Tropical Soils

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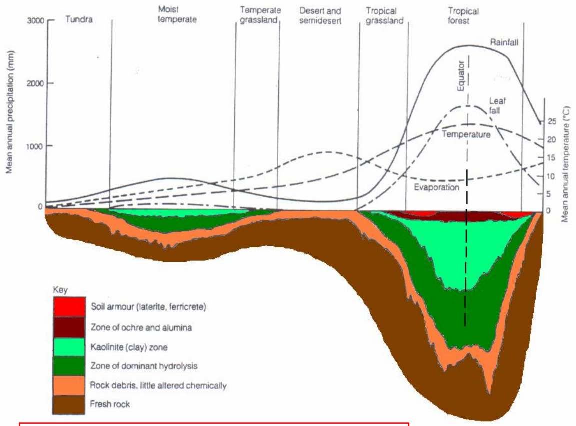

Fookes, P.G. (ed) (1997) *Tropical Residual Soils*, London: Geological Society.

Tropical Soil Terminology

Engineering Weathering Grades		Explanatory Terms	Adopted Terminology (Geol. Soc.)
VI	Residual Soil	Solum	Tropical Residual Soil
V	Completely Weathered	Saprolite	
IV	Highly Weathered		
III	Moderately Weathered	Weathered Bedrock	
II	Slightly Weathered		
I	Fresh	Bedrock	

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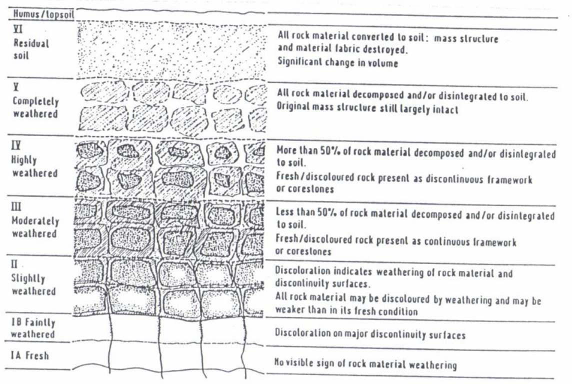

Duchaufour (1982) Classification

Phase 1 Fersiallitisation
FERSIALLITIC SOILS
Smectite clays dominant
Mediterranean, Subtropical climate

Phase 2 Ferrugination
FERRUGINOUS SOILS
Kaolinite and Smectites
Subtropical climate

Phase 3 Ferrallitisation
FERRALLITIC SOILS
Kaolinite and Gibbsite
Humid equitorial climate

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Comparisons of Terminology

Pedological Classifications			Common Geotechnical Terminology	Colour	Mineralogy
Duchaufour	USA	FAO/ UNESCO			
VERTISOL (Fersiallitic)	Vertisol	Vertisol	Black Cotton soil	Black, Brown, grey	Smectites (Montmorillonite) Kaolinite
ANDOSOL (Fersiallitic)	Inceptisol	Andosol	Halloysite/ Allophane soil	Red, yellow, purple	Kaolinite (Halloysite), Allophane
FERRUGINOUS	Alfisol	Nitosol, Alfisol, Lixisol	Red tropical soil	Red, yellow purple	Kaolinite, Hydrated iron oxide (Haematite, Goethite) Hydrated aluminium oxide (Gibbsite)
Ferrisol (transitional)	Ultisol	Ferralsol	Lateritic soil, Latosol	Red, yellow, purple	Kaolinite, Hydrated iron oxide (Haematite, Goethite), Hydrated aluminium oxide (Gibbsite)
FERRALLITIC	Oxisol	Plinthisol	Plinthite, Laterite	Red, yellow, purple	Kaolinite, Hydrated iron oxide (Haematite, Goethite), Hydrated aluminium oxide (Gibbsite)

