Dynamic Testing of Nebraska Soils and Aggregates

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The results of a study to develop an indirect test for the resilient modulus of Nebraska's aggregates and soils is summarized. Aggregate and soil samples were collected at 14 locations and tested for several engineering properties. The modulus of resilience was measured by the University of Nebraska soil mechanics laboratory, and other chemical and physical tests were performed by the Nebraska Department of Roads. Statistical comparisons were made between the resilient modulus and the other test results. It is concluded that it is possible to reliably determine the resilient moduli of subgrade materials by an indirect method.

The 1986 AASHTO *Guide for Design of Pavement Structures* uses the resilient modulus of soils in pavement determination equations. The purpose of our research was to find a reliable indirect, or proxy, method of determining the resilient modulus without elaborate triaxial testing equipment.

STUDY DESIGN

The study was structured in four stages. The first stage was to collect material samples and to conduct field tests. The next two stages were to be done concurrently, with the University of Nebraska at Lincoln, Civil Engineering Department, conducting the resilient modulus testing, while the Nebraska Department of Roads Materials and Tests (MAT) laboratory conducted the other tests. The last stage was the statistical analysis to find which of the laboratory data had the best relationship to the resilient modulus.

MATERIAL SAMPLING

The first stage of the study was to collect soil samples from various locations around the state. The intention was to select samples that would be representative of the state's major soil groups. Fourteen locations, presented in Figure 1, were selected, and the soils ranged from granular to fine-grained cohesive. At each location two bag samples of the parent soil were collected from the right-of-way, and thin-walled tube samples of the subgrade were taken through holes bored through the pavement.

Along with the soil sampling, deflection tests with a Dynaflect machine were conducted at the sites of the tube samples. No other field testing was necessary for the purpose of this study.

Table 1 presents the soil descriptions and characteristics. One bag sample from each site was delivered to the University of Nebraska, Civil Engineering Department, for the resilient modulus tests. All other tests were performed by the MAT laboratory.

TRIAXIAL TESTS

The resilient modulus measurements were made by using confined triaxial tests according to the provisions of AASHTO test T274-82. Deformations were measured with internally mounted linear variable differential transformers. The samples were prepared, using the procedures outlined in T274-82, with the cohesive soils compacted by kneading and the noncohesive soils compacted by impact (*1*). Much of the equipment and computer software used for the tests were developed by the University of Nebraska.

The testing was done in two phases. In phase 1, 15 to 25 tests were performed on six different soils. The tests were conducted at optimum moisture content, as was determined by AASHTO T99, and at several dynamic stress and cell pressure combinations (*1*). The purpose of phase 1 was to determine if the testing variability were within an acceptable range. Phase 2 was to be implemented only if the results of phase 1 were satisfactory.

The testing was totally automated, with the test results read directly by a computer. Each specimen was conditioned with 15,000 cycles of haversine loading prior to testing. The rate of loading was two cycles per second, with each cycle consisting of a 0.1-sec load application and a 0.4-sec recovery period.

Table 2 presents the result of the phase 1 testing. The coefficient of variation was found to be $\leq$10 percent for 71 percent of the tests and $\leq$12 percent for 84 percent of the tests. Those results were considered adequate to proceed with the phase 2 testing.

In phase 2, the triaxial tests were performed on samples from all 14 locations. The cohesive soils tests were conducted by using various combinations of three different cell pressures, five different dynamic stresses, and three different moisture contents. The nonplastic soils were tested according to the T274 procedure for granular soils, using combinations of five different cell pressures, up to 6 different dynamic stresses, and three different moisture contents (*1*).

Each sample was tested at optimum moisture content and at approximately optimum +1 percent and −1 percent. No attempt was made to test at saturation, because it was felt that it represented realistic field conditions. The aggregates and soils and the moisture contents where they were tested are presented in Table 3.

