"THE REMARKABLES" QUEENSTOWN NZ

MODELLING SOILS AND GRANULAR MEDIA

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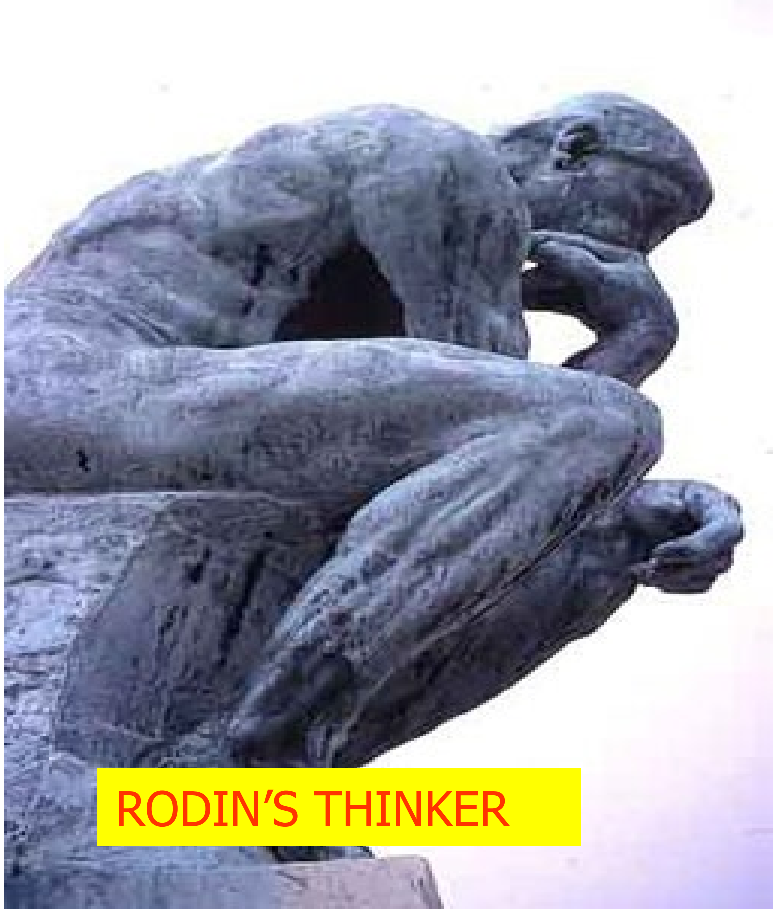
OVERALL OBJECTIVES

- TO GIVE AN OVERVIEW OF EXTANT MODELLING PROCEDURES COMMONLY USED IN GEOTECHNICAL ENGINEERING
- TO DISCUSS THEIR SHORT COMINGS
- TO PROPOSE A WAY FORWARD BASED ON MODERN THERMOMECHANICAL FORMULATIONS OF ELASTIC/PLASTIC SOLIDS

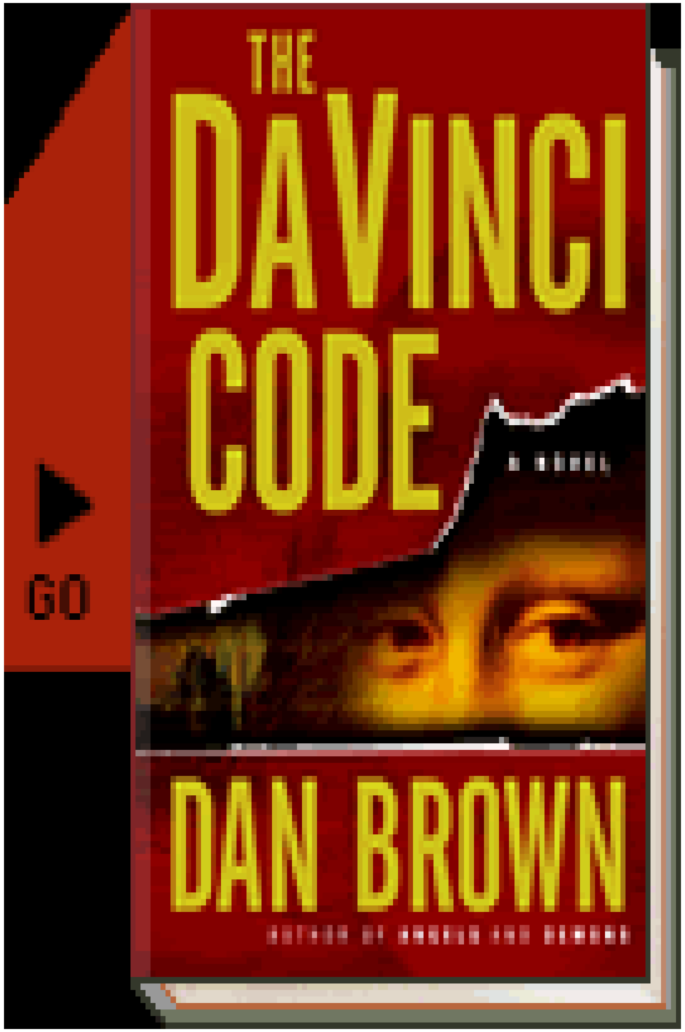
LECTURE 1
BASIC SOIL PROPERTIES



RODIN'S THINKER

SISLEY'S "SAND HEAPS"

HISTORICAL INTRODUCTION

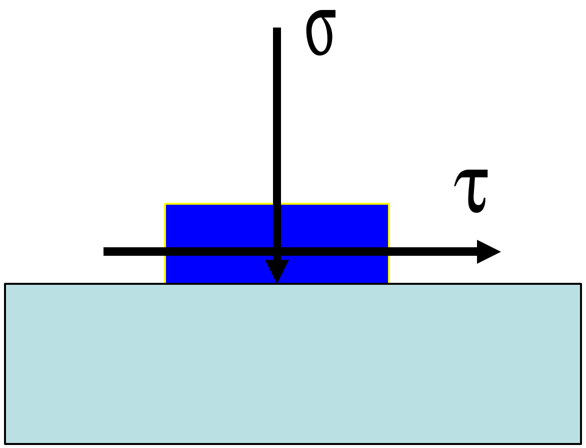


"Every heap of sand, whether it be on level ground or sloping, will have its base twice the length of its axis."