Duricrusts

DURICRUSTS	Common Geotechnical Terminology	Mineralogy
Silcrete		Silica
Calcrete		Calcium or Magnesium Carbonate
Gypcrete		Calcium sulphate dihydrate
Alucrete	Bauxite	Hydrated aluminium oxides
Ferricrete	Laterite	Hydrated iron oxides

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Parent Rock

Parent rock	Residual soil type	Relative susceptibility to tropical weathering
Calcareous rock (limestone, dolomite)	Gravel in clayey or silty matrix	1 (most vulnerable)
Basic igneous rock (gabbro, dolerite, basalt)	Clay (often grading into sandy clay with depth)	2
Acid crystalline rock (granite, gneiss)	Clayey sand or sany clay (often micaceous)	3
Argillaceous sedimentary rock (mudstone, shale)	Silt or silty clay	4
Arenaceous sedimentary or metamorphic rock (sandstone, quartzite)	Sand (clayey sand in the case of residual arkose or feldspathic sandstone)	5 (least vulnerable)

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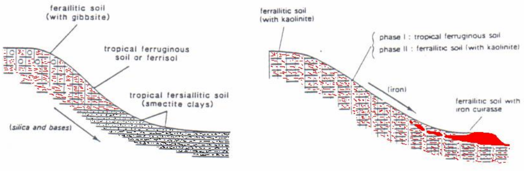
Soil Catenas



Simple soil catena on basic volcanic rocks in a humid tropical climate (adapted from Duchaufour, 1982).

Catena on acid crystalline rocks in a humid tropical climate . (after Duchaufour, 1982).

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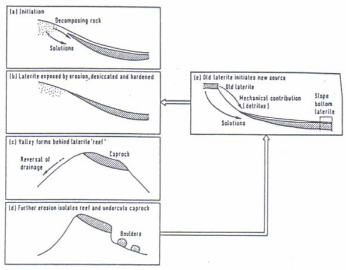
The Laterite Cycle



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"Red" Soils

- Red soils (Ferruginous, Ferrisols, Ferralitic) form in areas of good drainage such as on the crests or slopes of hills. They generally contain low activity kaolinite minerals, and do not usually present major engineering problems, although they may perform quite differently to temperate sedimentary soils.
- The term *Laterite* is used to describe a wide range of red soils, and has become almost meaningless in an engineering sense.

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Charman's Classification of Laterite

Age	Recommended name	Characteristic	Equivalent terms in the literature
Immature (young)	PLINTHITE	Soil fabric containing significant amount of lateritic material. Hydrated oxides present at expense of some soil material. Unhardened, no nodules present but may be slight evidence of concretionary development	Plinthite Laterite Lateritic clay
	NODULAR LATERITE	Distinct hard concretionary nodules present as separate particles	Lateritic gravel Ironstone Pisolitic gravel Concretionary gravel
	HONEYCOMB LATERITE	Concretions have coalesced to form a porous structure which may be filled with soil material	Vesicular laterite Pisolitic ironstone Vermicular ironstone Cellular ironstone Spaced pisolitic laterite
Mature (old)	HARDPAN LATERITE	Indurated laterite layer, massive and tough.	Ferricrete Ironstone Laterite crust Vermiform laterite Packed pisolitic laterite
	SECONDARY LATERITE	May be nodular, honeycomb or hardpan, but is the result of erosion of pre-existing layer and may display brecciated appearance.	

Charman, J.H. (1988) *Laterite in road pavements*, CIRIA Special Publication 47, London: Construction Industry Research and Information Assoc.

