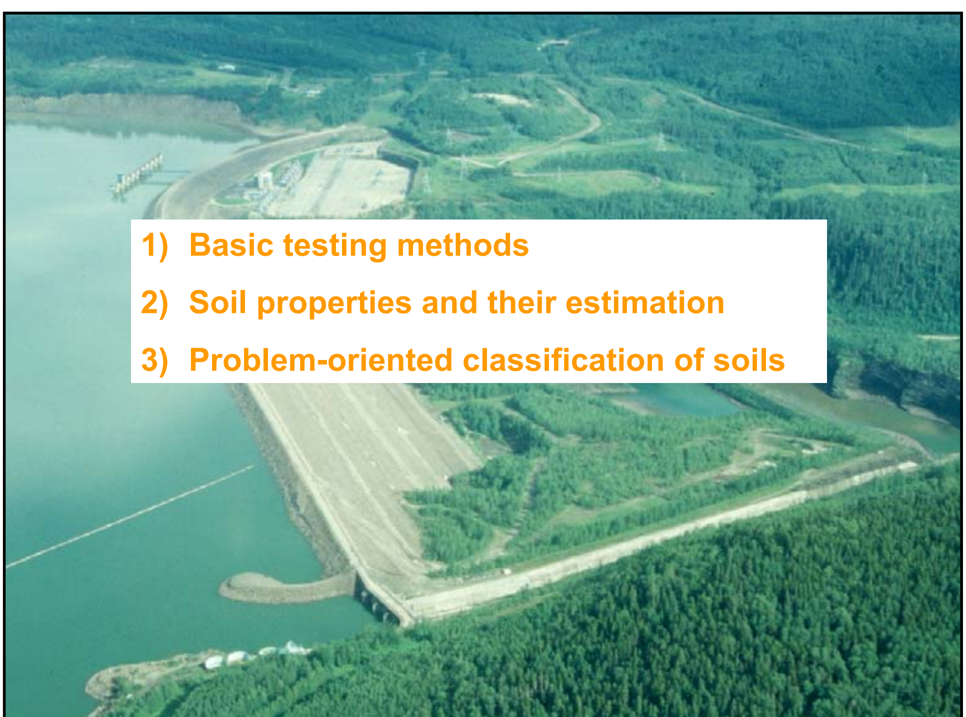
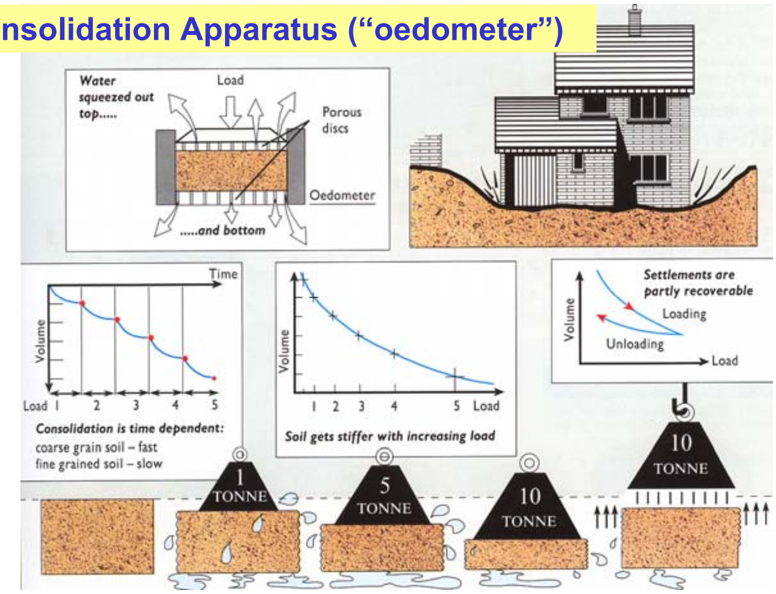
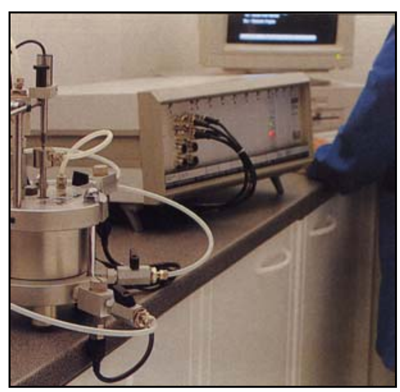

Soil and rock properties
W.A.C. Bennett Dam,
BC Hydro

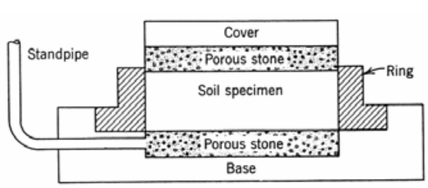

1) Basic testing methods
2) Soil properties and their estimation
3) Problem-oriented classification of soils

Consolidation Apparatus ("oedometer")



ELE catalogue

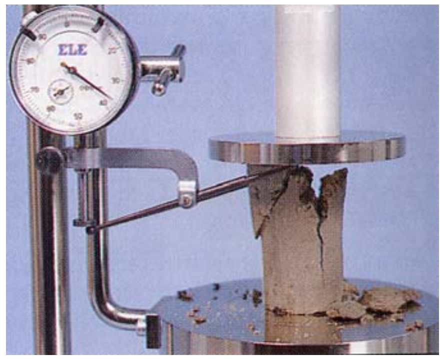




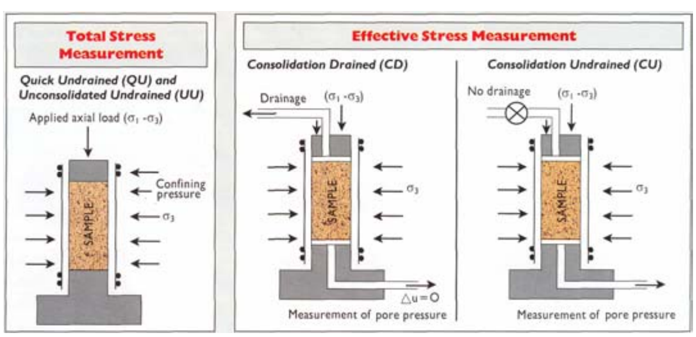
Oedometers

ELE catalogue

Unconfined compression test on clay (undrained, uniaxial)

