CE464 Ground Improvement

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Compaction

Compaction

The soil density and unit weight is increased by short-term application of mechanical energy.

Compaction of surface layers via sheepsfoot, vibratory, static, and pneumatic tired rollers is the most widely used ground modification method.

Compaction of cohesionless soils by deep dynamic compaction using heavy tampers, or vibrating probes is also a commonly used method.

Many types of earth structures, such as dams, retaining walls, highways, airports require man-placed soil, or fill.

Compaction is to force the soil to a denser state. It is only possible through the reduction of the air voids, with little or no reduction in the water content

Purpose of compaction is to :

- Decrease compressibility and future settlements
- Increase shear strength
- Increase bearing capacity
- Decrease permeability
- Placement of a compacted stiffer layer over a soft layer can reduce vertical stresses with depth underneath the loaded area

	Coarse-grained soils	Fine-grained soils
Laboratory	-Falling weight and hammers - Vibrating hammers	-Falling weight and hammers -Kneading compactors - Static loading
Field	- Hand-operated vibration plates - Motorized vibratory rollers - Rubber-tired rollers - Free-falling weight - Dynamic compaction	- Hand-operated tampers - Sheepsfoot rollers - Rubber-tired rollers

Hand-operated types: Light-compaction

(i) Rammers:

Rammers are used for compacting small areas by providing impact load to the soil. This equipment is light and can be hand or machine operated. The base size of rammers can be 15 cm x 15 cm or 20 cm x 20 cm or more

(ii) Vibrating Plate Compactors:

Vibrating plate compactors are used for compaction of coarse soils with upto 8% fines. These equipments are used for small areas. The usual weights of these machines vary from 100 kg to 2 tonne with plate areas between 0.16 m^2 and 1.6 m^2.

Smooth-Wheeled Roller

- 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

Vibrating Smooth Wheeled 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

Rubber-Tyred Roller

- 80% coverage under the wheel
- Contact pressure up to 700 kPa
- Can be used on all soil types of soils (granular and fine-grained)
- Compactive effort: static weight and kneading

Sheep-foot Roller

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


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.

Equipment	Most suitable soils	Typical application	Least suitable soils
Smooth wheeled rollers, static or vibrating	Well graded sand-gravel, crushed rock, asphalt	Running surface, base courses, subgrades	Uniform sands
Rubber tired rollers	Coarse grained soils with some fines	Pavement subgrade	Coarse uniform soils and rocks
Grid rollers	Weathered rock, well graded coarse soils	Subgrade, subbase	Clays, silty clays, uniform materials
Sheepsfoot rollers, static	Fine grained soils with > 20% fines	Dams, embankments, subgrades	Coarse soils, soils with cobbles, stones
Sheepsfoot rollers, vibratory	as above, but also sand-gravel mixes	Subgrade layers	
Vibrating plates	Coarse soils, 4 to 8% fines	Small patches	clays and silts
Tampers, rammers	All types	Difficult access areas	
Impact rollers	Most saturated and moist soils		Dry, sands and gravels

FACTORS AFFECTING FIELD COMPACTION

1. **Weight of roller**. Heavier rollers usually produce greater densities for fewer coverages (passes). However, if the bearing capacity of the soil conditions is exceeded, then heavier will not produce greater densities.
2. **Number of coverages**. A minimum of 4 to 8 passes is usually required for the efficient use rollers. A higher number of passes could lead to grain crushing and detrimental stratification among lifts. Therefore, minimizing the number of passes has both economical and technical advantages.
3. **Contact pressure**. Higher contact pressures by pneumatic tired rollers leads to deeper stress penetration and hence compaction of deeper lifts. Higher densities will result for greater tire pressures, provided the soil bearing capacity is not exceeded.
4. **Lift thickness**. The lift thickness is proportional to the pressure applied; i.e., higher pressures, thicker lifts. Forssblad (1977) suggests that a vertical stress of 50 to 100 kPa (7 to 14 psi) is sufficient for the vibratory compaction of cohesionless soils. Cohesive soils require greater stresses – 400 to 700 kPa (57 to 100 psi)
5. **Water content**. Water content is inversely proportional to bearing capacity, and thus is critical to field compaction efforts and equipment operation. A hierarchy exists for the number of passes for the density achievable at that water content; fewest to most: wet of optimum, optimum, and dry of optimum.

