# Evaluation of Pavement Subgrade Support Characteristics by Dilatometer Test

ROY H. BORDEN, CECEP N. AZIZ, WESLEY M. LOWDER, and N. PAUL KHOSLA

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## ABSTRACT

The problem of evaluating the as-compacted or existing properties of subgrade soils is an important aspect of the design and rehabilitation of flexible pavements. The dilatometer has been shown to have significant potential for obtaining this information both reliably and economically. The relationship between the dilatometer modulus and the as-compacted California bearing ratio (CBR) for three different natural soils has been investigated. In general, the test program may be characterized as having evaluated: (a) a range of sample sizes including cylindrical molds of 6.0 in. (152 mm) and 11 in. (280 mm) diameter, a 3 ft x 4 ft (approximately 1 m x 1.25 m) chamber, and several field tests; (b) compactive efforts equivalent to AASHTO T-180, T-99, 50 percent of T-99, and a lower effort that produced a density equivalent to 90 percent of T-99 maximum dry density; and (c) a moisture content range for each soil sufficient to establish maximum dry densities at each compactive effort. The results of the laboratory and field test program lead to the following conclusions: (a) Unique relationships between dilatometer modulus and CBR were found to exist for the as-compacted A-5 and A-6 soils regardless of density and moisture content conditions. (b) A laboratory technique was developed whereby dilatometer penetration could be performed in CBR molds 6 in. (152 mm) in diameter such that both pieces of data could be obtained on the same specimen. Although the boundary conditions appear unfavorable in the small mold, the results were consistent with those obtained in an 11-in. (280-mm) mold and a chamber 3 ft x 4 ft (approximately 1 m x 1.25 m). This small mold test did not work well for the A-2-4 soil and would probably not work for any soil that was dominated by granular material with little fine-grained component. (c) Limited field tests on a compacted embankment from which one of the soils (A-6) used in the study was obtained revealed excellent correlation with the laboratory test program.

The problem of evaluating the as-compacted or existing properties of subgrade soils is an important aspect of the design and rehabilitation of flexible pavements. At present, this estimate is generally obtained by conducting in-place California bearing ratio (CBR) tests or less frequently plate loading tests. These tests involve the removal of a section of pavement large enough that a technician can work in the excavated area at the subgrade level. The flat dilatometer, a device introduced in 1975 by Marchetti (1) for the in situ investigation of soil properties, offers significant promise for providing a reliable and economical method for obtaining strength and stiffness characteristics associated with pavement design.

The flat dilatometer, shown in Figure 1, consists of a stainless steel blade with a thin, flat, circular, expandable steel membrane on one side. The body of the dilatometer has a width of approximately 3.7 in. (95 mm) and a thickness of approximately 0.6 in. (14 mm). When at rest, the external surface of the membrane, approximately 2.4 in. (60 mm) in diameter, is flush with the surrounding flat surface of the blade. The blade is jacked into the ground and when located at the desired depth the membrane is inflated by means of pressurized gas through a small control unit at the ground surface (also shown in Figure 1). A longitudinal cross section of the dilatometer is shown in Figure 2. Readings are taken of the "A" pressure required to just begin to move the membrane (related to the lateral stresses existing in the ground) and of that "B" pressure required to move its center an additional approximate 0.04 in. (1 mm) into the soil (related to soil stiffness). Movements of the membrane are measured by extensometers behind the diaphragm within the body of the device. On the basis of the assumption of linear elasticity, Marchetti (2) proposed that the lateral soil modulus be represented by the expression

FIGURE 1 Dilatometer and control unit.

$$S_o = [2\Delta p D(1 - \mu^2)]/(\pi E) \qquad (1)$$

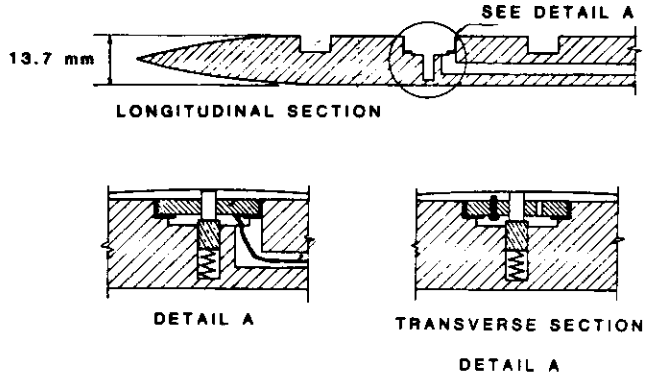

**FIGURE 2 Section and details of dilatometer blade.**

where $S_o$ is the approximate 0.04-in. (1-mm) deflection of the center of the membrane, $\Delta p$ is the difference in the A and B readings corrected for membrane stiffness, D is the 2.4-in. (60-mm) membrane diameter, E is Young's modulus, and $\mu$ is Poisson's ratio of the soil. The expression, $E/(1 - \mu^2)$, is then termed the dilatometer modulus ($E_d$).

The usefulness of lateral soil modulus data for predicting vertical stiffness has been demonstrated in a study by Briaud and Shields (3). In their study, lateral stiffness data were obtained using a small diameter pressure meter and were shown to be linearly related to pavement bearing strength as determined by McLeod plate tests.

