CURRENT BASE DESIGN PRACTICES IN NORTH CAROLINA

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SYNOPSIS

Relatively thin bituminous wearing surfaces (thickness less than 2 in.) should be placed on bases capable of supporting the wheel loads using the pavement over the existing subgrade. Most wearing surfaces of this thickness are placed on so-called low-cost bases composed of selected topsoil and sand-clay, soil-aggregate mixtures, or crushed stone and gravel. Stabilized base courses, or bases consisting of soil mixed with portland cement, bituminous materials, vinsol resin, and other agents which tend to change the natural properties of the soil are also used with thin bituminous wearing courses, but they are not considered in this paper. This paper deals with the thickness design of bases composed of untreated, selected soil and crushed stone or gravel.

The rational determination of the thickness of soil and aggregate base courses is dependent upon three main factors: (1) the load and its mode of application; (2) the bearing capacity of the materials used in the base structure as well as that of the subgrade; and (3) the distribution of the pressure exerted by the applied load. The methods used in determining the values for loads and bearing capacity are given in this paper together with the formula for the calculation of base thickness as developed by Vokac. An illustrative example is used to describe the methods. The paper also gives a table that may be used to determine the magnitude of loads from knowledge of the tire size, based on actual truck-weight survey data. Another table is included listing tentative "service" bearing capacities of subgrades in North Carolina composed of sandy soils, clay soils, and heavy clay soils, based on load test data and service behavior. Seven tables giving base thicknesses to use under 1 in. of bituminous surface treatment carrying wheel loads of 4,000, 5,000, 6,000, 7,000, 8,000, 9,000, and 10,000 lb over subgrades having bearing capacities of 10, 15, 20, and 30 lb per sq in. are included.

This article deals with the design of soil, gravel, and crushed stone bases upon which relatively thin (less than 2-in.) bituminous wearing surfaces are placed. Thousands of miles of this type of road are built in this country yearly. They carry a large number of vehicles which vary in weight from the light passenger car to the heavy truck. Roads of this type, when subjected to a large volume of the heavier type vehicles, are likely to fail unless the type and thickness of both base and wearing surface are adequate.

The travelled portion of a paved road consists of a pavement structure resting on a subgrade. The top portion of the pavement structure serves as a wearing surface while the lower portion reinforces the subgrade support. The pavement structure may consist of one course of material, such as a concrete pavement, or it may consist of two or more courses, a wearing course, a base course, and (or) a sub-base course. A design for base and sub-base thicknesses to suit subgrade bearing capacity and highway loads is presented in this paper. The base and sub-base materials are assumed to be soil or soil aggregate mixtures containing no chemical or bituminous admixture to change the natural properties of the soil.

Flexible pavement base design involves three important factors: (1) load and its mode of application; (2) the bearing capacity of the various materials used in the pavement structure as well as that of the subgrade; and (3) the distribution of the pressure produced by the applied loads.

Highway Loads and Their Application. The maximum wheel load of a vehicle using the highways is restricted by law in practically all States, but unless the designing engineer is certain that the law is enforced, he should determine and use the maximum wheel load of appreciable occurrence in his design. Data from truck-weight surveys, supplemented by tire size and pressure data will aid the designing engineer in selecting the proper load for the design of the base and enable him to determine the pressure applied and the area of contact of the wheel, which are important requisites for rational design. Table 1 shows loads carried by various sizes of tires over the highways in North Carolina. The pressures exerted by various wheel loads are given in Tables 3 through 9. The information contained in these tables was obtained from the 1945 truck-weight survey. A survey was conducted in August, 1946, but a study of the data has not been completed to the extent