COMPACTION CONTROL AND SPECIFICATION

Dry density and water content correlate well with the engineering properties, and thus they are convenient construction control parameters.

Since the objective of compaction is to stabilize soils and improve their engineering behavior, it is important to keep in mind the desired engineering properties of the fill, not just its dry density and water content.

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

Field compaction control tests are specified, and the results of these become the standard for controlling the project.

FIELD CONTROL TESTS

(a) Sand cone

(b) Balloon

(c) Oil (or water) method

Calculations

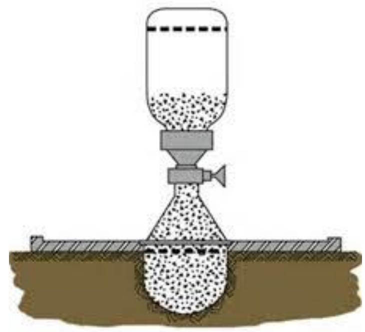
- Know M_{solid} and V_{total}
- Get dry density $\rho_{d,field}$ and w (water content)
- Compare $\rho_{d,field}$ with $\rho_{d,max\text{-}lab}$ and calculate relative compaction R.C.

Sand Cone Method

(ASTM D 1556 – 00, Standard Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone)

Measure the in-situ volume of hole, from which the material was excavated, using the weight of standard uniform sand with known density filling in the hole. The in-situ density of material is given by the weight of the excavated material divided by the in-situ volume.

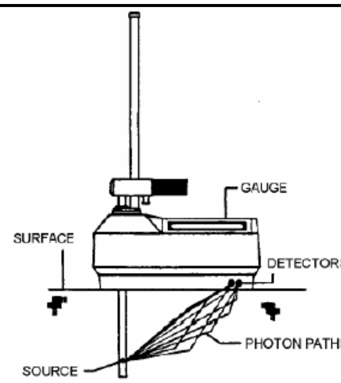
https://www.youtube.com/watch?v=ojH0W3xq3P0



Nondestructive Methods

Nuclear density gage
(Nuclear density meter)

(a) Direct transmission
(b) Backscatter
(c) Air gap



Principles

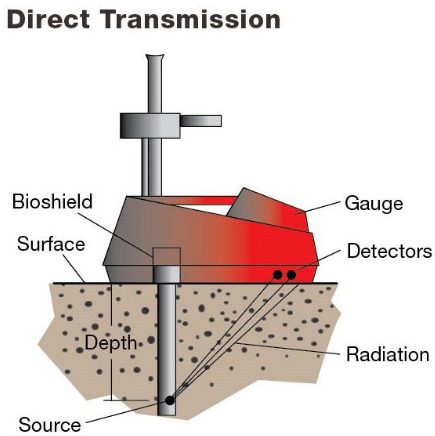
Density

The Gamma radiation is scattered by the soil particles and the amount of scatter is proportional to the total density of the material. The Gamma radiation is typically provided by the radium or a radioactive isotope of cesium.

Water content

The water content can be determined based on the neutron scatter by hydrogen atoms. Typical neutron sources are americium-beryllium isotopes.

