AN ANALYSIS OF WHEEL LOAD LIMITS AS RELATED TO DESIGN

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SYNOPSIS

A method for controlling load limits and for design of bases, using a cone bearing test and the Boussinesq method of load distribution is presented

Based on cone bearing tests on the subgrades of a large number of pavements, some of which had failed and some were in good condition, a curve was developed that shows for any given bearing the thickness of base and mat required by present traffic loads

The cone bearing curve when plotted on log paper becomes a straight line that can be expressed by the equation $T=\frac{65.7}{B^{0.888}}$, wherein T is the total base and mat thickness and B is the cone bearing value in pounds per square inch This offers a means of extrapolating for thicknesses required by heavier loads than those in the current highway range

Determinations of load bearing capacity aid in the design of pavement, in establishing legal load limits and in setting load limits during seasonal losses in stability The effects of single and dual tires on load bearing capacity, and the limitations of load restrictions per inch of tire width are discussed Maximum load limits per wheel are recommended

The problem of designing adequate bases to support traffic is one of long standing A soil subgrade is subject to an almost infinite number of factors that may influence its stability and its capacity to carry loads. Chief among these factors are density, moisture content, soil structure, and load distribution. Theories on base design are as numerous as the individuals making a study of the problem So far as I know, there has been no general agreement on the subject, probably due to the difficulty in making a complete series of comprehensive tests. The result has been a hodgepodge of laws governing legal load limits and a hit and miss design of bases (What was built two years ago was too thin; this time it has to be thicker.) This confusion is typified by the construction in North Dakota of four major air fields, two of which have designed bases in excess of 24 in, the other two with 8 in

Presented here is a plan for controlling both load and base. There are certain flaws in the theoretical assumptions made; but because it carries some logic and has the merit of consistency, it may prove useful as an aid to a clearer concept of the problem.

Two facts go hand-in-hand: for any given load the weaker the subgrade the thicker must be the base, and for any given subgrade bearing value the greater the load the thicker must be the base It is also clear that heavy loads passing over flexible bases and mats cause the pavement to depress slightly under the wheels. Under repeated loads, if this flexing action is pronounced, perhaps more than 0.2 in, then failure takes place The thickness of base and mat must be sufficient to reduce the pressure on the subgrade to an amount that can be carried without passing beyond the limit of safe deflection.

Just how the forces are transmitted through the base to the subgrade is not clear Housel of Michigan advances the theory that the load is carried by compression of the area beneath the load plus the force resisting punching shear around the perimeter This theory is now being advanced by the Asphalt Institute as a method for designing base thicknesses for both airports and highways Subgrade values under this system are variables and must be expressed in relation to the perimeter area of the load This makes a very complicated method that involves a complete series of actual field tests on the subgrade as it will be after construction, which appears a trifle difficult inasmuch as this could hardly be done until the work is completed. Hawthorne and Gray advanced the theory that load is transmitted through the base in the form of a cone with the angle of distribution of load varying from 20 to 45 degrees Spangler, Palmer and others have also developed equations for base thickness.

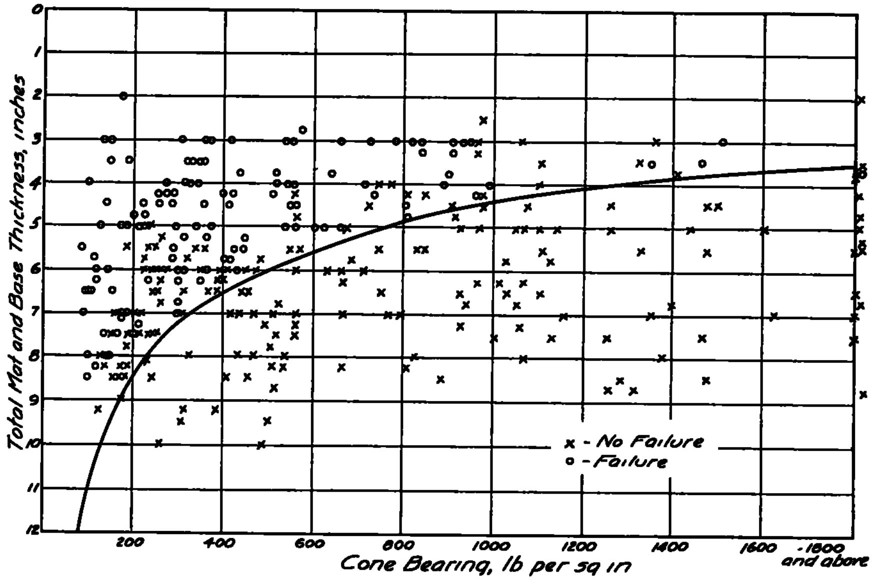

Figure 1. Cone Bearing Chart. North Dakota State Highway Department

Perhaps one of the oldest, and certainly the most generally accepted theory on load distribution, is that of Boussinesq The development of his formula and a complete explanation of the work may be studied in the *Proceedings* of the American Society of Civil Engineers for May 1933 All the charts accompanying this report, as well as the conclusions reached, are based on the results secured using the Boussinesq theory