TABLE 1
TIRE LOADS

Tire Size	Ply	Rated Capacity[a]	Average Measured Load[a]	Average of the Over-Loads[a]	Axle Load Group[b]
11.00 x 20	12	4,500	3,773	4,940	20,000
11.00 x 22	12	4,750	3,830		20,000
11.00 x 24	12	5,000	4,100	6,400	20,000
10.00 x 20	12	4,000	3,539	4,473	18,000
10.00 x 22	12	4,275	3,772	5,158	20,000
10.00 x 24	12	4,550	3,517		20,000
36 x 8					
9.00 x 20	12	3,850	2,967	4,050	16,000
9.00 x 20	10	3,450	3,133	3,989	16,000
8.25 x 20	10	2,750	2,792	3,311	14,000
34 x 7					
7.50 x 20	10	2,700	2,338	3,200	14,000
7.50 x 20	8	2,250	2,369	2,722	12,000
32 x 6					
7.00 x 20	10	2,250	2,324	2,738	12,000
7.00 x 20	8	1,950	2,163	2,500	10,000
32 x 6					
6.50 x 20	8	1,950	2,275	2,383	10,000
6.50 x 20	6	1,700			8,000
6.00 x 20	8	1,700			8,000

[a] For single tires.
[b] For dual tires. Use one-half value for single tires.

that it can be tabulated, however the tire inflation pressure information from the incompleted study agrees closely with that found in the 1945 survey.

Highway loads are transmitted to the pavement by pneumatic tires which exert pressures over the area of contact. The pressures exerted and the corresponding contact areas must be determined in order that the manner in which the loads are applied to the pavement may be established. This determination is generally made by dividing the wheel load by the inflation pressure plus a small percentage for stiffness of the tire.

Teller and Buchanan (*1*)[1] reported on tests conducted to determine the relationship of load, inflation pressure, contact area, and pressures transmitted to the area of contact for a 36 by 8 smooth pneumatic tire. They

[1] Italicized figures in parentheses refer to list of references at the end of the paper.

found that the contact area was less than, but approached, an area equal to the ratio of the load and the inflation pressure, when approximately the manufacturers' rated capacity for load and pressure was used. Their tests also disclosed that while the pressure

TABLE 2
TENTATIVE SUBGRADE BEARING VALUES

Subgrade Bearing Value	Description of Soil
30 psi	Sandy soils, containing not more than 35 percent material passing a No. 200 sieve. Good drainage. Subgrade should be below the frost line.[a] Thickness of stratum must not be less than 12 in. *Good subgrade*
20 psi	Clay soils, but not heavy clay soils (50 percent or more clay). Good drainage. The subgrade must be below the frost line.[a] *Fair subgrade*
15 psi	Heavy clay soils or clay soils where drainage is uncertain. Subgrade should be below frost line.[a] *Poor subgrade*
10 psi	Heavy clay soils with poor drainage. *Very poor subgrade*

[a] Frost line is the depth below which water in the underlying soil will not freeze.

TABLE 3
RECOMMENDED BASE AND SUB-BASE THICKNESSES BENEATH 1-INCH OF BITUMINOUS SURFACE TREATMENT FOR VARIOUS WHEEL LOADS

Type of Load: Trailer-truck combinations, heavily loaded—Axle loads not exceeding 20,000 lb

Wheel Load: 10,000 lb Air pressure + 10% = 100 psi.
Contact Area: 100 sq in. Equivalent Diameter = 11.3 in.

Subgrade Bearing	*30 psi*	*20 psi*	*15 psi*	*10 psi*
TBM base, inches	8	8	8	8
Sub-base, inches	0	3	5	8
Total base thickness without sub-base—TBM, inches	8	10½	12½	16

was not uniform over the entire area of contact, the greater portion of the area was under uniform pressure, equal to the inflation pressure. A small portion of the contact area, well within the outside boundary, varied in pressure from 116 to 123 percent of the inflation pressure.

Spangler (*2*) also conducted some tests along the same line in his investigation of pressures transmitted through soil bases to subgrades. He, too, found that pressures within the contact area were not uniform, with greater pressures near the center, and states that while the load-inflation quotient did not give the contact area in all cases, it did under certain conditions.

Goldbeck (*3*) suggests using 110 percent of the inflation pressure as the average pressure on the area of contact and the ratio of the load to this pressure as the contact area of the tire. He uses elliptically shaped areas with the major axis twice that of the minor axis, which is suggested by Teller and Buchanan (*1*).

TABLE 4

Type of Load: Trailer-truck combinations, loaded to capacity—Axle loads not exceeding 18,000 lb

Wheel Load = 9,000 lb   Air Pressure + 10% = 96 psi
Contact Area = 94 sq in.   Equivalent Diameter = 10.9 in.

