TECHNICAL NOTES

U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCES CONSERVATION SERVICE

ENGINEERING #4 **SPOKANE, WASHINGTON**

"Basic Principles of Compaction for Minimal Permeability"

BACKGROUND

Danny McCook, of the Fort Worth Soil Mechanics Center developed the attached paper. The purpose of the attached paper is to provide a procedure for selecting the optimum water content/dry density combination to use in design of compacted earthfill liners.

INTRODUCTION

To minimize permeability in compacted clays you can design for a wide range of water content/dry density combinations. The decision on which combination of dry densities and water contents to use can be confusing. The objective of this paper is to provide a planning procedure for selecting the optimum water content/dry density combination to use in design. Designers should strongly consider the natural water content of soils in design, and this paper assists in planning for construction for this factor.

Basic Principles of Compaction for Minimal Permeability

Lambe and Ladd's original work on the structure of compacted clay demonstrated the beneficial effect of compacting soils at a relatively high degree of saturation. Daniel's work emphasized the point. In his ASCE article, he introduced the principle for designing around a minimal density and a relatively high degree of saturation. Using those principles and NRCS experience with testing several thousand compacted clays, this procedure was developed. The basic assumptions involved in developing the procedure are as follows:

1. The procedure applies to Group III and IV soils as defined in Appendix 10D to the Agricultural Waste Management Field Handbook.
2. A minimum level of compaction is 95 percent of maximum Standard Proctor (ASTM D698A) dry density. While some soils may be shown to have an acceptably low permeability at lower degrees of compaction than this, a larger number of soils will be too permeable at a low degree of compaction. The increasing emphasis on

proper installation of clay liners using sheepsfoot rollers promises that obtaining 95 percent of maximum Standard Proctor dry density is a realistic goal.

3. The upper realistic goal for soil compaction is a dry density equal to one hundred percent of Modified Proctor (ASTM D1557A) dry density,
4. To achieve a minimal permeability, soils should be compacted at a water content/dry density combination that results in a degree of saturation of at least 80 percent. This assumption is based partly on Daniel's article and partly on NRCS experience.
5. The upper realistic limit of water content is that which corresponds to 90 percent saturation at the compaction dry density.
6. The specific gravity of soils solids, Gs, is used for several calculations in the procedure. It may be determine by laboratory tests, or may be assumed to be equal to 2.70 for many clay soils. Note that if the value is significantly different, results will be very different.

PROCEDURE

These principles are used to define a range of water content/dry density combinations that will likely result in a minimal permeability, less than 1 x 10^{-6} cm/second. The steps that can be used to define this range of combinations is described as follows:

1. Perform a Standard Proctor (ASTM D698A) compaction test. This defines the lower limit of acceptable compaction. The minimal acceptable dry density is assumed to be 95 percent of D698A dry density.

2. For preliminary planning, the maximum Standard Proctor dry density can be estimated from known values of LL and PI according to the following equation:

   $$\text{ASTM D698A } g_{dmax} = 130.28 - 0.82 * LL + 0.30 * PI$$

   The minimum considered dry density is then equal to 95 percent of this estimated value.

3. Either perform a Modified Proctor (ASTM D1557A) compaction test, or estimate the value from the known or estimated value of dry density obtained in steps 1 or 2 above. The performed test defines the maximum feasible compacted dry density, or it may be estimated from the Standard Proctor dry density according the following equation:

   $$\text{ASTM D1557A } g_{dmax} = 0.975 * \text{ ASTM D698A } g_{dmax} + 10.75$$

4. At 95 percent of Standard Proctor Dry Density, compute a value for theoretical saturated water content using the equation:

$$w_{sat}(\%) = \left(\frac{62.4}{g_{d\,\max}} - \frac{1}{2.70} \right) x100$$

5. Compute water contents equal to 80 % and 90 % of theoretical saturated water content. These become control points 1 and 2.

