Relationship Between Kentucky CBR and Slake Durability

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RELATIONSHIP BETWEEN KENTUCKY CBR
AND SLAKE DURABILITY

by

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in cooperation with
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Commonwealth of Kentucky

and
Federal Highway Administration
U.S. Department of Transportation

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**ABSTRACT**

The design of pavements requires a knowledge of the relative strength and durability of subgrade materials. In Kentucky, the CBR (California Bearing Ratio) test is used to define the relative bearing strength of subgrade materials. Pavement thickness can be obtained if traffic loadings and CBR values are known. Durability of subgrade materials can be characterized using the slake-durability test. The purposes of this study were to correlate values of (soaked) KYCBR and slake-durability indices and examine the swell potential of compacted shales. Correlations were developed between soaked KYCBRs and slake-durability indices obtained from three different slake-durability testing procedures. The first correlation used slake-durability indices from a testing procedure devised and proposed initially by Franklin and Chandra and modified by Gamble. The second and third correlations use slake-durability indices obtained from testing procedures proposed by Hopkins and Gilpin. Correlations of soaked KYCBRs and in situ water contents of unweathered shale and clay contents of shales are also presented. Based on these correlations, estimates of soaked values of KYCBRs of shales can be obtained. Consequently, the desirability or suitability of certain types of shales for use in pavement subgrades can be quickly estimated.
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INTRODUCTION

The design of pavements requires a knowledge of the relative strength and durability of subgrade materials. The relative strength of subgrade materials in Kentucky is determined from CBR (California Bearing Ratio) tests (1, 2, 3, and 4). Having a knowledge of the relative bearing strength of the subgrade materials and predicted traffic loadings, required pavement thickness can be obtained from pavement design charts (1, 2, 5, 6, 7, 8, and 9).

When shales are used to construct pavement subgrades, problems may arise depending on the nature and engineering characteristics of the shales. In many cases, shales when first excavated may have an appearance of good, sound rock. However, many problems encountered during and after construction are caused primarily by the tendency of shaly materials to decay or crumble from an indurated mass to a fine-grained mass of soil. Frequently, such reversion of certain types of shales produces weak clays or silts of low bearing strengths, although initially the indurated masses generally may have very high bearing strengths. Some shales tend to degrade when compacted. Furthermore, breakdown may occur due to chemical and physical weathering. Additionally, the breakdown of certain shales may accelerate when exposed to water and produce subgrades of very low bearing strength. The weathering of certain types of shales can cause nonuniform settlements and adversely affect the riding quality of pavements. Consequently, the durability of shales when used in pavement subgrades and exposed to weathering agents is an important consideration in pavement design.

A method used to evaluate the weathering resistance of shales, mudstones, siltstones, and other clay-bearing rocks is the slake-durability test, originated by Franklin and Chandra (10). The testing procedure was revised by Gamble (11,4) and is currently used by the Division of Materials, Kentucky Transportation Cabinet. Recently, Hopkins and Gilpin (12) examined various procedures to determine the most suitable testing procedure for Kentucky shales and proposed changes in the testing procedure. In that study, it was recommended that one 60-minute cycle and air-dried material be used. Presently, the test is generally performed using two 10-minute cycles and oven-dried material.

SCOPE AND OBJECTIVES

Both bearing strength and durability of shale subgrades are important considerations in pavement design. Although initially compacted shales may have high bearing strength, exposure of certain compacted shale to weathering agents, such as water, may over a period of time produce a subgrade of low bearing strength. Consequently, a decrease in the bearing strength of the subgrade can adversely affect pavement performance. The objectives of this study were to develop a relationship between Kentucky CBR (KYCBR) and slake durability and to examine the swelling potential of a variety of compacted Kentucky shales. Efforts were made to correlate various slake-durability indices reported previously (12) and KYCBR's. Such relationships can aid in selecting shales that are suitable, or in determining shales that are unsuitable, for use in pavement subgrades. Moreover, if the slake-durability indices of a given group of shales for a particular highway
project are known, KYCBR's of the shales can be quickly estimated and used to obtain preliminary estimates of pavement thicknesses. Alternatively, shales having undesirable slake-durability properties may be quickly identified and designated for use in other zones of the embankment rather than the subgrade.

