University of Salahaddin – Erbil
College of Engineering

GROUND IMPROVEMENT TECHNIQUES

(Code:1144)

Ground Improvement - Compaction

Bologna System

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1. Introduction

The natural ground conditions at the site may not always be totally suitable for supporting the proposed structures, such as

- buildings,
- bridges,
- highways, and
- dams.

One or more of the subsoil layers can be problematic and require some improvement.

- Near the surface, it is possible to replace problematic soil with better-performing ones.
- An alternative is to modify this soil through a ground improvement technique, such as compaction.

When these soils are present at large depths, soil replacement or compaction may not be possible. Other techniques, such as

- vibroflotation,
- vertical drains,
- stabilization using additives,
- deep mixing, and
- stone columns,

can be used for such situations.

The common problems that are associated with poor ground conditions and that necessitate some form of soil improvement are as follows:

1. Low shear strength
2. Low stiffness
3. High permeability
4. High swell–shrink potential

- Loose granular soil or soft clays have low shear strength and low stiffness.
- Low shear strength can lead to shear failure in the surrounding soil, and
- low stiffness can result in large deformations or settlements.

While there are several ground improvement techniques, they have their limitations. Not all techniques will work well in all soil conditions.

5.2 General Principles of Compaction

- Compaction is the oldest and simplest ground improvement technique.
- The soil is densified by applying external pressure using rollers.
- Water is added to act as a lubricant between the soil grains and enhance the compaction process. The moisture content at which the *maximum dry unit weight* [$\gamma_{d(max)}$] is achieved is referred to as the *optimum moisture content* (ω_{opt}).
- Good geotechnical properties are achieved when the soil is compacted near ω_{opt}.
- The standard Proctor (ASTM D-698) and modified Proctor (ASTM D-1557) are two common test procedures that apply different levels of compaction energy.
- The specifications for the two tests are given in Tables 5.1 and 5.2,

TABLE 5.1 Specifications for Standard Proctor Test (Based on ASTM Designation 698)

Item	Method A	Method B	Method C
Diameter of mold	101.6 mm	101.6 mm	152.4 mm
Volume of mold	944 cm^3	944 cm^3	2124 cm^3
Mass (weight) of hammer	2.5 kg	2.5 kg	2.5 kg
Height of hammer drop	304.8 mm	304.8 mm	304.8 mm
Number of hammer blows per layer of soil	25	25	56
Number of layers of compaction	3	3	3
Energy of compaction	600 $kN \cdot m/m^3$	600 $kN \cdot m/m^3$	600 $kN \cdot m/m^3$
Soil to be used	Portion passing No. 4 (4.75-mm) sieve. May be used if 20% *or less* by weight of material is retained on No. 4 sieve.	Portion passing 9.5-mm sieve. May be used if soil retained on No. 4 sieve *is more than* 20% and 20% *or less* by weight is retained on 9.5-mm sieve.	Portion passing 19.0-mm sieve. May be used if *more than* 20% by weight of material is retained on 9.5 mm sieve and *less than* 30% by weight is retained on 19.00-mm sieve.

TABLE 5.2 Specifications for Modified Proctor Test (Based on ASTM Designation 1557)

Item	Method A	Method B	Method C
Diameter of mold	101.6 mm	101.6 mm	152.4 mm
Volume of mold	944 cm^3	944 cm^3	2124 cm^3
Mass (weight) of hammer	4.54 kg	4.54 kg	4.54 kg
Height of hammer drop	457.2 mm	457.2 mm	457.2 mm
Number of hammer blows per layer of soil	25	25	56
Number of layers of compaction	5	5	5
Energy of compaction	2700 $kN \cdot m/m^3$	2700 $kN \cdot m/m^3$	2700 $kN \cdot m/m^3$
Soil to be used	Portion passing No. 4 (4.75-mm) sieve. May be used if 20% *or less* by weight of material is retained on No. 4 sieve.	Portion passing 9.5-mm sieve. May be used if soil retained on No. 4 sieve *is more than* 20% and 20% *or less* by weight is retained on 9.5-mm sieve.	Portion passing 19.0-mm sieve. May be used if *more than* 20% by weight of material is retained on 9.5-mm sieve and *less than* 30% by weight is retained on 19-mm sieve.

Figure 5.1 shows a plot of γ_d against ω (%) for a clayey silt obtained from standard and modified Proctor tests (method A).

