Flexible-Pavement Design with Cone Device

W. A. WISE, Materials Engineer
North Dakota State Highway Department

THIS paper describes the procedure being used in North Dakota for the design of flexible pavements in which the necessary thickness of subbase material underlying the standard base and pavement section is determined. Subbase material is called for where the cone bearing value of the subgrade is less than 400 psi. Since the cone tests are made generally, when the condition of the subgrade is good, the design of the pavement may not be adequate during the spring thawing period, and present practice in North Dakota provides for load limitation at this time.

● THE cone device has been in use by the North Dakota State Highway Department for more than 15 years. Its use provides a fairly rapid and simple method for determining the bearing power of fine textured subgrade soils. The equipment is simple, compact and portable.

CONE DETAILS AND DIRECTIONS FOR USE

The steel cone is 4 inches long, having an angle at the tip of 15 deg. 30 min. The cone tip is mounted downward on a ¾-inch round steel shaft that is inserted in a small steel frame. Figure 1 shows the details of the cone bearing device. The method of determining the bearing power of soil with the cone device is given in the Appendix.

FIELD OPERATIONS

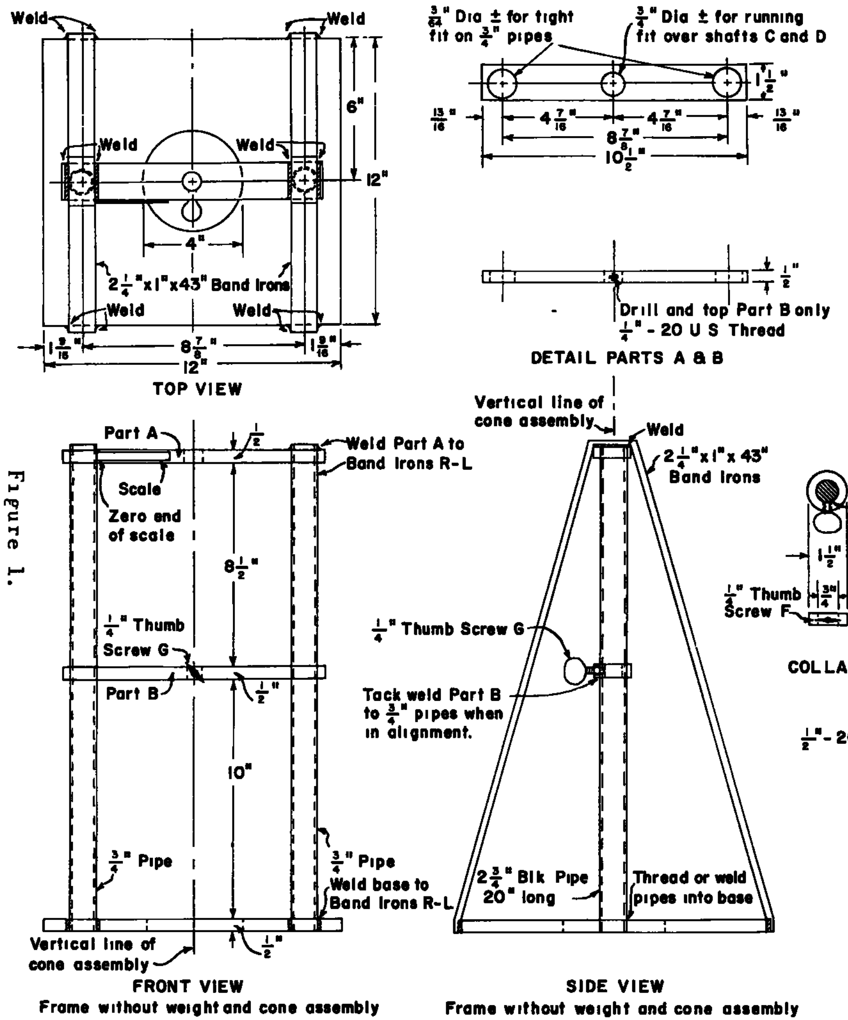
First the bearing is taken at an elevation 3 inches below the subgrade surface; then at points 9, 15, and 24 inches below the subgrade surface. These four readings are averaged to determine the bearing power of the subgrade at the test point. The bearing result is an average rating for the top 24 inches of the subgrade. This method was developed through practice and experience in order to arrive at an accurate reading having some factor of safety. Originally only the crust reading of the subgrade surface was tested and accepted as the true bearing power. Such bearings generally were "high" which often resulted in the selection of a flexible pavement section of insufficient thickness for efficient performance.

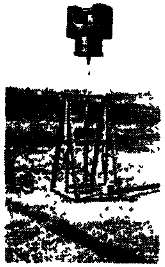
Now the four subgrade readings are taken as described in order to determine a more practical bearing power. In this procedure the high subgrade crust value is included but does not over influence the final result. This method of average rating is also believed practical because of the variable weather conditions which seriously affect subgrade bearing strengths. No scientific method has been devised to allow for these changes during the season. Therefore, the judgement and experience of the engineers associated with the cone bearing work largely govern. Their design recommendations receive great consideration.

