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THE SUITABILITY OF STABILIZED SOIL FOR BUILDING CONSTRUCTION

BY

EDWIN L. HANSEN

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ENGINEERING EXPERIMENT STATION
BULLETIN SERIES No. 333

THE SUITABILITY OF STABILIZED SOIL
FOR BUILDING CONSTRUCTION

BY
EDWIN L. HANSEN
Assistant in Agricultural Engineering and
Graduate Student in Civil Engineering

PUBLISHED BY THE UNIVERSITY OF ILLINOIS
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THE SUITABILITY OF STABILIZED SOIL FOR BUILDING CONSTRUCTION

I. INTRODUCTION

1. Object of Investigation.—Soil is one of the most abundant materials available throughout the world. This fact along with the demand for local construction material led to this investigation on the suitability of soil for use as a building material. Climatic conditions in most parts of the world make it necessary to treat the soil to make it durable. In this investigation emulsified asphalt has been used for this purpose.

2. Emulsified Asphalt.—This is an emulsion of asphaltic cement and water containing a small amount of emulsifying agent. (Emulsions are heterogeneous systems containing two normally immiscible liquid phases, one of which is dispersed as fine droplets or globules in the other.)

There are many types of asphaltic emulsions and great care must be exercised in selecting the proper one for the particular job at hand. Care must also be exercised in handling asphaltic emulsions. Whenever the balance in the proportion of asphalt to water is upset the emulsion will "break," or the asphalt settles out and cannot be gotten into solution again. This balance may be upset by stirring with a board that will take up water, by freezing, or by evaporation of the water. Some emulsions break more easily than others, therefore they are classified as fast-, medium-, or slow-breaking emulsions.

3. Acknowledgments.—This investigation is a part of the research program of the Engineering Experiment Station of the University of Illinois, of which Dean M. L. ENGER is the director, and of the Department of Civil Engineering, of which Professor W. C. HUNTINGTON is the head. The work was carried on in the Talbot Laboratory, as a graduate research problem, by the author under the supervision of Professor J. S. CRANDELL of the Civil Engineering Department. Professor E. E. BAUER granted the use of his laboratories and facilities and the testing equipment was made available by Professor W. M. WILSON and Professor FRANK E. RICHART.
II. COMPRESSIVE STRENGTH AND STABILITY

4. Effect of Asphalt.—The compressive strength of a dry soil block is increased by the addition of a small amount of emulsified asphalt, but it decreases after a certain amount is added. This is shown in Fig. 1. When the same specimen is allowed to absorb water the compressive strength increases with the increase in stabilizer content. Other tests indicate that a stabilizer content of 20 to 30 per cent of the 200-mesh content is most desirable.

5. Effect of 200-Mesh Content.—A range in compressive strength from 225 to 850 lb. per sq. in. was obtained by varying the percentage of 200-mesh material from 20 to 80, as shown in Fig. 2. The varying percentage of 200-mesh content was obtained by the addition of sand which passed the No. 4 and was retained on the No. 14 screen, or by adding 200-mesh material obtained by dry screening.

Figure 3 shows that stability varies as the percentage of 200-mesh material varies. A 200-mesh content of 20 to 30 per cent is most desirable.
FIG. 2. EFFECT OF 200-MESH MATERIAL ON COMPRESSIVE STRENGTH

FIG. 3. EFFECT OF 200-MESH MATERIAL ON STABILITY
6. Aggregate Gradation.—A preliminary test using different sizes of aggregates shown in Table 1 indicates that size of aggregate is important.

Tests made using the various aggregate gradations shown in Table 2 indicate that aggregate gradation is important when high compressive strength is desirable. The specimens tested were two inches in diameter and four inches high. Although it is impractical to grade the aggregate, care can be taken to use aggregate within a reasonable maximum and minimum size range. The results indicate that 95 per cent of the aggregate should pass a $\frac{3}{8}$-inch sieve, and not more than five per cent should pass a 100-mesh sieve. Table 3 summarizes these results. Bank run gravel is very satisfactory for use if a high percentage of it passes a $\frac{3}{8}$-inch sieve.