Classification of "Red" soils

- The presence of iron and aluminium oxides significantly affects the index properties of red soils. Newill (1961) demonstrated that the sesquioxides can suppress their plasticity, since on removal of the iron oxides the liquid limit was found to increase. This woild be the case if the oxides have an aggregating effect on the clay minerals. However it is possible for the oxides to contribute to plasticity, as was found by Townsend et al (1971). If the oxides are present as amorphous colloids they will have a large water retention capability due to their large specific surface and will then contribute to plasticity.
- Index property determinations on red soils are sensitive to the methods of preparation. These changes are irreversible, and a permanent change in plasticity is produced by drying. In addition the amount of mixing can change the index properties significantly. To overcome these problems Charman (1988) suggests a procedure for testing the susceptibility to the method of preparation. This involves testing at different drying temperatures and different periods of mixing. If sufficient time is not available for such a detailed test programme, possibly the best solution is to test the material without drying below the natural moisture content with a standard mixing time of 5 minutes.
- The measurement of clay content can also be affected by pre-test drying since the drying process causes the clay particles to aggregate. These aggregations are only partially dis-aggregated by standard dipsersion techniques, and clay fractions are often under-estimated. For example, a red clay from Sasamua, Kenya showed a clay fraction of 79% when testing at natural moisture content, but this reduced to an apparent value of 47% after oven drying.
- Another problem is that the coarse fraction of red soils often consists of weakly cemented particles which readily break down and change grading during seiving or compaction.

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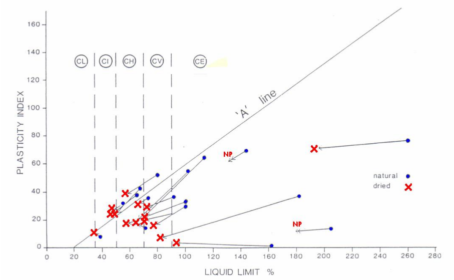
Effect of Drying on Atterberg Limits



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"Black" Soils

- Black soils (Vertisols) form in areas of impeded drainage such as on valley floors and contain smectite clay minerals. They often exhibit excessive shrinkage and swelling properties and present major engineering problems.

Clay mineral	Specific surface (m²/g)	Cation exchange capacity (meq per 100g)	Activity
Kaolinite	15	5-15	0.4 (Inactive)
Illite	80	20-40	0.9 (Normal)
Montmorillonite	800	80-100	7.2 (Active)

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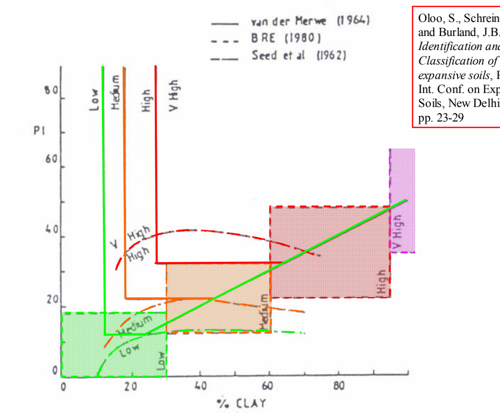
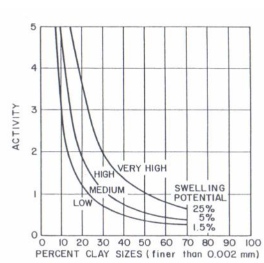
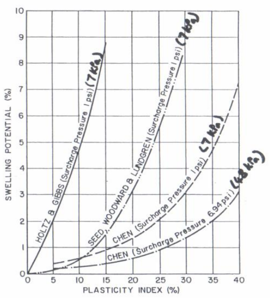


Oloo, S., Schreiner, H.D. and Burland, J.B. (1987) *Identification and Classification of expansive soils*, Proc. 6th Int. Conf. on Expansive Soils, New Delhi, Vol. 1, pp. 23-29

Comparison of three classification systems for degree of expansiveness

Swell Potential





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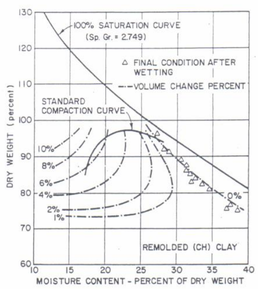
Nelson, J.D. and Miller, D.J. (1992) *Expansive Soils*, Wiley, New York

Percent expansion (Holtz, 1959)