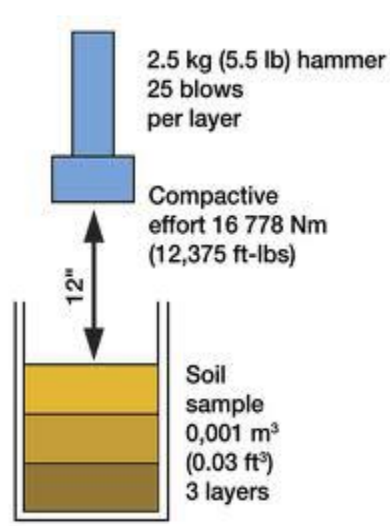
Nuclear density gage



A steel rod is hammered into the soil to create a hole into which a radioactive source is inserted. Gamma rays (photons) are emitted from a source into the soil. These collide with electrons in the soil materials. Some are scattered and some are absorbed. The quantity of photons reaching the Geiger counter detection device relates to the average soil unit weight of soil between the probe and Geiger counter.

LABORATORY COMPACTION

Standard Proctor Compaction



Modified Proctor Compaction was developed by the U.S. Army Corps of Engineers during World War-II to duplicate the compaction requirements for heavy aircraft on airfields.

LABORATORY COMPACTION

Table 2.1 Summary of Standard and Modified Proctor Tests

Text	Mold (height x diameter)	Hammer Wt. (lbs)	No. of Layers	Ht. of Hammer Drop (in)	No. of Drops per Layer	Compactive Energy per Unit Volume (ft-lbs / ft^3)
Standard Proctor	4.6 × 4 in. dia.	5.5	3	12	25	12400
Modified Proctor	4.6 × 4 in. dia.	10	5	18	25	56000

STANDARD PROCTOR ENERGY:
(5.5 lbs)(1-ft. Drop height)(25 blows/layer) (3 layers) / (1/30 ft3) = 12,375 ft-lbs/ft3 = equivalent to a light roller.

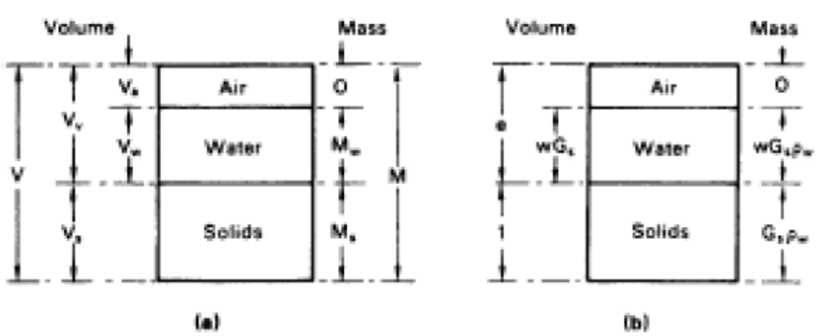
MODIFIED PROCTOR ENERGY:
(10 lbs)(1.5-ft. Drop height)(25 blows/layer) (5 layers)/(1/30th ft3) = 56,250 ft-lbs/ft3

(For both Standard and Modified Proctor, a larger mold can be used (5 in height x 6 in diameter). If larger mold is used, in both Standard and Modified Proctor, number of drops is 55, energies will still the same as in the table.)