7. Ramming, Moisture Content, Weight.—The density of a soil block or its weight depends on the amount of ramming and moisture content when molded. Only enough water should be used in mixing to assure thorough distribution of stabilizer when blocks are molded im-

### Table 1

<table>
<thead>
<tr>
<th>Size of Aggregate</th>
<th>Average Compressive Strength lb. per sq. in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passed Sieve No.</td>
<td>Retained on Sieve No.</td>
</tr>
<tr>
<td>$\frac{1}{2}''$</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>14</td>
<td>48</td>
</tr>
<tr>
<td>48</td>
<td>....</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Screen Size</th>
<th>Percentage Retained on Each Screen</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{1}{4}$-in.</td>
<td>0 0 0 0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>$\frac{3}{8}$-in.</td>
<td>15 10 5 0 15 10 5 0 15 10 5 0</td>
</tr>
<tr>
<td>No. 4</td>
<td>5 5 5 5 2.5 2.5 2.5 2.5 0 0 0 0</td>
</tr>
<tr>
<td>No. 14</td>
<td>35 40 45 30 20 25 20 35 5 10 15 20</td>
</tr>
<tr>
<td>No. 48</td>
<td>40 40 40 40 40 45 45 45 45 50 50 50</td>
</tr>
<tr>
<td>No. 100</td>
<td>5 5 5 5 13.5 13.5 13.5 13.5 22 22 22 22</td>
</tr>
<tr>
<td>Pan</td>
<td>0 0 0 0 4 4 4 4 4 8 8 8 8</td>
</tr>
<tr>
<td>Specimen</td>
<td>1 2 3 4 5 6 7 8 9 10 11 12</td>
</tr>
</tbody>
</table>


**Table 3**

**Summary of Effect of Aggregate Gradation on Compressive Strength**

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Fineness Modulus</th>
<th>Compressive Strength lb. per sq. in.</th>
<th>Moisture Content at Molding per cent</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>2.85</td>
<td>376</td>
<td>7.1</td>
</tr>
<tr>
<td>2</td>
<td>2.75</td>
<td>360</td>
<td>8.95</td>
</tr>
<tr>
<td>3</td>
<td>2.65</td>
<td>600</td>
<td>5.7</td>
</tr>
<tr>
<td>4</td>
<td>2.55</td>
<td>468</td>
<td>4.9</td>
</tr>
<tr>
<td>5</td>
<td>2.52</td>
<td>305</td>
<td>8.35</td>
</tr>
<tr>
<td>6</td>
<td>2.38</td>
<td>275</td>
<td>8.8</td>
</tr>
<tr>
<td>7</td>
<td>2.28</td>
<td>277</td>
<td>8.3</td>
</tr>
<tr>
<td>8</td>
<td>2.18</td>
<td>264</td>
<td>8.95</td>
</tr>
<tr>
<td>9</td>
<td>2.12</td>
<td>241</td>
<td>9.6</td>
</tr>
<tr>
<td>10</td>
<td>2.02</td>
<td>206</td>
<td>9.3</td>
</tr>
<tr>
<td>11</td>
<td>1.92</td>
<td>228</td>
<td>8.95</td>
</tr>
<tr>
<td>12</td>
<td>1.82</td>
<td>220</td>
<td>8.75</td>
</tr>
</tbody>
</table>

Immediately. When the mix is soft enough to slump it should be allowed to dry somewhat before molding. The most satisfactory moisture contents for ramming and molding are from seven to nine per cent; higher moisture contents are satisfactory when maximum strength is not required. The advantage of using mixes with higher moisture content is that less labor is required; disadvantages are less strength and greater shrinkage.

If rammed construction is employed instead of block construction the low moisture mixes must be used to reduce the shrinkage as much as possible.

The weight of stabilized soil varies with the percentage of 200-mesh material and the percentage of stabilizer. For 25 per cent of 200-mesh material and five per cent of stabilizer the weight per cubic foot is between 125 and 135 pounds.

8. Various Emulsions.—Stability tests on seven different emulsions gave values from zero to more than 10 500 lb. per sq. in. Fast-breaking emulsions are unsatisfactory for this type of work. Slow-breaking emulsions allow more time in mixing and molding, and are more certain for the average person to use. However, of the different emulsions used by the author only one was entirely satisfactory. This means that even though two emulsions have the same specification they may not give similar results. The relation of stability and absorption is shown in Fig. 8.