Research work carried on during the past few years and the development of the cone bearing curve replaces theoretical concepts in a large measure with actual field data taken from highways in service From a practical viewpoint and assuming no increase in the weights of the wheel loads now in use, it should not be necessary for us to concern ourselves with load distribution or the amount of critical deflection. However, it appears necessary to safeguard our highways by laws regulating the weights of vehicles Further, it appears possible to predict the necessary base and mat for any given load so that the method is particularly useful in the design of airport runways.

For several years by means of a cone, we have been making bearing tests,[1] of subgrades both under pavements that had failed and those that were in good condition. The thickness of base and mat was measured, and its condition noted. The pounds per square inch of bearing in the subgrade were plotted against the total base and mat thickness (Fig. 1). Fail-

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[1] "Factors Controlling Subgrade Stability and Base Design," presented at the Mississippi Valley Highway Conference, Jan 1942.

ures were spotted with a circle, non-failures with a cross We could see at once that the circles kept to themselves on one side, the crosses on the other with a zone between where both circles and crosses appear We divided the failures from the non-failures by means of a curved line. This curve shows, that for any given bearing, a definite thickness of base and mat is required to prevent failures under present traffic loads.

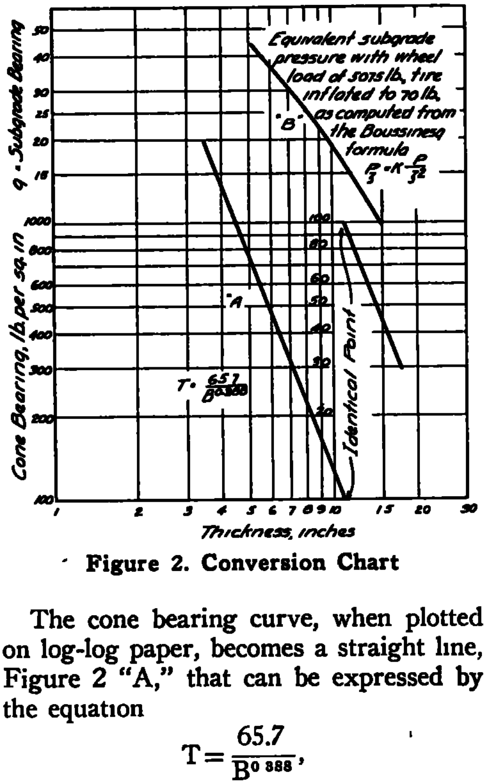

Figure 2. Conversion Chart

The cone bearing curve, when plotted on log-log paper, becomes a straight line, Figure 2 "A," that can be expressed by the equation

$$T = \frac{65.7}{B^{0\ 888}},$$

where T = total base and mat thickness in inches and B = cone bearing in pounds per square inch.

The curves of other methods for determining base thickness also become straight lines when plotted on log-log paper, so that our work is substantiated. Such straight lines can be extended to consider loads and thicknesses beyond the present limits.

The present laws in North Dakota set the legal wheel load at 9,000 lb and 550 lb. per inch width of tire A study of the planning survey records on gross weights shows that 96 per cent of all truck traffic weighs less than 20,000 lb., and 84 per cent less than 15,000 lb In addition, most of these trucks carry their loads on dual tires.

The average transport truck is equipped with 12-in. by 20-in. tires or smaller, inflated to 70 lb. per sq in, and capable of a load per tire, as recommended by the Tire and Rim Association, of 5,075 lb As this figure seems best to represent present traffic loads, it has been used as the normal load to be tied with the bearing curve. If a tire loaded to 5,075 lb. is inflated to 70 lb per sq. in pressure, then $5{,}075 \div 70 = 72\ 5$ sq. in of contact area, which may be assumed to be in the shape of a circle The radius,

$$a = \sqrt{\frac{72\ 5}{\pi}} = 4\ 8 \text{ in}$$

The maximum subgrade bearing, "P_s," can be found for any thickness of base "z" by the formula, from Boussinesq, $P_s = K\frac{P}{z^2}$. Figure 2 "B" shows the curve derived from this equation, plotting subgrade pressure against the base thickness using the same ordinate for base thickness as for "A" of Figure 2. Assuming a cone bearing of 500 lb, a base approximately 6 in. thick is required, reading up on the 6-in base line to the intersection of curve "B," we find the equivalent subgrade bearing to be 37 lb.

