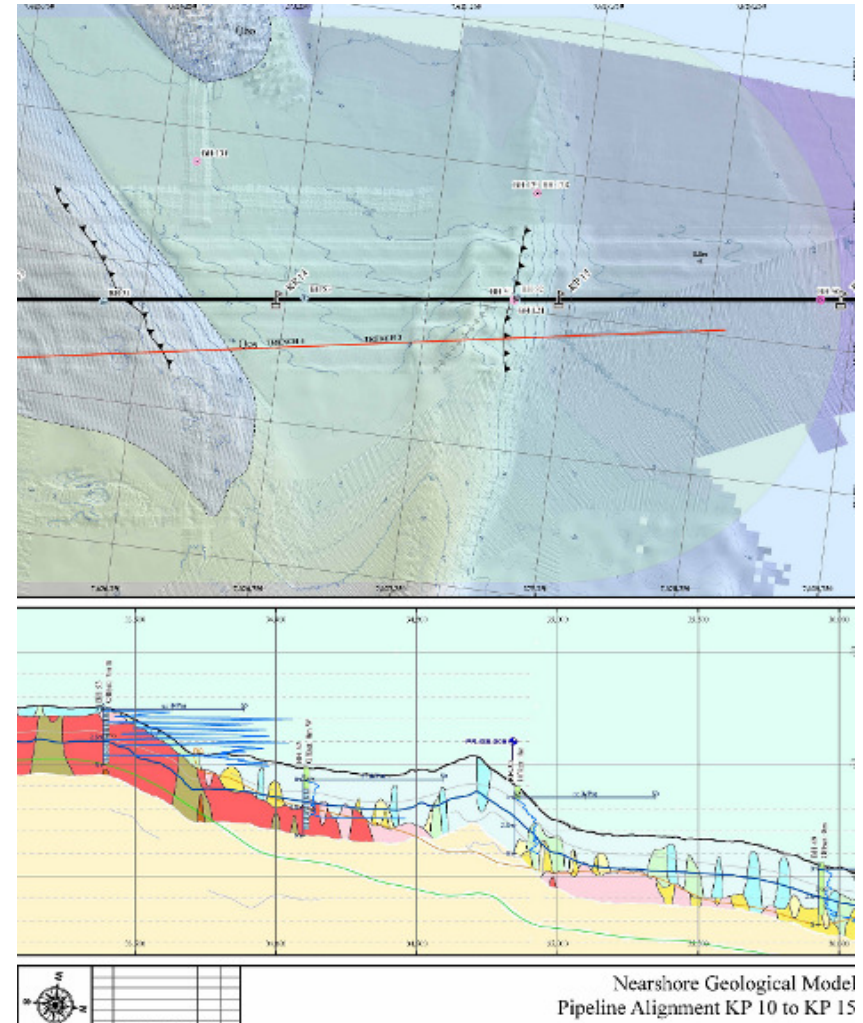


Engineering Soil Analysis

Text: Das, 2010. Principles of Geotechnical Engineering Ch 2.4 - 2.8

Coarse-grained soils have good load-bearing capacity and good drainage qualities, and their strength and volume change characteristics are not significantly affected by change in moisture condition.

Fine-grained soils have poor load-bearing capacities compared with coarse-grained soils. Fine-grained soils are practicably impermeable, are subject to change in volume and strength with variations in moisture conditions, and are frost susceptible.