9. Curing Temperature.—A range of curing temperatures from 70 to 175 deg. F. had no apparent effect on the stability. All specimens tested 10 500 lb. per sq. in. or over. Although no compressive strength
tests were made the stability and absorption results indicate that any drying temperature above freezing is satisfactory for curing stabilized soil.

10. Wall Section Tests.—The results of loading three wall sections as shown in Fig. 4 are given by the curves in Fig. 5. These walls were four feet high, 32 inches long, and eight inches thick. The blocks were 8 in. x 8 in. x 16 in., and were laid in stabilized soil mortar of the same mix except that only fine sand was used as aggregate. The maximum loads carried by these walls were 195, 165, and 175 lb. per sq. in., respectively.

11. Flocculating and Deflocculating Agents.—Mixing regular 20-minute plaster with stabilized soil may have some possibilities for interior plastering where an early set is required, or where conditions
require early handling of blocks. Five per cent of plaster gives an early set and has no effect on the stability. More water is required during mixing, however.

Other agents such as sodium carbonate, sodium oxalate, and sodium silicate, when mixed separately, will give the same working consistency with about 25 per cent less water, but lower the stability and have no beneficial effect. The effect on absorption is given in Section 19.

12. Various Soils.—The stabilities of all the soils tested were over 10,000 lb. per sq. in. when the 200-mesh content was below 30 per cent, and when the same stabilizer was used in equal amounts. Table 4 indicates that various soils do have different compressive strengths even though the 200-mesh content and percentage of stabilizer is constant.
### III. Durability

#### A. Absorption

13. Effect of Stabilizer.—The curves in Fig. 6 show that an increase in stabilizer content lowers the absorption. Other tests indicate that an amount of stabilizer equal to 20 percent of the 200-mesh content is sufficient for stabilizing the majority of soils.

14. Effect of 200-Mesh Content.—Absorption depends not only upon the amount of stabilizer used but also upon the 200-mesh content of the soil. Figure 7 shows that 20 to 30 per cent content of 200-mesh material in a soil will give much less absorption than contents of 40 per cent and over, even though the amount of stabilizer is increased proportionately.

15. Various Emulsions.—The percentage absorption of stabilized soil varies widely with different emulsions, as shown in Fig. 8. The same amount of emulsion was used in each case, and the results therefore indicate either that some emulsions are not satisfactory, or that more emulsion is needed to obtain low absorption. This would increase the cost even though good stabilization was obtained.

16. Aggregate Gradation.—The gradations tested had very little effect on absorption. Table 2 gives the gradations used. The percentage absorption for cylinders two inches in diameter and four inches high is given in Table 5. All specimens contained 25 per cent 200-mesh...
FIG. 6. RATE OF CAPILLARY ABSORPTION

FIG. 7. EFFECT OF 200-MESH MATERIAL ON CAPILLARY ABSORPTION
material and an amount of stabilizer equal to 20 per cent of the 200-mesh material. The values given are averages of three specimens after seven days in the absorption box. These results indicate that bank run gravel within the size range used in these tests is satisfactory.

17. Curing Temperature.—Specimens cured at from 130 to 140 deg. F. show least absorption; and temperatures as high as 175 deg. F. give better results than those below 100 deg. Under ordinary conditions however, the expense of kiln drying would not be justifiable. Table 6 shows the average absorption of 3 specimens after 7 days in the capillary absorption box.

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Absorption per cent</th>
<th>Specimen No.</th>
<th>Absorption per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.60</td>
<td>7</td>
<td>0.63</td>
</tr>
<tr>
<td>2</td>
<td>0.54</td>
<td>8</td>
<td>0.66</td>
</tr>
<tr>
<td>3</td>
<td>0.55</td>
<td>9</td>
<td>0.65</td>
</tr>
<tr>
<td>4</td>
<td>0.65</td>
<td>10</td>
<td>0.68</td>
</tr>
<tr>
<td>5</td>
<td>0.63</td>
<td>11</td>
<td>0.60</td>
</tr>
<tr>
<td>6</td>
<td>0.60</td>
<td>12</td>
<td>0.62</td>
</tr>
</tbody>
</table>
TABLE 6

Effect of Curing Temperature on Absorption

<table>
<thead>
<tr>
<th>Curing Temperature deg. F.</th>
<th>Absorption per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>2.16</td>
</tr>
<tr>
<td>130</td>
<td>1.59</td>
</tr>
<tr>
<td>140</td>
<td>1.22</td>
</tr>
<tr>
<td>175</td>
<td>1.60</td>
</tr>
</tbody>
</table>

18. Various Soils.—Even though each soil is mixed with enough sand to reduce the percentage of 200-mesh material to a certain amount and the same amount of stabilizer is used in each case, the amount of absorption will vary for different soils. Tests on four soils are recorded in Table 7.