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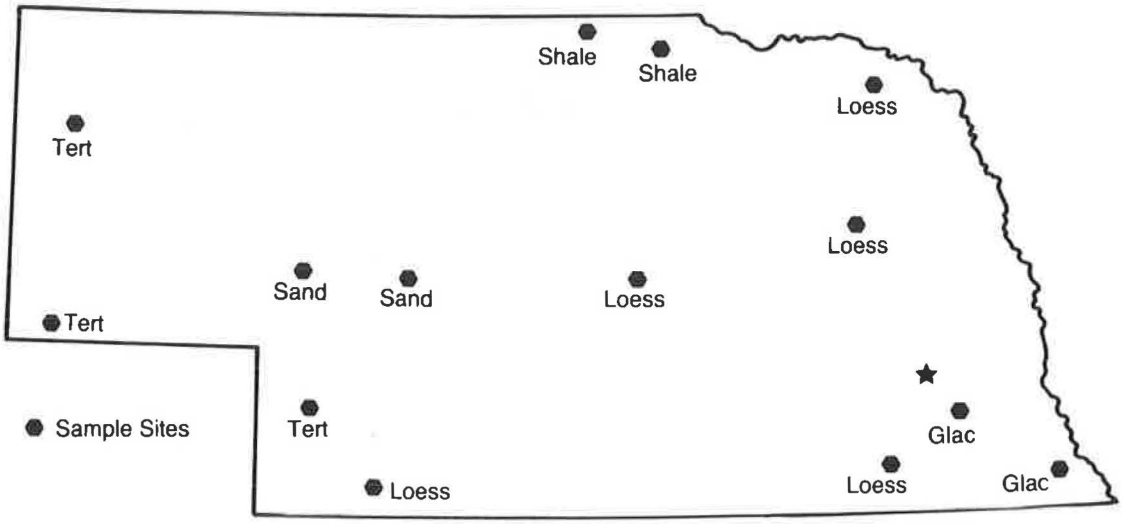


FIGURE 1 Sample locations.

TABLE 1 CHARACTERISTICS OF SOILS AND AGGREGATES

Smpl. No.	Soil Type	% Ret. on #4	% Ret. on #200	Sieve w/0 % Ret.	LL*	PI**	AASHO Class	Nebr. Group Index
171	Fine Sand	0	88	10	--	NP	A-2-4 (0)	-2.0
176	Fine Sand	0	88	10	--	NP	A-2-4 (0)	-2.0
174	Tertiary	0	44	10	--	NP	A-4(3.8)	4.2
223	Tertiary	11	65	1	24	2	A-2-4 (0)	-1.0
335	Tertiary	0	46	4	20	NP	A-4(4.2)	3.8
246	Loess	0	2	10	36	15	A-6(10)	10.0
172	Loess	0	1	100	31	8	A-4(8)	8.0
336	Loess	0	4	100	26	3	A-4(8)	8.0
184	Loess	0	1	100	43	22	A-7-6(13.8)	13.4
297	Loess	0	3	40	45	26	A-7-6(15.3)	15.4
278	Glacial	0	23	4	34	15	A-6(8.4)	10.0
313	Glacial	0	21	4	51	32	A-7-6(18.2)	19.0
247	Shale	0	4	4	68	46	A-7-6(20)	28.0
249	Shale	0	3	10	66	43	A-7-6(20)	26.4

*LL Liquid Limit
**PI Plastic Limit

TABLE 2 PHASE 1 OF VARIABILITY (*1*)

Soil Type	No. of Test	% with Coef. of Variation ≤10%	% with Coef. of Variation ≤12%
Fine Sand	25	80	84
Tertiary	15	67	80
Glacial	15	73	87
Medium Loess	15	47	80
High Loess	15	73	87
Pierre Shale	15	80	87

TABLE 3 MOISTURE CONTENT FOR RESILIENT MODULUS TESTING (*1*)

Sample No.	Soil Type	Avg. Dry Wt. pcf	Percentage Moisture Optimum	Wet	Dry
171	Fine Sand	112.0	11.3	12.3	10.2
176	Fine Sand	109.9	12.7	13.5	11.4
174	Tertiary	101.9	15.8	16.5	14.8
223	Tertiary	111.0	14.0	15.7	13.4
335	Tertiary	111.0	14.0	14.7	12.6
246	Loess	106.4	17.8	18.8	16.9
172	Loess	105.0	17.8	18.8	16.7
336	Loess	105.9	17.1	17.9	15.8
184	Loess	102.1	20.8	21.6	19.6
297	Loess	100.8	20.4	21.4	19.3
278	Glacial	116.2	15.5	16.5	14.5
313	Glacial	109.2	17.4	18.4	16.9
247	Shale	94.7	26.4	27.1	25.1
249	Shale	98.6	24.0	25.0	23.0

The test cell pressures for the cohesive soils were 0, 3, and 6 psi and for the granular soils 1, 5, 10, 15, and 20 psi. Statistical analysis was performed with all of the resilient modulus test results. However, the tests that used a confining pressure of 0 psi were considered the most important. For that reason, the 0 psi cell pressure test results are given the most attention.