<http://www.ag.com.au/services/geotechnical-engineering.aspx>

Safe bearing capacity for various soils

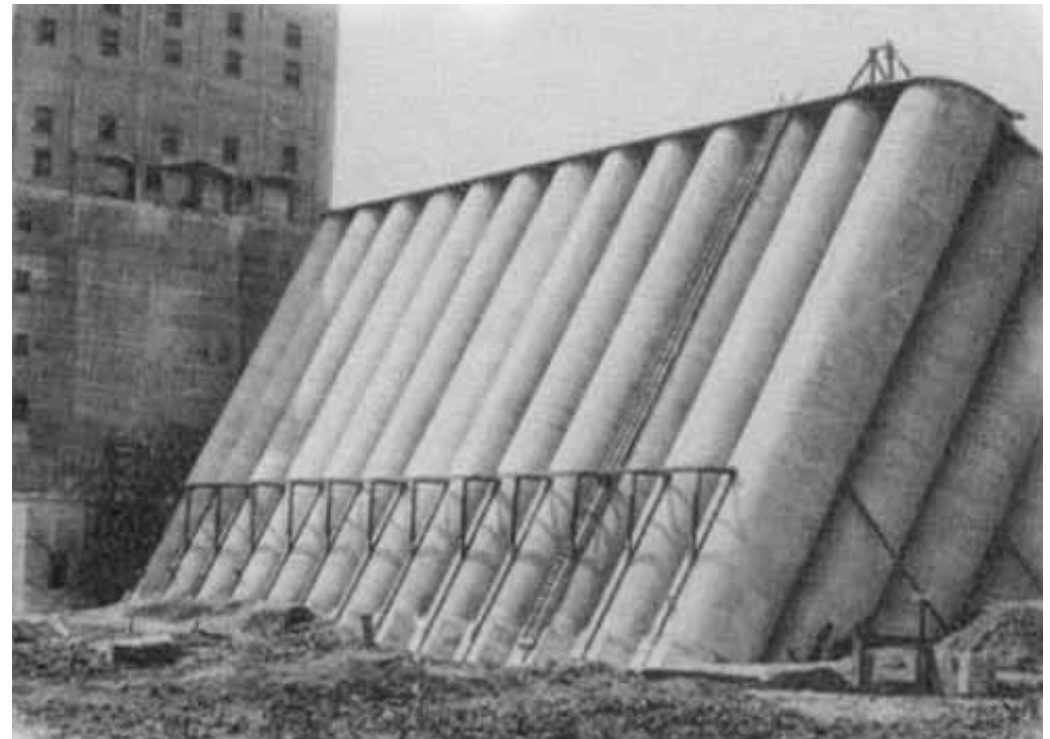
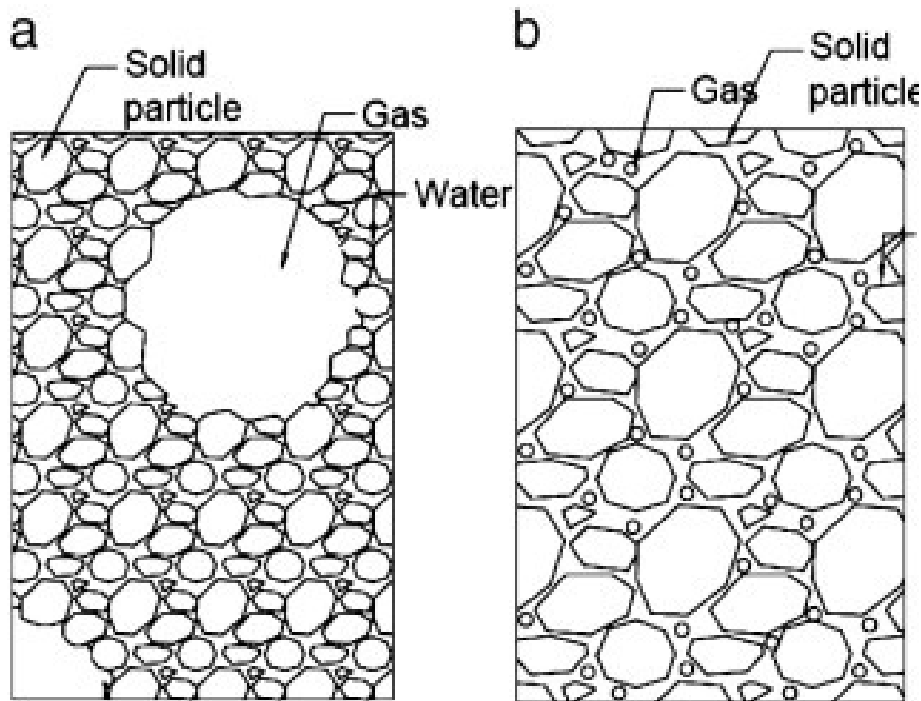
Soil type	Max. safe bearing capacity (kN/m ²)	Remarks
Rocks and compact gravel	>600	Width of foundation (B) not less than 1 m. Watertable at least B below base of foundation
Medium dense gravel and sand	200-600	
Loose gravel and sand	<200	
Compact sand	>300	
Medium dense sand	100-300	
Loose sand	<100	
Stiff clays	150-300	Susceptible to long-term consolidation settlement
Firm clays	75-150	
Soft clays and silts	<75	

(Source: Craig (1994), p. 299)

Coarse and Fine-grained Soils

The engineering properties of coarse-grained soils are controlled mainly by the grain size of the particles and their structural arrangement.

<http://geotechnical-engineer.blogspot.com.au/2007/12/geotechnical-engineering.html>



<http://www.forum-travaux-bricolage.com/forum-bricolage-entretien-volet-roulant-grippe.htm>

The engineering properties of fine-grained soils are controlled by mineralogical factors rather than grain size. Layers of fine-grained soils, even within thick deposits of coarse-grained soils, have been responsible for many geotechnical failures; therefore you need to pay special attention to fine-grained soils.

Soil Particle Size Analysis

Mechanical analysis is the determination of the size range of particles present in the soil, expressed as a percentage of the total dry weight. Three methods are used to find the particle size distribution of a soil:

1. Sieve analysis for particle sizes larger than 0.075 mm in diameter, and;
2. Hydrometer analysis or
3. Sedimentation analysis for particle sizes smaller than 0.075 m in diameter.