The laboratory and field tests reported in this paper were conducted in the first phase of a research program to evaluate the use of the dilatometer for obtaining subgrade support characteristics both for pavement under construction and for those requiring rehabilitation. In the initial phase of the program, the objectives were the development of laboratory testing techniques and the establishment of correlations between dilatometer moduli and CBR values for a range of soil types and moisture-density conditions. Field verification tests were also conducted in a newly compacted subgrade as were preliminary tests in an existing pavement system. In one instance, the dilatometer was hydraulically pushed through an asphalt pavement with the 7,500-lb. (33.4-kN) capacity of a Mobile drill rig. Research is continuing on developing field testing techniques for use beneath existing pavements and on correlating the lateral soil modulus obtained from the dilatometer with resilient modulus and constrained modulus response.

## EXPERIMENTAL PROGRAM

To evaluate the potential usefulness of the dilatometer for determining pavement subgrade support characteristics, an experimental program was designed using the three natural soils the characteristics of which are given in Table 1. These soils were chosen for their range of properties and significance as locally encountered materials. Most notably, the first soil has a significant mica content, the second has a higher silt-clay content, and the third has an extremely high sand content. Because the primary goal of this first phase of the research program was to identify the potential for predicting in-place subgrade characteristics (as indicated by CBR value) from the dilatometer modulus, it was deemed important to evaluate the significance of soil type on the functional relationship. It was also anticipated that the insertion of the dilatometer blade into a laboratory scale sample could produce results different from those that would be obtained in the field due to boundary effects. The experimental program evolved because the findings on the first soil tested influenced the subsequent procedures. In general, the test program may be characterized as having evaluated (a) a range of sample sizes including cylindrical molds 6 in. (152 mm) and 11 in. (280 mm) in diameter, a chamber 3 ft x 4 ft (approximately 1 m x 1.25 m), and several field tests; (b) compactive efforts equivalent to AASHTO T-180, T-99, 50 percent of T-99, and a lower effort that produced a density equivalent to 90 percent of the T-99 maximum dry density; and (c) a moisture content range for each soil sufficient to establish maximum dry densities at each compactive effort.

**TABLE 1 Soil Characteristics**

| | Soil 1 | Soil 2 | Soil 3 |
|---|---|---|---|
| Percentage passing no. 4 sieve | 88 | 97 | 100 |
| Percentage passing no. 40 sieve | 77 | 84 | 40 |
| Percentage passing no. 200 sieve | 43 | 65 | 18 |
| Liquid limit (%) | 46 | 37 | 26 |
| Plasticity index (%) | 3 | 15 | 4 |
| $\gamma_d$ max (pcf) | 102.4 | 111.0 | 118.0 |
| wopt (%) | 20 | 16.8 | 12.5 |
| $\gamma_d$ max (pcf) | 110.4 | 123.0 | – |
| wopt (%) | 16.8 | 12.2 | – |
| Specific gravity | 2.77 | 2.78 | 2.70 |
| AASHTO classification | A-5 | A-6 | A-2-4 |

Note: Dashes indicate not conducted.

The standard preparation technique for all samples involved the air drying of soil, followed by an increase in moisture content by means of a combination of hand and rotary mixing. All samples were then sealed in plastic bags and placed in a 100 percent humidity room for at least 72 hr to enhance moisture equilibration. All specimens 6 in. (152 mm) in diameter were compacted using an automatic drop weight device fitted with a sector-shaped hammer head. Standard AASHTO compaction procedures were used. A fresh batch of soil was used for each compaction test. This eliminated the question of any residual fabric effects that can arise in some soils from the reuse of previously compacted material.

For practical reasons it was not deemed feasible to compact the specimens 11 in. (280 mm) in diameter with the same drop weight procedure. Static compaction using an MTS loading frame was employed to compress layers of soil to the desired density. In this way densities could be obtained that corresponded to the densities (T-180, T-99, and so forth) from the impact tests. Three layers were used to make specimens approximately 13 in. (330 mm) to 13.8 in. (350 mm) in height. After the last layer was compacted, three CBR tests were conducted in the top layer. The dilatometer test was performed once in each layer with the dilatometer positioned in such a way that the center of the membrane was approximately at the middepth of each layer.

The CBR tests for each of the lower layers were performed after carefully removing the soils on top of them. The final wet unit weight of the compacted soil was determined as the ratio of the weight of soil in each layer divided by its final volume (taking into consideration the densification of the lower layers due to placing of the upper layers).

To more clearly identify the influence of sample size that resulted from the presence of constraining boundaries, an even larger laboratory sample was used in the first test series. A test chamber with plan dimensions of 3 ft x 4 ft (approximately 1 m x 1.25 m) and a height of 3 ft (approximately 1 m) was constructed. Soil for this sample was brought to the desired moisture condition by mixing in a concrete mixer. A layer of sand was placed and compacted in the bottom of the chamber, followed by compacted layers of soil approximately 5 in. (125 mm) thick. Each soil layer was compacted using a hand-held mechanical field compacter. The dilatometer was pushed into the sample by means of a hydraulic piston mounted on an overhead frame. The use of pressure-compensating flow control valves allowed the dilatometer to be inserted at a controlled rate. When the center of the dilatometer membrane was approximately at middepth of the first layer, the penetration was stopped and the membrane inflated. On completion of the test, the dilatometer was advanced to middepth of the next layer. This procedure continued until all three layers had been tested, with the sand layer providing a "cushion" to ensure that the tip of the dilatometer did not strike the bottom of the chamber when penetrating to the bottom layer. After the completion of numerous dilatometer insertions, the box was excavated allowing for (a) conducting "field" CBR tests at the middepth of the compacted layers and (b) an actual measurement of the as-compacted layer thickness and moisture content distribution.