SITE AND SHALE DESCRIPTIONS

Based on previous testing of some forty shales (12), thirteen different types of shales were selected for CBR testing. Historically, many shales selected for testing have caused pavement problems. The thirteen types of shales exhibit a wide range of slake-durability indices (12). Shale samples were obtained from the Jackson Purchase, Western Coal Field, Knobs, Mississippi Plateaus, Bluegrass, and Eastern Coal Field Physiographic Regions. Geologic periods represented by the samples included the Cretaceous-Tertiary, Pennsylvanian, Mississippian, Devonian, Silurian, and Ordovician. A listing showing the laboratory number, the geologic formation and period, and a brief description of each shale sample is given in Table 1. General locations of the sampling sites are shown in Figure 1.

SAMPLING PROCEDURES

Selection of a gradation to use in preparing shale specimens for testing presents a problem because of the fine-grained nature of shales and because shales exist in a natural form in an inundated state, or a highly overconsolidated condition. Different specimen gradations may yield different test results. Shales may be crushed, or broken down, to produce practically any desired gradation. As one approach to this problem and to simulate as closely as practicable the condition of a particular shale after several years in a pavement subgrade, weathered shale samples were obtained from talus piles that had accumulated near the bottom of highway cut sections. Each highway cut section selected for sampling consisted of only one type of shale. For example, when selecting samples of weathered New Albany Shale, the highway cut section consisted entirely of New Albany Shale. Highway cut sections were selected as close as practical to sampling sites previously choosen for obtaining unweathered samples for slake-durability testing (see Reference 12). Several bag samples of each shale were obtained from the various talus piles. The gradation of the weathered shale was assumed to represent to some degree the natural condition of the shale after exposure to weathering agents.

TESTING PROCEDURES

Routine geotechnical classification index tests were performed on each shale following ASTM procedures (13). Both weathered and unweathered shales were tested. These tests included Atterberg limits (liquid and plastic limits), specific gravity, and mechanical and hydrometer analysis. The Atterberg Limits were performed according to procedures of ASTM D 423-66 (72) and ASTM D 424-59 (71).
<table>
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<tr>
<th>SAMPL\ NUMBER</th>
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<th>BRIEF DESCRIPTION OF SPECIMEN</th>
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<td>Drakes</td>
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<td>Lower Caseyvillle</td>
<td>Pennsylvanian</td>
<td>Medium Hard Gray Shale</td>
</tr>
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<td>Tradewater</td>
<td>Pennsylvanian (Middle)</td>
<td>Medium Hard Gray Siltstone</td>
</tr>
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<td>Osgood</td>
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</tr>
<tr>
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<td>Crab Orchard (KY 52)</td>
<td>Silurian</td>
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<td>Kope (I-75)</td>
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<td>Kope (I-275)</td>
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<td>Golconda</td>
<td>Mississippian</td>
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<td>33-1</td>
<td>Clayton McNairy</td>
<td>Cretaceous &amp; Tertiary</td>
<td>Soft (Overconsolidated) Grayish Brown Clay</td>
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<td>New Providence</td>
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<td>Newman</td>
<td>Mississippian</td>
<td>Soft Gray Shale</td>
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</table>
COMMONWEALTH OF KENTUCKY
MAP OF SAMPLING SITES

FIGURE 1. MAP OF KENTUCKY SHOWING SAMPLING SITES
determinations were made according to procedures similar to D 421-58(78) and D 422-63(72). Specific gravity tests were performed according to ASTM D 854-58(79). The weathered shale specimens were classified using the Unified Soil Classification System, ASTM D 2487-69(75), and the AASHTO Classification System (14). Compaction of the weathered shales was performed following procedures described in ASTM D 698-(78), Method A.

Kentucky CBR tests were performed following procedures outlined elsewhere (1, 2, 3, and 4) and according to Kentucky Method KM-64-501-76. Only material passing the No.-4 sieve was used. CBR specimens were molded using values of optimum moisture content and maximum dry density obtained from ASTM D 698-(78), Method A; however, static compaction was used to mold the specimens. A static pressure of 2,000 pounds per square inch was maintained on the specimen for 2 minutes. In the KYCBR testing procedure, two penetrations may be made -- prior to soaking and after soaking. Specimens were inverted for the second penetration. Hence, unsoaked and soaked CBR values may be obtained. CBR specimens were placed in a water trough and allowed to absorb water until consecutive swell deflection readings were equal to or less than 0.003 inch; however, specimens were soaked a minimum of 72 hours. Generally, the final dry densities and moisture contents of the specimens after soaking and the completion of swell were slightly higher and lower, respectively, than maximum dry densities and optimum moisture contents obtained from ASTM D 698-78 (3). Other details of the Kentucky CBR test procedure are given in KM-64-501-76 (4). Since shales used in pavement subgrades may potentially weather and decay, the Kentucky CBR tests were performed on weathered shale samples in efforts to simulate, at least to some degree, the in situ, compacted conditions.