19. Flocculating and Deflocculating Agents.—Tests on specimens containing an amount of sodium carbonate which gave the best workable mix, or 0.1 per cent showed increased absorption. Three specimens averaged 3.72 per cent absorption, while specimens containing 5 per cent of 20-minute plaster averaged 5.13 per cent, and specimens containing a combination of plaster and sodium carbonate averaged 8.52 per cent. The average for specimen containing only the stabilizer was 1.8 per cent. The resulting increase in workability does not justify the addition of sodium carbonate even where absorption is not a limiting factor.

B. Freezing and Thawing

20. Stabilizer Content.—An accelerated test for freezing and thawing can be made by placing the specimen in the absorption box for one

TABLE 7

Absorption of Various Soils

<table>
<thead>
<tr>
<th>Soil No.</th>
<th>Percentage of 200-Mesh Material</th>
<th>Absorption per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original Soil</td>
<td>Test Specimen</td>
</tr>
<tr>
<td>1</td>
<td>68.4</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>92.5</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>99.0</td>
<td>25</td>
</tr>
<tr>
<td>4</td>
<td>54.2</td>
<td>25</td>
</tr>
</tbody>
</table>
day, then in a refrigerator at a temperature below freezing for one day, and then repeating. This test shows that the resistance to freezing and thawing depends upon the resistance to absorption. Therefore, factors such as amount of stabilizer and others which affect absorption also affect freezing and thawing. (See Fig. 9.)
21. Various Emulsions.—Specimens containing five different emulsions completed from 2 to 18 cycles before becoming too soft to handle.

22. Weathering Tests.—The behavior of the stabilized soil bricks shown in Fig. 10 indicates that a stabilizer content of 15 per cent of the 200-mesh material is insufficient for stabilization, at least for this soil. Under normal conditions 20 per cent is sufficient for the majority of soils. (See also Fig. 11.)

C. Shrinkage and Swelling

23. Effect of 200-Mesh Content.—As the percentage of 200-mesh material increases, the shrinkage and swelling increase; this is shown in Fig. 12. If the 200-mesh content is below 30 per cent, shrinkage and swelling are negligible. (Swelling takes place after the specimen is dried and allowed to reabsorb water.)

24. Effect of Stabilizer Content.—As the percentage of stabilizer increases, the shrinkage increases and the swelling decreases; this is shown in Fig. 13.

25. Effect of Temperature Change.—Expansion and contraction due to temperature change is very small for stabilized soil. Table 8 shows
the effect over a range of temperatures from $-17$ deg. F. to $+307$ deg F. The average change of length from 32 to 153 deg. F. is 0.005 inches per foot. For 100 feet this would amount to 0.5 of an inch.
D. Abrasion

26. Accelerated Test.—One hundred brisk strokes of a steel wire brush has very little effect on well-stabilized specimens. Figure 14 shows the effects on specimens containing 30, 15, and 0 per cent of
TABLE 8
EXPANSION AND CONTRACTION DUE TO TEMPERATURE

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Standard Length in.</th>
<th>Change in Length per Foot in.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Temperature, deg. F.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+32</td>
</tr>
<tr>
<td>1</td>
<td>3.1080</td>
<td>-0.0108</td>
</tr>
<tr>
<td>2</td>
<td>3.2677</td>
<td>-0.0039</td>
</tr>
<tr>
<td>3</td>
<td>3.2128</td>
<td>-0.0066</td>
</tr>
<tr>
<td>4</td>
<td>3.2850</td>
<td>-0.0055</td>
</tr>
<tr>
<td>5</td>
<td>3.9176</td>
<td>-0.0028</td>
</tr>
<tr>
<td>6</td>
<td>3.3510</td>
<td>-0.0036</td>
</tr>
</tbody>
</table>

stabilizer. Specimens containing 30 per cent merely take a polish while unstabilized soil specimens will lose nearly one-quarter of an inch of material.

