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See Attached Supplemental Information Sheet for Additional Requirements.

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COMMENTS:

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Date 10/4/84

Project No. E-20-628  School/CE

Includes Subproject No(s)

Project Director(s) Dr. Quentin L. Robnett

Sponsor USDA — Forest Service

Title Evaluation of Resilient Modulus of Selected Forest Haul Road Subgrade Soils

Effective Completion Date: 8/8/84 (Performance) 8/8/84 (Reports)

Grant/Contract Closeout Actions Remaining:

☐ None
☐ Final Invoice or Final Fiscal Report
☐ Closing Documents
☐ Final Report of Inventions
☐ Govt. Property Inventory & Related Certificate
☐ Classified Material Certificate
☐ Other

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Other A. Jones
Final Report

Project E20-628

EVALUATION OF RESILIENT MODULUS OF SELECTED FOREST HAUL ROAD SUBGRADE SOILS

prepared by

Dr. Quentin L. Robnett
School of Civil Engineering
Georgia Institute of Technology

submitted to

U.S. Forest Service
1720 Peachtree Road, N. W.
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August, 1984
INTRODUCTION

The structural response of the soil under a pavement structure has a profound influence on the behavior and performance of the pavement. Resilience or resilient modulus is an increasingly popular method to evaluate the subgrade supporting capability.

The new U.S. Forest Service Thickness Design method for example uses resilient modulus as a design input. Utilization of resilient modulus for design requires that a fairly complex and time consuming test be conducted on the soil. Furthermore, the response of the soil is not a unique value but rather one that depends on a number of factors including the following:

1. magnitude of applied stress
2. pulse duration of applied stress
3. degree of saturation (density-compaction moisture)
4. soil texture
5. soil plasticity

RESEARCH OBJECTIVE AND SCOPE

The primary objective of the research was to evaluate the resilient response of a broad range of soils which occur as typical forest haul road subgrades in the Southeast Region of the U.S. Forest Service.

Twenty-six different soil samples were subjected to the resilience test. These soils are listed, along with selected engineering properties in Table 1.

LABORATORY TEST METHOD

Georgia Tech was responsible for resilient testing of each soil sample while the U.S. Forest Service was for each soil sample.
responsible for:

1. collection and shipment of a bulk sample of soil to Georgia Tech.
2. determination of the moisture-density relation (ASTM D-698).
3. determination of the grain size distribution (ASTM D-422).
4. determination of the Atterberg Limits (ASTM D-423 and D-424).

The U.S. Forest Service supplied this information to Dr. Quentin L. Robnett, School of Civil Engineering, Georgia Institute of Technology. It is summarized in Table 1.

Initial Processing

Upon receipt of the bulk samples, they were air-dried and pulverized to pass a No. 4 sieve with all excess material, roots, etc. being discarded.

Resilience Testing

A test procedure similar to the one outlined in Ref. 1 (pp. 36-38) was used to evaluate the resilient behavior of the soil. This procedure is contained in detail in Appendix A. For each of the soils, two specimens were compacted approximately to each of the following conditions: (a) optimum moisture content and 100% of Proctor maximum dry density and (b) above optimum moisture (range was about 2 to 5 percentage points above) and 95% of the Proctor maximum dry density. The actual compaction conditions are summarized in Table 1. A kneading compaction method, shown schematically in Figure 1, was used to compact the 2.8 inch diameter by 5.6 inch high cylindrical specimens.
These specimens were carefully wrapped in plastic and stored at room temperature for at least 7 days prior to resilience to minimize thixotropic effects.

The specimens were then placed in the resilient test apparatus, Figure 2, and subjected to the following test sequence with a repeated loading of 20 applications per minute with a load pulse duration of 0.1 second:

1. apply 1000 loads at a specimen pressure of 7 psi (conditioning phase)

2. apply about 5 loads at specimen pressures incrementally changing as follows: 3 psi → 5 → 7 → 10 → 15 → 20 → 25 → 30 → 25 → 20 → 15 → 10 → 7 → 5 → 3 psi

3. for each repeatedly applied pressure, the specimen deformation was recorded by use of an LVDT, Figure 2, connected to a Hewlett-Packard strip chart recorder

4. the resilient (or elastic) component of this deformation was converted to resilient strain by dividing the specimen height

5. by dividing the resultant resilient strain into the applied specimen pressure, a resilient modulus, \( E_R \), was obtained; that is \( E_R = \sigma/\varepsilon_R \)

RESULTS

Results from the testing program are summarized in the figures contained on page 7 to 43 of this report.

