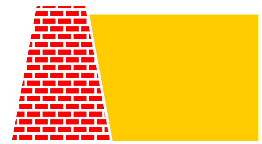
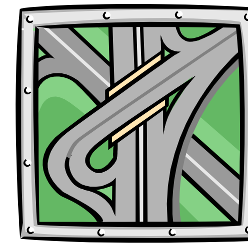
ROADBED SOILS – E

Compaction and Drainability

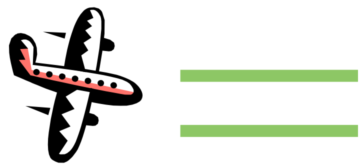
Compaction

- **Soil is used as a basic material for construction**
  - *Retaining walls,*

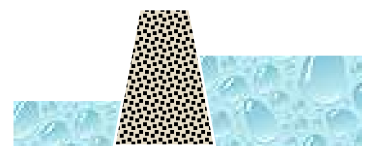




  - *Highways, Embankments, Ramps*



  - *Airports,*



  - *Dams, Dikes, etc.*

- **The advantages of using soil are:**

1. *Is generally available everywhere*
2. *Is durable - it will last for a long time*
3. *Has a comparatively low cost*

What is Compaction?

- **In most instances in civil engineering and/or construction practice, whenever soils are imported or excavated and re-applied, they are *compacted*.**

- **Defined as artificial increase ie densification by mechanical means.**

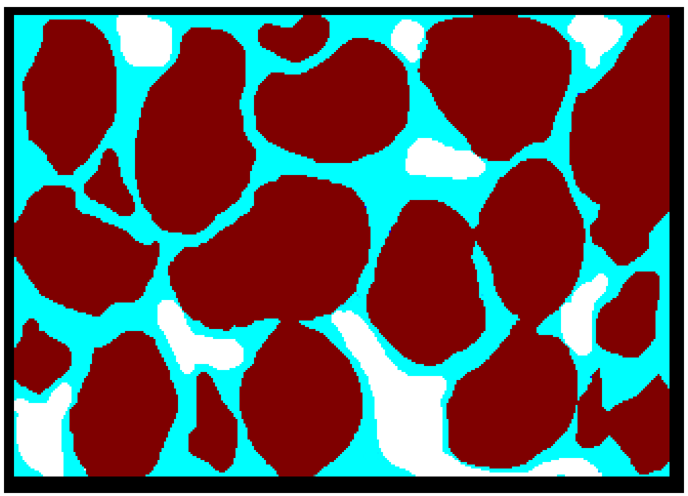
  - **The terms compaction and consolidation may sound as though they describe the same thing, but in reality they do not.**

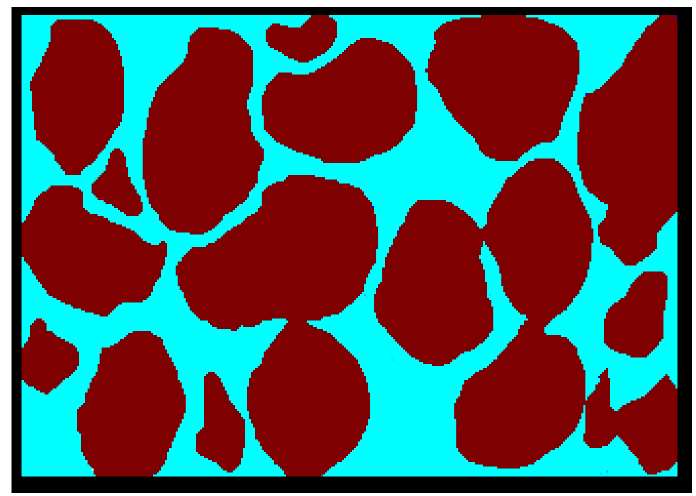
What is Consolidation?

- When a Static loads are applied to saturated soils, and over a period of time the increased stresses are transferred to the soil skeleton, leading to a reduction in void ratio.
- Depending on the permeability of the soil and the magnitude of the drainage distance, this can be a very time-consuming process.
- Typically applies to existing, undisturbed soil deposits that has appreciable amount of clay.

Compaction - Consolidation

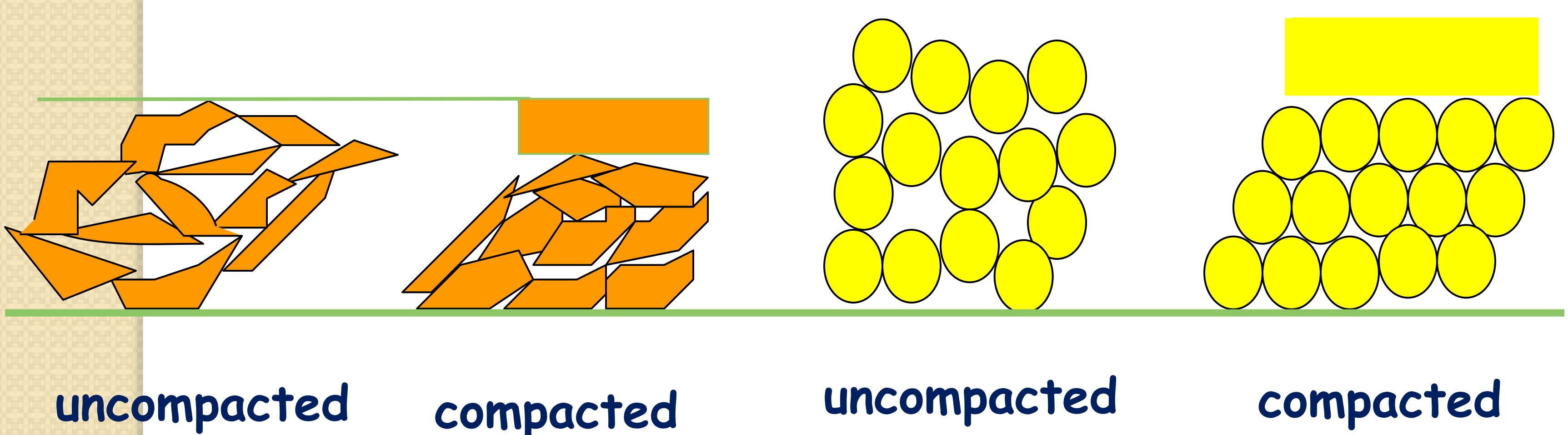
- Compaction means the removal of porosity.
- Consolidation means the removal of water-filled porosity.





Principles of Compaction

Compaction of soils is achieved by reducing the volume of voids. It is assumed that the compaction process does not decrease the volume of the solids or soil grains.



Principles of Compaction

- The degree of compaction of a soil is measured by the dry density/ unit weight of the skeleton.

- The dry unit weight correlates with the degree of packing of the soil grains.

$$\rho_d = \rho_s /(1+e)$$

- The more compacted a soil is:

✓ the smaller its void ratio (e) will be.

✓ the higher its dry density will be

What Does Compaction Do?

- 1) **Increased Shear Strength**
  - **This means that larger loads can be applied to compacted soils since they are typically stronger.**
- 2) **Reduced Permeability**
  - **This inhibits soils' ability to absorb water, and therefore reduces the tendency to expand/shrink and potentially liquefy**
- 3) **Reduced Compressibility**
  - **This also means that larger loads can be applied to compacted soils since they will produce smaller settlements.**
- 4) **Control Swelling & Shrinking**
- 5) **Reduce Liquefaction Potential**

Moisture Density Relationship

- General
  - mc definite relationship with dry density.

$$\rho_d = \rho_t / (1+\omega)$$

  - Specific soil, specific value with specific compactive effort.

Proctor Test M-D Relationship

Sand cone method T191-02

Specific Gravity of soil solids

Moisture Density Relationship

- Why lab tests?
  - Determine compaction curve.
  - Determine structural capacity of soil for estimation of design parameters.
  - Establish compaction specifications for adequate quality control.

Moisture Density Relationship

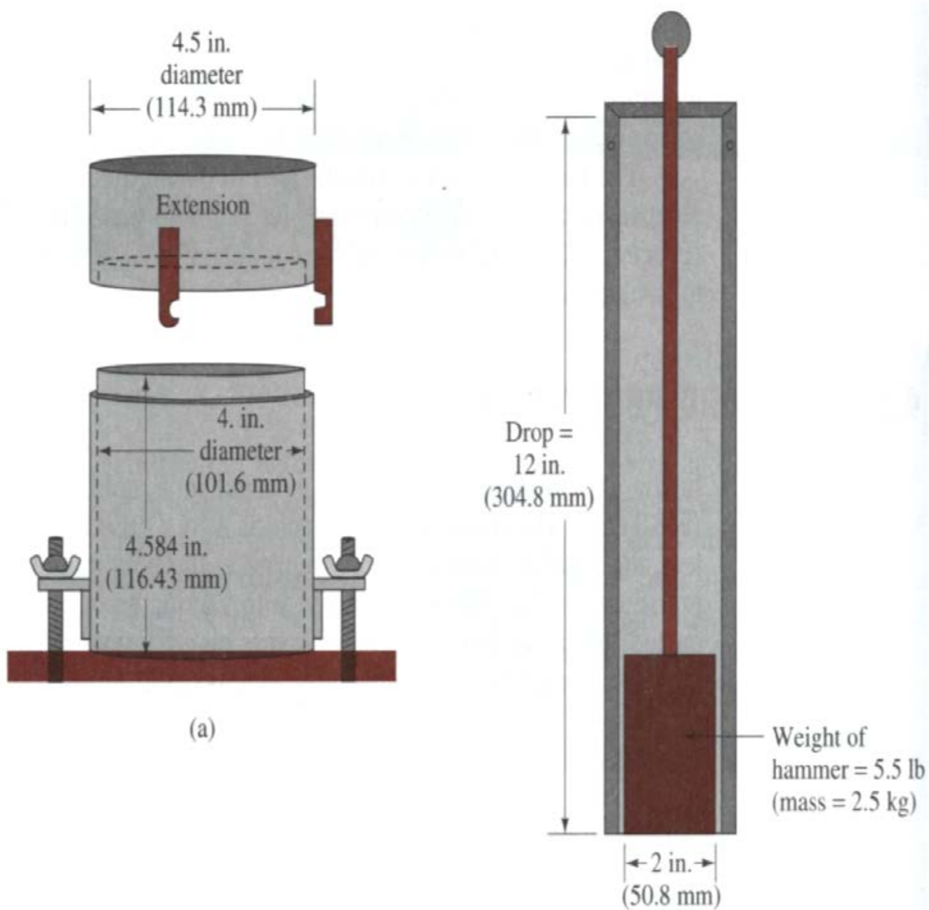
The Standard Proctor Test

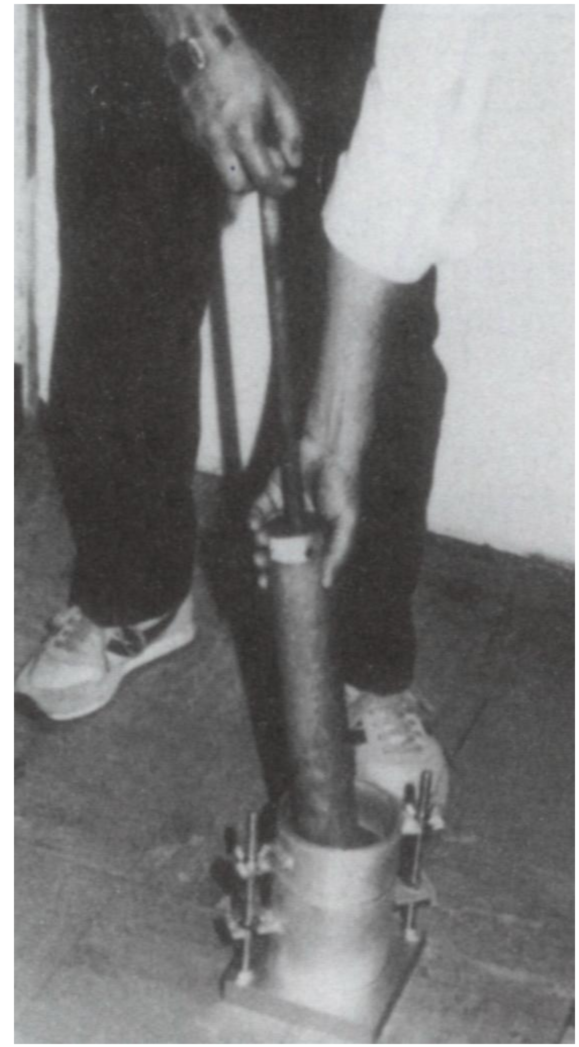
- **R.R. Proctor in the early 1930's was building dams for the old Bureau of Waterworks and Supply in Los Angeles, and he developed the principles of compaction in a series of articles in Engineering News-Record.**

Moisture Density Relationship

Test Equipment

Standard Proctor test equipment





Das, 1998

Moisture Density Relationship

General

- Air or oven dry, break aggregations
- Passing 2”, 30% or < retained 3/4”, above 2” discarded, 2” material replaced with ¾”passing retained on #4
- 5 and 13 lbf specimen for 4 and 6” moulds.
- Oversize correction, More than 5% coarser than specified

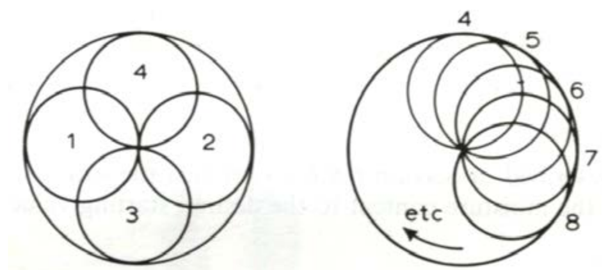
Moisture Density Relationship

Procedures and Results

Procedures

Several samples of the same soil, but at different water contents, are compacted according to the compaction test specifications.