Finally, for the second soil tested, a local field site was identified where a compacted embankment for a bridge abutment had recently been constructed. A series of field density tests, field CBR tests, and dilatometer tests was conducted. The CBR tests were conducted using the loaded reaction truck shown in Figure 3, which was jacked off of its springs and supported on concrete cylinders. The dilatometer was hydraulically inserted by using the Mobile drill rig shown in Figure 4. Only minor modifications in the coupling of the union were required to attach the dilatometer to the existing equipment.

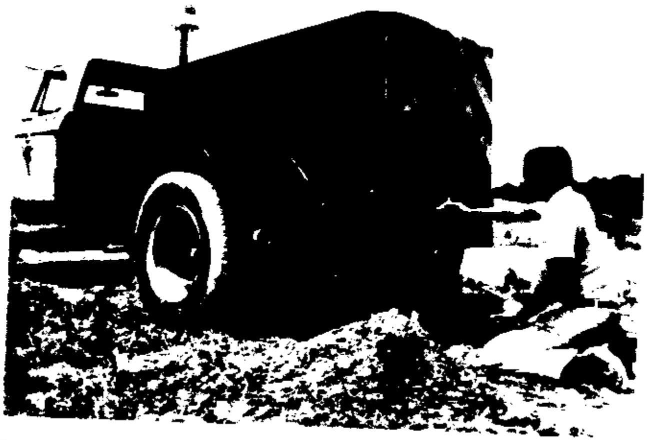

FIGURE 3 Field CBR test.

RESULTS

The results of the laboratory and field tests conducted in this study are presented in the sequence in which the three soils were tested because intermediate conclusions were reached and these findings influenced subsequent testing procedures. During the initial stages of the testing program special attention was focused on answering the following questions:

1. If specimens are made in a larger diameter mold, will differences in specimen preparation technique substantially influence the density-CBR and the CBR-dilatometer relationships?

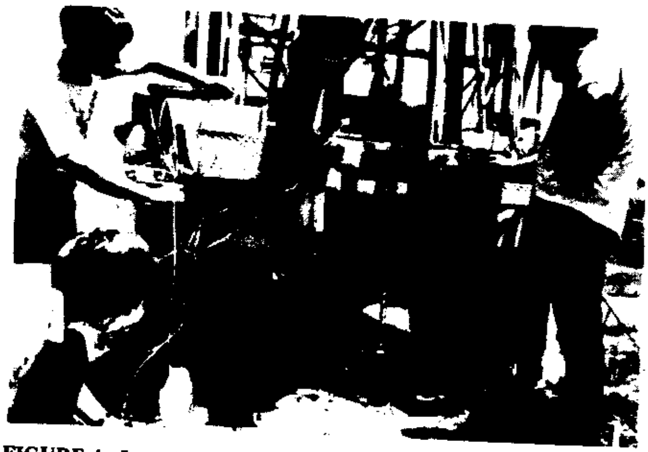

FIGURE 4 Insertion of dilatometer with drill rig.

2. How large does the mold into which the dilatometer is pushed need to be in order to reduce boundary effects to a minimal level for compacted soils?

3. Can a unique relationship between dilatometer modulus ($E_d$) and CBR be found, regardless of soil density or moisture content conditions, for each soil tested?

It was obvious that moisture-density relationships and CBR data would need to be developed in standard molds with conventional compaction procedures. However, it was initially believed that the dilatometer would probably need to be inserted into specimens that had a minimal diameter of the 11 in. (280 mm).

Figures 5 and 6 show the compaction characteristics and unsoaked CBR response, respectively, for the A-5 soil. For the lower moisture contents, the effect of increased compactive effort is to increase the CBR value. At higher moisture contents, the as-compacted CBR values are lower for the specimens compacted with the highest energy level. This is due to the increased initial degree of saturation and resultant influence on the effective stress state during penetration.

On the basis of the results of the impact-compacted specimens reported in Figures 5 and 6, and

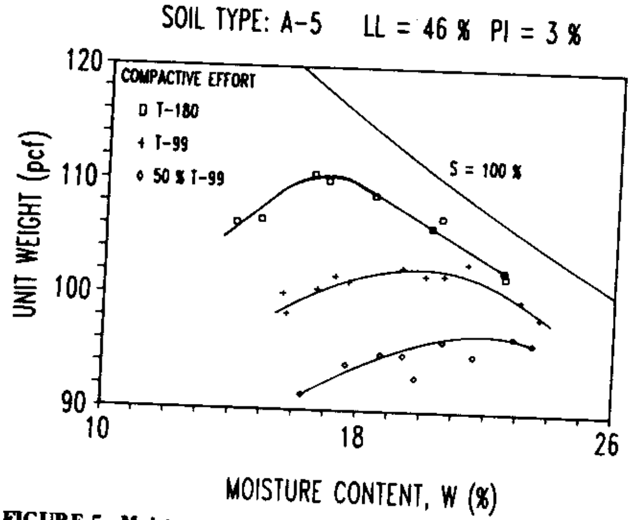

FIGURE 5 Moisture content versus unit weight for A-5 soil.