Figures 2–8 show some of the results of resilient modulus tests. The results of some of the tests, such as Figure 5, appear to be contrary to conventional wisdom. Those atypical results were observed with some of the low plasticity soils, and additional tests were conducted to verify the first tests. The curve inversion may be caused by negative pore water pressure, which develops during the load impulse and does not have time to equalize during the 0.1-sec load cycle. The following explanation was suggested by the University of Nebraska: "During the haversine load pulse, rapid shearing strains are

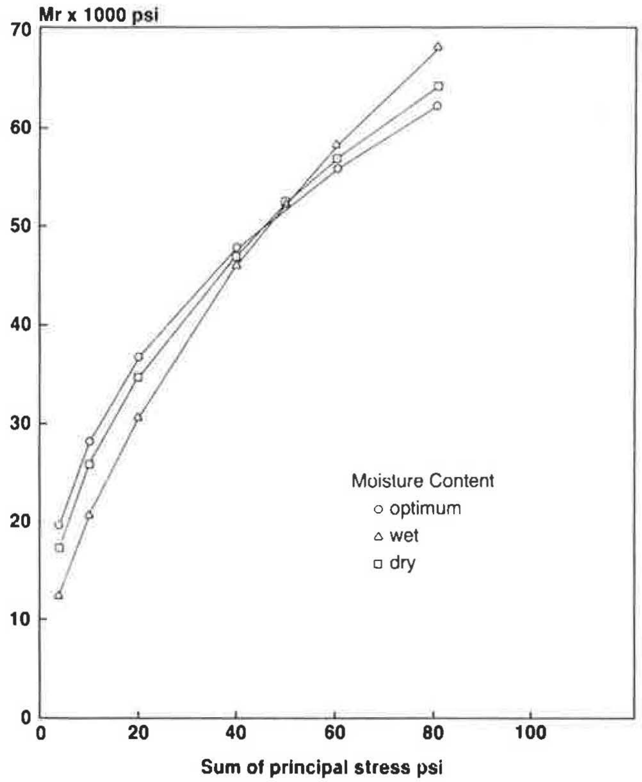


FIGURE 2 Resilient modulus, fine sand (1).

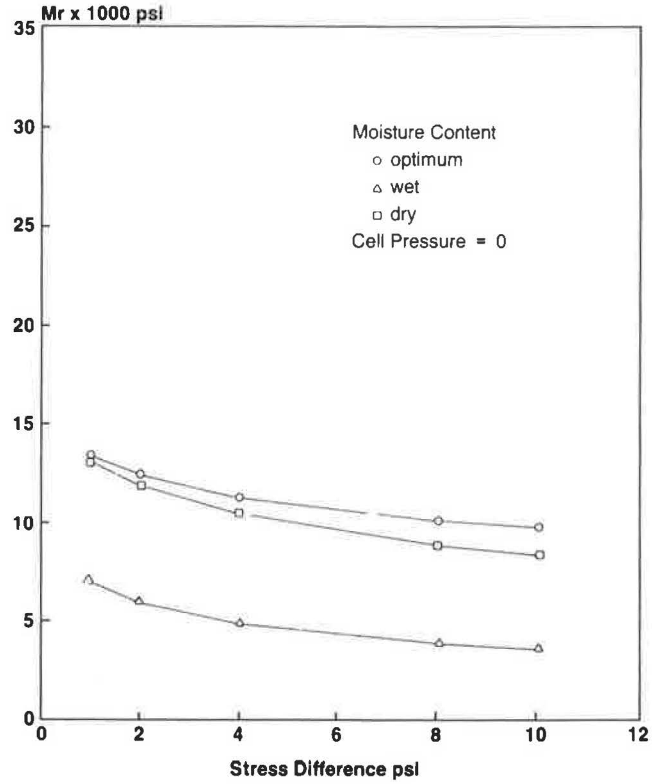


FIGURE 4 Resilient modulus, Peorian loess, medium plasticity (1).