Subgrade Bearing	*30 psi*	*20 psi*	*15 psi*	*10 psi*
TBM base, inches	7	7	7	7
Sub-base, inches	0	3	4½	8
Total base thickness without subgrade—TBM, inches	7	9½	11½	15

TABLE 5

Type of Load. Trailer-truck combinations, medium loaded Axle loads not exceeding 16,000 lb

Wheel Load = 8,000 lb   Air Pressure + 10% = 93 psi
Contact Area = 87 sq in.   Equivalent Diameter = 10.5 in.

Subgrade Bearing	*30 psi*	*20 psi*	*15 psi*	*10 psi*
TBM base, inches	6½	6½	6½	6½
Sub-base, inches	0	3	4½	7½
Total base thickness without sub-base—TBM, inches	6½	9	11	14

TABLE 6

Type of Load: Medium single-unit trucks, heavily loaded—Axle loads not exceeding 14,000 lb

Wheel Load = 7,000 lb   Air Pressure + 10% = 89 psi
Contact Area = 79 sq in.   Equivalent Diameter = 10.0 in.

Subgrade Bearing	*30 psi*	*20 psi*	*15 psi*	*10 psi*
TBM base, inches	6	6	6	6
Sub-base, inches	0	3	4	7
Total base thickness without sub-base—TBM or STBC, inches	6	8½	10	13

ment should be stronger due to confinement by the surrounding area.

It will be noted in Tables 3 through 9 that the pressures vary with the wheel loads, the higher pressures being exerted by wheels carrying the greater loads. These pressures were determined from the average inflation pressures of tires carrying those wheel loads,

TABLE 7

Type of Load: Medium single-unit trucks, medium loaded Axle loads not exceeding 12,000 lb

Wheel Load = 6,000 lb   Air Pressure + 10% = 83 psi
Contact Area = 72 sq in.   Equivalent Diameter = 9.6 in.

Subgrade Bearing	*30 psi*	*20 psi*	*15 psi*	*10 psi*
TBM base, inches	5½	5½	5½	5½
Sub-base, inches	0	3	4	6½
Total base thickness without sub-base—TBM or SBTC, inches	5½	7½	9½	12

TABLE 8

Type of Load: Light single-unit trucks, heavily loaded—Axle loads not exceeding 10,000 lb

Wheel Load = 5,000 lb   Air Pressure + 10% = 81 psi.
Contact Area = 62 sq in.   Equivalent Diameter = 8.9 in.

Subgrade Bearing	*30 psi*	*20 psi*	*15 psi*	*10 psi*
TBM base, inches	5	5	5	5
Sub-base, inches	0	3	3½	6
Total base thickness without sub-base—TBM or STBC, inches	5	7	8½	1

TABLE 9

Type of Load: Light single-unit trucks, medium loaded—Axle loads not exceeding 8,000 lb

Wheel Load = 4,000 lb   Air Pressure + 10% = 81 psi.
Contact Area = 49 sq in.   Equivalent Diameter = 7.9 in.

Subgrade Bearing	*30 psi*	*20 psi*	*15 psi*	*10 psi*
TBM base, inches	4	4	4	4
Sub-base, inches	0	3	3½	5½
Total base thickness without sub-base—TBM or STBC, inches	4	6	7½	9½

The author believes that the use of 110 percent of the inflation pressure as the unit contact pressure is sound; first, because it reduces the load-inflation quotient, a fact found to be true by test; and second, it does allow some pressure increase for the stiffness of the tire. While it does not reach the maximum of 123 percent of the inflation pressure, as found by Teller and Buchanan (*1*), this amount of increase is not considered necessary, as the increased pressure is located near the center of the contact area where the pavement should be stronger due to confinement by the surrounding area.

as revealed by the truck-weight survey, to which is added 10 percent for tire stiffness. Although these pressures were determined from the 1945 survey data, they are in almost exact agreement with the data from the 1946 survey.

The area of contact is determined by dividing the wheel load by the inflation pressure, plus 10 percent. The diameter of a circle having the same area is calculated for use in the formula for thickness which will be discussed later.