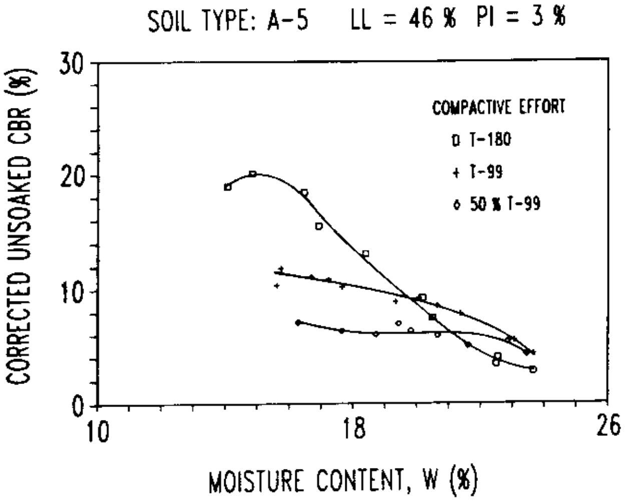

**FIGURE 6** Moisture content versus corrected unsoaked CBR for A-5 soil.

using the smooth curves fit through the data, Figure 7 was constructed (4). From this figure, the as-compacted CBR value can be predicted for any combination of moisture content and dry density. This allowed a comparison to be made between the CBR values obtained from tests on statically compacted samples and standard impact-compacted samples. The dry density and moisture content of the statically compacted sample were determined by excavating the sample after testing. When these two values had been determined, the predicted CBR value was found from Figure 7 and compared with the value obtained from the CBR test on the statically compacted sample. The degree to which these data agree is some measure of the similarity of the specimens. The results of this comparison are shown in Figure 8 with several typical values noted. The 45-degree line indicates complete agreement and the comparison is seen to be quite good. Although this is no guarantee that fabric or structural differences between impact-compacted and statically compacted specimens do not exist to any degree, it is an indication that they are not significant near the optimum moisture content where the statically compacted specimens were prepared.

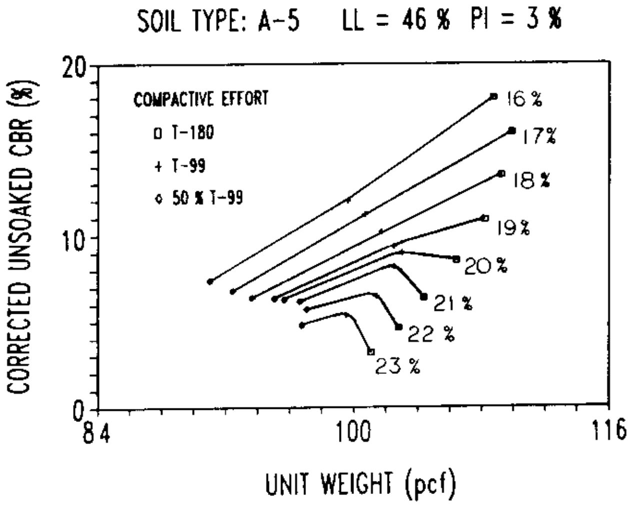

**FIGURE 7** Unit weight versus corrected unsoaked CBR for A-5 soil.

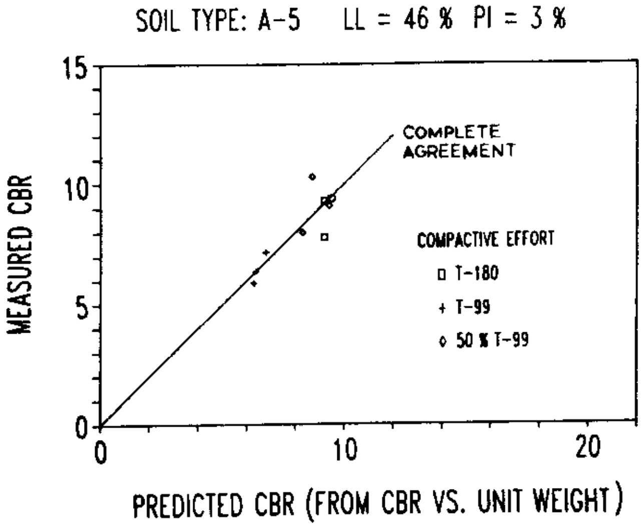

**FIGURE 8** Predicted CBR versus measured CBR for A-5 soil.

Figure 9 shows a summary plot of the CBR versus dilatometer modulus data for the tests conducted in the statically compacted specimens, the large test chamber previously described, and several tests conducted in a mold having the same diameter as the standard CBR mold but that was considerably taller and allowed the impact compaction of a specimen 12 in. (approximately 300 mm) thick. CBR tests were conducted on the surface and the dilatometer was inserted down to midheight of the mold. A linear regression was performed using all data points except those circled; this resulted in the regression coefficients a = 0.07, b = .041, and an $R^2$ value of 0.86. With an insignificant loss in predictive capability, the expression could be more simply stated as

$$CBR = 0.041\ E_d \tag{2}$$

with the CBR value expressed as a percentage and the $E_d$ value in tsf.

