REPORT OF COMMITTEE ON FLEXIBLE TYPE SURFACES

WHAT WE KNOW ABOUT THE DESIGN OF PAVEMENTS OF THE FLEXIBLE TYPE

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(In Abstract)[1]

The report presents a digest and discussion of published material pertinent to the problem of design of flexible pavements

It points out to begin with that while our knowledge has progressed to the point where subgrades can be prepared more or less according to scientific principles, adequate information is lacking concerning their quantitative bearing capacity, at least that type of information suitable for use in design formulas The reason for this is that most of the investigations of bearing power have dealt only with the reaction of soils to sustained pressures beneath bodies, essentially rigid in character, such as foundation structures

The forces to which subgrade soils are subjected are radically different in character First, the imposed pressures are seldom purely static and second, road surfaces through which the pressures are transmitted possess more or less flexibility resulting in nonuniform pressure distribution

Evidence is presented in the report to show that pressure distribution may not only depend upon the character of the subgrade soil but to a very marked extent upon the degree of flexibility of the road surface through which the pressure is transmitted, and in view of this evidence the statement is made that it does not appear that we should attempt to apply our knowledge or conceptions of rigid footing stress distribution in soils directly to the problem of flexible pavement design

It is generally recognized that most soils deform less under a dynamic than under a static load of the same intensity However, definite information is lacking as to the extent of the difference in soil supportability under these two types of load As far as flexible pavements are concerned this is an exceedingly important question because here the subgrade soil constitutes practically the direct medium of load support inasmuch as the areas of subgrade pressure are relatively small and the unit intensities of pressure high In other words the more the factor of subgrade support enters into the performance of a road surface, the more necessary it becomes to take into account the dynamic properties of the subgrade soil

This question is discussed in considerable detail in the report and some space is devoted to a description of the German oscillator method of test[2] that appears to have promising possibilities for studying the dynamic properties of soils and road surfaces This method of test involves the application of periodic forces, the intensity of which varies according to a sine law, to a material and the study of its physical reaction by measurements of displacement and speed of propagation A machine, consisting essentially of two parallel shafts that rotate in opposite directions and to each of which is attached an eccentric weight is used to

[1] The complete report has been published in Public Roads Vol 18, No 11, January 1938

[2] See R K Bernhard, Discussion on "Stresses in Concrete Pavement Slabs," page 230

apply the forces The displacement of the soil medium or road surface is measured at different points with electrically operated instruments

According to a number of German Engineers the method of test can be used for developing quantitative information regarding the ability of road surfaces laid upon different types of subgrade soil to support loads of a dynamic nature, as well as for studying their vibratory properties

The fact that it is possible to apply repeated dynamic forces of known magnitude and characteristics to a road structure with an oscillating machine, is cited as one of the advantages of the method of testing It should be possible with such a machine to apply forces that are similar in character to those which are imposed upon pavements by moving vehicles inasmuch as the revolving eccentric weights are analogous to the unsprung mass of a vehicle and the weight of the machine is analogous to that of the sprung load

Another section of the report describes and discusses the methods of design of flexible pavements that have been suggested to date It is pointed out that these methods are premised more upon theoretical conceptions of soil resistance and pressure distribution than upon pertinent or comprehensive test data

The fact is mentioned also that before the required thickness of flexible pavements can be determined for a given set of conditions by any formula, the question as to what is the critical wheel load must be answered In other words, if, at the present time, a formula is used to calculate the thickness of surface, one must make some sort of an arbitrary allowance to compensate for the possible dynamic or impact effects that moving vehicles may have upon the pavement This is evident from the fact that in some instances an allowance of 50 percent over and above the permissible static wheel load is advocated In others no allowance is specified because it is contended that the dynamic resistance of flexible pavements, i e , the resistance that materials composing such pavements offer to deformation under quickly applied loads, may entirely outweigh any actual impact forces

In the summary of the report the major parts of the general problem that need attention are itemized They include

1 A study of the load supporting and pressure-distributing ability of typical surfaces of the nonrigid type as influenced by—

(a) The magnitude of the load
(b) The area of load application and the distribution of pressure intensity over the area
(c) The time duration of the load
(d) The physical characteristics of the surface course and of the subgrade

2 The development of data that indicate more directly the safe load-supporting value of soils when subject to forces and displacements such as obtain under road surfaces of the nonrigid type Factors that probably exert an important influence are—

(a) The size of the area of applied pressure
(b) The rigidity of the surface through which the pressure is applied
(c) The effect of restraint to vertical movement around the area of applied pressure
(d) The physical characteristics of the subgrade material

3 The determination of the relative effects of slowly applied and suddenly applied forces in order that the critical load for design purposes may be known

DISCUSSION ON FLEXIBLE TYPE PAVEMENTS

Prof D P Krynine, *Yale University* Mr Benkelman rightly states that it is not known whether the action of a static wheel should be taken into consideration in designing a flexible pavement or whether a dynamic force prevails, and this question is to be studied and discussed At this time there are quite a few formulas which permit us to design a flexible pavement The speaker wishes to emphasize the fact that all these formulas are based on the static approach to the problem