Slake-durability tests were performed following procedures described elsewhere (12). In that study, some ten different test procedures were used to examine the slake-durability behavior of unweathered shale samples selected for KYCBR testing. Slake-durability results obtained from the ten different testing procedures have been reported previously by Hopkins and Gilpin (12). Efforts were made to correlate results obtained from three of the ten slake-durability test procedures and KYCBRs. The three slake-durability test procedures included 1) the so called "standard" method (12, 4), currently used in Kentucky (KM-64-513-78(4)), 2) the 60-minute cycle method devised by Hopkins and Gilpin (12), and 3) the decay index method devised by Hopkins and Gilpin (12).

The "standard" slake-durability method used oven-dried material and two 10-minute cycles (4). The second testing procedure consisted of using air-dried material and one 60-minute cycle. The decay index procedure consists of performing a series of slake-durability tests using air-dried material at different time intervals to develop a "slake-durability decay curve" as illustrated in Figure 2. Other details of the slake-durability decay index are given elsewhere (12, 4).

Jar slake tests were performed on unweathered samples according to procedures described by Kentucky Method 64-514-77 (4).

TEST RESULTS AND ANALYSIS

RESULTS

Results obtained from geotechnical index tests are summarized in
Figure 2. Definition of Slake-Durability Decay Index, $D_1$ (12).
Table 2. Particle-size distribution curves for weathered and unweathered shale specimens are shown in APPENDIX A and B, respectively. Only material passing the No.-10 sieve was tested. Liquid limits of weathered shales ranged from non-plastic to 40 percent. Plasticity indices ranged from non-plastic to 15.4 percent. None of those values are exceptionally high. Specific gravities ranged from 2.52 to 2.85.

Previous index values obtained from tests on unweathered shale specimens are shown in Table 3 and are shown for comparative purposes. Generally, the liquid limits, plasticity indices, and clay-size particles finer than 0.002 mm by weight of weathered shale specimens were larger than values obtained for unweathered specimens. In situ water contents of unweathered specimens ranged from 1.7 to 23.2 percent.

Results obtained from moisture-density tests using weathered shales (ASTM D 698-78) and the first penetrations of the Kentucky CBR tests are summarized in Table 4. Moisture-density curves are presented in APPENDIX C. Stress-penetration curves for the first penetration (before soaking) of the KYCBR test are shown in APPENDIX D. Results obtained from the second penetrations, after the specimens had been soaked, are listed in Table 5. Stress-penetration curves for the second penetrations are shown in APPENDIX E.

Slake-durability indices obtained from the three different testing procedures using unweathered shales are summarized in Table 6.

Maximum dry densities of weathered shale specimens ranged from 96.8 (New Albany) to 123.8 (Osgood) pounds per cubic foot. Optimum moisture contents ranged from 10.3 (Drakes) to 20.3 (Clayton-McNairy) percent. Dry densities obtained after the first static compaction (prior to the first penetration) in the KYCBR test generally were higher than maximum dry densities obtained from the compaction tests. Relative values of compaction ranged from 106.7 percent to 115.7 percent and averaged 111.2 percent. Moisture contents of the unweathered shales before soaking ranged from 8.6 to 18.5 percent. The ratio of the molding moisture content to optimum moisture content ranged from 0.69 to 0.99 and averaged 0.86. The molding water content was lower than optimum moisture content in all cases. After the shale specimens had been soaked and allowed to swell, relative values of compaction ranged from 100.4 to 116.0 percent and averaged 104.6 percent. Hence, the dry densities of the shale specimens were slightly higher than maximum dry density. The ratios of the final water contents of the shale specimens after soaking ranged from 0.74 to 1.34 and averaged 1.12. Generally, the final average water contents of the soaked specimens were about 1.4 percent higher than the average optimum water contents. Dry densities of the shale specimens before soaking and after soaking are shown in Figure 3 as a function of maximum dry density.

