Lecture 4

Mechanical Modification

- **Shallow Compaction**
- **Deep Compaction**

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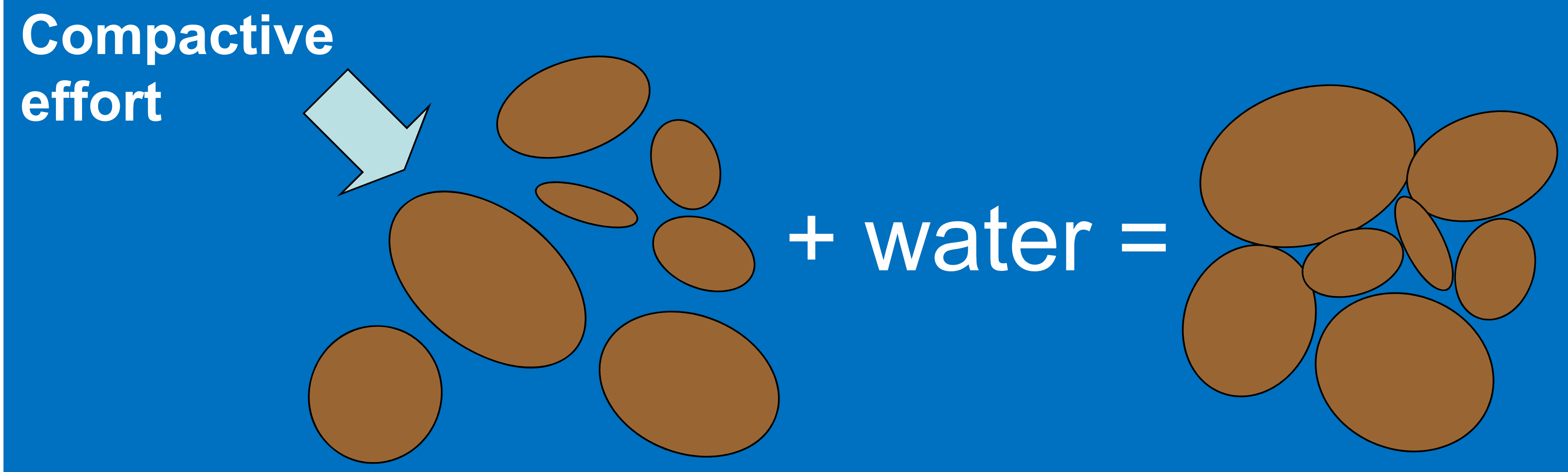
What is compaction?

A simple ground improvement technique, where the soil is densified through external compactive effort.



Advantages of Compaction

1. Increases shear strength
2. Reduces compressibility
3. Reduces permeability
4. Reduces liquefaction potential
5. Controls swelling and shrinking
6. Prolongs durability

Strategies for compaction process are

- In the case of constructed fills, specify placement conditions (water content, density,depth of layers, etc.)
- Select appropriate equipment (roller compactor, tamping) and method of operation (number of passes, patterns of tamping,etc.).
- Set up adequate control procedures (type and number of tests, statistical evaluation,etc.).

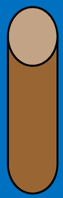
Detail	Standard compaction	Modified compaction
Mold volume, cm^3	1000	1000
Diameter,mm	105	105
Height,mm	115.5	115.5
Rammer diam,mm	50	50
Drop,mm	300	450
Mass,Kg	2.7	4.9
Number of blows	3	5
Blows /layer	25	25
Energy input, KJ/m^3	596	2703

Laboratory Compaction Test

- to obtain the compaction curve and define the optimum water content and maximum dry density for a specific compactive effort.

Standard Proctor:

- 3 layers
- 25 blows per layer
- 2.7 kg hammer
- 300 mm drop



hammer

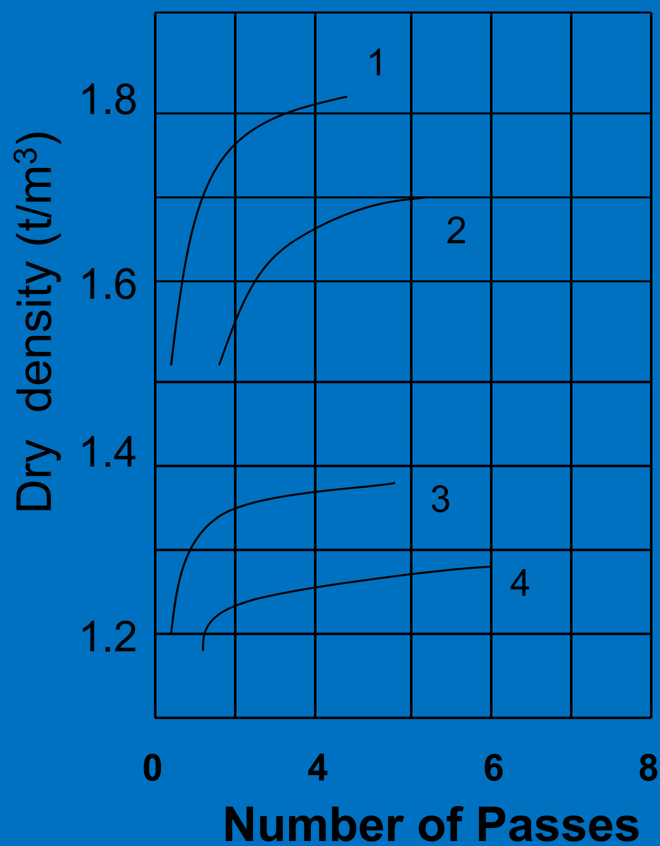
1000 ml compaction mould

Modified Proctor:

- 5 layers
- 25 blows per layer
- 4.9 kg hammer
- 450 mm drop

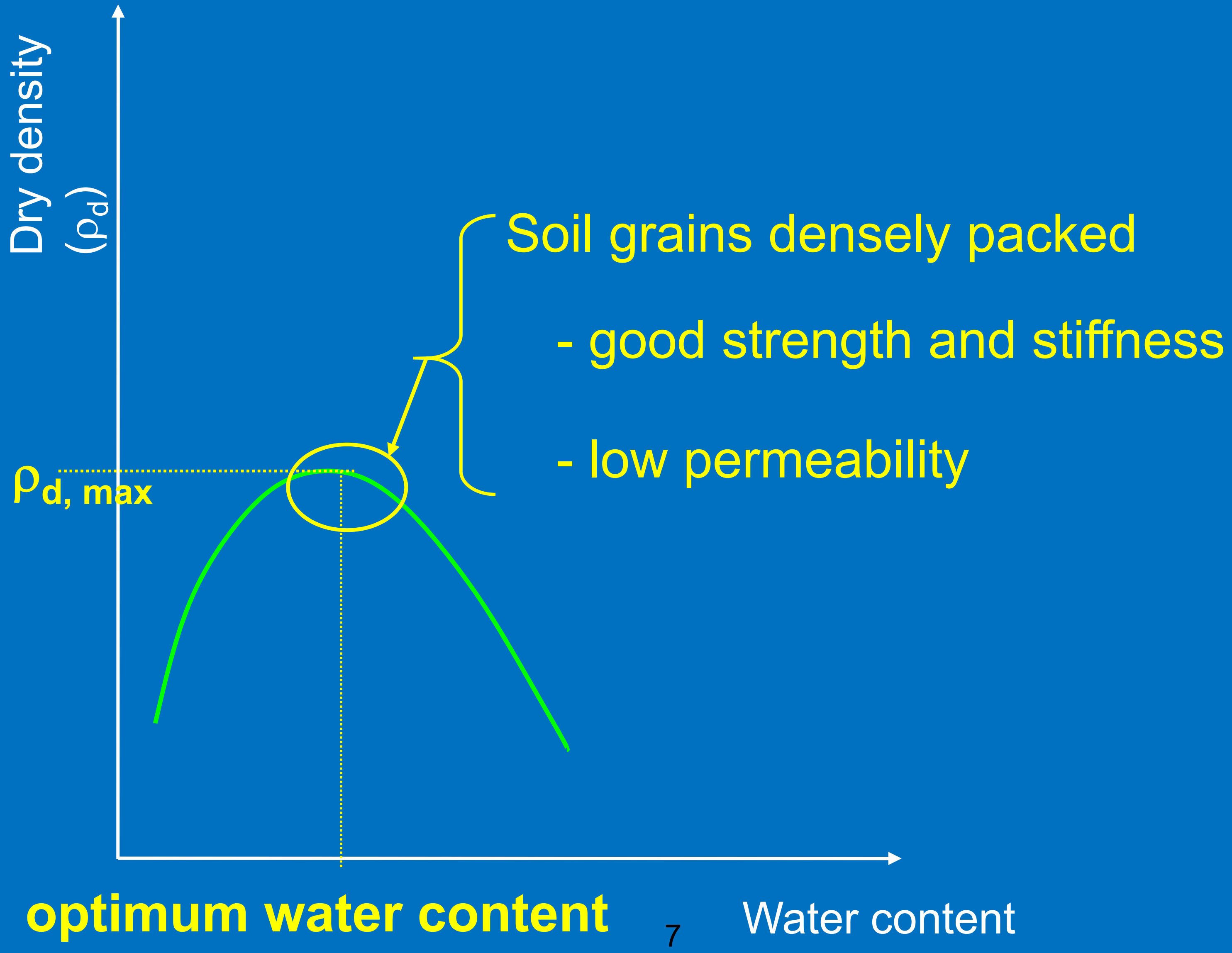
Operational aspects of shallow compaction:

- Operating frequency
- Number of passes
- Depth of layers.
- Compaction at Freezing temperatures.



