CE 240
Soil Mechanics & Foundations
Lecture 3.3

Soil Compaction

(Das, Ch. 5)

Class Outlines

- Soil compaction introduction
- Standard Proctor Compaction Test
- Effect of Compaction Energy
- Modified Proctor Compaction Test

Compaction

- In construction of highway embankments, earth dams and many other engineering structures, loose soils must be compacted to improve their strength by increasing their <u>unit weight;</u>
- Compaction - Densification of soil by removing air voids using mechanical equipment;
- The degree of compaction is measured in terms of its <u>dry unit weight.</u>

Objectives for Compaction

- Increasing the bearing capacity of foundations;
- Decreasing the undesirable settlement of structures;
- Control undesirable volume changes;
- Reduction in hydraulic conductivity;
- Increasing the stability of slopes.

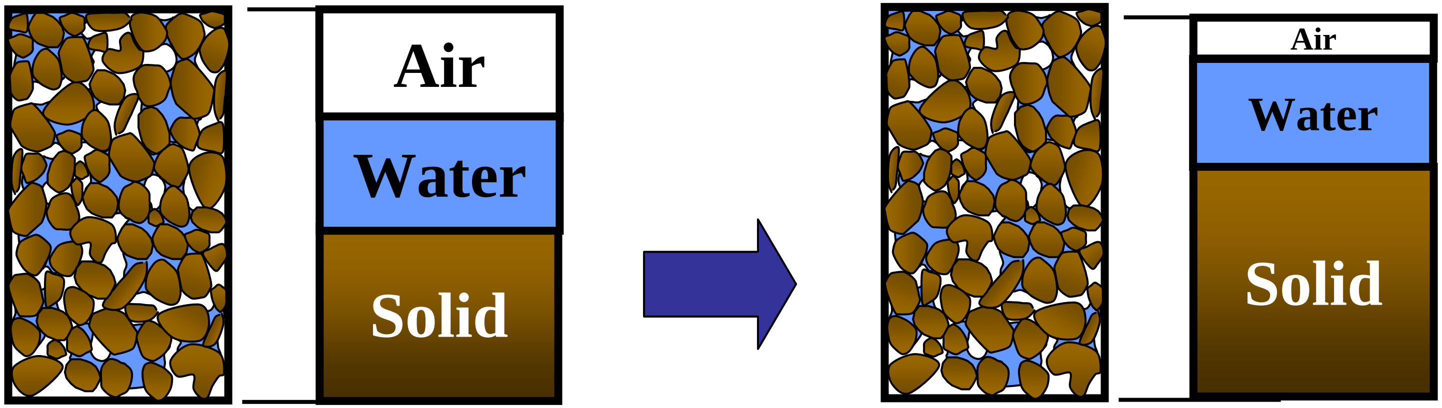
In general, soil densification includes compaction and consolidation.

Compaction is one kind of densification that is realized by rearrangement of soil particles without outflow of water. It is realized by application of mechanic energy. It does not involve fluid flow, but with moisture changing altering.

Consolidation is another kind of densification with fluid flow away. Consolidation is primarily for clayey soils. Water is squeezed out from its pores under load.

This chapter of the textbook concentrates on compaction, and the consolidation will be discussed later in Chapter 10.

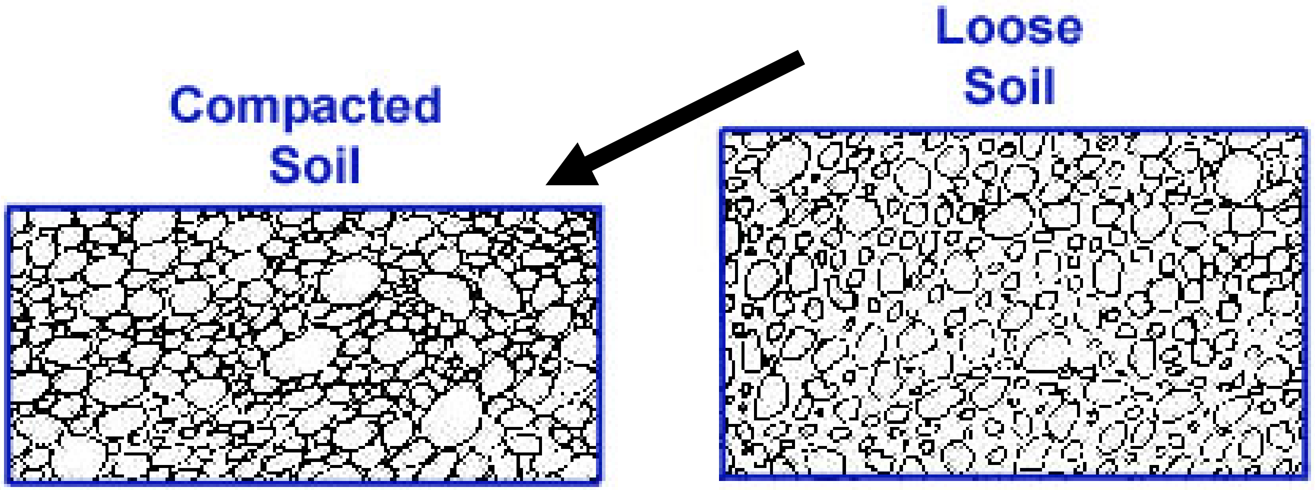
Compaction Effect



Loose soil **Compacted soil**

There are 4 control factors affecting the extent of compaction:

1. **Compaction effort;**
2. **soil type and gradation;**
3. **moisture content; and**
4. **dry unit weight (dry density).**



Effect of Water on Compaction

- In soils, compaction is a function of water content
- Water added to the soil during compaction acts as a softening agent on the soil particles
  - Consider 0% moisture - Only compact so much
  - Add a little water - compacts better
  - A little more water - a little better compaction
  - Even more water – Soil begins to flow
- What is better compaction?
  - The dry unit weight (γ_d) increases as the moisture content increases **TO A POINT**
  - Beyond a certain moisture content, any increase in moisture content tends to reduce the dry unit weight

