

Compaction

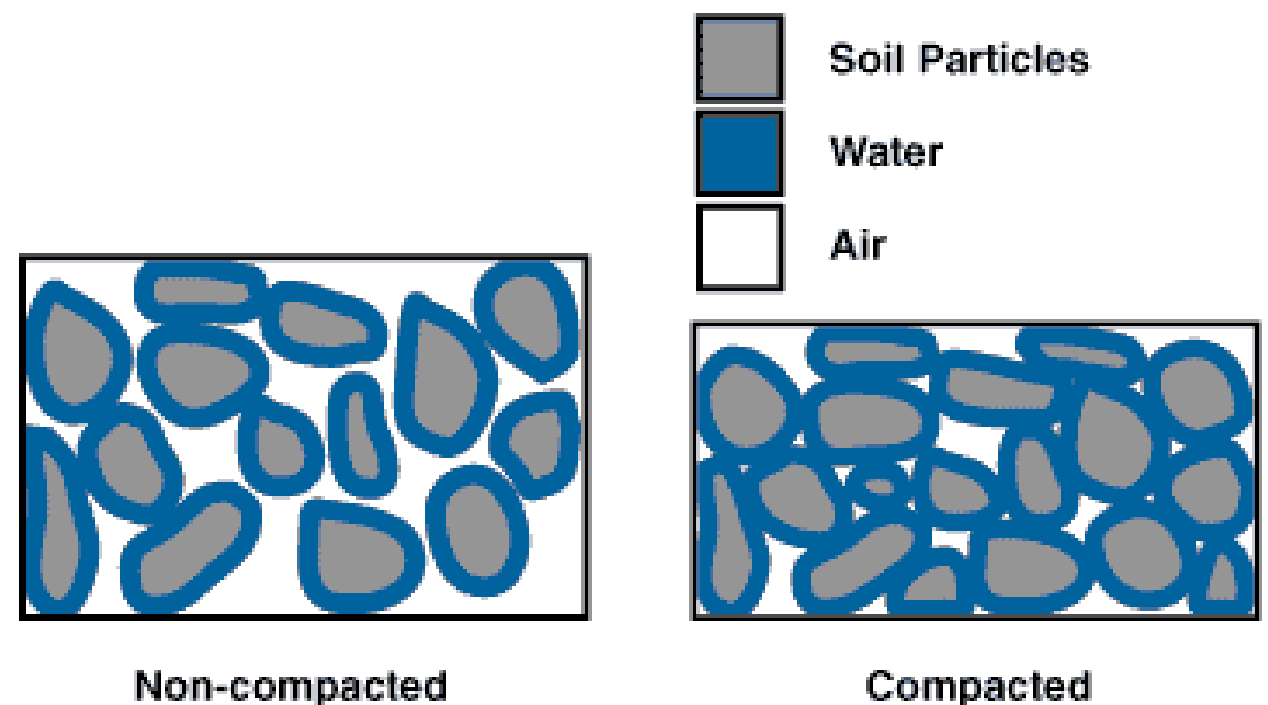
Text: Das, 2010. Principles of Geotechnical Engineering Ch 6

In the construction of highway embankments, earth dams and many other engineering structures, loose soils must be compacted to increase their strength and durability, and to decrease their permeability.

Compaction increases the strength characteristics of soils, which increases bearing capacity.

Compaction also reduces settlement of structures, and increases the stability of slopes.

http://commons.wikimedia.org/wiki/File:Seabees_compactor_roller.jpg



http://www.artistic-arborist.com/apr_2005.htm

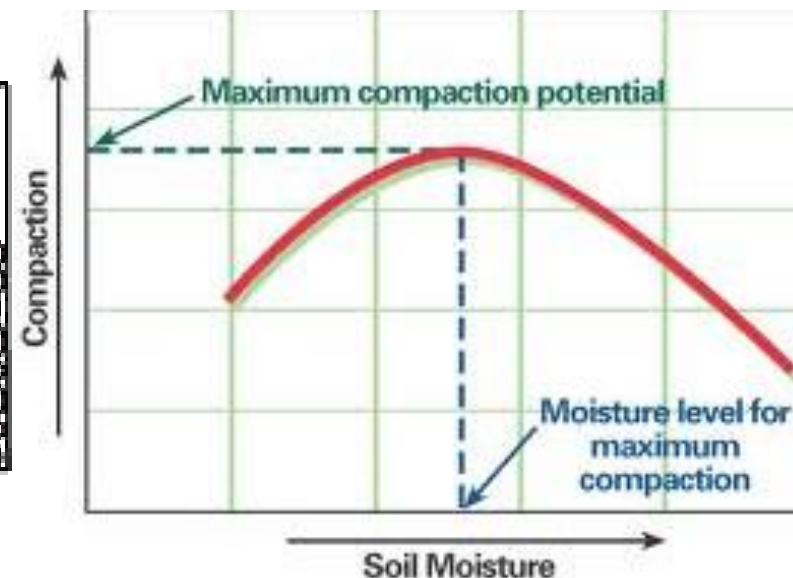
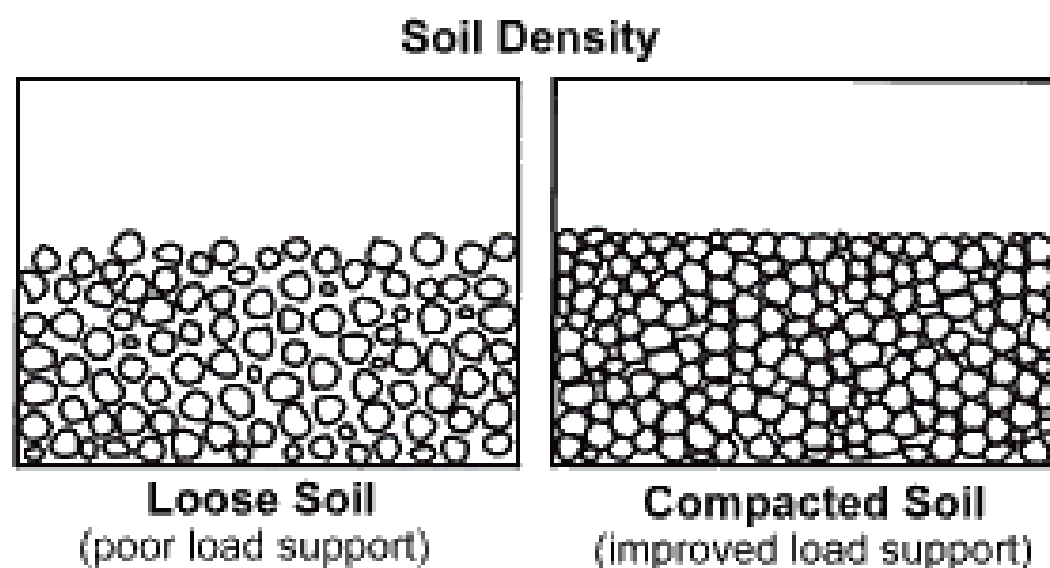
Compaction - General Principles

Compaction increases soil density by removing air. This requires mechanical energy.

The degree of compaction of soil is measured in terms of its dry unit weight. Soil is not necessarily dry after compaction. Dry density can be assessed from measured characteristics such as moisture content, which varies during the compaction process.

When water is added to soil during compaction it acts as a softening agent on soil particles. These can slip over each other and move into a more densely packed position.

Beyond an *optimum moisture content*, around 15%, adding more water reduces the compacted density as the additional water adds to the volume of the soil. Water displaces solid particles and leaves air-filled pore spaces when dry.



Wet soil becomes "boggy"; cannot support compaction effort

Optimum Moisture Content

The Proctor Test

In the Proctor test, soil is compacted in a mould. Moisture content is gradually increased in successive tests.