Bearing tests are taken as often as required to represent the project involved and the soils encountered. Under normal conditions one subgrade test station per mile is usually sufficient. At each test station three separate test holes are utilized on the right or left side of the centerline by random choice. By the method of average bearings for the top 24 inches of the subgrade and the utilization of engineering judgement, a flexible pavement section is selected which is fairly uniform in thickness. Necessary reinforcements for limited distances are made by use of additional pit-run granular subbase material. These reinforcements are placed before construction of the standard base and pavement section begins. Typical standard flexible pavement design sections are shown in Figure 3.

DESIGN PROCEDURE

By means of the chart in Figure 2 the required total base and surface thickness is selected to suit the subgrade bearing value. However, the standard section of 9½ inches





A plate which with the weights of cone, shafts C and D, collar E and weight holder, shall weigh 10 lb. will be required Other weights are used in combination with this to provide desired loads In this case three 10 lb. and one 50 lb. weight provide desired 10-, 20-, 40- and 80-lb. loads

Connect weight holder to upper end and shaft C to lower end of shaft D Place shaft through A, E and B in order named and connect cone to end

Screw G is used to hold shaft at any desired point and to start and stop loading cone at time desired

Collar E is fixed to shaft and against bottom of A by F when cone is at zero penetration. Total penetration at any time thereafter is measured by Caliper and Scale from bottom of A to top of E

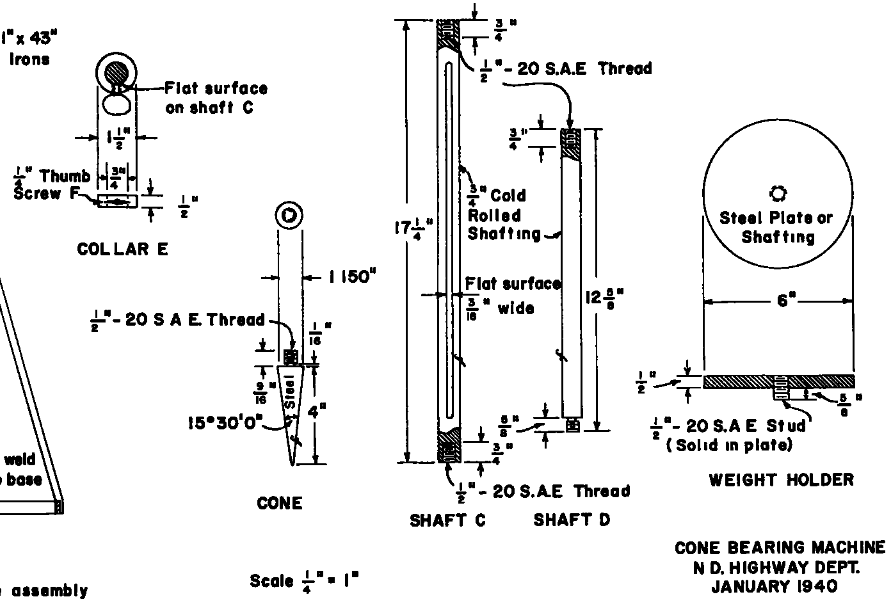


Figure 1.

total base and surface thickness is used regardless if the subgrade bearing tests more than 400 psi. This procedure has proven necessary because of the extreme weather conditions in this state and also to provide a reasonable factor of safety. If the subgrade tests under 400 psi., the necessary additional thickness is provided by the use of pit-run granular subbase prior to the placement of the standard 9½-inch flexible-pavement section.

This standard pavement section consists of a 5-inch pit-run granular subbase, a 2-inch stabilized base (either gravel or bituminous as specified), and a 2½-inch asphaltic-concrete wearing course as shown in Figure 3. This pavement section, for subgrades testing 400 psi. or more, is considered suitable for a wheel load of 9,000 lb., except in the spring thawing period. During that period load limits must be applied to preserve the highway pavements until the subgrades have recovered sufficiently to carry normal loads again. Incidentally, the loss in subgrade bearing power during the spring thawing period has been determined to be approximately 50 percent by research work being conducted by the Highway Research Board Maintenance Committee No. 7. The research project's title is "Investigation of Load Carrying Capacity of Roads as Affected by Frost Action."

CORRELATION WITH OTHER METHODS

Research work developed by Norman McLeod, of Canada, as reported on Page 77 of the June 9, 1949, issue of the Engineering News-Record, indicates the following approximate correlation of subgrade test results by three standard methods:

North Dakota Cone Device	400 psi.
California Bearing Ratio	10.25
Housel Penetrometer	24 blows for 6 inches of penetration

McLeod's more recent report in the March-April 1954 issue of "County and Township Roads" indicates a flexible pavement section of 9½ inches is safe for a 9,000-lb. wheel load. This result is in substantial agreement with North Dakota's standard design practice. The bulk of the North Dakota highway system mileage falls in the medium traffic classification with less than 2,000 vehicles per day of which no more than 50 are heavy vehicles carrying maximum legal loads.