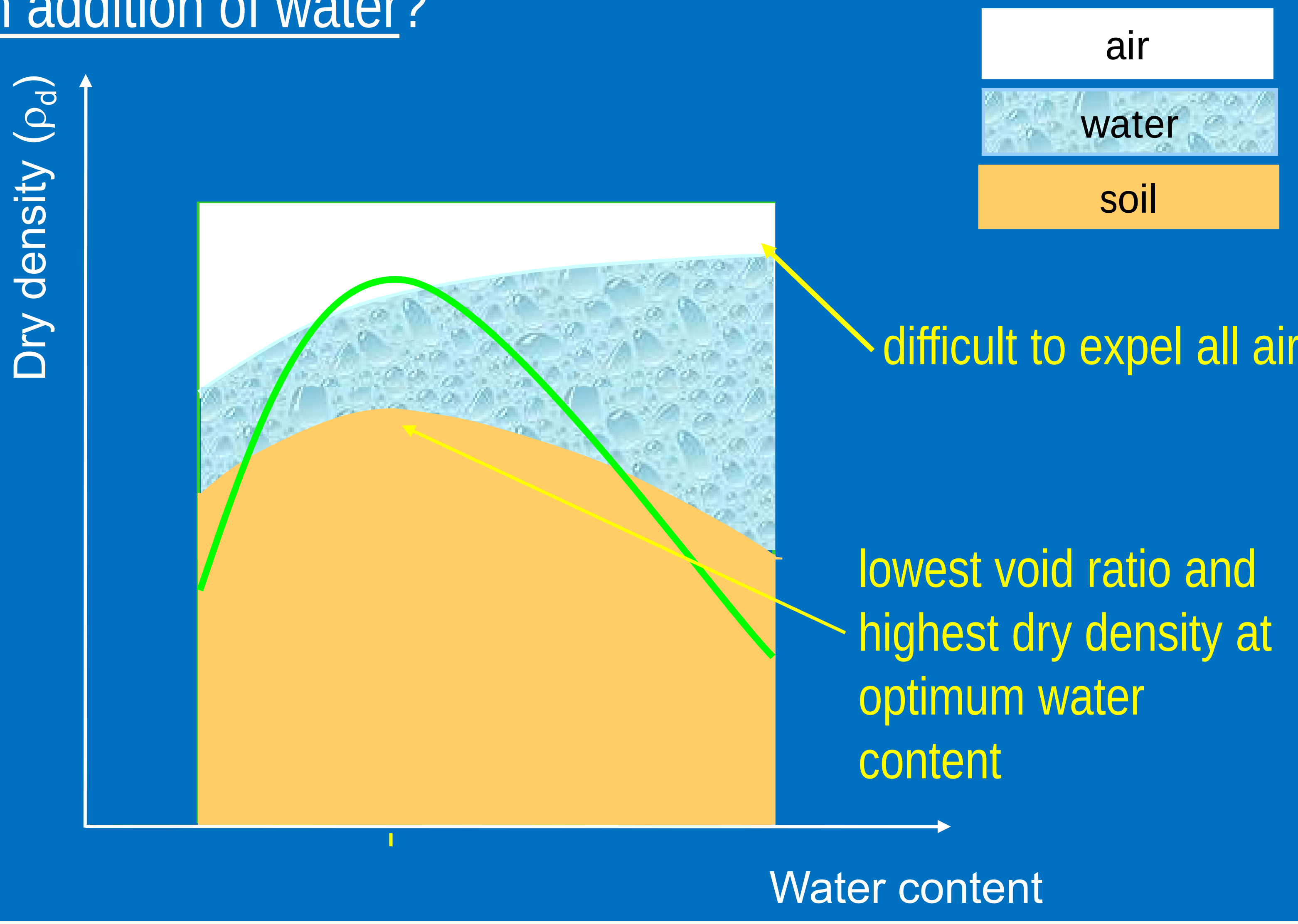
Relationship between number of passes of a roller and the density obtained.

Compaction Curve



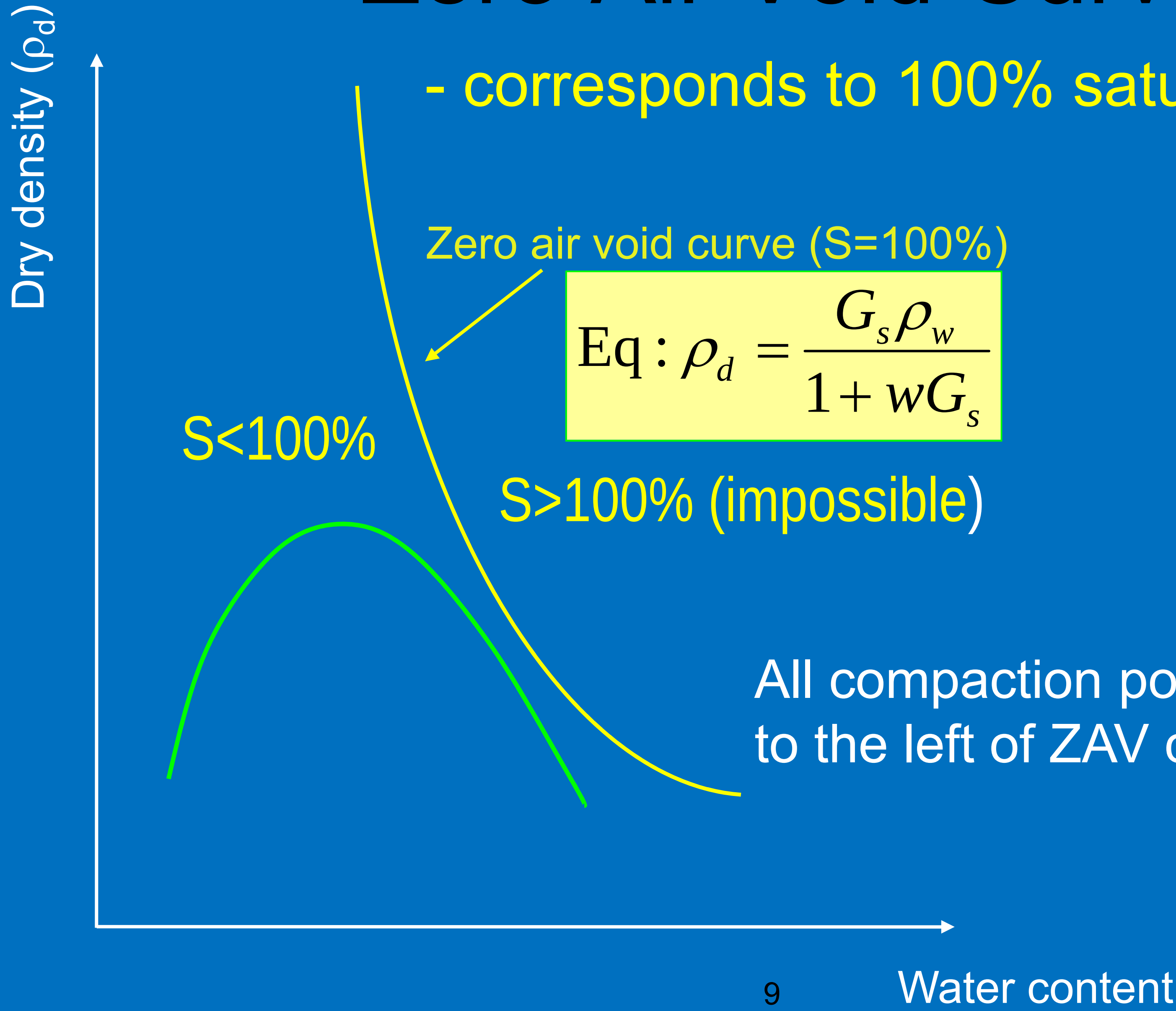
Compaction Curve

What happens to the relative quantities of the three phases with addition of water?