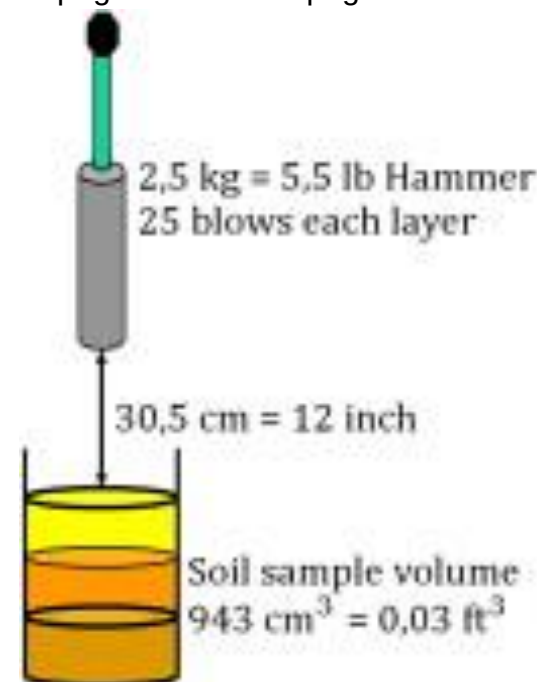
The Australian Standard test is described in AS1289.5.1.1 (Reading 5). A standard compaction is applied: three equal layers in a standard 1 litre mould with a 2.7kg drop hammer delivering 25 blows to each layer.

The collar of the mould is removed and the compacted soil surface is levelled to the true volume, this volume of soil is weighed, dried and weighed again.

<http://www.atia.org/i4a/pages/index.cfm?pageid=3586>



<http://www.industrialscientific.in/proctor-compaction-apparatus.htm>



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<http://soilweb.landfood.ubc.ca/labmodules/compaction/soil-bulk-density>

Optimum Moisture Content

Moist and dry density

Given the wet (M_b) and dry (M_s) mass of soil and the mould volume V , the wet (ρ_b) and dry (ρ_d) densities are calculated as:

$$\rho_b = \frac{M_b}{V} = \rho_s \frac{1 + W}{1 + e}$$

$$\text{where } W = \frac{M_b - M_s}{M_s}$$

$$\text{thus } \rho_d = \rho_s \frac{1 + 0}{1 + e} = \frac{\rho_b}{1 + W}$$

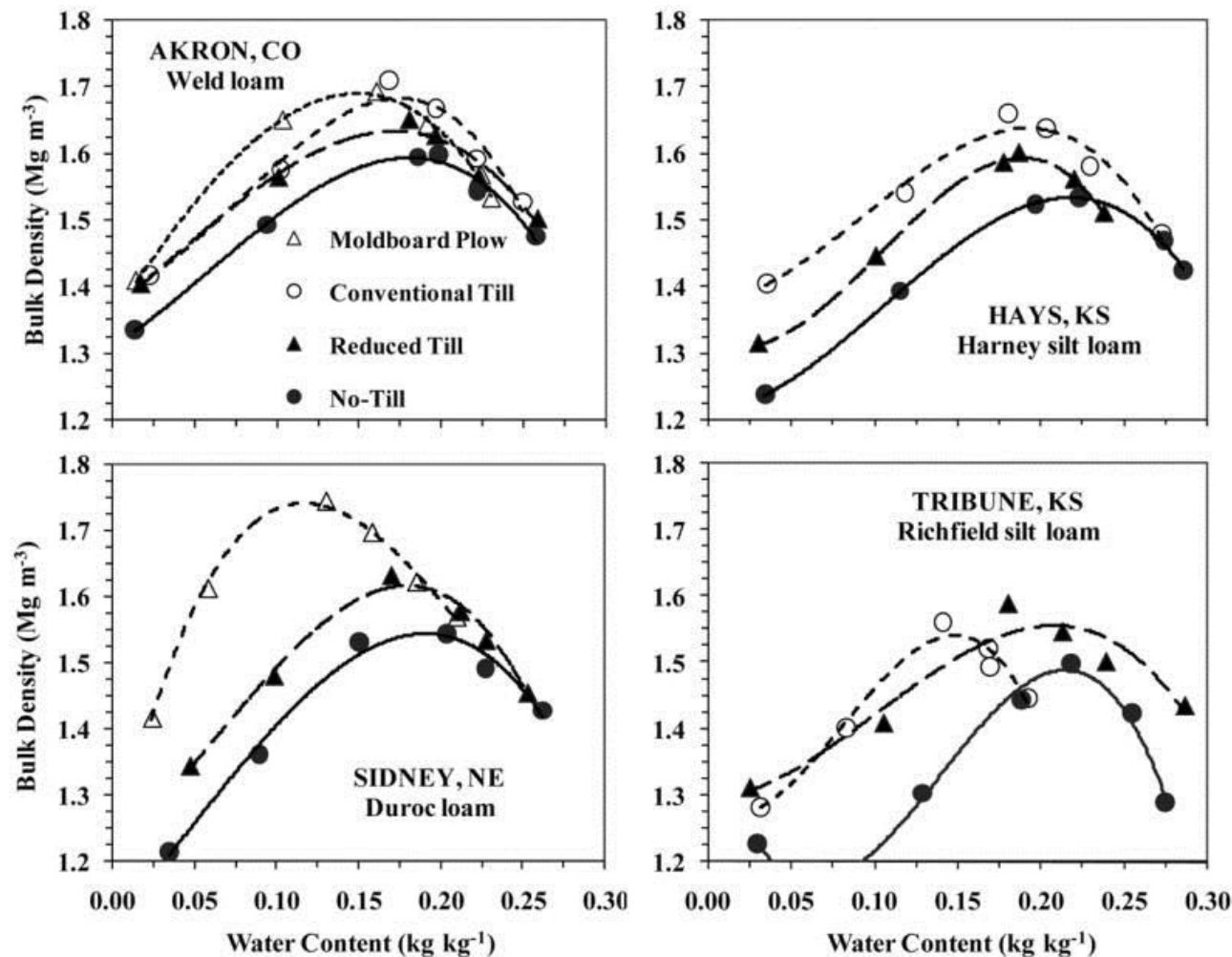
$$\text{and } e = G(1 + W) - 1$$

The dry density ρ_d is plotted against moisture content W . G can be measured directly by a sedimentation test (lecture 4) or taken as the standard value of 2.7.

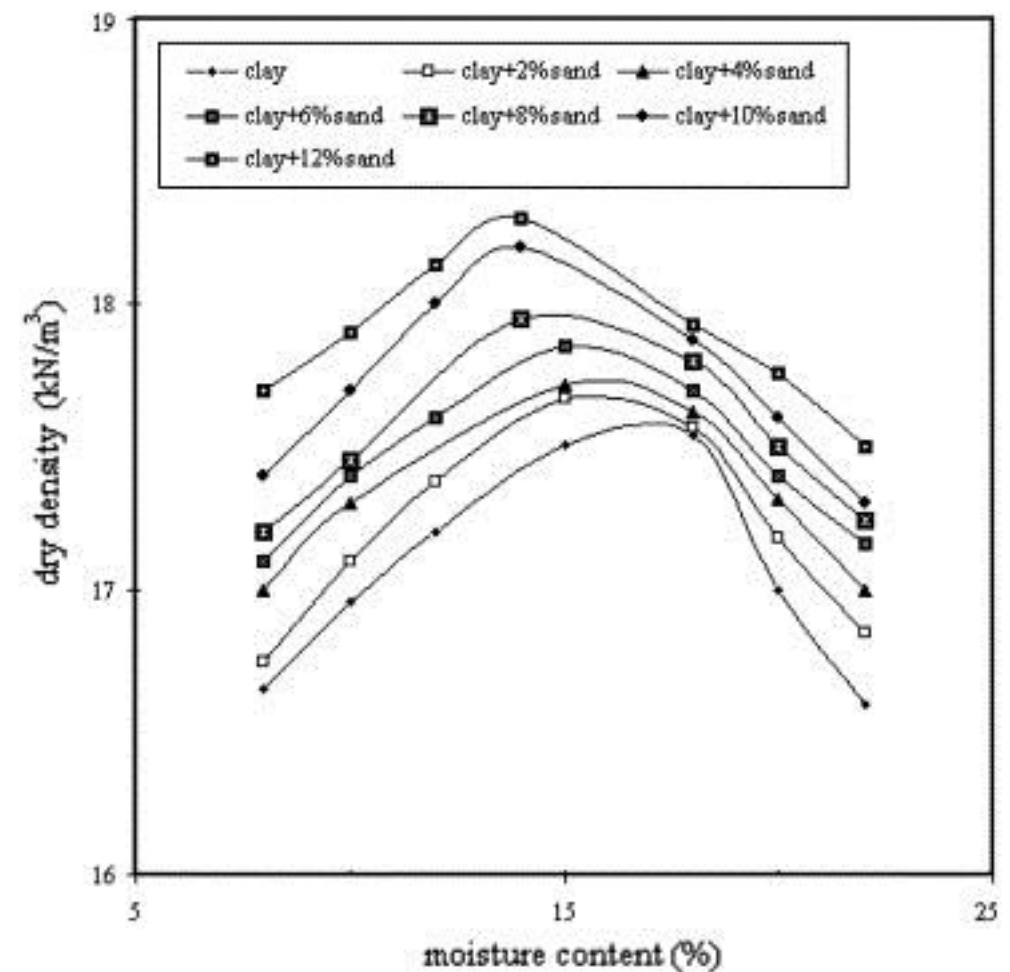
Optimum Moisture Content

Moist and dry density

The plot of dry density against moisture content is roughly parabolic, and depends on the soil type (coarse or fine) for optimum moisture content and maximum dry density:



<http://www.nature.com/neuro/journal/vaop/ncurrent/full/nn.3594.html>

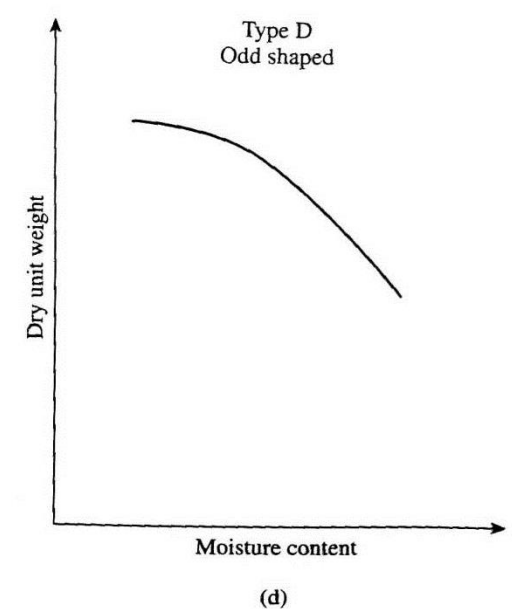
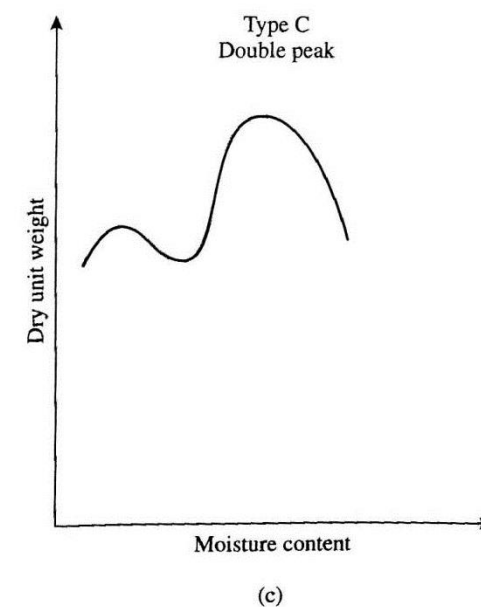
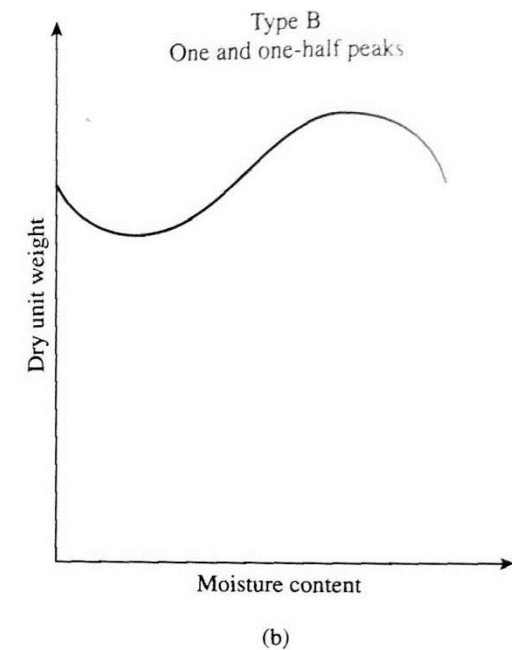
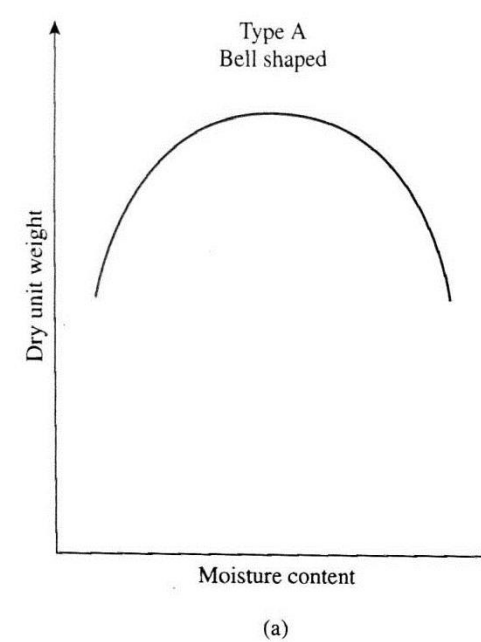
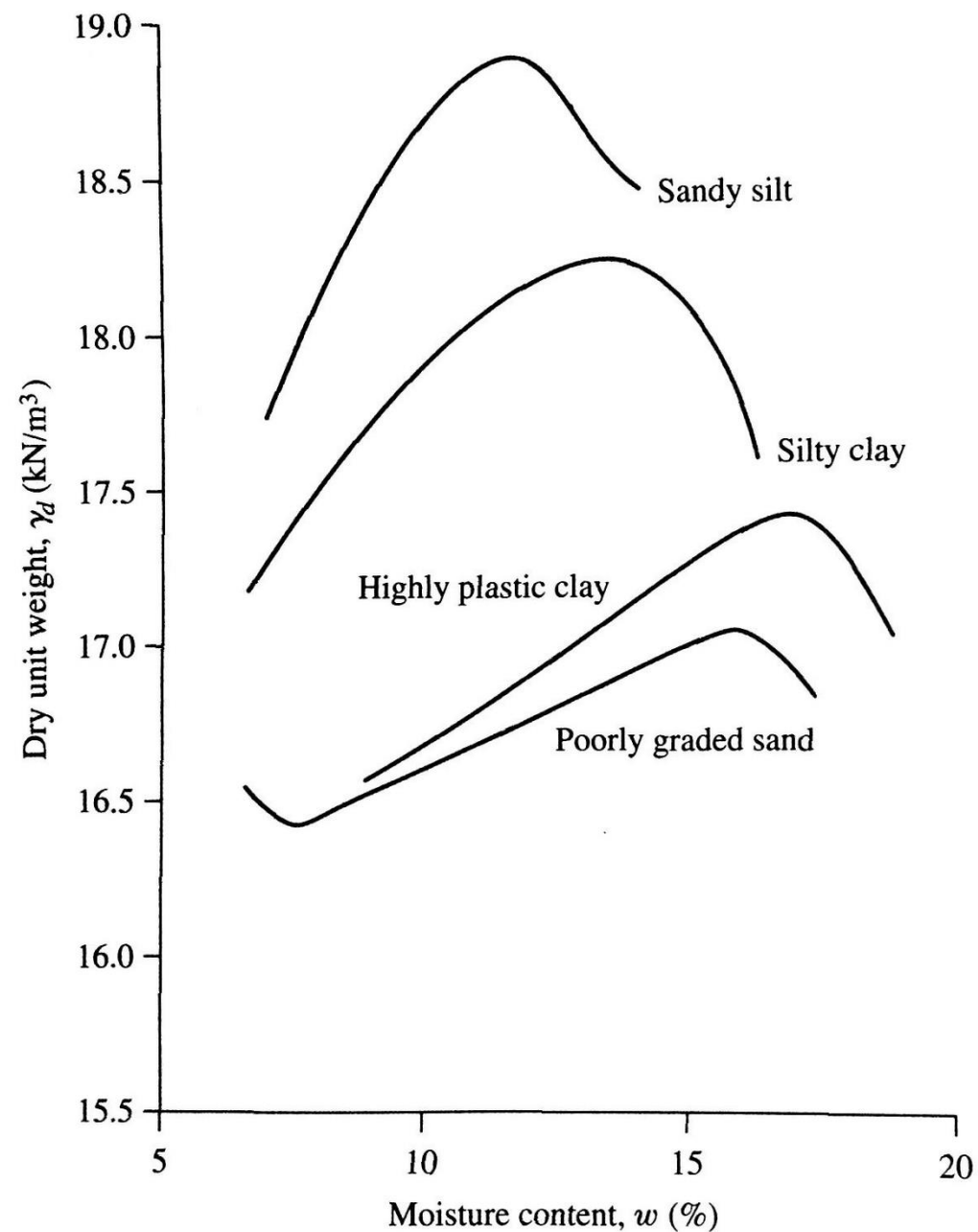