1 ft = 12 inches 1 inch = 2.54 cm 1 lbs = 0.45 kg

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

$$\gamma_{dry} = \frac{G_s\,\gamma_w}{1 + w\,G_s/S}$$



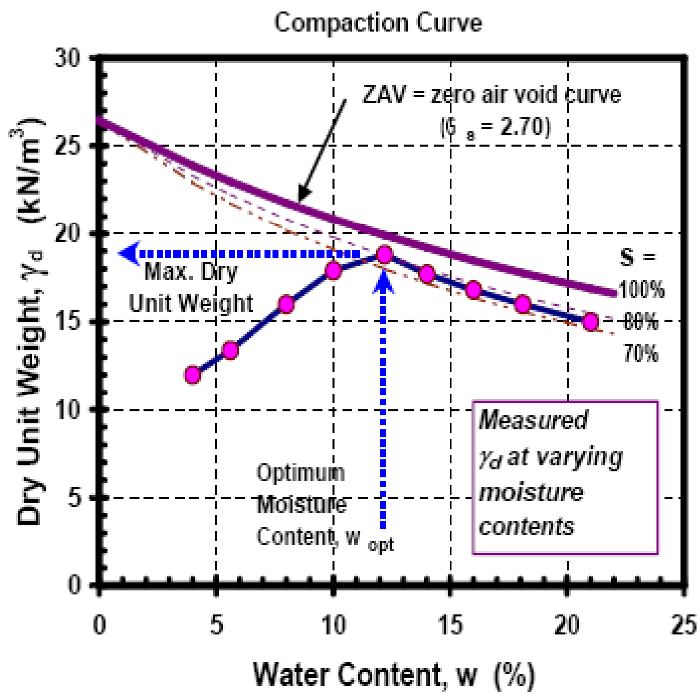
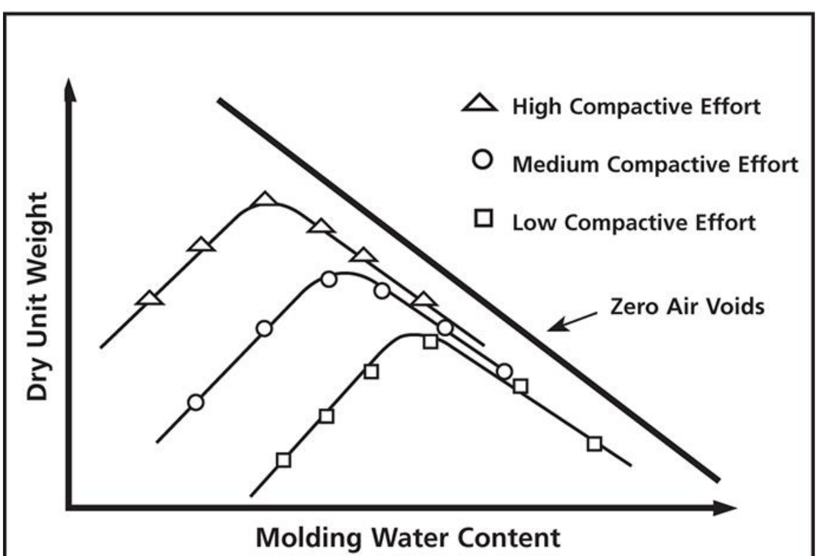
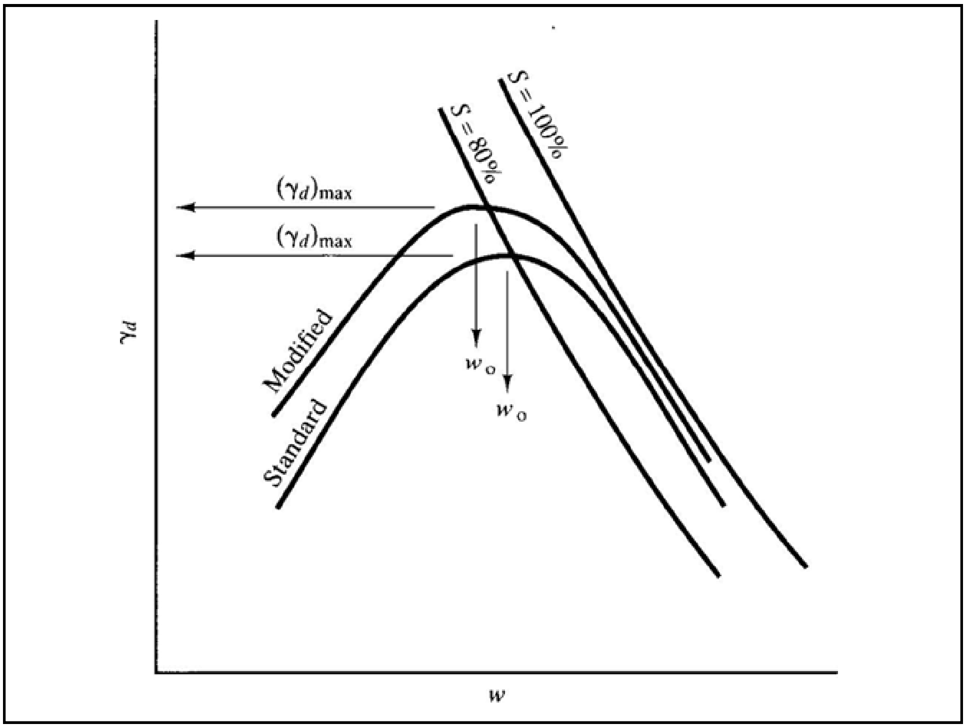
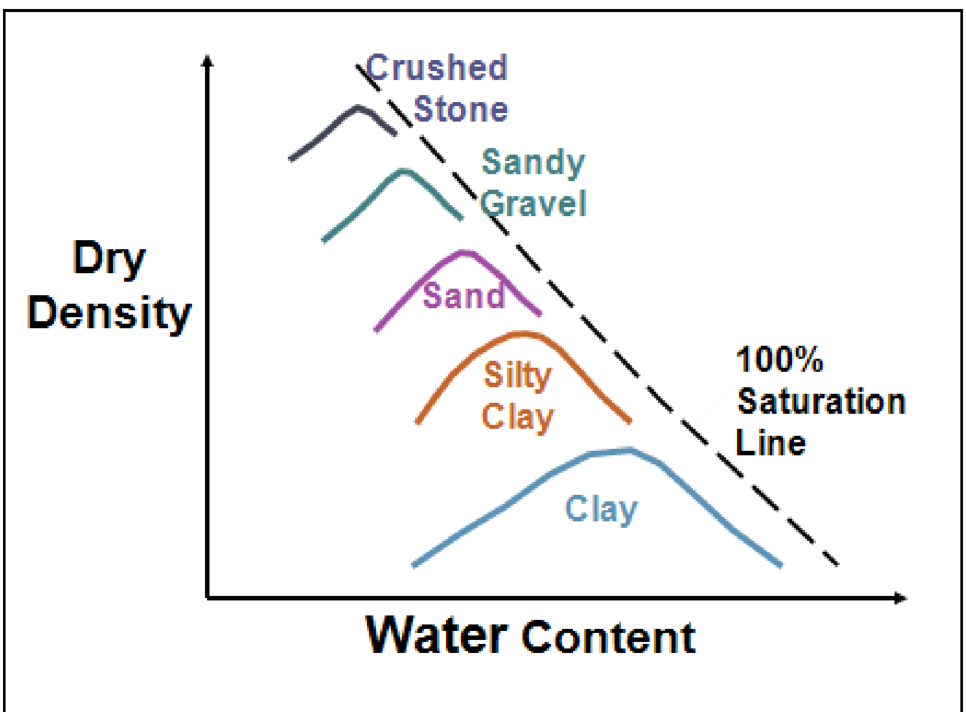