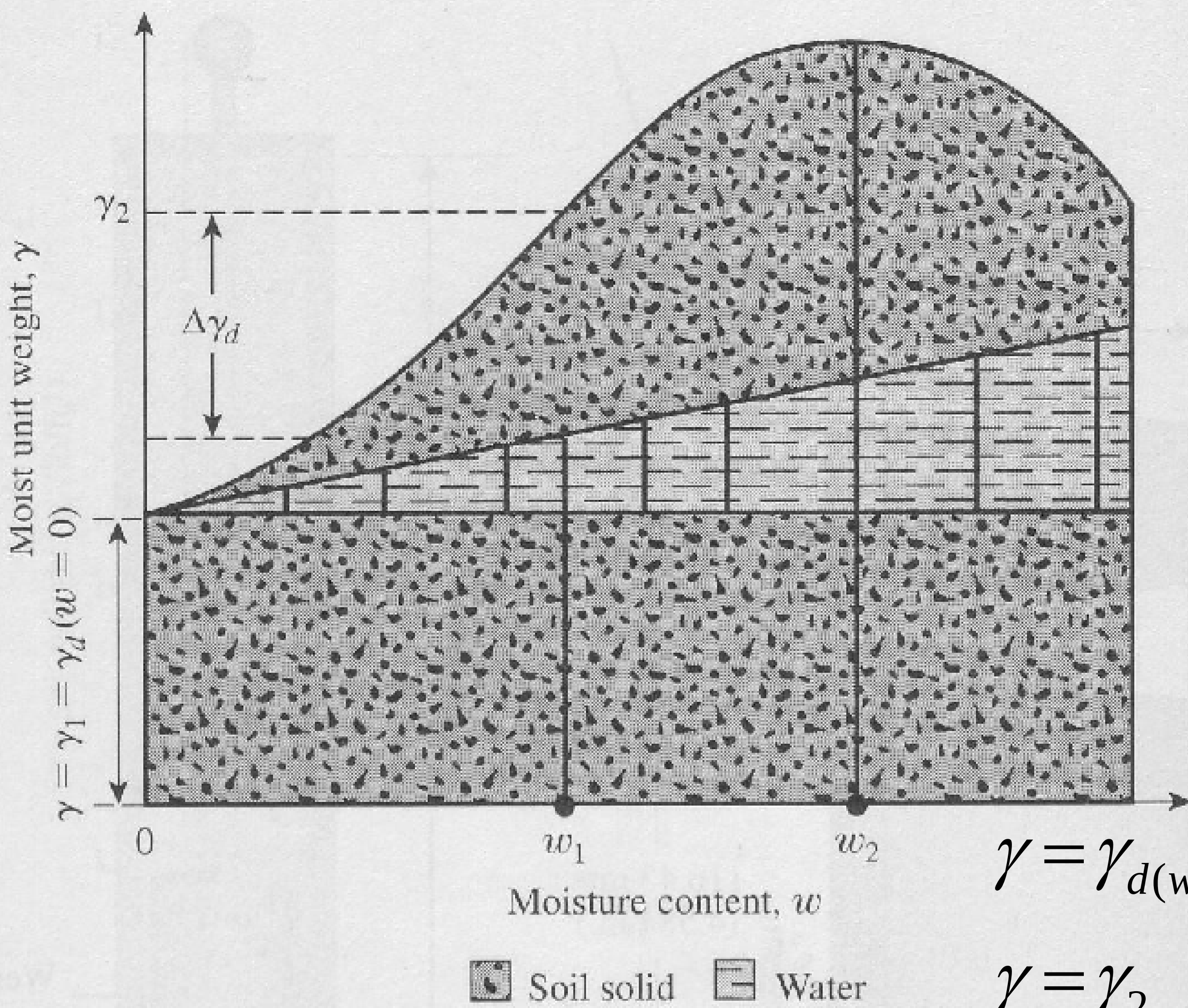


Figure 5.1 Principles of compaction

$$\gamma = \gamma_{d(w=0)} = \gamma_1$$

$$\gamma = \gamma_2 \quad \text{while} \quad w = w_1$$

$$\gamma_{d(w=w_1)} = \gamma_{d(w=0)} + \Delta\gamma_d$$

Das, Figure 5.1

Standard Proctor Compaction Test

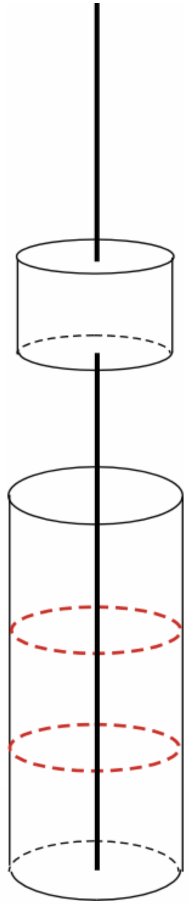
- The standard was originally developed to simulate field compaction in the lab
- Purpose: Find the optimum moisture content at which the maximum dry unit weight is attained
- ASTM D 698
- Equipments;
  - Standard Proctor
    - 1/30 ft^3 mold
    - 5.5 lb hammer
    - 12” drop
    - 3 layers of soil
    - 25 blows / layer

Compaction Effort

Compaction Effort is calculated with the following parameters

- Mold volume = 1/30 cubic foot
- Compact in 3 layers
- 25 blows/layer
- 5.5 lb hammer
- 12" drop

