SOIL COMPACTION

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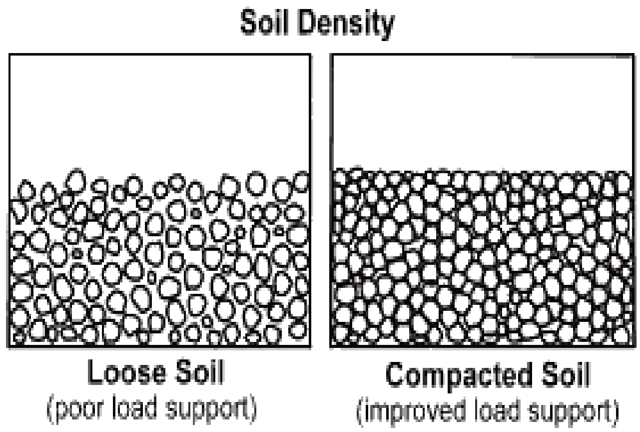
Soil Compaction

Soil compaction is defined as the method of mechanically increasing the density of soil.

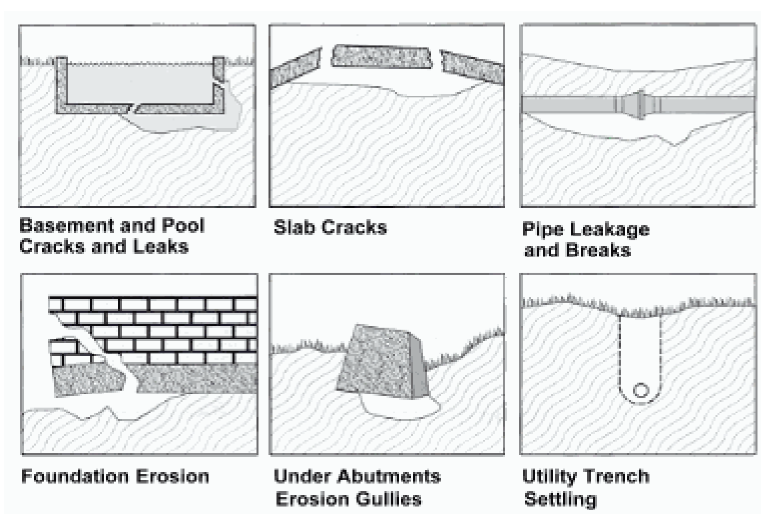
In construction, this is a significant part of the building process.

If performed improperly, settlement of the soil could occur and result in unnecessary maintenance costs or structure failure.

Almost all types of building sites and construction projects utilize mechanical compaction techniques.

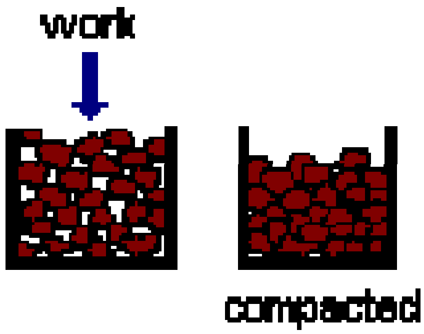


Results of Poor Compaction



SOIL COMPACTION

- Compaction is a process of increasing soil density and removing air, usually by mechanical means.



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By reducing the air voids, more soil can be added to the block.

When moisture is added to the block (water content, wc, is increasing)

- *the soil particles will slip more on each other causing more reduction in the total volume, which will result in adding more soil and,*
- *hence, the dry density will increase, accordingly.*

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Moisture vs. Soil Density

Moisture content of the soil is vital to proper compaction.

Moisture acts as a lubricant within soil, sliding the particles together.