<http://www.personal.psu.edu/nrs5031/blogs/english202/assignment-4.html>



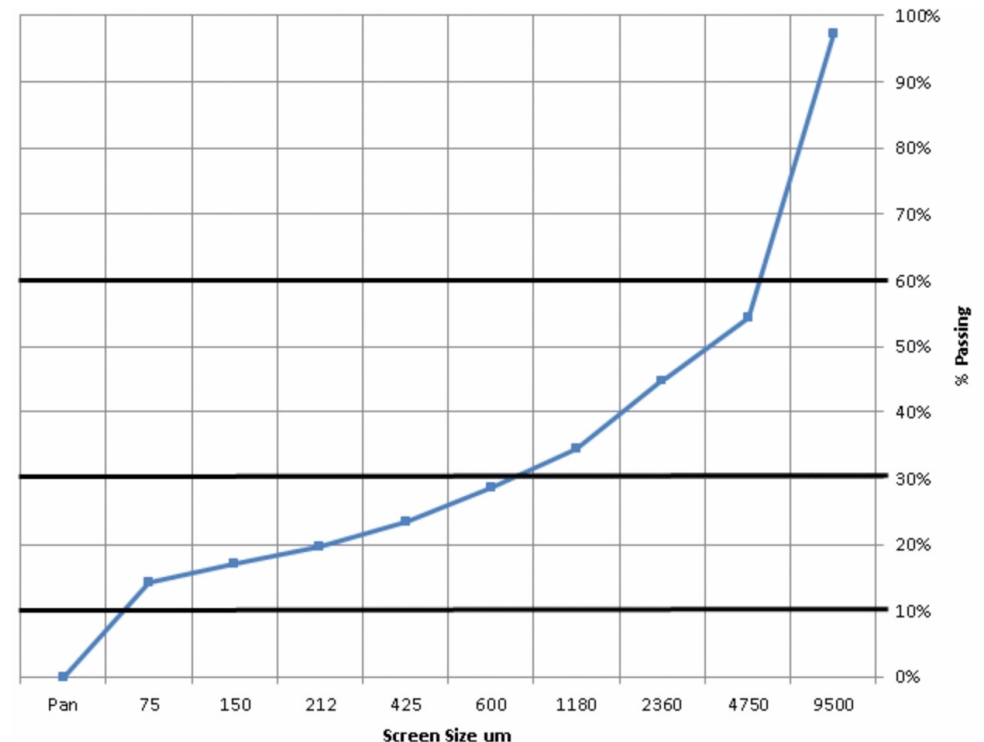
Sieve Analysis: Grading

Sieve analysis consists of agitating a soil sample through a set of sieves, otherwise known as *screens*, that have progressively smaller mesh sizes.

The soil sample must be prepared by oven drying, then breaking all aggregates into individual grains. Some residual aggregation such as a film of clay on gravel grains is unavoidable.

The proportions of mass retained on each sieve are then analysed as a distribution known as a *grading curve*. The table and graph below use AS1289.3.6.1 sieve sizes.

	Sieve size µm	Mass retained g	Cumul. Mass g	Mass Passing g	% Passing
Gravel	9500	2.0	2.0	68.0	97%
	4750	30.0	32.0	38.0	54%
Sand	2360	6.7	38.7	31.3	45%
	1180	7.2	45.9	24.1	34%
	600	4.1	50.0	20.0	29%
Atterberg Sands	425	3.6	53.6	16.4	23.4%
	212	2.7	56.3	13.7	19.6%
	150	1.8	58.1	11.9	17.0%
	75	1.9	60.0	10.0	14.3%
Silt, Clay	Pan	10.0	70.0	0	0%
	Total	70.0	g	70	100.0%



Sieve Analysis: % Passing

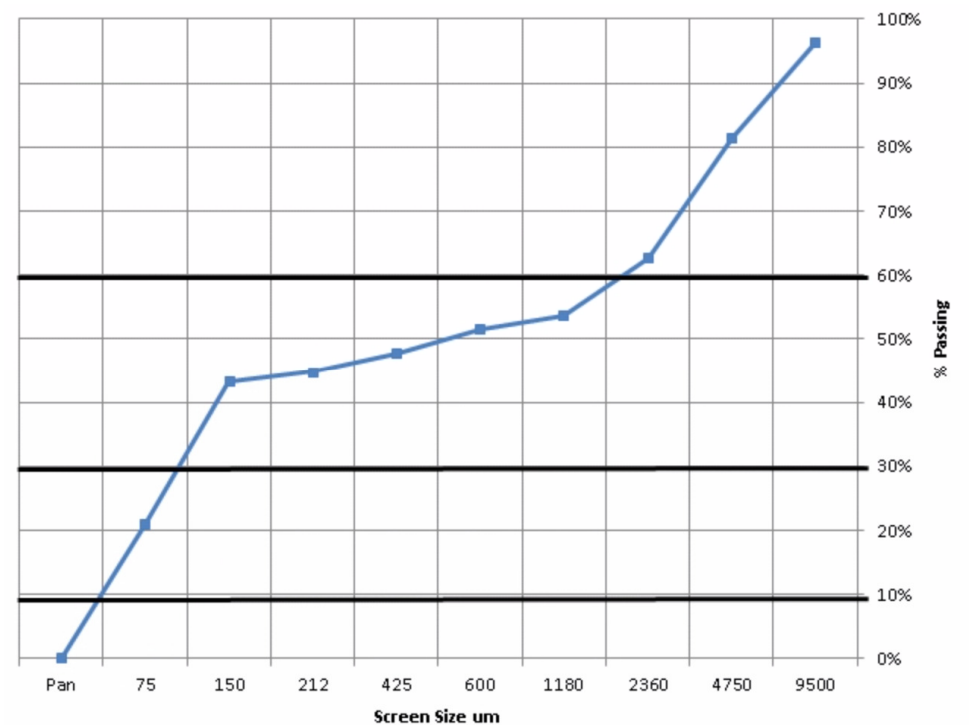
The cumulative mass retained on each sieve is analysed to provide a complementary distribution known as the *percentage passing*. This is a more useful measure of the particle size distribution. The analysis has the following steps, easily amenable to spreadsheet analysis:

1. Determine the mass retained on each sieve (M_1 , M_2 etc) and in the bottom pan (M_0)
2. Determine the total mass of soil $\Sigma M_t = M_1 + M_2 + \dots + M_0$
3. Determine the cumulative mass of soil retained above each sieve. For the i th pan this is $\Sigma M_i = M_1 + M_2 + \dots + M_i$
4. The mass of soil *passing* the i th sieve is then $M_{Pi} = \Sigma M_t - \Sigma M_i$
5. The percentage of soil passing each sieve is then $\%P_i = M_{Pi} \times 100 / \Sigma M_t$