LIMITATIONS

The cone device has its limitations and must be used with judgement to be of practical value. When testing subgrades of finished pavement work, it is necessary to open a test hole through the pavement and base. The cone device rests on the pavement surface and an extended shaft is used to make the test through a small diameter hole in the pavement section. Although the test hole is carefully refilled and tamped this procedure requires time and destroys the homogeneity of the pavement section at the test point. Therefore, the cone device has its most practical use in testing fine textured earth subgrades before the next stage of construction begins.

Correlation of field and laboratory cone test results has not proven successful. Field cone tests of in-place subgrades are accepted and used. But cone tests on the same soils compacted in the laboratory have never been in consistent agreement with field tests and have considerable fluctuation. Therefore, the field tests govern.

ACTUAL PERFORMANCE PROCEDURE

Typical design procedure for new pavement, and resurfaced pavement, and a report of actual performance of pavement subgrades follow.

New Base and Surface Work

Federal Aid Secondary Project No. S-254(11) on US 13 from Wishek East in McIntosh County was placed under contract August 30, 1954. The pavement section specified was a 5-inch pit-run gravel subbase, a 2-inch stabilized gravel base and a 2½-inch asphaltic concrete surface. On high-type primary road projects, a 2-inch asphaltic concrete

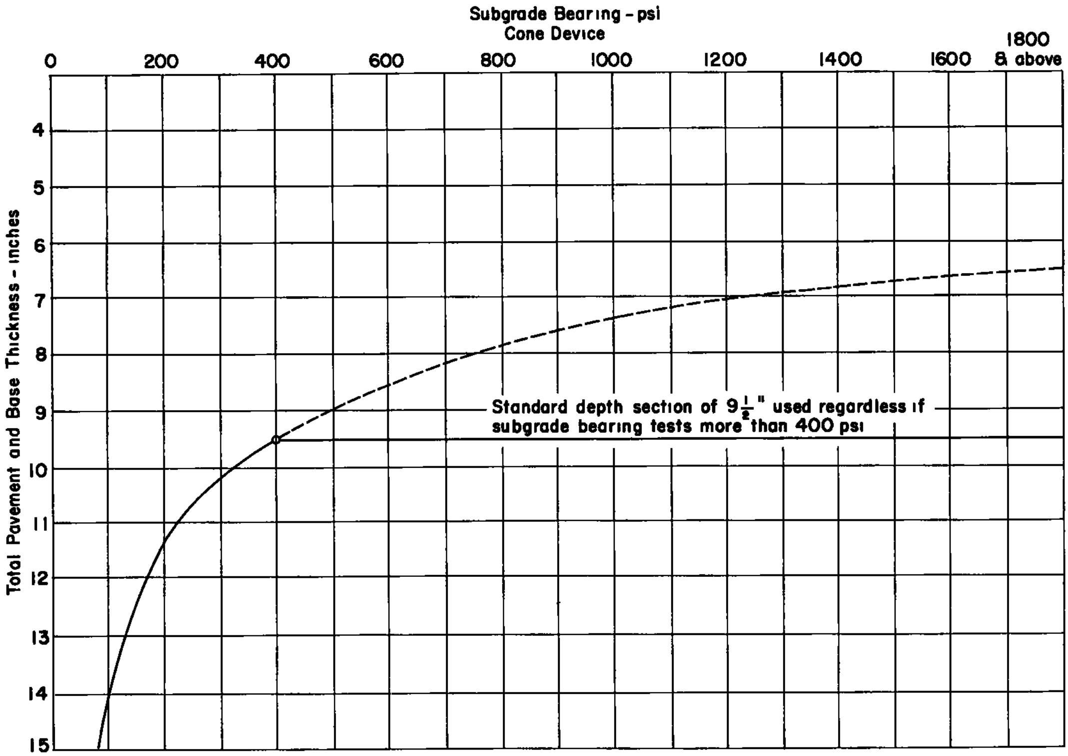


Figure 2.

base is usually substituted for the 2-inch stabilized gravel base; 10 percent additional material of the plan quantity of granular subbase was allowed for subgrade reinforcing. Such reinforcing is used on all work of this kind as the conditions require and as may be authorized by the engineer.

This project was graded in 1952 and 1,200 cubic yards of traffic service gravel were placed per mile for temporary usage until the route was paved. In North Dakota design procedure this limited amount of temporary gravel is considered to be dissipated and of no apparent structural value when the paving work proceeds. Traffic is maintained through all projects during construction.

The traffic count on this unpaved project in 1953 was 340 vehicles including 85 trucks.

Subgrade bearing tests for two typical test point stations on this project in 1954 are shown in Table 1.