Zero Air Void Curve

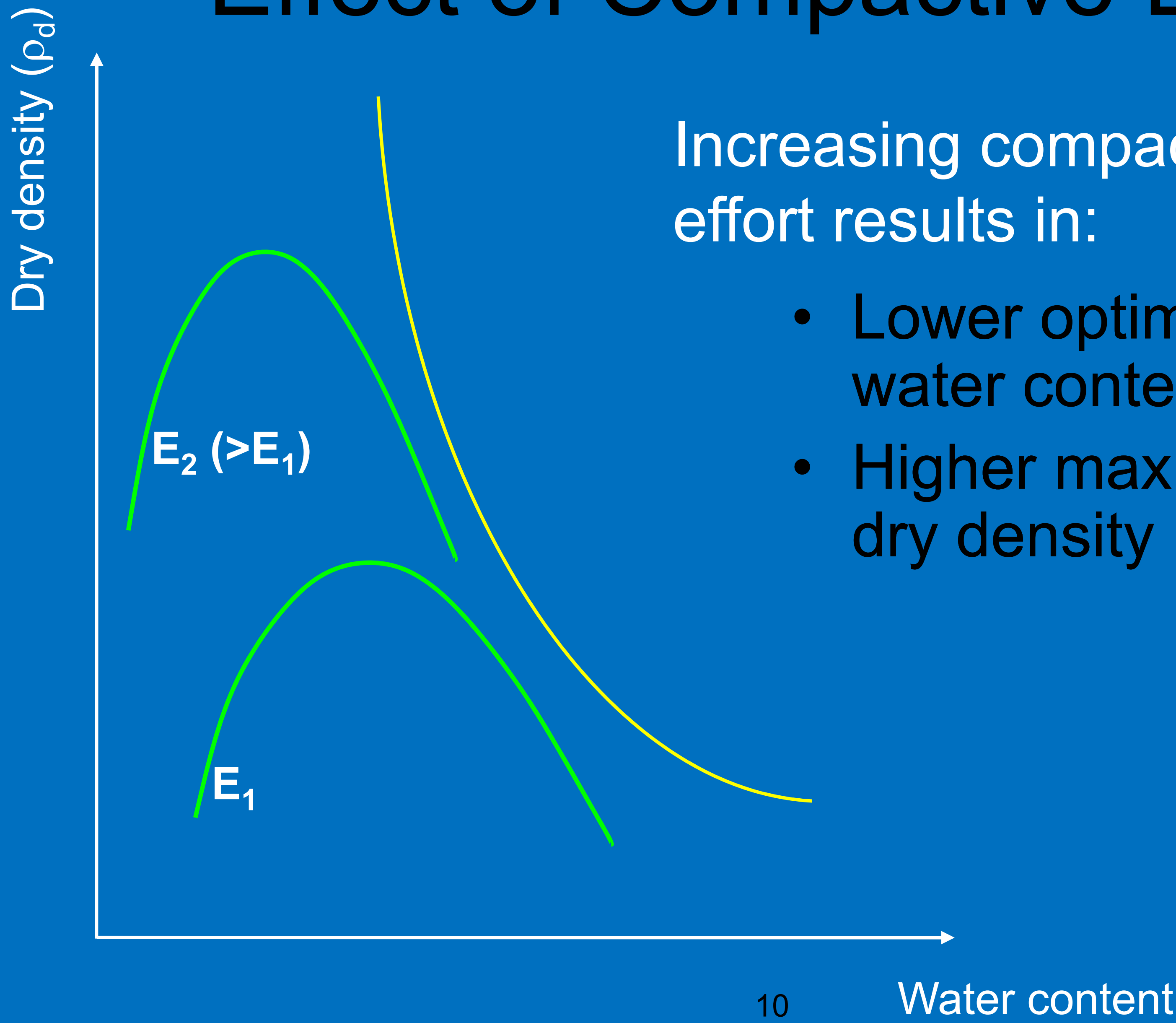
- corresponds to 100% saturation



$$\text{Eq}: \rho_d = \frac{G_s \rho_w}{1 + wG_s}$$

All compaction points should lie to the left of ZAV curve

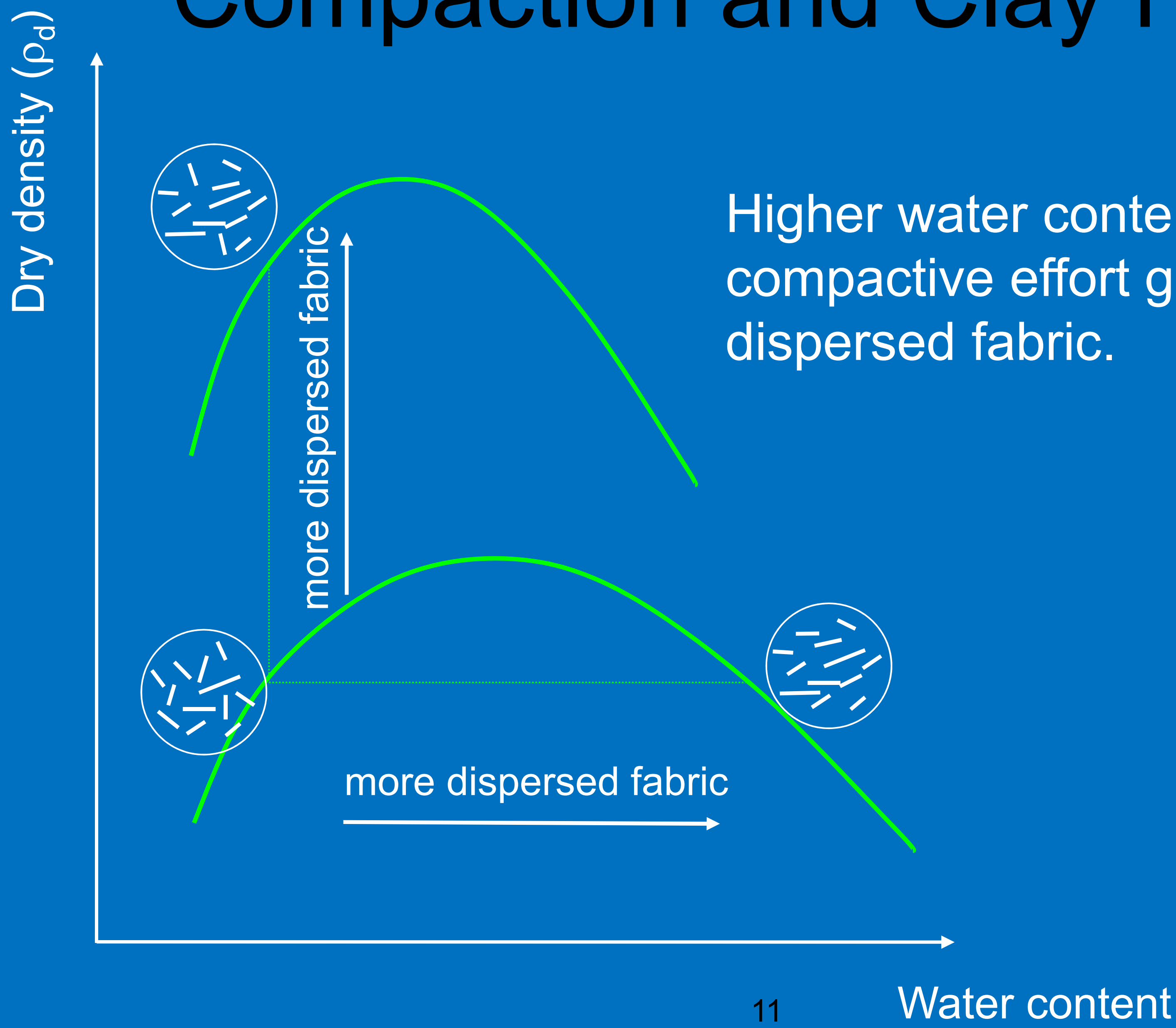
Effect of Compactive Effort



Increasing compactive effort results in:

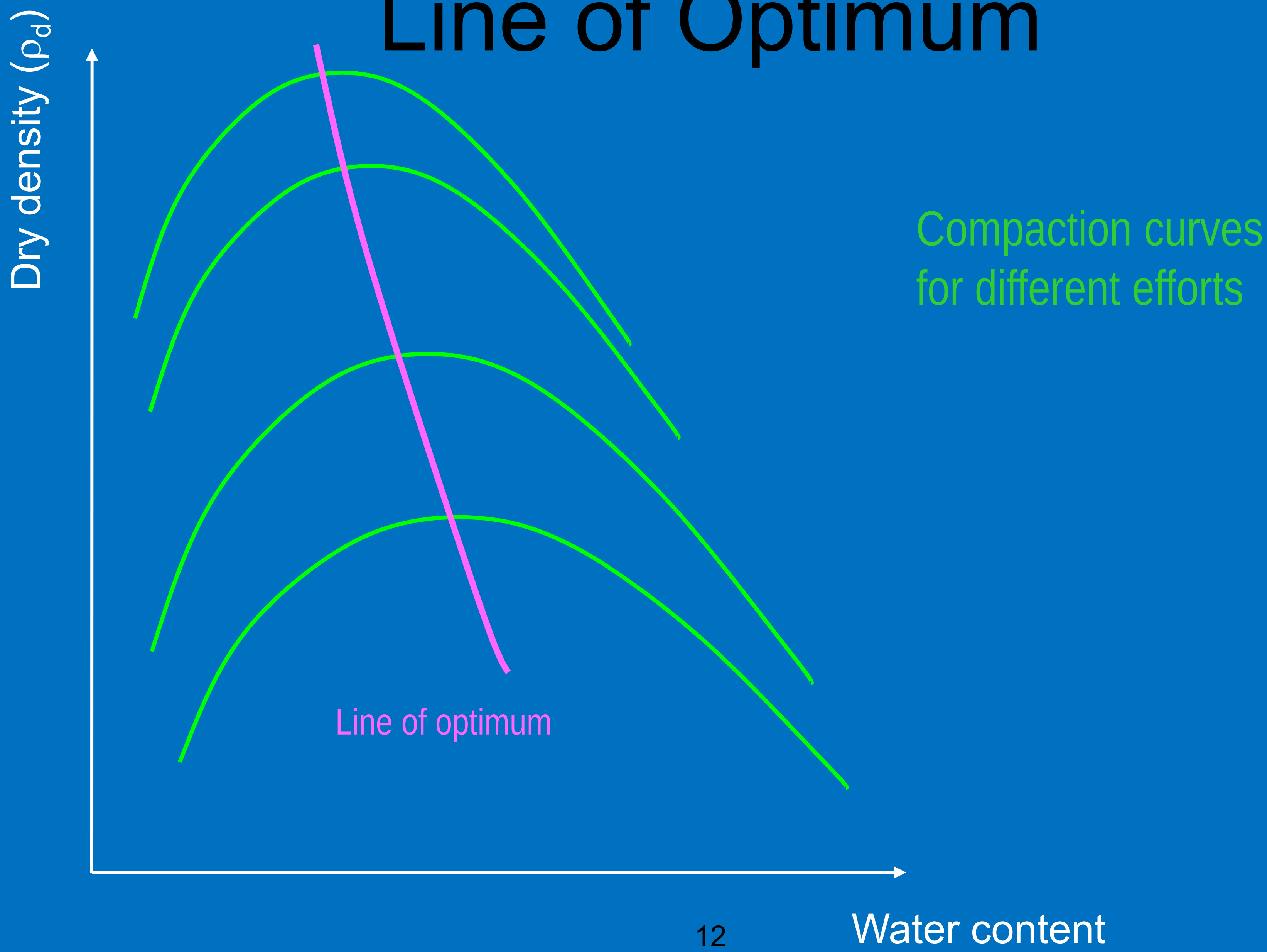
- Lower optimum water content
- Higher maximum dry density

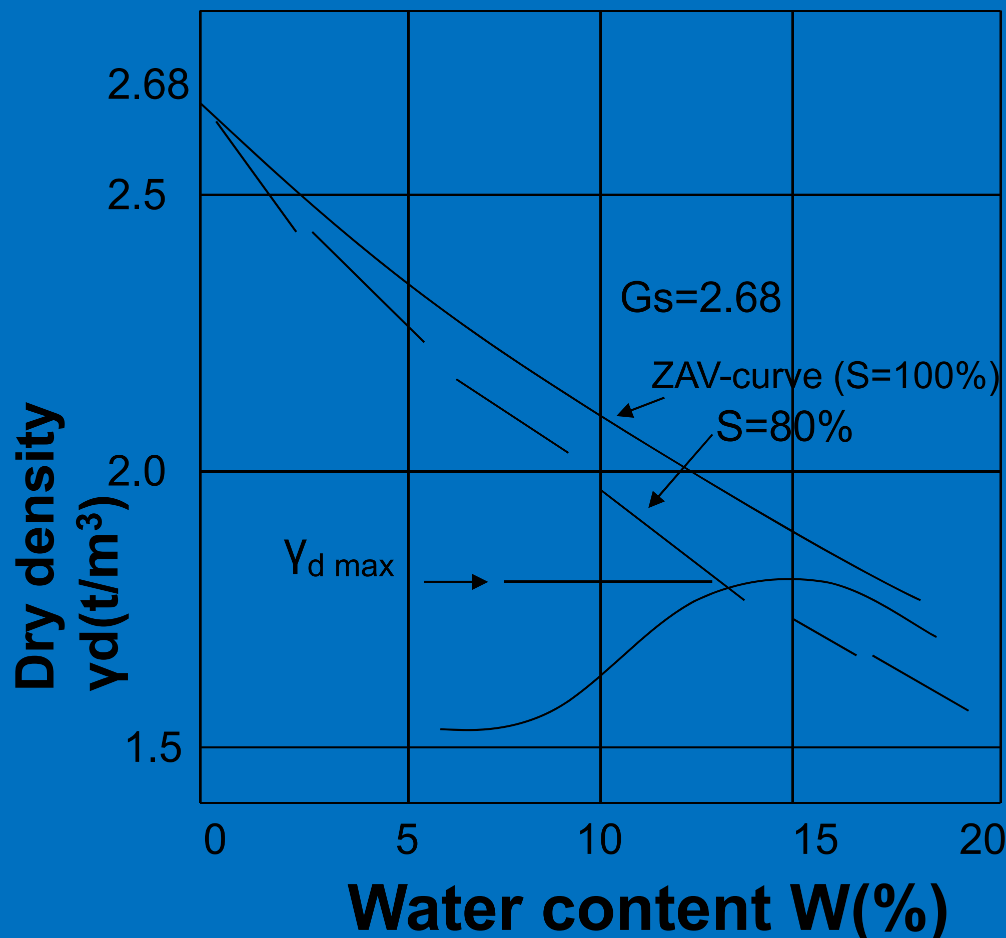
Compaction and Clay Fabric



Higher water content or higher compactive effort gives more dispersed fabric.