6. At 100 percent of the Modified Proctor (ASTM D1557A) dry density, compute a value for theoretical saturated water content using the above equation.

7. Compute the water contents equal to 80 percent and 90 percent of theoretical saturated water content. These become control points 3 and 4.

8. The natural water content of the soils to be used constructing the clay liner should be plotted on the graph to assist designers in selecting the most appropriate level of compaction energy. In some cases, using a different energy may be more economical than adding water on the fill or drying the soils.

9. For soils in Group III and IV, drying the soils by over 2-3 percent will be difficult because they have relatively high plasticity. Likewise, adding water content by over 2-3 percent by watering the fill will also be difficult. Pre-irrigation of the borrow area will be needed to increase water contents by over 2-3 percent. Scheduling construction for different times of the year may be necessary where water contents are excessively high.

EXAMPLE PROBLEM

Given the following basic information. A soil has a LL value of 40 and a PI of 20. A Standard Proctor (ASTM D698A) compaction test was performed and the following results were obtained. The maximum dry density is 102.5 pcf and the optimum water content is 20.5 percent. The specific gravity (G_S) value is assumed to be 2.70. The natural water content is 22 percent. What is recommended for compaction energy if no water is to be added or the soil is not to be dried?

Determine the 4 control points for obtaining minimal compacted permeability.

1. Compute the minimal dry density equal to 95 percent of the D698A dry density. The minimum dry density is 0.95 * 102.5 pcf = 97.4 pcf

2. Estimate the Modified Proctor dry density from the equation:

3. ASTM D1557A g_{dmax} = 0.975 * ASTM D698A g_{dmax} + 10.75

   ASTM D1557A g_{dmax} = 0.975 * 102.5 pcf + 10.75 = 110.7 pcf

4. Compute the theoretical saturated water content at the dry density from step 1 above:

$$w_{sat}(\%) = \left(\frac{62.4}{97.4} - \frac{1}{2.70}\right) x100 = 27.0\%$$

5. Compute 80 % and 90 % of the saturated water content. Eighty percent of 27.0 percent is 21.6 percent, and 90 percent is 24.3 percent. These are control points 1 and 2.