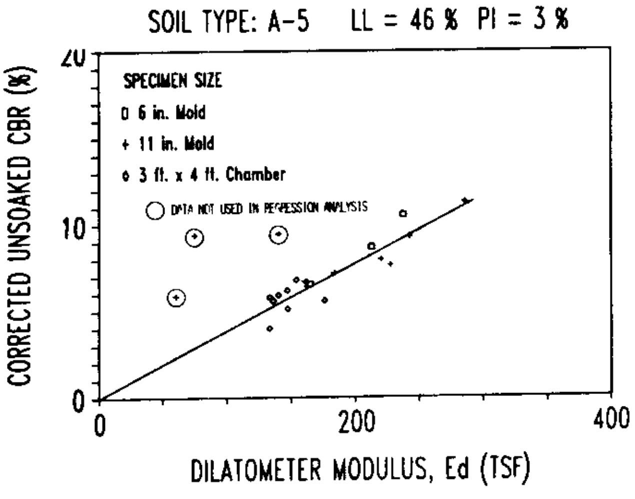

**FIGURE 9** Dilatometer modulus versus corrected unsoaked CBR for A-5 soil.

The three values that are circled in Figure 9 represent dilatometer data obtained in the top layer of the statically compacted three-layer specimens. In each case the top layer was approximately 4 in. (100 mm) thick and the dilatometer membrane 2.4 in. (60 mm) in diameter was only 0.8 in. (20 mm) to 1.2 in. (30 mm) below the soil surface. It appears that the insertion of the blade created enough disturbance of the adjacent soil to cause a loss of lateral support. This was noted by visual observation. In subsequent tests on the third soil (predominated by its sand component) actual bearing capacity failures with significant uplifted zones were noted in some specimens. The data from the large box actually represent the average of two or three dilatometer modulus values within a 10-in. (254-mm) radius of the three CBR tests conducted in the center of each of the three layers. The CBR tests were conducted along the centerline of the box at the one-quarter, one-half, and three-quarter points on the plan area.

An analysis of the data shown in Figure 9 resulted in two important conclusions:

1. The modulus data obtained in the 6-in. (152-mm) mold (standard CBR mold diameter) provided data consistent with the larger mold and large box although the boundary conditions are obviously less favorable and
2. The 0.8- to 1.2-in. (20- to 30-mm) penetration of the dilatometer diaphragm below the 11-in. (280-mm) mold surface was not sufficient.

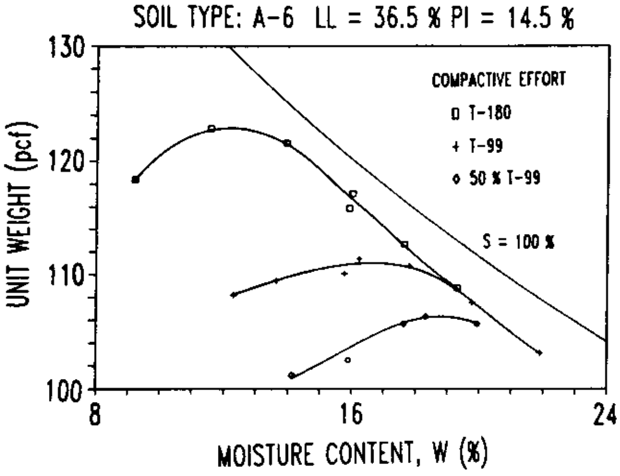

FIGURE 10 Moisture content versus unit weight for A-6 soil.

The similarity of the results obtained in the three different size test specimens was not anticipated. It was postulated that the compression of the soil adjacent to the dilatometer membrane during insertion of the blade must have been essentially the same in each environment. This could explain the consistent lateral stiffness observed. The densification that occurred at distances away from the dilatometer may well have been a function of specimen size, but this behavior was not investigated.

Therefore, two modifications were incorporated in subsequent testing. First, a technique was developed whereby the CBR mold could be used as a specimen for dilatometer testing after the CBR test was conducted. Simply stated, the surcharge weights were removed, the top volume of the mold was filled with sand, the base plate was then disassembled and attached to the top of the mold, the mold was inverted, and penetration was made from the opposite end. This allowed for the generation of a large number of CBR and dilatometer data on identical specimens over a wide range of moisture and density conditions. Second, the layer thickness in the large mold was altered to provide a thicker top layer. All subsequent 11-in. (280-mm) mold tests were conducted on specimens with lower layers approximately 3.9 in. (100 mm) thick and a top layer of approximately 5 in. (125 to 130 mm). With the penetration of the dilatometer to near the bottom of the top layer, the top of the membrane was now approximately 2.4 in. (60 mm) (or one diaphragm diameter) below the free surface. Because the dilatometer modulus did not appear to be influenced by sample size, it was determined that the large test chamber would only be used if future results indicated the presence of a size influence when data generated in the 6-in. (152-mm) and 11-in. (280-mm) molds were compared.