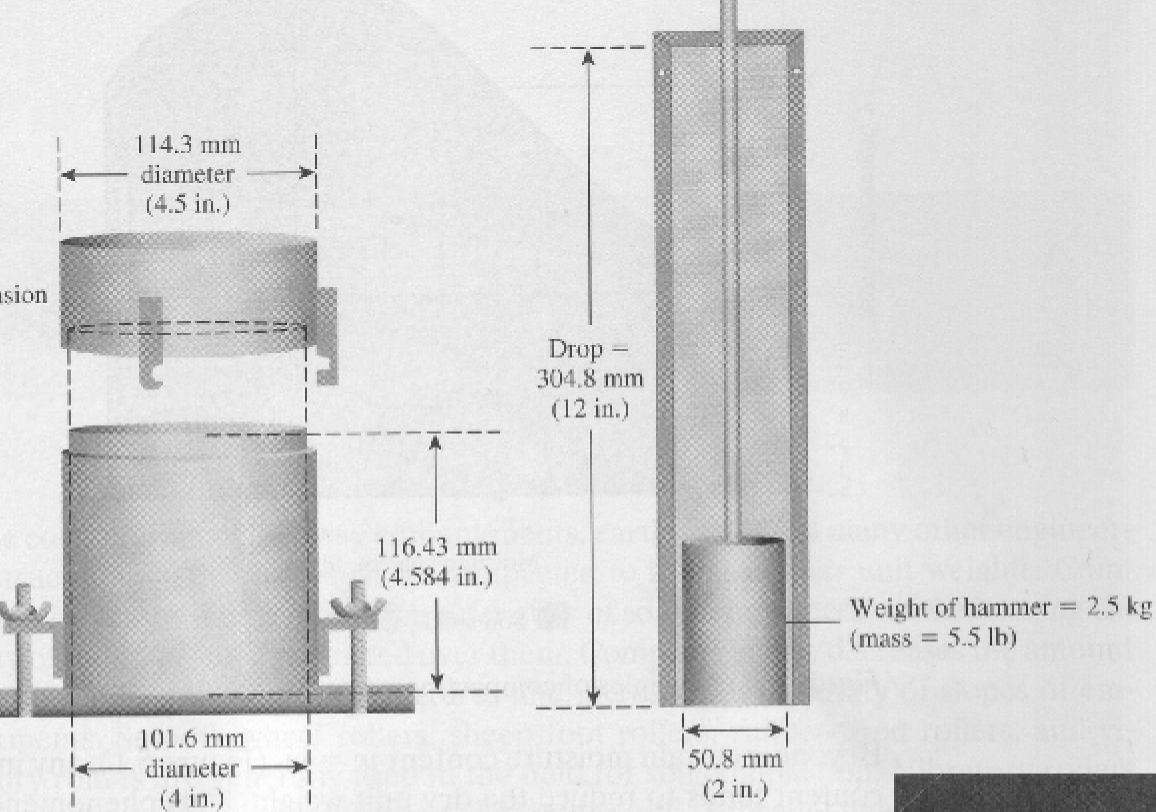
By W=F×S



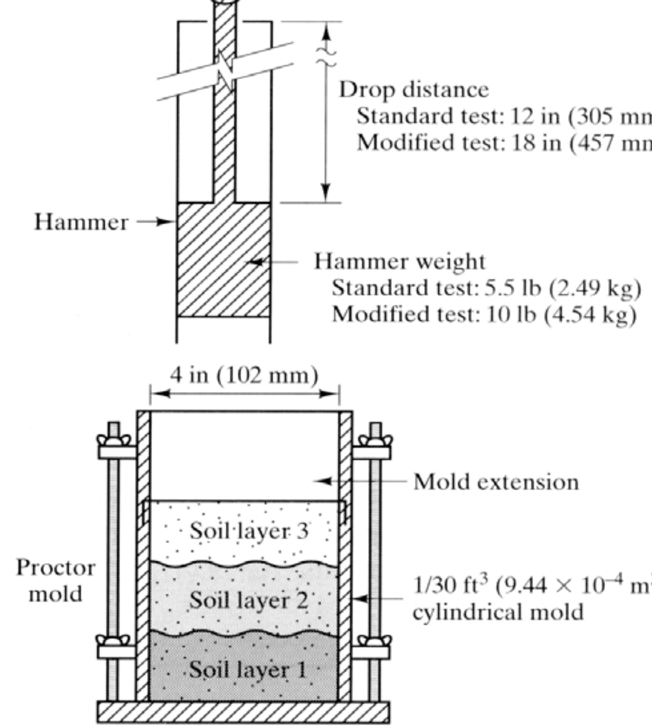
E = Compaction Energy

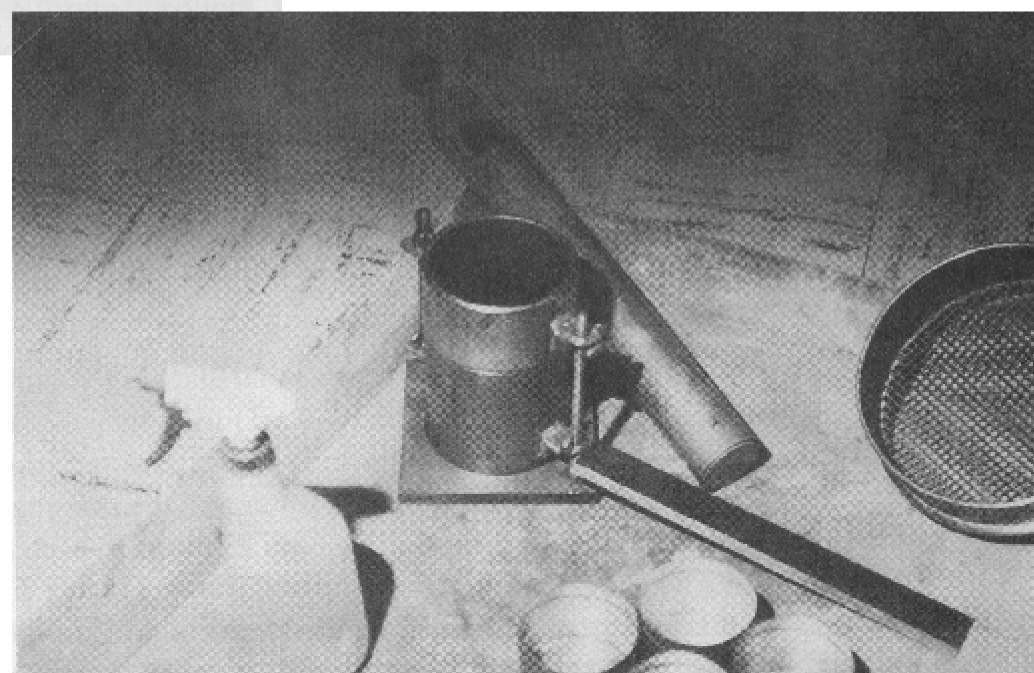
$$E = \frac{(25\ blows/layer)(3\ layers)(5.5\ lb)(1\ ft)}{1/30\ ft^3} = 12{,}375\ \frac{ft \bullet lb}{ft^3}$$