Bearing Capacity. The second factor to be considered in flexible pavement base design is the bearing capacity of the elements that support the wearing surface, which are the base, sub-base, if any, and subgrade. The bearing capacity of a material is the load it will carry within the elastic limit of the material, when the material is of infinite thickness, or supported by a material whose bearing capacity is such that its elastic limit will not be exceeded before that of the overlying material.

Bearing capacities are best determined from load tests, although several other tests are used in their determination. The author prefers the load test and uses it for the determination of the bearing capacities of soil base, sub-base, and subgrade materials. The bearing capacities of crushed stone and gravel base materials are not determined as their values exceed the pressures exerted by highway loads.

Full scale load tests have been conducted in the field in North Carolina, but due to lack of control of densities and moistures and the difficulty of conducting the tests, they are now performed in the laboratory. The soil is compacted in a suitable box, 42 in. square and 24 in. deep, at the moisture content and density desired, which is generally standard optimum moisture and standard density for the soil. Compaction is accomplished with a pneumatic tamper and the soil covered to prevent evaporation of moisture. The compacted soil is allowed to "season" for about 48 hr before testing. Loads are applied to the soil by means of a Black and Decker Loadometer of 50,000-lb capacity, equipped with special twin dials. One dial has 25-lb graduations with a maximum range of 5,000 lb, and the other has 100-lb graduations with a maximum range of 20,000 lb. The Loadometer is attached to the cross-beam of an "H" frame for reaction. Deflections are measured to the nearest 0.001 in. by means of four micrometer dials diametrically opposed and attached to suitable stationary reference supports.

The load test is performed using the technique developed by Housel (*4*), which the writer considers as being the best suited for the purpose of determining bearing capacity. The results obtained are considered quite reliable when properly used. Briefly, the test consists of applying loads to the soil in a sufficient number of equal increments to allow the selection of a value for the elastic limit, or bearing capacity of the soil. This value may be determined graphically or analytically from the test data. Each load increment is allowed to remain on the soil for 1 hr before adding the next increment, and deflections are measured to 0.001 in. and recorded at time intervals of 5, 20, 35, 50, and 60 min. The loads are applied to the soil through a rigid steel plate, 12 in. in diameter, which is considered the equivalent diameter of the largest contact area on highways. Smaller plates of 9- and 6-in. diameter are also used, but the values of bearing capacity obtained are for information only.

As stated before, bearing capacities of soils are determined at optimum moisture and standard density for the soil. In North Carolina, these values are used in the design of bases and sub-bases without correction for anticipated moisture increases. This procedure would not be advisable in other localities, unless supported by sufficient investigation which indicated that the moisture in the base, sub-base, or subgrade did not exceed this figure in service. Such an investigation has been made in North Carolina, and while the results indicate some fluctuations in moisture contents in excess of optimum for the soil, the fluctuations are not greatly in excess of that figure in most cases. The investigation is being continued and, if results indicate the necessity, corrections will be made of the bearing capacity values now being used. The amount of this correction can be determined from a shear test by comparing the shear value at a bearing capacity value of known moisture content and density to that determined at the desired moisture content and density.

The bearing capacity value of a particular type of soil as determined by test is not necessarily the proper value to use in the design. Such influencing factors as climatic conditions, drainage, frost action, and the physical characteristics of the soil itself should be taken into consideration before selecting the design bearing value. This procedure might be called "rating" the soil. Table 2 gives tentative ratings for three types of soil; sandy soils, clay soils, and heavy clay soils, when they occur as subgrades. These ratings are for subgrades serving under climatic conditions prevalent in North Carolina. The same subgrades might be rated differently in other localities where the factors influencing the "service" bearing values vary from those prevailing in this State.

The subgrade bearing values given in Table 2 seem rather broad and in many instances rather conservative, however, they are not merely assumed values; they are based on some actual tests and the behavior of the soil types in service. Load tests are being performed in the laboratory from time to time on many different soils to further check the values given in Table 2 and to permit specific ratings of soil types intermediate between the types given. As this work progresses, future tables will be more specific and reliable, and consequently less conservative.