The compaction characteristics and unsoaked CBR response for the second soil, classification A-6, are shown in Figures 10 and 11, respectively. The correlation between the results obtained in the impact-compacted CBR molds and the larger statically

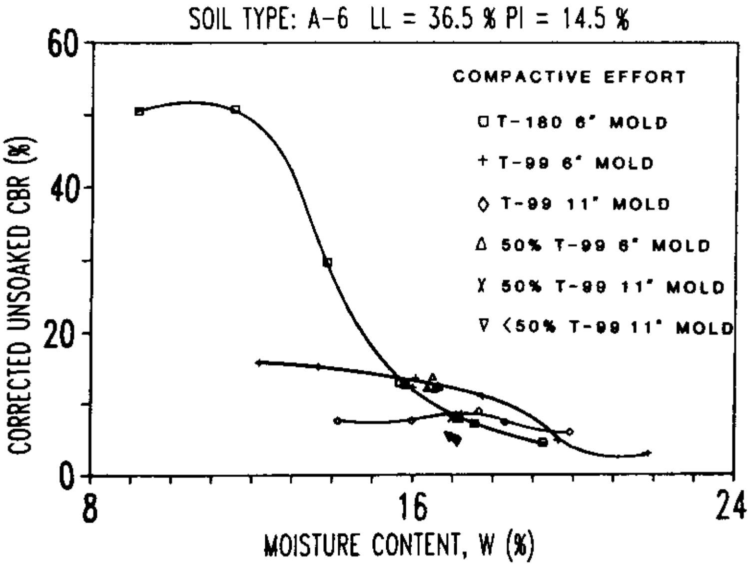

FIGURE 11 Moisture content versus corrected unsoaked CBR for A-6 soil.

compacted molds was excellent. Although plots similar to Figures 7 and 8 for soil 1 were developed, the degree of agreement is clearly shown in Figure 11. The lower compactive effort data were generated in the 11-in. (280-mm) mold by statically compacting the soil at the optimum moisture content (for the T-99 compactive effort) to a density representative of approximately 90 percent of the T-99 dry density. Figure 12 shows the dilatometer data generated for this soil. The linear regression coefficients utilizing all the laboratory data are a = 0.16, b = 0.052, and an $R^2$ value of 0.89. As with the first soil tested, the intercept value is negligible and the relationship may be expressed as

$$\mathrm{CBR} = 0.052\ E_d \tag{3}$$

with the CBR value expressed as a percentage and the $E_d$ value in tsf.

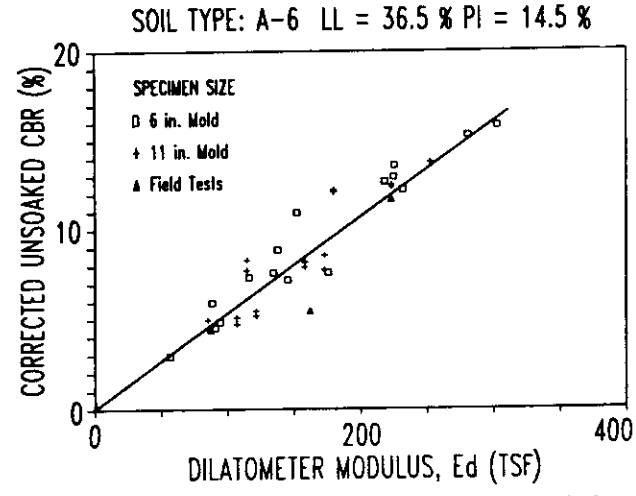

FIGURE 12 Dilatometer modulus versus corrected unsoaked CBR for A-6 soil.

In all but one instance two CBR tests were conducted on each of the three layers of the three 11-in. (280-mm) specimens. In order that the consistency of the CBR data might be shown, each of the values obtained was plotted versus the single dilatometer reading from that layer. It is also notable that the data furthest to the left of the regression line were again those obtained from the top of the 11-in. (280-mm) mold, although the magnitude of the difference was not as observable as it was with the first soil. It appears that the increased depth of membrane insertion (to one membrane diameter) in these tests helped solve the problem identified previously. However, because a loss of lateral support due to dilatometer insertion has clearly been identified as the reason for low readings in previous tests, it may be suspected that this factor is still operating to some degree in these tests.

Finally, the compaction characteristics and the unsoaked CBR response for the third soil, an A-2-4, are shown in Figures 13 and 14. Due to the extremely high density and corresponding high CBR values for the T-99 compacted specimens, it was deemed more interesting from a practical point of view to evaluate a lower compactive effort in place of the previously used T-180. Several high compactive effort specimens were prepared with moisture contents of 10 and 12 percent with resulting CBR values in excess of 50. However, none of these specimens could be penetrated with the 5,000-lb. (22.2-kN) capacity of the laboratory hydraulic piston used for dilatometer insertion.