$$E = \frac{(\#\ blows/layer)\times(\#\ layers)\times(weight\ of\ hammer)\times(height\ of\ drops)}{Volume\ of\ mold}$$



(a) **(b)**





Compaction Lab Equipment

Das, Figure 5.2

Procedure

1. Obtain 10 lbs of soil passing No. 4 sieve
2. Record the weight of the Proctor mold without the base and the (collar) extension, the volume of which is 1/30 ft^3.
3. Assemble the compaction apparatus.
4. Place the soil in the mold in 3 layers and compact using 25 well distributed blows of the Proctor hammer.
5. Detach the collar without disturbing the soil inside the mold
6. Remove the base and determine the weight of the mold and compacted soil.
7. Remove the compacted soil from the mold and take a sample (20-30 grams) of soil and find the moisture content
8. Place the remainder of the molded soil into the pan, break it down, and thoroughly remix it with the other soil, plus 100 additional grams of water.

Compaction - Procedure

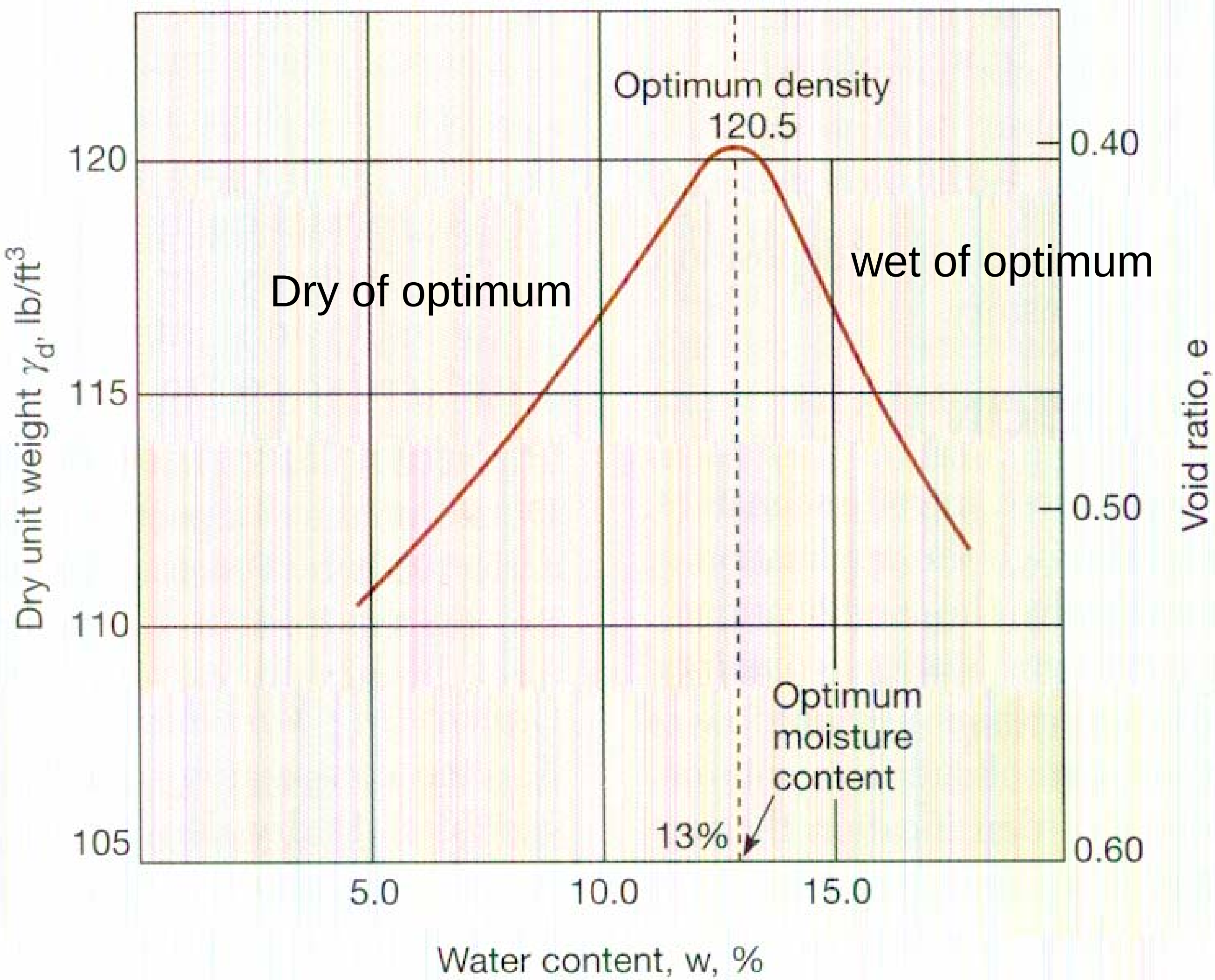
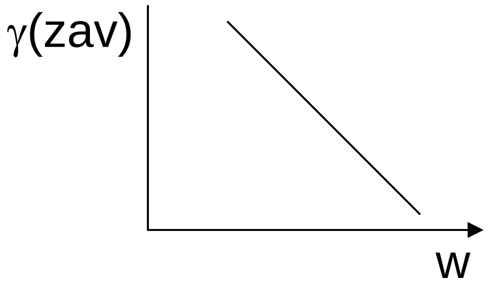


FIGURE 7.16 Standard Proctor compaction Curve.