IV. THERMO-CONDUCTIVITY AND WATER VAPOR PERMEABILITY

27. Comparison With Typical Walls.—Using a conductivity of 3.50* (expressed in B.t.u. per hr. per sq. ft. per in. thickness per deg. F. difference in temperature) the equivalent wall thickness of stabilized soil as compared with typical walls is shown in Table 9.t

28. Comparison With Other Materials.—Comparing the conductivity of stabilized soil with that of other materials shows that it is lower than that of light-weight concrete. Table 10 lists the conductivities of some of the common materials.

29. Water Vapor Permeability.—Tests by Dr. H. J. Barre on slabs furnished by the author give a water vapor permeability of 8.49 gm. per sq. ft. per day per lb. per sq. in. difference in pressure.‡ These specimens contained 25 per cent 200-mesh material and five per cent stabilizer. More stabilizer would lower the amount of vapor lost.

V. SURFACE TREATMENT

30. Painting.—Excellent results are obtained when an aluminized asphalt paint is used, as shown in Fig. 15. This may be applied as an

*Tests were made by Dr. H. J. Barre, Agricultural Engineer, Iowa State College, Ames, Iowa.
‡A description of the apparatus used and the procedure followed may be obtained from Bulletin 271, Agricultural Experiment Station, Iowa State College, Ames, Iowa.
FIG. 14. ABRASION SPECIMENS

Abrasion from 100 strokes of steel wire brush.
Specimens contain (left to right) 30, 15, 0 per cent of stabilizer (per cent of 200-mesh material).

TABLE 9
COMPARISON OF WALL CONDUCTIVITIES

<table>
<thead>
<tr>
<th>Type of Construction</th>
<th>Thickness in.</th>
<th>Equivalent Thickness of Stabilized Soil in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid Brick (4 in. hard, remainder soft)</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>Hollow Tile (stucco exterior)</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>Concrete (monolithic)</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>6</td>
</tr>
<tr>
<td>Cinder Concrete (monolithic)</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>Haydite (monolithic)</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>Frame construction of Wood siding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 in. wood sheathing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 in. x 4 in. studding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>½ in. plaster board</td>
<td></td>
<td></td>
</tr>
<tr>
<td>½ in. plaster</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Same frame construction as above, with rock wool fill</td>
<td></td>
<td>26</td>
</tr>
</tbody>
</table>
TABLE 10
CONDUCTIVITIES (k) AND CONDUCTANCES (c) OF BUILDING MATERIALS

The coefficients are expressed in B.t.u. per hour per square foot per degree F. per one inch thickness

<table>
<thead>
<tr>
<th>Material</th>
<th>Conductivity (k)</th>
<th>Conductance (c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stabilized Soil</td>
<td>3.50</td>
<td></td>
</tr>
<tr>
<td>Sand and Gravel Concrete (av.)</td>
<td>12.62</td>
<td></td>
</tr>
<tr>
<td>Cinder Concrete (av.)</td>
<td>4.86</td>
<td></td>
</tr>
<tr>
<td>Haydite</td>
<td>3.96</td>
<td></td>
</tr>
<tr>
<td>Brick (low density)</td>
<td>5.00</td>
<td></td>
</tr>
<tr>
<td>Brick (high density)</td>
<td>9.20</td>
<td></td>
</tr>
<tr>
<td>Cement mortar</td>
<td>12.00</td>
<td></td>
</tr>
</tbody>
</table>

undercoat or as a finish coat. Any alkaline base paint is also suitable. Slight discoloration may occur, however, if no undercoat of aluminum paint is applied or some other treatment given. A cement wash made by mixing one sack of Medusa white cement with about six gallons of water may also be used. This is mixed to a creamy consistency and applied with a brush after the walls have been washed and brushed to remove all loose material. After application this coating is wetted several times daily for five or six days until fully set and hardened. The application is best made in damp weather.

Red and black and combinations of the two can be obtained by mixing certain paint pigments with the stabilized soil. Persian Gulf

**FIG. 15. CORNER SECTION OF WALL**
Left side painted with aluminized asphalt paint
oxide (red) gives a pleasing shade when mixed in the proportion of about one part to 60 of stabilized soil, and carbon black gives a satisfactory shade when mixed one part to 300 parts of stabilized soil. It is not necessary to color the entire block; a thin layer on the outer edge is all that is needed.