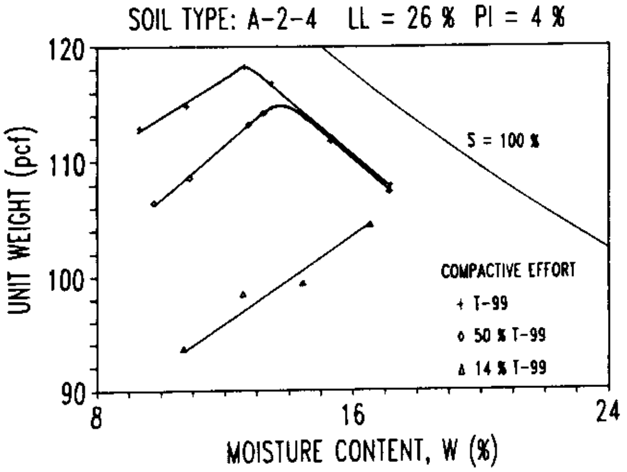

FIGURE 13 Moisture content versus unit weight for A-2-4 soil.

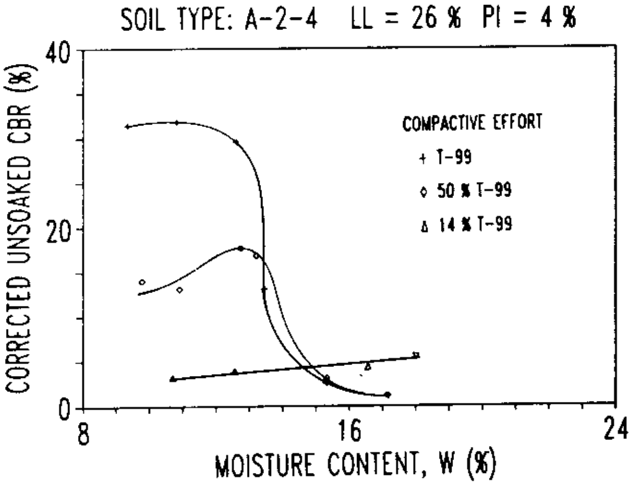

FIGURE 14 Moisture content versus corrected unsoaked CBR for A-2-4 soil.

The CBR-versus-dilatometer relationship shown in Figure 15 exhibits significant scatter. The symbols used in Figure 15 differ somewhat from those used previously in order to illustrate several significant points. First, in numerous instances the insertion of the dilatometer into this soil resulted in obvious heaving of the surface; in some instances wedges of soil lifted from the molds resulting in a loss of lateral support. This response was seen for both the 6-in. (152-mm) and the 11-in. (280-mm) molds. All of these points are circled in Figure 15 and were not used in the subsequent regression analysis. In one instance, in the 11-in. (280-mm) mold test on the T-99 compacted specimens, no dilatometer data were obtained for the top layer due to the amount of soil displaced during penetration. Second, the data obtained in the lower layers of the 11-in. (280-mm) mold appear to be consistent. The limited capacity of the laboratory hydraulic piston prevented penetration of the dilatometer in several instances. For example, only the top layer of the T-99 compacted specimen could be penetrated, but no dilatometer data were obtained as previously mentioned; for the 50 percent of T-99 specimen, the first and second layers were penetrated, but the

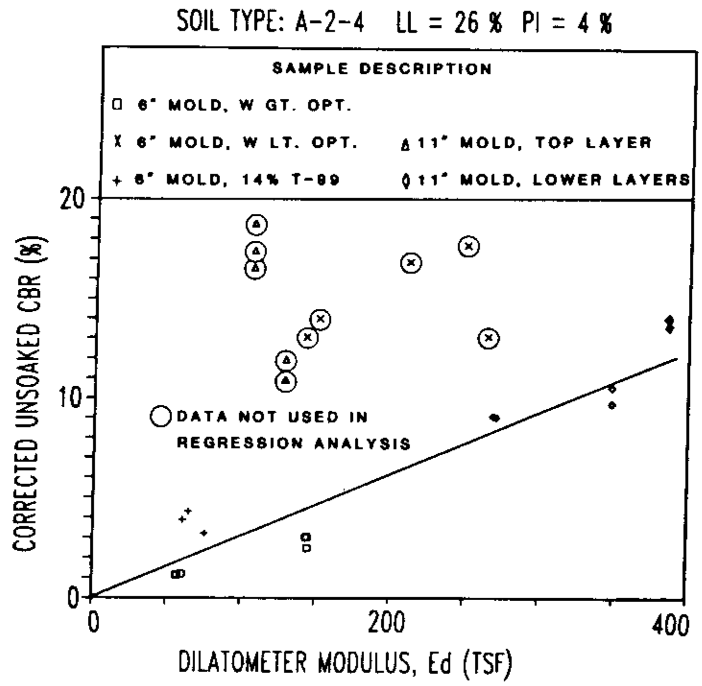

**FIGURE 15 Dilatometer modulus versus corrected unsoaked CBR for A-2-4 soil.**

lowest layer could not be penetrated. The top layer data are shown in Figure 15 with CBR values between 16 and 19 and with a low dilatometer modulus of 100 due to soil heaving. The middle layer data are plotted at approximately a dilatometer modulus of 400 tsf and a CBR value of 16.5. Penetration was achieved in all layers of the lower density specimen, and apart from the top layer data ($E_d$ approximately 125 tsf and CBR between 10.5 and 12), the bottom two layers appear consistent with the middle layer of the 50 percent T-99 specimen.