<http://astro.uchicago.edu/sza/primer.html>

Optimum Moisture Content

Some exceptions

Not all soils conform to this basic picture however:

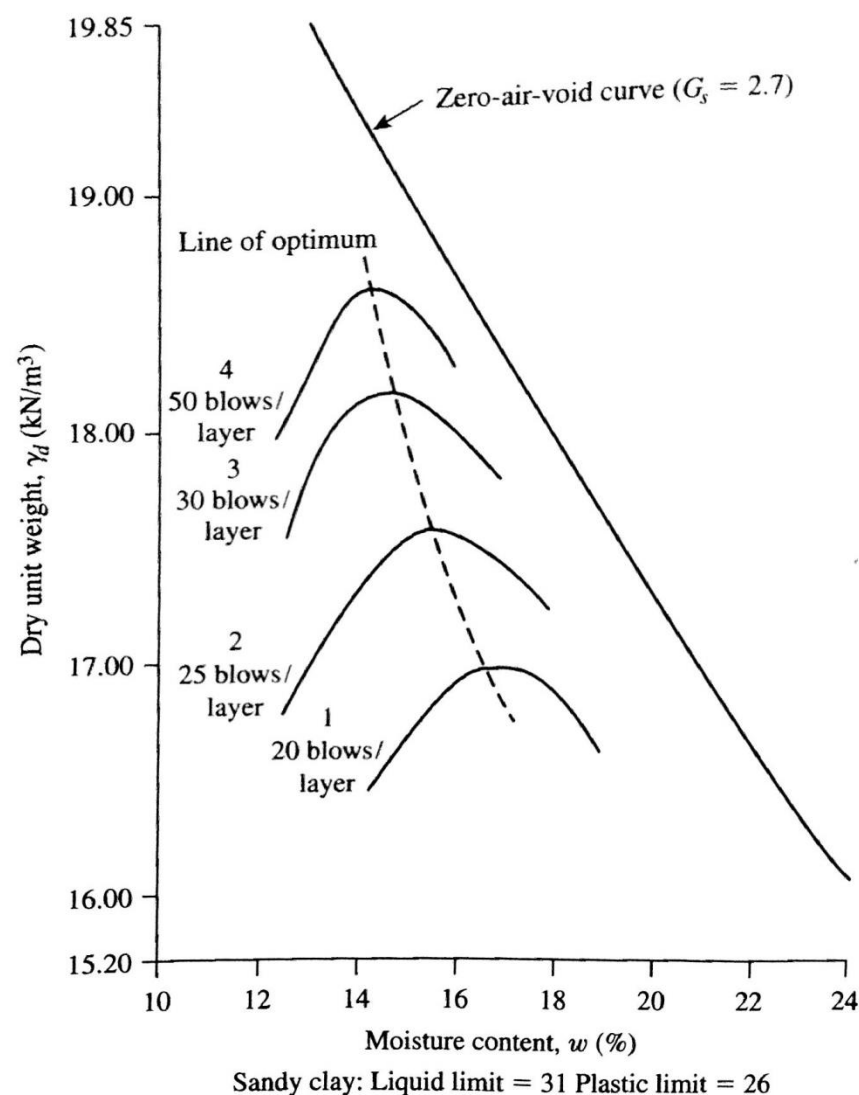


Effect of Compactive Effort

The more energy is put into compaction, the higher the final dry density.

There is a limit however. Irregularly-shaped particles cannot be brought into perfectly close contact so there remains an irreducible pore space.

For comparison purposes it is common to calculate and plot a theoretical maximum dry density based on the idea of a *zero air voids* end point:



The zero air voids curve assumes that all air is squeezed out so that voids are filled with water.

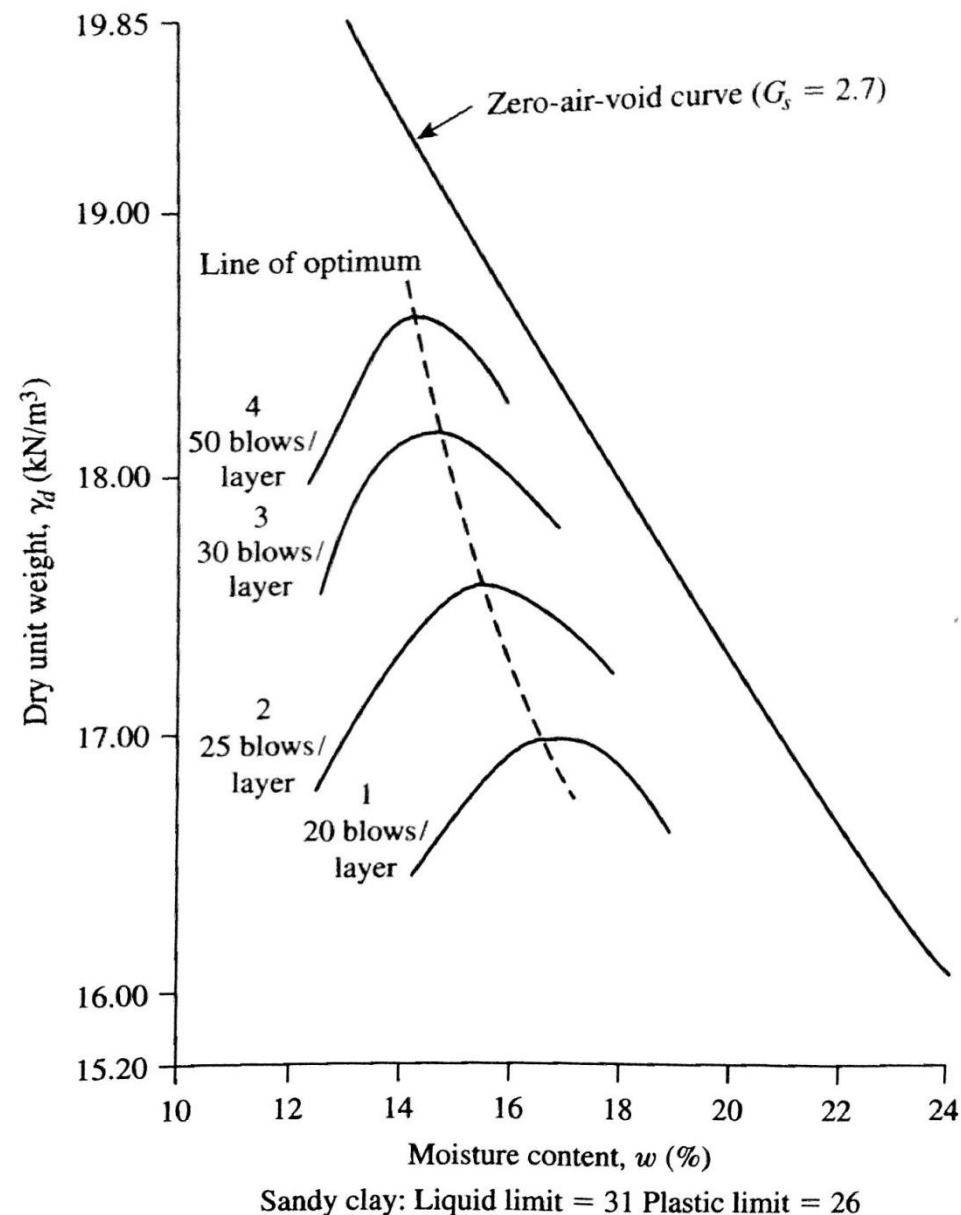
In other words the theoretical maximum compaction increases the saturation to 100%

$$S = \frac{GW}{e_z} = 100\%$$

$$e_z = WG$$

At theoretical maximum compaction for a given moisture content, the void ratio is proportional to W .