The first four blows



The successive blows

The total or wet density and the actual water content of each compacted sample are measured.

$$\rho = \frac{M_t}{V_t}, \rho_d = \frac{\rho}{1+w}$$

Derive ρ_d from the known ρ and w

Plot the dry densities ρ_d versus water contents w for each compacted sample. The curve is called as a *compaction curve*.

Moisture Density Relationship

Each data point on the curve represents a single compaction test, and usually four or five individual compaction tests are required to completely determine the compaction curve.

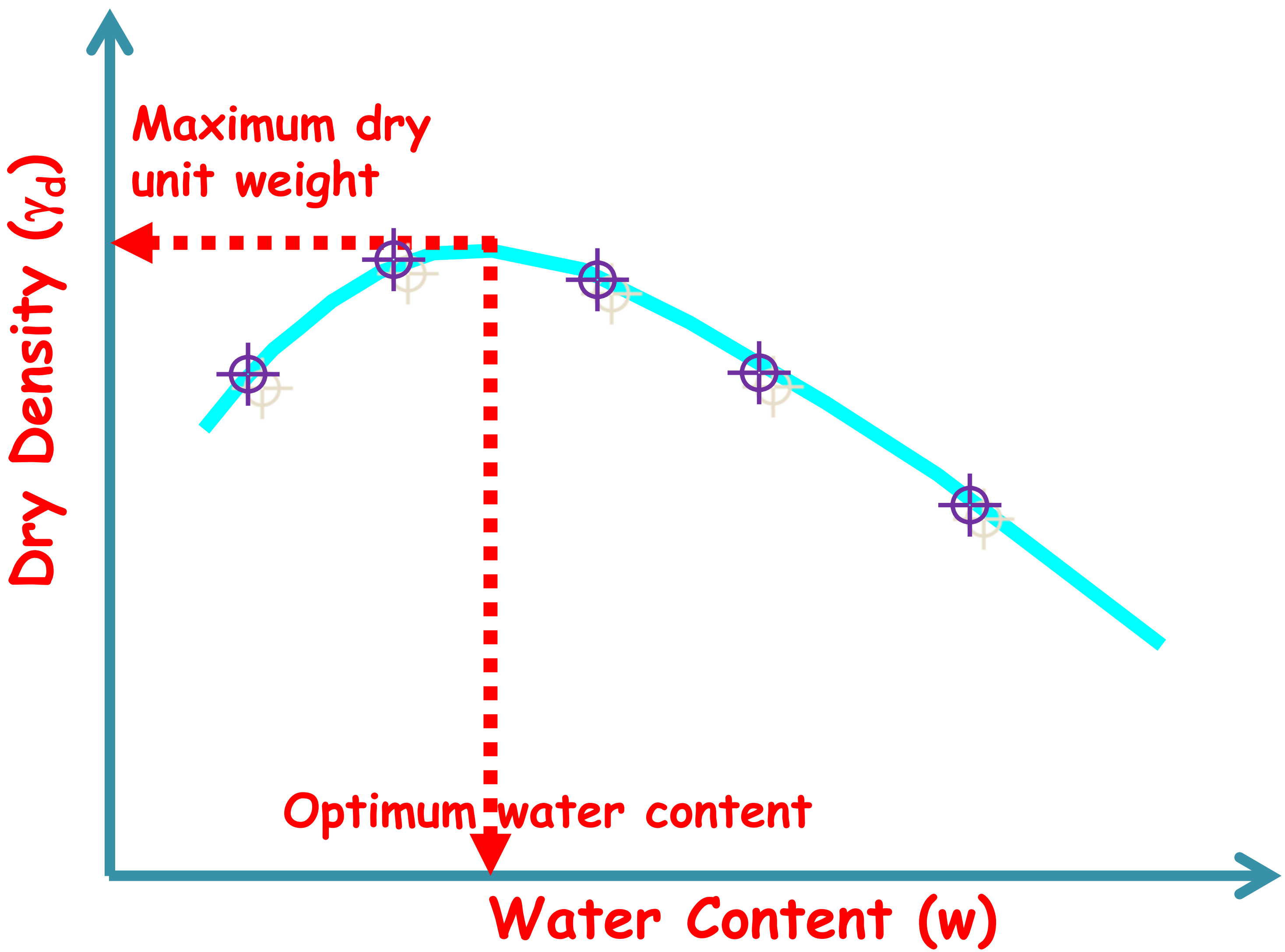
At least two specimens wet and two specimens dry of optimum, and water contents varying by about 2%.

Optimum water content is typically slightly less than the plastic limit (ASTM suggestion).

Typical values of maximum dry density are around 1.6 to 2.0 Mg/m^3 with the maximum range from about 1.3 to 2.4 Mg/m^3. Typical optimum water contents are between 10% and 20%, with an outside maximum range of about 5% to 40%.

Holtz and Kovacs, 1981

Results from Standard Proctor Test



Moisture Density Relationship

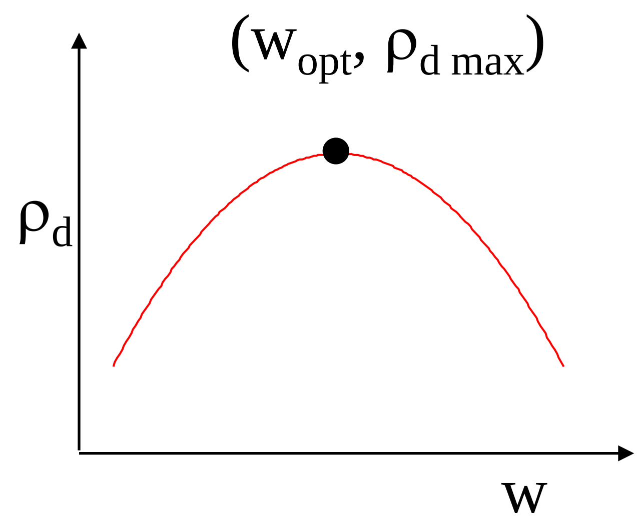
Lubrication or loss of suction??

Below w_{opt} (dry side of optimum):

As the water content increases, the particles develop larger and larger water films around them, which tend to "lubricate" the particles and make them easier to be moved about and reoriented into a denser configuration.

At w_{opt}:

The density is at the maximum, and it does not increase any further.



Above w_{opt} (wet side of optimum):

Water starts to replace soil particles in the mold, and since $\rho_w << \rho_s$ the dry density starts to decrease.

Holtz and Kovacs, 1981

Moisture Density Relationship

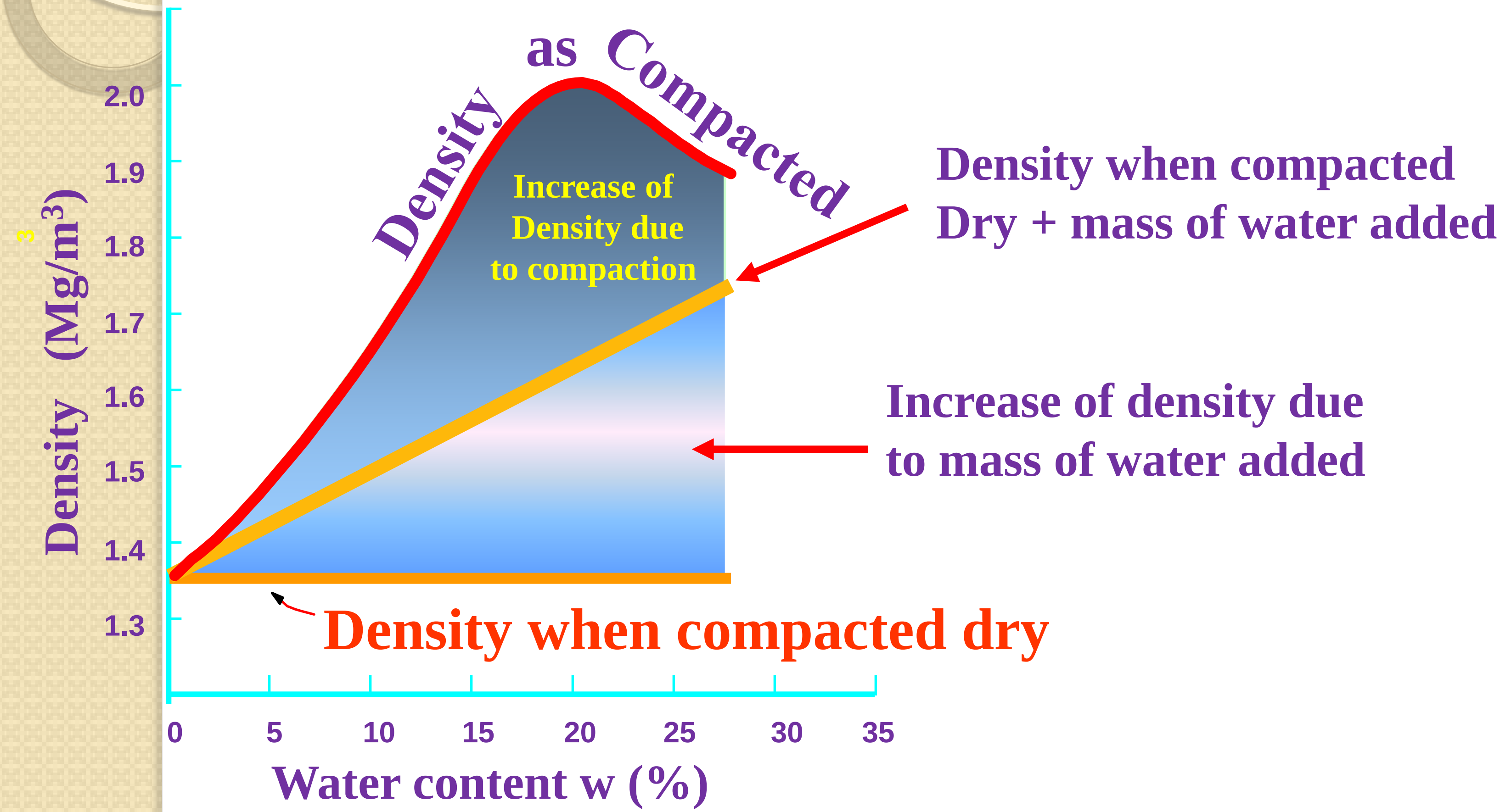
Water Role in Compaction Process

- A little bit of water facilitates compaction

- too much water inhibits compaction.