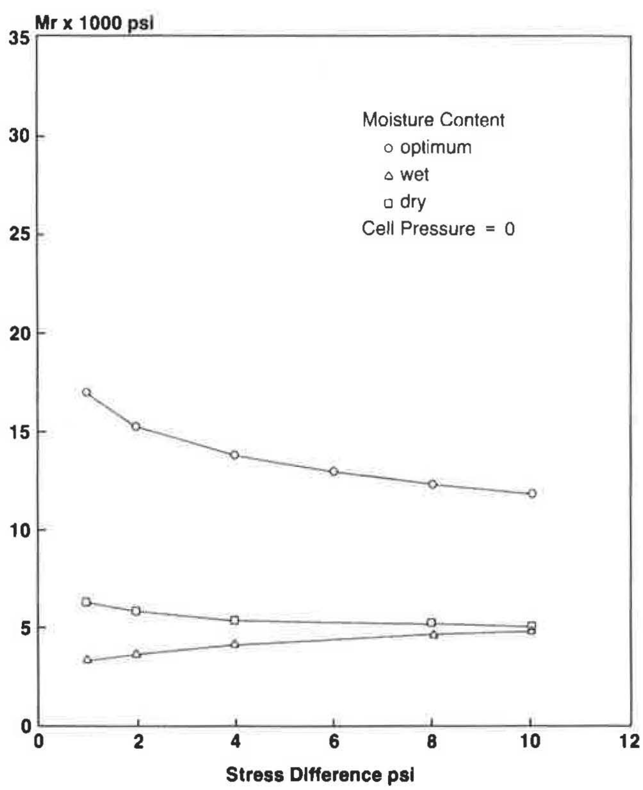


FIGURE 3 Resilient modulus, tertiary (1).

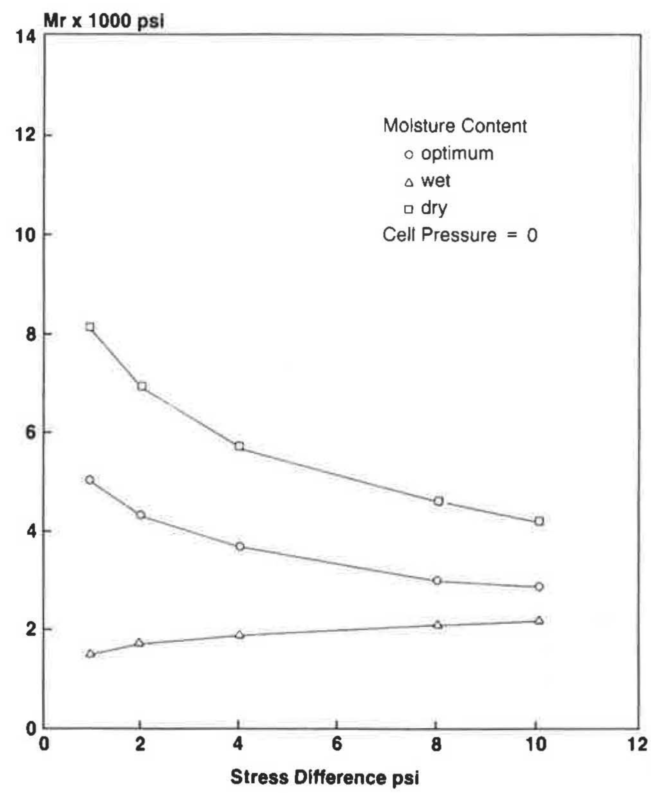


FIGURE 5 Resilient modulus, Peorian loess, low plasticity (1).

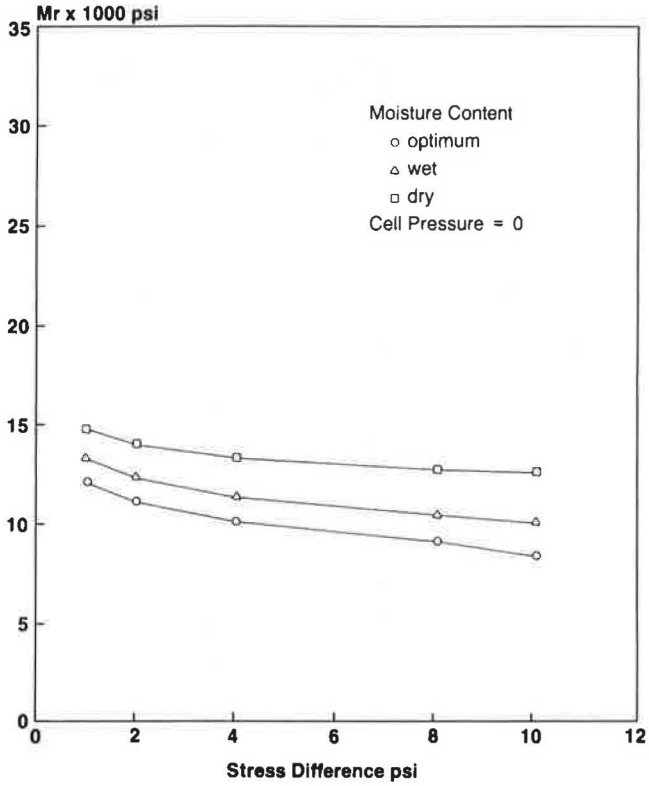


FIGURE 6 Resilient modulus, Peorian loess, high plasticity (*1*).