31. **Waterproofing.**—If stabilized soil walls are exposed to water for long periods, such as in a fruit storage cave, the walls should be waterproofed. This may be done with any of the materials commonly used, such as preparations of asphalt and tar. Hot paraffin can be applied also and is very satisfactory. It should be put on the blocks while they are hot; this may require the use of a blow torch.

32. **Plastering.**—Interior plastering may be done if it is desired. The blocks should not be smooth if plaster is applied directly to the wall. Hard plaster bonds very well to stabilized soil, but a scratch coat will pull loose after it absorbs moisture from the hard finish coat.

Plastering is unnecessary for this type of construction, since painted interiors are very satisfactory.

### VI. SOIL ANALYSIS AND COMPUTATIONS

33. **Proportioning Soil, Sand, and Asphalt.**—Steps for obtaining the correct proportions are as follows:

1. Select a representative sample of subsoil from the soil pit and dry it.
2. Weigh out 100 grams of dry soil.
3. Place the dry soil in a standard 200-mesh screen and run water through it until all of the 200-mesh material is washed out. The water will be clear when it is all out.
5. Wash the material left on the screen into the evaporating dish and dry.
6. Weigh again after drying. The weight of the material retained on the screen is found by subtracting the weight of the evaporating dish from the final weight.
7. The amount of 200-mesh material is found by subtracting the weight of the retained material from 100, or the original weight; for example:

   - Weight of sample = 100 gm.
   - Weight of evaporating dish = 300 gm.
   - Weight of evaporating dish and retained soil = 340 gm.
Weight of soil retained on 200-mesh sieve = 340 - 300 = 40 gm.
Weight of 200-mesh material = 100 - 40 = 60 gm.

= 60 per cent 200-mesh.

(8) Reduce the percentage of 200-mesh material to about 25 by adding sand; for example:

\[ x = \text{grams of soil at 60 per cent 200-mesh} \]
\[ 100 = \text{grams of soil desired at 25 per cent} \]
\[ x (0.60) = (100) (0.25) \]
\[ x = 41.7 \text{ gm. of soil required} \]

100 - 41.7 = 58.3 gm. of sand required.

(9) The amount of stabilizer is found by multiplying the amount of 200-mesh material in the final mix by the percentage of stabilizer desired; for example:

Desired stabilizer content = 20 per cent of 200-mesh material

Therefore, in 100 gm. of stabilized soil at 25 per cent 200-mesh there would be 25 gm. of 200-mesh, and multiplying, \((25) \times (0.20)\) = 5 per cent of stabilizer by weight.

VII. CONSTRUCTION

34. Block Construction Specifications.—Stabilized soil construction has followed the old style adobe construction of solid walls laid up by using large soil bricks. Considerable construction experience of a business concern manufacturing an asphaltic soil stabilizer has led this company to issue definite specifications for the manufacture of stabilized soil blocks using their stabilizer, and for construction.

In general, the following suggestions should be observed:

**Materials**

The soil should be taken only from locations established after testing according to methods described in Chapter VI.

Only a thoroughly tested stabilizer should be used.

The water used in mixing should meet Public Health drinking water standards.

The sand should be free from acids, alkalis, and soluble salts. Good concrete bank run gravel is very satisfactory.

**Equipment**

The casting bed should be a flat area of ground leveled and smoothed with fine earth or sand. This area should be large enough for several days’ runs, with space for bricks to dry before removal to piles.
Common sizes of blocks are 8" x 8" x 16", 4" x 12" x 18", or multiples of common burned brick, such as 4½" x 12½" x 18½".

FIG. 16. FORMS USED FOR MOLDING STABILIZED SOIL

The molds must be made to conform to the size of the soil bricks. They may be made of metal, wood, or wood with metal linings, the latter being very satisfactory. Figure 16 shows a typical mold. These may have one or more compartments.

The best types of mixers are pug mills or paddle mixers. All clods must be disintegrated and thoroughly mixed. Other mixers may be used if the soil is pre-wetted in the pile so that the clods are softened.