REFERENCE

### Table 1

**Summary of Soils Tested, Selected Properties and Compaction Conditions**

<table>
<thead>
<tr>
<th>Soil Designation</th>
<th>Y&lt;sub&gt;d max&lt;/sub&gt;,pcf</th>
<th>Optimum Moisture,%</th>
<th>Liquid Limit</th>
<th>Plasticity Index</th>
<th>%Y&lt;sub&gt;d max&lt;/sub&gt;</th>
<th>ω (c)</th>
<th>%Y&lt;sub&gt;d max&lt;/sub&gt;</th>
<th>ω (c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arkansas 1A</td>
<td>120.3</td>
<td>13.4</td>
<td>34</td>
<td>16</td>
<td>92.4</td>
<td>+2.2%</td>
<td>92.4</td>
<td>+0.5%</td>
</tr>
<tr>
<td>2B</td>
<td>116.4</td>
<td>15.0</td>
<td>26</td>
<td>6</td>
<td>94.7</td>
<td>+1.6%</td>
<td>99.0</td>
<td>opt.</td>
</tr>
<tr>
<td>3A</td>
<td>108.2</td>
<td>18.6</td>
<td>49</td>
<td>22</td>
<td>94.3</td>
<td>+1.7%</td>
<td>92.8</td>
<td>+2%</td>
</tr>
<tr>
<td>4A</td>
<td>103.1</td>
<td>21.5</td>
<td>52</td>
<td>28</td>
<td>94.5</td>
<td>+2.4%</td>
<td>98.0</td>
<td>+1.1%</td>
</tr>
<tr>
<td>North Carolina</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-1B-NC-ARMS-A</td>
<td>105.5</td>
<td>17.6</td>
<td>NP</td>
<td>NP</td>
<td>94.7</td>
<td>+1.6%</td>
<td>98.8</td>
<td>-3%</td>
</tr>
<tr>
<td>S-2B-NC-ARMS-H</td>
<td>115.6</td>
<td>14.5</td>
<td>22.5</td>
<td>1</td>
<td>94.8</td>
<td>+0.25%</td>
<td>97.9</td>
<td>+2%</td>
</tr>
<tr>
<td>S-3B-NC-ARMS-I</td>
<td>108.4</td>
<td>19.0</td>
<td>33</td>
<td>7</td>
<td>95.4</td>
<td>+1.6%</td>
<td>98.8</td>
<td>-6.5%</td>
</tr>
<tr>
<td>S-4B-NC-ARMS-AF</td>
<td>104.7</td>
<td>20.4</td>
<td>35</td>
<td>4</td>
<td>96.2</td>
<td>+2.0%</td>
<td>99.7</td>
<td>-0.7%</td>
</tr>
<tr>
<td>S-4B-NC-ARMS-AF</td>
<td>104.7</td>
<td>20.4</td>
<td>35</td>
<td>4</td>
<td>92.0</td>
<td>+5.0%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S-5B-NC-ARMS-AH</td>
<td>108.4</td>
<td>18.3</td>
<td>38</td>
<td>7</td>
<td>96.2</td>
<td>+1.4%</td>
<td>96.8</td>
<td>-1%</td>
</tr>
<tr>
<td>South Carolina</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-1B-SC-ARMS-AF</td>
<td>105.0</td>
<td>21.0</td>
<td>45</td>
<td>12</td>
<td>95.7</td>
<td>+1.5%</td>
<td>96.2</td>
<td>opt.</td>
</tr>
<tr>
<td>S-2B-SC-ARMS-AH</td>
<td>94.4</td>
<td>27.1</td>
<td>71</td>
<td>34</td>
<td>95.6</td>
<td>+3.8%</td>
<td>99.8</td>