Sieve Analysis: Example

- Sieve-retained masses $M_1, M_2 \dots M_0$
- Total mass $\Sigma M_t = M_1 + M_2 + \dots + M_0$
- Cumulative masses $\Sigma M_i = M_1 + M_2 + \dots + M_i$
- Mass passing $M_{Pi} = \Sigma M_t - \Sigma M_i$
- *Percentage Passing* $\%P_i = M_{Pi} \times 100 / \Sigma M_t$

	A	B	C	D	E	F
1		Sieve size	Mass retained	Cumul. Mass	Mass Passing	% Passing
2		μm	g	g	g	
3	Gravel	9500	5.0	5.0	129.0	96%
4		4750	20.0	25.0	109.0	81%
5	Sand	2360	25.0	50.0	84.0	63%
6		1180	12.0	62.0	72.0	54%
7		600	3.0	65.0	69.0	51%
8	Atterberg Sands	425	5.0	70.0	64.0	47.8%
9		212	4.0	74.0	60.0	44.8%
10		150	2.0	76.0	58.0	43.3%
11		75	30.0	106.0	28.0	20.9%
12	Silt, Clay	Pan	28.0	134.0	0	0%
13		Total	134.0	g	134	100.0%



Grading Curve Interpretation

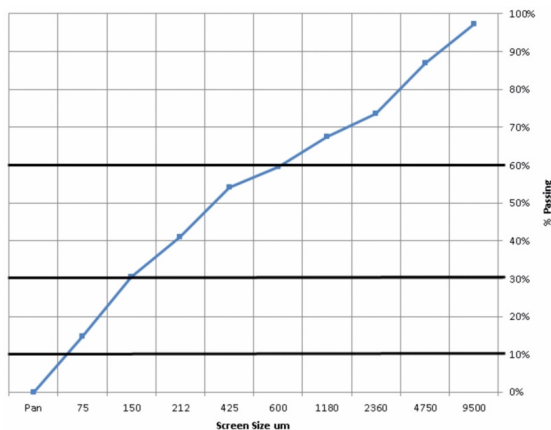
Grading curves provide a visual analysis of particle size distributions. A few general types can be identified as well-graded, poorly graded or gap-graded:

1. Well-graded: a wide and roughly equal range of particle sizes is present.

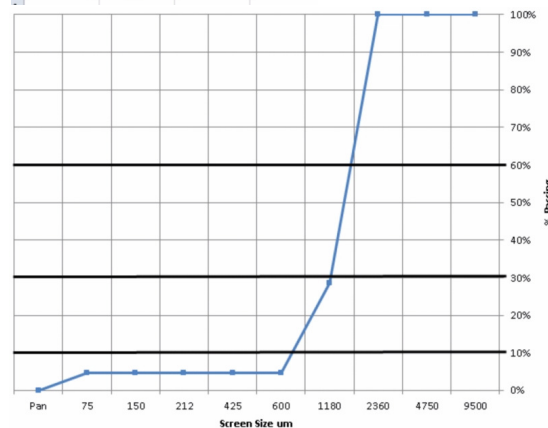
1. Poorly graded: a small range of particle sizes, or a single size.

- Gap-graded: low proportion of intermediate sizes produces a characteristic gap in the grading

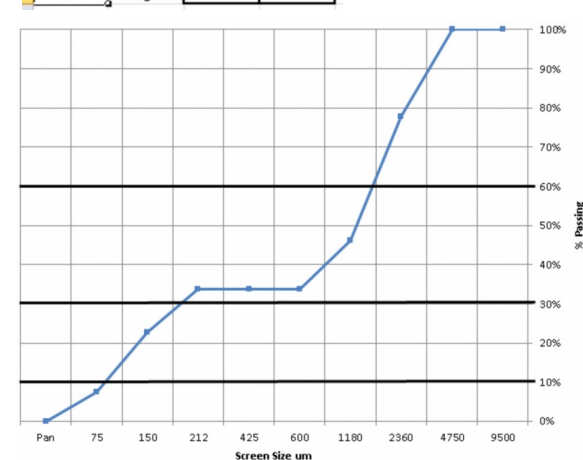
Mass retained	Cumul. Mass	Mass Passing	% Passing
g	g	g	
5.0	5.0	185.0	97%
20.0	25.0	165.0	87%
25.0	50.0	140.0	74%
12.0	62.0	128.0	67%
15.0	77.0	113.0	59%
10.0	87.0	103.0	54.2%
25.0	112.0	78.0	41.1%
20.0	132.0	58.0	30.5%
30.0	162.0	28.0	14.7%
28.0	190.0	0	0%
190.0	g	190	100.0%



Mass retained	Cumul. Mass	Mass Passing	% Passing
g	g	g	
0.0	0.0	105.0	100%
0.0	0.0	105.0	100%
0.0	0.0	105.0	100%
75.0	75.0	30.0	29%
25.0	100.0	5.0	5%
0.0	100.0	5.0	4.8%
0.0	100.0	5.0	4.8%
0.0	100.0	5.0	4.8%
0.0	100.0	5.0	4.8%
5.0	105.0	0	0%
105.0	g	105	100.0%



Mass retained	Cumul. Mass	Mass Passing	% Passing
g	g	g	
0.0	0.0	202.0	100%
0.0	0.0	202.0	100%
45.0	45.0	157.0	78%
64.0	109.0	93.0	46%
25.0	134.0	68.0	34%
0.0	134.0	68.0	33.7%
0.0	134.0	68.0	33.7%
22.0	156.0	46.0	22.8%
31.0	187.0	15.0	7.4%
15.0	202.0	0	0%
202.0	g	202	100.0%



Grading Curve Analysis: Applications

The results of a grading curve analysis can be used to infer some of the main engineering properties of a coarse grained soil:

A large range of grain sizes is desirable as this promotes the interlocking of grains into a stable supportive or slope structure. Most faces of each grain are supported by mutually interlocking grains.