Leonardo da Vinci (Diaries)

The strength of sands is determined by certain critical angles!!!

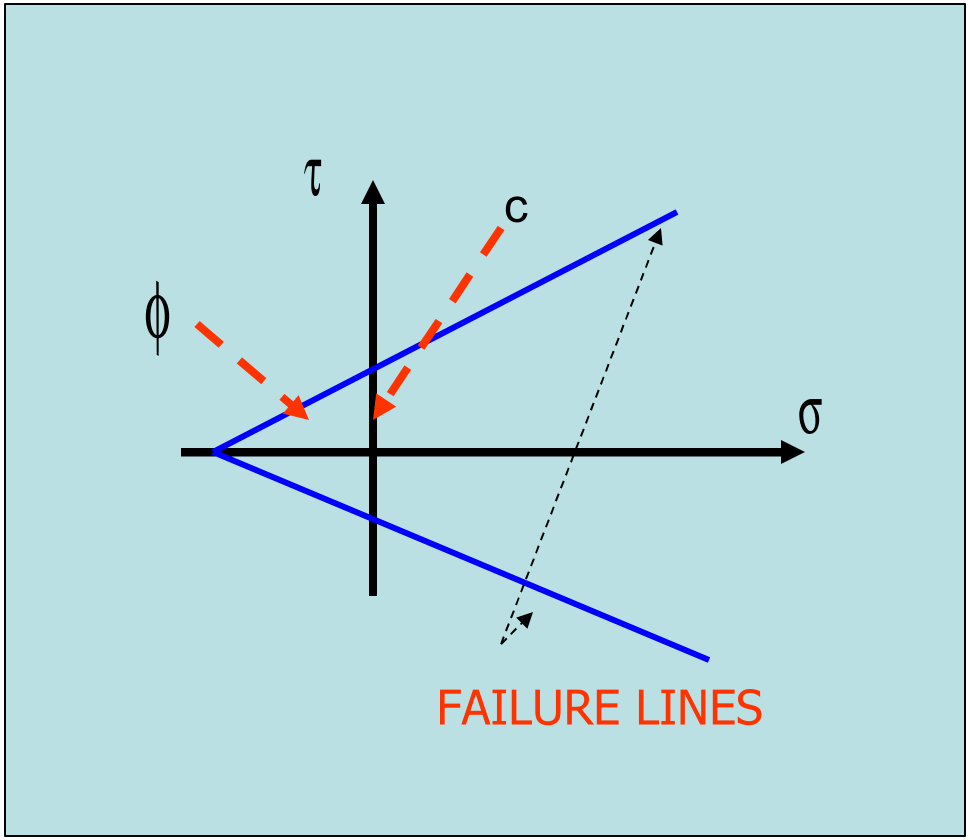
COULOMB 1736-1806

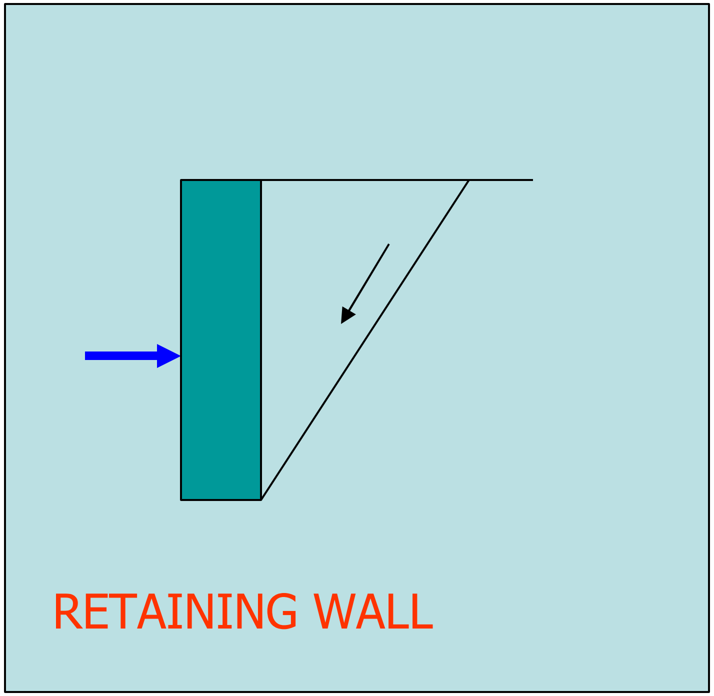


$$|\tau| = c + \sigma \tan\phi$$

cohesion