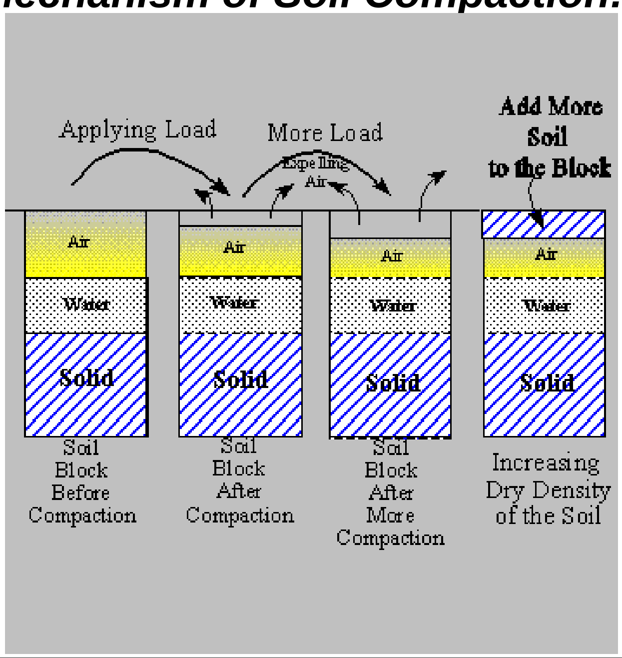
Too little moisture means inadequate compaction - the particles cannot move past each other to achieve density.

Too much moisture leaves water-filled voids and subsequently weakens the load-bearing ability.

The highest density for most soils is at a certain water content for a given compaction effort. The drier the soil, the more resistant it is to compaction.

In a water-saturated state the voids between particles are partially filled with water, creating an apparent cohesion that binds them together. This cohesion increases as the particle size decreases (as in clay-type soils).

Mechanism of Soil Compaction:



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General Principles:

The degree of compaction of soil is measured by its

unit weight, and
optimum moisture content, wc.

The process of soil compaction is simply expelling the air from the voids.
or reducing air voids

Reducing the water from the voids means consolidation.

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MOISTURE DENSITY RELATIONSHIPS (SOIL COMPACTION)

In the construction of highway, embankments, earth dams, and many other engineering projects, loose soils must be compacted to increase their unit weight.

Compaction improves characteristics of soils:

1- Increases Strength
2- Decreases permeability
3- Reduces settlement of foundation
4- Increases slope stability of embankments

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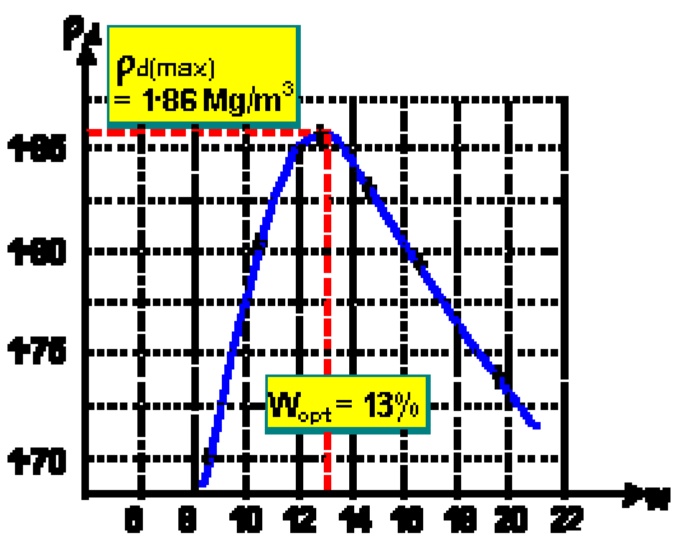
Laboratory Compaction:

Two Tests are usually performed in the laboratory to determine the maximum dry unit weight and the OMC.

1- Standard Proctor Compaction Test

2- Modified Proctor Compaction Test

The mechanical effort used is normally ramming with a 2.5kg hammer for the BS light compaction test or a 4.5kg rammer for the BS heavy compaction test.



Dry-density/water-content relationship

- The aim of the test is to establish the maximum dry density that may be attained for a given soil with a standard amount of compactive effort.

- When a series of samples of a soil are compacted at different water content the plot usually shows a distinct peak.

The **maximum dry density** occurs at an **optimum water content**

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- For most soils and for a given compactive effort, the density of the soil will increase to a certain point, as the moisture content is increased.
- That point is called the **maximum density.**
- After that point, the density will start to decrease with any further increase in moisture content.
- The moisture content at which maximum density occurs is called the **optimum moisture content** (OMC).
- Each compactive effort for a given soil has its own OMC. As the compactive effort is increased, the maximum density generally increases and the OMC decreases.