Unsoaked (minimum) KYCBR values are shown in Table 4. These values ranged from 15.1 to 46.4 and averaged 26.8 percent. All of the shale specimens exhibited high unsoaked KYCBR values. Soaked values of KYCBR ranged from 1.5 to 33.4 and averaged 7.0 percent as shown in Table 5. Consequently, unsoaked values were much higher than KYCBR values of soaked specimens. Unsoaked and soaked KYCBR values are compared in Figure 4. That figure illustrates the affects of water on the bearing strengths of certain shales. For example, the value of KYCBR of the Crab Orchard shale prior to soaking was 23; after soaking the KYCBR value was only 2.
<table>
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<th>LIQUID LIMIT</th>
<th>PLASTIC INDEX</th>
<th>SPECIFIC GRAVITY</th>
<th>PARTICLE-SIZE ANALYSIS*</th>
<th>ACTIVITY</th>
<th>UNIFIED SOIL CLASSIFICATION</th>
<th>AASHTO CLASSIFICATION</th>
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<td>NP</td>
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<td>Hance</td>
<td>NP</td>
<td>NP</td>
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<td>100.0</td>
<td>80.0</td>
<td>8.0</td>
<td>0.00</td>
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<td>3-1</td>
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<td>15.0</td>
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<td>NP</td>
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<td>92.5</td>
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<td>88.0</td>
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* Hydrometer tests performed on weathered shale specimens that passed the No. 10 sieve.
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* Hydrometer tests performed on unweathered shale specimens that had been crushed to pass the No. 10 sieve.

** Unified Soil Classification System (13, 14)
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<th>STANDARD COMPACTI ON</th>
<th>IN SITU MOLDING CONDITIONS</th>
<th>MINIMUM RELATIVE RATIO OF MOLDING WATER</th>
<th>CONTENT OF OPTIMUM WATER</th>
<th>DRY CONTENT</th>
<th>OPTIMUM WATER CONTENT</th>
<th>DENSITY (pcf)</th>
<th>RELATIVE RATIO OF DRY TO OPT. WATER CONTENT</th>
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<td>1.7</td>
<td>13.9</td>
<td>112.0</td>
<td>30.2</td>
<td>115.7</td>
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<td>Hence</td>
<td>11.8</td>
<td>124.7</td>
<td>2.9</td>
<td>8.6</td>
<td>140.0</td>
<td>26.4</td>
<td>112.4</td>
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<td>130.2</td>
<td>4.5</td>
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<td>5.1</td>
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<td>109.4</td>
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<td>Kope(1275)</td>
<td>13.0</td>
<td>116.3</td>
<td>--</td>
<td>12.9</td>
<td>128.9</td>
<td>32.1</td>
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<td>8.0</td>
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<td>--</td>
<td>10.7</td>
<td>127.5</td>
<td>43.1</td>
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<td>Newman</td>
<td>15.0</td>
<td>113.9</td>
<td>11.6</td>
<td>12.9</td>
<td>128.6</td>
<td>26.9</td>
<td>112.9</td>
<td>0.86</td>
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</table>
| SAMPLE | GEOLOGIC IDENTIFICATION | SECOND PENETRATION (SOAKED SPECIMEN) | MAXIMUM VERTICAL
|---------|--------------------------|---------------------------------------|---------------------------
| I       | WATER DRY MINIMUM RELATIVE RATIO OF SWELL |
| 1-2     | New Albany 14.7 112.3 33.3 | 116.00 0.74 1.3 |
| 13-1    | Hance 10.1 134.4 18.3 107.8 0.86 2.2 |
| 3-1     | Drakes 10.0 139.7 10.1 107.3 0.97 2.2 |
| 23-1    | Lower Caseyville 13.7 125.2 3.3 103.3 1.08 5.3 |
| 27-1    | Tradewater 14.0 119.2 4.7 102.2 1.25 7.2 |
| 17-4    | Nancy 15.4 122.0 2.5 102.2 1.26 7.2 |
| 20-1    | Osgood 11.7 131.6 5.8 106.3 1.12 4.9 |
| 1-1     | Crab Orchard 16.9 117.7 1.9 99.3 1.48 12.4 |
| 12-1    | Kope 16.7 119.0 2.0 101.2 1.15 6.5 |
| 35-1    | Kope (1275) 17.4 116.8 2.1 100.4 1.34 10.6 |
| 32-1    | Golconda 14.9 124.4 6.6 108.0 1.00 3.3 |
| 33-1    | Clay- McNairy 22.6 102.8 5.9 103.6 1.15 5.4 |
| 34-1    | New Providence 12.6 119.1 1.5 105.8 1.11 15.6 |
| 19-1    | Newman 18.2 115.8 1.9 101.6 1.22 13.3 |
TABLE 6 SUMMARY OF SLAKE DURABILITY INDICES OBTAINED FROM THREE DIFFERENT SLAKE-DURABILITY TESTING PROCEDURES (4, 12)