Figure 1. Typical moisture density relationships or compaction curves




γ_d
w
$(\gamma_d)_{max}$
$(\gamma_d)_{max}$
$S = 80\%$
$S = 100\%$
Modified
Standard
w_o
w_o


Dry Density
Water Content
Crushed Stone
Sandy Gravel
Sand
Silty Clay
Clay
100% Saturation Line

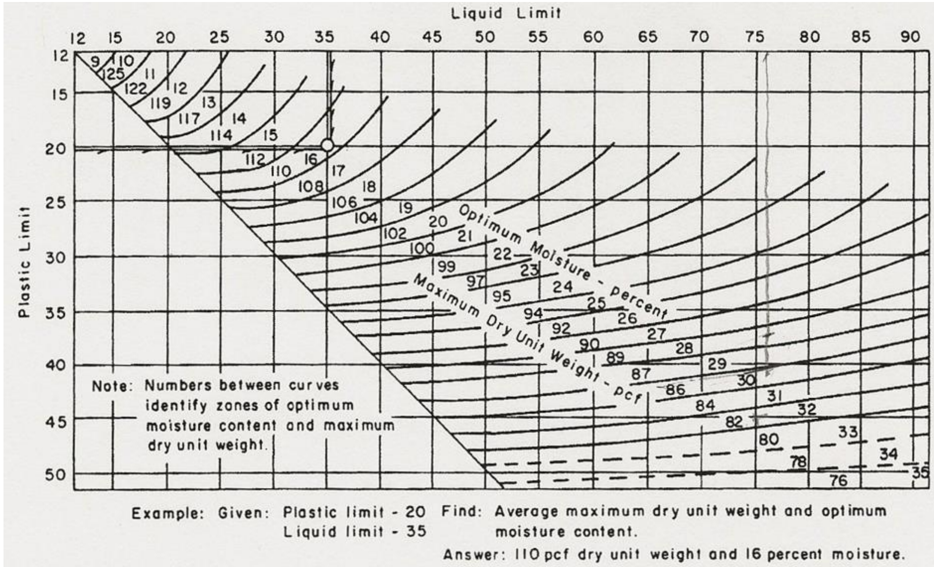
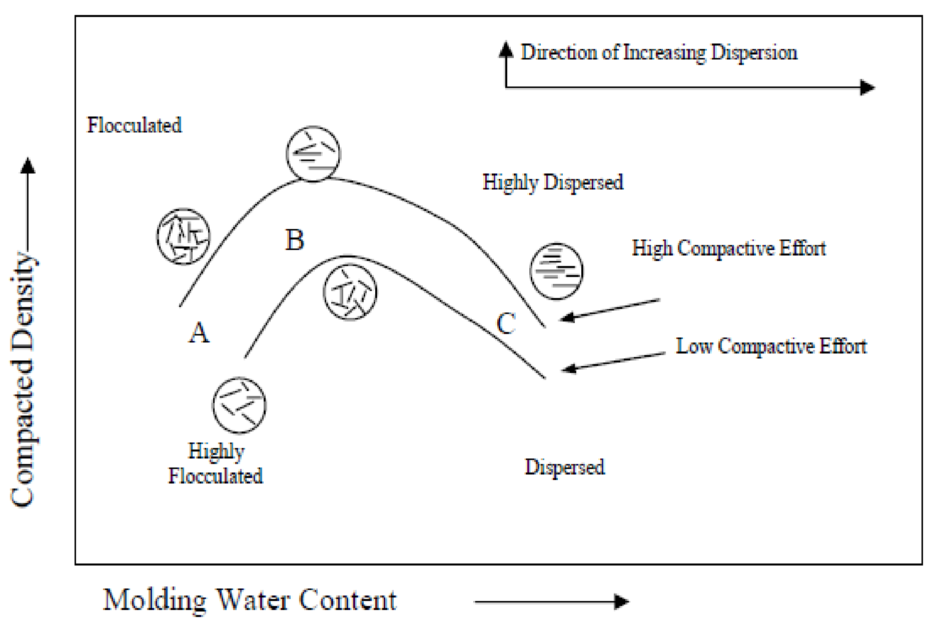


Figure 109. Relation of average maximum dry unit weight and optimum moisture content (AASHO T99-49) to plastic limit and liquid limit (135).

Average maximum dry unit weight and optimum moisture content achieved by standard Proctor Tests (ASTM D698) with plastic limit (PL) and liquid limit (LL).



GROUND IMPROVEMENT

Compaction is usually an economical method of improving the bearing capacity of site soils.

It may be accomplished by excavating to some depth, then carefully backfilling in controlled lift thicknesses, each of which is compacted with the appropriate compaction equipment.