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Nelson, J.D. and Miller, D.J. (1992) *Expansive Soils*, Wiley, New York

Residual Soils from Singapore

- The Jurong Formation
  - Rock types include conglomerate, sandstones and mudrocks (sedimentary)
  - Late Triassic and Lower to Middle Jurassic age
- The Bukit Timah Formation
  - Mainly acidic igneous rocks (varies from granite to granodiorite)
  - Lower to Middle Triassic age

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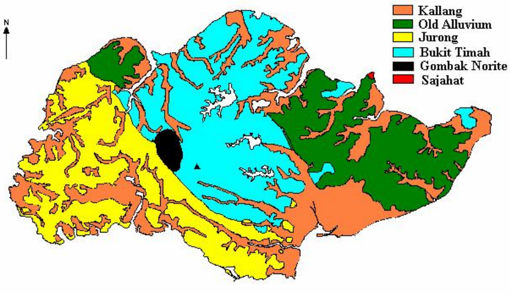
Geology of Singapore



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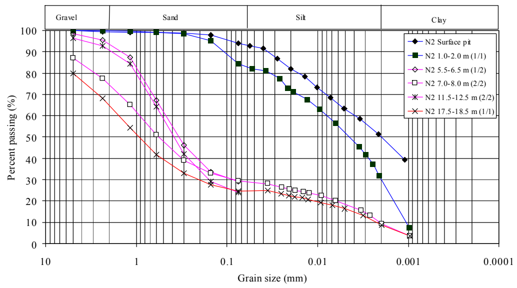
Grain size distribution of Jurong Soils



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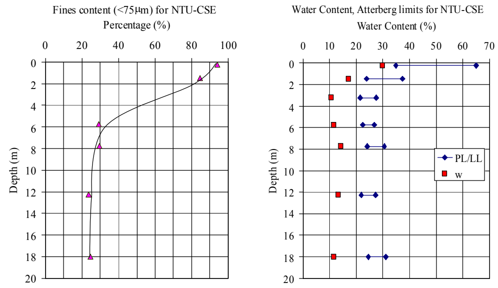
Classification tests for Jurong Soils



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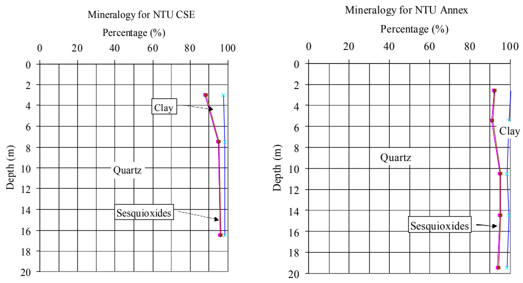
Mineralogy for Jurong Soils



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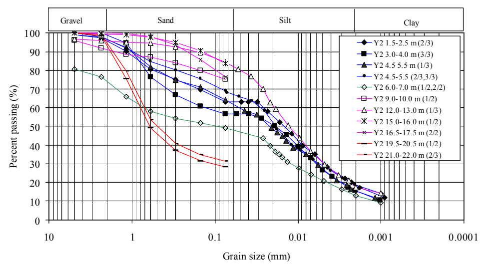
Grain size distribution of Bukit Timah Soils