Moisture Density Relationship

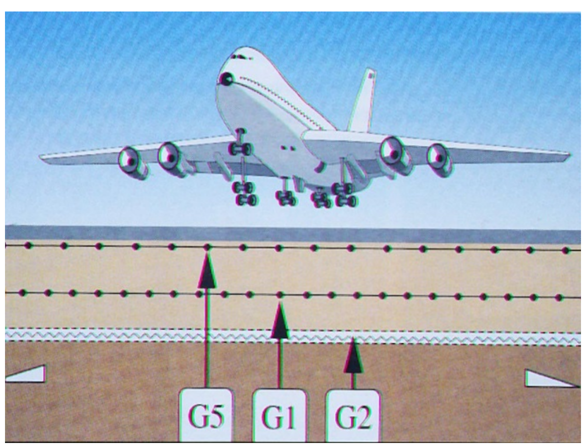
Unit Weight/ Density



Can soil be fully saturated with compaction?

Modified Proctor Test

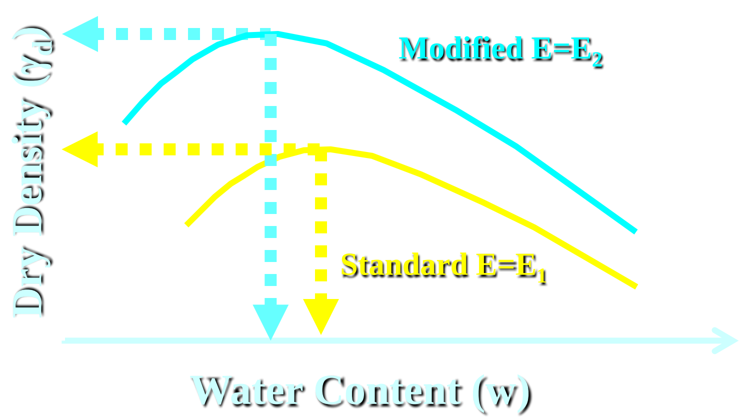
- Was developed during World War II
- By the U.S. Army Corps of Engineering
  - For a better representation of the compaction required for airfield to support heavy aircraft.



Moisture Density Relationship

Comparison-Summary

Standard Proctor Test	Modified Proctor Test
Mold size: 1/30 ft^3	Mold size: 1/30 ft^3
12 in height of drop	18 in height of drop
5.5 lb hammer	10 lb hammer
3 layers	5 layers
25 blows/layer	25 blows/layer
Energy 12,375 $ft \cdot lb/ft^3$	Energy 56,250 $ft \cdot lb/ft^3$



The Standard Proctor Test

Using standard effort12400 ft-lbf/ft^3			
Method	A	B	C
Mould	4”	4”	6”
Material	↓#4	↓ 3/8”	↓3/4”
Layer	3	3	3
Blows/ layer	25	25	56
Use	20% or < on #4	20% or < on 3/8” and >20% on #4	20% or < on 3/4” and >20% on 3/8”
Drop	12”	12”	12”
Rammer mass 5.5 lbf, Mould Volume 4” 0.0333 cft, 6” 0.075 cft			

Standard Energy

- Compactive (E) applied to soil per unit volume:

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

$$E_{SP} = \frac{(25\text{blows/layer}) * (3\ \text{of layers}) * (5.5\ \text{lbs}) * (1.0\ \text{ft})}{(1/30)\text{ft}^3} = 12{,}375\ ft - lb/\ ft^3$$

Modified Proctor Test

Using modified effort 56,000 ft-lbf/ft^3			
Method	A	B	C
Mould	4”	4”	6”
Material	↓#4	↓ 3/8”	↓3/4”
Layer	5	5	5
Blows/ layer	25	25	56
Use	20% or < on #4	20% or < on 3/8” and >20% on #4	20% or < on 3/4” and >20% on 3/8”
Drop	18”	18”	18”
Rammer mass 10 lbf, Mould Volume 4” 0.0333 cft, 6” 0.075 cft			

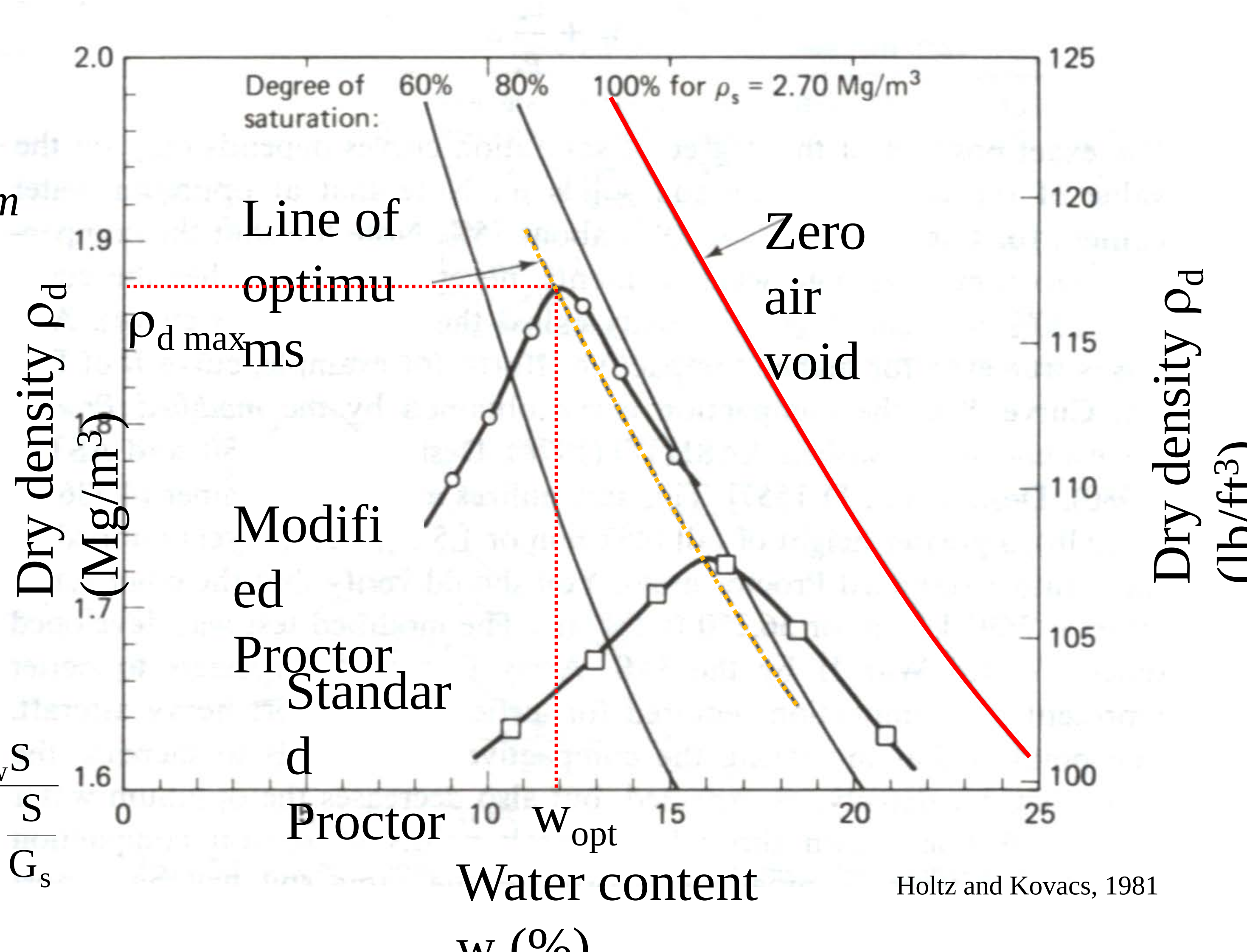
Moisture Density Relationship

Results

Peak point

Line of optimum

Zero air void



$$\rho_d = \frac{\rho_w S}{w + \frac{\rho_w}{\rho_s} S} = \frac{\rho_w S}{w + \frac{S}{G_s}}$$

Holtz and Kovacs, 1981

Moisture Density Relationship

The peak point of the compaction curve

The peak point of the compaction curve is the point with the maximum dry density $\rho_{d\ max}$. Corresponding to the maximum dry density $\rho_{d\ max}$ is a water content known as the optimum water content w_{opt} (also known as the optimum moisture content, OMC). Note that the **maximum dry density is only a maximum for a specific compactive effort and method of compaction.** This does not necessarily reflect the maximum dry density that can be obtained in the field.

Zero air voids curve

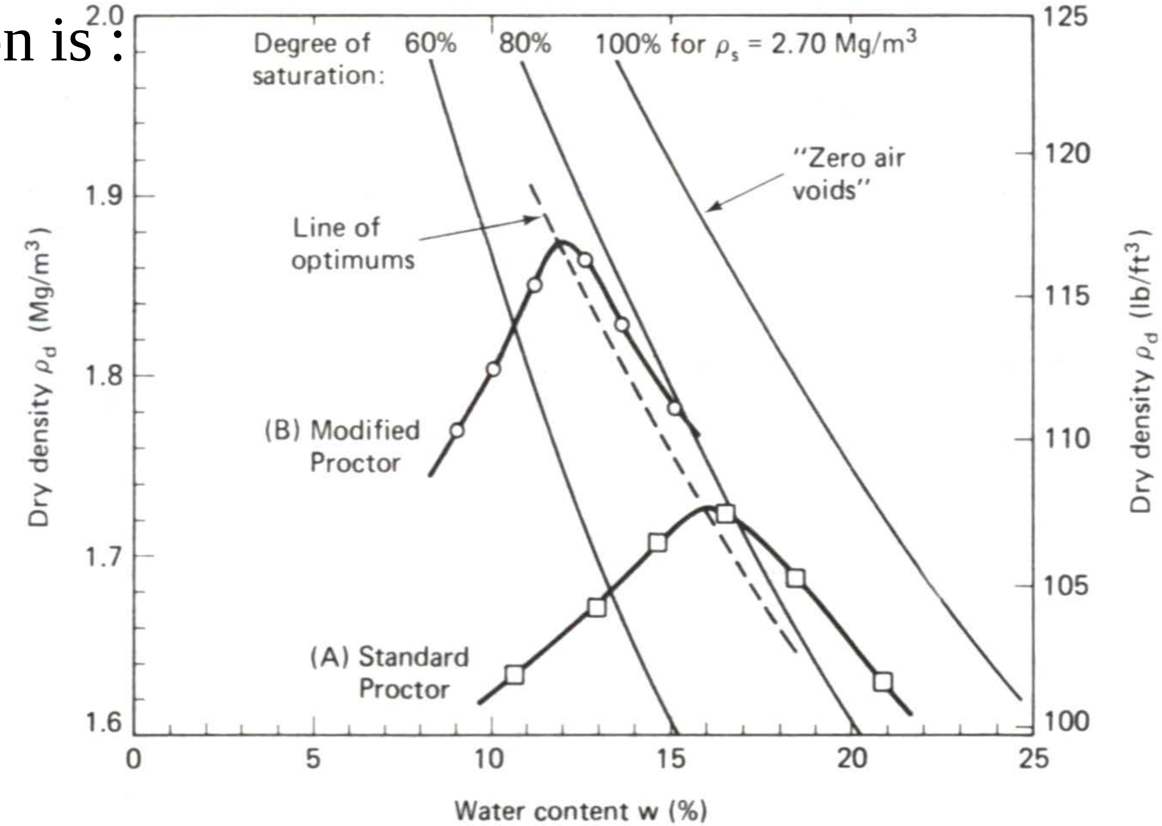
The curve represents the fully saturated condition (S = 100 %). (*It cannot be reached by compaction*)

Line of optimums

A line drawn through the peak points of several compaction curves at different compactive efforts for the same soil will be almost parallel to a 100 % S curve, it is called the line of optimums

Moisture Density Relationship

The Equation for the curves with different degree of saturation is :



$$\rho_d = \frac{\rho_w S}{w + \frac{\rho_w}{\rho_s} S} = \frac{\rho_w S}{w + \frac{S}{G_s}}$$

Holtz and Kovacs, 1981

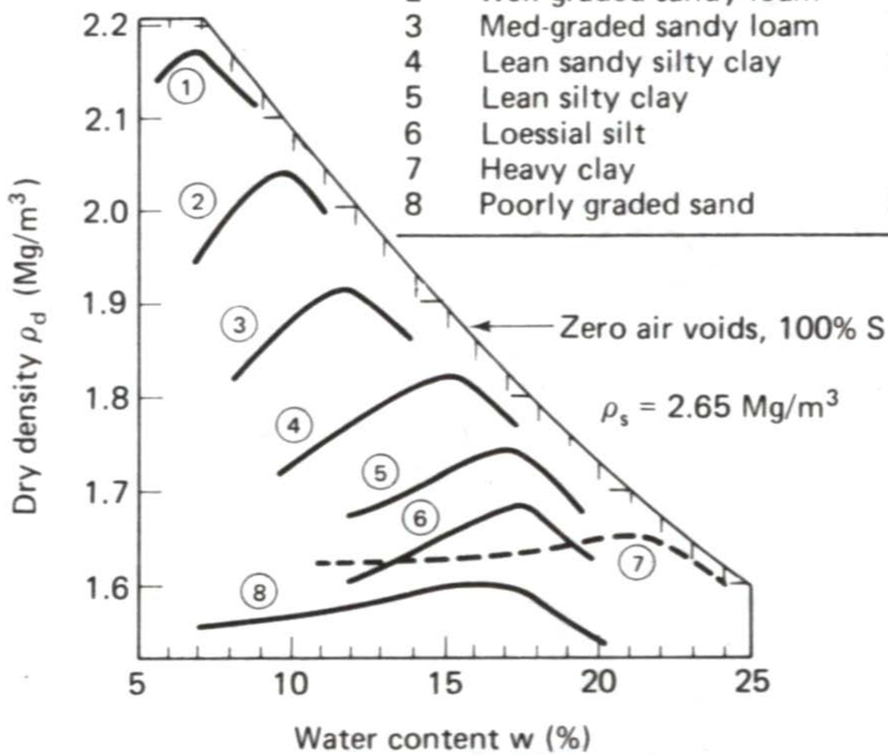
Moisture Density Relationship

Effects of Soil Types on Compaction

The soil type-that is, grain-size distribution, shape of the soil grains, specific gravity of soil solids, and amount and type of clay minerals present.