Line of Optimum





Dry density versus moisture content

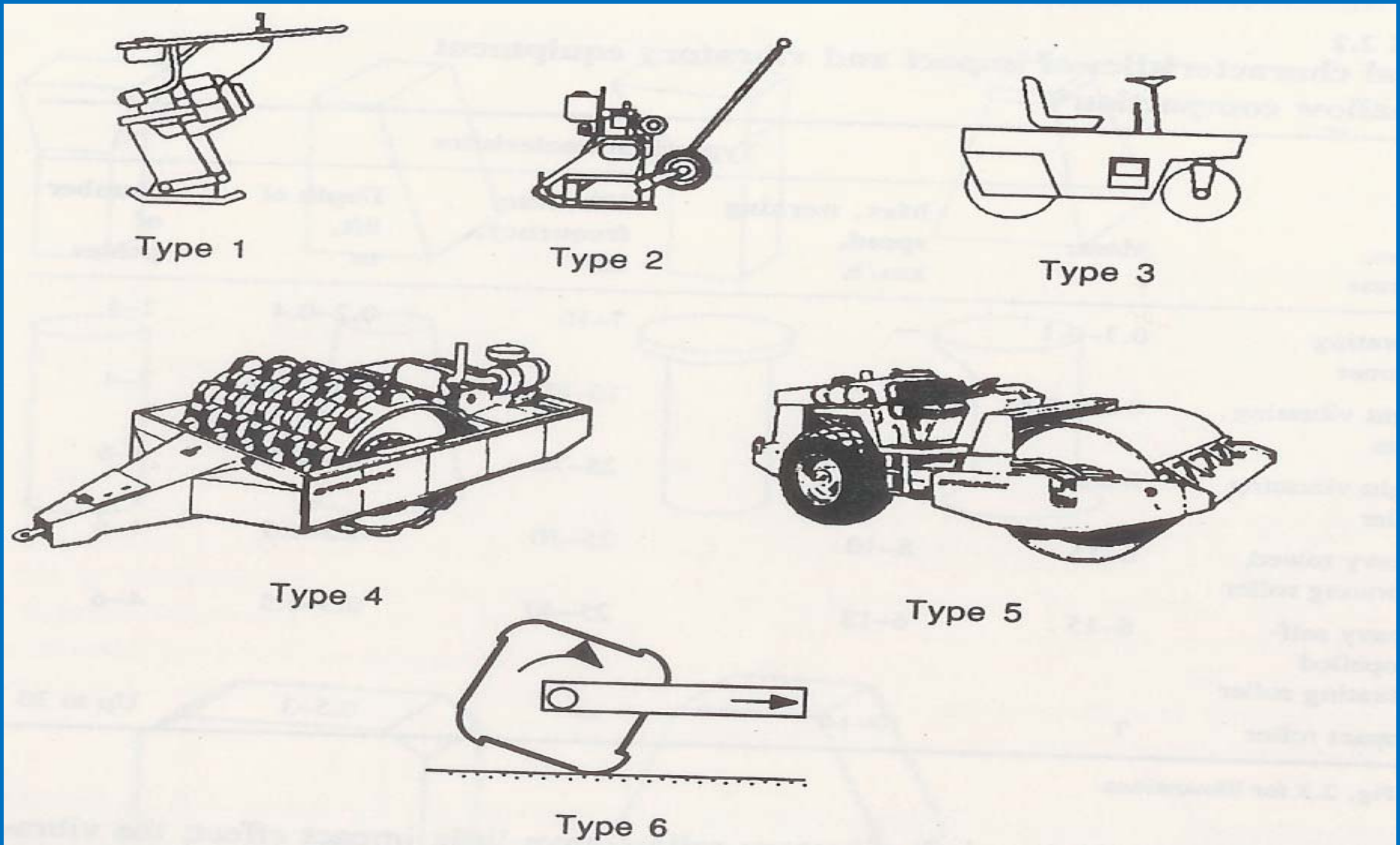
Shallow Surface Compaction:

Static rollers:

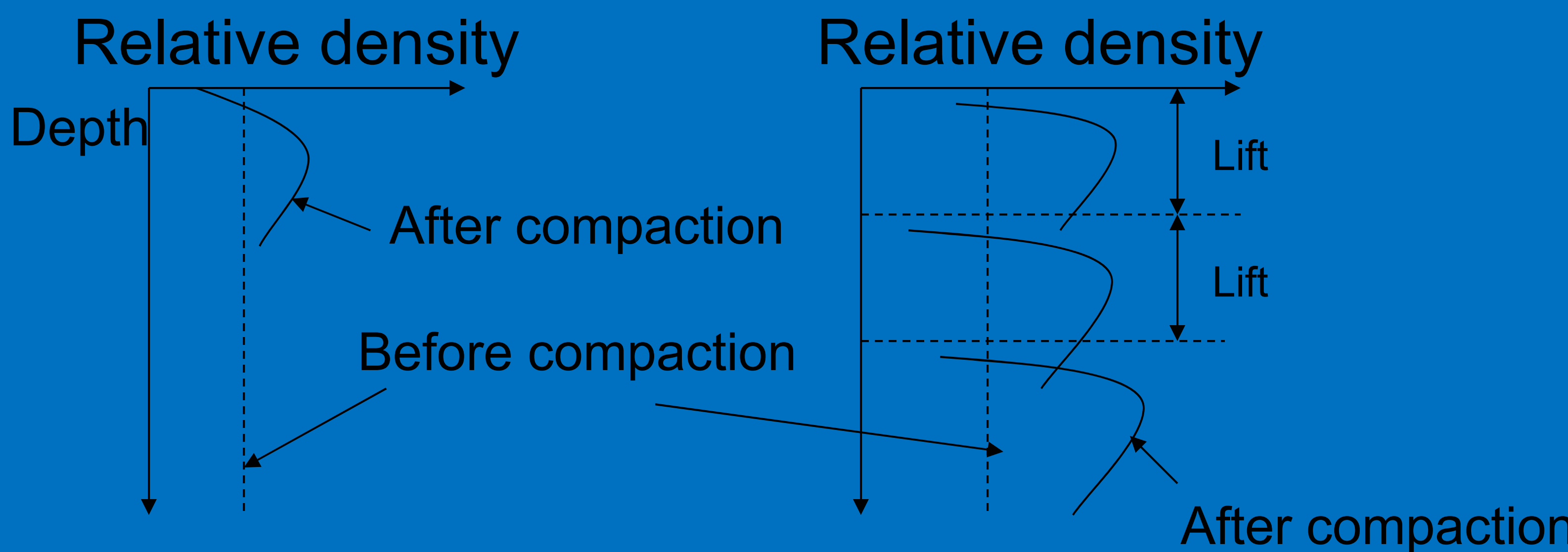
- Smooth steel rollers and pneumatic rollers.
- Sheepsfoot rollers.
- Grid rollers.

Impact and vibratory equipment:

- Tampers,rammers and plate compactors
- Vibrating rollers.
- Impact rollers.



Vibratory and impact compactors for shallow compaction.



One lift **Several lifts**

showing density in sand before and after compaction

Table showing typical characteristics of impact and vibratory equipment for shallow compaction:

Type no. and Name	Mass,t	Max.speed, Km/hr	Vibrating frequency, HZ	Depth of lift,m	Number of passes
1.Vibrating rammer	0.3-0.1	-	7-10	0.2-0.4	2-4
2.Light vibrating plate	0.06-0.8	1	10-80	0.15-0.5	2.-4
3.Light vibrating roller	0.6-2	2-4	25-70	0.3-0.5	4-6
4.Heavy towed roller	6-15	8-10	25-30	0.3-1.5	4-6
5.Heavy self propelled roller	6-15	6-13	25-40	0.3-1.5	4-6
6.Impact roller	7	10-14	-	0.5-3	Up to 30

Field Compaction

Different types of rollers (clockwise from right):

- Smooth-wheel roller
- Vibratory roller
- Pneumatic rubber tired roller
- Sheepsfoot roller

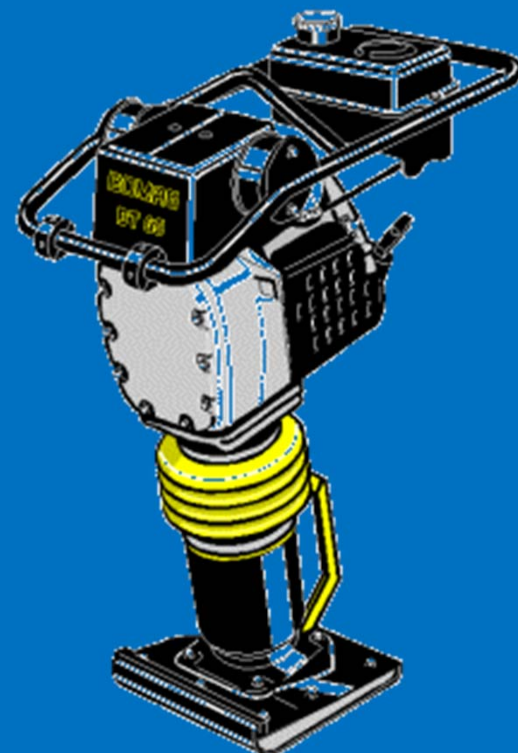
Field Compaction

Smooth Wheeled Roller

Compacts effectively only to 200-300 mm; therefore, place the soil in shallow layers (lifts)

Field Compaction

Vibrating Plates



- for compacting very small areas
- effective for granular soils

Field Compaction

Sheepsfoot Roller

- Provides kneading action; “walks out” after compaction
- Very effective on clays

Field Compaction

Impact Roller

- Provides deeper (2-3m) compaction. e.g., air field

Compaction Control

-a systematic exercise where you check at regular intervals whether the compaction was done to specifications.