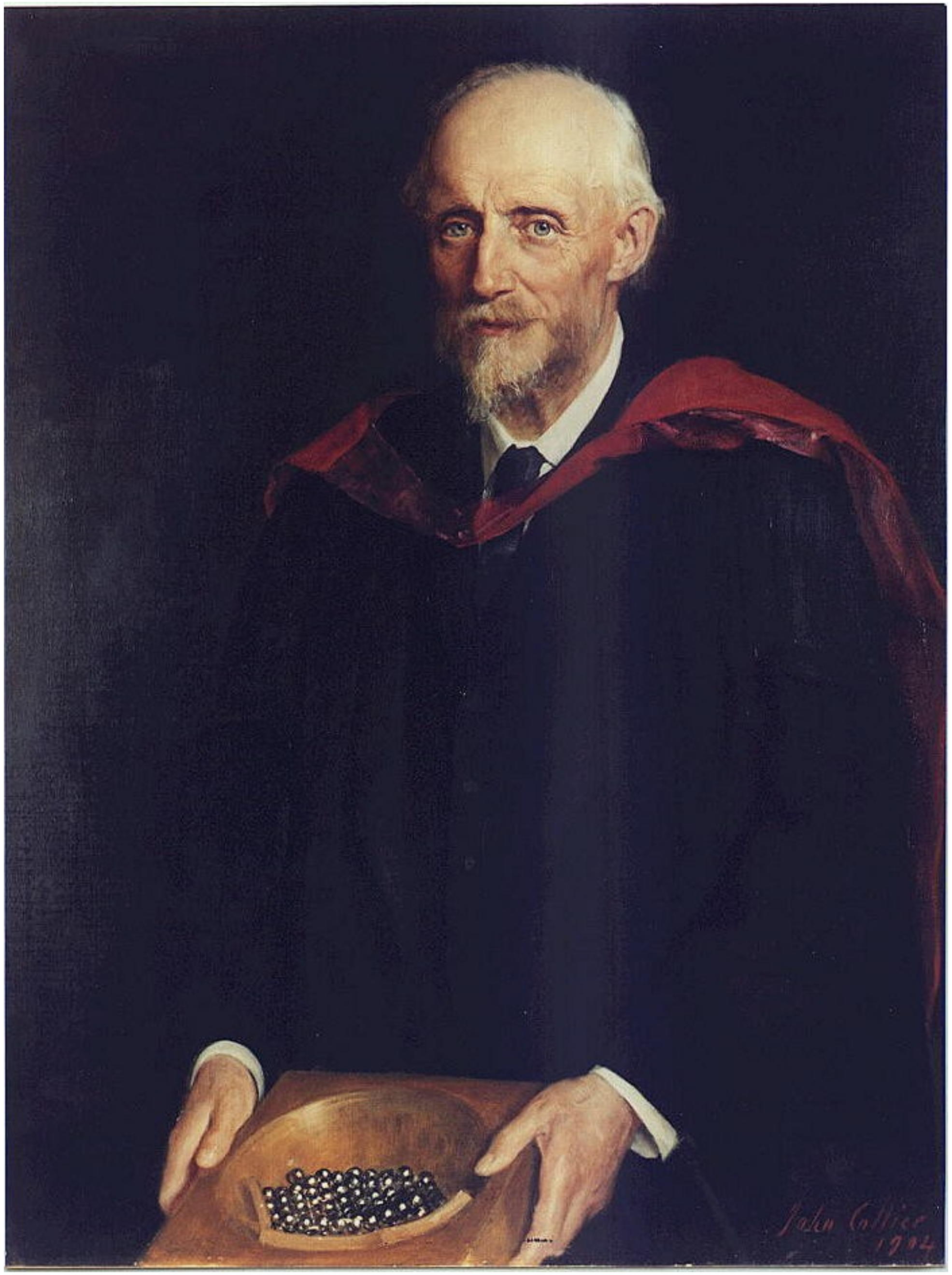
friction angle





Analysed “stress system” behind retaining walls, and introduced notions of active and passive failures

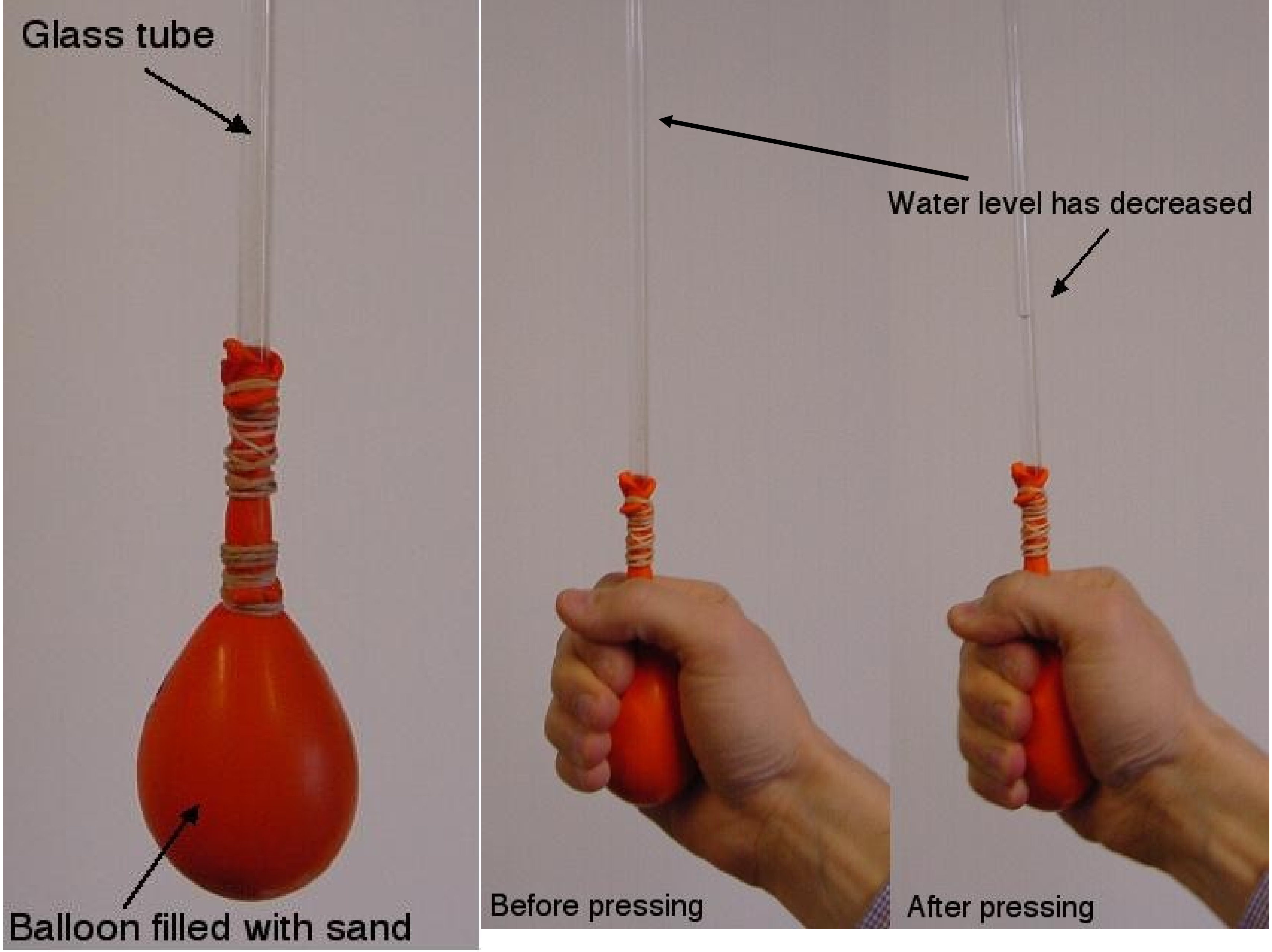
- Professor William Rankine (Glasgow) (1820-1872)