Keeping the base thickness and the tire pressure constant, the subgrade bearing created by varying the tire load may be computed. Figure 3 shows the subgrade bearings developed by various tire loads at 70-lb tire pressure and for 6, 8, 10, 12, 15 and 20-in. bases. Knowing the subgrade bearing and depth of base, the safe load may be read directly For example, on an 8-in. base and a subgrade bearing of 30 lb per sq. in the safe load would be 6,400 lb It should be noted that this entire problem has been based on a tire pressure of 70 lb per sq in Increasing the tire pressure reduces the contact area and increases the amount of maximum subgrade bearing; lowering the tire pressure increases the contact area and decreases the subgrade bearing. However, the difference is not so much as might be expected This is borne out by the findings of Spangler, Volumes 20 and 21 of the Highway Research Board While other curves can easily be built around other tire pressures, it is believed that one curve is sufficiently accurate for our purpose. Figure 4 illustrates graphically the effect of changing tire pressures. For a 10-in base and 19-lb subgrade, the tire load varies from 5,500 lb. for 60 lb. pressure to 4,800 lb. for 90 lb pressure.

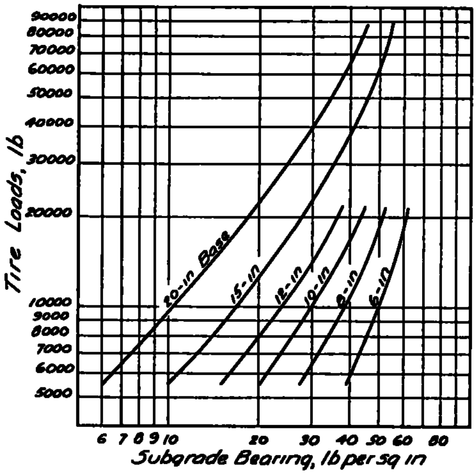

Figure 3. Subgrade Bearings for 70-lb. Tire Pressure

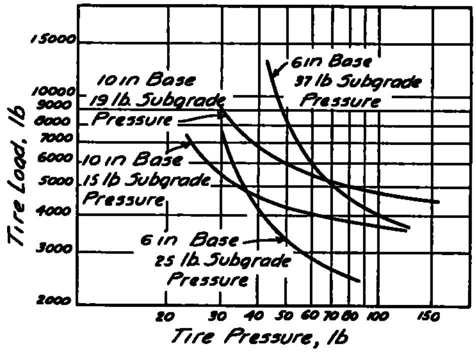

Figure 4. Relation of Tire Inflation Pressure to Total Tire Load

From the data of the curves shown on Figure 3, and with a constant tire pressure, the safe tire loads for various subgrade bearings may be plotted against the various depths of base as in Figure 5.

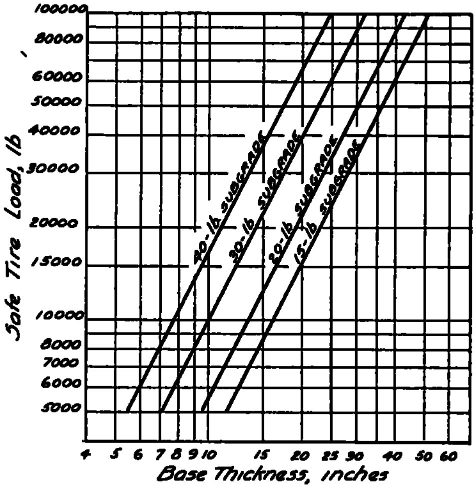

Figure 5. Base Design Chart. From North Dakota Cone Bearing Chart and Boussinesq Theory of Load Distribution.

Plotted on log-log paper, straight lines are produced. Thus, for 30-lb subgrade, a 10-in base will carry 10,000 lb per tire; a heavy bomber carrying 100,000 lb on each tire would require a 32-in. base. The safe load for other subgrade bearing values may, of course, be easily plotted. However, it is our experience that probable subgrade bearing values may be predicted only within very broad limits. Depending on moisture conditions, drainage, type of compaction and temperature range, probably two and certainly not more than three values would be assigned to soils ranging from good to poor. For example, under favorable conditions, very good soils might have bearing values of 40 lb. and poor soils a bearing value of 20 lb Under less favorable conditions, these same soils might be assigned values of 30 and 15 lb., respectively. From actual experience, we know what these bearing values will be for the type of construction a[illegible]limatic conditions existing in North Dakota. Our soil surveys enable us to locate and classify the material to be used, and from this information the proper thickness of base is selected for each soil type.