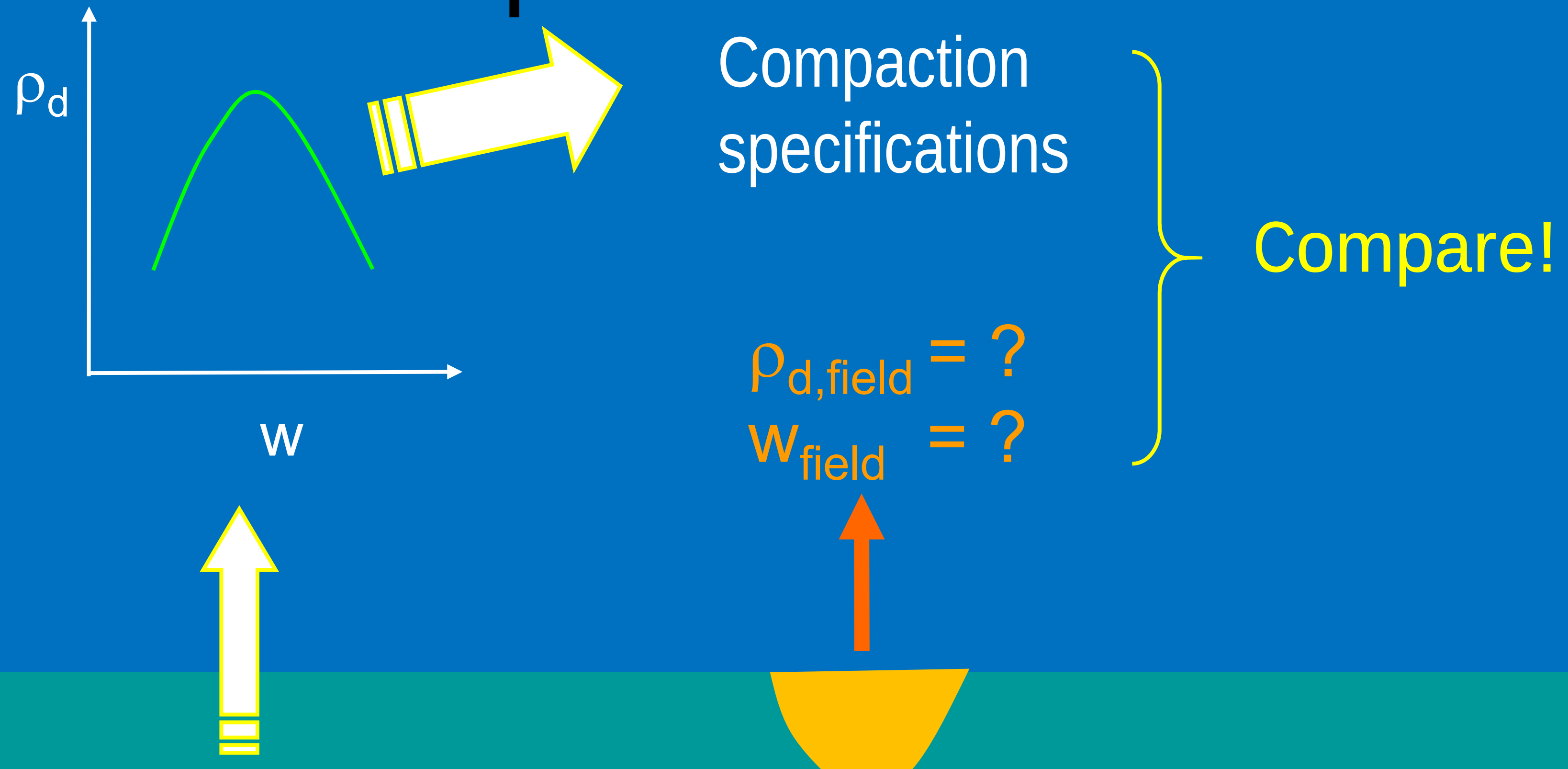
e.g., 1 test per 1000 m^3 of compacted soil

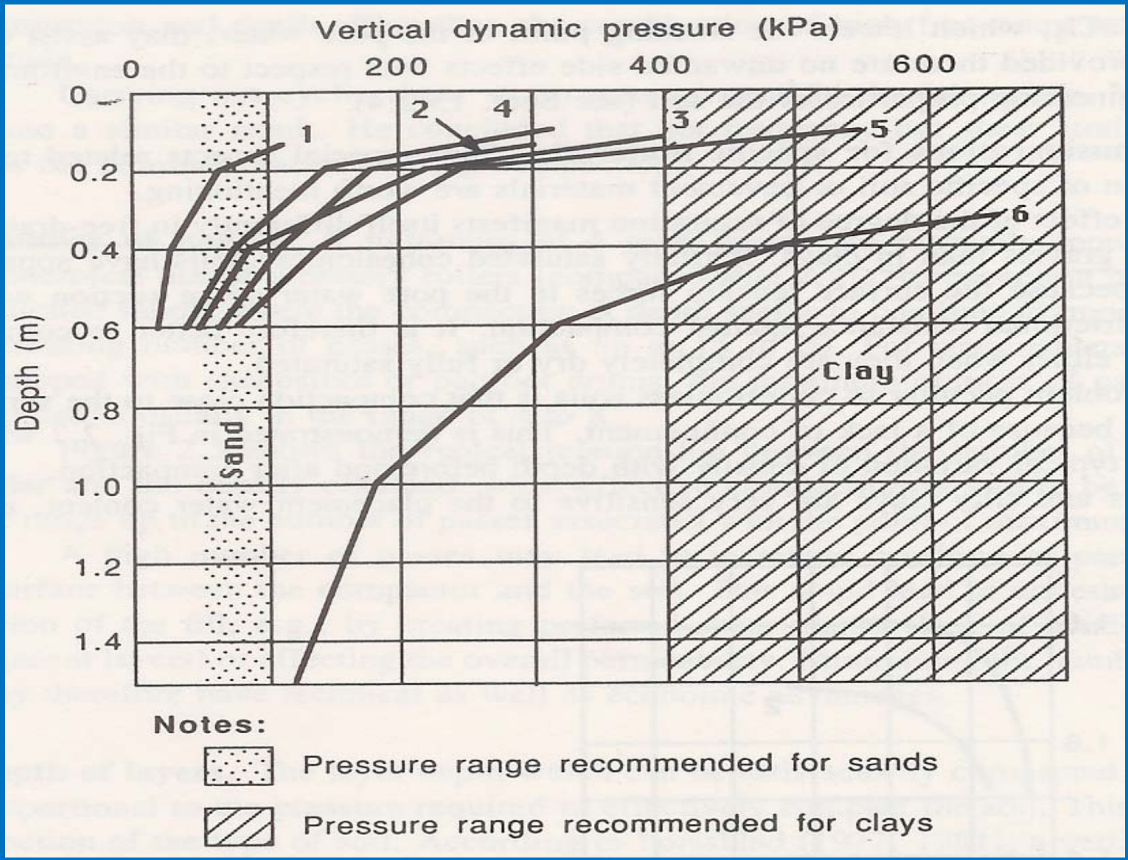
- Minimum dry density
- Range of water content

Field measurements (of ρ_d) obtained using

- **sand cone**
- **nuclear density meter**

Compaction Control Test





Dynamic pressures at various depths during compaction

PROPERTIES OF COMPACTED SOIL

Properties of Compacted Cohesive Soil

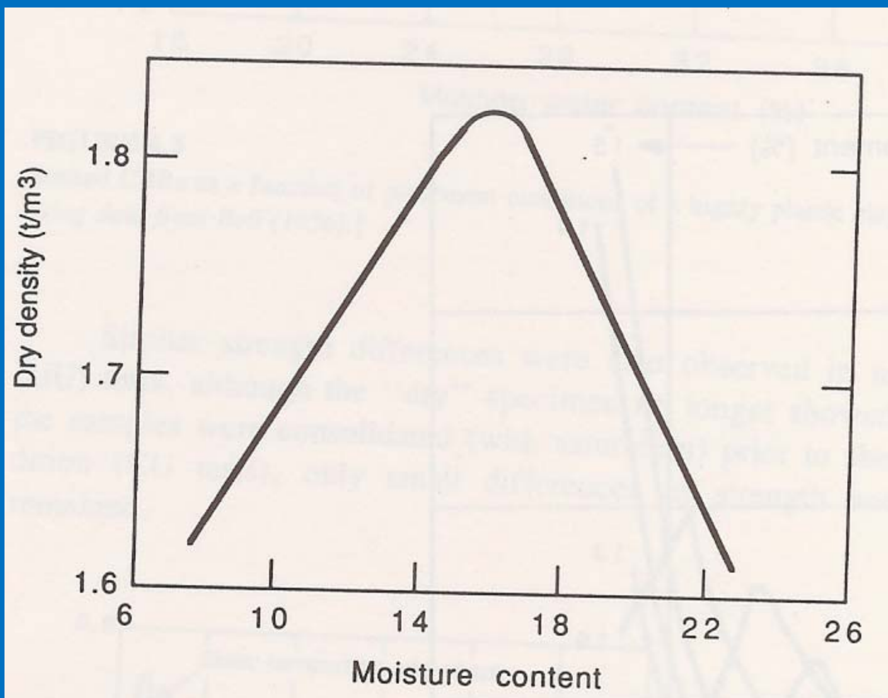
- **OMC increases and MDD decreases with increase in plasticity of soil**
- **Empirical relationships connecting the above to liquid limit, plastic limit are available in literature**