In the area represented by the bearing results at Station 548+15 the engineer will increase the subbase thickness of ½ inch during construction in order that the total depth of paving section of 10 inches will meet the requirements of the design curve chart. The limits of the area involved are determined by visual inspection, by noting the amount of subgrade deflection under heavy wheel loads, and by additional cone bearing tests when considered necessary.

Leveling Course and Resurfacing Work

Federal Aid Primary Project No. F-71(5) on US 13 from Wyndmere East in Richland County was placed under contract on March 23, 1954. The current contract specified an asphaltic concrete leveling course of 1½ -inch average depth. This course is used for the purpose of re-establishing proper crown and grade and also for minor structural reinforcements where major reconditioning work is unnecessary. The final wearing course specified was a 2-inch depth of asphaltic concrete. The traffic count in 1953 was 795 vehicles including 200 trucks.

The project was graded in 1939 with 700 cubic yards of traffic service gravel placed

TABLE 1

FAS PROJECT No. S-254(11)

Date	Sta.	Dist. from ℄	Subgrade Test Depth	Cone Bearing	Av. Bear. for 24 inch Depth	Remarks
		feet	inches	psi.	psi.	
			3	1341		
			9	569		
9/2/54	401+10	4 Lt.	15	586	706	
			24	329		Average bearing for test station is 686 psi. O.K. for Stand. 9½-inch paving section.
			3	1970		
			9	1025		
9/2/54	401+10	8 Lt.	15	374	948	
			24	424		
			3	559		
			9	474		
9/2/54	401+10	12 Lt.	15	235	403	
			24	344		
			3	971		
			9	496		
9/3/54	548+15	4 Lt.	15	229	481	
			24	230		Average bearing for test station is 347 psi. By curve chart 9.88 inch paving section required. 10 inches accepted as practical depth to use.
			3	606		
			9	234		
9/3/54	548+15	8 Lt.	15	224	311	
			24	178		
			3	379		
			9	234		
9/3/54	548+15	12 Lt.	15	174	250	
			24	214		

per mile for temporary usage. The original paving section was placed in 1940. It consisted of a 6-inch stabilized gravel base and a 1½-inch hot mixed bituminous surface course containing SC-4 bitumen. While this original paving section would not meet current design standards, it has given satisfactory service. It has received minor routine maintenance, periodic seal coats at approximately five year intervals, and patching at some spot failures. There is no record of the bearing power of the original subgrade but it is assumed to have been at least 400 psi. by the cone device method. To preserve the pavement section after fourteen years service it was necessary to provide for reconditioning the pavement in 1954 by adding structural strength, providing satisfactory riding quality and a new asphaltic wearing course.

Subgrade bearing tests for three typical test point stations on this project in 1954 are shown in Table 2.

The area represented by test station 129+50 had an average bearing of 322 psi. It required a paving section with a total depth of 10 inches from Figure 2. The existing base and surface depth was found to be 8¾ inches. The project plan specified the placement of a new 2-inch asphaltic surface. Total depth of section would then be 10¾ inches which was satisfactory as it exceeded the required design depth of 10 inches. In addition to this procedure a thin asphaltic leveling course was used at the Engineer's discretion as provided by the plan to satisfactorily recondition the existing surface pertaining to crown and grade prior to the placement of the final 2-inch wearing course.

TABLE 2

FEDERAL AID PROJECT No. F-71(5)

Date	Sta.	Dist. from ℄	Subgrade Test Depth	Cone Bearing	Av. Bear. for 24 inch Depth	Remarks
		feet	inches	psi.	psi.	
			3	397		
			9	292		
8/25/54	129+50	4 Lt.	15	598	359	
			24	151		
			3	266		
			9	No test (Grav.)		
8/25/54	129+50	8 Lt.	15	481	297	Average bearing for test station is 322 psi. Total depth required from Curve Chart "C", is 10 inches. Existing base and surface is 8¾ inches. New 2-inch asphaltic surface O. K.
			24	144		
			3	322		
			9	No test (Grav.)		
8/25/54	129+50	12 Lt.	15	499	310	
			24	110		
			3	275		
			9	1300		
8/26/54	187+85	4 Lt.	15	285	494	
			24	114		
			3	1340		
			9	554		
8/26/54	187+85	8 Lt.	15	338	585	Average bearing for test station is 457 psi. Total depth required from Curve Chart "C" is 9½ inches. Existing base and surface is 8¼ inches. New 2-inch asphaltic surface O. K.
			24	108		
			3	303		
			9	474		
8/26/54	187+85	12 Lt.	15	254	293	
			24	140		
			3	189		
			9	302		
8/26/54	230+25	4 Rt.	15	735	379	
			24	290		
			3	268		
			9	292		
8/26/54	230+25	8 Rt.	15	692	377	Average bearing for test station is 336 psi. Total depth required from Curve Chart "C" is 10 inches. Existing base and surface is 8¼ inches. New 2-inch asphaltic surface O. K.
			24	255		
			3	465		
			9	186		
8/26/54	230+25	12 Rt.	15	163	252	
			24	194		