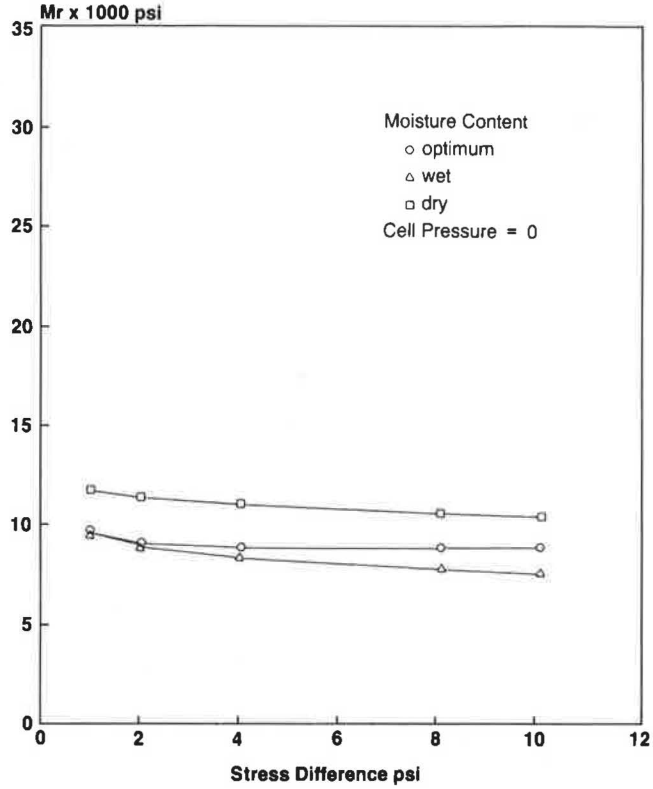


FIGURE 8 Resilient modulus, Pierre shale (*1*).

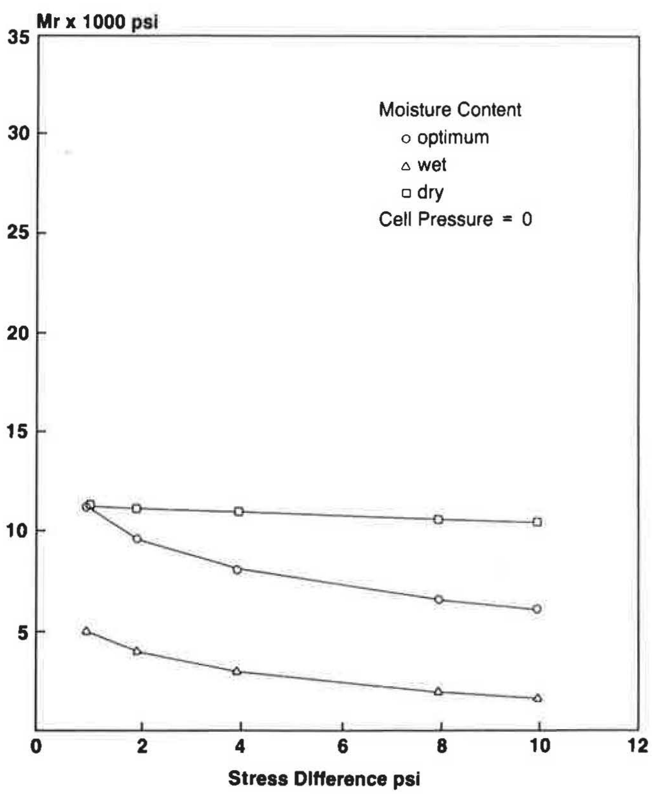


FIGURE 7 Resilient modulus, glacial (*1*).