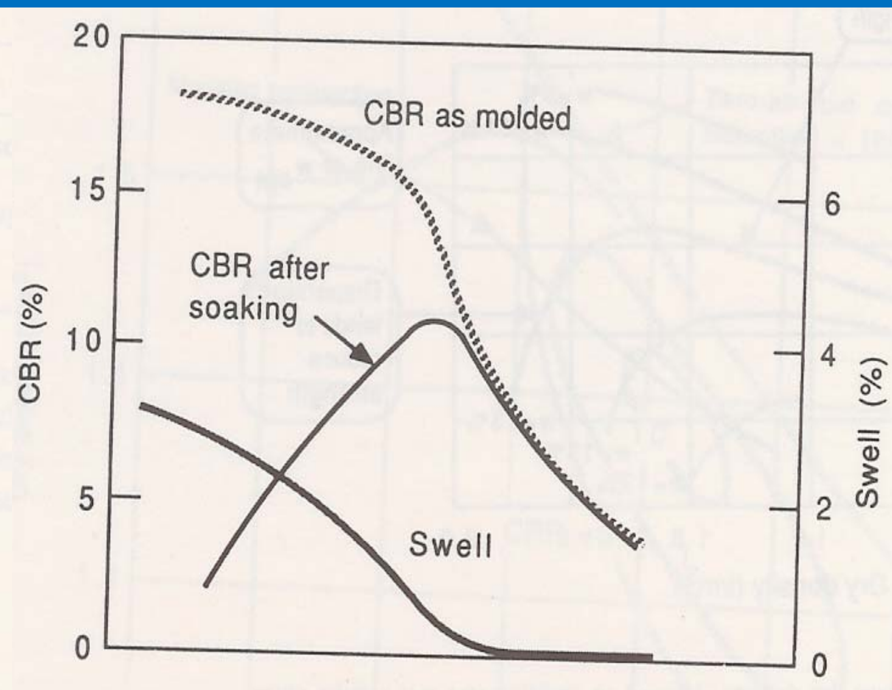
Properties of Compacted Cohesionless Soil

- **MDD is connected to the grain size distribution parameters**

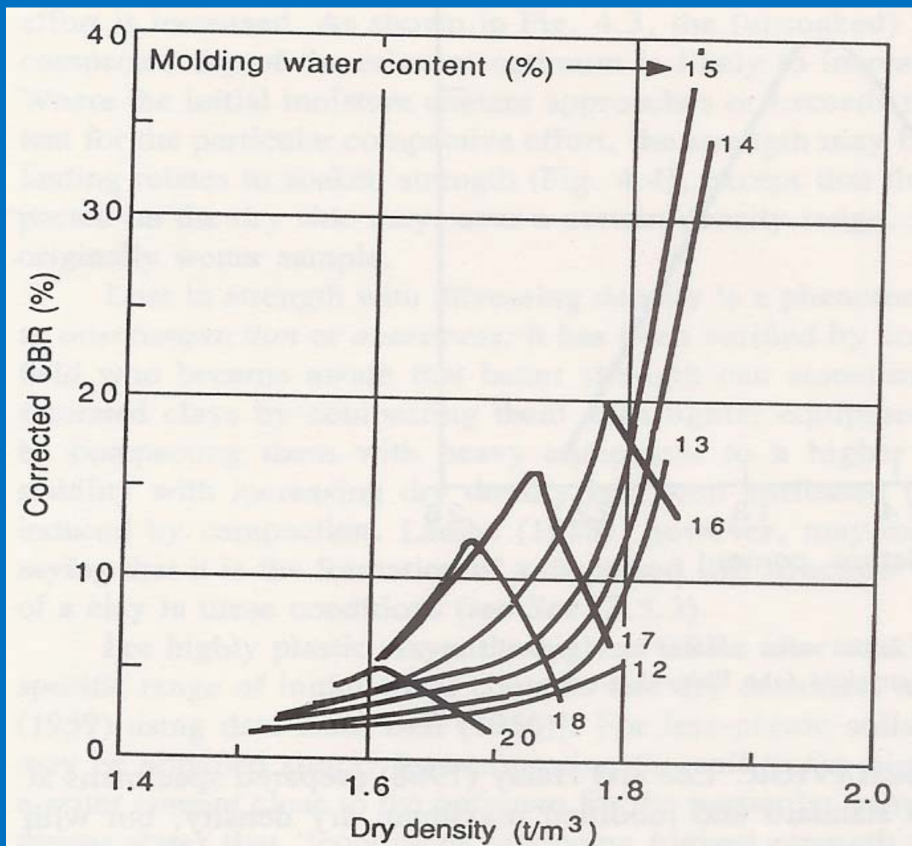
Properties of compacted cohesive soil

Strength of Cohesive Soil

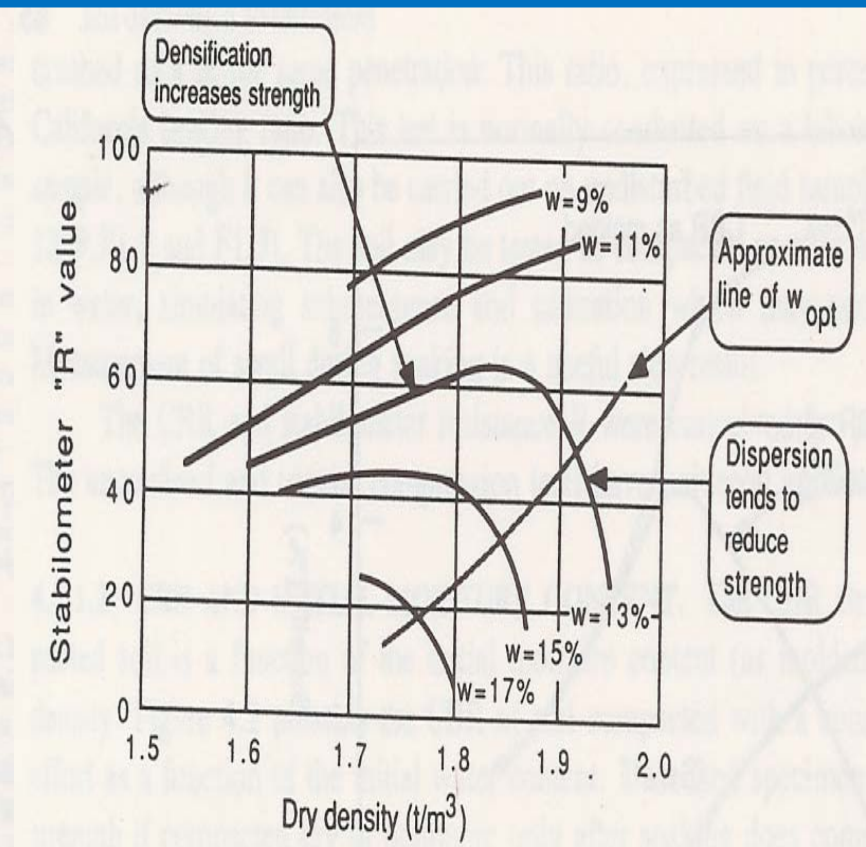




CBR as a function of initial water content for a typical silty clay

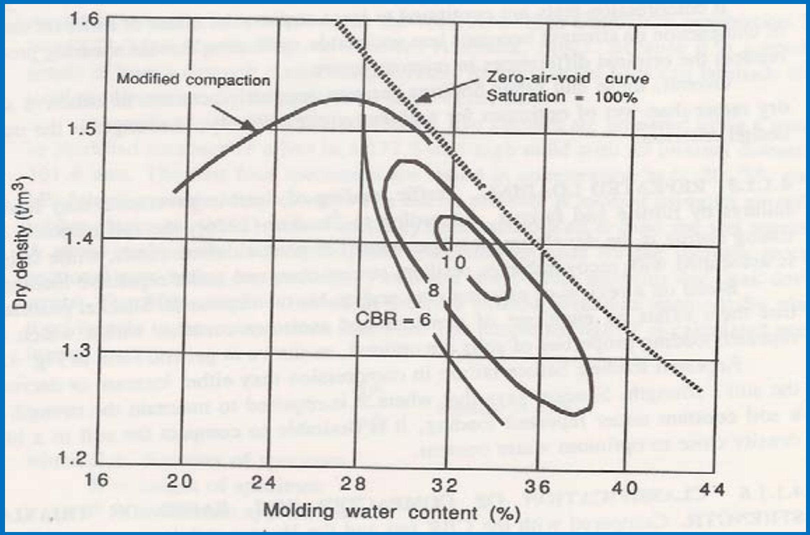


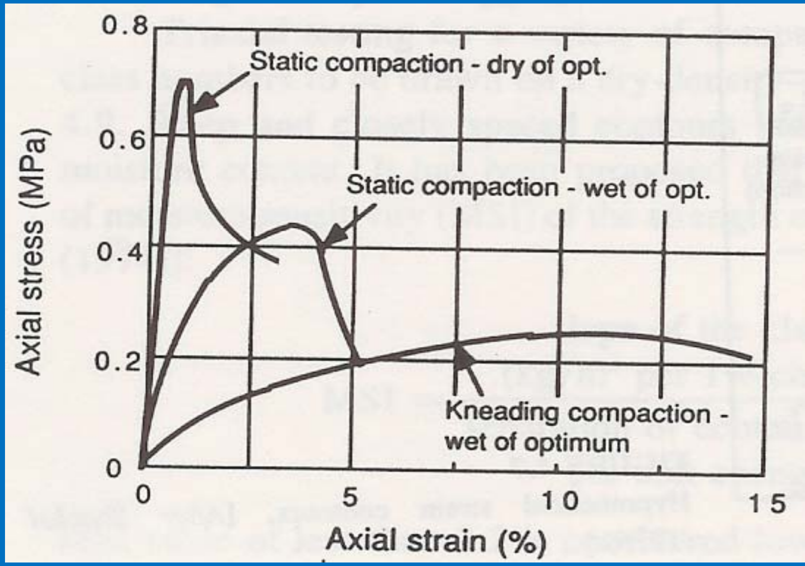
Molding water content (%)
Corrected CBR (%)
Dry density (t/m3)
40
30
20
10
0
1.4
1.6
1.8
2.0
15
14
13
16
17
12
18
20