A linear regression on the data from the lower layers in the 11-in. (280-mm) molds and that from tests conducted on lower density specimens and those compacted wet of optimum yielded the following coefficients: $a = 0.19$, $b = 0.031$, and $R^2 = 0.89$. Simplifying, as before, yields the expression

$$CBR = 0.031\ E_d \qquad (4)$$

with the CBR value expressed as a percentage and the $E_d$ value in tsf. The inclusion of the 6-in. (152-mm) mold data on the lower compactive effort specimens and those compacted wet of optimum was done because no visual observations were made that indicated that they should be discarded. The observance of surface heaving in numerous tests indicated that the results of small mold tests and unconfined near-surface tests in compacted soils that are predominately sand with little cohesive component must be viewed with caution.

## FIELD TESTING

In an effort to validate the results of the laboratory study reported in this paper, field tests were conducted at the location of a new bridge structure that was under construction in the Research Triangle Park area of North Carolina. This location served as the borrow site for the A-6 soil used in the laboratory study. In cooperation with the Geotechnical Unit and Materials and Test Unit of the North Carolina Department of Transportation (NCDOT), field CBR and field density tests were conducted on the surface layer of a compacted embankment that will serve as the approach for the overpass. Because the surface had not been cut to final grade, the three in-place density and CBR tests were conducted at a depth of approximately 8 in. (200 mm) below the existing surface. No attempt was made in this study to evaluate the near-surface dilatometer response by varying the depth of penetration. The dilatometer was hydraulically pressed into the compacted fill using the Mobile drill rig shown in Figure 2 at locations approximately 12 in. (300 mm) away from the CBR and density tests. The dilatometer was pushed until the center of the diaphragm was at the desired 8 in. (200 mm) depth. Subsequent advances were made in 8-in. (200-mm) increments through the fill to a maximum depth of approximately 20 ft' (6 m). However, because CBR and density data were only obtained at the surface, the rest of the dilatometer data are not presented in this context.

The results of the field CBR and dilatometer tests are presented with the laboratory data previously discussed in Figure 12. Although the data are limited, the correlation with the many laboratory tests is encouraging. The time required to conduct the field dilatometer tests was on the order of 1 min per test when near-surface data were being gathered. For the approximately 20-ft (6-m) penetrations, readings were taken at every 8 in. (200 mm) for a total of 29 readings. The assembly and disassembly of rods increased the average time to approximately 1.5 min, or a total of 45 min. This indicates the great economy that can be achieved in obtaining subgrade support characteristics compared with in-place CBR tests.

## SUMMARY AND CONCLUSIONS

The problem of evaluating the as-compacted or existing properties of subgrade soils is an important aspect of the design and rehabilitation of flexible pavements. The dilatometer has been shown to have significant potential for obtaining this information both reliably and economically. In this paper, the relationship between the dilatometer modulus and as-compacted CBR for three different natural soils has been investigated. Current research is extending this work to include resilient modulus and one-dimension compression modulus (constrained modulus) correlations.

On the basis of the results of the laboratory and field test program reported herein, the following conclusions are advanced:

1. Unique relationships between dilatometer modulus and CBR were found to exist for the as-compacted A-5 and A-6 soils regardless of density and moisture content conditions. The relationships were found by linear regression to be CBR = 0.041 $E_d$ for the A-5 soil and CBR = 0.052 $E_d$ for the A-6 soil. The data for the A-2-4 soil yielded the relationship CBR = 0.031 $E_d$, although many more tests were found unacceptable due to heaving of the soil surface and loss of lateral support. Reasonable data were obtained when the dilatometer diaphragm was at a depth of approximately 7 in. (175 mm) or more below the mold surface.

2. A laboratory technique was developed whereby dilatometer penetration could be performed in CBR molds 6 in. (152 mm) in diameter such that both the dilatometer modulus and CBR value could be obtained on the same specimen. Although the boundary conditions appeared unfavorable in the small mold, the results were consistent with those obtained in an 11-in. (280-mm) mold and a chamber 3 ft x 4 ft (approximately 1 m x 1.25 m). It was postulated that the compression of the soil adjacent to the dilatometer blade during penetration was essentially the same in each of the specimens. Thus the stiffness of the soil within the zone of influence for the 0.04-in. (1-mm) diaphragm expansion was observed to be similar. This small mold test did not work well for the A-2-4 soil and probably would not work well for any soil that was dominated by granular material with little fine-grained component.

3. Limited field tests on a compacted embankment from which one of the soils (A-6) used in the study was obtained revealed excellent correlation with the laboratory test program. The economical use of the dilatometer was shown in the ability to obtain data at a given location in approximately 1 min per test point desired. A 3.3-ft (1-m) penetration with five tests conducted at depth increments of approximately 8 in. (200 mm) took a total of about 5 min. This was in sharp contrast to the time that it took to obtain the limited CBR data. In addition, the problems of surface preparation, equipment alignment, and maintaining constant CBR penetration rates are eliminated.

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