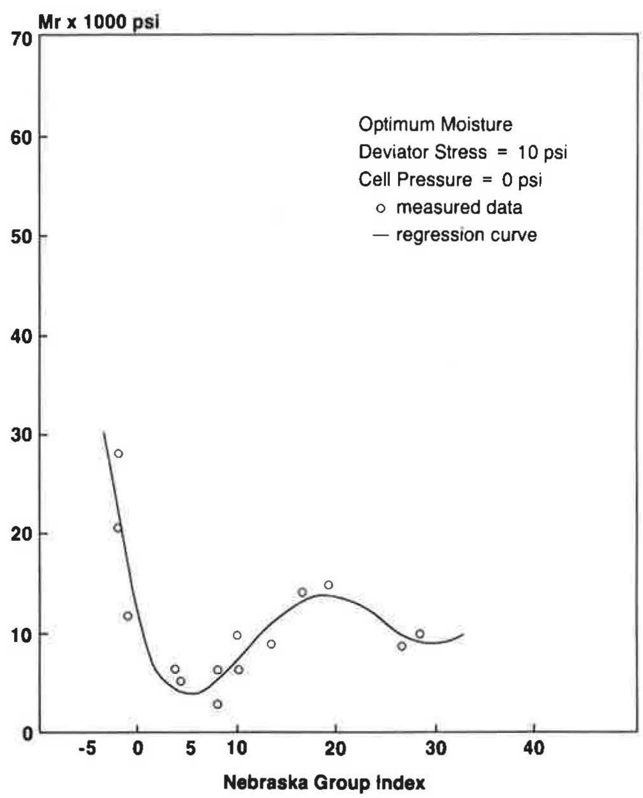
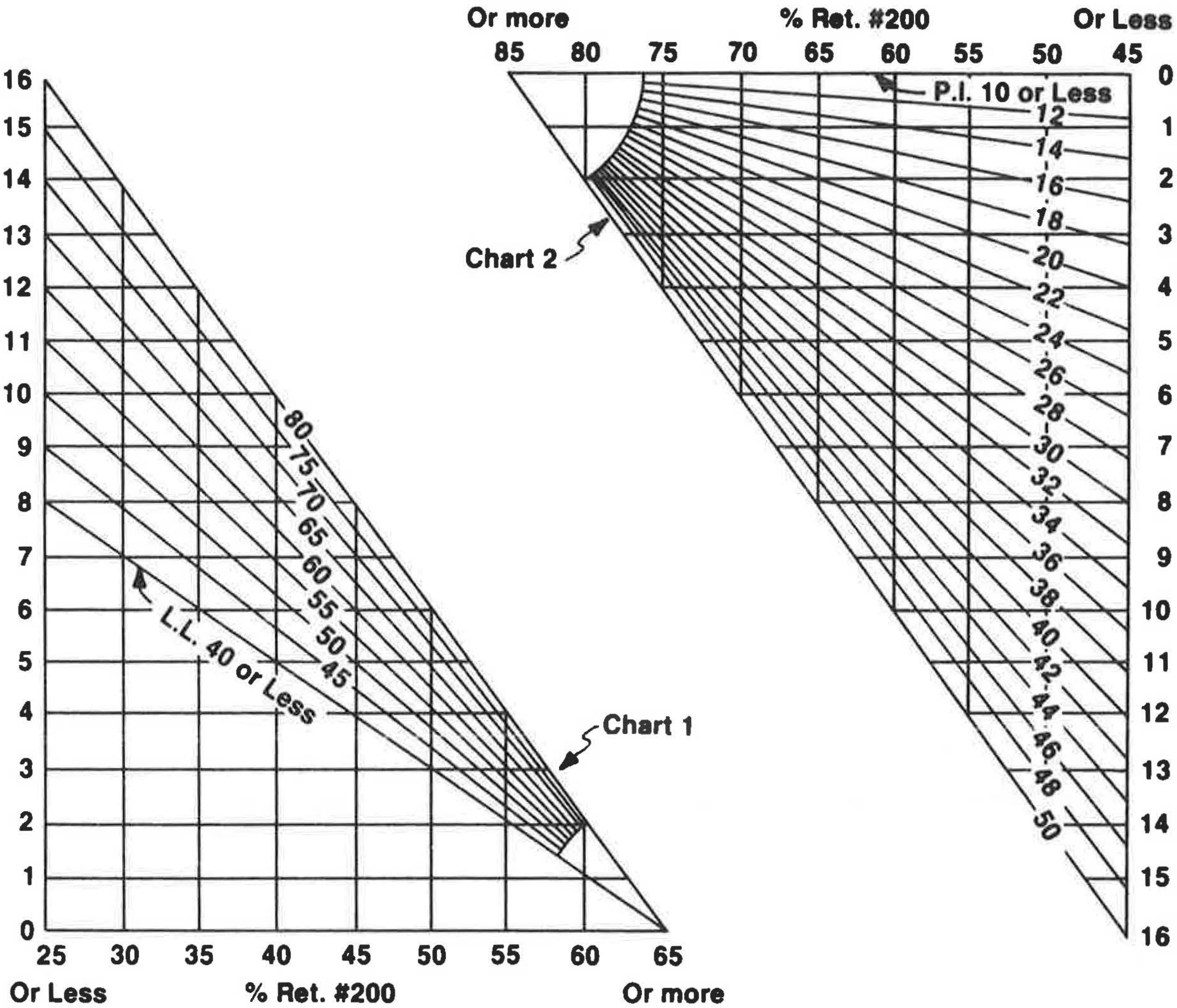


FIGURE 9 Resilient modulus versus Nebraska Group Index.