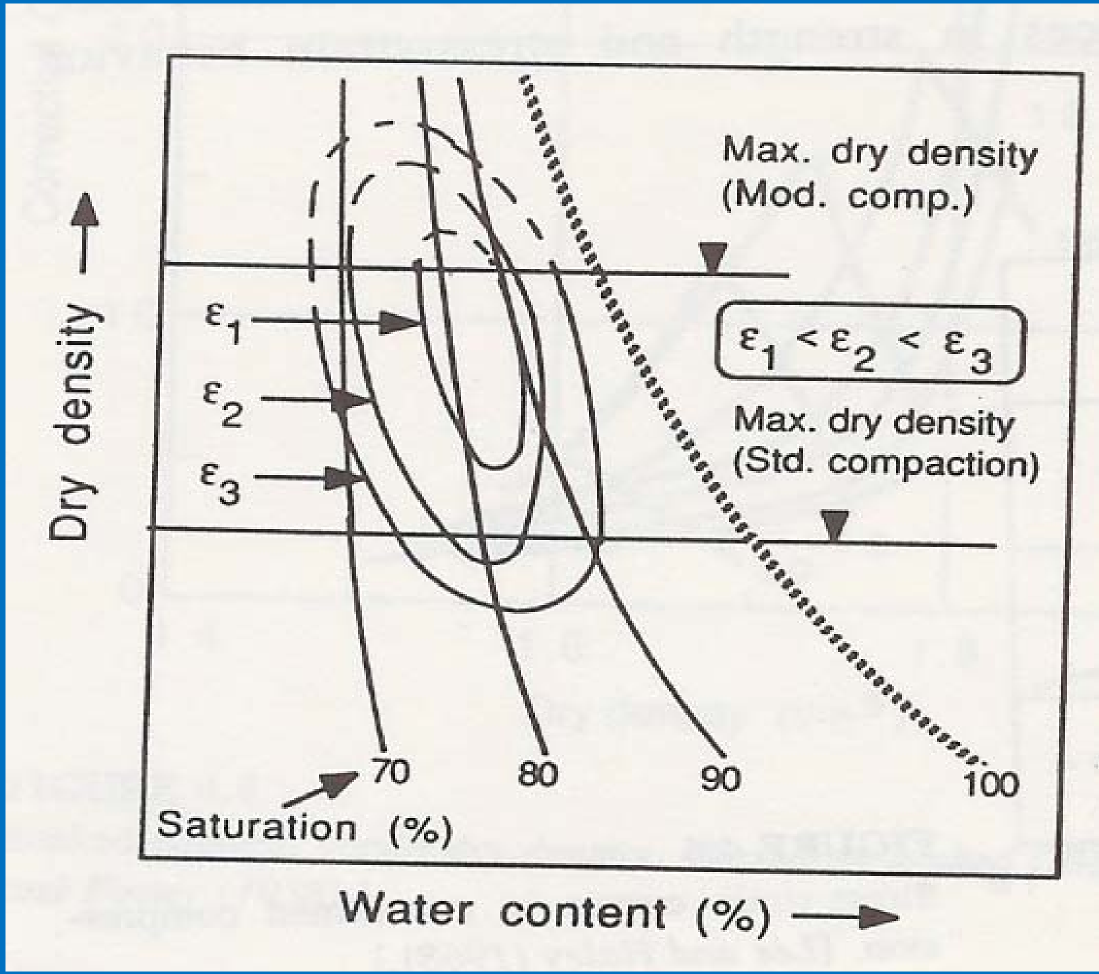
Densification increases strength
Approximate line of w opt
Dispersion tends to reduce strength
Stabilometer "R" value
Dry density (t/m3)
100
80
60
40
20
0
1.5
1.6
1.7
1.8
1.9
2.0
w=9%
w=11%
w=13%
w=15%
w=17%

Stress- Strain Behavior



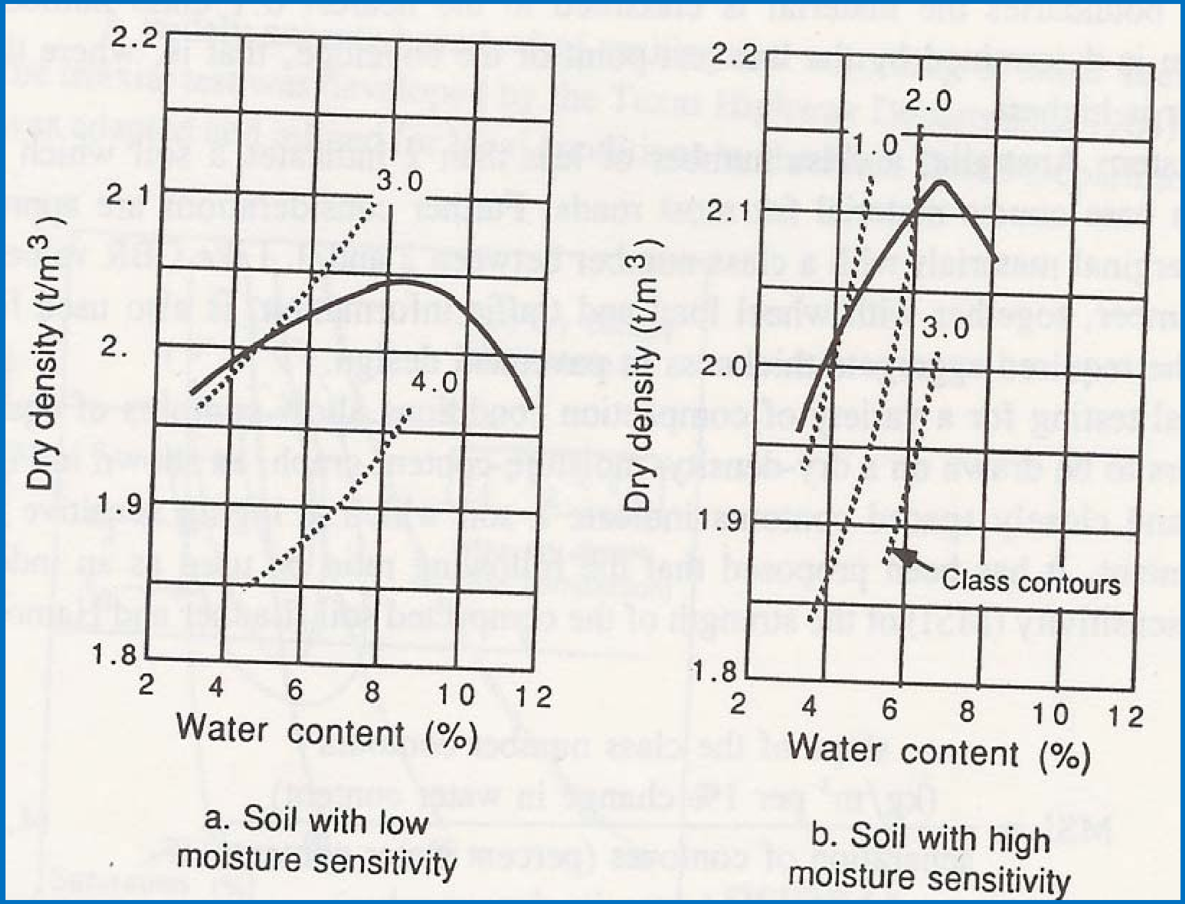


Repeated loading

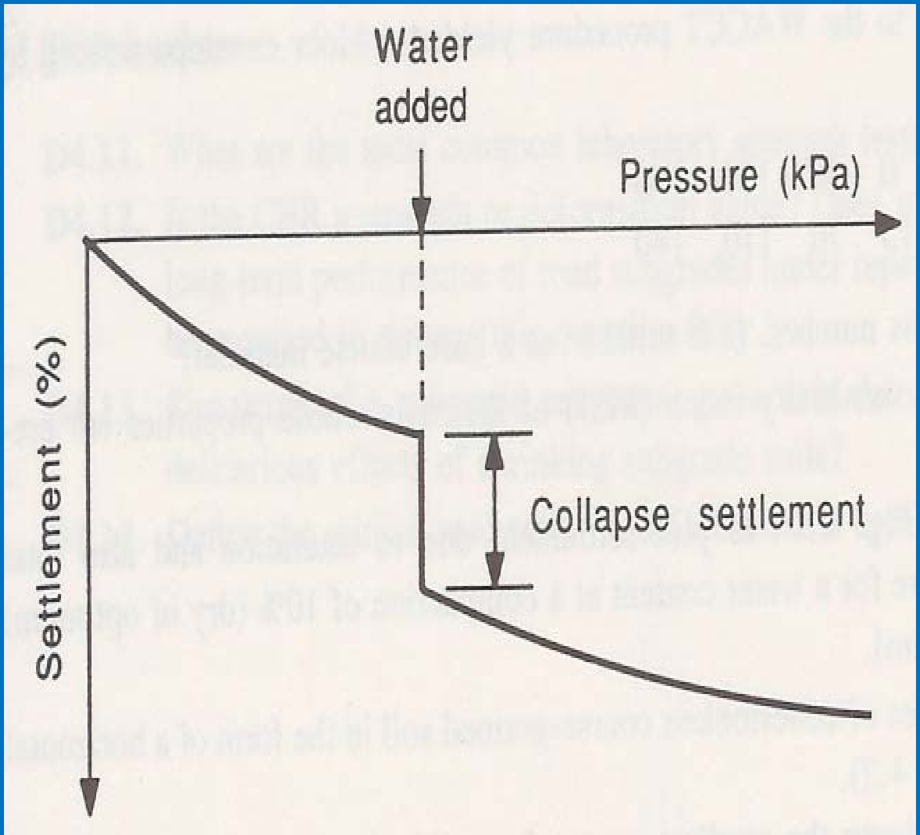


Hypothetical strain contours.