Zero-air-void unit weight:

At certain water content, what is the unit weight to let no air in the voids

$$\gamma(z.a.v) = \frac{G_s \gamma_w}{1 + wG_s}$$

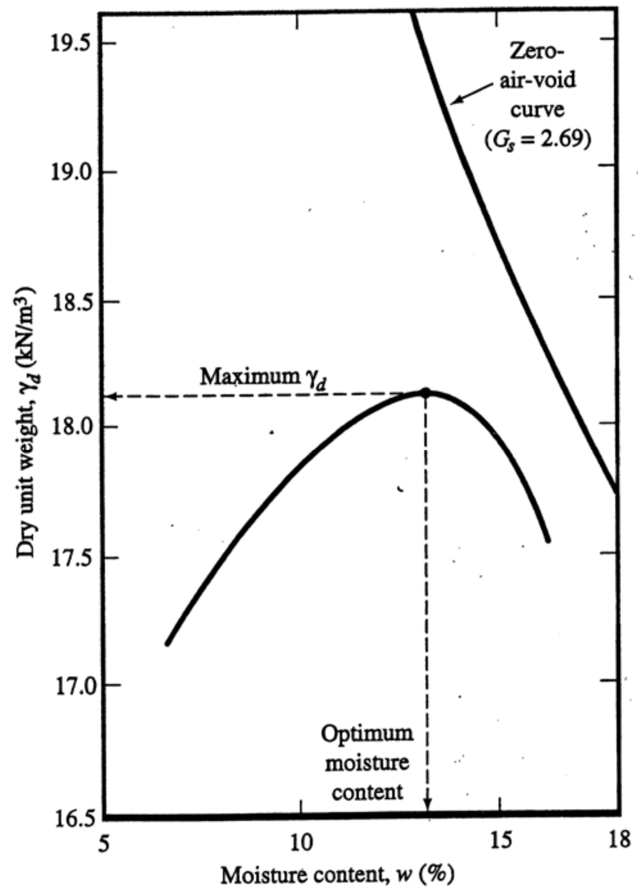


It is clear that in the above equation, specific gravity of the solid and the water density are constant, the zero-air-void density is inversely proportional to water content w. For a given soil and water content the best possible compaction is represented by the zero-air-voids curve. The actual compaction curve will always be below. For dry soils the unit weight increases as water is added to the soil because the water lubricates the particles making compaction easier. As more water is added and the water content is larger than the optimum value, the void spaces become filled with water so further compaction is not possible because water is a kind like incompressible fluid. This is illustrated by the shape of the zero-air-voids curve which decreases as water content increases.

Compaction Curve

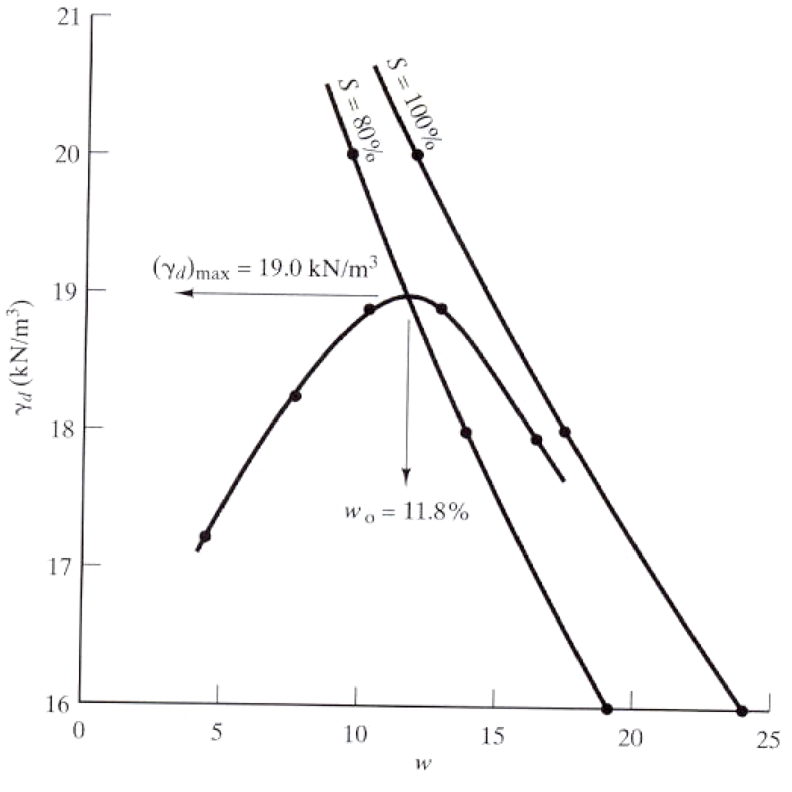
- Compaction curve plotted γ_d vs. w
- The peak of the curve is the Maximum Compaction ($\gamma_{d\ max}$) at Optimum Moisture Content (w_{opt})

$$\gamma_d = \frac{\gamma}{1 + \frac{w(\%)}{100}} \quad or \quad \gamma_d = \frac{G_s \gamma_w}{1+e}$$



Results

- Plot of dry unit weight vs moisture content
- Find $\gamma_{d\ (max)}$ and w_{opt}
- Plot Zero-Air-Void unit weight
  (only S=100%)



Example 5.1

The laboratory test data for a standard Proctor test are given below. Find the maximum dry unit weight and optimum moisture content.