Group Index { Positive Values - Sum of Readings on Vertical Scale of Charts 1 & 2.
Negative Values - Use Chart 3.

	Well Graded Gravel Base	**Clean Coarse Sand**	**Clean Fine Sand**	**Loamy Coarse Sand**	**Loamy Fine Sand**	**Loamy Very Fine Sand**
Group Index	- 4	- 3	- 2		- 1	0
% Ret. #10	40 Min.					
% Ret. #40	60 Min.	35 Min.	34 Max.	35 Min.	34 Max. 10 Min.	9 Max.
% Ret. #200	85 Min.	85 Min.	85 Min.	84 Max. 65 Min.	84 Max. 65 Min.	84 Max. 65 Min.
P.I.	4 Max.	4 Max.	4 Max.	10 Max.	10 Max.	10 Max.

The first group from the left into which the test data will fit is the correct classification.

FIGURE 10 Nebraska Group Index charts.

induced. At low confining pressures and high degrees of saturation, a drop in pore water pressure is produced, caused by dilation of the well-compacted granular material. Since the load pulse is only 0.1 sec in duration, there is not sufficient time for pore water migration as the sample dilates; thus the pore water pressure must drop. The drop in pore water pressure increases the effective stress and the sample appears more stiff" (*1*). This effect was most apparent under wet conditions and low confining pressures.

No tests have been conducted to try to prove the theory.

OTHER LABORATORY TESTS

The following tests were performed by the MAT laboratory: soil gradations, liquid limit, plastic limit, X ray diffraction, optimum moisture content, and in situ moisture content from the tube samples. The data from the laboratory tests and the deflection tests were used for the statistical analysis.

STATISTICAL ANALYSIS

Regression equations were derived both individually and in combinations for the resilient moduli and for the other measurements. The initial results were not encouraging. Most of the comparisons yielded little more than scatter-gun graph patterns. However, certain characteristics yielded better results than others did: the percent retained on the No. 200 sieve, the liquid limit, and the plasticity index. Because those are the characteristics used to determine the soil group index, regression equations were developed by using group indices as the known variables. This procedure yielded a very close fit to the measured data, as indicated by Figure 9.

The group index used in the regression analysis is the Nebraska Group Index (NGI). The NGI, as determined from Figure 10, is similar to that developed by AASHTO, but it is somewhat more sensitive and permits negative values for granular materials.

Regression analyses were performed for resilient moduli produced by a cell pressure of 0 psi with a deviator stress of 10 psi and a cell pressure of 6 psi with a deviator stress of 10 psi. Although a cubic equation seemed to give the best fit for the low plasticity soils, the best overall fit, under all three moisture levels, turned out to be the fourth-order equations given in Equations (1) and (2).

$$Mr = 100[B_0 + B_1(G) + B_2(G^2) + B_3(G^3) + B_4(G^4)] \quad (1)$$

where Mr is the resilient modulus (psi) and G is the Nebraska Group Index.

	Optimum	*Wet*	*Dry*
B_0 =	123.69	92.15	99.51
B_1 =	−38.81	−32.66	−36.39
B_2 =	5.52	4.33	6.42
B_3 =	−0.25	−0.17	−0.33
B_4 =	0.004	0.002	0.005
[R square	0.96	0.92	0.93]

The deviator stress is 10 psi, and the cell pressure is 0 psi.

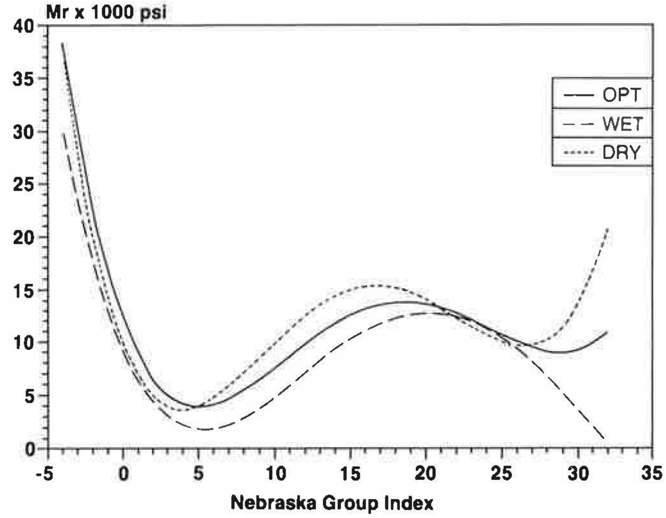


FIGURE 11 Resilient modulus versus Nebraska Group Index, deviator stress = 10, confining pressure = 0.