Reynolds, O.

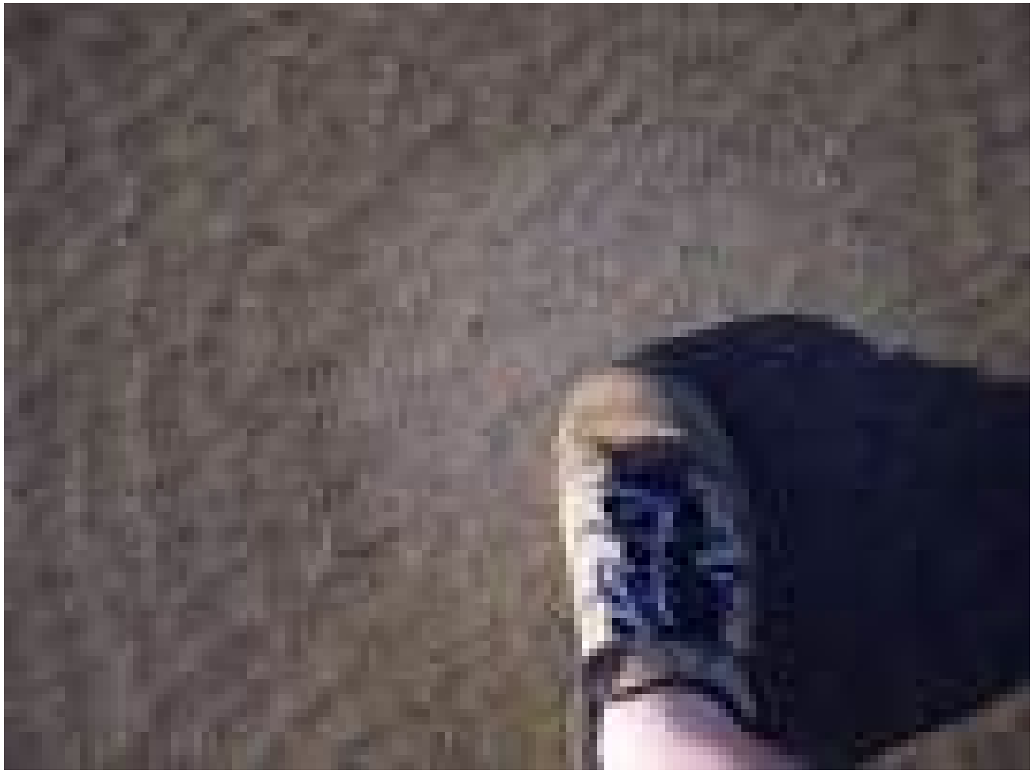
"On the DILATANCY of media composed of rigid particles in contact,with experimental observations"

Philosophical Magazine, 20 (S5) 469-481, Dec 1885.



Reynolds Demonstration

A FAMILIAR EXAMPLE OF “REYNOLDS DILATANCY”



OSBORNE REYNOLDS, 1842-1912.

Second Professor of Engineering in England. (Manchester)

Two Books:

(c) "Sewer gas and how to keep it out of homes" (1876).

(b) "On the Sub-Mechanics of the Universe" (1903)

Karl von Terzaghi

The Father of Soil Mechanics

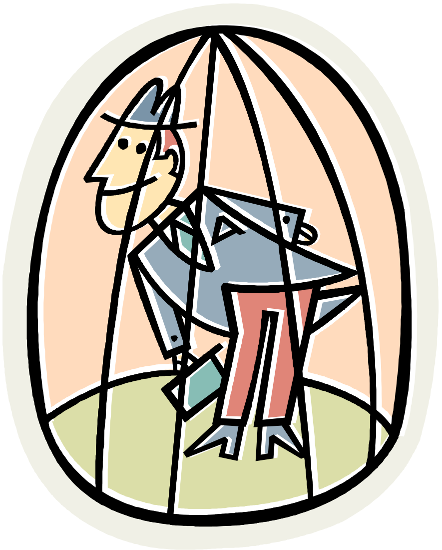
He who said "Erdbaumechanik" in 1923

MATHEMATICIANS ARE USEFUL ANIMALS

WHO SHOULD BE KEPT IN A GOLDEN CAGE

AND FED PROBLEMS JUDICIOUSLY

Karl Terzaghi



KARL TERZAGHI, 1883-1963, Thoughts occasioned by the centenary of his birth, R. B. Peck, Geotechnique (1983), 349-350.