<table>
<thead>
<tr>
<th>SAMPLE NUMBER</th>
<th>GEOLOGIC IDENTIFICATION</th>
<th>SLAKE-DURABILITY INDICES</th>
<th>JAR SLAKE</th>
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<tr>
<td></td>
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<td>(Standard)</td>
<td>(60-Minute Cycle)</td>
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<td>98.6</td>
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<td>96.1</td>
<td>91.0</td>
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<td>Drakes</td>
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<td>75.4</td>
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<td>84.1</td>
<td>62.4</td>
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<td>Tradewater</td>
<td>89.3</td>
<td>47.1</td>
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<td>17-4</td>
<td>Nancy</td>
<td>84.1</td>
<td>59.0</td>
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<td>Osgood</td>
<td>81.6</td>
<td>48.1</td>
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<td>Creb Orchard</td>
<td>16.3</td>
<td>10.3</td>
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</table>
FIGURE 4. Values of Soaked KYCBR's Plotted as a Function of Unsoaked KYCBR's.
CORRELATIONS

To determine the relationship between soaked KYCBR and slake-durability, KYCBRs were plotted as a function of three different slake-durability indices (Table 6). In Figure 5, KYCBR's are shown as a function of slake-durability indices (SDI) obtained from the standard procedure, Kentucky Method KM-64-513-78 (oven-dried material, two 10-minute cycles). The relationship can be expressed as

\[
\text{KYCBR} = 10 \left( \frac{1}{(3.57 - 0.00788\text{SDI} - 0.000217(\text{SDI})^2)} \right)
\]  

(1)

For shales having a slake-durability index of less than about, 92 percent, the actual KYCBR's ranged from approximately 1.5 to 10. Generally, the values averaged about 4. The predictor relationship, Equation 1, can be used to obtain a very approximate estimate of the KYCBR if the slake-durability index is known.

Variation of the KYCBR as a function of slake-durability index obtained using air-dried material and a 60-minute cycle (SDI

\[60\]  

is shown in Figure 6. The relationship can be approximated from

\[
\text{KYCBR} = 10 \left( 0.000125(\text{SDI}_{60})^2 + 0.2769 \right)
\]  

(2)

For shales having a slake-durability index (60-minute cycle) less than about 75 percent, actual KYCBR values vary from about 1.5 to 6.6. The curve in Figure 6 is a somewhat better relationship than the curve shown in Figure 5. As shown previously (12), the 60-minute slake-durability test using air-dried material appeared to be more suitable for characterizing slake-durability properties of Kentucky shales than the standard slake-durability procedure.

A relationship between soaked KYCBR and slake-durability decay index (DI) (12) is shown in Figure 7. That relationship can be expressed as

\[
\text{KYCBR} = 10 \left( 0.067069 + 1.319135\log_{10}\text{DI} - 0.12868(\log_{10}\text{DI})^2 \right)
\]  

(3)

The influence of the swelling of compacted shale specimens, when immersed in a water, on the value of soaked KYCBR is illustrated in Figure 8. With an increase in the value of swell (S), the KYCBR value decreases. At vertical axial swells of less than about three percent, the KYCBR is greater than about 10. The relationship can be expressed as

\[
\text{KYCBR} = 10 \left( 1.779 - 2.1956\log_{10}\text{S} + 0.73258(\log_{10}\text{S})^2 \right)
\]  

(4)

Efforts to develop a rapid means of estimating the soaked value of KYCBR from simple geotechnical index tests are shown in Figures 9, 10, and 11. The variation of KYCBR as a function of in situ water content (WC) of unweathered shales is shown in Figure 9. That relationship can be expressed as

\[
\text{KYCBR} = 10 \left( 1.88527 - 1.55026\log_{10}\text{WC} \right)
\]  

(5)

For unweathered shales having in situ water contents less than about 4 percent, the soaked KYCBR was in excess of 10. However, if the in situ water content is greater than about 4 percent the KYCBR ranged from 1.5 to 10. At large values of water content (in excess of about 7
**LEGEND**