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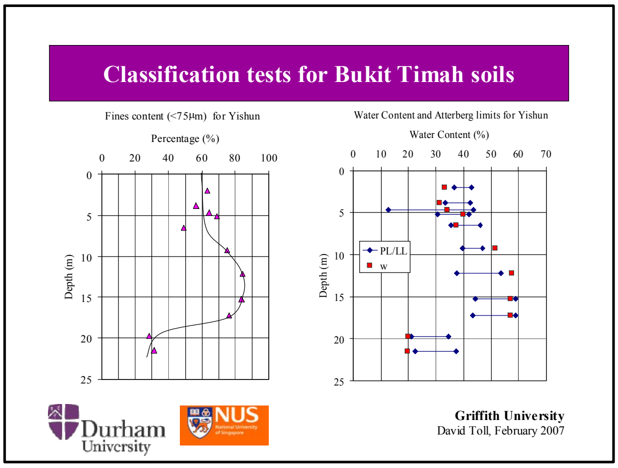
Classification tests for Bukit Timah soils
Fines content (<75μm) for Yishun
Percentage (%)
Depth (m)
Water Content and Atterberg limits for Yishun
Water Content (%)
PL/LL
w
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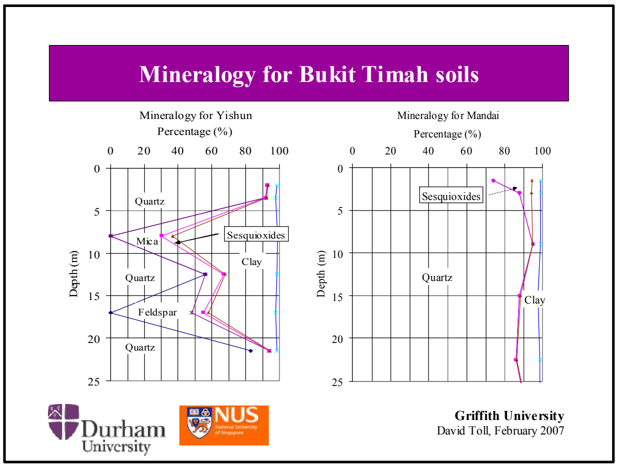
Mineralogy for Bukit Timah soils
Mineralogy for Yishun
Percentage (%)
Depth (m)
Quartz
Mica
Sesquioxides
Clay
Feldspar
Mineralogy for Mandai
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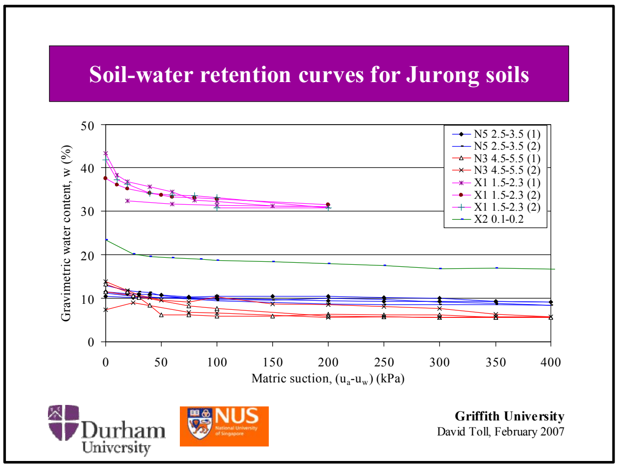
Soil-water retention curves for Jurong soils
Gravimetric water content, w (%)
Matric suction, (ua-uw) (kPa)
N5 2.5-3.5 (1)
N5 2.5-3.5 (2)
N3 4.5-5.5 (1)
N3 4.5-5.5 (2)
X1 1.5-2.3 (1)
X1 1.5-2.3 (2)
X1 1.5-2.3 (2)
X2 0.1-0.2
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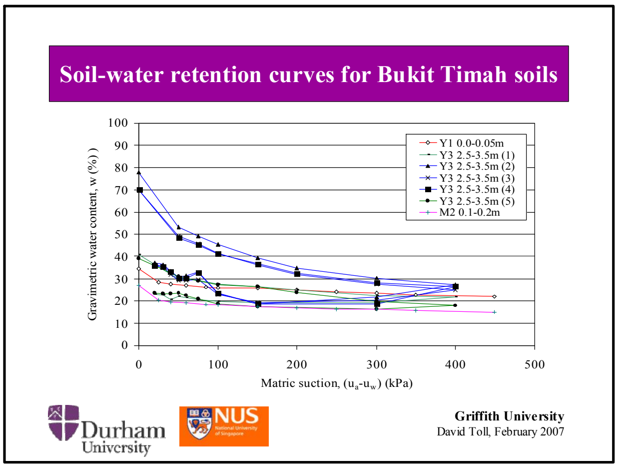