Purpose of compaction is to :

- Decrease compressibility and future settlements
- Increase shear strength
- Increase bearing capacity
- Decrease permeability
- Placement of a compacted stiffer layer over a soft layer can reduce vertical stresses with depth underneath the loaded area

	VERY LOOSE	LOOSE	MEDIUM DENSE	DENSE	VERY DENSE
SPT- N VALUE	< 4	4-10	10-30	30-35	> 50
CPT tip resistance Q_C (KG/CM^2)	< 50	50-100			> 200
EQUIVALENT Relative density D_R (%)	< 15	15-35	35-65	65-85	85-100
DRY UNIT WEIGHT (kN/m^3)	< 14	14-16	16-18	18-20	> 20
FRICTION ANGLE	< 30	30-32	32-35	35-38	> 38

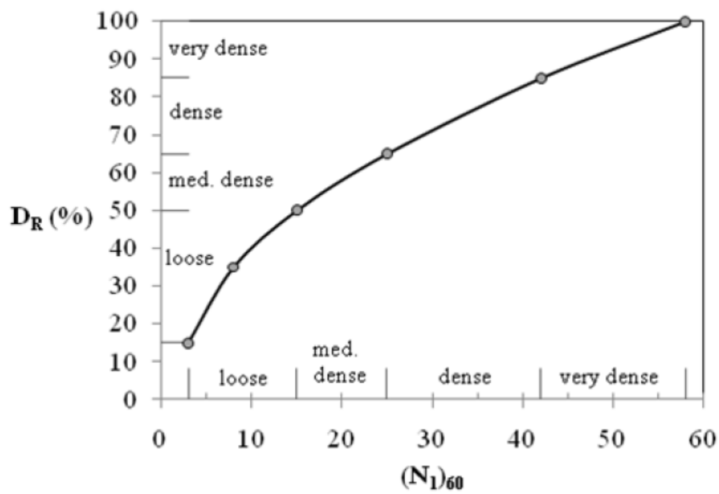
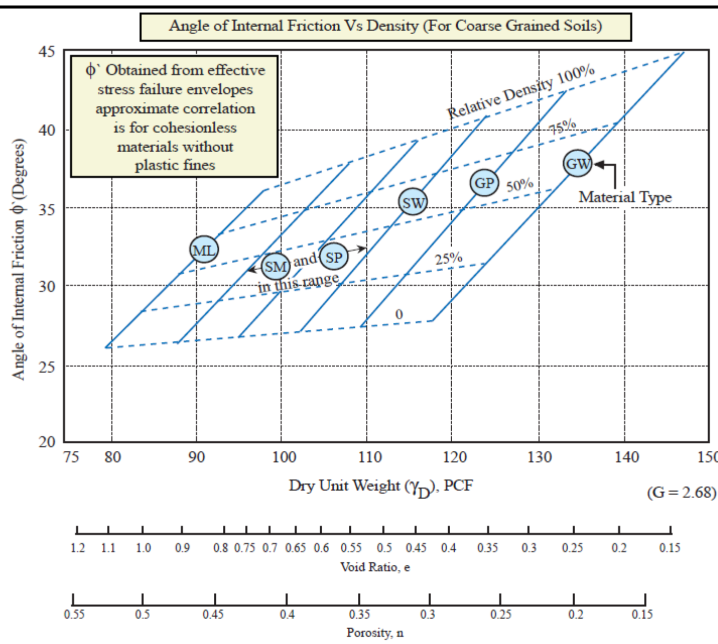


Figure 2.12. Correlation of relative density with normalized SPT blowcount (Terzaghi and Peck, 1948 as modified by Skempton, 1986).