- NEW ALBANY 1-2
- HANCE 13-1
- DRAKE 3-1
- CASEYVILLE 23-1
- TRADENWATER 27-1
- NANCY 17-4
- OSGOOD 20-1
- CRAB ORCHARD 1-1
- KOP 12-1
- GOLCONDA 32-1
- CLAYTON & MCAJAY 33-1
- NEWMAN 19-1

\[ Y = 10^{[(1/3.57) - 0.00786x - 0.000217x^2]} \]

\[ Y = KT CBR \]

\( X = \text{SLAKE-DURABILITY INDEX} \)

("STANDARD")

**FIGURE 5.** KYCBA's Plotted as a Function of Slake-Durability Indices Obtained from Kentucky Method-64-501-76(4) (Oven Dried Material, Two 10-Minute Cycles).
LEGEND

- NEW ALBANY 1-2
- HANCE 13-1
+ DRAKES 3-1
× CASEYVILLE 23-1
◊ TRADEWATER 27-1
+ NANCY 17-4
× OSGOOD 20-1

LEGEND

N CRAB ORCHARD 1-1
> KOPE 12-1
× KOPE (1275) 35-1
× GOLCONDA 32-1
× CLAYTON & MCNAIRY 33-1
× NEW PROVIDENCE 34-1
× NEWMAN 19-1

\[ Y = 10^{0.000125x^2 + 0.27691} \]

\[ Y = SOAKED\ KYCBR \]

\[ X = SDI_{60} \]

FIGURE 6. KYCBR's Plotted as a Function of Slake-Durability Indices Obtained from the One 60-Minute Cycle Test (12).
**LEGEND**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>○</td>
<td>NEW ALBANY 1-2</td>
</tr>
<tr>
<td>□</td>
<td>HANCE 13-1</td>
</tr>
<tr>
<td>+</td>
<td>DRAKES 3-1</td>
</tr>
<tr>
<td>×</td>
<td>CASEYVILLE 23-1</td>
</tr>
<tr>
<td>◇</td>
<td>TRADEWATER 27-1</td>
</tr>
<tr>
<td>O</td>
<td>NANCY 17-4</td>
</tr>
<tr>
<td>×</td>
<td>OSGOOD 20-1</td>
</tr>
<tr>
<td>N</td>
<td>CRAB ORCHARD 1-1</td>
</tr>
<tr>
<td>&gt;</td>
<td>KOPe 12-1</td>
</tr>
<tr>
<td>*</td>
<td>GOLCONDA 32-1</td>
</tr>
<tr>
<td>□</td>
<td>CLAYTON &amp; MCNAIRY 33-1</td>
</tr>
</tbody>
</table>

\[ Y = 10^{0.057069 + 1.319135 \log_{10}X - 0.12068 (\log_{10}X)^2} \]

\[ Y = (\text{SOAKED KYCBR})^2 \]

\[ X = \text{SLAKE DURABILITY DECAY INDEX} \]

**FIGURE 7. KYCBR's Plotted as a Function of Slake-Durability Decay Index (12).**
FIGURE 8. Relationship Between Kycbr's and Vertical Swell Values Obtained during the Kycbr Test.

\[ Y = 10^{(1.779 - 2.1956 \log_{10} x + 0.73258 (\log_{10} x)^2)} \]

\[ Y = \text{SOAKED KycBR} \]

\[ X = \text{AXIAL SWELL} \]
FIGURE 9. Relationship between KYCB's and In Situ Water Contents of Unweathered Shales.
FIGURE 10. Variation of the KTCBR and Percent of Clay Particles Finer Than 0.002 mm by Weight Obtained from the Hydrometer Test Using Unweathered Shale Crushed to Pass the No. -10 Sieve.
Figure 11. Variation of the KYCBR and Percent of Clay Particles Finer than 0.002 mm by Weight Obtained from the Hydrometer Test Using Weathered Shale Passing the No. -10 Sieve.
percent soaked KYCBR's may be on the order of 1.5 to 6.

Variation of the soaked value of KYCBR as a function of percent of clay-size particles finer by weight than 0.002 mm is shown in Figure 10. The percent of clay particles was obtained from the hydrometer test using unweathered shale which had been crushed to pass the No.-10 sieve. Generally, shales having values less than about 18 percent, as measured above, probably will have KYCBR's in excess of 10. If the percent of clay particles is in excess of 18 percent, then the KYCBR will be low. The relationship between KYCBR and percent of clay particles finer than 0.002 mm (C) by weight can be expressed as

\[
\text{KYCBR} = 10 (1.578475 - 0.00209C^2 + 0.000000834C^4)
\]  

(6)

Variation of KYCBR as a function of the percent finer than 0.002 mm by weight obtained from hydrometer tests using weathered shales passing the No.-10 sieve is shown in Figure 11. A considerable amount of scatter occurred in the data. However, a trend relationship was present. As the percent of clay particles increased the KYCBR decreased. For weathered shales having more than about 20 percent clay, the KYCBR ranged from 1.5 to 10.