<td>+3%</td>
</tr>
<tr>
<td>S-3B-SC-ARMS-AG</td>
<td>109.7</td>
<td>17.3</td>
<td>41</td>
<td>19</td>
<td>95.9</td>
<td>+1.9%</td>
<td>99.5</td>
<td>-3%</td>
</tr>
<tr>
<td>S-4B-SC-ARMS-AJ</td>
<td>99.9</td>
<td>22.7</td>
<td>51</td>
<td>18</td>
<td>95.6</td>
<td>+1.9%</td>
<td>99.5</td>
<td>-2%</td>
</tr>
<tr>
<td>S-5B-SC-ARMS-H</td>
<td>105.8</td>
<td>19.6</td>
<td>40</td>
<td>5</td>
<td>95.8</td>
<td>+1.6%</td>
<td>98.5</td>
<td>-1%</td>
</tr>
<tr>
<td>S-6B-SC-ARMS-J</td>
<td>95.0</td>
<td>26.1</td>
<td>63.5</td>
<td>29.5</td>
<td>94.9</td>
<td>+1.2%</td>
<td>100.6</td>
<td>-2%</td>
</tr>
<tr>
<td>Oklahoma 1 (CL8363)</td>
<td>119.6</td>
<td>12.9</td>
<td>23</td>
<td>5</td>
<td>94.8</td>
<td>+2.0%</td>
<td>94.8</td>
<td>+3%</td>
</tr>
<tr>
<td>Mississippi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OV-1-F</td>
<td>83.4</td>
<td>34.8</td>
<td>92</td>
<td>63</td>
<td>94.0</td>
<td>+5.0%</td>
<td>100.7</td>
<td>opt.</td>
</tr>
<tr>
<td>EJ-1-W</td>
<td>92.6</td>
<td>25.2</td>
<td>66</td>
<td>41</td>
<td>98.2</td>
<td>+5.2%</td>
<td>103.3</td>
<td>+2%</td>
</tr>
<tr>
<td>2 Mph-S</td>
<td>98.5</td>
<td>23.7</td>
<td>62</td>
<td>42</td>
<td>93.8</td>
<td>+4.8%</td>
<td>100.0</td>
<td>opt.</td>
</tr>
<tr>
<td>3 Pap-W</td>
<td>98.1</td>
<td>24.6</td>
<td>65</td>
<td>37</td>
<td>93.2</td>
<td>+5.0%</td>
<td>98.9</td>
<td>+4%</td>
</tr>
<tr>
<td>Texas Reklaw</td>
<td>111.2</td>
<td>20.7</td>
<td>38</td>
<td>14</td>
<td>94.5</td>
<td>+1.8%</td>
<td>98.2</td>
<td>+2%</td>
</tr>
<tr>
<td>Lufkin (Fleming)</td>
<td>90.8</td>
<td>27.8</td>
<td>68</td>
<td>45</td>
<td>94.5</td>
<td>+3.0%</td>
<td>101.3</td>
<td>-4%</td>
</tr>
<tr>
<td>Lufkin (Yazoo)</td>
<td>96.6</td>
<td>24.5</td>
<td>55</td>
<td>31</td>
<td>96.3</td>
<td>+2.9%</td>
<td>100.0</td>
<td>-3%</td>
</tr>
<tr>
<td>Lufkin (Cook Mt.)</td>
<td>96.8</td>
<td>26.8</td>
<td>60</td>
<td>31</td>
<td>95.5</td>
<td>+3.0%</td>
<td>99.6</td>
<td>-4%</td>
</tr>
<tr>
<td>Lufkin (Nash Creek)</td>
<td>82.8</td>
<td>33.0</td>
<td>66</td>
<td>36</td>
<td>94.9</td>
<td>+5.3%</td>
<td>98.65</td>
<td>opt.</td>
</tr>
<tr>
<td>Work Center</td>
<td>102.0</td>
<td>20.0</td>
<td>45</td>
<td>16</td>
<td>96.7</td>
<td>+3.2%</td>
<td>100.2</td>
<td>+4%</td>
</tr>
</tbody>
</table>