Effect of Compactive Effort



Theoretical maximum moist and dry densities depend on moisture content and the theoretical void ratio:

$$\rho_z = \rho_s \frac{1 + W}{1 + e_z} = G \rho_w \frac{1 + W}{1 + WG}$$

The void ratio is assumed to be unchanged as the soil dries, ie all water volume is replaced with air volume:

$$\rho_{zd} = \rho_s \frac{1 + 0}{1 + WG} = \frac{G \rho_w}{1 + WG}$$

ρ_z is the theoretical maximum moist density for a given moisture content.

ρ_{zd} is the theoretical maximum dry density. Again, G may be measured or estimated as $G = 2.7$

$$S = \frac{GW}{e_z} = 100\%$$

$$e_z = WG$$

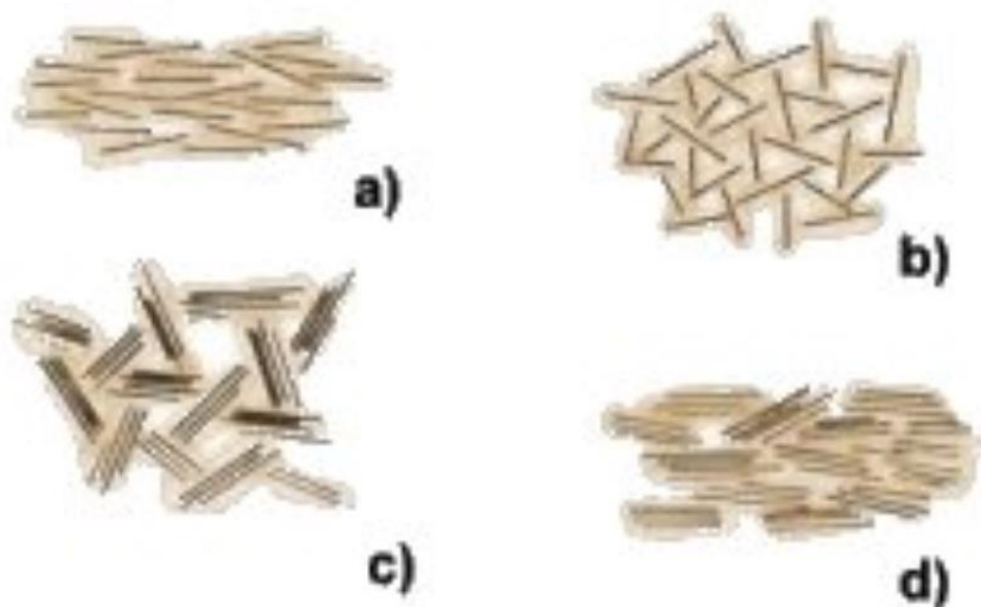
Compaction of Cohesive Soil

Dispersion and Flocculation of compacted clays

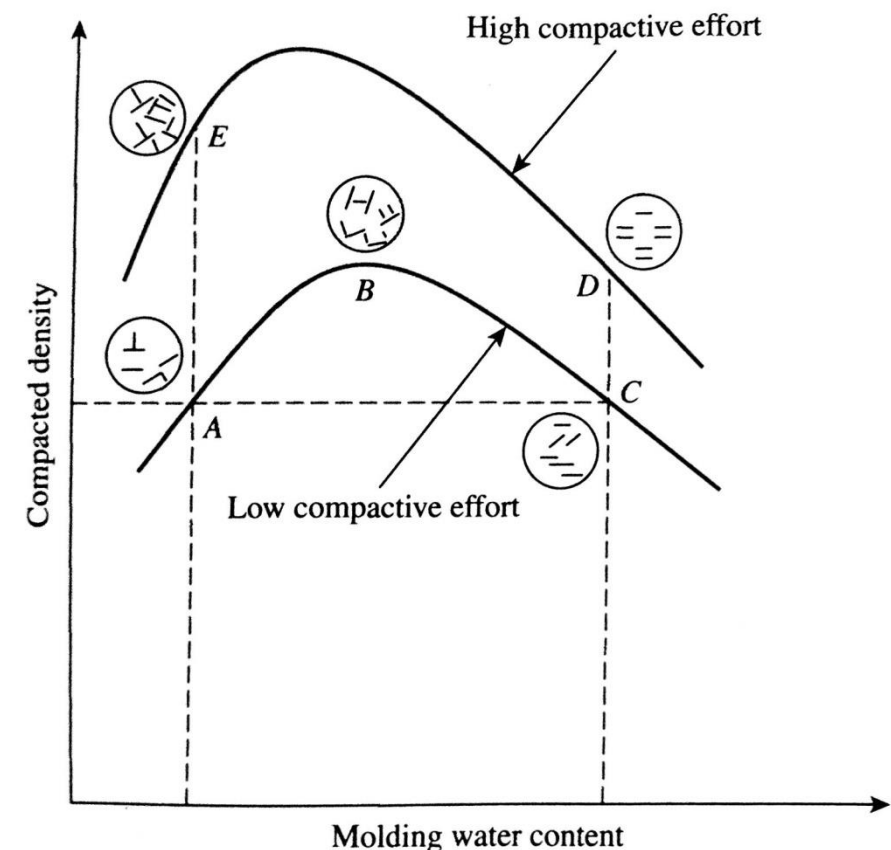
Compaction at low moisture content prevents full development of the diffuse double layer, so clay domains remain in a flocculated state.

At higher moisture levels, the diffuse double layer forms and a dispersed orientation develops with higher dry density.

Further increases in moisture content tend to displace solids with water so the dry density decreases.



