture will not readily pass through, the most effective means is to provide a dense graded mixture in which the pore sizes are small enough to prevent the passage of water. I might call attention to the fact that the size of the pores cannot be determined by measuring the void volume. A fairly dense pavement with a few large pores will permit the passage of water, whereas a fine graded mixture moderately well oiled will not, even though the relative density is not particularly high.

Briefly, then, the requirements of a pavement and the important fundamentals might be summarized as follows. For the best stability, a harsh, crushed stone with some gradation, mixed with only a sufficient asphalt to permit a high compaction with the means available. For greatest resistance to abrasion, raveling, aging, and deterioration, and imperviousness to water, a high asphalt content, broadly spreading, the richer the better. For impermeability, a uniformly graded mixture with a sufficient quantity of fine sand (fine sand is more important than filler dust). For non-skid surfaces, a large quantity of the maximum size aggregate within the size limits used. For workability and freedom from segregation, a uniformly graded aggregate. To reduce the above factors to as simple a consideration as possible, it seems to be the best rule to use a dense, uniformly graded mixture without an excess of dust and add as much oil or asphalt as the mixture will tolerate without losing stability.

*For description see "Role of the Laboratory in the Preliminary Investigation and Control of Materials for Low Cost Bituminous Pavements" by T. E. Stanton and F. N. Hveem, published in the Proceedings of the Fourteenth Annual Meeting of the Highway Research Board, December, 1934, Part II.

Experimental Asphalt Concrete Pavement Using Hard and Soft Asphalt

In view of the rapidly accumulating evidence pointing to the detrimental effect of hardening and oxidizing of asphaltic cement in service. California has recently constructed several miles of experimental pavement in which asphalts of varying penetration were used in standard asphalt concrete construction. Each section was approximately one-half mile in length. The asphalts used included 55, 76, 110, 170, and 225+ penetration, this latter grade being designated as 90-95 road oil.

The standard construction procedures were followed throughout, with the exception that plant mixing temperatures were reduced with the softer grades of asphalt, and in some cases final rolling operations were delayed one or two days after the material was spread. The percentage of asphalt was reduced from 5.3 in the case of the 50-60 grade to 4.8 with the 90-95 oil.

This road has been under very heavy traffic for about two months. The temperatures in this area are quite high, frequently reaching 110°F. At the present time, it is not possible for the casual observer to detect any difference in appearance between the several types used.

No construction difficulties were encountered, with the exception that with the very soft grades it was necessary to delay the final rolling operations until the following morning, when the pavement was cool. Stabilometer tests on all types of mixtures were amply high, and there seems to be little reason to fear any lack of stability in the pavement. Whether or not this pavement will have any greater resistance to cracking can only be determined with time. However, thus far results appear to be quite encouraging.