(A) Compaction is about 95% Y<sub>d max</sub> and 2 to 5% above optimum moisture content.

(B) Compaction to about 100% Y<sub>d max</sub> and optimum moisture content.

(C) Actual compaction moisture content relative to optimum moisture content.
Regulated Air Pressure
Bellofram Air Cylinder
Extension Rod
Compaction Foot
Split Mold
Diam. = 2.8 inch
Height = 5.6 inch
Reaction Beam

a. Compaction Equipment Schematic

Rad. = 2 inch
Concave Bottom Side

b. Compaction Foot - Plan View

c. Compaction Foot - Elevation View

FIGURE 1. COMPACTION EQUIPMENT
FIGURE 2. SCHEMATIC OF RESILIENCE TEST APPARATUS
NOTE: $\sigma_3 = 0$
ARK #1

92.4% Tₚₚₚₚ
+2.2% opt.

NOTE: σ₃ = 0

Resilient Modulus, E', ksi

Applied Deviator Stress, psl
ARK #2
4.7% σ_{r,ref} + 1.6% opt

NOTE: σ_3 = 0
ARK #2
99.0% T_{0,max}
0.0% opt.

NOTE: \sigma_3 = 0

Resilient Modulus, E_r, ksi

Applied Deviator Stress, psi
ARK # 3

X = + L
O = + 2
MAN COMP
10 LAYERS
15 blows kr.

94.3% \theta_{omax}
+1.7% \theta_{pf}

NOTE: \sigma_3 = 0

Resilient Modulus, Er, ksi

Applied Deviator Stress, psl
ARK4

Sample: 0.17 psi at 60 blows

94.5% of max
+2.4% opt.

NOTE: $\sigma_3 = 0$
ARK # 4

Equip comp

x + 1 × 117 psi 90 trials
O + 2 × 130 psi 80 trials

95% Dmax
+ 8.1% opt.

NOTE: σ_3 = 0
North Carolina 1A

94.75% \( \sigma_{\text{omax}} \)

+1.6% opt

\text{NOTE: } \sigma_3 = 0
NORTH CAROLINA
1A

99.8% \gamma_{\text{Dmax}}
-0.3% opt

NOTE: \sigma_3 = 0
Applied Deviator Stress, psi

NORTH CAROLINA 2A

94.8% 60 max
+0.25% opt

NOTE: σ₃ = 0
North Carolina ZA

98% γ_{0,max}

+0.2% φ_{T}

NOTE: σ_{3} = 0

Resilient Modulus, E_r, ksi

Applied Deviator Stress, psi
North Carolina
3A
95.4% \( \sigma_{D_{\text{max}}} \)
+1.6% \( \sigma_{gT} \)

Note: \( \sigma_3 = 0 \)
NORTH CAROLINA
3A

98.8% YOmax
-0.65% op⁺

NOTE: σ₃ = 0

Resilient Modulus, E_r, ksi

Applied Deviator Stress, psi
NOTE: \( \sigma_3 = 0 \)
4A-NC-ARMS
92% — 06/25/84
R (92% c. opt+5.0%)

No X: Sample:
Sample # Bender
NOTE: 3 = 0 exersisivly
after 2nd cycle.
NORTH CAROLINA 4A

99.7% Y_{dmax}

-0.07% opt.

NOTE: \( \sigma_3 = 0 \)

Applied Deviator Stress, psi

Resilient Modulus, \( E_r \), ksi
NOTE: $\sigma_3 = 0$
NORTH CAROLINA 5A

96.8% D_0_max
- 0.1% v next

NOTE: σ3 = 0

Resilient Modulus, E_r, ksi

Applied Deviator Stress, psi
SOUTH CAROLINA
SC-1A

100% \( \gamma_D + \sigma_3 \)
(96.2% \( \sigma_3 \))

91% \( \gamma_D + \sigma_3 \)
(95.7% \( \sigma_3 \))

\[ \sigma_3 = 0 \]
NOTE: $\sigma_3 = 0$
NOTE: $a_3 = 0$
NOTE: $\sigma_3 = 0$
Resilient Modulus, $E_r$, ksi

Applied Deviator Stress, psi

NOTE: $\theta_3 = 0$
NOTE: $\sigma_3 = 0$

$\{95\% \sigma_D + \sigma_{12}\}$

$\{100\% \sigma_D + \sigma_{12}\}$

$\{103.3\% \sigma_D + \sigma_{12}\}$

Miss EJ-1-W

Applied Deviator Stress, psi

Resilient Modulus, $E_r$, ksi
NOTE: $\sigma_3 = 0 (93.8\% \cdot \sigma_{opt} + 4.8\%)$
NOTE: $c_3 = 0$
NOTE: $\sigma_3 = 0$
NOTE: $\sigma_3 = 0$
Resilient Modulus, $E_r$, ksi

Applied Deviator Stress, psi

Texas Nash Creek
95% -- 06/28/84

L
R

(94.9% + $\sigma_3$ + 5.3%)

Note: $\sigma_3$ = 0
NOTE: $\sigma_3 = 0$
Applied Deviator Stress, psi

Resilient Modulus, $E_r$, ksi

NOTE: $\sigma_3 = 0$
APPENDIX A

SIMPLIFIED TEST METHOD FOR DETERMINING THE RESILIENT MODULUS OF COHESIVE SOILS

The simplified test method described in this chapter is similar to the method for cohesive soils described in the section on resilience testing of unstabilized soils. This simplified method is part of a production-type resilience testing procedure that has been developed for and used extensively with fine-grained cohesive soils. A more complete description of the simplified testing procedure is given elsewhere (4).