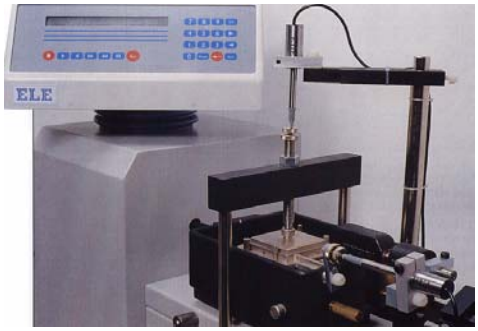


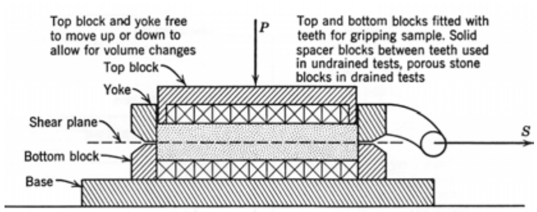
ELE catalogue



Triaxial test on soil

ELE catalogue





Direct shear (shear box) test on soil

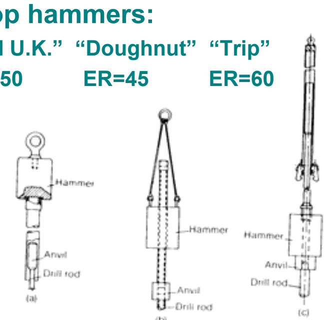
ELE catalogue

Field test: Standard Penetration Test (STP)

ASTM D1586

Drop hammers:

"Old U.K."	"Doughnut"	"Trip"
ER=50	ER=45	ER=60



Corrections:

1) Energy ratio:

$$N_{60} = \frac{ER}{60} N$$

2) Overburden depth

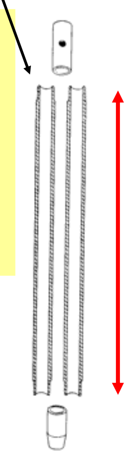
$$N_1 = \frac{1.7N}{0.7 + \sigma_v'}$$

Effective vertical pressure (tons/ft^2)

Standard "split spoon" sampler (open) 18" (30.5 cm long)

Test:

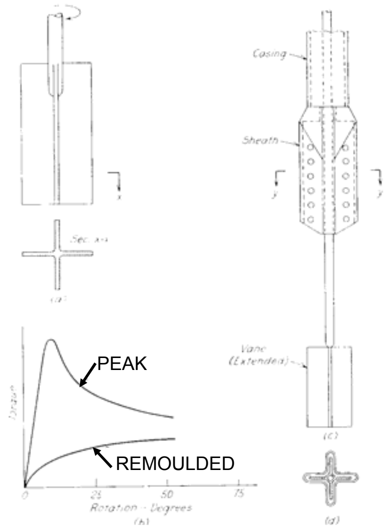
1) Place sampler to the bottom
2) Drive 18", count blows for every 6"
3) Recover sample. "N" value = number of blows for the last 12"



Precautions:

1) Clean hole
2) Sampler below end of casing
3) Cobbles

Field test: Borehole vane (undrained shear strength)

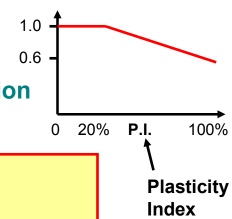


Procedure:

1) Place vane to the bottom
2) Insert into clay
3) Rotate, measure peak torque
4) Turn several times, measure remoulded torque
5) Calculate strength

Correction:

Bjerrum's correction



Precautions:

1) Clean hole
2) Sampler below end of casing
3) No rod friction

ASTM D2573

Soil properties relevant to slope stability:

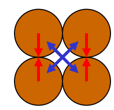
1) **"Drained" shear strength:**
   - friction angle, true cohesion
   - curved strength envelope
2) **"Undrained" shear strength:**
   - apparent cohesion
3) **Shear failure behaviour:**
   - contractive, dilative, collapsive
   - pore pressure response, stress path
4) **Time-dependent changes:**
   - softening
5) **Mechanical changes:**
   -pre-shearing, residual strength
6) **Moisture-dependency:**
   - loss of strength on wetting

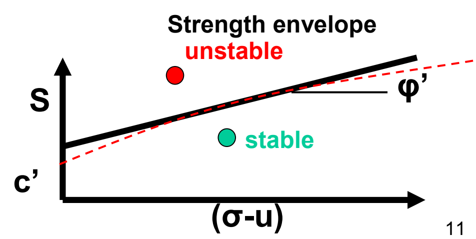
Basic soil strength model:

Mohr-Coulomb ("drained") peak shear strength :

$$S = c' + (\sigma - u)\tan\phi'$$

Where:
(σ-u) = "effective stress"
c' = "drained" cohesion
φ' = drained friction angle

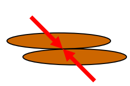


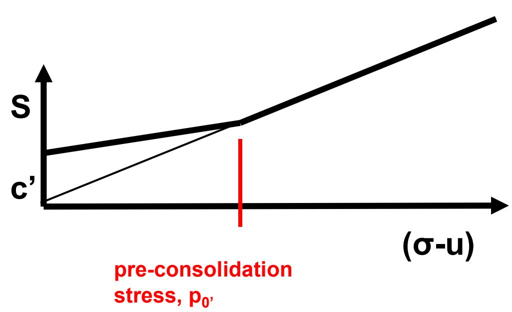


Types of cohesion:

1) **Electrostatic forces (in stiff overconsolidated clays): 5-24 kPa**

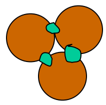
May be lost through weathering





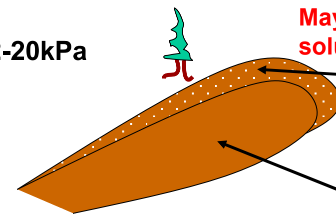
Types of cohesion:

2) Cementing by Fe_2O_3, $CaCO_3$, NaCl etc.: up to 500kPa

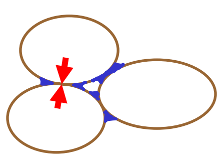


3) Root cohesion: 2-20kPa

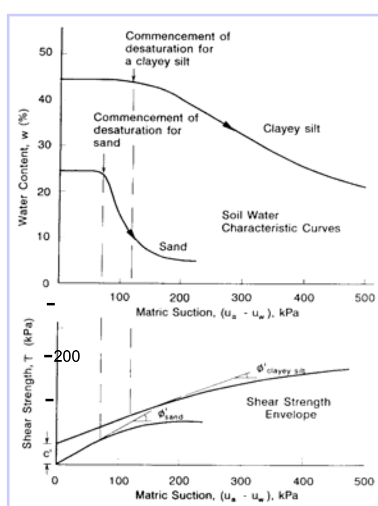
May be lost through logging or fire



3) Apparent cohesion in unsaturated soil:



As soil dries out, water menisci form at grain contacts. These are under negative capillary pressure. When capillary forces are netted over a unit area, we refer to "matric suction stress", which creates interparticle forces→apparent cohesion

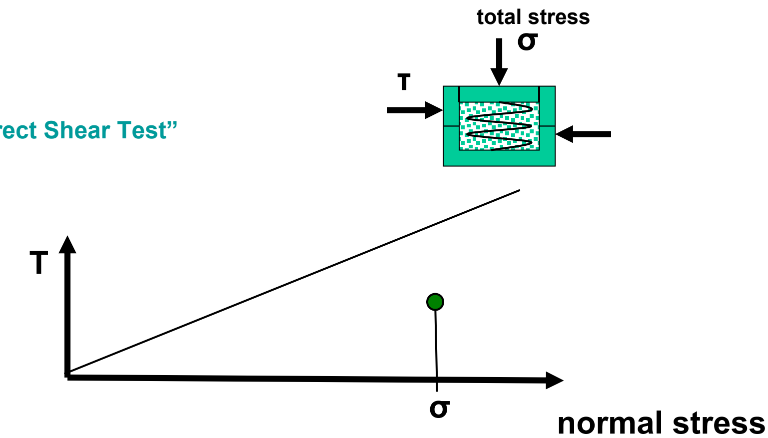


(Fredlund and Rahardjo, 1993)

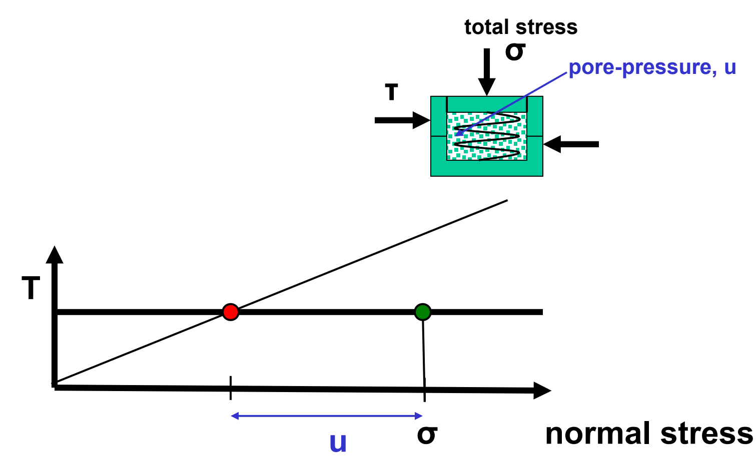
Problem: cohesion will disappear on wetting

5) Apparent cohesion due to pore-pressure response during relatively fast ("undrained") loading

"Direct Shear Test"

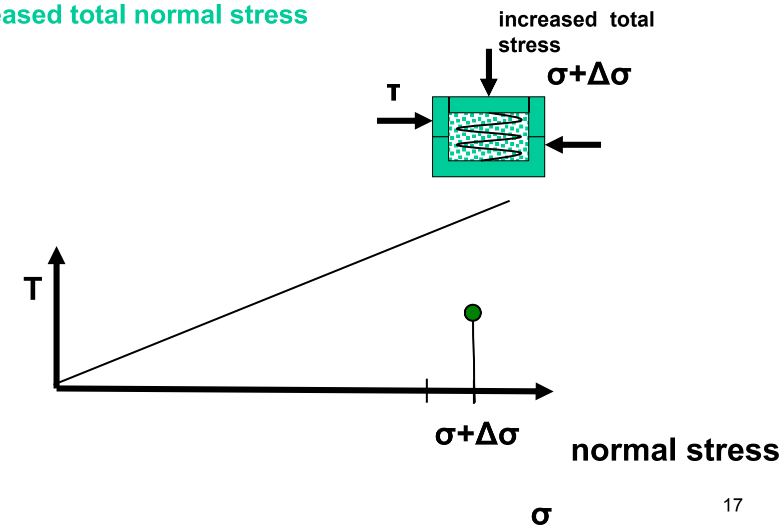


Apparent cohesion:



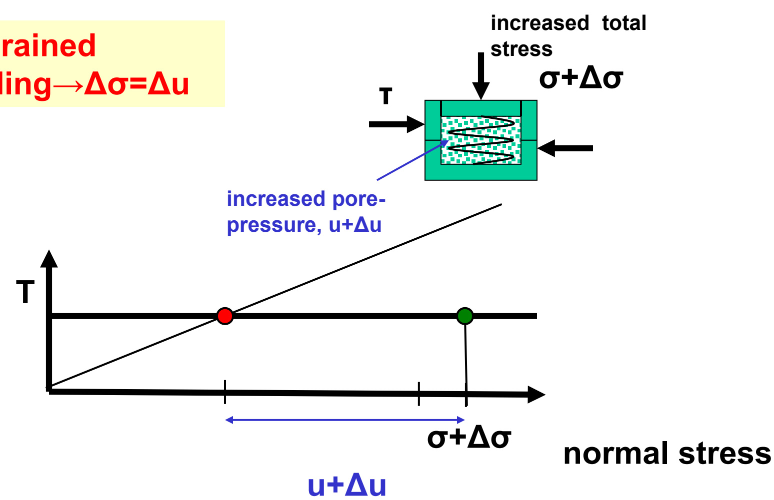
Apparent cohesion:

Increased total normal stress



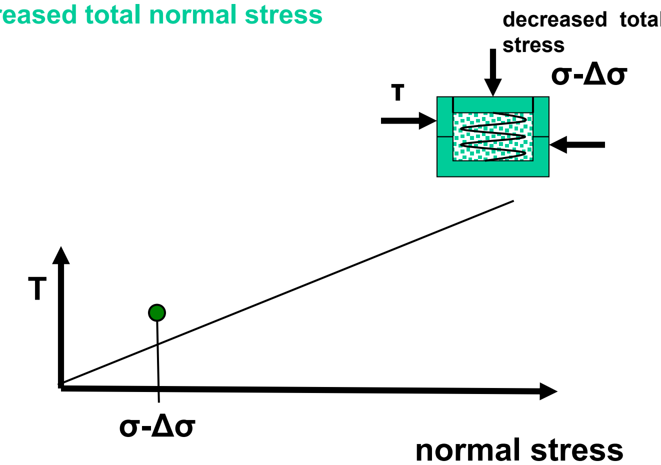
Apparent cohesion:

Undrained loading→Δσ=Δu



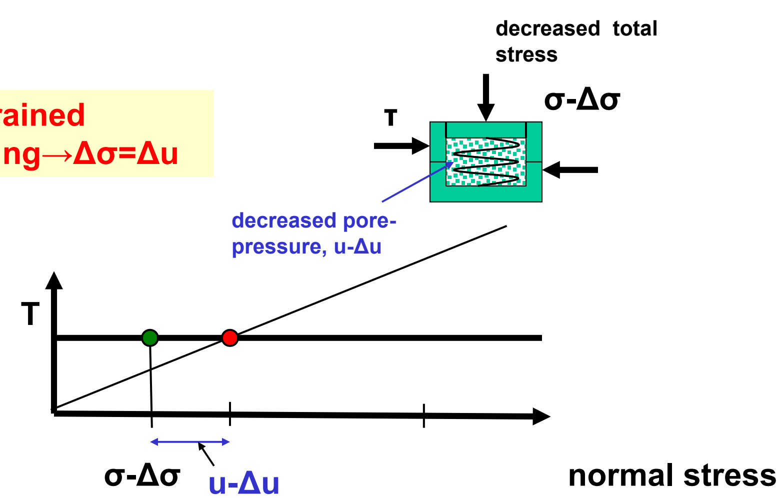
Apparent cohesion:

Decreased total normal stress



Apparent cohesion:

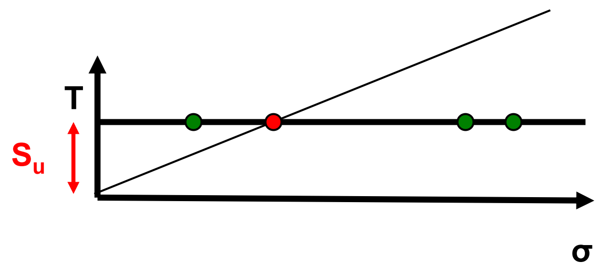
Undrained loading→Δσ=Δu



Apparent cohesion (Undrained shear strength):

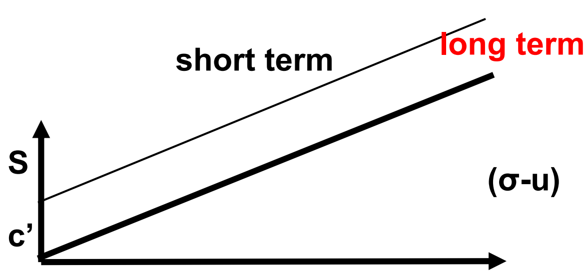
Clay will have a constant short-term strength (Undrained Shear Strength, S_u)

May be lost through time (delayed failure)

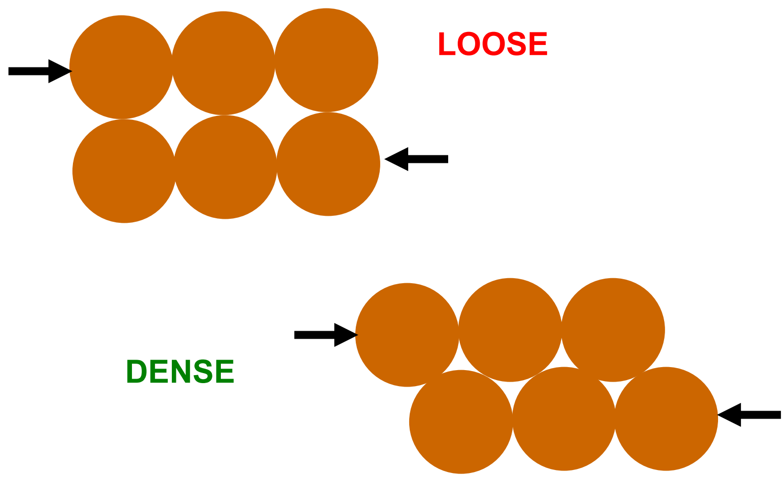


"φ = 0" condition

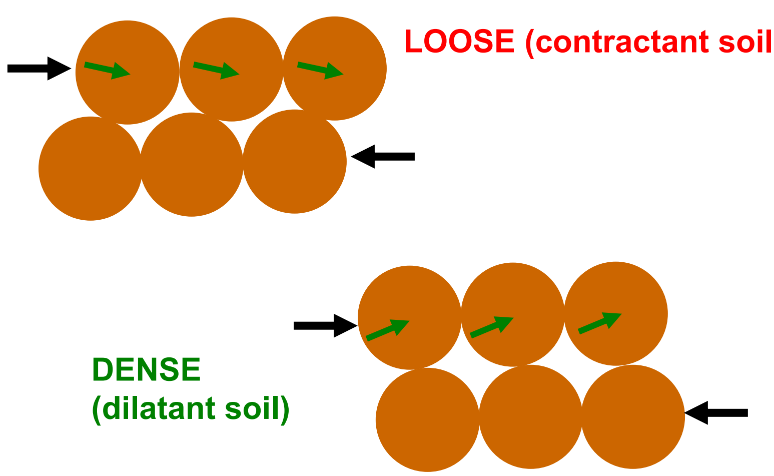
Softening:



Friction angle:

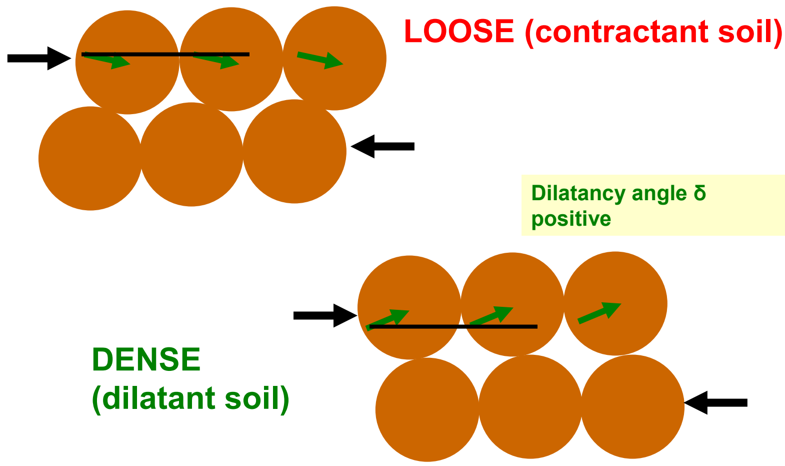


Friction angle:

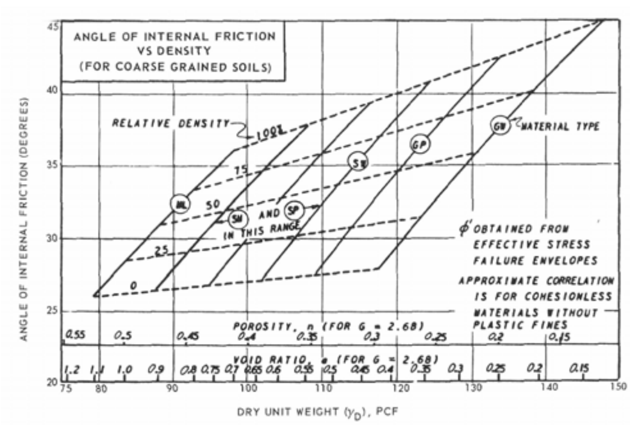


Friction angle:

$$\phi' = \phi_{basic} + \delta$$



Dependence of friction angle on density in sands:

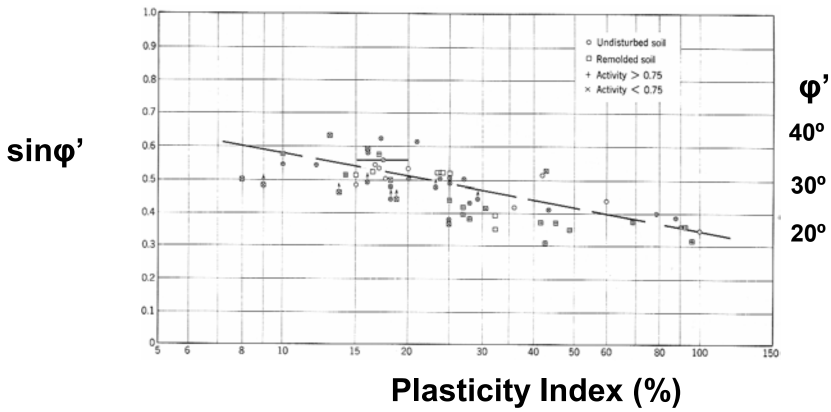


Relative density from SPT test:

N	D_r
0-4	0-15
4-10	15-35
10-30	35-65
30-50	65-85
>50	>85

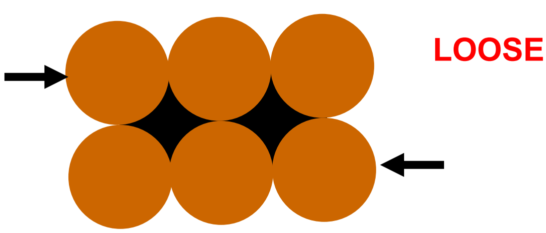
NAVFAC, 1971

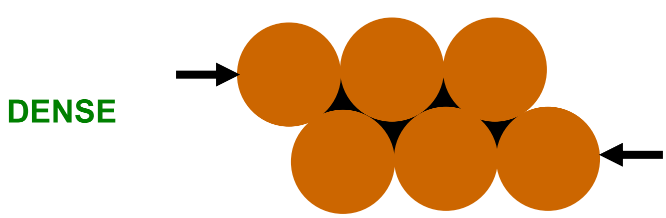
Dependence of friction angle on plasticity in clays:



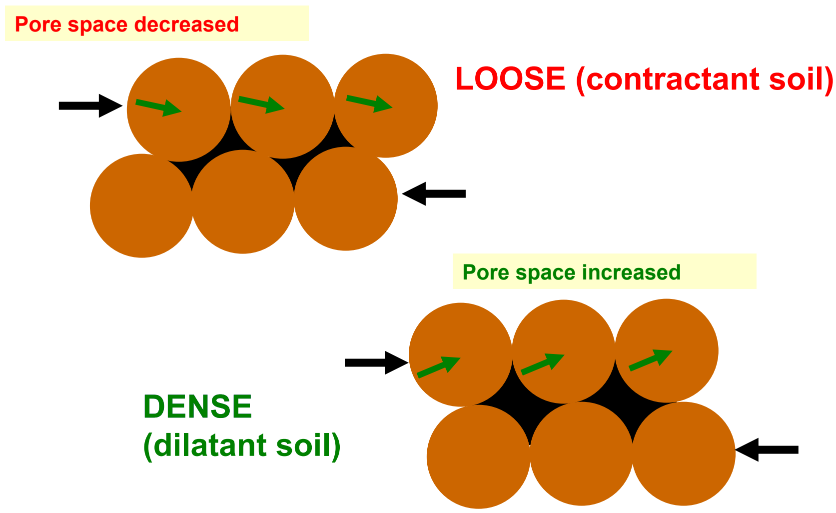
Lambe and Whitman (1979)

Pore-pressure response:

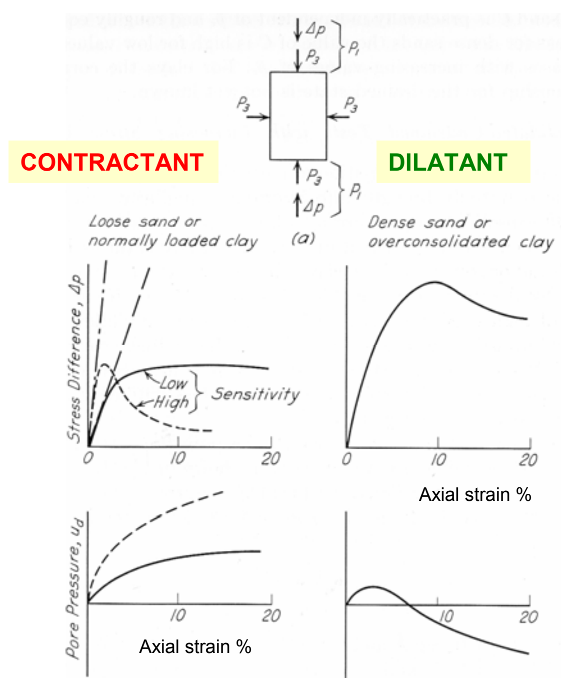




Pore-pressure response:

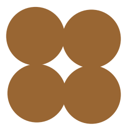


Results of a typical triaxial test on soil

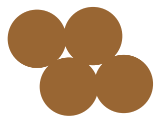


Terzaghi and Peck, 1967

Soil structure collapse

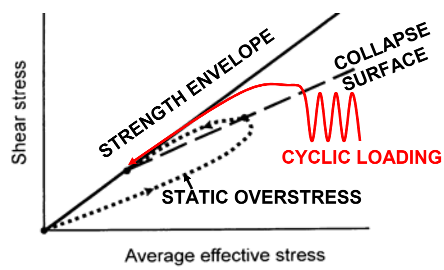


Loose packing



Dense packing

Soil collapse: sudden change from loose to dense packing, volume change. If soil is saturated, volume change cannot occur and pore-pressure increases, reducing effective stress ("liquefaction")



(Mc Roberts and Sladen, 1990)

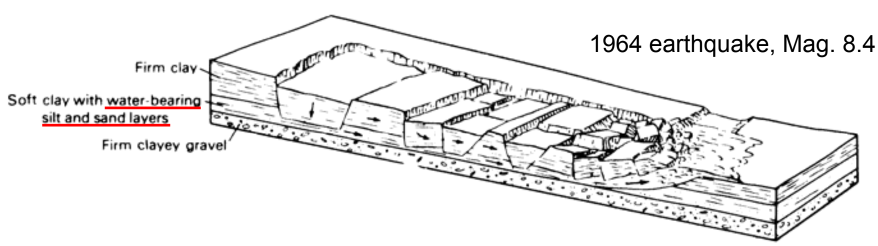
What causes collapse:

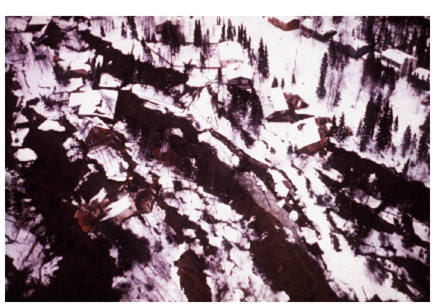
1) loose, saturated soil (N<8)
2) Static overstress (caused by added loading, or increase in pore pressure)
3) Earthquake shaking (cyclic loading)\

Effect more dramatic, if accompanied by cohesion loss

Turnagain Hts. Slide, Anchorage, Alaska

1964 earthquake, Mag. 8.4

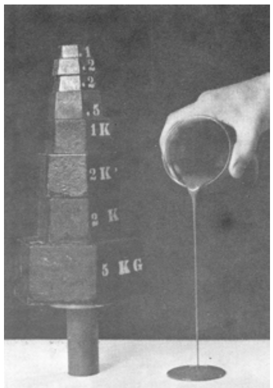




(Seed and Wilson, 1967)

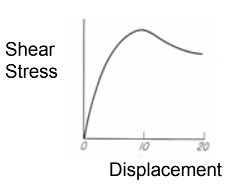
Remolding of highly-sensitive ("quick") clays

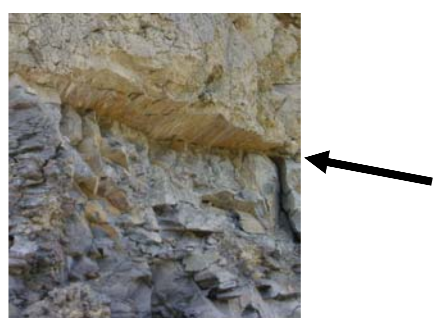
Usually leached clays of marine origin, may be overconsolidated and low plasticity

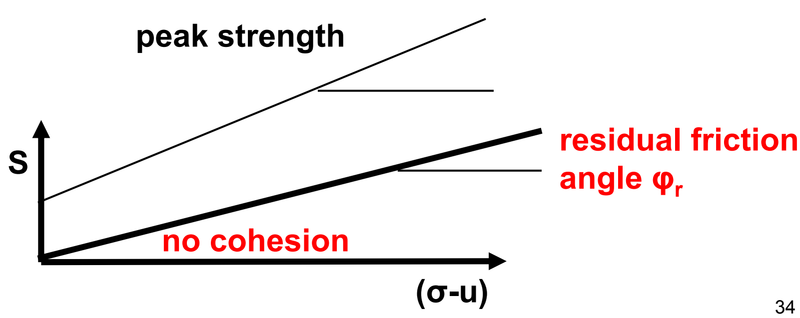


peak **remoulded**

Pre-shearing:

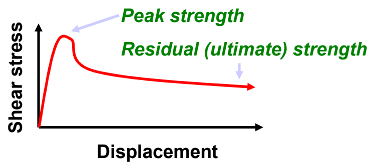


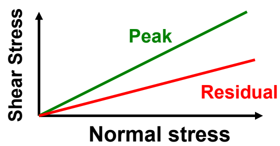


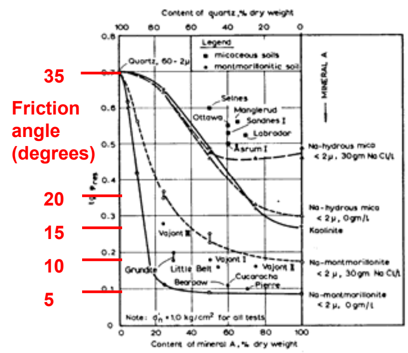


Pre-Shearing

- The friction angle of clay decreases from peak to
- residual value due to particle alignment, when sheared.