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- The curve is drawn with axes of dry density and water content and the controlling values are values read off:
- $\rho d(max)$ = maximum dry density
- wopt = optimum water content
- Different curves are obtained for different compactive efforts

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Expressions for calculating density

- A compacted sample is weighed to determine its mass: **M** (grams)
- The volume of the mould is: **V** (ml)
- Sub-samples are taken to determine the water content: **w**

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The calculations are:

$$\text{Bulk density, } \rho = \frac{M}{V} \quad [g/ml = Mg/m^3]$$

$$\text{Dry density, } \rho_d = \frac{\rho}{1+w} \quad [g/ml = Mg/m^3]$$

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Dry density and air-voids content

A fully saturated soil has zero air content.

In practice, even quite wet soil will have a small air content

$$\text{Air-voids content, } A_v = \frac{\text{Volume of air}}{\text{Total volume}}$$

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- The maximum dry density is controlled by both the water content and the air-voids content. Curves for different air-voids contents can be added to the ρd / w plot using this expression:

$$\rho_d = \frac{G_s \rho_w}{1 + wG_s}\left(1 - A_v\right)$$

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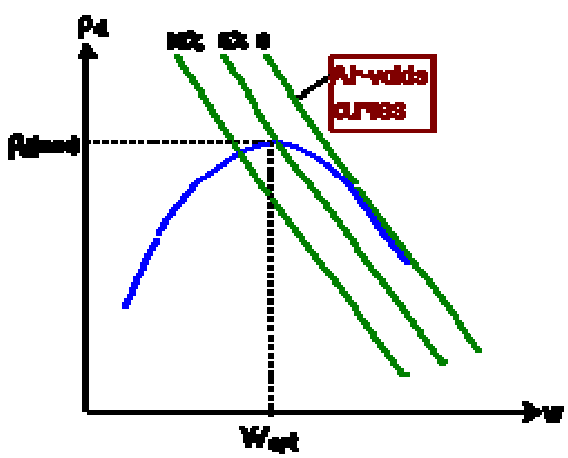

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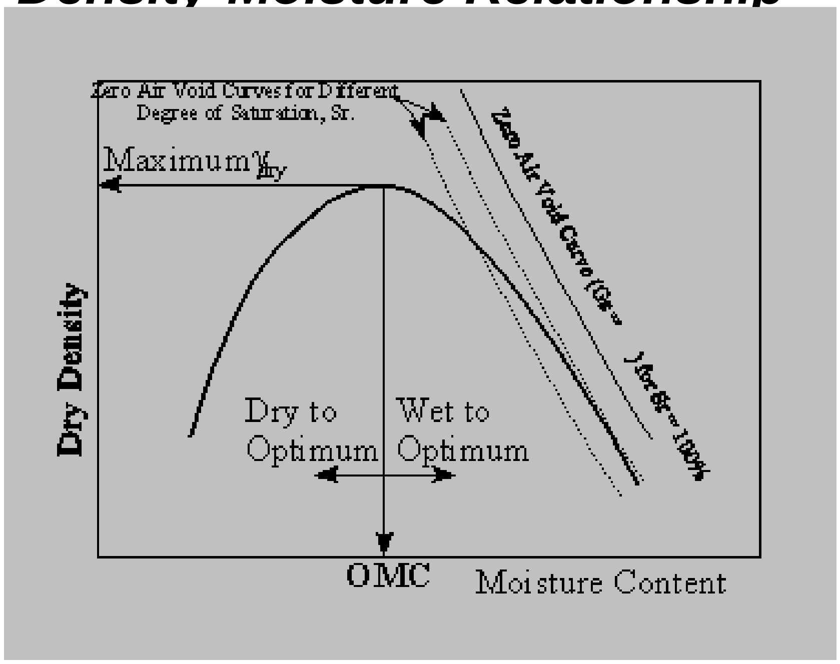
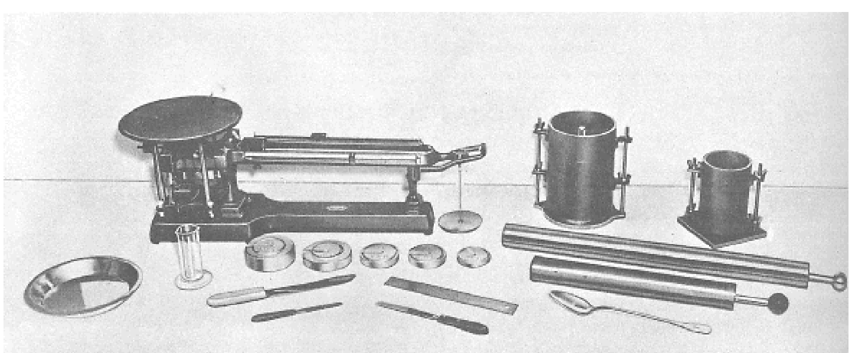
Density-Moisture Relationship