<http://www.gypsoil.com/what-is-gypsoil/how-it-works>

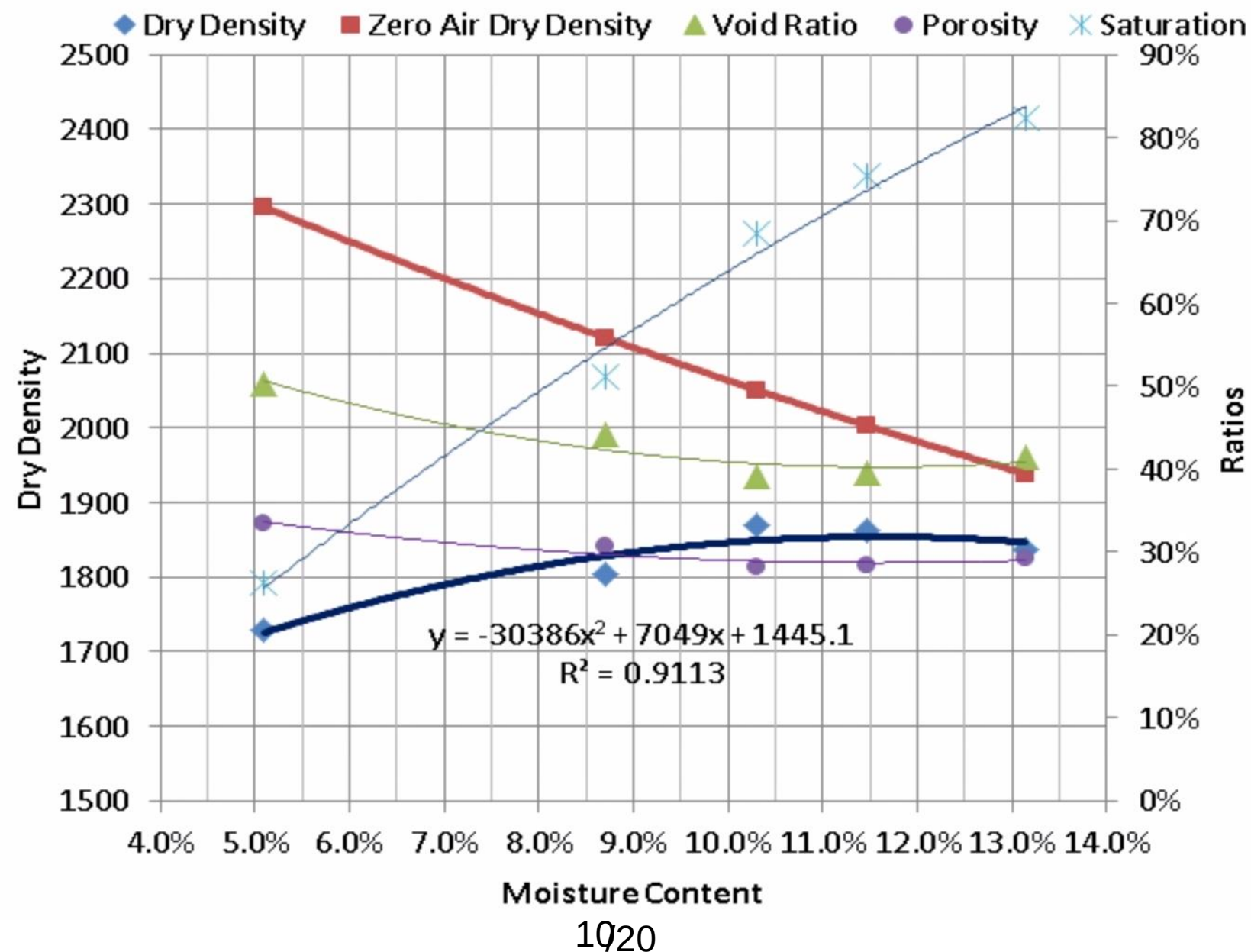


Compaction: Graphs and Models

Measured and theoretical values can be plotted on the same scale.

Polynomial regression analysis can be quite accurate ($R^2 > 0.9$).

Note that the saturation tends to 100% as the actual and theoretical densities converge.



Compaction in Practice: Equipment

Most compaction in the field is done with rollers. The four most common type of rollers are:

- Smooth wheeled (or drum) rollers;
- Pneumatic rubber tyred rollers;
- Sheepsfoot rollers;
- Vibratory rollers.



<http://www.ritchiewiki.com/wiki/index.php/Roller>



<http://www.shutterstock.com/g/kadmy/sets/453733-machinery?page=2>



http://www.fansshare.com/community/uploads103/6671/seabees_compactor_roller/



<http://www.tradeindia.com/Seller-2702423-JAYPEE-INDIA-LTD-/Construction-Machinery-258.html>

Compaction Equipment

Smooth wheeled rollers

Smooth wheel rollers are suitable for proof rolling subgrades and for finishing operations of fills with sandy and clay soils.

Drums provide 100% coverage under the wheels with ground contact pressures as high as 310 to 380 kPa.

Drums are not suitable for producing high unit weights of compaction when used on thicker layers.



Compaction Equipment

Pneumatic rollers

Pneumatic rubber tired rollers are better in many respects than smooth wheel rollers.

Pneumatic rollers are heavily loaded with several rows of tyres. The tyres are closely spaced, 4 to 6 in a row.

The contact pressure under the tyres can range from 600 to 700 kPa and they produce about 70 to 80% coverage.

Pneumatic rollers can be used for sandy and clay soil compaction.

Compaction is achieved by a combination of pressure and kneading action.



Compaction Equipment

Sheepsfoot rollers

Sheepsfoot rollers are drums with a large number of projections. The area of each projection may range from 25 to 85 cm².

These rollers are most effective in compacting clay soils.

The contact pressure under the projections can range from 1400 to 7000 kPa.

Compaction takes place in stages, with lower stages (known as lifts) compacted with different equipment to later lifts.



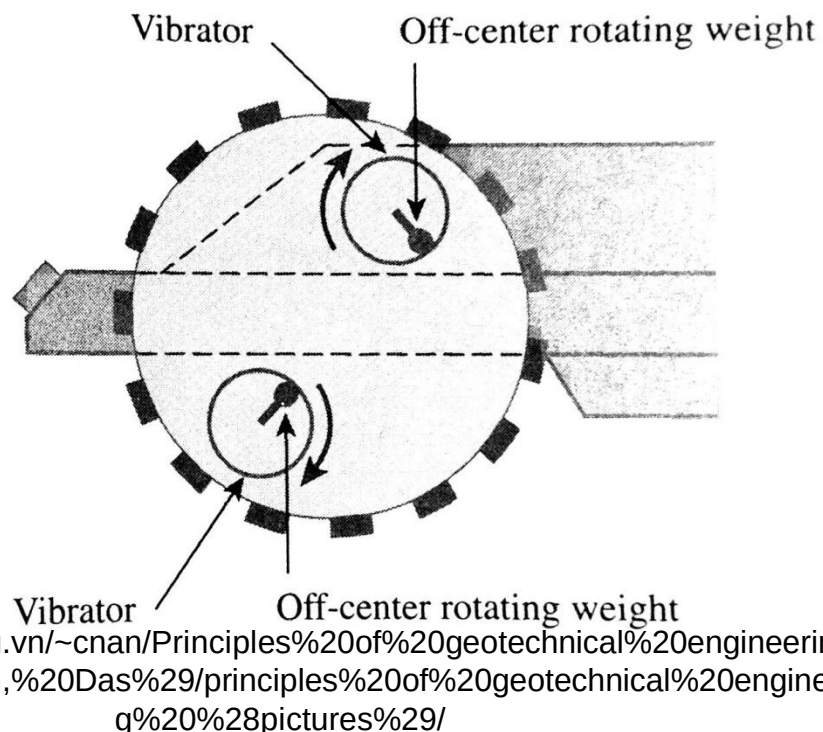
Compaction Equipment

Vibratory rollers

Vibratory rollers are extremely efficient in compacting granular soils.

Vibrators can be attached to smooth wheel, pneumatic or sheepfoot rollers to provide vibratory effects.

Hand-held vibrating units can be used in confined spaces.