Eventually, the advantages to be gained from this or other methods of determining load capacity will be threefold

(1) Highways will be designed to carry uniform loads over all types of subgrades.
(2) Legal limits can be established that will not overload the designed bases
(3) Logical load limits can be set for local roads that suffer temporary loss of stability during seasonal breakups

The effect the tire load under one dual tire has on the subgrade pressure under the other tire of the dual has also been analyzed The increase varies with the depth of base, but a general statement can be made that the tire load should be decreased by 10 per cent when duals are used. That is, a single tire may be loaded to 5,000 lb. If dual tires are used, the load on neither should exceed 4,500 lb

In my opinion, we are not now designing bases to carry single tire loads of 9,000 lb. Neither is it necessary to make such a design Practically the entire trucking industry operates on dual tires, with a load capacity per tire of about 5,000 lb To increase our design to 9,000 lb would mean increasing the thickness of our 11½-in. bases to 15½ in. and that of our 6-in. bases to 9 in This adds cost to construction that does not seem justified.

I would recommend a revision in our law to set the maximum wheel load for single tire at 5,000 lb and for each tire of a dual to 4,500 lb So far as the road surface is concerned, it then would be unimportant how large the total vehicle load is so long as it is carried on additional axles. The net result would be the same as several individual trucks closely following each other. The total load should be fixed by the capacity of the bridges.

TABLE 1

SAFE LOADS ON TIRES COMPUTED FROM THE 1942 YEAR BOOK, TIRE AND RIM ASSOCIATION, INC

Tire size—in	Load per in of width—lb
7 00—20	280
7 50—20	300
8 25—20	333
9 00—20	380
10 00—20	400
11.00—20	430
12.00—20	455
13 00—24	580
14.00—24	650

The legal restriction of 550 lb. per inch width of tire is not entirely satisfactory Listed in Table 1 is the load per inch width of tire that can be safely carried by tires, as computed from the 1942 Year Book of the Tire and Rim Association Incorporated.

Therefore, a maximum of 550 lb. only restricts the 13 and 14-in. tires to a less than capacity load, and permits severe overloading on the smaller tires. It has been useful to the extent that with ordinary sized tires it has been legally impossible to load single tires to 9,000 lb. Limiting single tires to a 5,000-lb load also permits overloading of the small sized tires. This, of course, is damaging to the tires, but is a separate problem entirely. As previously noted, the maximum subgrade pressure under a normal 12 by 20-in. tire, loaded to 5,075 lb., is 37 lb. per sq. in under a 6-in base Now, for example, consider a 7 50 by 20-in tire The normal inflation pressure is 55 lb and the recommended load 2,250 lb. The maximum subgrade pressure developed beneath a 6-in base is 20 5 lb per sq in, or far less than the 37 lb produced by the larger tire. If this small tire must carry a 5,000-lb. load, then the inflation pressure must be increased, say to 90 lb This develops a maximum subgrade pressure of 40 lb. per sq. in, or 3 lb more than the larger tire

In the case of a 12 by 20-in. tire, at 550 lb per inch width of tire, the tire may be loaded to 6,600 lb. Assuming the tire is inflated to 90 lb pressure to carry this overload, the maximum subgrade pressure at a 6-in. depth is 47 lb. This amounts to a 27 per cent increase over the 37-lb. limit, and failure of the base could be expected

It is recognized that the correct method of controlling load should be determined by the tire pressure and size of the contact area. This should be done for special loads such as earth moving equipment or airplanes; for ordinary trucks the simple restriction shown should prove adequate

During the spring breakups, subgrade bearings may drop temporarily Poor soils may drop from a subgrade bearing of 19 lb. to 15 lb per sq in; good soils may drop from a subgrade bearing of 37 lb to 25 lb. From Figure 4, a 10-in. base under such conditions should have a load limit of 4,000 lb per tire, while on a 6-in base the load limit should be 2,500 lb. Because of the variation in the thickness of the base on any given road, it would not be practical to impose more than one restriction. Therefore, for ease in enforcement, the load should not exceed 2,500 lb. when load limits are placed on certain roads. For an ordinary truck with rear dual wheels, the total gross load could be 15,000 lb

APPENDIX

THE CONE BEARING TEST

The cone bearing test consists in measuring the penetration of a steel cone of the dimension shown in Figure 6 into the soil under 10-lb increments of weight In order that the cone may be held perpendicular to the soil while the weights are applied it is necessary to support the shaft of the cone by a rigid frame Figure 7 is a picture of the installation of cone, frame and weights used in North Dakota