Soil texture and plasticity data

No.	Description	Sand	Silt	Clay	LL	PI
1	Well-graded loamy sand	88	10	2	16	N.P.
2	Well-graded sandy loam	72	15	13	16	N.P.
3	Med-graded sandy loam	73	9	18	22	4
4	Lean sandy silty clay	32	33	35	28	9
5	Lean silty clay	5	64	31	36	15
6	Loessial silt	5	85	10	26	2
7	Heavy clay	6	22	72	67	40
8	Poorly graded sand	94	— 6 —		N.P.	—

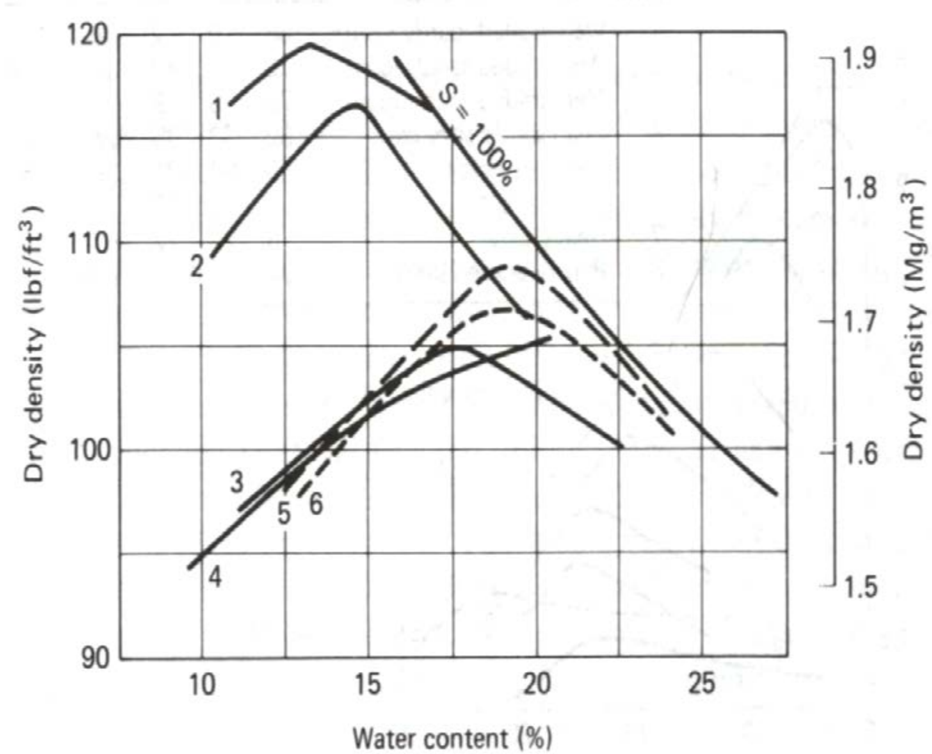


Holtz and Kovacs, 1981; Das, 1998

Moisture Density Relationship

Field and Laboratory Compaction

- It is difficult to choose a laboratory test that reproduces a given field compaction procedure.
- The laboratory curves generally yield a somewhat lower optimum water content than the actual field optimum.



(From Lambe and Whitman, 1979)

Curve 1, 2,3,4: laboratory compaction

Curve 5, 6: Field compaction

Moisture Density Relationship

Significance

- Increasing engineering properties by compaction. MD relationship difficult in certain cases.
- Go for test fill in the field. Which plant, passes, lift thickness.
- Density correction to oversize fraction.
- Replacement over size technique, not good?
- Degradation of certain soils. More in lab so difficult to achieve results
- Gap gradation.
- Same method for aggregate bases and sub bases.

Uses

- To establish specifications for adequate quality control.
- To assist providing desired structural capacity.
- To assess seasonal variation in engineering properties of soil.

Properties and Structure of Compacted Fine-grained Soils

Structure of Compacted Clays

- For a given compactive effort and dry density, the soil tends to be more flocculated (random) for compaction on the dry side as compared on the wet side.
- For a given molding water content, increasing the compactive effort tends to disperse (parallel, oriented) the soil, especially on the dry side.

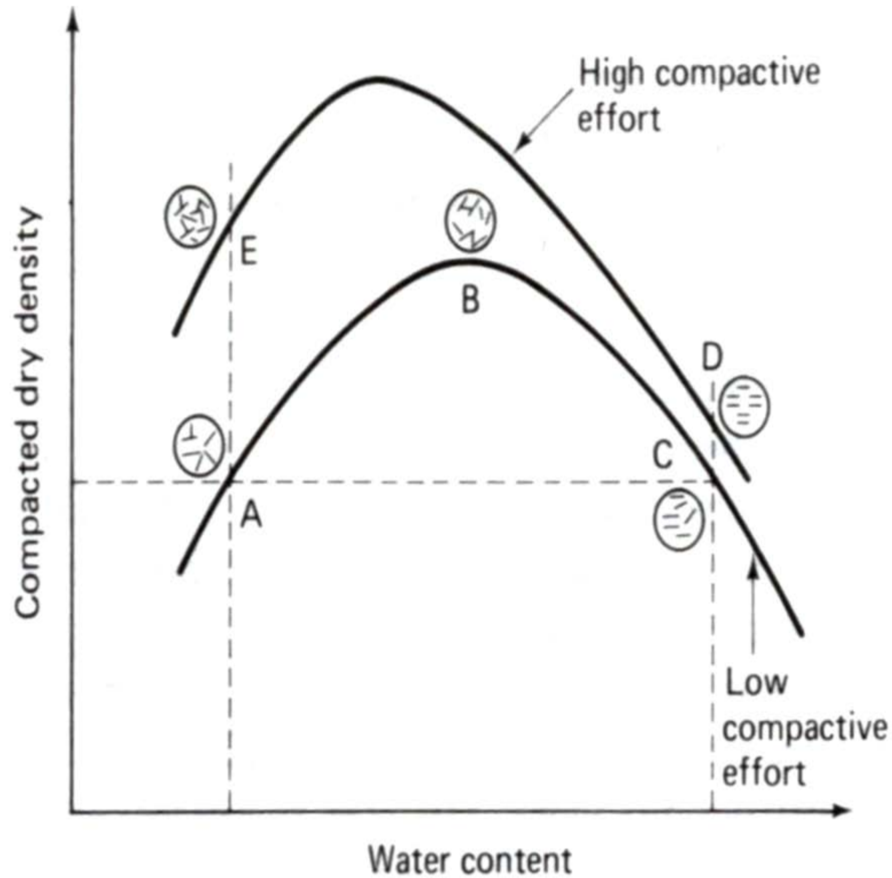
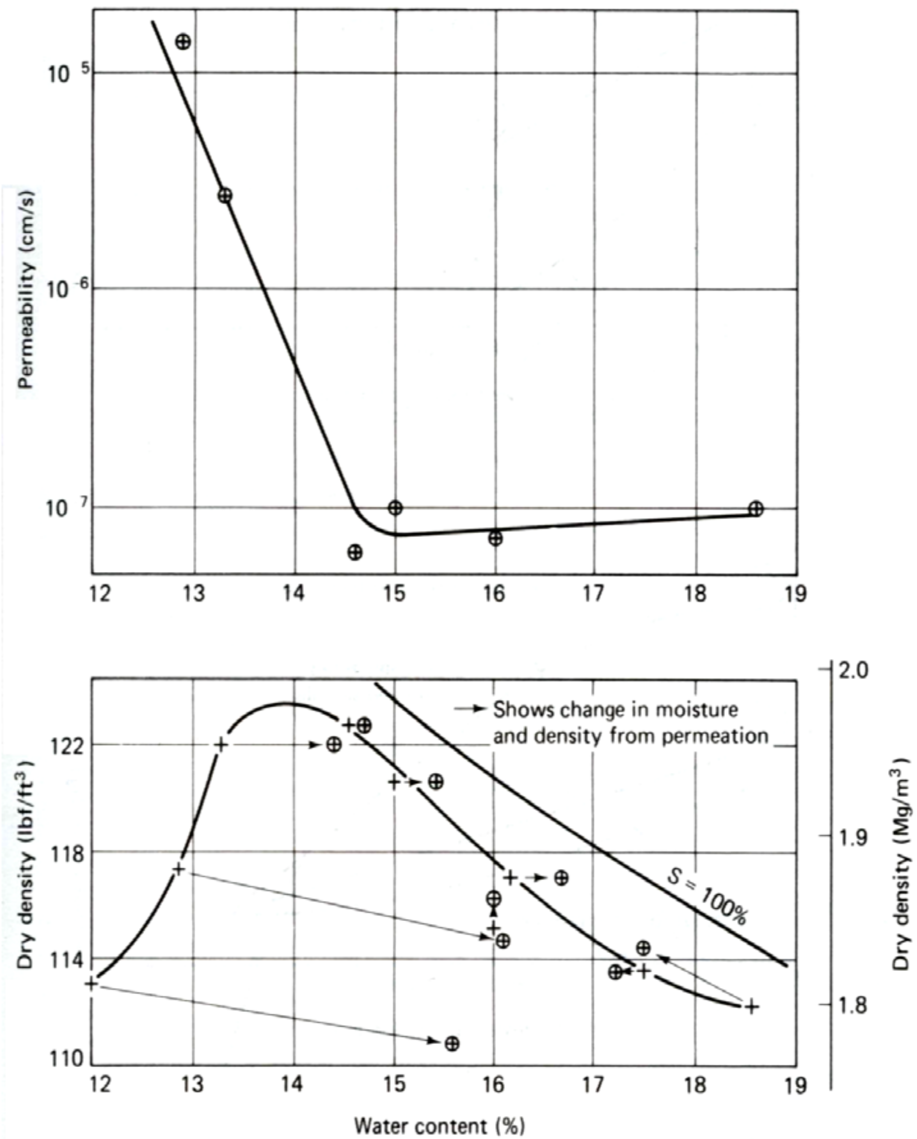


Fig. 5.5 Effect of compaction on soil structure (after Lambe, 1958a).