<https://www.proxibid.com/asp/LotDetail.asp?ahid=3786&aid=47576&lid=12478929>



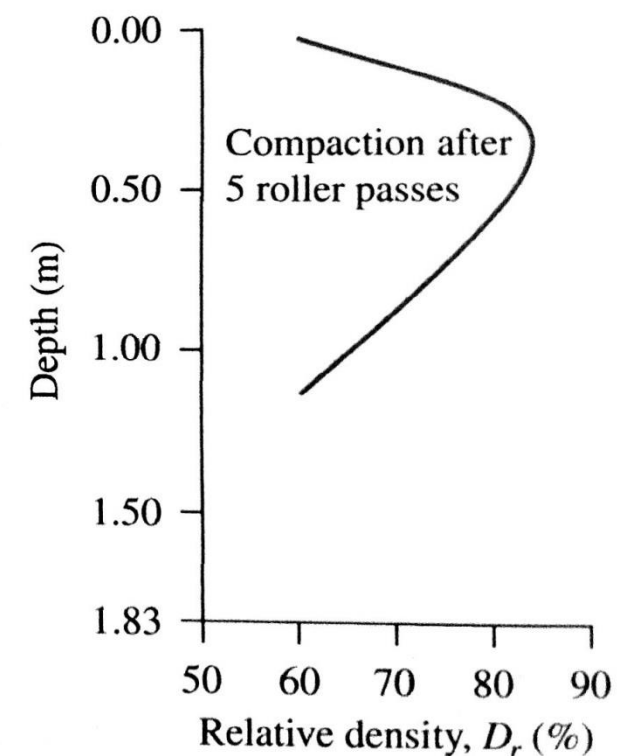
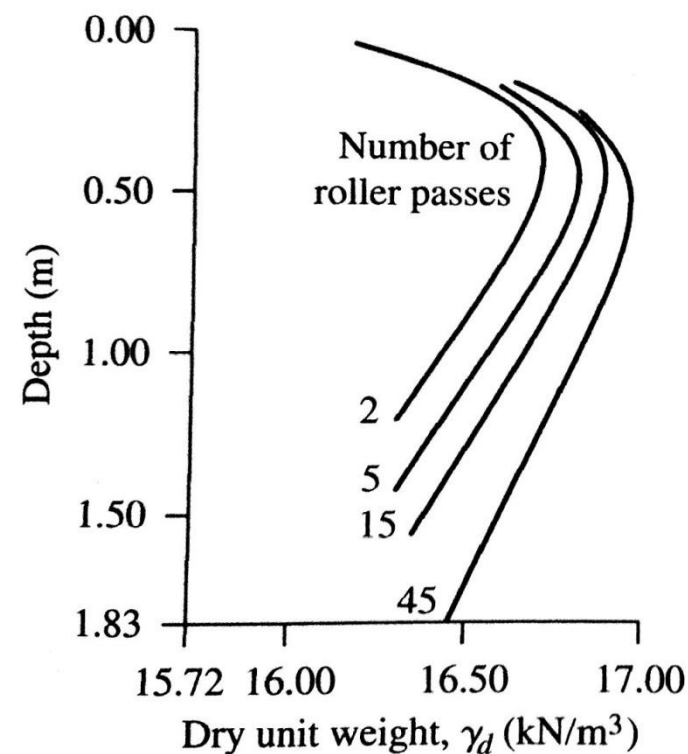
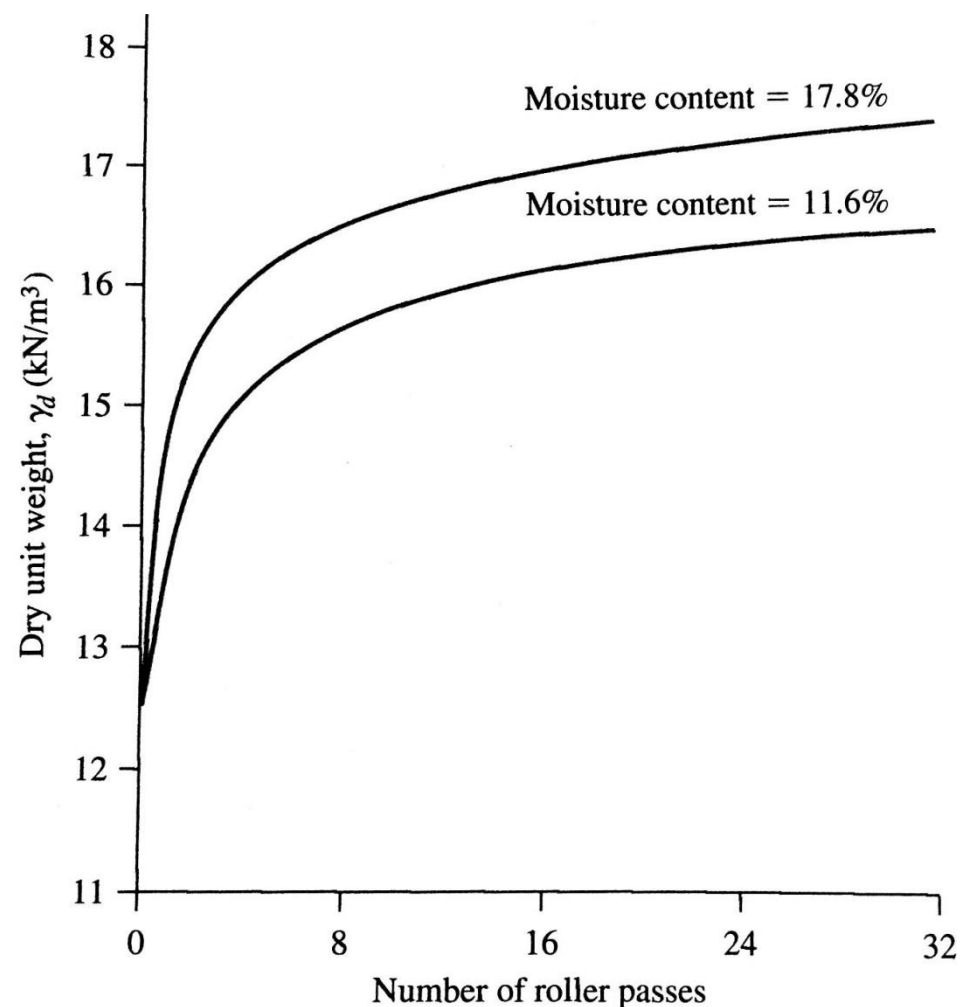
http://www.cabs-st.fr/index.php?affiche=accueil&type=machine_de_chantier&langue=UK

Factors Affecting Compaction

As well as moisture content and the type of roller, compaction is effected by the number of roller passes (equivalent to compactive effort) and the depth of the lift.

Contact pressure decreases with depth, so shallower lifts may be more effective in achieving progressive compaction.

In most cases about 10 to 15 passes at optimum moisture content are sufficient to produce the most economical degree of compaction.



Equipment type	Applicability	Compacted lift thickness	Passes or coverages	Dimensions and weight of equipment			Possible variations in equipment
Sheepsfoot rollers	For fine-grained soils or dirty coarse-grained soils with more than 20% passing the No. 200 sieve. Not suitable for clean, coarse-grained soils. Particularly appropriate for compaction of impervious zone for earth dam or linings where bonding of lifts is important.	150 mm	4 to 6 passes for fine-grained soil	Soil type			For earth dam, highway, and airfield work, a drum of 1.5 m diameter, loaded to 45 to 90 kN per linear meter of drum is generally utilized. For smaller projects, a 1 m diameter drum, loaded to 22 to 50 kN per linear meter of drum, is used. Foot contact pressure should be regulated to avoid shearing the soil on the third or fourth pass.
				Fine-grained soil, $PI > 30$	Foot contact area 30 to 80 cm ²	Foot contact pressures 1700 to 3400 kN/m ²	
			6 to 8 passes for coarse-grained soil	Fine-grained soil, $PI < 30$	45 to 90 cm ²	1400 to 2800 kN/m ²	
				Coarse-grained soil	65 to 90 cm ²	1000 to 1800 kN/m ²	
				Efficient compaction of soils on the wet side of the optimum requires less contact pressure than that required by the same soils at lower moisture contents.			
Rubber-tired rollers	For clean, coarse-grained soils with 4 to 8% passing the No. 200 sieve.	250 mm	3 to 5 coverages	Tire inflation pressures of 400 to 550 kN/m ² for clean granular material or base course and subgrade compaction. Wheel load, 80 to 110 kN.			A wide variety of rubber-tired compaction equipment is available. For cohesive soils, light-wheel loads, such as provided by wobble-wheel equipment, may be substituted for heavy-wheel loads if lift thickness is decreased. For cohesionless soils, large-size tires are desirable to avoid shear and rutting.
	For fine-grained soils or well-graded, dirty, coarse-grained soils with more than 8% passing the No. 200 sieve.	150 to 200 mm	4 to 6 coverages	Tire inflation pressures in excess of 450 kN/m ² for fine-grained soils of high plasticity. For uniform clean sands or silty fine sands, use larger-size tires with pressures of 280 to 350 kN/m ²			

Smooth-wheel rollers	Appropriate for subgrade or base course compaction of well-graded sand-gravel mixtures.	200 to 300 mm	4 coverages	Tandem-type rollers for base-course or sub-grade compaction, 90 to 135 kN weight, 53 to 88 kN per linear meter of width of rear roller.	Three-wheel rollers are obtainable in a wide range of sizes. Two-wheel tandem rollers are available in the 9 to 180 kN weight range. Three-axle tandem rollers are generally used in the 90 to 180 kN weight range. Very heavy rollers are used for proof rolling of subgrade or base course.
	May be used for fine-grained soils other than in earth dams. Not suitable for clean, well-graded sands or silty, uniform sands.	150 to 200 mm	6 coverages	Three-wheel roller for compaction of fine-grained soil; weights from 45 to 55 kN for materials of low plasticity to 90 kN for materials of high plasticity.	
Vibrating baseplate compactors	For coarse-grained soils with less than about 12% passing the No. 200 sieve. Best suited for materials with 4 to 8% passing the No. 200 sieve, placed thoroughly wet.	200 to 250 mm	3 coverages	Single pads or plates should weigh no less than 0.9 kN. May be used in tandem where working space is available. For clean, coarse-grained soil, vibration frequency should be no less than 1600 cycles per minute.	Vibrating pads or plates are available, hand-propelled or self-propelled, single or in gangs, with width of coverage from 0.45 to 4.5 m. Various types of vibrating-drum equipment should be considered for compaction large areas.
Crawler tractor	Best suited for coarse-grained soils with less than 4 to 8% passing the No. 200 sieve, placed thoroughly wet.	250 to 300 mm	3 to 4 coverages	No smaller than D8 tractor with blade, 153 kN weight, for high compaction.	Tractor weights up to 265 kN
Power tamper or rammer	For difficult access, trench backfill. Suitable for all inorganic soils.	100 to 150 mm for silt or clay; 150 mm for coarse-grained soils	2 coverages	130 N minimum weight. Considerable range is tolerable, depending on materials and conditions.	Weights up to 1.1 kN, foot diameter, 100 to 250 mm

Advanced Compaction Techniques

Dynamic compaction and blasting

Dynamic compaction involves repeatedly dropping a heavy weight onto the soil. The resulting compaction is similar to a large scale Proctor test.