The area represented by test Station 187+85 with an average bearing of 457 psi. required a paving section with a total depth of 9¼ inches from Figure 2. Therefore, a 9½-inch section was required as that is the standard minimum depth of paving section used regardless if the subgrade bearing strength tests more than 400 psi. The existing

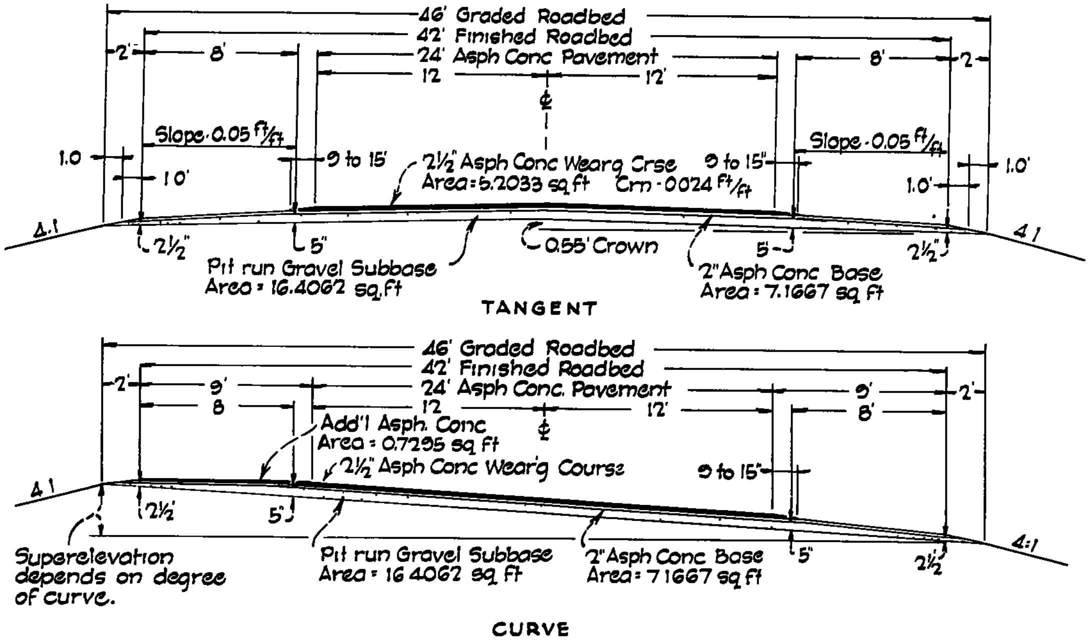


Figure 3. Typical flexible pavement sections, North Dakota State Highway Department.

base and surface depth was 8¼ inches. The project plan specified a new 2-inch asphaltic wearing course plus necessary leveling course to restore crown and grade. This resulted in a total depth of more than 10¼ inches which was greater than the 9½-inch section required and was therefore satisfactory.

The area represented by test station 230+25 with an average bearing of 336 psi. required a paving section with a total depth of 10 inches from Figure 2. The existing base and surface depth was found to be 8¼ inches. The project plan specified the placement of a new 2-inch asphaltic surface. Total depth of section would then be 10¼ inches which was satisfactory as it slightly exceeded the required design depth of 10 inches. A thin leveling course was also used as specified by the plan to satisfactorily recondition the crown and grade.

Occasionally on this type of project the total depth of section required by the design curve may be 1 inch to 2 inches greater than that which will be obtained by adding only the new 2-inch wearing course and a thin leveling course. In such a case the additional depth required is obtained by use of an increased amount of leveling course for the area involved. The plan quantity of leveling course material is provided for use in variable thicknesses to properly recondition the existing surface. This result is generally obtained within the limits of the quantity shown on the plan for this purpose. Overruns in the leveling course quantity sometime occur during construction operations because of unforseen deterioration of the existing paving section after the design is completed and before construction work begins. Substantial recoveries of such overruns are made by laying the final wearing course slightly thinner than the required plan thickness. The specifications accept a wearing course that is at least ⅞ of the required plan thickness. This procedure has proven practical because the required total depth of paving section is obtained due to the extra depth of leveling course used. In this practical manner the project is completed satisfactorily and an overrun in total construction cost rarely occurs.

Subgrade Performance of Completed Projects

Subgrade performance history of four permanent test points for projects of varying types and ages follows. The top 24 inches of the subgrades have been evaluated in the standard manner described in this report by means of cone tests each year from the spring to the fall season. The first tests were made in the fall of 1948. The results of these four test points are typical of the performance information being obtained from a total of twelve test points. In general the construction subgrade bearing values were much greater than the minimum requirements of 400 psi. for the standard 9½-inch flexible pavement section now used. During each year of service there has been a rather continuous loss in subgrade bearing power until some current results have become alarmingly low. This progressive decline in strengths has occurred because after the annual loss in bearing power during the spring thawing periods, the subgrades have not fully regained their former strengths in the subsequent summertime recovery periods. The minimum point at which the subgrade strengths may be expected to level off without further permanent losses has not been determined.