The bearing capacities of base materials are not given in Table 2 with subgrade materials as this type of material rarely occurs as subgrade. If it did, no base would be necessary. Soil type base materials, referred to in Tables 3 through 9 as STBC (Soil Type Base Course) are covered by specification and consist of well graded soils with maximum values of liquid limit and plasticity index of 25 and 6 respectively. The North Carolina specifications for soil type base course materials are as follows:

"Soil type base courses shall be classified as Fine Aggregate Type, Case I, or Coarse Aggregate Type, Case II. The use of either type will be permitted unless otherwise specified. Each type shall be as hereinafter provided and shall comply with physical requirements as designated below. The base course material shall be free from vegetable matter and lumps or balls of clay, and shall meet the requirements for one of the gradings given below, using AASHO Methods T-11 and T-27.

"Case I. The Fine Aggregate Type shall not contain more than 40 percent of aggregate passing the 1-inch and retained on the No. 10 sieve, and its soil mortar (material passing the No. 10 sieve) shall conform to the following grading requirements:

Sieve Designation	*Percentage by Weight Passing*
No. 10	100
No. 40	40–70
No. 200	5–35

"The fraction passing the No. 200 sieve shall be less than ⅔ the fraction passing the No. 40 sieve. The material passing the No. 40 sieve shall have a plasticity index not greater than 6 and a liquid limit not greater than 25, when tested in accordance with AASHO Methods T-89, T-90 and T-91.

"A tolerance of 10 percent of aggregate retained on the 1-in. seive will be permitted provided the maximum size does not exceed 1½ in.

"Case II. The Coarse Aggregate Type shall contain at least 40 percent of aggregate retained on the No. 10 sieve and shall conform to the following grading requirements:

Sieve Designation	*Percentage by Weight Passing*
1-inch	100
No. 10	30–60
No. 40	20–45
No. 200	8–25

"The fraction passing the No. 200 sieve shall be less than ⅔ the fraction passing the No. 40 sieve. The material passing the No. 40 sieve shall have a plasticity index not greater than 6 and a liquid limit not greater than 25, when tested in accordance with Methods of the AASHO T-89, T-90 and T-91.

"A tolerance of 10 percent of aggregate retained on the 1-inch sieve will be permitted provided the maximum size does not exceed 1½ inches."

Crushed stone or gravel base materials, referred to in Tables 3 through 9 as TBM (Traffic Bound Macadam), are also covered by specification and consist of well graded aggregate with sufficient fine material to form a dense mass when compacted. The North Carolina specifications for Traffic Bound Macadam Base Course materials are as follows:

"The material retained on the No. 4 sieve shall consist of clean, tough, durable pieces of aggregate which, when tested in accordance with AASHO Method T-96, will show a loss not greater than 60 percent. Shales or shaly aggregate not approved by the Laboratory shall not be used.

"The material passing the No. 4 sieve shall be known as 'binder' and shall consist of screenings, sand and clay or other material of satisfactory binding value. The material passing the No. 40 sieve shall have a plasticity index not greater than 6 and a liquid limit not greater than 25, when tested in accordance with AASHO Methods T-89, T-90 and T-91.

"The aggregate, including the binder naturally present or added, shall meet the grading requirements for Grading A, Size No. 7, or Grading B, Size No. 8, as follows:

Sieve Designation	Percentage by Weight Passing Grading A	Grading B
2-inch		100
1½-inch	100	90–100
1-inch	90–100	55– 90
½-inch	55– 90	45– 75
No. 4	35– 60	30– 60
No. 40	10– 35	10– 35
No. 200	5– 20	5– 20

"Grading A material may be used for the entire thickness of the base course unless otherwise stipulated. Grading B material may be used for constructing the base course with the exception of the top 3 inches which shall always consist of Grading A material."

The bearing capacity of soil type base course materials, Case I (fine aggregate type) has been found by load tests to be from 85 to 90 lb per sq in. when tested with a rigid steel plate, 12 in. in diameter, at standard density and optimum moisture. The load tests were performed on the non-plastic, but well bonded, variety of material in an unconfined state. Future tests are planned to cover the plastic variety of material with plasticity index values up to 6.

The bearing capacity of soil type base course materials, Case II (coarse aggregate type), and traffic bound macadam base course materials (crushed stone or gravel) is above 100 lb per sq in., which is in excess of the maximum pressures exerted by tires carrying highway loads.