Generally, unweathered shales having high soaked KYCBR values had jar slake values of 5 or 6. Shales having jar slake numbers of 1 or 2 generally had KYCBR's less than 6 or 7. Usually the values were very low.

SUMMARY AND CONCLUSIONS

Based on data presented herein, the following conclusions are made:

1. The dry densities and water contents of soaked and unsoaked KYCBR specimens were generally higher and lower, respectively, than maximum dry densities and optimum water contents obtained from compaction tests (ASTM D 698-78).

2. All shales tested had fairly high unsoaked KYCBR values. Those values ranged from 15 to 46. After soaking, KYCBR values specimens ranged from 1.9 to 33.3.

3. The data showed that KYCBR and slake durability are related. As the slake-durability of unweathered shale decreased, the minimum soaked KYCBR decreased. Relationships were developed between KYCBR and three different slake-durability indices obtained from the standard method of performing slake-durability tests (oven-dried material, two 10-minute cycles), a method that used air-dried material and one 60-minute, and a method that yielded a slake-durability decay index. The later two methods appeared to yield more suitable relationships between soaked KYCBR and slake-durability than the relationship developed from the standard slake durability test. Mathematical expressions describing relationships between KYCBR and the three different slake-durability indices are given by equations 1, 2, and 3.

4. Based on the standard slake-durability test, the soaked KYCBR of a shale having an index equal to or lower than 92 percent will most likely be equal to or less than 10. The soaked KYCBR of a shale having a slake-durability index of 76 percent as measured by the one cycle, 60-minute test, will most likely be equal to or smaller than 10.

5. There was a direct correlation between axial swell of a KYCBR
specimen (compacted shale) and the soaked KYCBR. For specimens having an axial swell larger than about 3 percent, the KYCBR was less than 10. If the axial swell was less than 3 percent, then the KYCBR was greater than 10.

6. A fair correlation was obtained between in situ water content of a shale and the soaked value of KYCBR. If the in situ water content (unweathered) was less than about 4 percent, then the soaked KYCBR value will probably be larger than 10. At large values of in situ water content (>7 percent) the soaked KYCBR will most likely be on the order of 1.5 to 6.

7. A fair correlation between clay-size particles finer than 0.002 mm (by weight) and soaked KYCBR was obtained. Clay percentages were obtained from hydrometer tests performed on unweathered shales crushed to pass the No.-10 sieve. If the clay percentage was less than about 18 percent, then the soaked value of KYCBR was probably greater than 10.

8. For weathered shale samples, if the percent finer than the 0.002 mm size was greater than 20 percent, then the soaked KYCBR was most likely less than 10.

9. Shales having low jar slake numbers generally had very low values of KYCBR.

REFERENCES


2. Drake, W. B.; and Havens, J. H.; Kentucky Flexible Pavement Design Studies, Engineering Experiment Station Bulletin No. 52, University of Kentucky, June 1959.


APPENDIX A

PARTICLE-SIZE DISTRIBUTION CURVES
FOR UNWEATHERED SHALES
SIEVE SIZES

% PASSING, BY WEIGHT

DIAmeter in mm

FINE GRAVEL

COARSE SAND

MED SAND

FINE SAND

SILT

CLAY

CASEYVILLE 23-1
SIEVE SIZES

% PASSING, BY WEIGHT

FINE GRAVEL
COARSE SAND
MED SAND
FINE SAND
SILT
CLAY

DIAMETER IN MM

KOPE 12-1
APPENDIX B

PARTICLE-SIZE DISTRIBUTION CURVES
FOR WEATHERED SHALES
APPENDIX C

MOISTURE-DENSITY RELATIONSHIPS
OF WEATHERED SHALES
NEW ALBANY MT. PARKWAY 1+2 (WEATHERED)

OPTIMUM MOISTURE CONTENT (%) = 19.7

ML = WP = DEG = 6

OPTIMUM DRY DENSITY = 96.8 PCF
HANCE (WEATHERED)