Volume of Proctor mold (ft^3)	Weight of wet soil in mold (lb)	Moisture content (%)
$\frac{1}{30}$	3.88	12
$\frac{1}{30}$	4.09	14
$\frac{1}{30}$	4.23	16
$\frac{1}{30}$	4.28	18
$\frac{1}{30}$	4.24	20
$\frac{1}{30}$	4.19	22

Solution

The following table can now be prepared:

Volume, V (ft^3)	Weight of wet soil, W (lb)	Moist unit weight, γ^a (lb/ft^3)	Moisture content, w (%)	Dry unit weight, $\gamma_d{}^b$ (lb/ft^3)
$\frac{1}{30}$	3.88	116.4	12	103.9
$\frac{1}{30}$	4.09	122.7	14	107.6
$\frac{1}{30}$	4.23	126.9	16	109.4
$\frac{1}{30}$	4.28	128.4	18	108.8
$\frac{1}{30}$	4.24	127.2	20	106.0
$\frac{1}{30}$	4.19	125.7	22	103.0

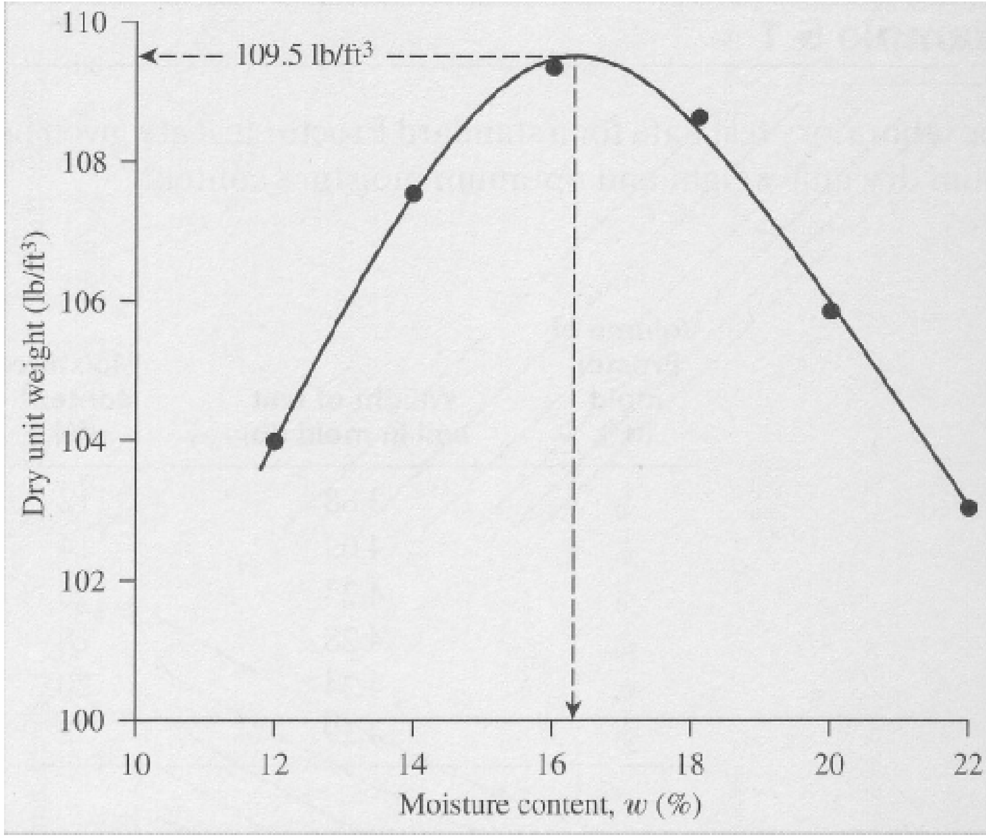
$^a\gamma = \frac{W}{V}$

$^b\gamma_d = \frac{\gamma}{1 + \frac{w\%}{100}}$

The plot of γ_d against w is shown in Figure 5.12. From the graph

Maximum dry unit weight = **109.5 lb/ft³**

Optimum moisture content = **16.3%**.