Workmanship

Mixing must be thorough, and the ingredients must be accurately proportioned. It is best to weigh the material first to determine the number of shovelsful of material to use, and to obtain the correct amount of stabilizer. Water should be added first, then soil, stabilizer, and the sand last. If a continuous type mixer is used, the water may contain the stabilizer. Mixing should continue until the asphalt is evenly distributed throughout the material and until all clods are broken and mixed. The mix should be only wet enough to be workable.

For molding, burlap strips, corrugated cardboard, or absorbent paper should be spread on the casting bed, and the brick molds be placed thereon. Newspapers are not satisfactory because they stick to the brick and are hard to remove. The mix is placed in the molds and rammed well to fill the corners. Excess material is struck off with a shovel or straight edge, and the upper edge is smoothed off. The form is then lifted immediately.

Curing requires several days. The bricks should not be moved until they have hardened sufficiently to handle. They are turned first on edge and allowed to dry from ten to thirty days, depending upon weather conditions. They may then be raked loosely in tiers until ready for use. The bricks should be dried until further loss of weight
in the drying test does not exceed four per cent of the final weight. Figure 17 shows a pile of stabilized soil blocks ready for use.

Construction of Walls

The footings should be of concrete, and concrete foundation walls should be carried about six inches above ground for large structures. If the soil blocks are waterproofed and are used in a well-drained location then they may extend below grade for inexpensive structures. A reinforced concrete footing should be used in either case to prevent uneven settling. The top of the foundation wall should be waterproofed to prevent capillary water from entering the soil blocks.

Mortar used in laying up the blocks may be stabilized soil with the large material screened out of the aggregate, or a cement mortar consisting of 1 part cement, 2½ parts concrete sand, and 1½ gallons of stabilizer to each sack of cement. The soil mortar is satisfactory, but does not set as quickly as the cement mortar; however, the loss of heat through cement mortar joints is much greater. Both work equally well. Mortar joints are made about ½ inch thick, and all vertical joints should be rodded.

Minimum design requirements for stabilized soil brick masonry are given in Fig. 18.

Sub-floors may be made by leveling below the floor grade, watering, compacting, and drying. Then sand is spread about four inches deep and soil bricks are laid and mortared.
Chimneys may be lined with stabilized soil blocks, but the blocks should not be exposed to the fire or to excessive heat.

The thickness of the wall should be proportional to the height, and experience indicates the following proportions:

<table>
<thead>
<tr>
<th>Height of Wall ft.</th>
<th>Thickness of Wall in.</th>
<th>Height of Wall ft.</th>
<th>Thickness of Wall in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>12</td>
<td>13</td>
<td>16</td>
</tr>
<tr>
<td>10</td>
<td>13</td>
<td>14</td>
<td>18</td>
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<tr>
<td>11</td>
<td>14</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>12</td>
<td>15</td>
<td>16</td>
<td>22</td>
</tr>
</tbody>
</table>

35. **Rammed Construction.**—Another type of construction which should receive some consideration is the rammed-earth type. The mix is rammed directly into the wall. A layer is rammed into the form, then the form is raised and another layer is rammed in. The amount of labor is reduced in this type of construction and there are no mortar joints. A dry mix is necessary and a set of movable forms must be used. Stabilized soil should work very well with this type of building. For details of this method of construction see Reference 20 in the Bibliography.

36. **Cost.**—There are no cost figures available for this type of construction in the Middle West. Information from other states indicates that the labor requirement for adobe brick is about \( \frac{1}{2} \) man-hour per cubic foot of completed wall. The cost of stabilized soil brick should be about the same, plus the cost of the stabilizer. The average amount of stabilizer required is five per cent of the mix when 25 per cent of the 200-mesh material is used, or about 6.5 lbs. per cubic foot. Since the cost of the stabilizer depends upon the quantity purchased, the cost per cubic foot may run from 8 to 12 cents for the stabilizer.

Stabilized soil construction is not a low-cost type of construction when labor is figured in the total. The first cost is about equal to that of cheaply constructed wood frame houses. It is a type of construction, however, which utilizes ordinary labor and local materials, and the cash outlay need not be great.

**VIII. Other Uses of Stabilized Soil**

37. **Walks, Drives, Floors, Etc.**—Very satisfactory walks and drives can be made of stabilized soil. Cinders are sometimes used
instead of gravel in the soil mix. Thorough packing or rolling until the surface is hard gives the best results. If neither cinders nor soil are available dry finely-ground limestone may be used. This should contain from 20 to 30 per cent of 200-mesh material, and should not have been wetted and dried out before mixing with the stabilizer. The amount of stabilizer is figured in the same manner as with soil.