Poorly graded or gap-graded soils have significant porosity, which tends to be air- or water-filled, giving a relatively low density and for various reasons low support strength as a foundation. Permeable soils promote drainage, eg uniform railway ballast or gap-graded eco-concrete

Well-graded soils are relatively impermeable as flow pathways are blocked by a matrix of interlocking grains within pore spaces.

<http://www.bethyl.com/product/IHC-00192>



Grading Curve Parameters

A grading curve can be further analysed by calculating ratios of particle diameters at definitive percentages such as 10, 30 and 60%. These parameters provide an analysis separate to the subjective visual analysis of the grading curve.

The *effective size* D10 is the diameter at 10% passing. D10 a good measure of the hydraulic conductivity and drainage through the soil.

The uniformity coefficient C_u is the ratio of the 60th to the 10th % diameter.

The curvature coefficient C_c is of the 30th, 60th and 10th % diameters

Well graded soils have large C_u , typically >4 , and C_c between 1 and 2.

$$C_u = \frac{D_{60}}{D_{10}}$$

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}}$$

Diameter at 10%, 30%, 60%:

D10 = 87 μm

D30 = 191 μm

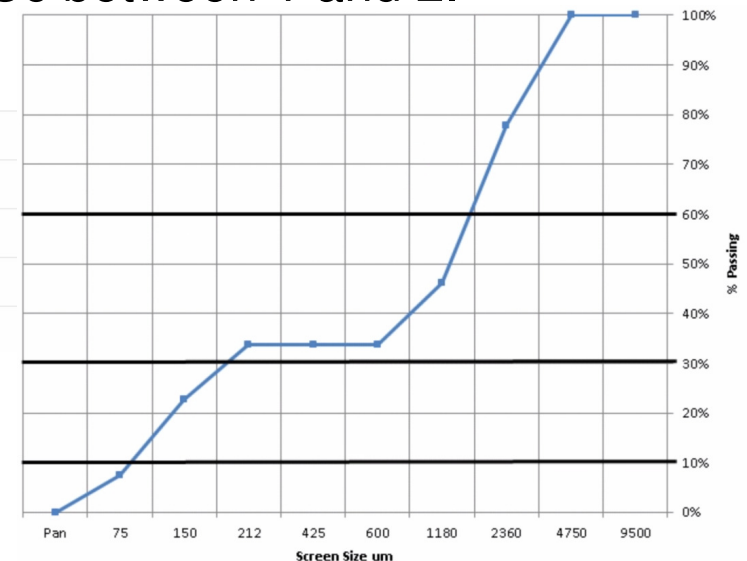
D60 = 1699 μm

Uniformity Coefficient:

$C_u = 19.5$

Curvature Coefficient:

$C_c = 0.2$



Grading Curve Diagnostics

A grading curve can also be analysed to classify the soil as coarse or fine grained; whether coarse soils are gravel or sand, and also whether coarse grained soils are clean (no or few fine particles) or dirty (a significant fraction of fines):

- If % passing 75 μm < 50% : coarse-grained, otherwise fine-grained
- If % passing 4750 μm < 50% : gravel, otherwise sand
- If % passing 75 μm < 5 : clean ; 5-12% some fines ; > 12% : dirty

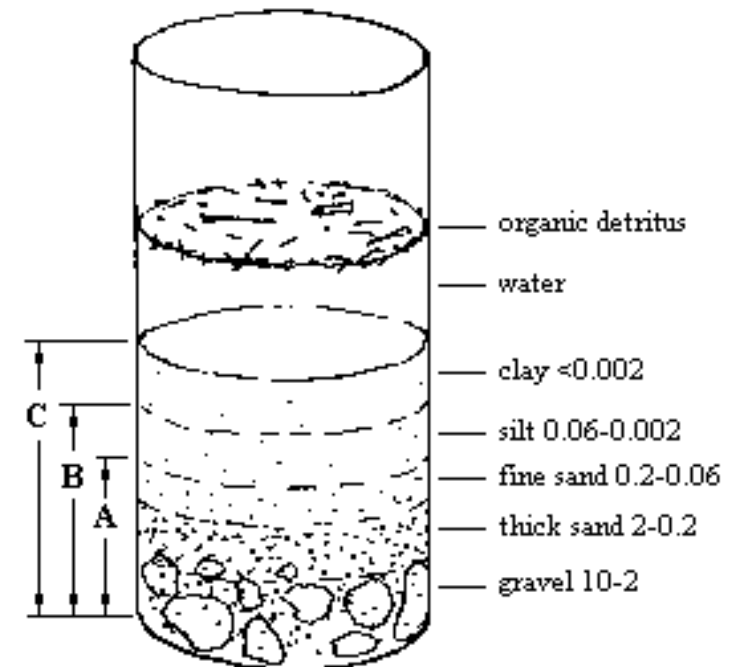
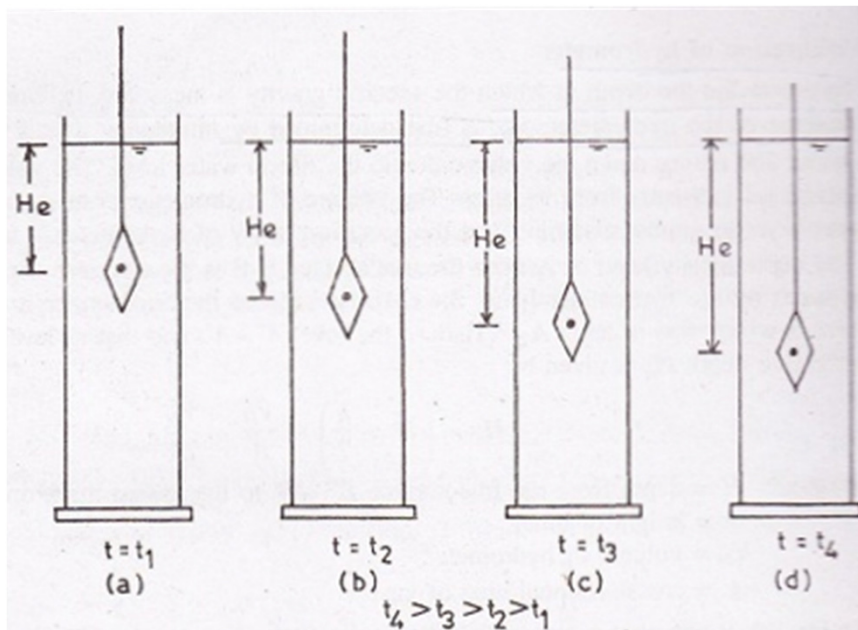
Particle Grading Analysis:			
% passing 75 μm :	7.4%	Coarse Grained	
% passing 4750 mm :	100%	Some Fines; Sand	
		SP: Poorly Graded Sand	