Lambe and Whitman, 1979

Engineering Properties-Permeability

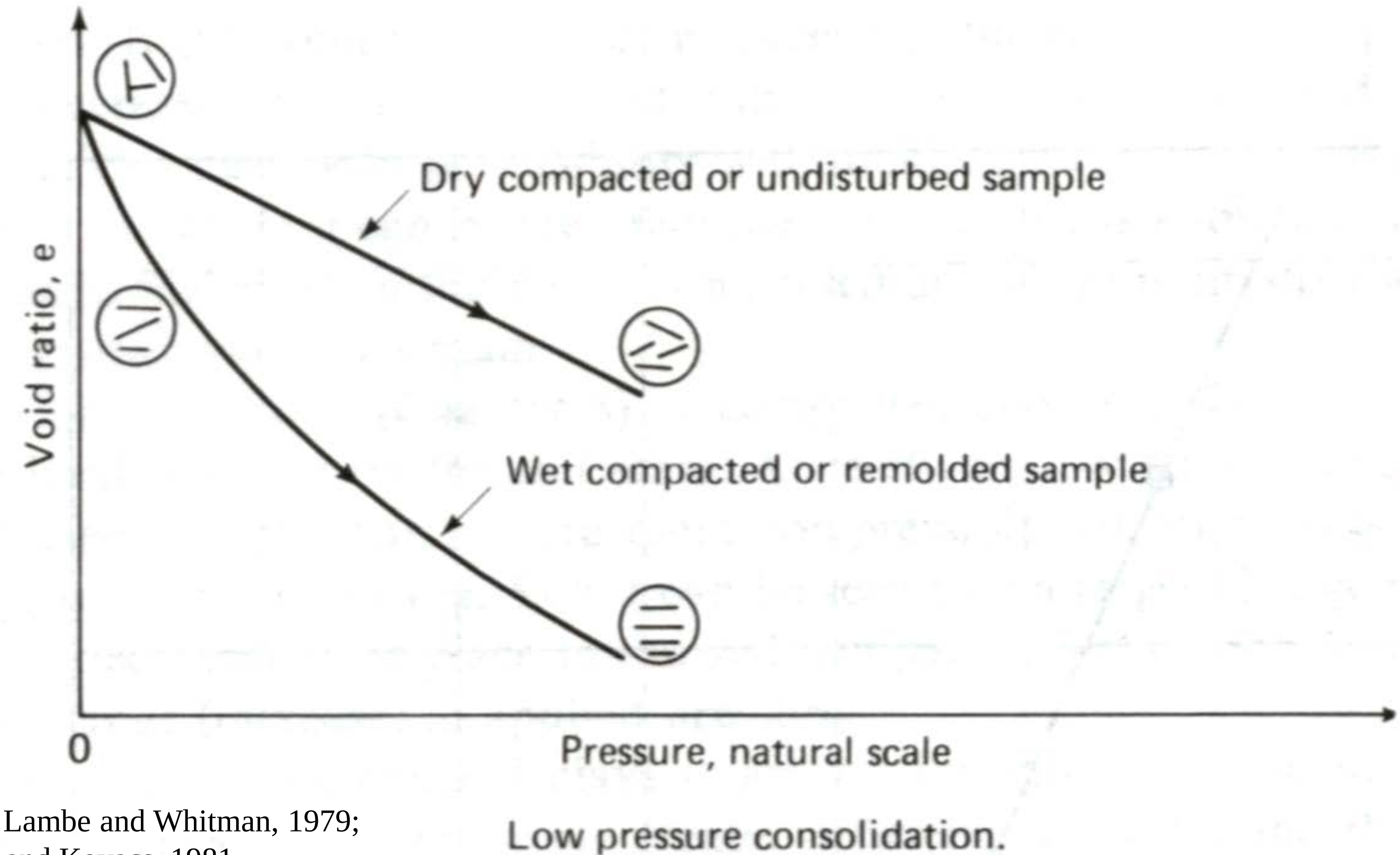
- Increasing the water content results in a decrease in permeability on the dry side of the optimum moisture content and a slight increase in permeability on the wet side of optimum.
- Increasing the compactive effort reduces the permeability since it both increases the dry density, thereby reducing the voids available for flow, and increases the orientation of particles.



From Lambe and Whitman, 1979;
Holtz and Kovacs, 1981

Engineering Properties-Compressibility

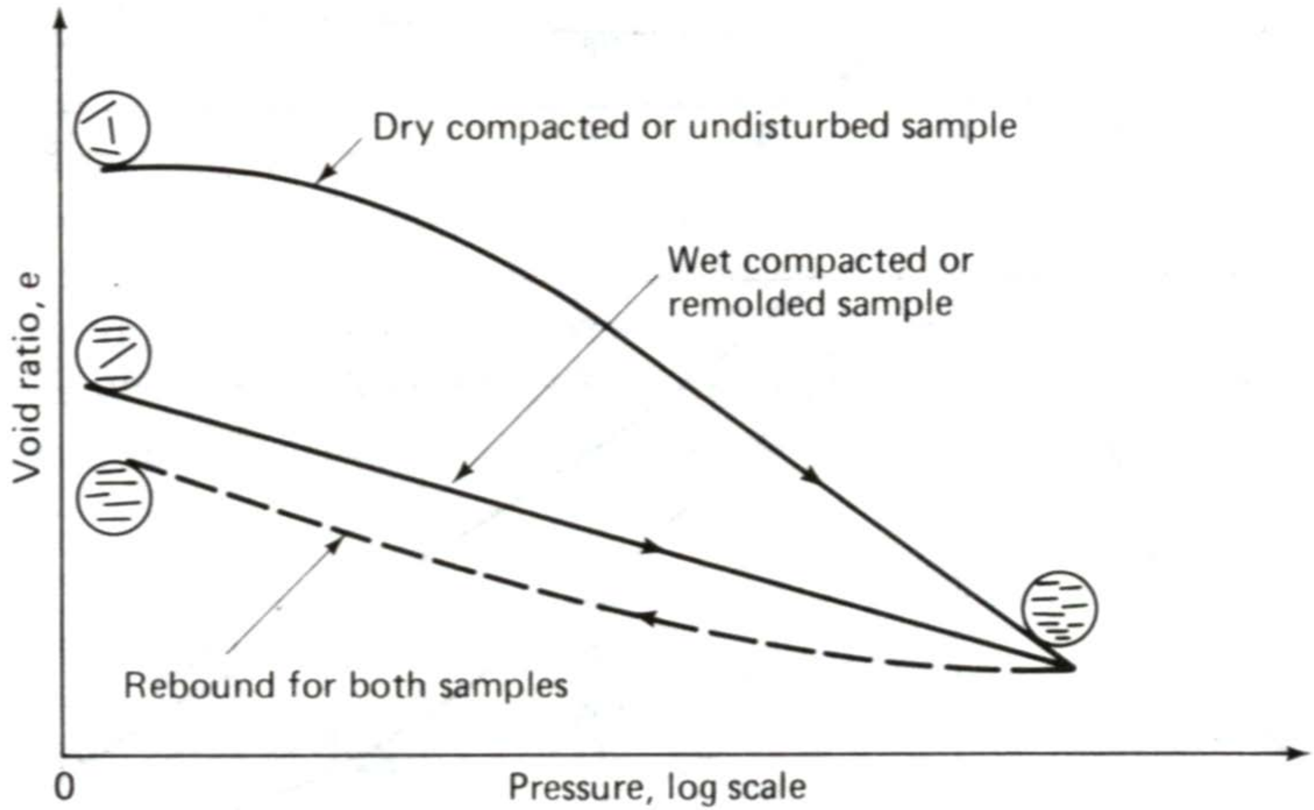
At low stresses the sample compacted on the wet side is more compressible than the one compacted on the dry side.



From Lambe and Whitman, 1979;
Holtz and Kovacs, 1981

Engineering Properties-Compressibility

At the high applied stresses the sample compacted on the dry side is more compressible than the sample compacted on the wet side.

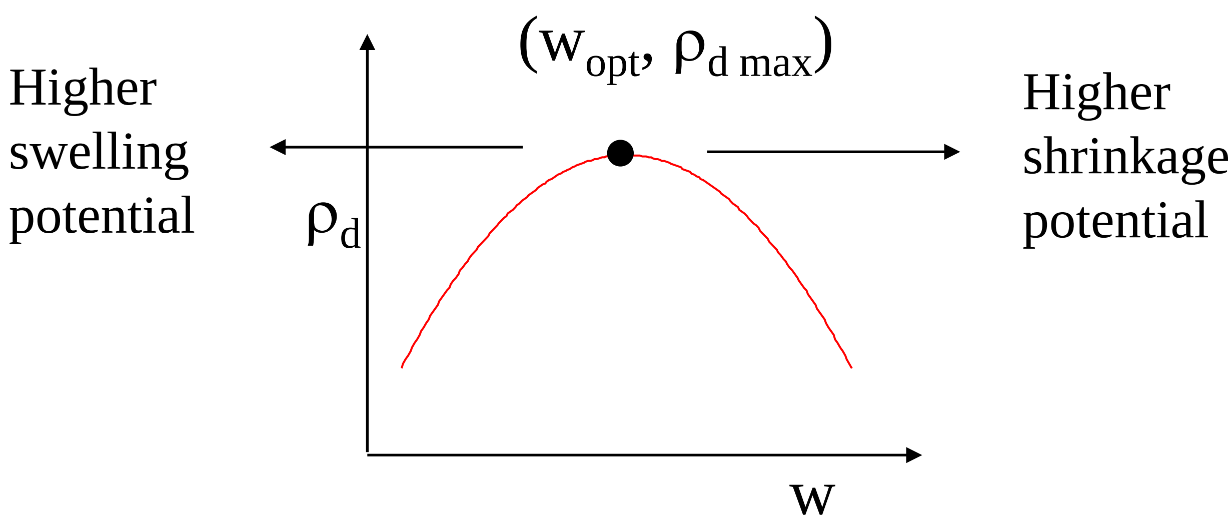


From Lambe and Whitman, 1979;
Holtz and Kovacs, 1981

High-pressure consolidation.

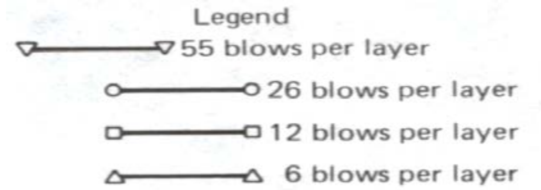
Engineering Properties-Swelling

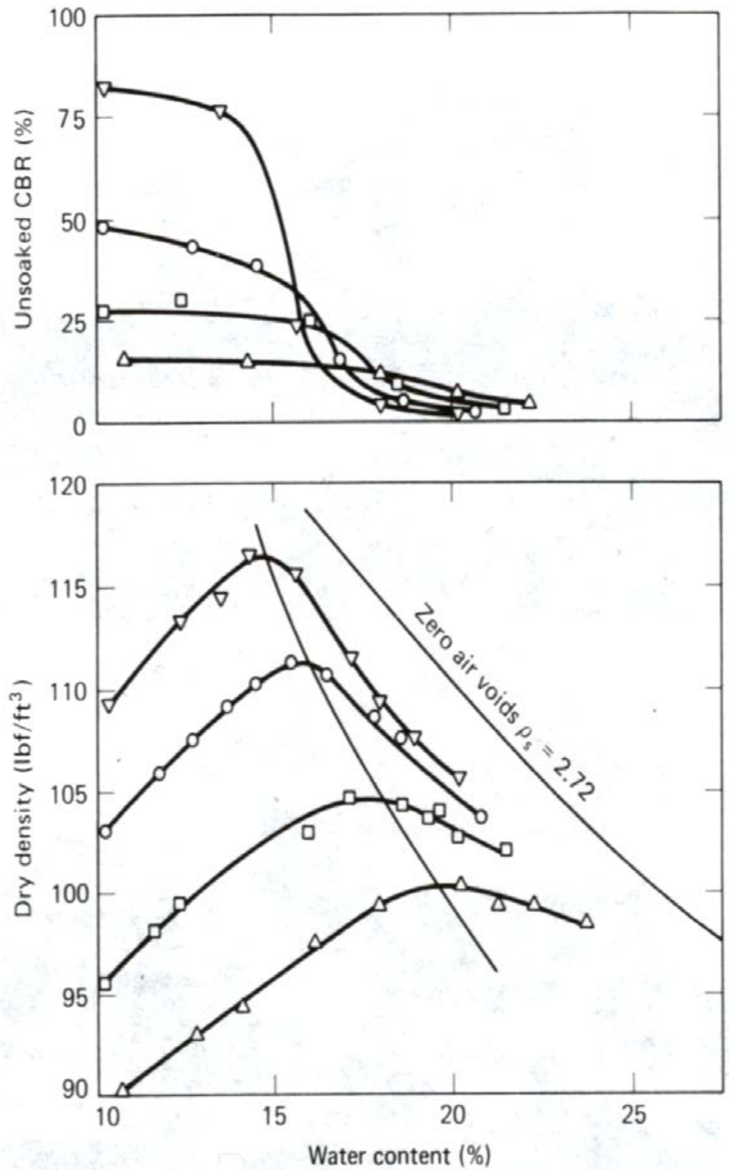
Swelling of compacted clays is greater for those compacted dry of optimum. They have a relatively greater deficiency of water and therefore have a greater tendency to adsorb water and thus swell more.