Professor Karl Terzaghi was in the witness chair in a courtroom as an expert witness (some time in the late 1950's).

The opposing lawyer quoted K.T. from his 1943 Theoretical Soil Mechanics book and asked Terzaghi if that is not what he had written.

Terzaghi said "Yes".

"Then," replied the lawyer triumphantly, "the testimony you just gave contradicts what you wrote, does it not Dr. Terzaghi???".

Those who knew K.T. in the courtroom were hushed into disbelief until Terzaghi replied:

"Sir, you think I am such a vegetable that I have not learned anything new since then?".

CONCEPT OF EFFECTIVE STRESS

TERZAGHI:

$$F = \sigma' A + u A$$

EFFECTIVE STRESS — PORE PRESSURE

FILLUNGER:

$$F = \sigma' A_s + u A_w$$

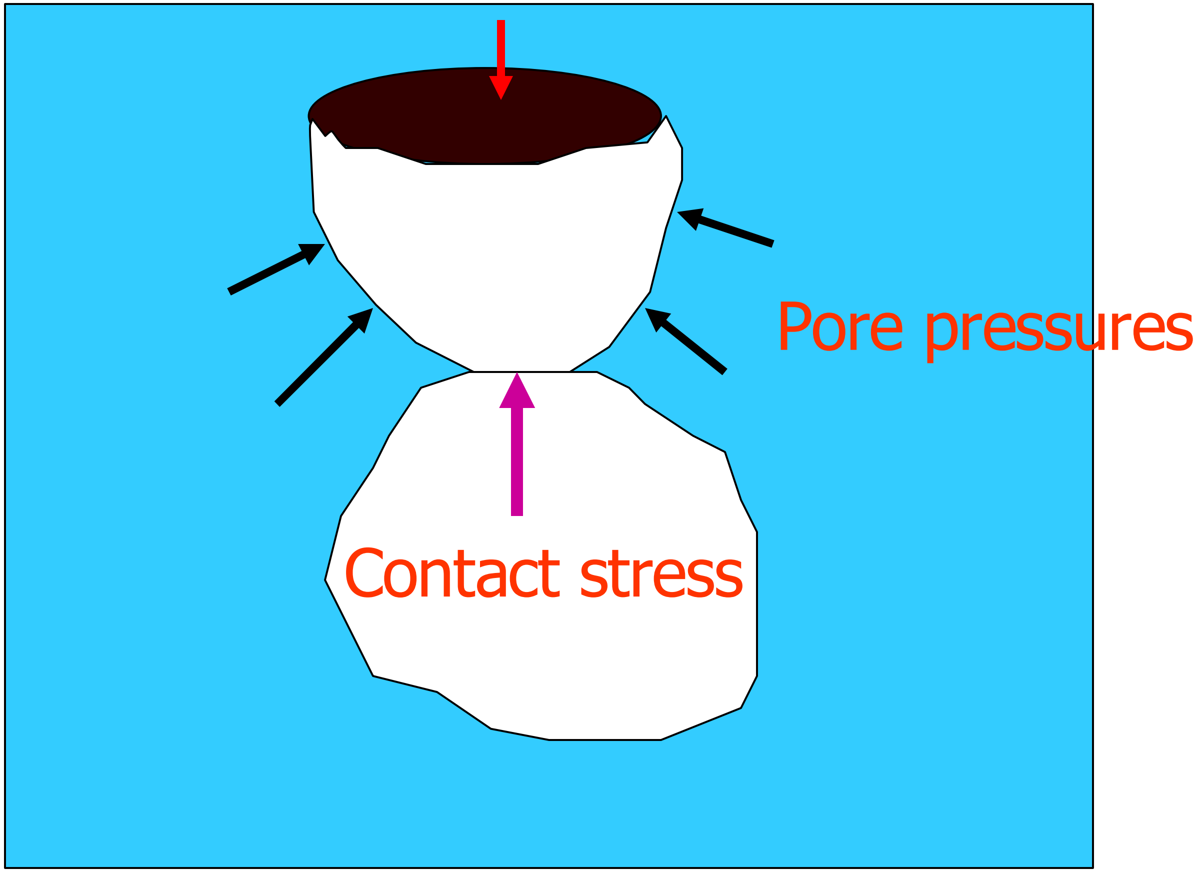
A – TOTAL AREA

A_s – SOLID AREA

A_w – WATER AREA

THE TERZAGHI – FILLUNGER DISPUTE

JUSTIFICATION OF EFFECTIVE STRESS CONCEPT



Relative Volume Measures

- VOIDS RATIO e
- SPECIFIC VOLUME v
- POROSITY n

$$e = \frac{\Delta V_V}{\Delta V_S},$$

$$v = \frac{\Delta V}{\Delta V_S} = 1 + e,$$

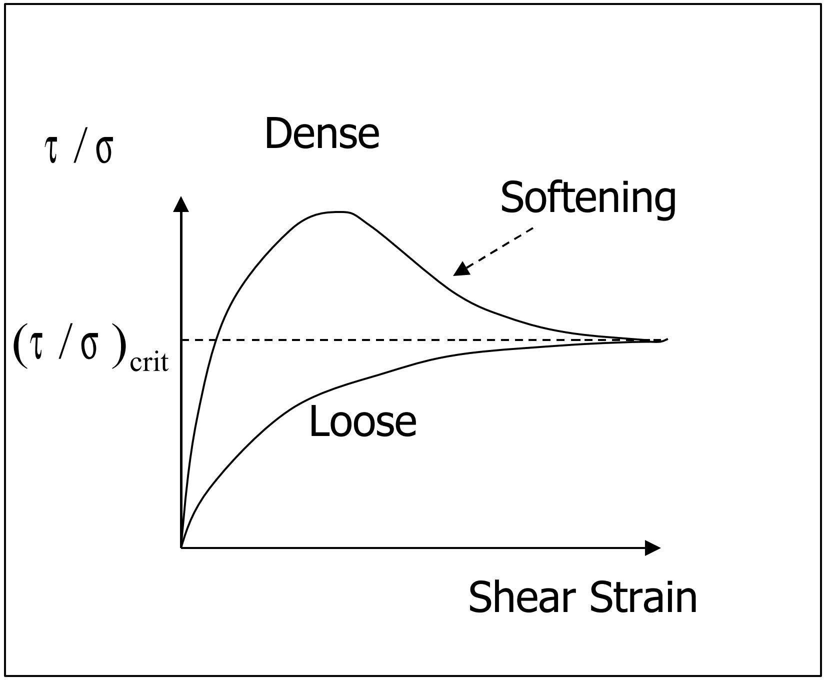
$$n = \frac{\Delta V_V}{\Delta V} = e/(1 + e)$$