No subgrade bearing results for 1954 have been compiled for release at this time for the four typical test points being reported on herein. Average bearing results for these four points from the fall of 1948 to the fall of 1953 follow:

A. Test Point No. 7 is on US 10 east of Sterling in Burleigh County. The project was graded in 1946 and surfaced in 1947. In the grading operation a 3¾-inch temporary gravel surface was placed. This was largely dissipated and incorporated into the subgrade by weather and traffic action by the time construction of the pavement section began. The pavement section consisted of a 5-inch stabilized gravel base and a 2½-inch hot mixed surface containing SC-4 bitumen. In 1953 the traffic count was 1645 vehicles including 410 trucks.

Average bearing values for the top 24 inches of the subgrade for this test point from the fall of 1948 to the fall of 1953 follow:

Project	Station	Pave. Const.	Actual Depth of Sect.	Year Tested	Average Spring Value	Average Fall Value
			inches		psi.	psi.
SN-FAI 306(25)	336+00	1947	7.5	1948	No Tests	656
			7.75	1949	413	650
			6.9	1950	299	557
			7.0	1951	357	385
			7.1	1952	158	269
			7.75	1953	186	277

The design curve was revised since this project was constructed. Therefore, the pavement section on this project is less than that required by the design curve now in use. It will be noted that the subgrade bearings have steadily declined since the original construction and since 1951 have been seriously low. The performance of this section of pavement is being watched carefully but thus far no visible distress has been detected. The deferment of anticipated deterioration may be due to the subgrade crust lying above the first cone test elevation at the 3-inch depth having been sufficiently upgraded by the original temporary gravel surface placed in 1947 to prevent any noticeable deterioration to date.

B. Test Point No. 8 is on US 10 east of Menoken in Burleigh County. This project was graded and paved in 1947. With the grading work a temporary traffic service gravel course was placed at the rate of 1,200 cubic yards per mile. The paving section consisted of a 5-inch gravel subbase, a 2-inch stabilized gravel base, and a 2½-inch asphaltic wearing course. The traffic count in 1953 was 1955 vehicles including 490 trucks.

Average bearings for the top 24 inches of the subgrade for this test point from the fall of 1948 to the fall of 1953 follow:

Project	Station	Pave. Const.	Actual Depth of Sect.	Year Tested	Average Spring Value	Average Fall value
			inches		psi.	psi.
SN-FAI 174B	26+00	1947	9.25	1948	None	746
			9.3	1949	343	623
			9.0	1950	281	512
			9.0	1951	343	390
			9.0	1952	230	405
			9.1	1953	308	427

This test point also indicates a steady loss in subgrade bearing power although the minimum maintained since 1951 approximates the 400 psi. required for the standard 9½-inch pavement section. The total depth of pavement section measures slightly less than the required 9½-inch thickness. The pavement on this project has shown progressive distress in recent years and it developed considerable map cracking. In 1954 this project was strengthened by the placement of a 2-inch road mix course containing MC-4 bitumen.

C. Test Point No. 9 is on US 10 west of Jamestown in Stutsman County. This project was graded in 1941 and a temporary traffic service gravel course at the rate of 1,200 cubic yards per mile was included in the same contract. A 5¾-inch stabilized base was placed in 1942 and sealed with MC-4 bitumen and a sand aggregate cover. Further improvement was deferred due to World War II. Then a 2½-inch hot mixed bituminous surface was placed in 1944 containing MC-3 bitumen. The traffic count in 1953 was 2,090 vehicles including 548 trucks.

Average bearing values for the top 24 inches of the subgrade from the fall of 1948 to the fall of 1953 follow:

Project	Station	Pave. Const.	Actual Depth of Sect.	Year Tested	Average Spring Value	Average Fall Value
			inches		psi.	psi.
SN-FAP 279A	255+00	1944	9.75	1948	No Tests	845
			9.5	1949	481	886
			9.9	1950	514	759
			10.4	1951	577	762
			10.5	1952	609	906
			10.0	1953	352	522

This point has consistently tested higher than all other performance test points. For four years no continuous loss in bearing power was indicated. However, a sudden alarming decrease occurred in 1953. The future performance of this test point is being watched with much interest to attempt to determine plausible reasons for its actions.

D. Test Point No. 10 is on US 52 southeast of Donnybrook in Renville County. Grading work began in 1946 and was completed in 1947. In 1947 a temporary traffic service gravel course at the rate of 1,000 tons per mile was placed. The pavement section was placed in 1948 and consists of the standard 9½-inch section having a 5-inch pit-run subbase, 2-inch stabilized gravel base, and 2½-inch asphaltic wearing course. The project was resealed in 1952 with an application of RC-2 bitumen and a sand type aggregate cover. The traffic count in 1953 was 790 vehicles including 160 trucks.