From Holtz and Kovacs, 1981

Engineering Properties-Strength





The CBR (California bearing ratio)

CBR= the ratio between resistance required to penetrate a 3-in^2 piston into the **compacted specimen** and resistance required to penetrate the same depth into a standard sample of **crushed stone**.

Holtz and Kovacs, 1981

Engineering Properties-Strength

A greater compactive effort produces a greater CBR for the dry of optimum. However, the CBR is actually less for the wet of optimum for the higher compaction energies (overcompaction).

Holtz and Kovacs, 1981

Engineering Properties-Summary

	Dry side	Wet side
Structure	More random	More oriented (parallel)
Permeability	More permeable	
Compressibility	More compressible in *high* pressure range	More compressible in *low* pressure range
Swelling	Swell more, higher water deficiency	Shrink more
Strength	Higher	

Properties and Structure of Compacted Fine-grained Soils

Engineering Properties-Summary

TABLE 5-1 Comparison of Soil Properties between Dry of Optimum and Wet of Optimum Compaction*

Property	Comparison
1. Structure:	
A. Particle arrangement	Dry side more random
B. Water deficiency	Dry side more deficient; thus imbibes more water, swells more, has lower pore pressure
C. Permanence	Dry side structure sensitive to change
2. Permeability:	
A. Magnitude	Dry side more permeable
B. Permanence	Dry side permeability reduced much more by permeation
3. Compressibility:	
A. Magnitude	Wet side more compressible in low pressure range, dry side in high pressure range
B. Rate	Dry side consolidates more rapidly
4. Strength:	
A. As molded:	
(a) Undrained	Dry side much higher
(b) Drained	Dry side somewhat higher
B. After saturation:	
(a) Undrained	Dry side somewhat higher if swelling prevented; wet side can be higher if swelling permitted
(b) Drained	Dry side about the same or slightly greater
C. Pore water pressure at failure	Wet side higher
D. Stress-strain modulus	Dry side much greater
E. Sensitivity	Dry side more apt to be sensitive

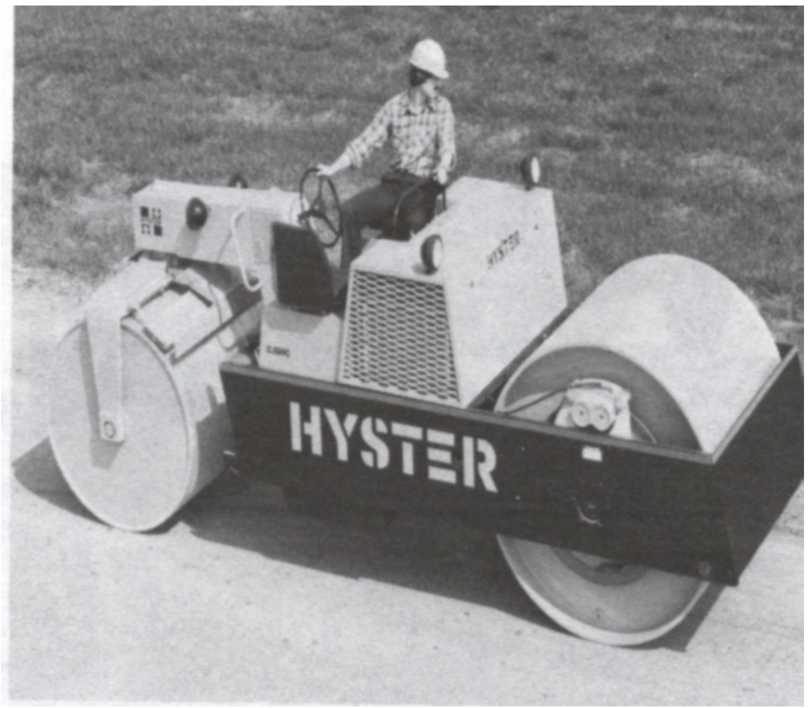
Holtz and Kovacs, 1981

Field Compaction Equipment and Procedures

- General
  - Plant and equipment
  - Shovels, dragline and SP Scrappers
  - Soil mixed; Shovels vs scrapper
  - Pressure, impact, vibrating, kneading

Field Compaction Equipment and Procedures

Smooth-wheel roller (drum)

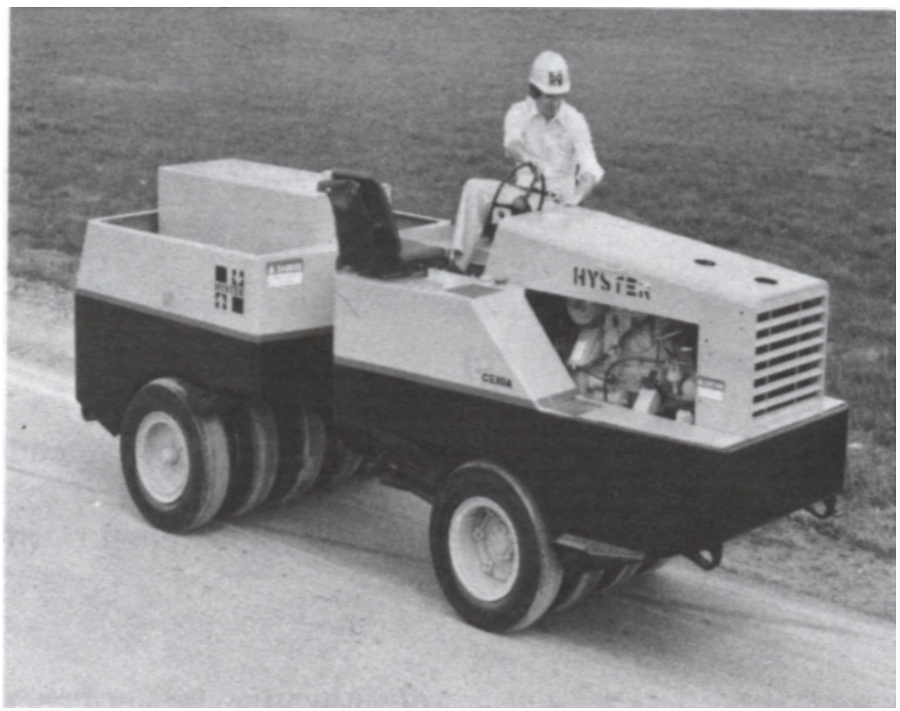


- 100% coverage under the wheel
- Contact pressure up to 380 kPa
- Can be used on all soil types except for rocky soils.
- Compactive effort: static weight
- The most common use of large smooth wheel rollers is for proof-rolling subgrades and compacting asphalt pavement.

Holtz and Kovacs, 1981

Field Compaction Equipment and Procedures

Pneumatic (or rubber-tired) roller

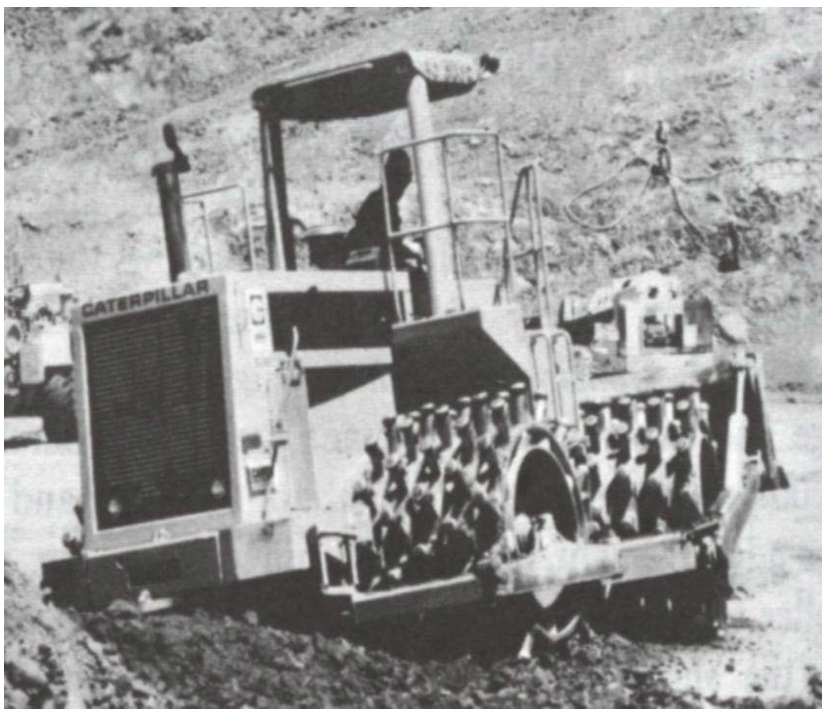


- 80% coverage under the wheel
- Contact pressure up to 700 kPa
- Can be used for both granular and fine-grained soils.
- Compactive effort: static weight and kneading.
- Can be used for highway fills or earth dam construction.

Holtz and Kovacs, 1981

Field Compaction Equipment and Procedures

Sheep foot rollers



- Has many round or rectangular shaped protrusions or "feet" attached to a steel drum
- 8% ~ 12 % coverage
- Contact pressure is from 1400 to 7000 kPa
- It is best suited for clayed soils.
- Compactive effort: static weight and kneading.

Holtz and Kovacs, 1981

Field Compaction Equipment and Procedures

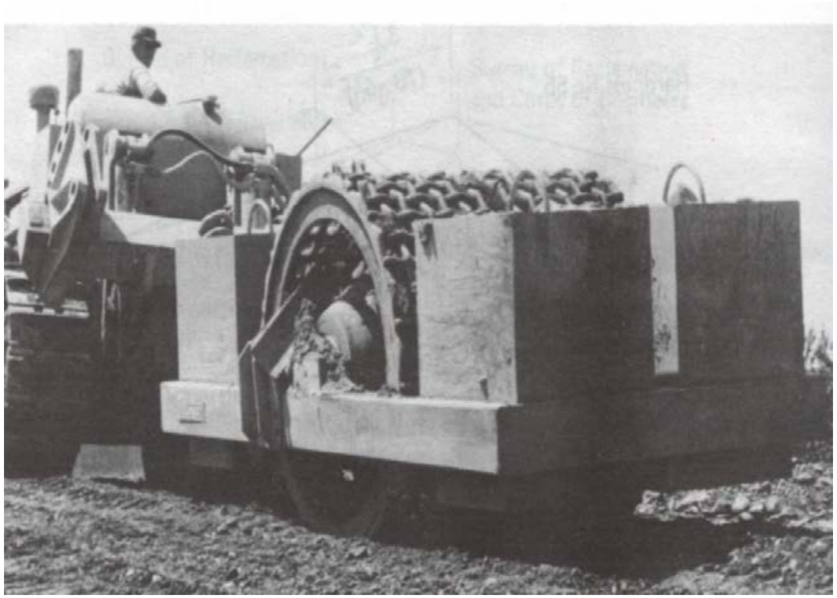
Tamping foot roller

- About 40% coverage
- Contact pressure is from 1400 to 8400 kPa
- It is best for compacting fine-grained soils (silt and clay).
- Compactive effort: static weight and kneading.

Holtz and Kovacs, 1981

Field Compaction Equipment and Procedures

Mesh (or grid pattern) roller



- 50% coverage
- Contact pressure is from 1400 to 6200 kPa
- It is ideally suited for compacting rocky soils, gravels, and sands. With high towing speed, the material is vibrated, crushed, and impacted.
- Compactive effort: static weight and vibration.

Holtz and Kovacs, 1981

Equipment (Cont.)