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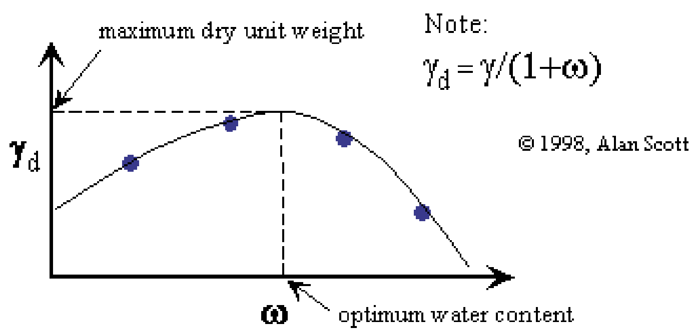
The Standard Proctor Test

The Standard Proctor Test is a laboratory test used to determine the optimum water for a given compaction energy, for a given soil.



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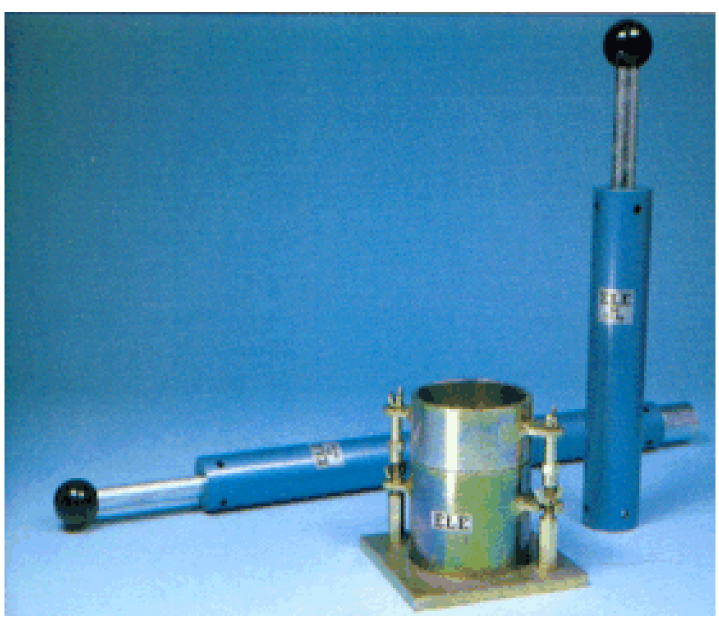

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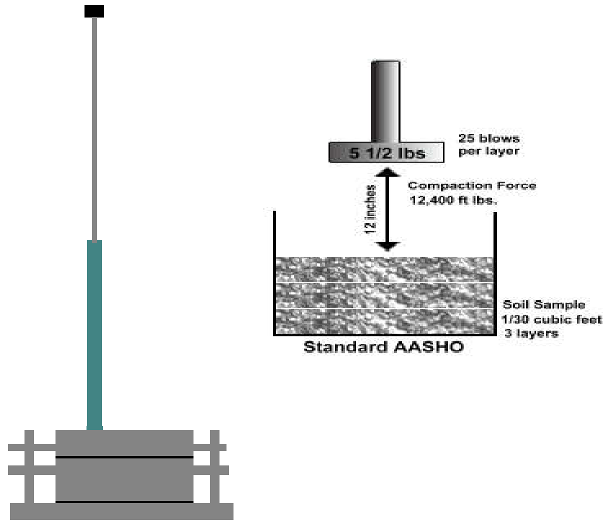

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STANDARD PROCTOR TEST

- Apply 25 blows from the rammer dropped from a height of 300mm above the soil.
- Distribute the blows uniformly over the surface and ensure that the rammer always falls freely and is not obstructed.
- Place a second quantity of moist soil in the mould such that when compacted it occupies a little over two-thirds of the height of the mould body.
- Repeat procedure once more so that the amount of soil used is sufficient to fill the mould body, with the surface not more than 6mm proud of the upper edge of the mould body.