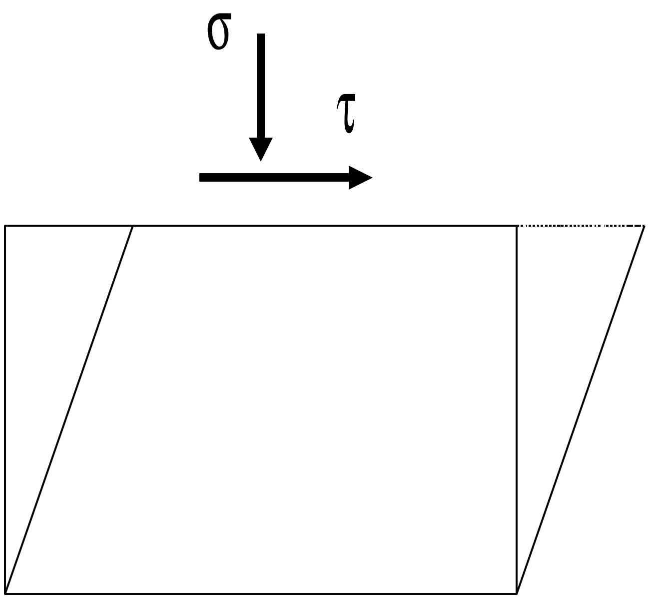
PROF ARTHUR CASGRANDE HARVARD (193?)

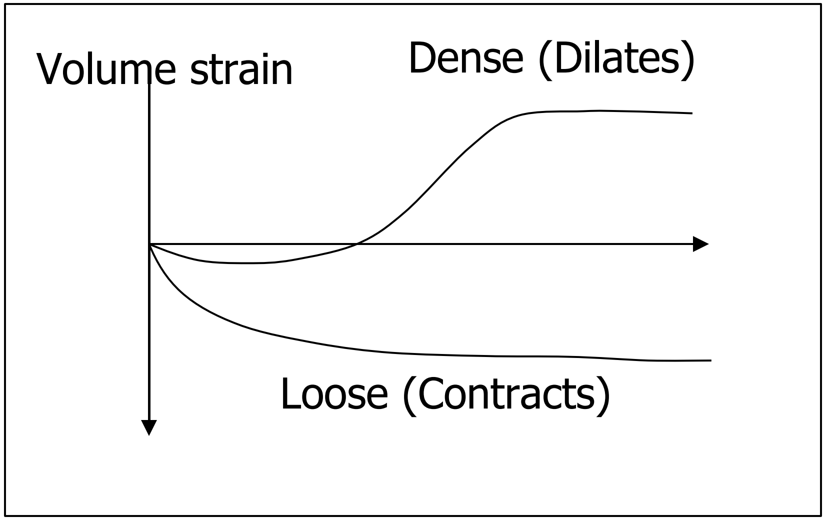
INTRODUCED THE
NOTION OF A
"CRITICAL VOIDS RATIO".
ANY SHEARED SAND
SAMPLE WOULD
EVENTUALLY REACH
A CRITICAL VOIDS RATIO
IRRESPECTIVE OF INITIAL CONDITIONS.