Soil-water retention curves for Bukit Timah soils
Gravimetric water content, w (%))
Matric suction, (ua-uw) (kPa)
Y1 0.0-0.05m
Y3 2.5-3.5m (1)
Y3 2.5-3.5m (2)
Y3 2.5-3.5m (3)
Y3 2.5-3.5m (4)
Y3 2.5-3.5m (5)
M2 0.1-0.2m
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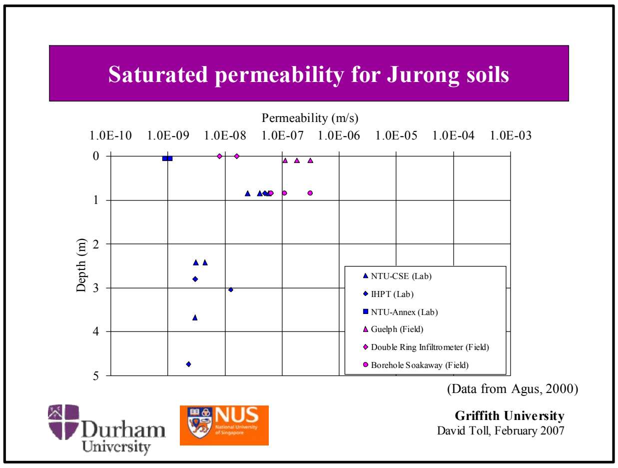
Saturated permeability for Jurong soils
Permeability (m/s)
Depth (m)
NTU-CSE (Lab)
IHPT (Lab)
NTU-Annex (Lab)
Guelph (Field)
Double Ring Infiltrometer (Field)
Borehole Soakaway (Field)
(Data from Agus, 2000)
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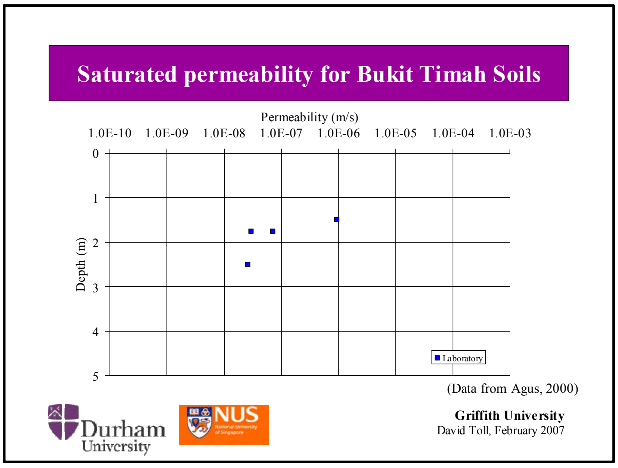
Saturated permeability for Bukit Timah Soils
Permeability (m/s)
Depth (m)
Laboratory
(Data from Agus, 2000)
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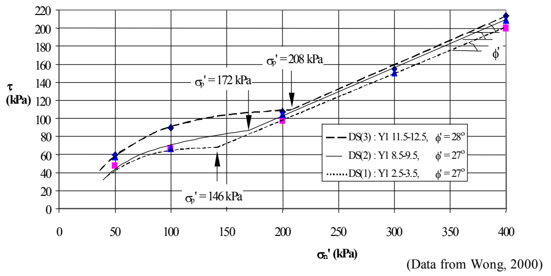
Failure envelopes for Bukit Timah soil