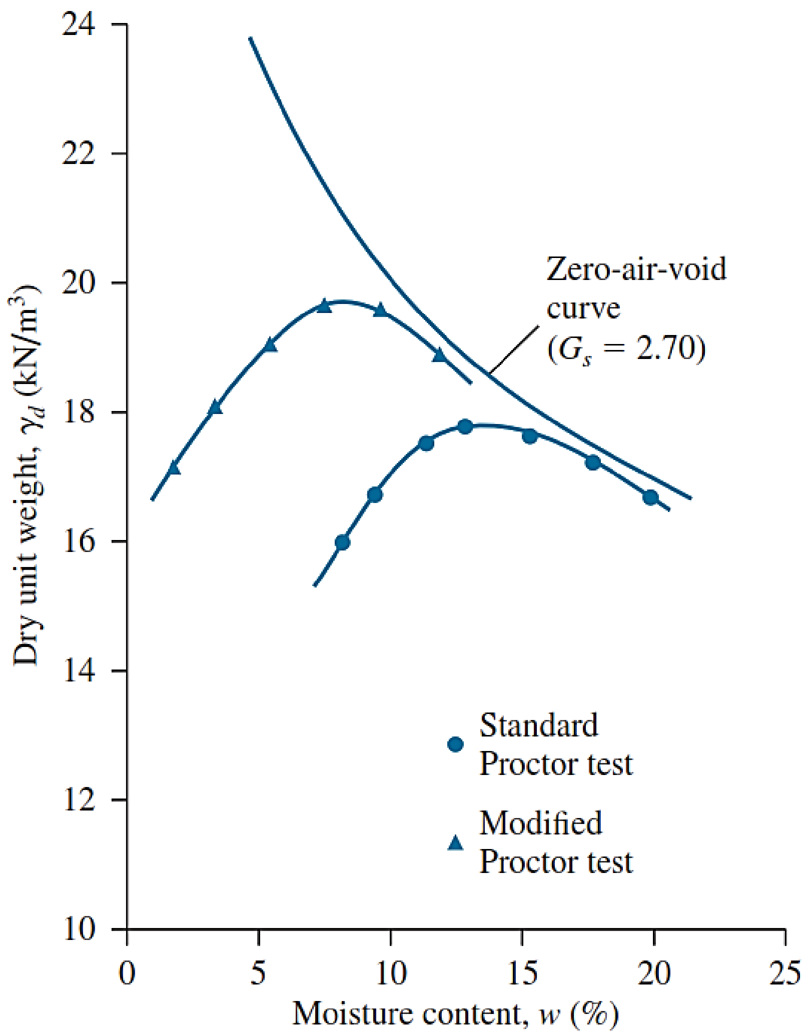

FIGURE 5.1 Standard and modified Proctor compaction curves for a clayey silt (method A)

The following conclusions may be drawn:

1. The $\gamma_{d(max)}$ and the ω_{opt} depend on the degree of compaction.

2. The higher the energy of compaction, the higher the $\gamma_{d(max)}$.
3. The higher the energy of compaction, the lower the ω_{opt}.
4. No portion of the compaction curve can lie to the right of the zero-air-void line. The zero-air-void dry unit weight, γ_{zav}, at a given moisture content is the theoretical maximum value of γ_d, which means that all the void spaces of the compacted soil are filled with water, or

$$\gamma_{zav} = \frac{\gamma_w}{\frac{1}{G_s} + \omega} \quad (5.1)$$

Where:
γ_w = unit weight of water
G_s = specific gravity of the soil solids
ω = moisture content of the soil

5. The $\gamma_{d(max)}$ of compaction and the ω_{opt} content will vary from soil to soil.

- In most cases, the contractor is required to achieve a relative compaction of 90% or more on the basis of a specific laboratory test (either the standard or the modified Proctor compaction test).
- These days, the modified Proctor compactive effort is specified more commonly
- Some typical requirements, as suggested by the U.S. Navy (1982) and Hausmann (1990), are summarized in Table 5.3

TABLE 5.3 Typical Compaction Requirements [Based on U.S. Navy (1982) and Hausmann (1990)]

Fill used for	% of $\gamma_{d(\max)}$ from modified Proctor	Moisture content range about optimum (%)
Roads:		
Depth of 0–0.5 m	90–105*	−2 to +2
Depth > 0.5 m	90–95*	−2 to +2
Small earth dam	90–95	−1 to +3
Large earth dam	95	−1 to +2
Railway embankment	95	−2 to +2
Foundation for structure	95	−2 to +2
Backfill behind walls/trenches	90	−2 to +2
Canal linings of clays	90	−2 to +2
Drainage blanket or filter	90	Thoroughly wet

*Depending on soil type, traffic, and function of the layer

- The relative compaction is defined as

$$RC = \frac{\gamma_{d(field)}}{\gamma_{d(max)}} \qquad (5.2)$$

Relative density (for the compaction of granular soil), defined as

$$D_r = \left[\frac{\gamma_d - \gamma_{d(min)}}{\gamma_{d(max)} - \gamma_{d(min)}}\right]\frac{\gamma_{d(max)}}{\gamma_d}$$

Where:

γ_d = dry unit weight of compaction in the field

$\gamma_{d(max)}$ = maximum dry unit weight of compaction as determined in the laboratory

$\gamma_{d(min)}$ = minimum dry unit weight of compaction as determined in the laboratory

- For granular soil in the field, the degree of compaction obtained is often measured in terms of relative density. Comparing the expressions for relative density and relative compaction reveals that

$$RC = \frac{A}{1 - D_r(1 - A)} \qquad (5.3)$$

Where $A = \frac{\gamma_{d(min)}}{\gamma_{d(max)}}$

Here it is assumed that $\gamma_{d(max)}$ determined from the compaction test (ASTM D-698 or D-1557) is the same as that determined in defining the densest state corresponding to e_{min} (ASTM D-4253). Because the procedures are different, the two values for $\gamma_{d(max)}$ can be slightly different.