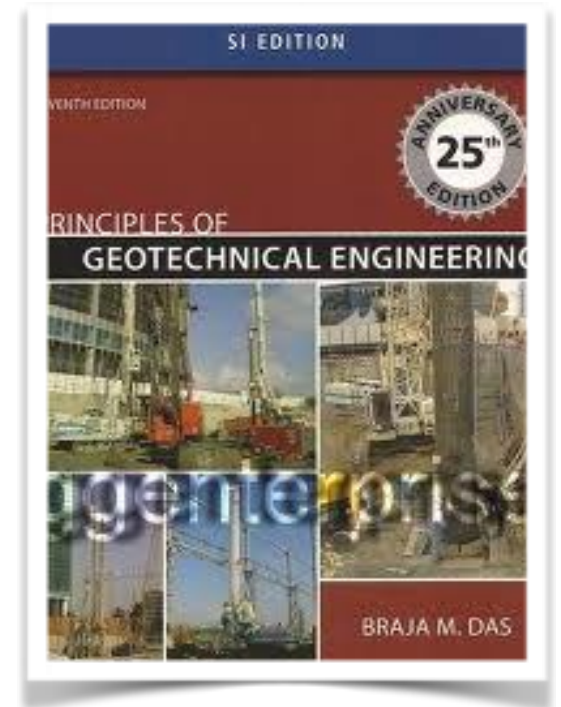
Blasting requires specialist techniques in the containment of explosive force to produce compaction rather than demolition.



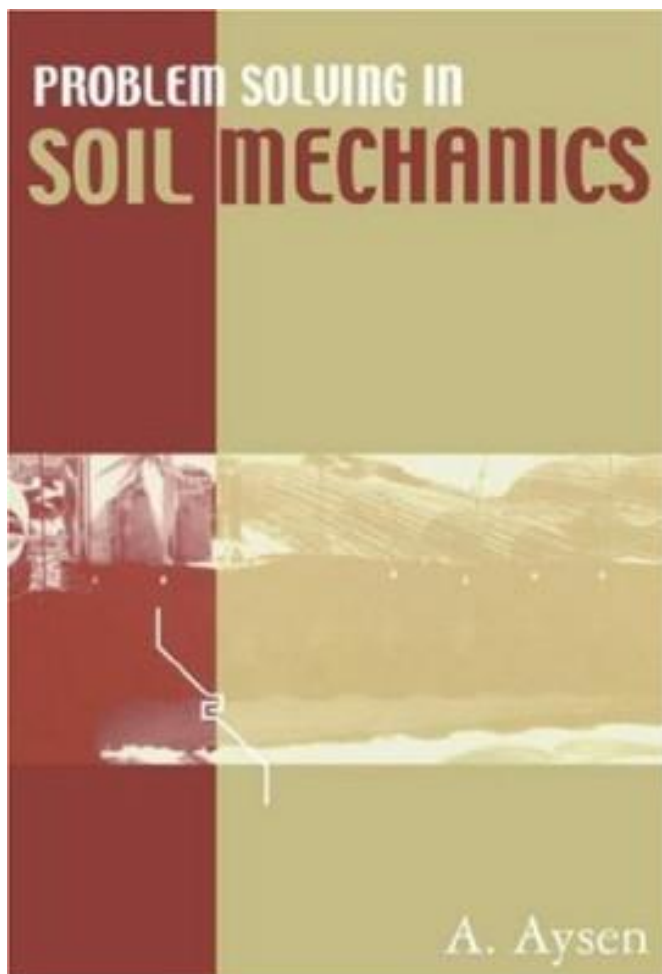
Readings

Chapter 6 Das

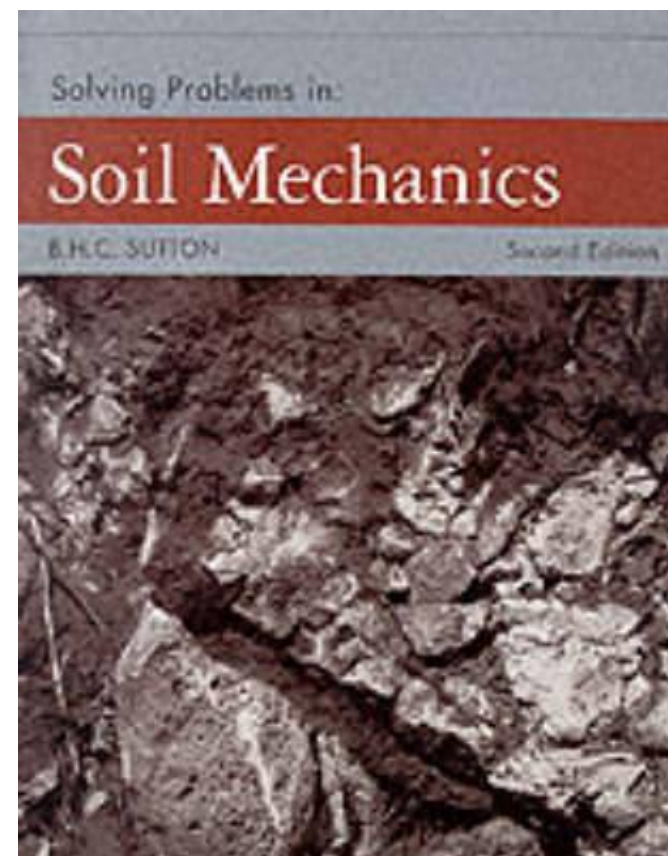
AS1289.5.1.1 (Reading 5)



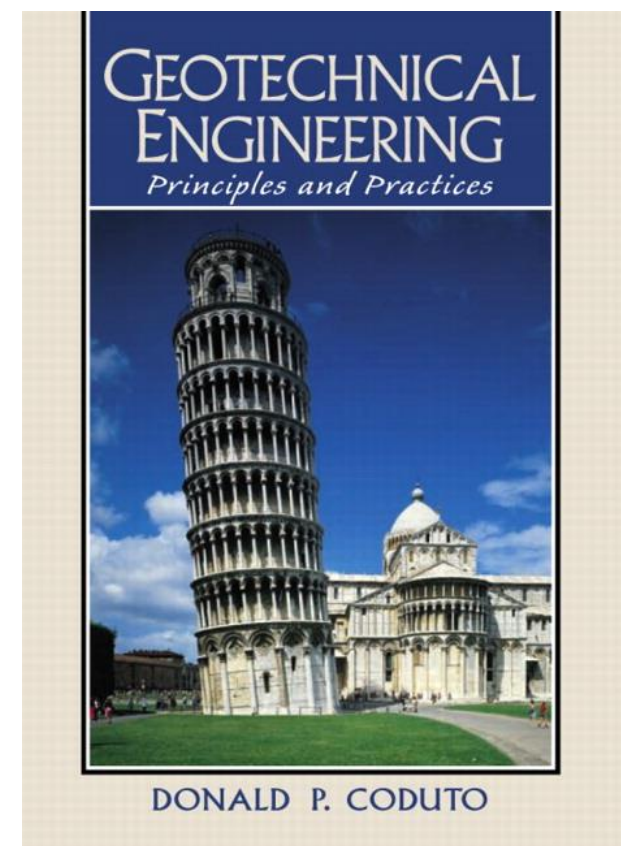
<http://www.bookdepository.com/Solving-Problems-Soil-Mechanics-BHC-Sutton/9780582089716>



<http://www.ebay.com/ctg/Problem-Solving-Soil-Mechanics-A-Aysen-2004-Paperback-/52853454>



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<http://www.tower.com/foundation-design-principles-practices-donald-p-coduto-hardcover/wapi/100501083>