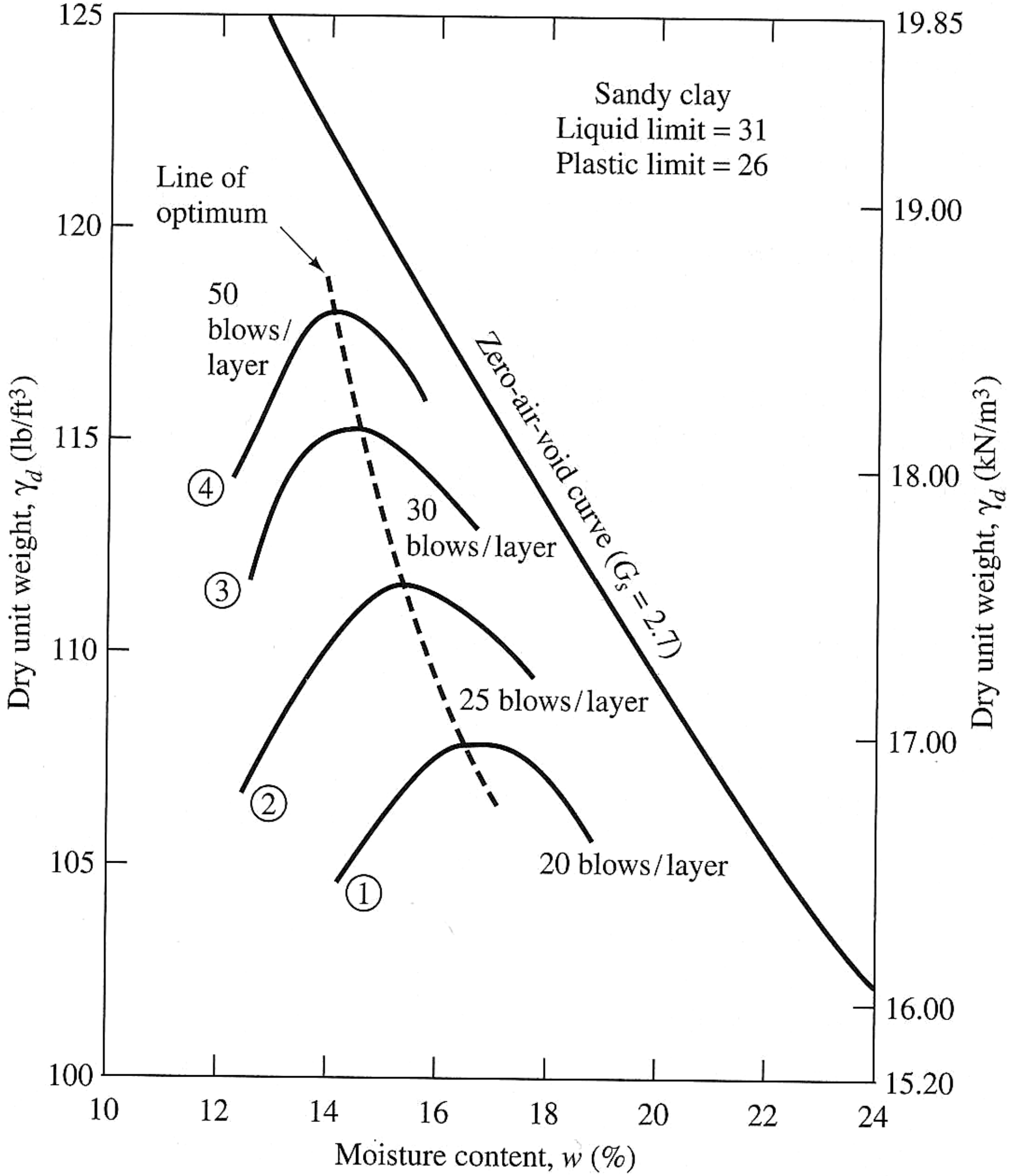


Das, Example 5.1

Effect of Compaction Energy

- With the development of heavy rollers and their uses in field compaction, the Standard Proctor Test was modified to better represent field compaction
- As the compaction effort increases,
  - the maximum dry unit weight of compaction increase
  - The optimum moisture content decreases to some extend
- Compaction energy per unit volume

Effect of Compaction Energy (Cont.)



Modified Proctor Test

- The modified was developed to simulate larger compaction effort for more serious loads and bigger equipment
- ASTM D 698
- Modified Proctor
  - 1/30 ft^3 mold
  - 10 lb hammer
  - 18" drop
  - 5 layers of soil
  - 25 blows / layer