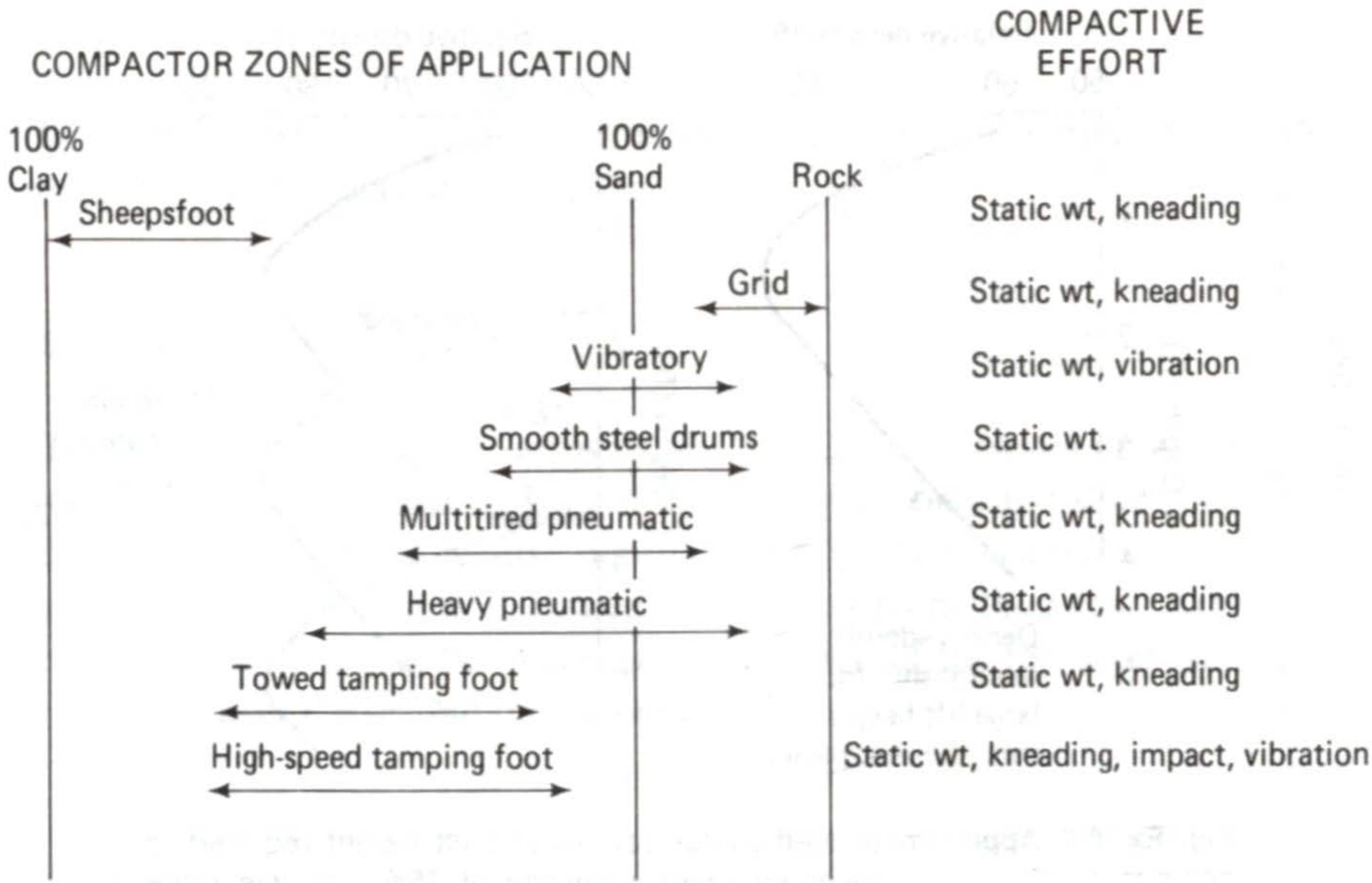
Vibrating drum on smooth-wheel roller

- Vertical vibrator attached to smooth wheel rollers.
- The best explanation of why roller vibration causes densification of granular soils is that particle rearrangement occurs due to cyclic deformation of the soil produced by the oscillations of the roller.
- Compactive effort: static weight and vibration.
- Suitable for granular soils

Holtz and Kovacs, 1981

Field Compaction Equipment and Procedures

Equipment-Summary



Field Compaction Equipment and Procedures

Variables-Vibratory Compaction

There are many variables which control the vibratory compaction or densification of soils.

Characteristics of the compactor:

(1) Mass, size

(2) Operating frequency and frequency range

Characteristics of the soil:

(1) Initial density

(2) Grain size and shape

(3) Water content

Construction procedures:

(1) Number of passes of the roller

(2) Lift thickness

(3) Frequency of operation vibrator

(4) Towing speed

Holtz and Kovacs, 1981

- Compactive effort and where used
- Field control of moisture.
- Mixing in the field.

$$R.C. = \frac{\rho_{d-field}}{\rho_{d\max-laboratory}} \times 100\%$$

Design-Construct Procedures

Laboratory tests are conducted on samples of the proposed borrow materials to define the properties required for design.

After the earth structure is designed, the compaction specifications are written. Field compaction *control tests* are specified, and the results of these become the standard for controlling the project.

From Holtz and Kovacs, 1981

Specifications

(1) End-product specifications

This specification is used for most highways and building foundation, as long as the contractor is able to obtain the specified *relative compaction* , how he obtains it doesn't matter, nor does the equipment he uses.

Care the results only !

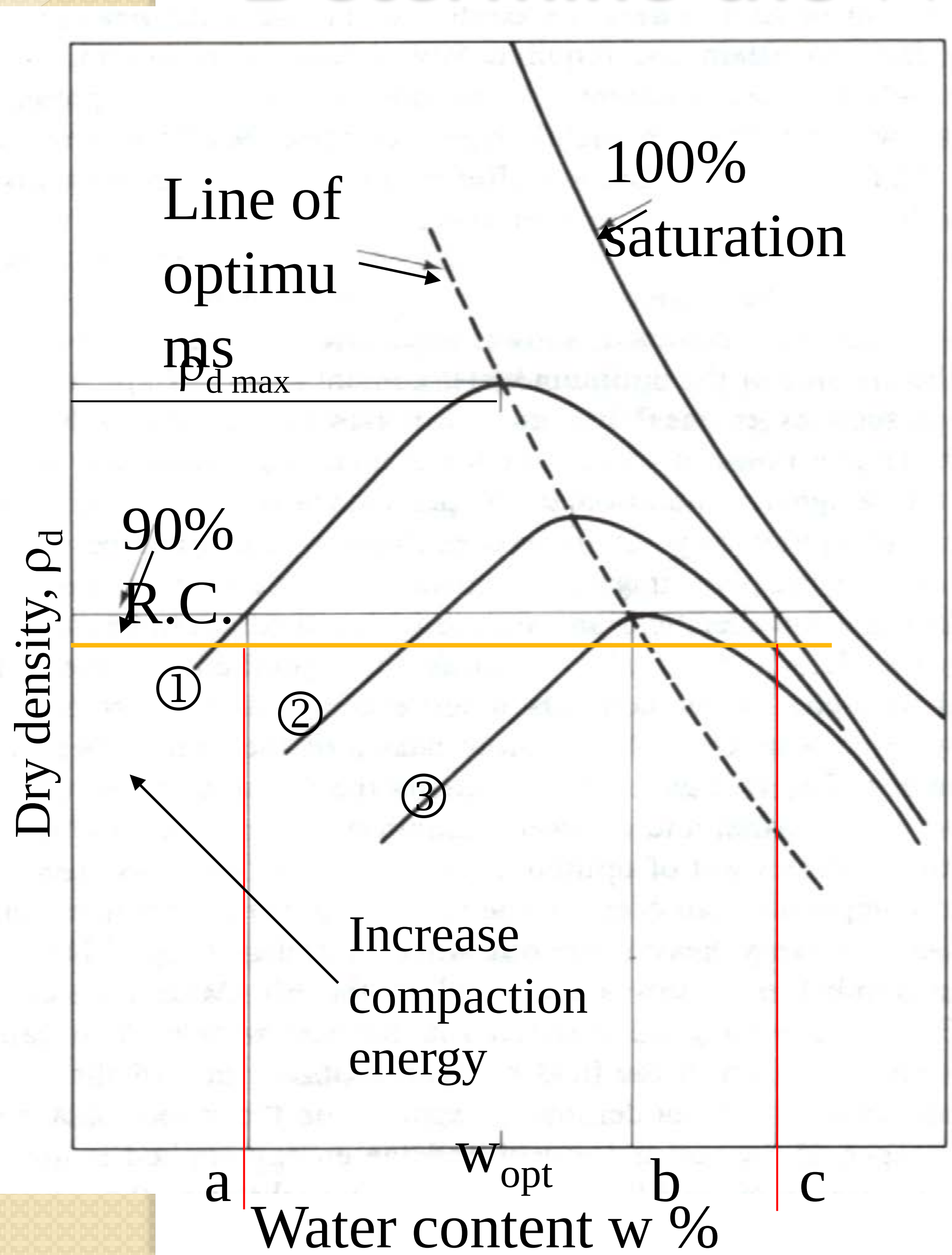
(2) Method specifications

The type and weight of roller, the number of passes of that roller, as well as the lift thickness are specified. A maximum allowable size of material may also be specified.

It is typically used for large compaction project.

From Holtz and Kovacs, 1981

Determine the Water Content (in Field)



Control

(1) Relative compaction

(2) Water content (dry side or wet side)

Note: the engineering properties may be different between the compacted sample at the dry side and at the wet side.

Holtz and Kovacs, 1981

Determine the Relative Compaction in the Field

Where and When

First, the test site is selected. It should be representative or typical of the compacted lift and borrow material. Typical specifications call for a new field test for every 1000 to 3000 m^2 or so, or when the borrow material changes significantly. It is also advisable to make the field test at least one or maybe two compacted lifts below the already compacted ground surface, especially when sheepsfoot rollers are used or in granular soils.

Method

Field control tests, measuring the dry density and water content in the field can either be *destructive* or *nondestructive*.

Holtz and Kovacs, 1981

Methods

Destructive Methods

(a) Sand cone

(b) Balloon

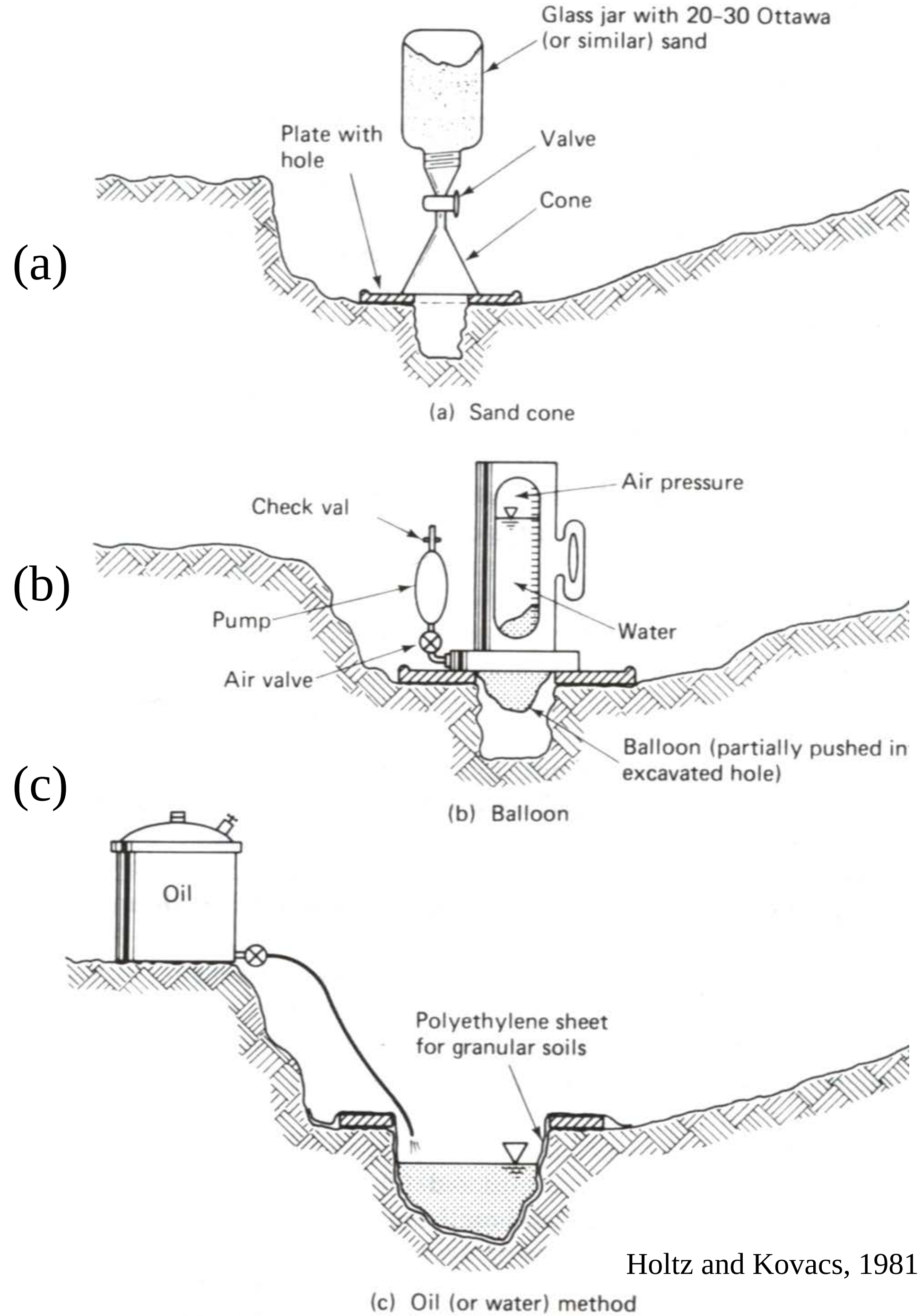
(c) Oil (or water) method

Non Destructive , Nuclear density meter

(a) Direct transmission

(b) Backscatter

(c) Air gap



Holtz and Kovacs, 1981

Field Compaction Test

- Sand Cone Apparatus
  - Dry mass of the soil is determined
  - Volume of the test hole is obtained from the mass of loose sand required to fill the hole
  - Sand is a uniform medium sand with a constant loose density
  - Volume=mass of sand / loose density of sand
  - density is calculated
  - water content determined
  - *Study at your own*