Pressure Distribution. A load applied to a soil mass exerts a pressure on the area of contact which is transmitted to the underlying soil in such a manner that the unit pressure on any plane below the area of contact is less than the unit pressure exerted on that area. Also, the unit pressure on a plane below the area of contact decreases with increase in the depth of that plane. Experiments have shown that this decrease in unit pressure is due to an increase in the area of the plane under stress, and that the area under stress increases with depth. This is known as "distribution of pressure".

Many designers assume that the areas of the stressed planes below an area of contact increase uniformly with their depth, forming a zone whose outer boundary makes a certain angle with the horizontal. This angle is assumed to be 45 degrees by most designers and to vary with different materials by others. This is the straight line distribution theory.

A curved line distribution theory is advanced by some designers whose reasoning supports the fact that the distribution is not uniform, but varies with the depth. Among the advocates of the curved line distribution theory is Roland Vokac who, in December, 1943, presented a paper advancing this theory at the annual meeting of the Association of Asphalt Paving Technologists which was published in Vol. 15 of the *Proceedings* under the title, "A Practical Way to Design Flexible Pavements". The same theory was advanced in a paper by Mr. Vokac and published in the *Proceedings* of the Highway Research Board, Vol. 23 (1943), under the title, "Flexible Pavement Thickness".

Mr. Vokac's concept is based on the "pressure bulb" theory in which he assumes the bulbs to be spherical for the purpose of simple mathematical analysis. The author will not attempt to present Mr. Vokac's analysis in this paper as the subject has been ably presented in the two articles referred to above.

In his analysis Mr. Vokac derives a formula for the thickness of a soil or gravel base course, which he designates as h in inches, that is necessary to support a load exerting a unit pressure, p, on a circular contact area, b inches in diameter, constructed on a subgrade whose bearing capacity is p_o. The formula is

$$h = \frac{b}{2}\sqrt{\frac{p}{p_o} - 1}$$

h is also the depth to which the subgrade, having a bearing capacity of p_o, will fail when subjected to unit pressure, p, on the contact diameter, b. Expressed in another manner, h is the depth below the soil surface where the intensity of the unit pressure, p, applied on the surface of the subgrade by contact diameter, b, has been reduced by distribution over an area of greater diameter to the extent that it equals the bearing capacity, p_o, of the subgrade soil. In other words, p equals p_o at h inches below the surface of contact.

It is, of course, logical that the base consist of materials whose minimum bearing capacity, at conditions of moisture and density expected during service, is equal to or greater than the unit pressure, p. The use of stronger materials will not reduce the value of h, nor will the bearing capacity of the base constructed of them be greater, unless h is greater. The base thickness necessary to utilize the full bearing capacity of the material may be calculated by substituting the value of its bearing capacity for p in the formula.

The foregoing has been a discussion of the three main factors in the determination of the thickness of soil, gravel, and crushed stone bases, on which is placed a relatively thin bituminous wearing surface of not more than 2 in. The applied pressure on a wearing surface of this thickness is transmitted to the base without appreciable reduction; so, in the design of a pavement structure of this type, the thickness of the wearing surface is just considered a part of h in the formula. The following is an illustrative example of the design of this type of pavement using the procedure described in this paper.

EXAMPLE

Load Data. From a one-day traffic count, it was decided to design the pavement to suit trucks using 8.25 by 20 dual tires, as vehicles of this type were of appreciable occurrence. Data in Table 1 indicate that the axle load of a vehicle using this size of tire is likely to be 14,000 lb or the wheel load to be 7,000 lb. From Table 6 it is found that wheel loads of this magnitude have average tire inflation pressures of 81 psi. Adding 10 per cent for tire stiffness, we have 89 psi, which is the unit pressure on the pavement exerted by this wheel load. The contact area will be the wheel load, 7,000 lb, divided by the pressure exerted, 89 psi, or 79 sq in. The diameter of a circle having this area is 10.0 in., which will be used as the diameter of the contact area in this problem.