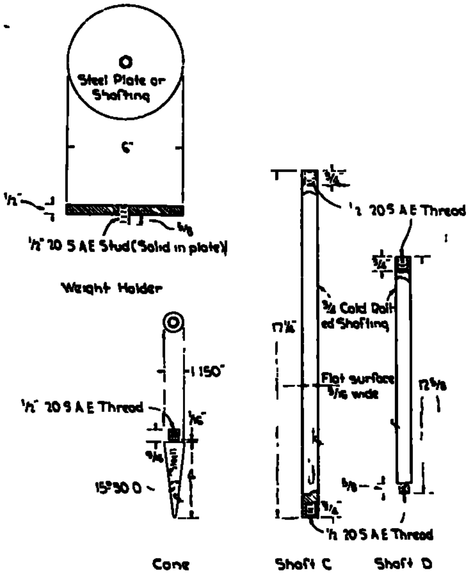

Figure 6. Cone, Sectional Shaft and Weight Holder

Procedure

The subsoil should first be scraped level at the point where the bearing is to be taken The cone machine is then set in place and the cone adjusted so that it just touches the subsoil The collar on the cone shaft is locked in place against the top cross-piece

The cone is loaded to 10-lb, released slowly to prevent impact, and allowed to settle for 1 min The cone shaft is then locked in place and the penetration measured This penetration is the distance between collar and top cross-piece, and is measured with calipers to the nearest hundredth of an inch.

The load is then increased to 20-lb. and the cone is released slowly, allowing it to settle for another minute. The total penetration is measured. The loads are then increased to 40 and 80 pounds successively, using the same procedure. All of the loads include the weight of the cone and shaft.

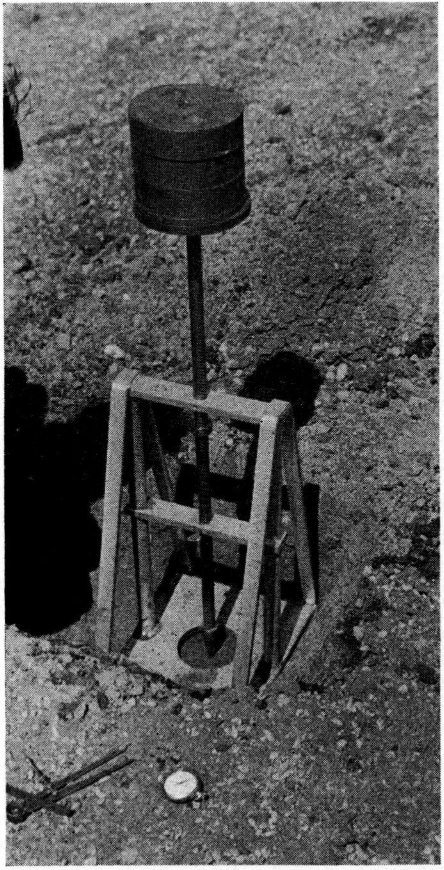

Figure 7. Apparatus for Cone Bearing Test

The bearing power of the soil is expressed in pounds per square inch and is equal to the load on the cone divided by the cross sectional area of the cone in inches at the ground line. The radius of this cross section may be calculated by the formula: radius = penetration × tan 7° 45′.

Theoretically, ignoring the effects of friction in the apparatus, the bearing values for a cone of these dimensions should be the same for each load and the penetration for any load should be one-half that for a load four times as large. For example, the correct penetration for the 20-lb. load should be one-half of that for the 80-lb load. The readings are never correct to this extent on account of an index error affecting all readings of penetration. This index error is due to the impracticability of starting the test with the point of the cone exactly touching the soil surface, and to the fact that the end of the cone is slightly rounded and is not the exact point of the cone assumed by the theory.

It is therefore necessary to determine a correction to be added to or subtracted from all readings in order to get the correct penetrations for each load. This correction should be such that when added or subtracted from all readings the penetration for the 20-lb. load will be one-half that for the 80-lb. and so forth. The amount of the correction may be calculated from the simple expression:—

$$C = P_{80} - 2P_{20}$$

where C is the required correction to be added to or subtracted from the penetration readings according to its sign, P_{80} is the penetration reading at 80-lb. load and P_{20} is the penetration reading at 20-lb. load.

Owing to the initial adjustments the 10-lb. load is usually omitted in determining the average bearing value.

Table 2 shows the way in which the corrections are applied.

Computations of bearing values may be facilitated by use of Table 3, which gives the bearing values for a considerable range of corrected penetrations for 10, 20, 40, and 80-lb. loads.