Field Compaction Test

Example 3-4 Sand-Cone Apparatus: A sand cone holds 851.0 g. The loose density of the sand is 1.430 g/cm^3

Field Test Results:

Total weight of the soil	639.5 g
Dry weight of the soil	547.9 g
Initial weight of the sand-cone apparatus	4527.8g
final weight of the sand-cone apparatus	3223.9g

Field Compaction Test

Calculations:

Mass of the sand used 4527.8g-3223.9g = 1303.9g

Mass in test hole 1303.9g-851.0g = 452.9 g

Volume of test hole $\frac{452.9\ g}{1.430\ g/cm^3} = 316.7\ cm^3$

Field dry density $547.9g/316.7\ cm^3 = 1.730\ g/\ cm^3$

Field water content $\frac{639.5-547.9}{547.9} = 16.7\%$

Field Compaction Test

Class Exercise

Field Compaction Test

Specific Gravity Test

- Gs & Gb - which is more?
- Required for 'e', hydrometer analysis and ZAV M-D relationship.
- Outline conduct of practical.

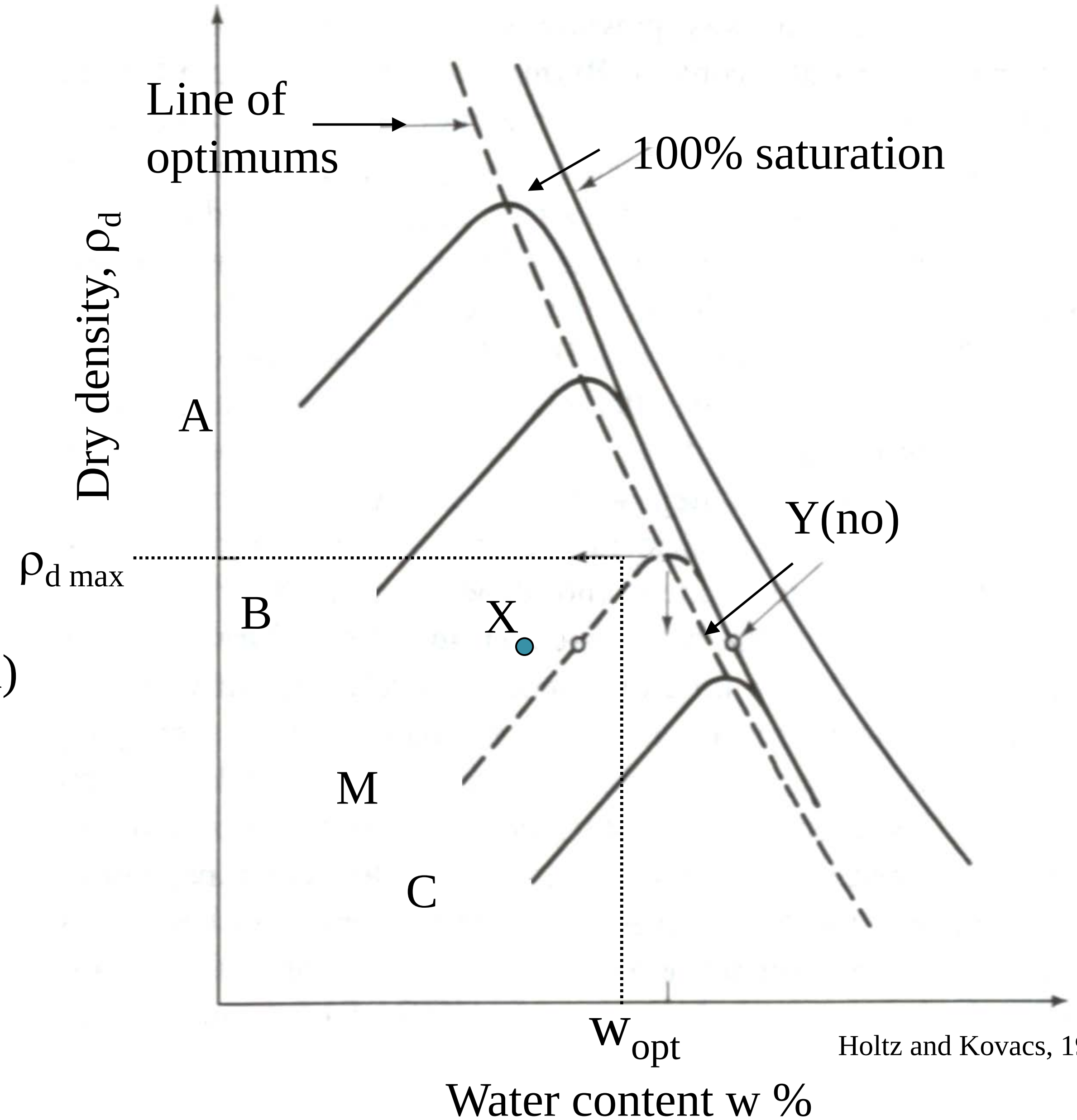
Destructive Methods (Cont.)

Sometimes, the laboratory maximum density may not be known exactly. It is not uncommon, especially in highway construction, for a series of laboratory compaction tests to be conducted on "representative" samples of the borrow materials for the highway. If the soils at the site are highly varied, there will be no laboratory results to be compared with. It is time consuming and expensive to conduct a new compaction curve. The alternative is to implement a ***field check point***, or 1 point Proctor test.

Holtz and Kovacs, 1981

Destructive Methods (Cont.)

- 1 point Proctor test
- Known compaction curves A, B, C
- Field check point X (it should be on the dry side of optimum)



Holtz and Kovacs, 1981

Characteristics Pertinent to Roads and Airfield

Major Divisions (1)	(2)	Symbol: Letter (3)	Symbol: Hatching (4)	Symbol: Color (5)	Name (6)	Value as Subgrade When not Subject to Frost Action (7)	Value as Subbase When not Subject to Frost Action (8)	Value as Base When not Subject to Frost Action (9)	Potential Frost Action (10)	Compressibility and Expansion (11)
COARSE-GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	GW		Red	Well-graded gravels or gravel-sand mixtures, little or no fines	Excellent	Excellent	Good	None to very slight	Almost none
		GP		Red	Poorly graded gravels or gravel-sand mixtures, little or no fines	Good to excellent	Good	Fair to good	None to very slight	Almost none
		GM d		Yellow	Silty gravels, gravel-sand-silt mixtures	Good to excellent	Good	Fair to good	Slight to medium	Very slight
		GM u		Yellow		Good	Fair	Poor to not suitable	Slight to medium	Slight
		GC		Yellow	Clayey gravels, gravel-sand-clay mixtures	Good	Fair	Poor to not suitable	Slight to medium	Slight
	SAND AND SANDY SOILS	SW		Red	Well-graded sands or gravelly sands, little or no fines	Good	Fair to good	Poor	None to very slight	Almost none
		SP		Red	Poorly graded sands or gravelly sands, little or no fines	Fair to good	Fair	Poor to not suitable	None to very slight	Almost none
		SM d		Yellow	Silty sands, sand-silt mixtures	Fair to good	Fair to good	Poor	Slight to high	Very slight
		SM u		Yellow		Fair	Poor to fair	Not suitable	Slight to high	Slight to medium
		SC		Yellow	Clayey sands, sand-clay mixtures	Poor to fair	Poor	Not suitable	Slight to high	Slight to medium

Holtz and Kovacs, 1981

Characteristics Pertinent to Roads and Airfield (Cont.)

Major Divisions (1)	(2)	Symbol: Letter (3)	Symbol: Hatching (4)	Symbol: Color (5)	Drainage Characteristics (12)	Compaction Equipment (13)	Unit Dry Densities: lbf/ft^3 (14)	Unit Dry Densities: Mg/m^3 (15)	Typical Design Values: CBR (16)	Typical Design Values: Subgrade Modulus k (lbf/in.^{3}) (17)
COARSE-GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	GW		Red	Excellent	Crawler-type tractor, rubber-tired roller, steel-wheeled roller	125-140	2.00-2.24	40-80	300-500
		GP		Red	Excellent	Crawler-type tractor, rubber-tired roller, steel-wheeled roller	110-140	1.76-2.24	30-60	300-500
		GM d		Yellow	Fair to poor	Rubber-tired roller, sheepsfoot roller; close control of moisture	125-145	2.00-2.32	40-60	300-500
		GM u		Yellow	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	115-135	1.84-2.16	20-30	200-500
		GC		Yellow	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	130-145	2.08-2.32	20-40	200-500
	SAND AND SANDY SOILS	SW		Red	Excellent	Crawler-type tractor, rubber-tired roller	110-130	1.76-2.08	20-40	200-400
		SP		Red	Excellent	Crawler-type tractor, rubber-tired roller	105-135	1.68-2.16	10-40	150-400
		SM d		Yellow	Fair to poor	Rubber-tired roller, sheepsfoot roller; close control of moisture	120-135	1.92-2.16	15-40	150-400
		SM u		Yellow	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	100-130	1.60-2.08	10-20	100-300
		SC		Yellow	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	100-135	1.60-2.16	5-20	100-300

Please refer to the handout

Holtz and Kovacs, 1981

Drainability

- General
  - Due consideration to intercept and remove water before it reaches roadbed soil.
  - Detrimental effects on road performance. Failures caused by ground or seepage flows can be classified: -
    - Piping and erosion failure as a result of water movement cause soil particles to migrate out of material.
    - Weakening/ Uplifting failure as a result of water movement cause saturation and flooding of materials leading to weakening / uplift.

Drainability

- Controlling Moisture Problems
    - Seal Pavement. Seal cracks and joints, impervious layers, intercepting drains.
    - Use Moisture Insensitive Materials. Use granular material with low % of fines.
    - Adequate Drainage. Permanently lower water table, quick removal once water enters.

- Forms of subsurface water in Pavements.
  - Water vapours. Above Z of S, negligible effect in 'no freeze thaw regions'
  - Bound Moisture. 'Hydroscopic' which is immobile and tightly bound. 'Oriented', loosely bound 'and moves under attraction gradient'.
  - Capillary Moisture. Above Z of S. Height function of pore size & distribution which is related to grain size distribution and density of soil. How controlled? lowering WT & barrier.
  - Gravitational Moisture. Free to move under gravity induced pressure gradient.

- Enhancing Drainage of Road bed Soil

  - Installation of transverse slotted drainage pipes linked to drainage ditches.
  - Installing sand drains to the depth of pervious layer.
  - Cutoff blanket at sub grade level- water moves to drainage ditches.
  - Transfer elevation should not be a bathtub.

Thanks