(Data from Wong, 2000)

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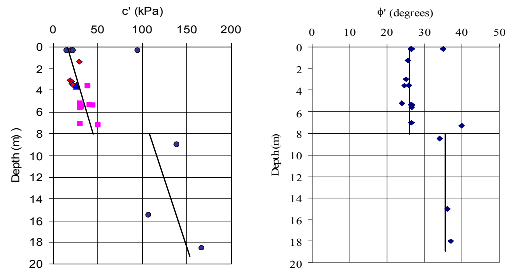
Shear strength parameters for Jurong soils



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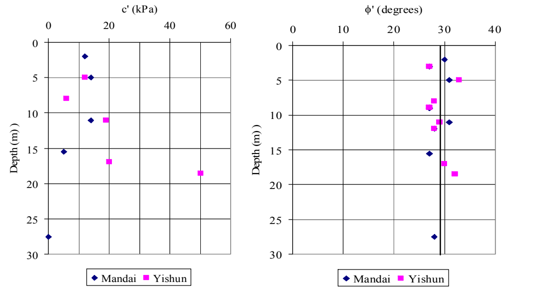
Shear strength parameters for Bukit Timah soils



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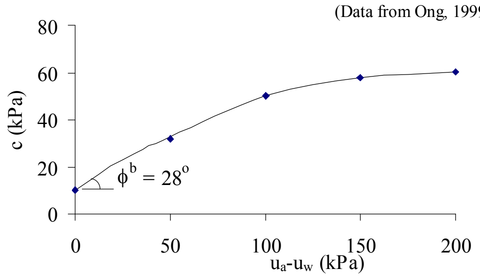
Bukit Timah residual soil

(Data from Ong, 1999)



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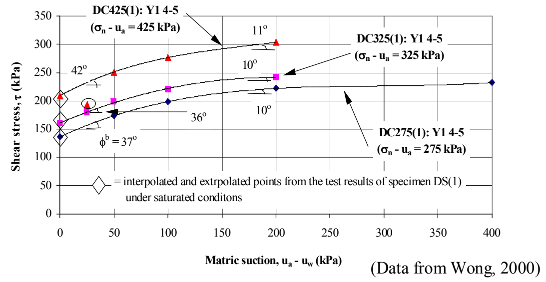
Bukit Timah residual soil



(Data from Wong, 2000)

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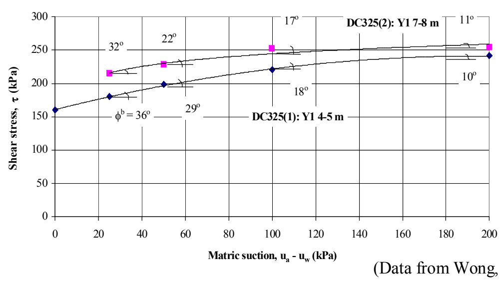
Bukit Timah residual soils



(Data from Wong, 2000)

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Conclusions (Tropical Soils)

- Terminology is confusing – with pedological, geological, geochemical and geotechnical sets of terminology
- Geological Society adopted terminology (Fersiallitic, Ferruginous, Ferralitic) is useful in defining the stage of development. However, it relates to changes in mineralogy – which may not be the dominant factor for engineering purposes
- "Red" soils can often be good engineering materials, but we cannot use frameworks developed for sedimentary soils to classify them
- "Black" soils (vertisols) are often rich in smectites and pose many engineering challenges

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Conclusions (Singapore Residual Soils)

- The mineralogy of the residual soils soils is primarily quartz and kaolinite although some soils derived from weathered granite soils show a more complex pattern.
- Soil-water characteristics show considerable variation, particularly in the saturated water contents. Saturated permeabilities are around 10^{-8} m/s for the Grade VI residual soil.
- The angle of friction (ϕ') for Jurong soils is around 26° for the Grade VI residual soil and around 35° for the Grade V material. Effective cohesion (c') for Grade VI varies with depth from 15 to 50kPa, whereas c' for Grade V exceeds 100 kPa.
- The angle of friction (ϕ') for Bukit Timah soils is around 29° and c' is generally less than 20 kPa.
- The angle of friction with respect to suction (ϕ^b) is near to ϕ' at low matric suctions but drops to values less than 10° as suctions reach 200 kPa.

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