Bearing Values. The road to be constructed lies in the Piedmont section of the State where all of the soils are residual and have clay sub-soils. Examination of a county soil map of the area indicated that all of the soils were of granitic origin, and this fact was verified by the soil investigator sent to the project, who also reported that the soils belong to the Cecil, Durham, and Appling series. Soils of these series have clay subsoils, which rarely contain sufficient clay for them to be classified as heavy clay soils. They are well drained and are considered as fair subgrade soils. These soils fit the description given in Table 2 for fair subgrade, which is given a service rating for bearing capacity of 20 psi.

Calculation of Base Thickness. All of the values needed in the thickness formula have been determined. Collecting them, we have

b, the contact diameter, = 10.0 in.

p, the unit pressure exerted by the wheel = 89 psi.

p_o, the bearing value of the subgrade = 20 psi.

Substituting these values in the thickness formula, we have

$$h = \frac{b}{2}\sqrt{\frac{p}{p_o} - 1} = \frac{10}{2}\sqrt{\frac{89}{20} - 1}$$

= 9.3 in. of wearing surface and base

The wearing surface of this project is to be a bituminous surface treatment whose thickness is one inch, so the pavement structure will consist of:

9.3 in. − 1 in. = 8.3 in. or

1 in. Bituminous Wearing Surface and

8½ in. Base

It will be noted from Table 6 that the total base thickness required beneath 1 in. of bituminous surface treatment resting on a 20 psi subgrade for a 7,000-lb wheel load is 8½ in.

Designing the Base to Suit Local Materials. In the above design no consideration has been given to local materials. If a sufficient amount of granular topsoil is available which meets the material requirements for soil type base course (STBC), given elsewhere in this paper, it will be economical to construct the entire base of this type of material as load tests indicate it to have a bearing capacity of 90 psi. This would be the cheapest and most economical design. In many parts of the State, however, no suitable base materials are available locally, and under these circumstances the entire base is constructed of crushed stone or gravel occurring locally or shipped-in. This type of base is rather costly when compared with bases constructed of local STBC materials.

There are also many areas in the State where granular materials of an inferior quality occur locally. These materials are inferior, generally, only because they contain an excess of fine sand and will not produce a base that can develop and preserve a bearing capacity high enough to withstand the pressures exerted by the loads. These materials are capable of producing a sub-base whose bearing capacity is 30 psi or higher, which allows the construction of a sub-base and base whose total thickness is the same as that required for a base alone.

The calculation of sub-base and base thicknesses for the same condition of loading and subgrade bearing capacity used in the previous example follows. In the previous problem the base rested on a subgrade whose bearing capacity was rated as 20 psi, while in this problem the base is to rest on a sub-base whose bearing capacity is rated as 30 psi. The same formula for thickness can be used in this determination except the value for p_o, 20 psi, becomes 30 psi.

$$h = \frac{10}{2}\sqrt{\frac{89}{30} - 1}$$

= 7.0 in of wearing surface and base

In the previous problem the thickness of the wearing surface and base was found to be 9.3 in., so the sub-base thickness must be 9.3 in. − 7.0 in. = 2.3 in. It has been found impractical to construct a soil layer less than about 3 in. thick, so the above value for sub-base thickness is rounded off to 3 in. The pavement structure designed to suit the local materials available and to carry the same loads over the same subgrade as in the previous problem consists of

1 in. Bituminous Wearing Surface on
7.0 in. − 1 in. =
6 in. Crushed Stone or Gravel Base and
3 in. Sub-base.

It will be noted that these thicknesses agree with those in Table 6. The letters "TBM" are used to designate traffic bound macadam base courses, which consist of crushed stone or gravel. It will also be noticed that the total base and sub-base thickness is greater by ½ in. than the total base thickness when only one material is used. The reason for this is that the minimum thickness of sub-base that can be constructed is 3 in.

In conclusion the author wishes to state that the foregoing method of design is being used in North Carolina and the thicknesses given in Tables 3 through 9 were calculated as demonstrated. The reader's attention is called to the fact that the subgrade ratings given in Table 2 are for the state of North Carolina and may be conservative for some areas and inadequate for others. Table 1 and Tables 3 through 9 are applicable to practically any locality provided the correct subgrade rating for the soil serving in that locality is used.

REFERENCES

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