TABLE 2

CORRECTED PENETRATIONS AND BEARING VALUES

Load, lb.	Penetration readings, in.	Corrected penetration, in.	Bearing, lb. per sq. in.
10	0.48	0.58	. . .
20	0.66	0.76	596
40	0.98	1.08	592
80	1.42	1.52	596
Average Bearing Value.			595

TABLE 3

Bearing Values in pounds per sq. in for Corrected Penetrations Given

10-lb load

Corrected penetration, inches	00	02	04	06	08
0		431,500	107,875	47,944	26,968
1	17,260	11,986	8,804	6,741	5,325
2	4,315	3,566	2,996	2,553	2,201
3	1,918	1,685	1,492	1,331	1,195
.4	1,078	978	891	815	750
5	690	638	592	550	513
6	479	449	421	396	373
.7	352	332	315	299	283
.8	273	256	244	233	223
9	213	204	195	187	179
1.0	173	166	160	154	148
1.1	143	138	132	128	124
1 2	120	116	112	108	105
1 3	102	99	96	93	91
1.4	88	86	83	81	79
1 5	77	75	73	71	69

20-lb load

Corrected penetration, inches	00	02	04	06	.08
2	8,630	7,132	5,992	5,106	4,400
.3	3,832	3,370	2,986	2,662	2,390
.4	2,156	1,956	1,782	1,630	1,498
5	1,380	1,278	1,182	1,100	1,024
6	958	896	842	792	746
.7	704	664	630	596	567
8	538	512	488	466	445
9	426	408	390	374	359
1.0	345	331	319	307	296
1 1	285	275	265	256	248
1 2	240	232	224	217	211
1 3	204	198	192	186	181
1 4	176	171	167	162	158
1 5	153	149	145	142	138
1 6	135	131	128	125	122
1 7	119	116	114	111	109
1 8	106	104	101	99	97
1 9	95	93	91	89	88
2 0	86	84	82	80	78

TABLE 3—CONTINUED

40-LB. LOAD

Corrected penetration, inches	00	02	04	06	08
.3	7,668	6,741	5,972	5,325	4,780
.4	4,315	3,912	3,566	3,260	2,996
.5	2,760	2,553	2,364	2,201	2,052
.6	1,918	1,796	1,685	1,584	1,492
.7	1,408	1,331	1,260	1,195	1,132
.8	1,078	1,024	978	932	891
.9	852	815	782	750	719
1.0	690 4	654	638	620	592
1.1	570	550	531	513	496
1.2	479	464	449	435	421
1.3	408	396	384	373	363
1.4	352	342	332	324	315
1.5	307	299	291	283	276
1.6	273	263	256	250	244
1.7	238	233	228	223	218
1.8	213	208	204	200	195
1.9	191	187	183	179	176
2.0	173	169	166	163	160
2.1	157	154	151	148	145
2.2	143	141	138	135	132
2.3	130	128	126	124	122
2.4	120	118	116	114	112
2.5	110	108	107	105	104
2.6	102	101	99	98	96
2.7	95	93	92	91	89
2.8	88	87	86	84	83

TABLE 3—Continued

80-lb load

Corrected penetration, inches	00	02	04	06	08
.4	8,630	7,824	7,132	6,520	5,992
.5	5,520	5,106	4,734	4,400	4,104
.6	3,832	3,592	3,370	3,168	2,986
.7	2,816	2,662	2,520	2,390	2,264
.8	2,158	2,052	1,956	1,867	1,782
.9	1,704	1,630	1,562	1,498	1,437
1.0	1,380	1,327	1,278	1,228	1,182
1.1	1,136	1,100	1,062	1,024	991
1.2	958	927	896	869	842
1.3	816	792	768	746	725
1.4	704	685	664	647	630
1.5	613	596	582	567	552
1.6	538	526	512	501	488
1.7	478	466	456	445	435
1.8	426	417	408	399	390
1.9	382	374	366	359	352
2.0	345	338	331	325	319
2.1	313	307	301	296	290
2.2	285	280	275	270	265
2.3	261	256	252	248	244
2.4	240	236	232	228	224
2.5	220	217	214	211	208
2.6	204	201	198	195	192
2.7	189	186	184	181	179
2.8	176	174	171	169	167
2.9	164	162	160	158	155
3.0	153	151	149	147	145
3.1	144	142	140	138	136
3.2	135	133	131	129	128
3.3	127	125	124	122	121
3.4	119	118	116	115	114
3.5	112	111	110	109	107
3.6	106	105	104	102	101
3.7	100	99	98	97	96
3.8	95	94	93	92	91
3.9	90	89	88	88	87
4.0	86	85	84	83	82

DISCUSSION ON WHEEL LOAD LIMITS AND DESIGN

Mr T. A Middlebrooks, *United States Engineer Department:* Mr. Boyd is to be highly complimented upon his excellent paper covering an analysis of North Dakota's Highway experience and his use of the elastic theory for extrapolating the experience for higher wheel load. Although one may not like either the cone test or the elastic theory, it must be recognized that this method of approach to the problem—that is, rating the soils by a simple test and tying the results into highway experience, then extrapolating the results by the best known theory—is basically sound. This is an excellent use of empirical data and theory.