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MODIFIED PROCTOR TEST

- As for 2.5kg rammer method, but the rammer has a weight of 4.5kg and dropped from a height of 450mm.
- In this compaction test the mould and the amount of dry soil used is the same as for the 2.5kg rammer method but the heavier compactive effort is applied to the test sample.
- The rammer has a mass of 4.5kg with a free fall of 450mm above the surface of the soil.
- The number of blow per layer remains the same, 25, but the number of layers compacted is increased to five.

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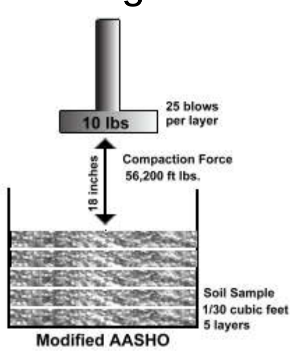
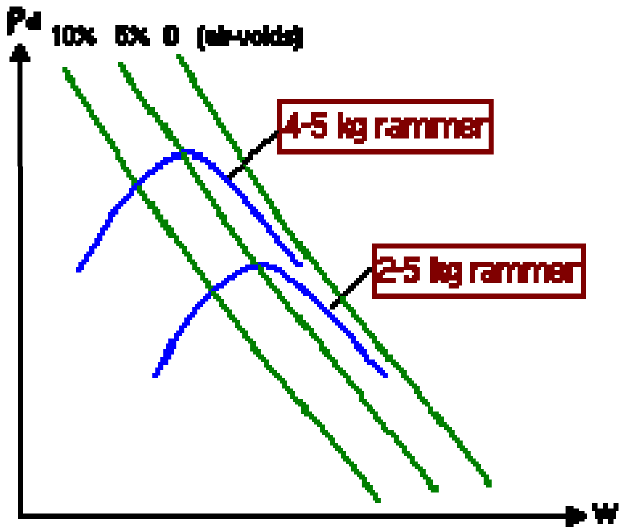
Modified Proctor Test

This is similar to the Proctor Test except a hammer is used to compact material for greater impact.

The test is normally preferred in testing materials for higher shearing strength.




ρd
10%
5%
0
(air-voids)
4-5 kg rammer
2-5 kg rammer
w

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ρd
0 air-voids
well-graded sand
sandy clay
clay: low plasticity
clay: high plasticity
uniform sand
w

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In both tests the compaction energy is:

$$E = \frac{\text{Number of blows per layer x Number of layers x Weight of hammer x Height of drop of hammer}}{\text{volume of mold}}$$

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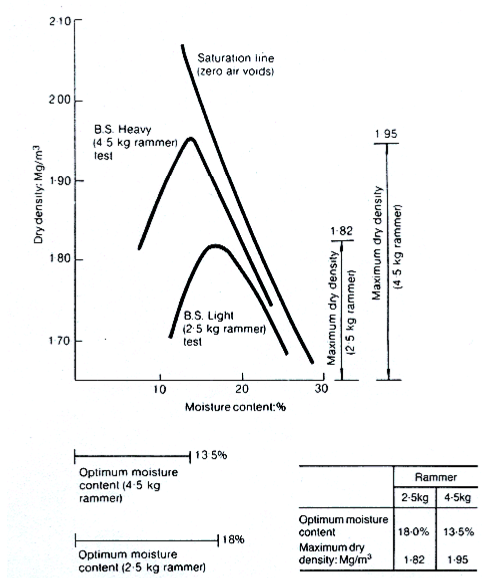

	Rammer	
	2·5kg	4·5kg
Optimum moisture content	18·0%	13·5%
Maximum dry density: Mg/m³	1·82	1·95

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Compaction Characteristics and Soil Grouping in USCS

Group Symbol	Compaction Characteristics	Compressibility and Expansion	Value as Embankment Material	Value as Subgrade Material
GW	Good	Very Little	Very Stable	Excellent
GP	Good	Very Little	Reasonably Stable	Excellent to Good
GM	Good	Slight	Reasonably Stable	Excellent to Good
GC	Good	Slight	Reasonably Stable	Good
SW	Good	Very Little	Very Stable	Good
SP	Good	Very Little	Reasonably Stable when Dense	Good to Fair
SM	Good	Slight	Reasonably Stable when Dense	Good to Fair
SC	Good to Fair	Slight to Medium	Reasonably Stable	Good to Fair
ML	Good to Poor	Slight to Medium	Poor, gets better with high density	Fair to Poor
CL	Good to Fair	Medium	Stable	Fair to Poor
OL, MH, CH, OH, PT	Fair to Poor	High	Poor, Unstable	Poor to Not Suitable