Correlations Of Strength Characteristics For Granular Soils

Adapted from NAVFAC DM-7.1 (5/82) p 7.1 - 149

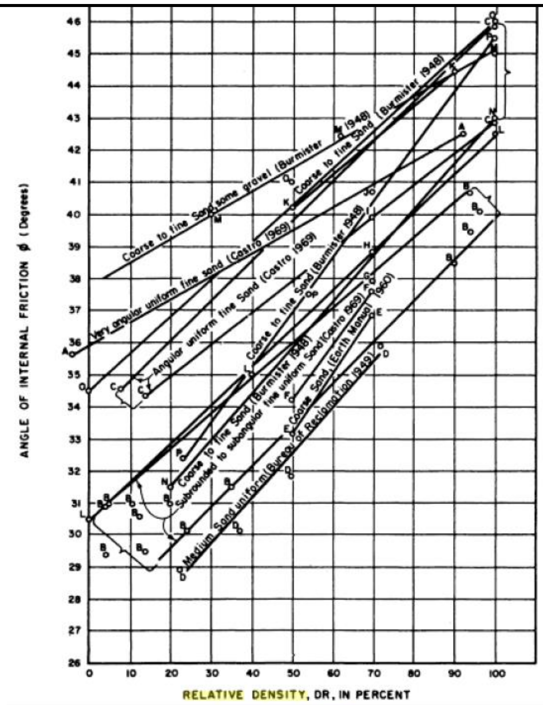


Fig. 8.28 Relative density vs. friction angle for cohesionless soils.

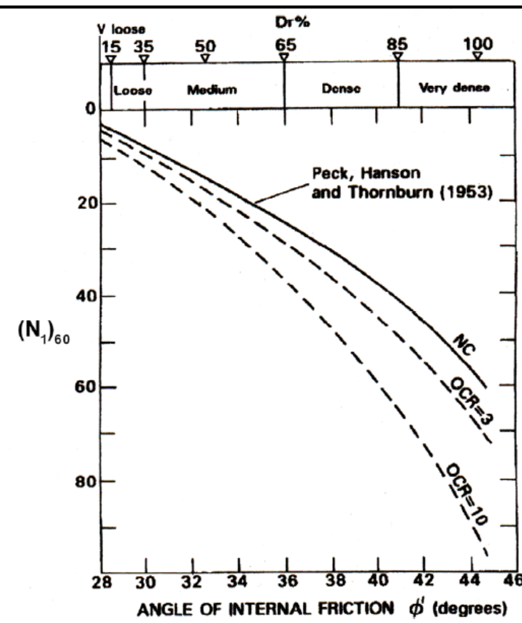


Figure 2.15 Relationship between angle of friction and SPT $(N_1)_{60}$, including the effect of Overconsolidation Ratio (OCR) (Stroud 1989)

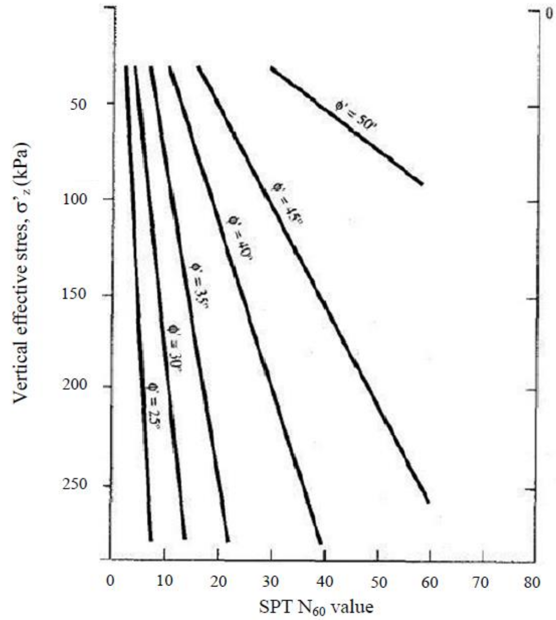


Figure 2.14. Relationship between effective vertical stress, SPT N_{60} values and friction angle for uncemented sands (after DeMello 1971).

Table 2.3 Consistency of Clays and Approximate Correlation to the Standard Penetration Number, N_{60}

Standard penetration number, N_{60}	Consistency	Unconfined compression strength, q_u (kN/m^2)
0-2	Very soft	0-25
2-5	Soft	25-50
5-10	Medium stiff	50-100
10-20	Stiff	100-200
20-30	Very stiff	200-400
>30	Hard	> 400