The North Dakota Highway Department is to be complimented on its farsightedness in making this service behavior survey and the adoption of the cone test for relative evaluation of the different types of subgrade. It is regrettable that other states, besides California and North Dakota, have not made similar surveys and evaluated the subgrades and base materials in a similar manner. The type of test to be used in rating the subgrade is of minor importance, as long as it gives a relative evaluation which is reasonably correct. However, since the shearing strength, at a small deformation, is the governing factor in predicting the action of soils under flexible pavements, the test should be some type of shear test, such as: direct shear, unconfined compression, triaxial, North Dakota cone, or California bearing ratio. The latter two are not truly shear tests, but they do give a relative evaluation of the resistance of the different soils to plastic deformation (shear deformation without volume change). Since the resistance of a soil to plastic deformation is a function of the shearing strength at that deformation, these tests (North Dakota and California) can be expected to give reasonably correct relative values. In speaking of the shearing strength of soils, most people think of ultimate shearing strength and fail to recognize that a soil has a definite shearing strength at any given deformation. It should be strongly emphasized that the ultimate shearing strength is of no value in the design of flexible pavements. The shearing strength used in design must be sufficiently low to allow for a high number of repetitions of load.

It would be extremely valuable if other highway departments would follow the lead of California and North Dakota and make condition surveys with the proper evaluation of the subgrade. Since the cost of making the soil tests is small, it is considered highly desirable to run several types of tests. I would recommend that the California bearing ratio and the North Dakota cone tests be made for all surveys, and, where equipment is available, a shear test such as triaxial or direct shear (the vertical or confining load to be equal to the overburden) be made.

The writer does not agree with the author that the 9,000-lb. load on duals should be analyzed as a 5,000-lb. load on a single tire. This might be true for designing the top few inches of the pavement; however, where thick bases are used, the total load of 9,000 lb. should definitely be used. This, of course, would not change North Dakota Highway experience, but it would make a difference in the extrapolated results on either side of this experience.

The elastic theory was one of the methods used as a rough guide by the writer, in arriving at his version of the extrapolated curves. However, the writer used the shearing stresses as determined by the elastic theory, while the author used vertical stresses. Although in this case there is a fairly good check between the two methods (vertical stress and shearing stress), it appears that the shearing stress would be the controlling factor for flexible pavements.

A comparison of the thickness required by the Engineer Department curves and Boyd's extrapolated values is given in Table 1. There is also given, in the same table, Boyd's values modified by the writer, using a 9,000-lb. wheel load instead of 5,000 lb. It is not surprising that these thicknesses check fairly closely, since they are both based on empirical data obtained from actual highway experience. It should be recognized, however, that any of the above comparisons are necessarily only rough approximations, since the relationship between cone bearing value, California bearing ratio, and plate bearing value can not be closely defined at the present time.

TABLE 1

REQUIRED THICKNESS OF FLEXIBLE PAVEMENTS (BASE AND SURFACE)

15,000-LB. WHEEL LOAD

California bearing ratio	Thickness, in.		
	Boyd		Engineer dept.
Per cent	From Figure 5	Modified[a]	
35	9.5	7.0	6.0
20	12.5	9.5	8.0
10	16.5	12.5	12.5
5	20.0	15.0	18.0

37,000-LB. WHEEL LOAD

Per cent	From Figure 5	Modified[a]	
35	15.0	11.0	8.0
20	19.0	15.0	11.5
10	26.0	19.0	17.5
5	31.0	23.5	27.0

60,000-LB. WHEEL LOAD

Per cent	From Figure 5	Modified[a]	
35	19.0	14.0	9.5
20	25.0	19.0	14.0
10	33.5	25.0	22.0
5	40.0	30.0	34.0

[a] Extrapolating from 9,000-lb. wheel load instead of 5,000-lb. wheel load.

MR. BOYD. The data shown by Mr. Middlebrooks in Table 1 illustrate the essential need for additional base for increased tire loads. Here, placed side by side, are the results secured from two completely independent studies, each involving different laboratory procedure or field test and mathematical formula for their final development. The exact correlation for comparative purposes is difficult for two reasons: first, the relationships may not be applied to identical soils under the same conditions, and second, the writer at least is not thoroughly acquainted with the derivation of the Engineer Department curves.