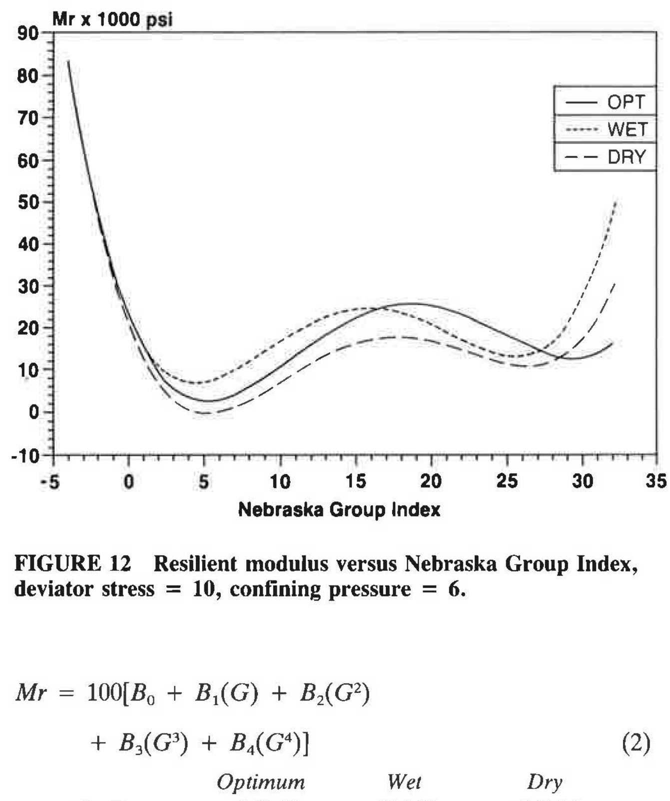


FIGURE 12 Resilient modulus versus Nebraska Group Index, deviator stress = 10, confining pressure = 6.

$$Mr = 100[B_0 + B_1(G) + B_2(G^2) + B_3(G^3) + B_4(G^4)] \quad (2)$$

	Optimum	*Wet*	*Dry*
B_0 =	249.44	226.31	241.26
B_1 =	−98.38	−105.03	−95.17
B_2 =	13.51	14.93	15.63
B_3 =	−0.60	−0.71	−0.82
B_4 =	0.008	0.011	0.013
[*R* square	0.92	0.88	0.88]

The deviator stress is 10 psi, and the cell pressure is 6 psi.

The equations, as indicated by Figures 11 and 12, conform fairly well to the observed data. Within an NGI range of approximately −3 to +28, the equations are fairly well behaved. However, the equations should not be used for aggregates and soils outside of this range, because the fourth-order term begins to dominate and the results are no longer reliable. The effective range, however, covers most soil-aggregate mixtures used for Nebraska road construction.

SUMMARY

The purpose of the study was to determine if there was a reliable, easily performed test for the resilient moduli of subgrade soils and aggregates. While there was some initial concern, the small sample and the variability within soils and aggregates of the same classification were not fatal problems.

The regression analysis demonstrated that it is possible to reliably determine the resilient modulus of soils through indirect methods. The results of the study did raise some questions about using resilient modulus, as measured by AASHTO test T274-82 for pavement design. The main problems are the apparent increase in strength with increasing load of some low plasticity soils.

CONCLUSIONS

From the results of the various tests and the statistical regression analysis it has been determined that

1. The resilient moduli of soils can be reliably determined by indirect methods.
2. Some high plasticity soils show very high strengths under dynamic loading.
3. Pavement deflection results, as measured with a Dynaflect, did not show enough relationship to the resilient modulus to be used as an indicator.
4. The Nebraska Group Index is a reliable indicator of the resilient moduli of soils within an NGI of -3 to $+28$.

ACKNOWLEDGMENTS

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REFERENCE

1. R. V. Sneddon. *Resilient Modulus Testing of 14 Nebraska Soils.* University of Nebraska, Lincoln, Nov. 1988.

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