Floors in buildings also may be made of stabilized soil. If a soft top is desired, a thin layer of stabilized soil with hardwood sawdust
mixed in may be placed on top. Such a floor may need patching occasionally, but could be used in many places.

Ornamental flower boxes and many other things may be made if one has a thorough knowledge of the material, its advantages, and limitations.

38. *Erosion Control.*—Stabilized soil blocks could be used for small semi-permanent erosion control structures. If waterproofed and laid carefully they should be very satisfactory. Waterways and terrace outlets would apparently afford other uses of stabilized soil. Information respecting best construction practices is not available for erosion control work, and in the past asphalts of various kinds have been used with some failures. This is not at all surprising after a study of the various emulsions used in this investigation. It is believed, however, that if a good stabilizer is used in accordance with the results of this investigation many uses will be found for stabilized soil in erosion control work.
APPENDIX A

LABORATORY TESTS

Stability Test.—Resistance to displacement is the object of this test. Specimens are tested after they have completed the absorption test or have been in the capillary box for seven days. The apparatus shown in Fig. 19 consists of a 2$\frac{1}{16}$-inch cylinder, in which the specimen is placed, with a tool steel orifice having an area of exactly one square inch in the bottom. This is placed on the stand and a two-inch plunger is used to apply the load to the specimen. The load is applied in a regular testing machine.

To make the test the specimen is placed in the cylinder with the orifice plugged. A load of approximately 3000 pounds is applied to press the specimen into contact with the cylinder and the orifice plate. The load is then released and the plug removed. A mark is made on the plunger $\frac{1}{4}$ inch above the top of the cylinder, and then the load is applied again at the rate of $\frac{1}{2}$ inch per minute. The load on the beam when the $\frac{1}{2}$-inch mark is reached is the stability of the material. This load may run from 25 000 to 35 000 lb. on specimens prepared according to the results of this investigation. The stability in pounds per square inch is determined by dividing by 3.1416. For complete details see Reference 43.

Fig. 19. Stability Apparatus
Compression Test.—Specimens are prepared in the usual manner by capping the two ends parallel with plaster of Paris and leading in a testing machine. All compression tests in this investigation were made on cylinders two inches in diameter by four inches high. Four-inch cubes may also be used.

Absorption Test.—Specimens are dried to constant weight, cooled, and placed in an absorption box, as shown in Fig. 20a, which is en-
closed and contains a pan filled first with a layer of Ottawa sand and then a layer of diatomaceous earth covered with a photographic pure blotter, and with a water-feeding apparatus which keeps the water level exactly at the underside of the blotting paper. Before the specimens are placed in the box they are wrapped in cellophane except for the bottom to reduce evaporation, as shown in Fig. 20b. Another very satisfactory method is to cover the specimen with half of a paper milk container. Cylinders two inches in diameter and four inches high are used, and the difference in weight after seven days in the box is considered the absorption of the specimen.

_Molding._—Brass tubing two inches in diameter and five inches high is used to mold specimens four inches high. The mix is rammed in three successive layers by 25 strokes of a one-inch tamping rod for each layer. A large plunger slightly under two inches in diameter is then used to apply a load of about 3000 pounds on the specimen. The mold is inverted and the specimen is forced out immediately.

_Drying._—Specimens may be placed in an oven at 140 deg. F. immediately and dried to constant weight.
## Appendix B

### Bibliography

<table>
<thead>
<tr>
<th>No.</th>
<th>Year</th>
<th>Author</th>
<th>Title and Reference</th>
</tr>
</thead>
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<td>No.</td>
<td>Year</td>
<td>Author</td>
<td>Title and Reference</td>
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<tr>
<td>27</td>
<td>1932</td>
<td>W. L. Hudson</td>
<td>“Penetration Emulsions for Paving.” Special problem under J. S. Crandell, June.</td>
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<td>51</td>
<td>1941</td>
<td>H. R. Chapin</td>
<td>&quot;How to Sling Mud—Constructively; We Build Adobe House With Our Own Hands.&quot; Better Homes and Gardens, v. 19, No. 5, p. 14.</td>
</tr>
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</table>
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