Fine-grained Soil Grading

The methods described above give adequate detail on the coarse fraction of a soil. However the fine fractions of silt and clay are smaller than 0.075 mm, and thus are lumped together in the pan.

Hydrometer analysis provides an indirect estimate of the fine particle distribution, by measuring the sedimentation of a soil settling out of water over time and estimating particle diameters corresponding to settlement velocities by Stoke's law.

Sedimentation analysis is similar to hydrometer analysis in that a soil is allowed to settle out of water, but gives a more direct measure of the mass of soil fractions between grain sizes.



Hydrometer Analysis

Hydrometer analysis is based on simplified principles of sedimentation of soil grains in water:

When a soil specimen is dispersed in water the particles settle at different velocities depending on their shape, size, weight and the viscosity of water.

For simplicity it is assumed that all soil particles are spheres and that the velocity of soil particles can be expressed by Stokes' Law.

Thus for a sedimentation cylinder of depth L , the diameter of particles settling after a sedimentation period t is given by

$$D(mm) = K \sqrt{\frac{L(cm)}{t(min)}}$$

$$K = \sqrt{\frac{30\eta}{G_s - 1}}$$

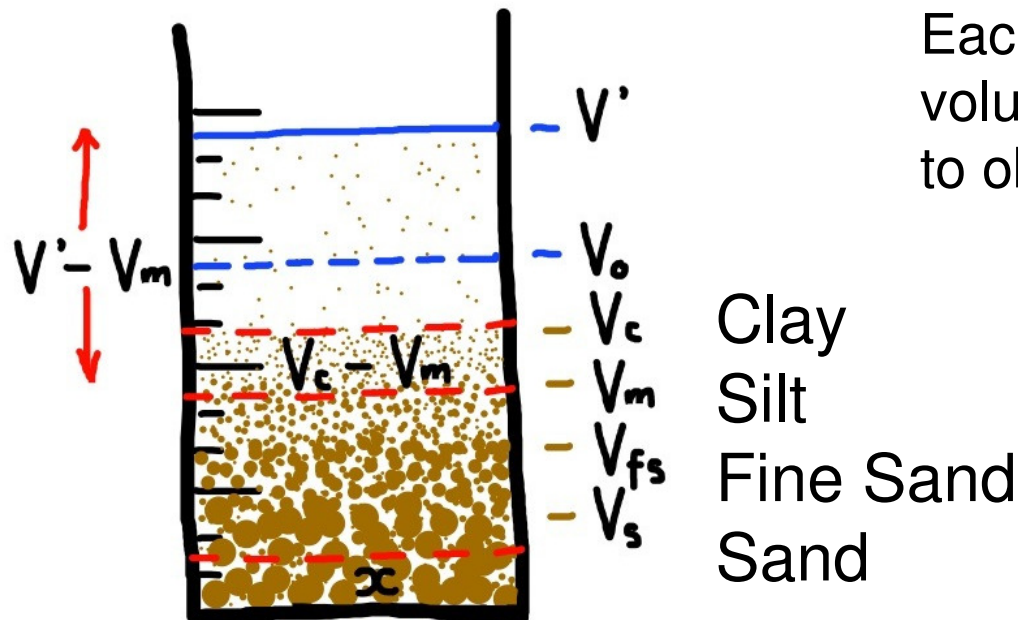
- η is the fluid viscosity in centipoise; $\eta \sim 0.00001$
- G_s is the specific gravity of the soil particles; $G_s \sim 2.7$

Sedimentation Analysis

Sedimentation analysis requires fewer assumptions, simpler equipment and more straightforward calculations than hydrometer analysis.

A soil including coarse and fine fractions is dispersed in water (use a tall graduated flask) and allowed to settle. Volumes before and after are recorded.

After settling for 24 hours the volume markers at discernible changes in texture or visible divisions of grain size are noted. Divisions are partly arbitrary but can be related to actual grain sizes if samples are taken for microscope.