In general, the procedure consists of preparing sets of at least three 2-in.-diameter (50.8-mm-diameter) by 4-in.-high (101.6-mm-high) cylindrical specimens by using a miniature kneading compactor. The specimen sets are prepared at moisture and density conditions representative of expected field conditions and then are tested by using the simplified method.

The method takes advantage of the simplicity, ease of testing, and minimal equipment requirements normally associated with an unconfined compression-type repeated load test (i.e., $\sigma_3 = 0$). Because no confining pressure is required, a triaxial cell is not needed.

Justification for not using a confining pressure during the testing of cohesive soils lies in the fact that (a) the magnitude of confining pressure normally encountered in a subgrade is typically in the range of 1 to 5 lbf/in.\(^2\) (6.9 to 34.5 kPa) and (b) the effect of small magnitudes of confining pressure on the resilient response of fine-grained cohesive soils is very slight and typically is less than "between specimen" testing variability.

An additional advantage inherent in the simplified method is the use of an LVDT mounted in line with the longitudinal axis of the test specimen, which eliminates the need for mounting deformation measuring equipment on the specimen. It is important that the LVDT be mounted in this position because of the effect that eccentricity has if the LVDT is mounted to the side. A schematic diagram of the mounting position of the LVDT and the resilience testing equipment is shown in Figure 22.

As indicated in the section on fundamental considerations, something such as LVDT clamps or optical tracking equipment should be used for deformation measurement if the resilient modulus is greater than about 15,000 lbf/in.\(^2\) (103 500 kPa). However, for fine-grained cohesive soils, the axially mounted LVDT is satisfactory provided a sufficiently rigid machine is used.

It is suggested that at least 3 specimens be tested for a given set of variables and that the results be averaged. The reason for this is that "between specimen" variability for typical laboratory resilient testing is substantial (typical coefficients of variation of 10 to 15 percent or higher are not uncommon for cohesive soils and this type of test); thus the results from 1 specimen may be substantially different from the average of the results from a number of specimens.
SIMPLIFIED TEST METHOD

Ten steps make up the simplified test method.

1. Carefully place the specimen on the loading base.
2. Carefully place the loading cap on top of the specimen.
3. Stretch a rubber membrane tightly over the interior surface of a membrane stretcher. Carefully slip the stretched membrane over the specimen. Roll the membrane off the stretcher onto the base and cap. Remove the stretcher. Place O-ring seals or rubber bands around the base and cap. (The purpose of the membrane is to prevent loss of moisture during the test.)
4. Place the membrane-encapsulated specimen into position in the loading machine as shown in Figure 22. A steel ball bearing is placed between the top loading cap and the axial loading device. It is important to obtain proper alignment of the specimen and axial loading device to minimize eccentricities.

Resilient properties of cohesive soils are greatly dependent on the magnitude of the deviator stress (total repeated axial stress in this case). It is therefore necessary to conduct the test over a range of deviator stress values, for example: 3, 5, 7.5, 10, 15
lbf/in.² (20.7, 34.5, 51.75, 69, 103.5 kPa) and possibly higher values.

A conditioning phase is used to properly seat the loading cap and base and eliminate or minimize initial loading effects.

5. Condition the specimen with 1,000 applications (load duration of 0.060 s and cycle duration of 3 s) of an axial stress equal to about 7 lbf/in.² (48.3 kPa) followed by 20 applications each of an axial stress of 3, 5, 7.5, 10, and 15 lbf/in.² (20.7, 34.5, 51.75, 69, and 103.5 kPa). (Observe permanent axial deformation during the latter stages of the conditioning phase. If appreciable permanent deformation starts to accumulate, then eliminate the higher values of axial conditioning stress from the conditioning phase.)

6. Decrease the deviator stress to about 3 lbf/in.² (20.7 kPa).

7. Apply approximately 10 to 20 deviator stress applications and record the resilient axial deformation.

8. Increase the axial stress level incrementally about 3 lbf/in.² (20.7 kPa).

9. Repeat step 7.

10. Repeat step 8 and step 7 until the desired upper value of axial stress is reached. An upper value of at least 20 to 25 lbf/in.² (138 to 172.5 kPa) is recommended.