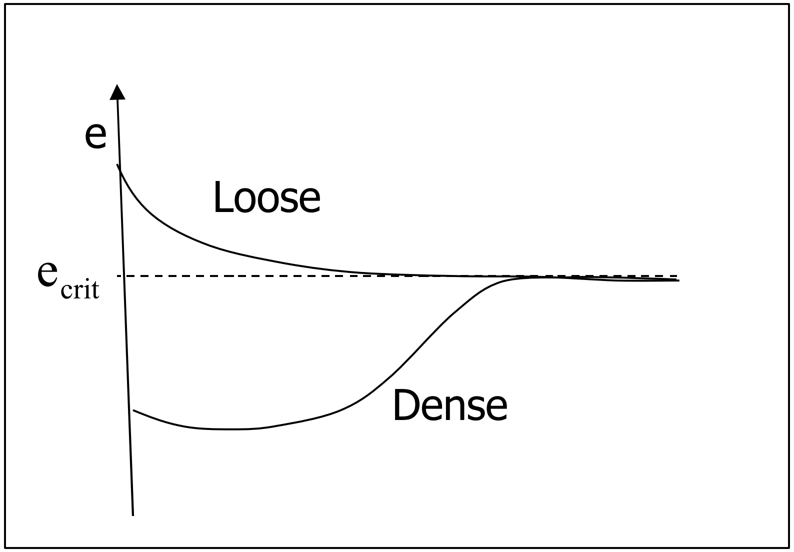
CASAGRANDE

BEHAVIOUR UNDER SHEAR



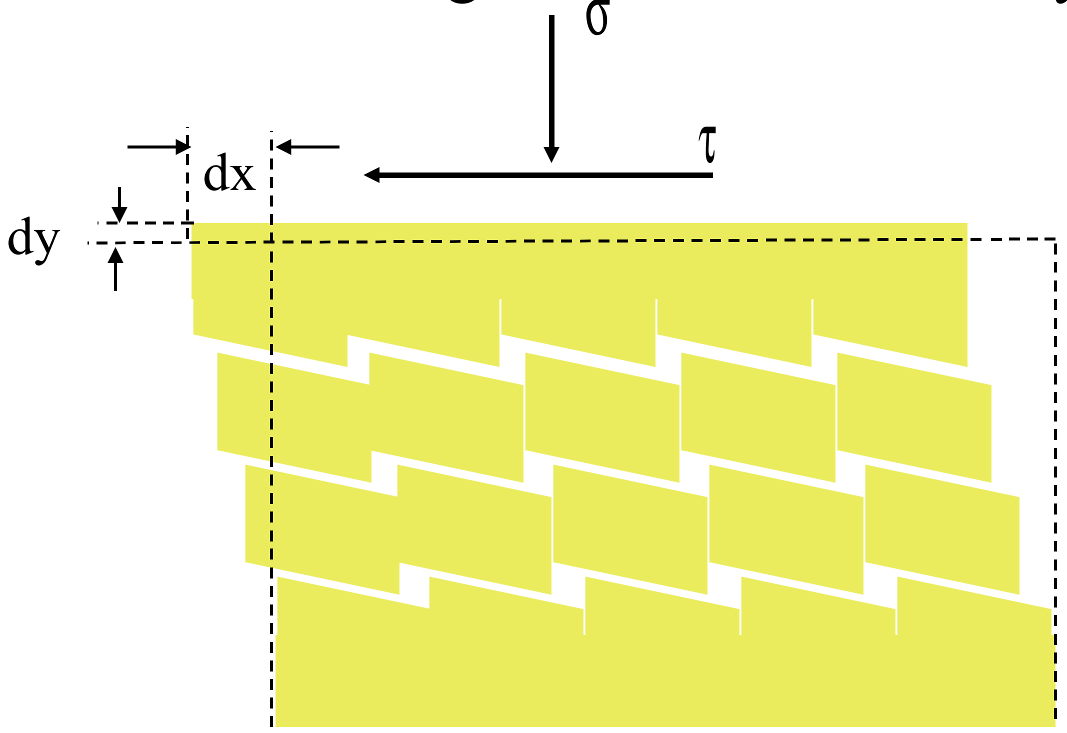






TAYLOR "STRESS DILATANCY" RELATION "INTERLOCKING

The serrated block model provides a simple analogy of the effects of volume change and induced dilatancy and anisotopy.

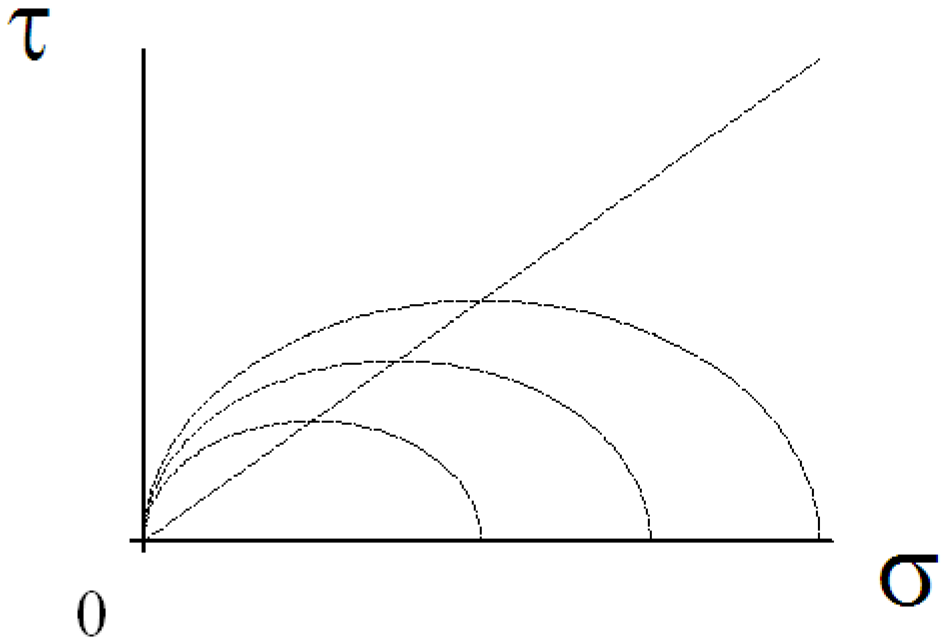


$$\frac{\tau}{\sigma} = \tan(\phi + \nu), \quad \text{where} \quad \tan\nu = \frac{dy}{dx}$$

THE "CAMBRIDGE MODELS 1960'S"