The principal difference between a static and a dynamic stress distribution through a flexible pavement is that in the former, forces are immobile, and the whole pattern is stiff and dead, while in the latter the stress pattern is living and moving as it is in reality If we could apply elastic formulas to a flexible pavement and to the earth mass underneath, we could compute displacements under a static wheel This problem treated as a three dimensional one is unusually complicated, but may be simplified considering it in a plane If the car is moving, it is questionable whether elastic formulas may be applied unconditionally If, for instance, the speed is forty or more miles per hour, displacements probably will not be the same as under a static wheel, and it is not even known whether stresses have time enough to penetrate into the interior of the earth mass The speaker thinks that this limitation as to the depth of propagation of stresses under a dynamic load is an important one, not only for the problem of pavements, but for railroad engineering as well The problem in question has never been solved

Displacements under a car take the form of a hollow (so-called "crater") in the flexible pavement, and at every given moment the car is at the bottom of this hollow Hence the car may be imagined as moving along a curved elastic line, and perhaps in this case centrifugal force acting in a vertical plane should be taken into consideration It is true that in an ideally homogeneous horizontal flexible pavement the action of this vertical centrifugal force vanishes, since after all the car moves along a horizontal plane But if there are inequalities within the body of the pavement or if the car moves up hill, the vertical centrifugal force may produce a certain effect Admittedly, the existence of such a centrifugal force should be proved by adequate research But if it exists, it certainly produces a much larger effect in a flexible pavement than in a rigid concrete pavement because of the smaller radius of curvature of the elastic line in the former In an analogous way, the weaker the earth mass under a flexible pavement, the deeper is the hollow under the car Hence comes the idea of reinforcing and stabilizing earth under a flexible pavement

In a really flexible pavement the car should press very strongly against the bottom of the hollow already referred to Hence the speaker does not believe very much in the possibility of a considerable impact action on flexible pavements The case of a rigid concrete pavement is different, because the smallest inequality on the surface of such a pavement causes the car to drop from a certain height to the level of the pavement with consequent development of kinetic energy It is difficult to visualize a similar action in a really flexible pavement, although it may partially develop Again this is a problem to be solved by adequate research

The speaker believes that stresses in a flexible pavement may be determined from actual displacements under the moving car, and to determine the shape and the size of this elastic line or rather elastic surface observations must be made Before this difficult job is undertaken consideration should be given to the problem of whether stresses can be determined in some other way One thing is clear, however static formulas and the angle of pressure distribution of 45° can hardly be of great help in this case

Finally in studying the stress distribution in a flexible pavement the gradual increase in pressure should be taken into consideration The stress at a point develops gradually as the car approaches It starts at a zero value when the car is theoretically at infinity, and practically at a certain distance from the given point The maximum value is reached when the car is exactly over the given point, and as the car goes away, the stress decreases in the same manner In this stress increasing-decreasing process the effect of vibrations may be of importance, and the speaker is concluding his discussion with a wish that German methods of studying vibrations as described by Mr Benkelman might be introduced in this country as soon as possible

MR J A BUCHANAN, *Bureau of Public Roads* If I understand Professor Krynine correctly, he said that impact is not developed on flexible type pavements If by flexible type pavement you mean a bituminous mat laid on the subgrade, such as that commonly known as black top pavement, then I would like to say that impact is developed on that type of pavement We have measured the forces developed and, the impact forces are in general of the same order as developed on the rigid pavements for a given surface roughness

PROFESSOR KRYNINE The static load may be increased by the centrifugal force

MR BUCHANAN Definite impact reaction is developed because of the inequalities on the surface of the road

MR ROCKWELL SMITH, *Minnesota Highway Department* Mr Benkelman has done a great amount of work in reviewing and reporting tests on soil loading, but there is nothing in these tests which can be translated into a mathematical treatment of a design problem The tests as described, however, indicate that our present empirical method of design is not contrary to established facts As Mr Benkelman mentions, we have the qualitative means but no method of applying these means in a quantitative manner

There is one point not clarified in Mr Benkelman's report He speaks of flexible surfaces and foundation courses without any special distinction as to their flexibility We have found that a good stabilized gravel base may be regarded as semi-rigid to a certain extent As a real flexible course, I would mention most bituminous treatments and water bound macadam such as we have in Minnesota To cite an example of my point, there is a 200 or 300 ft section south of Spring Valley on which the subgrade has displaced both laterally and vertically the latter displacement to an extent of 3 in Over this displacement the flexible macadam and bituminous mat has remained without breaking

It has been our experience that with much less displacement a stabilized gravel mat would have broken and disintegrated Or if thick enough its beam action would have bridged the area and prevented the displacement In the laboratory we have developed stabilized sand beams with a modulus of rupture of 200 lb and compressive strength of 600 lb per sq in in a 2-in cube

Thus various so-called flexible surfaces will vary greatly in their load distributing action and in their performance under displacement

The use of the numerous formulas

reported is not practical in our design work With the best available information these formulas give values of base thickness much greater than those we are using in our design As Mr Benkelman points out there is a great lack of information concerning the actual loading a pavement receives under moving wheel loads Also there is no adequate knowledge of the bearing capacity of subgrade soils He sums this up very completely on page 50 of his report

Mr Benkelman also points out that the methods described have contributed to our understanding of the problem, but that they are premised on conceptions of resistance and distribution rather than on actual data This is in complete accord with our thought of the methods described