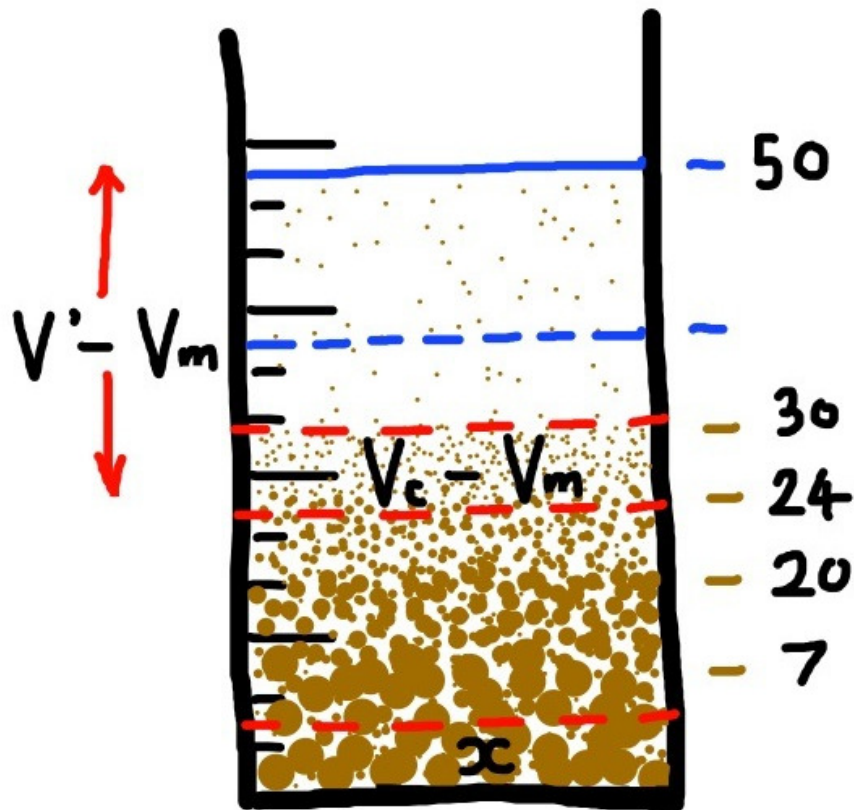
Each layer has an unknown additional volume, x , in lower layers. x is proportional to observed volumes.

$$V_{clay} = V_c - V_m + x$$

$$\frac{x}{V_m} = \frac{V_c - V_m}{V' - V_m}$$

Sedimentation Analysis

Example:



$$V_{\text{clay}} = 30 - 24 + 24(30 - 24)/(50 - 24) = 11.5$$

$$V_{\text{silt}} = 24 - 20 + 20(24 - 20)/(50 - 20) = 6.7$$

$$V_{\text{fsand}} = 20 - 7 + 7(20 - 7)/(50 - 7) = 15.1$$

$$V_{\text{sand}} = 7$$

$$V_{\text{total}} = 11.5 + 6.7 + 15.1 + 7 = 40.3$$

$$\% \text{clay} = 11.5/40.3 = 28.6\%$$

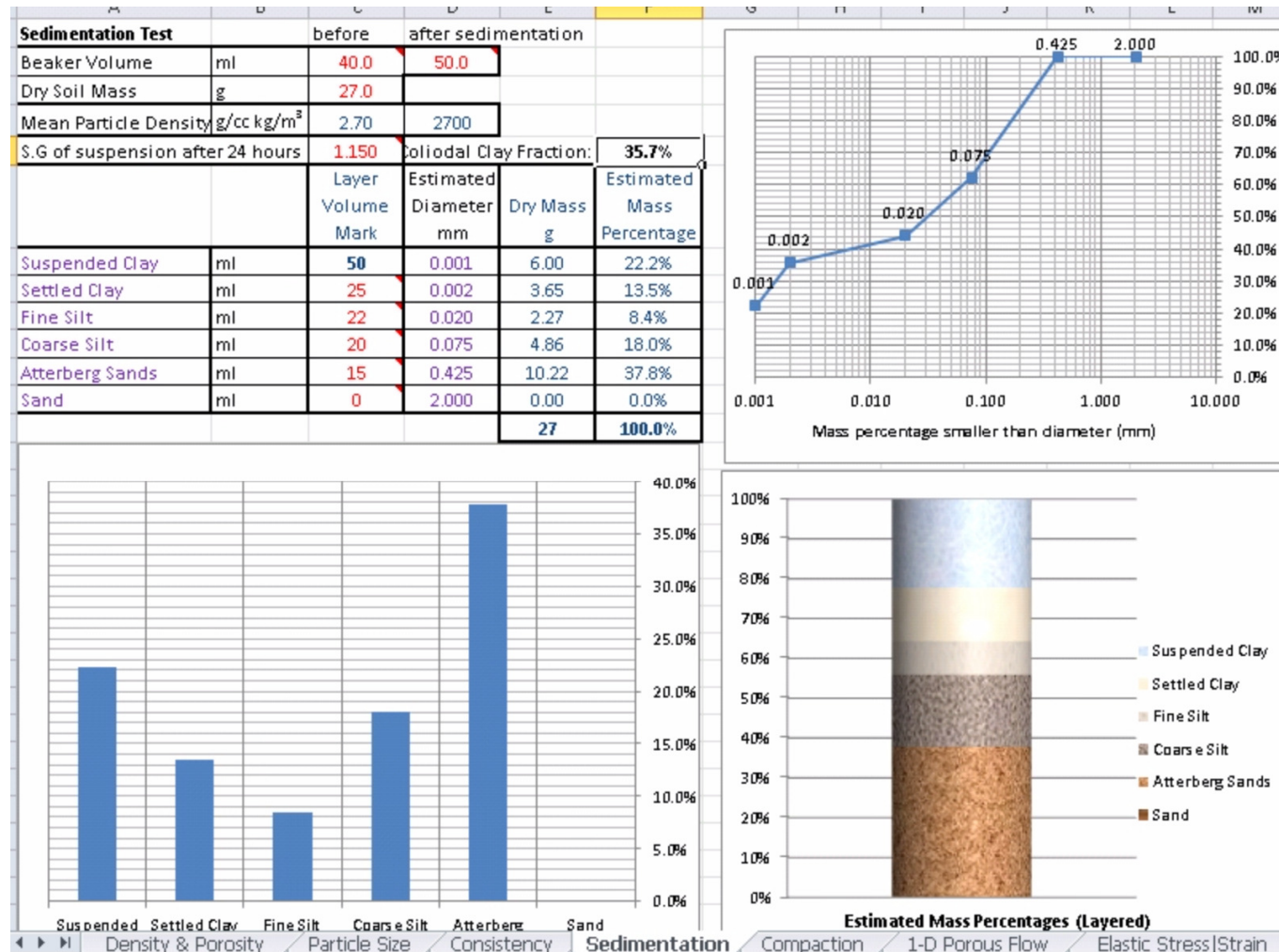
$$\% \text{silt} = 6.7/40.3 = 16.5\%$$

$$\% \text{fsand} = 15.1/40.3 = 37.5\%$$

$$\% \text{sand} = 7/40.3 = 16.4\%$$

Sedimentation Analysis

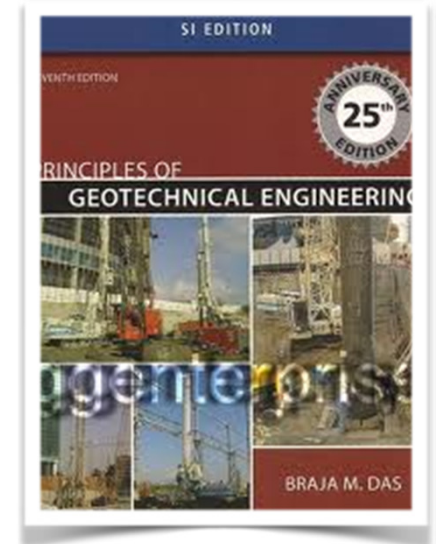
Some residual sediment will remain in suspension after 24 hours. This can be flocculated by addition of gypsum (eg plaster of Paris) or a correction can be based on the S.G of the suspension:



Readings

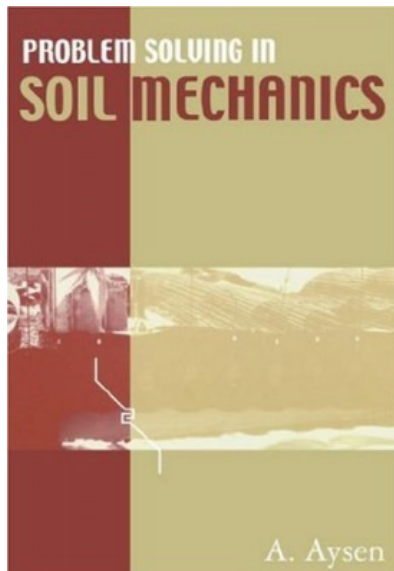
Chapter 2.4 - 2.8 Das

Craig, R.F. (1992). *Soil Mechanics* (5th ed.). Melbourne, Vic.: Chapman & Hall.

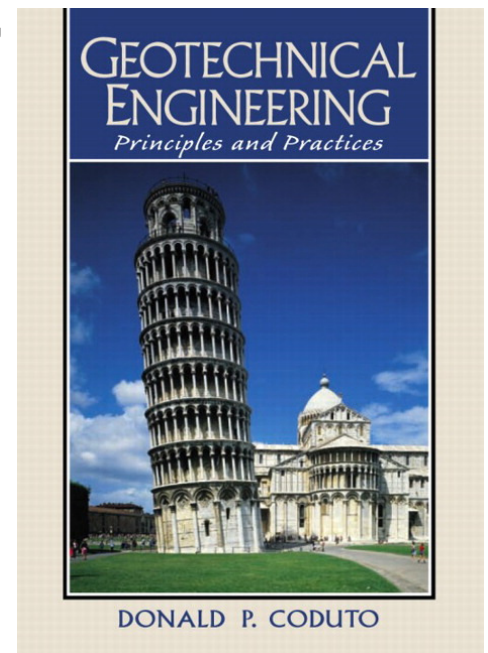
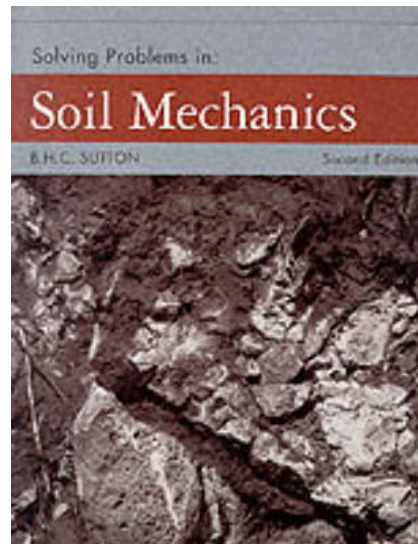


<http://www.bookdepository.com/Solving-Problems-Soil-Mechanics-BHC-Sutton/9780582089716>

Internet research keywords: soil particle sizes, soil grading, engineering soil structure.



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