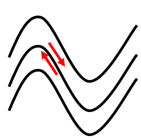


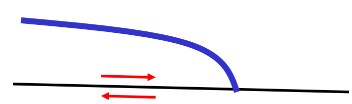




(Kenney, 1967)

Reasons for pre-shearing of clay surfaces





1) **Tectonics: flexural slip (in sedimentary rocks)**

2) **Glacier drag (lacustrine clays, shales)**

3) **Relict landslides**

Loss of soil strength, summary

a) Long-term strength loss, leading to delayed failure:

Process:	*Time frame*	*Materials*
Increase of pore-pressure through drainage	**Weeks to years**	**clay, silt**
Softening of fissured clay, loss of cohesion	**Decades**	**Stiff, fissured clay**
Reduction in friction angle through shearing (progressive failure)	**Variable**	**Stiff clays**

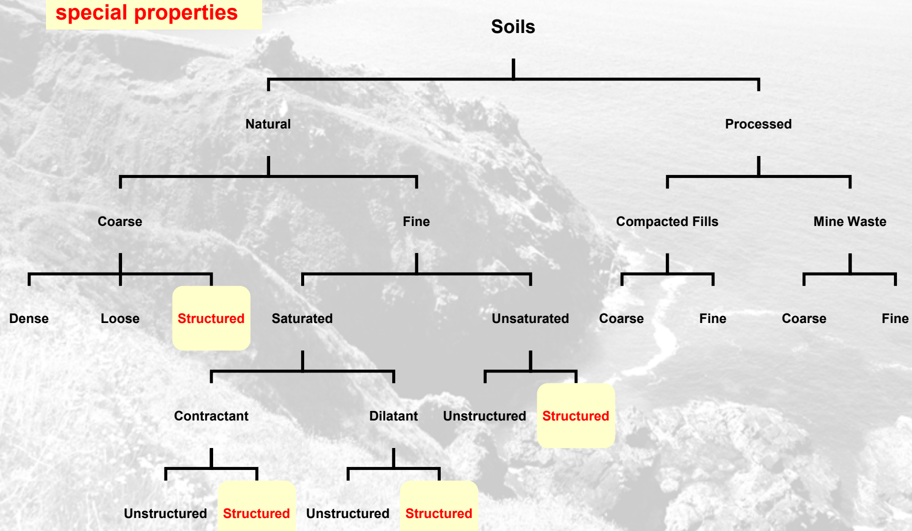
b) Sudden strength loss, leading to extremely rapid failure

Process:	*Materials*
Sudden remoulding	**Extra-sensitive (quick) clay**
Static or earthquake liquefaction	**Loose, saturated sand, silt**
Loss of apparent cohesion on wetting	**Unsaturated silt**
Loss of true cohesion due to overstress	**Weakly cemented sand, silt**

A problem-oriented classification of soils.

Morgenstern, 1985

special properties



A problem-oriented classification of soils.

Morgenstern, 1985

Soils

Natural Processed

-We have no control
> less reliable

-Can control properties and placement
> more reliable

A problem-oriented classification of soils.

Morgenstern, 1985

Soils

Natural

Coarse

sand, gravel, boulders

- rapid drainage

Fine

>50% silt and clay

-slow drainage
-cohesive

Processed

Compacted Fills

-select material
-designed placement
-controlled properties

> reliable

Mine Waste

-uncompacted
-random material
-poor foundations

> unreliable

A problem-oriented classification of soils.

Morgenstern, 1985

- **Soils**
  - **Processed**
    - **Compacted Fills**
      - **Coarse**
        - Design problems:
          - -compaction
          - -stable drainage (filters)
      - **Fine**
        - Design problems:
          - -deformability
          - -shear strength
          - -internal erosion (filters)
    - **Mine Waste**
      - **Coarse**
        - Waste pile problems:
          - -loose, possibly collapsive (flow slides)
          - -poor foundations
          - -complex drainage
      - **Fine**
        - Tailings dyke problems:
          - -loose, possibly collapsive (liquefaction)
          - -internal erosion
          - -poor drainage (overtopping)

A problem-oriented classification of soils.

Morgenstern, 1985

- **Soils**
  - **Natural**
    - **Coarse**
      - **Dense**
        - Rd>35%
        - N>10-20
        - - Few problems
        - - erodible?
      - **Loose**
        - - May be collapsive in undrained failure (liquefaction) if saturated (submarine flow slides?)
        - -erodible?
      - **Structured**
        - -Cemented
        - -Weak cement may sustain loose structure!
        - - may be collapsive
        - - erodible?

A problem-oriented classification of soils.

Morgenstern, 1985

Soils
Natural
Fine
Unsaturated

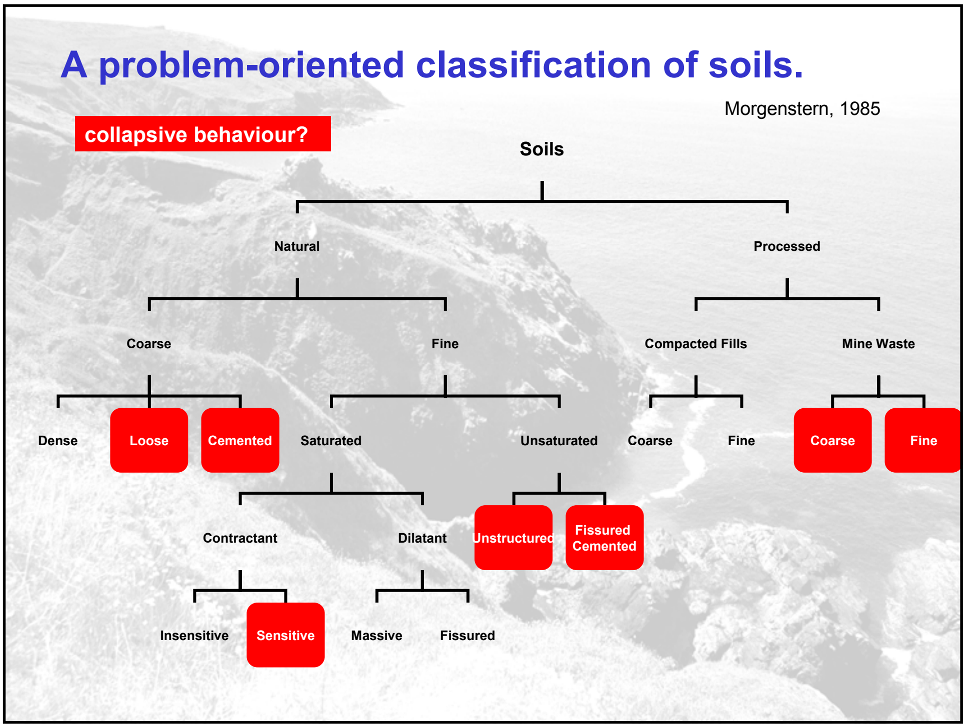
- Unstructured
  - -Apparent cohesion
  - -Non-linear strength envelope, dependent on moisture content
  - -Stability strongly dependent on infiltration
  - >low reliability
- Structured
  - -May be cemented, fissured (secondary permeability) or collapsive.
  - >very low reliability