11-04-91

OPTIMUM MOISTURE CONTENT (%) = 11.8

WL = WP = DEG = 3

OPTIMUM DRY DENSITY = 126.5 PCF
DRAKES (WEATHERED)

OPTIMUM MOISTURE CONTENT (%) = 10.4

WL = WP = DEG = 3

OPTIMUM DRY DENSITY = 132.1 PCF
CASEYVILLE (WEATHERED) 8-25-80

OPTIMUM MOISTURE CONTENT (%): 12.6
ML =  W = DEG = 3
OPTIMUM DRY DENSITY = 121.2 PCF

MOISTURE CONTENT, W% 7.00 8.00 9.00 10.00 11.00 12.00 13.00 14.00 15.00

DRY DENSITY, PCF 75.20 76.00 76.80 77.60 78.40 79.20 80.00 80.80 81.60

8-25-80
TRADEWATER (WEATHERED)

0-25-80

OPTIMUM MOISTURE CONTENT (%) = 11.9

ML =  W =  DEG = 3  OPTIMUM DRY DENSITY = 116.5 PCF

5.00 6.00 7.00 8.00 9.00 10.00 11.00 12.00 13.00 14.00 15.00 16.00 17.00 18.00 19.00 20.00 21.00 22.00

MOISTURE CONTENT, W%
NANCY 17-4 (WEATHERED)

08-16-78

OPTIMUM MOISTURE CONTENT (%) = 12.2

WL = WP = DEG = 3

OPTIMUM DRY DENSITY = 119.4 PCF

---

![Graph showing moisture content vs. dry density]
OSGOOD 20-1 (WEATHERED)

OPTIMUM MOISTURE CONTENT (%) = 10.5

WL = WP = DEG = 4

OPTIMUM DRY DENSITY = 123.8 PCF
CRAB ORCHARD (WEATHERED)

11-04-81

OPTIMUM MOISTURE CONTENT (%) = 11.5

WL = WP = DEG = 3

OPTIMUM DRY DENSITY = 119.6 PCF
KOPE I-75 (WEATHERED)

OPTIMUM MOISTURE CONTENT (%) = 14.5

WL = WF = DEG = 4

OPTIMUM DRY DENSITY = 117.6 PCF
KOPE I-275 (WEATHERED)

08-23-79

OPTIMUM MOISTURE CONTENT (%) = 13.0

WL = WP = DEG = 4

OPTIMUM DRY DENSITY = 116.3 PCF
GOLCONDA 32-1 (WEATHERED)

OPTIMUM MOISTURE CONTENT (%) = 14.8

WL = WP = DEG = 3
OPTIMUM DRY DENSITY = 115.2 PCF
CLAYTON MCNAIRY (WEATHERED)

OPTIMUM MOISTURE CONTENT (%) = 20.3

WL = WP = DEG = 4  
OPTIMUM DRY DENSITY = 99.2 PCF
NEW PROVIDENCE (WEATHERED)

11-04-81

**OPTIMUM MOISTURE CONTENT (%) = 11.4**

**WL = **  
**WF = **  
**DEG = 5**  
**OPTIMUM DRY DENSITY = 114.5 PCF**

MOISTURE CONTENT, W%  |  DENSITY,pcf
--- | ---
6.00 | 106.00
8.00 | 108.00
10.00 | 110.00
12.00 | 116.00
14.00 | 118.00
16.00 | 120.00
18.00 | 122.00
NEWMAN (WEATHERED)

OPTIMUM MOISTURE CONTENT (%) = 14.9

WL = WP = DEG = 3

OPTIMUM DRY DENSITY = 115.7 PCF
APPENDIX D

KYCER PENETRATION STRESS – PENETRATION CURVES FOR WEATHERED SHALE SPECIMENS BEFORE SOAKING
BEFORE SOAKING
BEFORE SOAKING

- CASEYVILLE 23-1
- TRADEWATER 27-1
- NANCY 17-4
X KOP (I-275) 35-1
X GOLCONDA 32-1
X CLAYTON & MC NAIRY 33-1

BEFORE SOAKING
APPENDIX E

KYCBR PENETRATION STRESS – PENETRATION CURVES FOR WEATHERED SHALE SPECIMENS AFTER SOAKING
CASEYVILLE 23-1
TRADEWATER 27-1
NANCY 17-4

AFTER SOAKING
- NEW PROVIDENCE 34-1
- NEWMAN 19-1

STRESS (PSI)

PENETRATION (INCHES)

AFTER SOAKING