Average bearing values for the top 24 inches of the subgrade from the fall of 1948 to the fall of 1953 follow:

Project	Station	Pave. Const.	Actual Depth of Sect.	Year Tested	Average Spring Value	Average Fall Value
			inches		psi.	psi.
SN-FAI 180(3)	199+30	1948	10.0	1948	No tests	662
			9.5	1949	450	533
			10.2	1950	166	257
			10.6	1951	172	237
			10.2	1952	166	231
			9.5	1953	171	241

This test point has shown a continuous loss of bearing power and up to date is the poorest point being tested. The project pavement shows progressive distress and is cracking badly. It may require prompt strengthening and reconditioning to prevent excessive deterioration.

SUMMARY

1. The cone device is rapid to use and is simple, compact, inexpensive and readily portable.
2. Its use is limited to testing the bearing power of fine textured subgrade soils.
3. Correlation of field and laboratory cone test results for the same soils has been unsuccessful.
4. The plate bearing method appears to be practical for testing a finished pavement section. For cone tests to be made a test hole must be opened through the base and pavement into the earth subgrade and the test hole refilled after the test is completed.
5. Regardless of its limitations the cone device has valuable practical usage. North Dakota expects to continue its usage in the standard manner developed by practice and experience.

Appendix

NORTH DAKOTA STATE HIGHWAY DEPARTMENT

Method of Determining Bearing Power of Soil with Cone Device

PROCEDURE OF TEST

The subsoil should first be scraped level at the point where the bearing is to be taken. The cone machine can then be 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 now loaded with a 10-lb. load and is released slowly to prevent impact, and is allowed to settle for one minute. The cone shaft is then locked in place and the amount of penetration recorded. This is the distance between collar and top cross-piece and is measured with calipers to the nearest hundreth 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 lb. successively, using the same procedure.

All of the above loads include the weight of the cone and shaft.

The bearing power of the soil is expressed in psi. based on the cross sectional area of the cone at the ground line, and the load. Tables have been prepared for each load so that the corresponding bearing value is read directly for each penetration.

Theoretically, discounting friction, etc., the penetration of the 10-lb. load is ½ of the penetration of the 40-lb. load; and the penetration of the 20-lb. load is ½ of the 80. Actually, this never works without first making a correction.

Sometimes when starting a test the cone is not exactly touching the subsoil, but may have penetrated slightly, or may be above; in either case all of the readings may be too small or too large. Then the cone has a rounded point and all the readings are too small on that account. Both of the above corrections can be taken care of at the same time by adding or subtracting the same amount to or from all the readings till the penetration of the 20-lb. load is ½ of the penetration of the 80 lb.

Example:

Load Lb.	Penetration 100ths Inch	Correction Penetration	Bearing psi.
10	44	54	592
20	66	76	596 (Average
40	98	108	592 594)
80	142	152	596

Computations: 44 x 2 = 88. 98 - 88 = +10, the correction required to restore all penetrations to the correct figures. (66 x 2 = 132. 142 - 132 = +10—Check).

The bearings for each load may vary a small amount and the true bearing is taken as the average.

TABLE A

PENETRATION RESISTANCE—PSI.

10-lb. Weight on Narrow Cone

		.02	.04	.06	.08
		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	356	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
1.6	67	66	64	62	61
1.7	59	58	57	55	54
1.8	53	52	50	49	48
1.9	47	46	45	44	44
2.0	43	42	41	40	39
2.1	39	38	37	36	36
2.2	35	35	34	33	33
2.3	32	33	31	30	30
2.4	29	29	28	28	28
2.5	27	27	26	26	25
2.6	25	25	24	24	24
2.7	23	23	22	22	22
2.8	22	21	21	21	20
2.9	20	20	19	19	19
3.0	19	18	18	18	18
3.1	17	17	17	17	17
3.2	16	16	16	16	16
3.3	15	15	15	15	15

Table A (continued)

		.02	.04	.06	.08
		431,500	107,875	47,944	26,968
3.4	14	14	14	14	14
3.5	14	13	13	13	13
3.6	13	13	13	12	12
3.7	12	12	12	12	12
3.8	11	11	11	11	11
3.9	11	11	11	11	10
4.0	10	10	10	10	10

TABLE B

PENETRATION RESISTANCE—PSI.

20-lb. Weight on Narrow Cone

		.02	.04	.06	.08
		863,000	215,750	95,888	53,936
.1	34,520	23,972	17,612	13,484	10,654
.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
2.1	78	77	75	74	73
2.2	71	70	68	67	66
2.3	65	64	63	62	61
2.4	60	59	58	57	56
2.5	55	54	53	52	51
2.6	51	50	49	48	48
2.7	47	46	46	45	45
2.8	44	43	43	42	41
2.9	41	40	40	39	39
3.0	38	38	37	37	36
3.1	36	35	35	34	34
3.2	33	33	32	32	32
3.3	31	31	30	30	30
3.4	29	29	29	28	28
3.5	28	27	27	27	26
3.6	26	26	26	25	25
3.7	25	24	24	24	24
3.8	23	23	23	23	22
3.9	22	22	22	22	21
4.0	21	21	21	21	21

TABLE C

PENETRATION RESISTANCE—PSI.