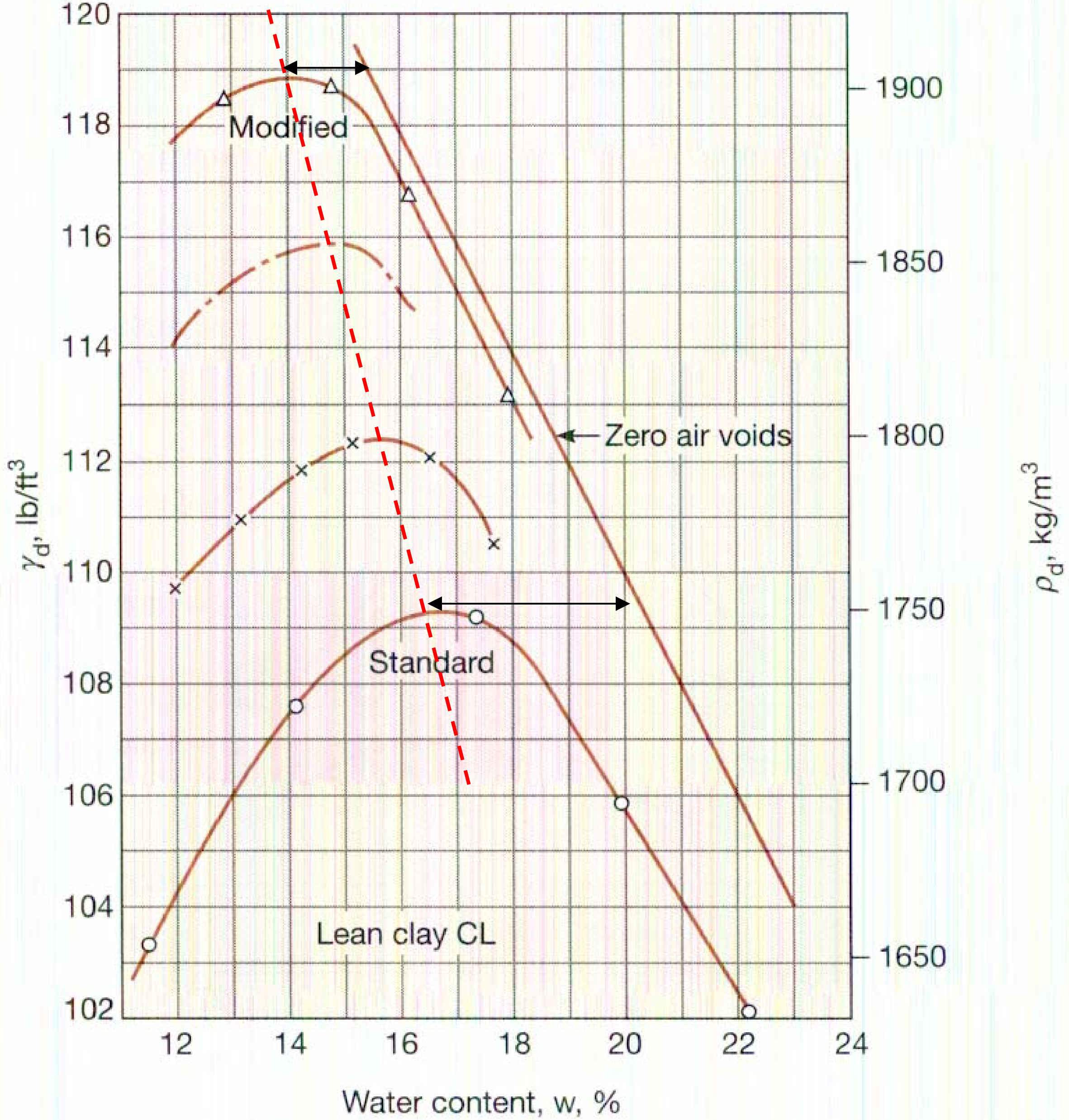
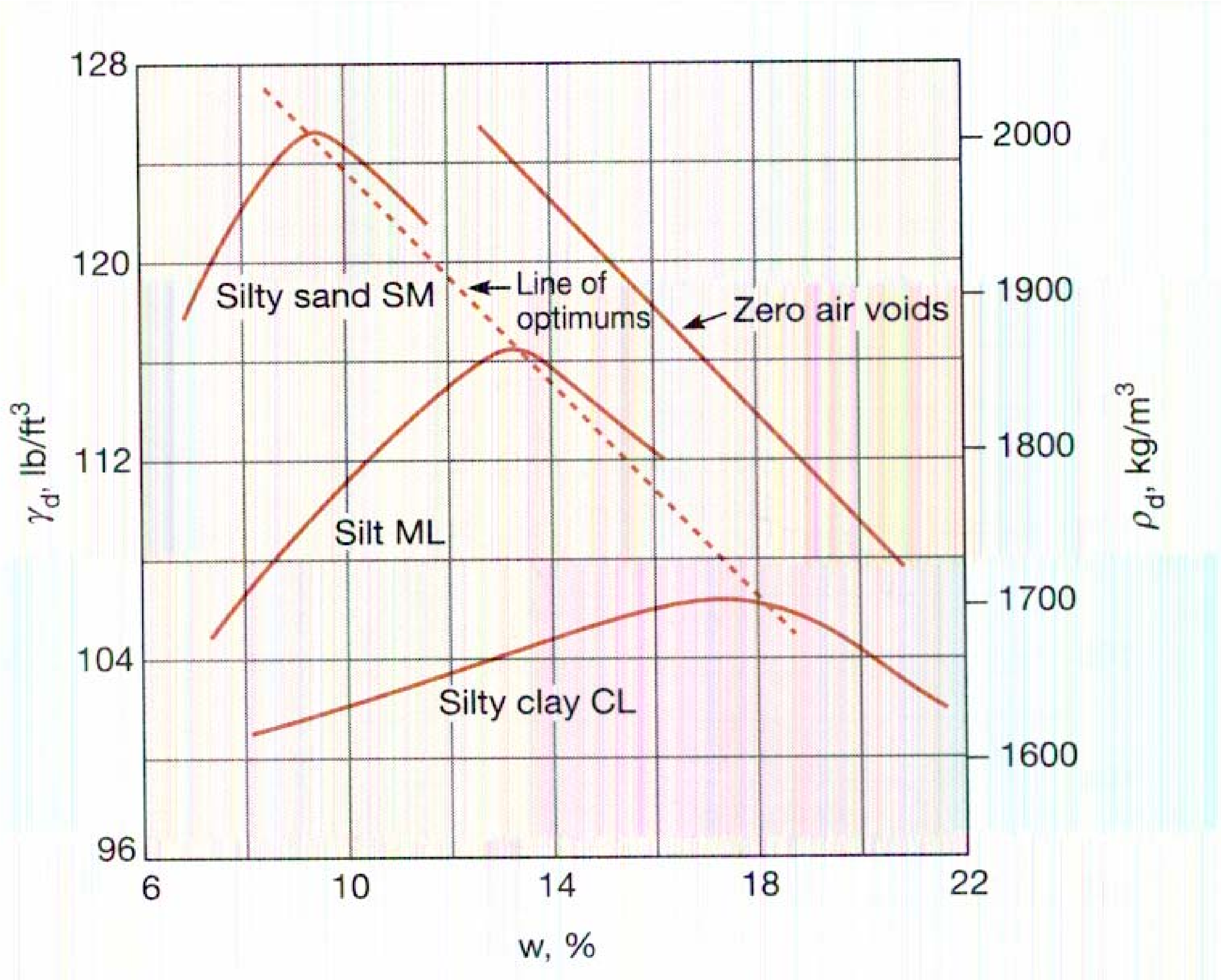


FIGURE 7.17 Modified and standard Proctor compaction Curves.

Effect of Soil type and gradation

- **fine grain soil needs more water to reach optimum; and**
- **coarse grain soil needs less water to reach optimum.**



Compaction curves for different soils with the same compact effort (West, Figure 7.19); fine grain soil needs more water to reach optimum and coarse grain soil needs less water to reach optimum.

The empirical relationship between the optimum moisture content and the plastic limit PL

More recently, Gurtug and Sridharan (2004) proposed correlations for optimum moisture content and maximum dry unit weight with the plastic limit (PL) of cohesive soils. These correlations can be expressed as:

$$w_{\text{opt}}(\%) = [1.95 - 0.38(\log CE)](PL) \tag{5.7a}$$

$$\gamma_{d(\max)}\,(\text{kN/m}^3) = 22.68e^{-0.0183 w_{\text{opt}}(\%)} \tag{5.7b}$$

where PL = plastic limit (%)
CE = compaction energy (kN-m/m^3)

For modified Proctor test, $CE = 2700$ kN/m^3. Hence,

$$w_{\text{opt}}(\%) \approx 0.65(PL)$$

and

$$\gamma_{d(\max)}\,(\text{kN/m}^3) \approx 22.68e^{-0.012(PL)}$$

Das, p118

Summary

Now we can make another description of compaction in the engineering sense:

Compaction is for making the optimum density as close as the zero-air-void as possible

Also we can conclude that more compaction effort make the optimum density closed to ρ(zav) by the fact of the 2 linear lines have different slopes.

Reading assignment:

Ch. 5

Homework:

Problems 5.3, 5.5