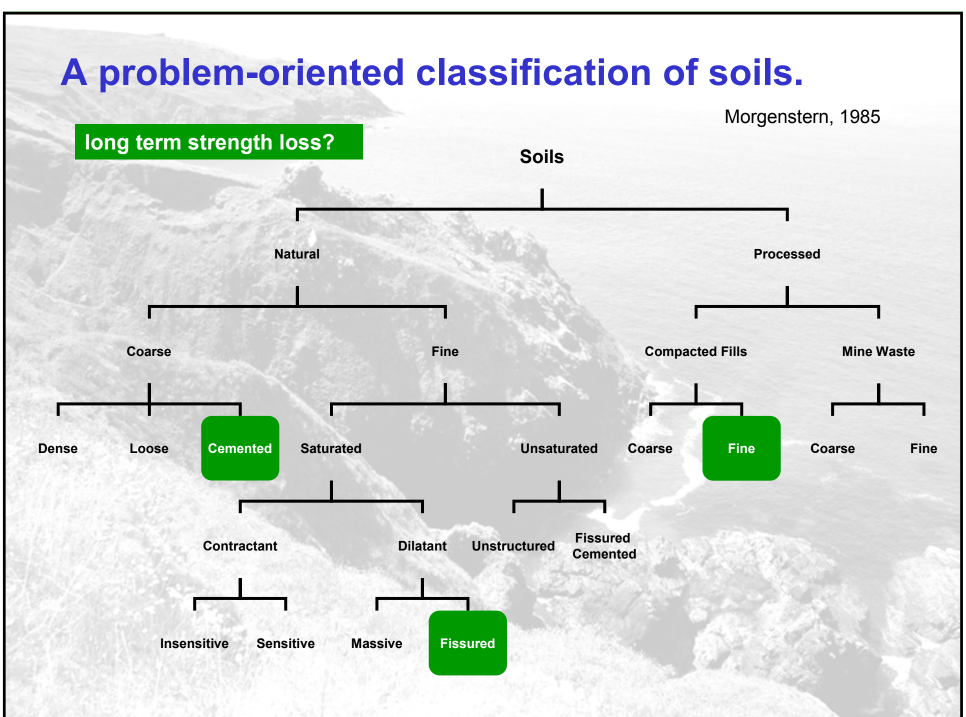
A problem-oriented classification of soils.

Morgenstern, 1985

Soils
Natural
Fine
Saturated

- Contractant
  - Unstructured
    - -Insensitive soft clays
    - -“Textbook” materials:
    - -Problem: accurate measurement of undrained shear strength
    - -Watch for loose sand lenses!
  - Structured
    - -Sensitive clays
    - -Collapsive (flow slides)
    - -“Quick clays”
- Dilatant
  - Unstructured
    - -Intact stiff clays
    - -Cohesive tills
    - -Few problems
    - -(rare)
    - -But: Watch for pre-sheared horizons and progressive failure
  - Structured
    - -Fissured stiff clays
    - -Cohesion and friction loss due to:
    - -Softening
    - -Pre-shearing
    - -Progressive failure
    - Also: secondary permeability


A problem-oriented classification of soils.
Morgenstern, 1985
collapsive behaviour?
Soils
Natural
Processed
Coarse
Fine
Compacted Fills
Mine Waste
Dense
Loose
Cemented
Saturated
Unsaturated
Coarse
Fine
Coarse
Fine
Contractant
Dilatant
Unstructured
Fissured Cemented
Insensitive
Sensitive
Massive
Fissured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long term strength loss?
Soils
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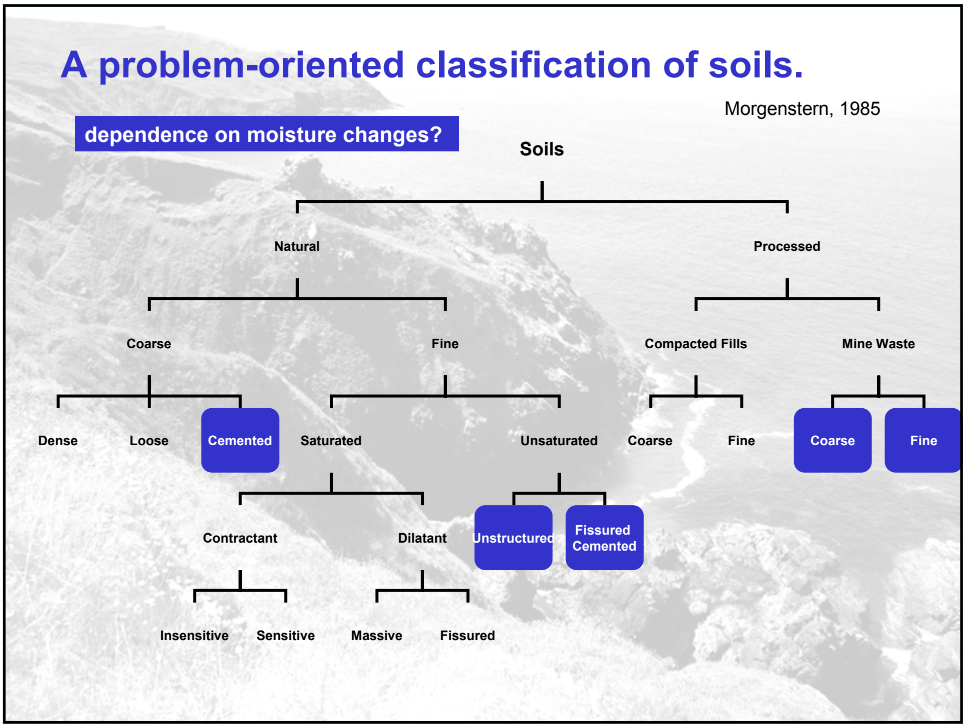

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dependence on moisture changes?
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