Mr. Middlebrooks objects to the 5,000-lb. tire load as a basis of design and feels that the 9,000-lb. load carried by dual tires should more properly apply. The assumption of a tire load is made for the purpose of calibrating the soil, to determine the maximum subgrade bearing the soil can carry without serious deformation leading to surface failures. This calibration was made in the North Dakota method, using bases of from 4 to 10 in. in thickness. As originally stated, the amount of load transferred from one tire of a dual, to the point of maximum subgrade pressure beneath the other tire is not large, usually less than 10 per cent for thin bases. If a 9,000-lb. load is carried on dual tires, each tire carries 4,500 lb. Increasing the 4,500-lb. tire load by 10 per cent places a total equivalent load of 4,950 lb. on a single tire and agrees closely to the 5,075-lb. tire load taken for the analysis. The assumption of a 9,000-

lb load attributes strength to the subgrade that it does not possess and when projected to the design for heavier loads, may result in seriously under designed base thicknesses At greater depths, of course, Mr. Middlebrooks is entirely correct, and the subgrade bearing is the amount determined by the combined pressure bulb from the two tires.

TABLE 2

REQUIRED THICKNESS OF FLEXIBLE PAVEMENTS (BASE AND SURFACE)

15,000-LB WHEEL LOAD

Engineer department		North Dakota	
California bearing ratio %	Thickness in	Subgrade bearing lb per sq in	Thickness in
35	6 0	50	7 5
20	8 0	42	9 0
10	12 5	25	14 0
5	18 0	16	18 5

37,000-LB WHEEL LOAD

35	8 0	50	11 5
20	11 5	42	14 0
10	17 5	25	22 0
5	27 0	16	29 5

60,000-LB WHEEL LOAD

35	9 5	50	15 0
20	14 0	42	18 0
10	22 0	25	28 0
5	34 0	16	37 0

In Table 1 of Mr Middlebrooks' discussion, he compares the Engineer Department's curves for 35, 20, 10 and 5 per cent soil with North Dakota subgrade bearing values of 40, 30, 20 and 15 lb When the Engineer Department's curves are plotted as shown in Figure 8, it becomes apparent that this assumption of equal bearing values is incorrect When these curves are extended to show the base thickness for a 5,000-lb. wheel load, a definite point is fixed from which both methods may be compared on an equal basis Thus, 35, 20, 10 and 5 per cent soils are comparable to 50-, 42-, 25- and 16-lb subgrades, respectively Table 2 lists the comparative base thickness required by the two methods as taken from the curves shown in Figure 8.

Referring again to Figure 8, it is seen that the difference in base thickness is due to the difference in the slope of the Engineer Department's curves and the North Dakota curves The Engineer Department curves are not under discussion but it may be pertinent to point out that the slope of the curves for each per cent of soil value is different from all others This leads to the interpretation that equal loads and base thickness, transfer to the subgrade below, pressures of varying intensity depending on the bearing capacity of the subgrade Therefore, the strength of a base is not constant and varies both with the applied load and the base thickness. The slope of the curve for 5 per cent soil compares very closely to the North Dakota curves In most equations for base

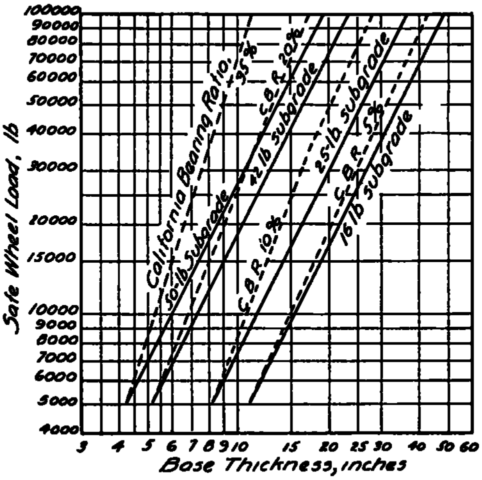

Figure 8. Base Design Comparisons

thickness, the load varies with the square of the depth. That is, twice the depth of base permits four times the load. This is true for all North Dakota values and very nearly true for the Engineer Department values, excepting 35 per cent soil It would be interesting to determine if the subgrade pressure is the same beneath a load of 15,000 lb. transmitted through a 6-in base as it is for 60,000 lb transmitted through a 9.5-in. base.

It might be wise to point out in closing that this discussion has reached the hair-splitting stage From the practical viewpoint, both methods indicate nearly identical design data