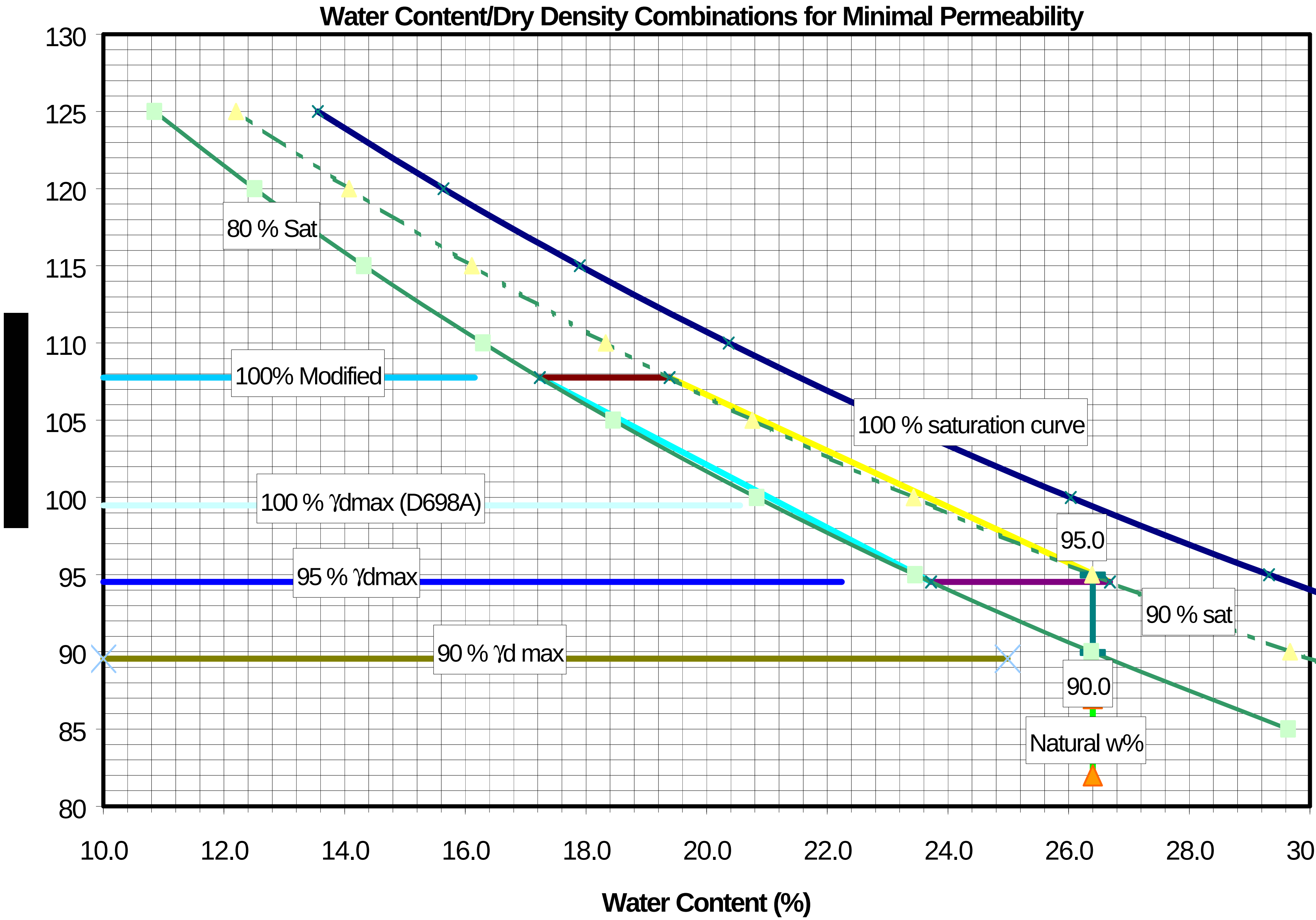
6. Compute the theoretical saturated water content at the dry density from step 2 above:

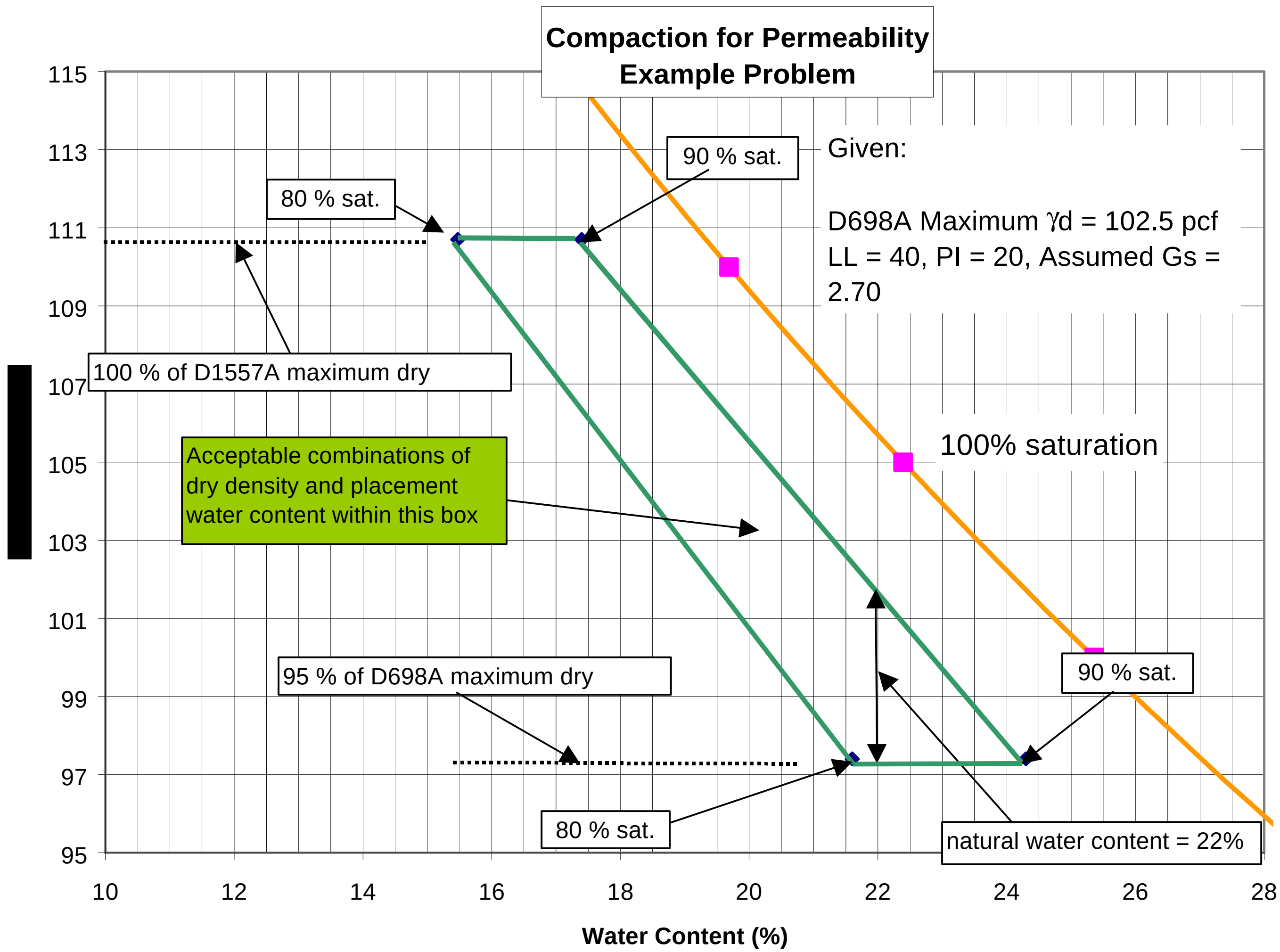
$$w_{sat}(\%) = \left(\frac{62.4}{110.7} - \frac{1}{2.70}\right) x100 = 19.3\%$$

7. Compute 80 % and 90 % of the saturated water content. Eighty percent of 19.3 percent is 15.5 percent, and 90 percent is 17.4 percent. These are control points 3 and 4.

8. Then, the range of acceptable dry densities and water contents defined by control points may be plotted on a graph paper as shown on the attached illustration.

9. With a natural water content of 22.0 percent, a design should consider a relatively low energy of compaction – the plotted envelope on the attached graph shows that desirable permeabilities can probably be obtained at dry densities between about 97 and 102 pcf. With a maximum Standard Proctor dry density of 102.5 pcf, this then corresponds to a degree of compaction of between about 95 and 100 percent of maximum Standard Proctor dry density.


Water Content/Dry Density Combinations for Minimal Permeability
[redacted]
130
125
120
115
110
105
100
95
90
85
80
80 % Sat
100% Modified
100 % saturation curve
100 % γdmax (D698A)
95.0
95 % γdmax
90 % sat
90 % γd max
90.0
Natural w%
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
28.0
30.0
Water Content (%)


Compaction for Permeability
Example Problem
Given:
D698A Maximum γd = 102.5 pcf
LL = 40, PI = 20, Assumed Gs = 2.70
80 % sat.
90 % sat.
100 % of D1557A maximum dry
Acceptable combinations of dry density and placement water content within this box
100% saturation
95 % of D698A maximum dry
90 % sat.
80 % sat.
natural water content = 22%
115
113
111
109
107
105
103
101
99
97
95
[redacted]
10
12
14
16
18
20
22
24
26
28
Water Content (%)