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Soil Classification

Major Division		Symbol	Description	Value as a Base, Subbase, or Subgrade	Potential Frost Action
Coarse grained soils with 50% or more larger than No 200 sieve opening	Gravel and/or gravelly soils	GW	Well graded gravels or gravel-sand mixture with 5% or less amount of fines	Good to excellent for subbase and subgrade. Fair to good for base.	None to very slight
		GP	Poorly graded gravels or gravel-sand mixture with little or no fines	Fair to good for all.	None to very slight
		GM	Silty gravel, gravel-sand-silt mixtures	Not suitable for base, 15% or less less of fines with PI of 5 or less. 50% or less of fines for subbase and subgrade.	Slight to medium
		GC	Clayey gravel, gravel sand clay mixture	Not suitable for base, 15% or less of fines with PI of 5 or less. Poor to good for subbase and subgrade.	Slight to medium
	Sand and/or sandy soils	SW	Well-graded sands or gravelly sand mixture with 5% or less amount of fines	Poor for base. Fair to good for subbase and subgrade.	None to very slight
		SP	Poorly graded sands or gravelly sand mixture with 5% or less amount of fines	Poor to not suitable for base. Poor to fair for subbase and subgrade.	None to very slight
		SM	Silty sands, sand silt mixture	Not suitable for base. Poor to good for subbase and subgrade.	Slight to high
		SC	Clayey sands, sand-clay mixture	Not suitable for base. Poor to fair for subbase and subgrade.	Slight to high
Fine-grained soils with more than 50% smaller than No 200 sieve opening	Silt and clays with LL < 50	ML	Inorganic silt, silty fine sands	Not suitable for base or subbase. Poor to fair for subgrade.	Medium to very high
		CL	Inorganic clay of low to medium plasticity, lean clays	Not suitable for base or subbase. Poor to fair for subgrade.	Medium to high
		OL	Organic silt and organic silt-clay of low plasticity	Not suitable for base or subbase. Poor to very poor for subgrade.	Medium to high
	Silt and clays with LL > 50	MH	Inorganic silt micaceous or diatomaceous silty soil	Not suitable for base or subbase. Poor to fair for subgrade.	Medium to very high
		CH	Inorganic clay of high plasticity, fatty clays	Not suitable for base or subbase. Poor to fair for subgrade.	Medium
		OH	Organic clay of medium to high plasticity	Not suitable for base or subbase. Poor to very poor for subgrade.	Medium

* NOT recommended

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Types of Compaction

There are four types of compaction effort on soil or asphalt:

- Vibration
- Impact
- Kneading
- Pressure

These different types of effort are found in the two principle types of compaction force:

static and vibratory.

Static force is simply the deadweight of the machine, applying downward force on the soil surface, compressing the soil particles.

The only way to change the effective compaction force is by adding or subtracting the weight of the machine.

Static compaction is confined to upper soil layers and is limited to any appreciable depth.

Kneading and pressure are two examples of static compaction.

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Vibratory force uses a mechanism, usually engine-driven, to create a downward force in addition to the machine's static weight.

The vibrating mechanism is usually a rotating eccentric weight or piston/spring combination (in rammers). The compactors deliver a rapid sequence of blows (impacts) to the surface, thereby affecting the top layers as well as deeper layers.

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Vibration moves through the material, setting particles in motion and moving them closer together for the highest density possible.

Based on the materials being compacted, a certain amount of force must be used to overcome the cohesive nature of particular particles.

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EXAMPLE

The following results were obtained from a standard compaction test on a soil:

Mass (g) :	2010	2092	2114	2100	2055
Water content (%):	12.8	14.5	15.6	16.8	19.2

The value of Gs= 2.67

The volume of the mold is 1000 cm3.

a) Plot the dry density-water content curve
b) Give the compaction characteristics of the soil
c) Plot also the curves of zero, 5% and 10% air content lines.
d) Give the value of air content at max. dry density.