Classification of compacted soil based on triaxial strength



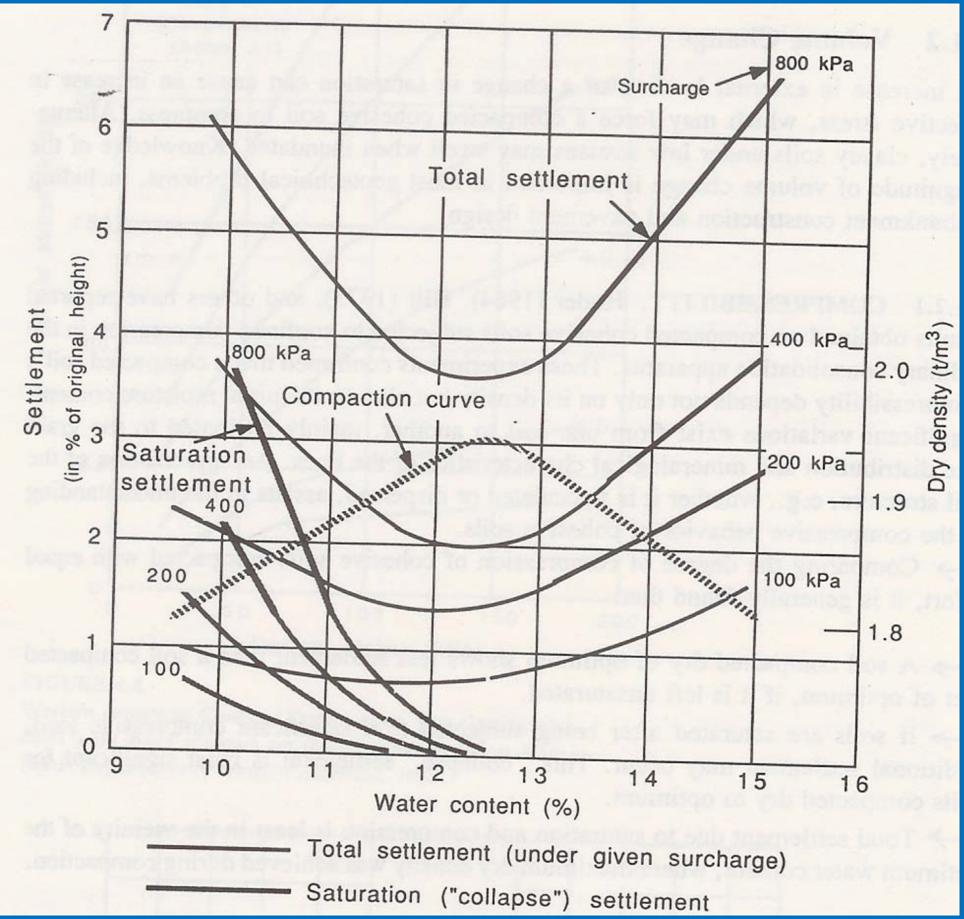
Examples of class contours



collapse settlement due to saturation in a one –dimensional consolidation test.

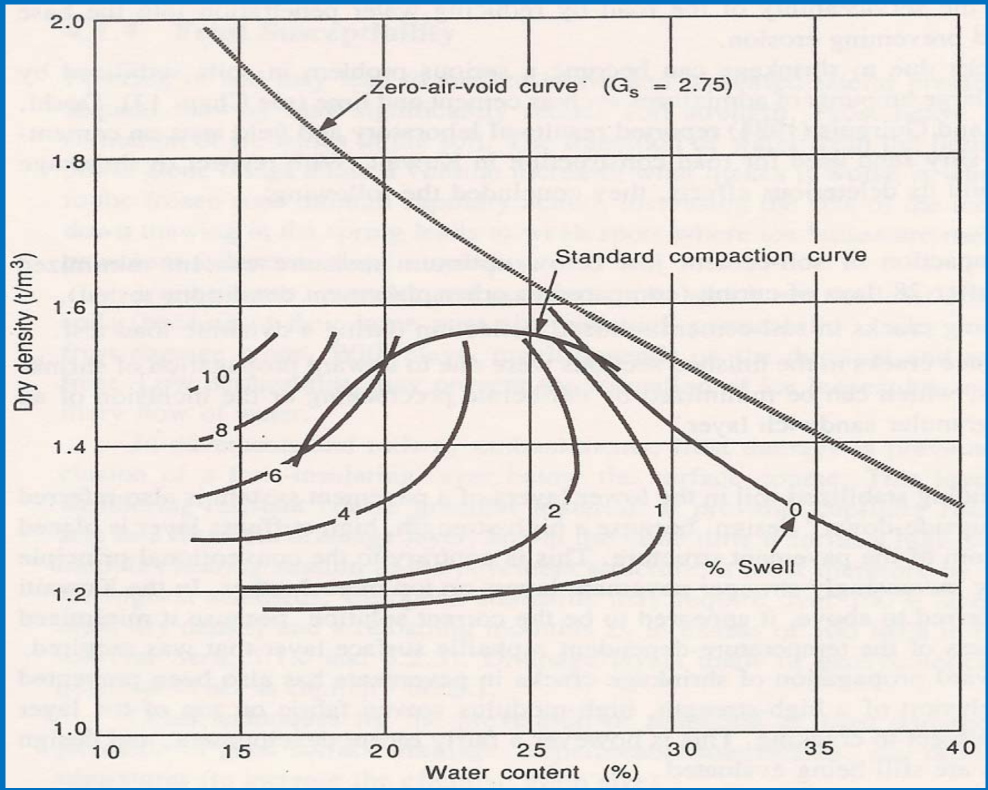
Volume Change:

Compressibility



"Collapse" settlement and total settlement of compacted soil under load.

Swelling



Percent swell related to placement conditions

Properties of Compacted Cohesionless Soil

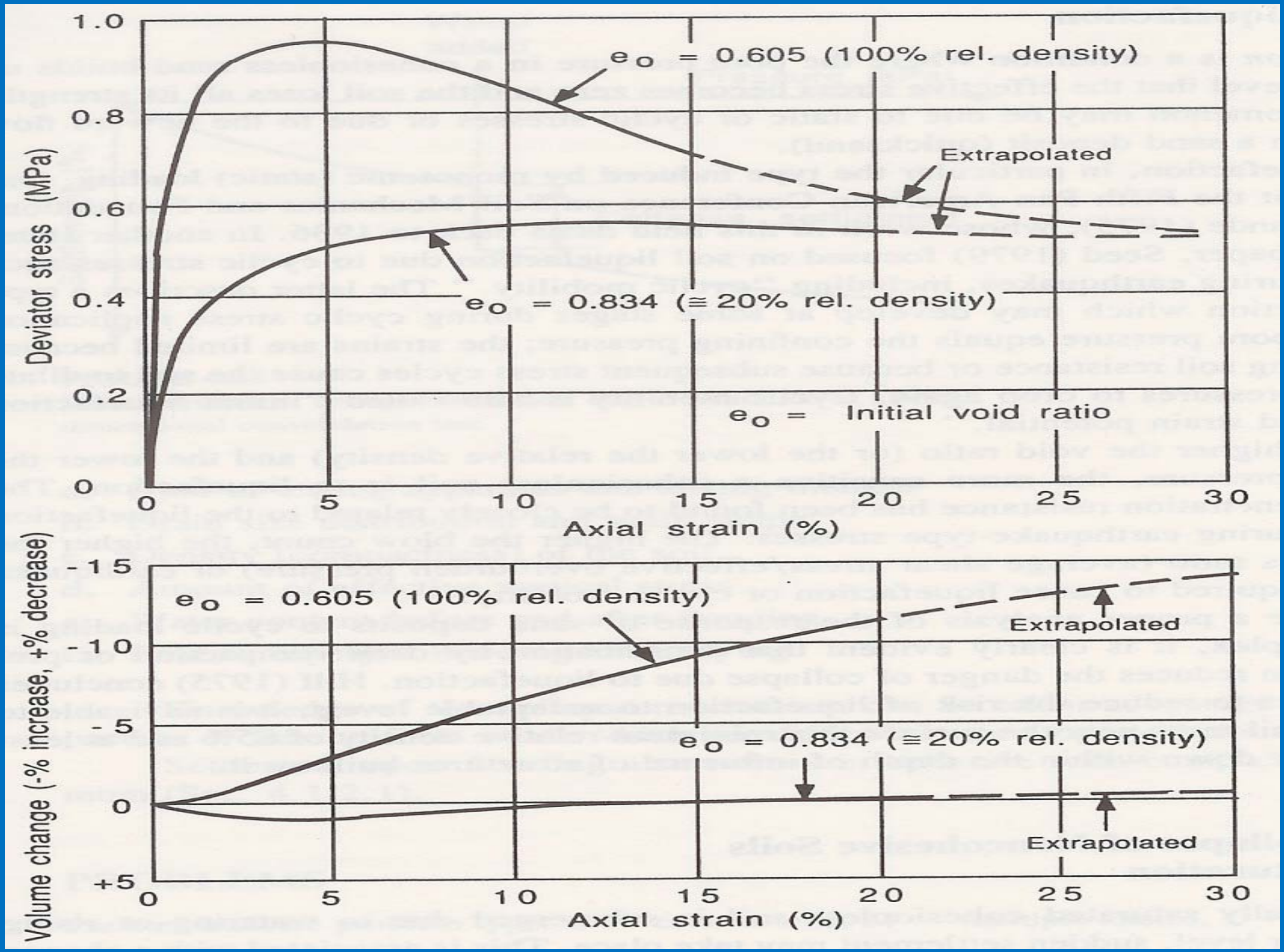
Compactibility and Relative Density

Soil classification	Very loose state	Laboratory std. compaction	Very dense state
	Range of densities, t/m^3		
GW	1.8–1.9	2.0–2.2	2.2–2.3
GW-GM, GM, GW-GP, GP-GM	1.7–1.9	1.8–2.1	2.1–2.3
GP	1.8	1.8–2.0	2.2
SW	1.5–1.7	1.8–2.1	2.1
SW-SM, SP-SM, SM	1.3–1.6	1.8–2.0	1.9–2.1
SP	1.4–1.6	1.6–1.9	1.8–2.0

Typical ranges of densities in cohesionless soils

Sand properties	0–15 (very loose)	15–35 (loose)	35–65 (medium dense)	65–85 (dense)	85–100 (very dense)
	Density index,* %				
N value, blows/300 mm	< 4	4–10	10–30	30–50	> 50
CPT resistane,† MPa	< 5	5–10	10–15	15–20	> 20
Dry unit weight, kN/m^3	< 14	14–16	16–18	18–20	> 20
Friction angle, degrees	< 30	30–32	32–35	35–38	> 38

Sand properties related to the density index



Typical Stress-Strain volume change characteristics for a medium fine sand.

Summary

The methods of shallow compaction, properties of compacted soils and its implications in engineering response are discussed.