40-lb. Weight on Narrow Cone

		.02	.04	.06	.08
		1,726,000	431,500	191,776	107,872
.1	69,040	47,944	35,224	26,968	21,308
.2	17,260	14,264	11,986	10,212	8,804
.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
2.9	82	81	80	79	78
3.0	77	76	75	74	73
3.1	72	71	70	69	68
3.2	67	66	66	65	64
3.3	63	62	61	61	60
3.4	59	59	58	57	57
3.5	56	56	55	54	53
3.6	53	52	52	51	50
3.7	50	49	49	48	48
3.8	47	47	46	46	45
3.9	45	44	44	44	43
4.0	43	42	42	41	41

TABLE D

PENETRATION RESISTANCE—PSI.

80-lb. Weight on Narrow Cone

		.02	.04	.06	.08
		3,452,000	863,000	383,552	215,750
.1	138,080	95,888	70,448	53,936	42,616
.2	34,520	28,528	23,972	20,424	17,612
.3	15,336	13,484	11,944	10,654	9,460
.4	8,630	7,824	7,132	6,520	5,992

Table D (continued)

		.02	.04	.06	.08
		3,452,000	863,000	383,552	215,750
.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

CHARLES W. JOHNSON, Materials Engineer, and E. B. BAIL, Special Consultant, New Mexico State Highway Department—The cone device is admirably suited to the conditions existing in North Dakota, where great areas of fine-grained, relatively homogeneous soils exist. An impressive indication of soil uniformity is presented by Wise when he states that one subgrade test per mile is usually sufficient. On such soils it is practicable and structurally safe to design and build a flexible pavement of uniform thickness from end to end.

By contrast there is not, to our knowledge, any area in New Mexico where subgrade tests could be safely spaced more than 500 feet apart. Our soils are heterogeneous in the extreme; a relief map of this state shows a succession of mountain ranges separated by valleys in which are mixed all the products of erosion, and it is upon, and from this heterogeneous base that we must build our highways.

With a rather small field force at our disposal and a large mileage to test, the cone device is scarcely practicable for us. Furthermore, the method of averaging the bearing values at different depths, which, judging by the test results submitted by Wise, does not, in the cases cited, require the reconciliation of vastly different values, would, in the case of our greatly differing underground composition, give rise to considerable doubt as to the validity of the average.

Wise presents an interesting correlation with other methods of test for determining thickness of flexible base, and refers to McLeod's paper published in Engineering News, June 9, 1949, Page 77. It is noted that he rates the 400 psi. cone bearing as indicating a pavement thickness of 9½ inches, and, further, that this thickness is satisfactory for a 9,000-lb. wheel load. He states that this corresponds to a CBR of 10.25 and to 24 blows for 6-inch penetration of the Housel Penetrometer.

The correlation of 400 psi. for the cone device and a CBR of 10.25, both indicating approximately 9½ inches of flexible base for 9,000-lb. wheel load is quite in agreement with the estimated thickness given by a method developed at the New Mexico Highway Testing Laboratory and presented at the 1947 meeting of the Highway Research Board. In this method the soil is compacted at a moisture content equal to the highest water content found under existing bituminous pavements in the same general area as the proposed construction. The CBR at 0.1 inch penetration is taken as the subgrade resistance value S. The resulting thickness d is taken as the thickness of granular foundation required to support a given wheel load. It is of interest to note from the curves shown on Page 101 of the 1947 Proceedings that a CBR of 10 requires 9 inches of base for a 9,150-lb. load.

By the use of the New Mexico Chart that we used on the Correlation Design of WASHO Materials, for a CBR of 10 we obtain a thickness requirement of 2 inches of asphaltic concrete plus 10½ inches of a good granular base or 3 inches of asphaltic concrete and 5½ inches of granular base.

By working backward from California's Thickness Design Chart III, starting with 9½ inches on Scale 1, and laying a scale through the center of Asphaltic Concrete on Scale H, Cohesiometer Value, a value of 14 inches is obtained on Scale G for the gravel equivalent. Now by laying the straightedge from 14 inches through the traffic index of 7, we obtain an R value requirement of 38. It would be interesting to know what the R value would be on typical subgrade soils having a psi. of 400 by the cone device.

We are much interested in the progressive decrease in bearing values reported by Wise. Data on this type are much needed and the North Dakota Highway Department is to be congratulated on initiating such a study. We would like to know if this decrease in bearing value is accompanied by a significant rise in moisture content. We would appreciate also information as to the gradation of the soil and the Atterberg limits.