ROSCOE, SCHOFIELD, WROTH, BURLAND

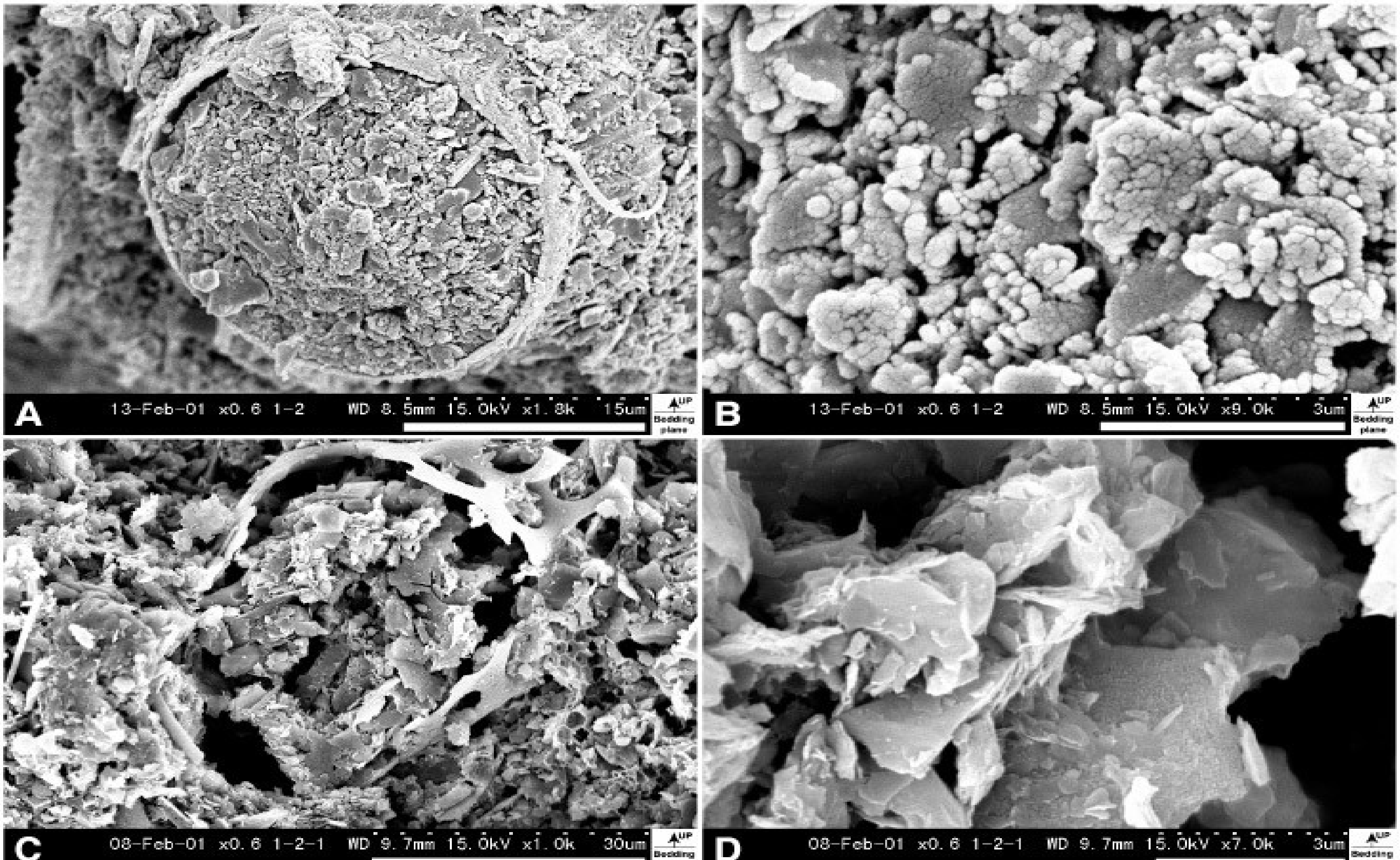
THE COULOMB LINE REPLACED
BY THE CRITICAL STATE LINE



AN ELASTIC/PLASTIC "CRITICAL STATE MODEL"

MATERIAL PROPERTIES

CLAYS-1



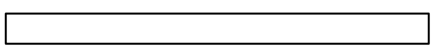
A
13-Feb-01 x0.6 1-2 WD 8.5mm 15.0kV x1.8k 15um
UP
Bedding plane
B
13-Feb-01 x0.6 1-2 WD 8.5mm 15.0kV x9.0k 3um
UP
Bedding plane
C
08-Feb-01 x0.6 1-2-1 WD 9.7mm 15.0kV x1.0k 30um
UP
Bedding plane
D
08-Feb-01 x0.6 1-2-1 WD 9.7mm 15.0kV x7.0k 3um
UP
Bedding plane

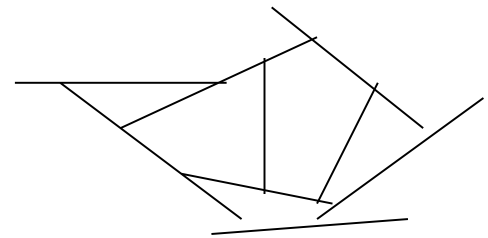
Kaolinite

Illite and Montmorillonite

Silica

Alumuna

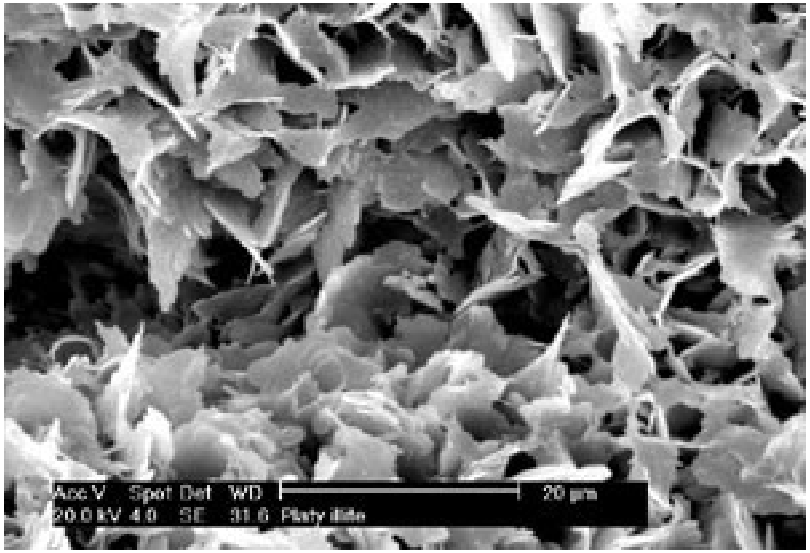




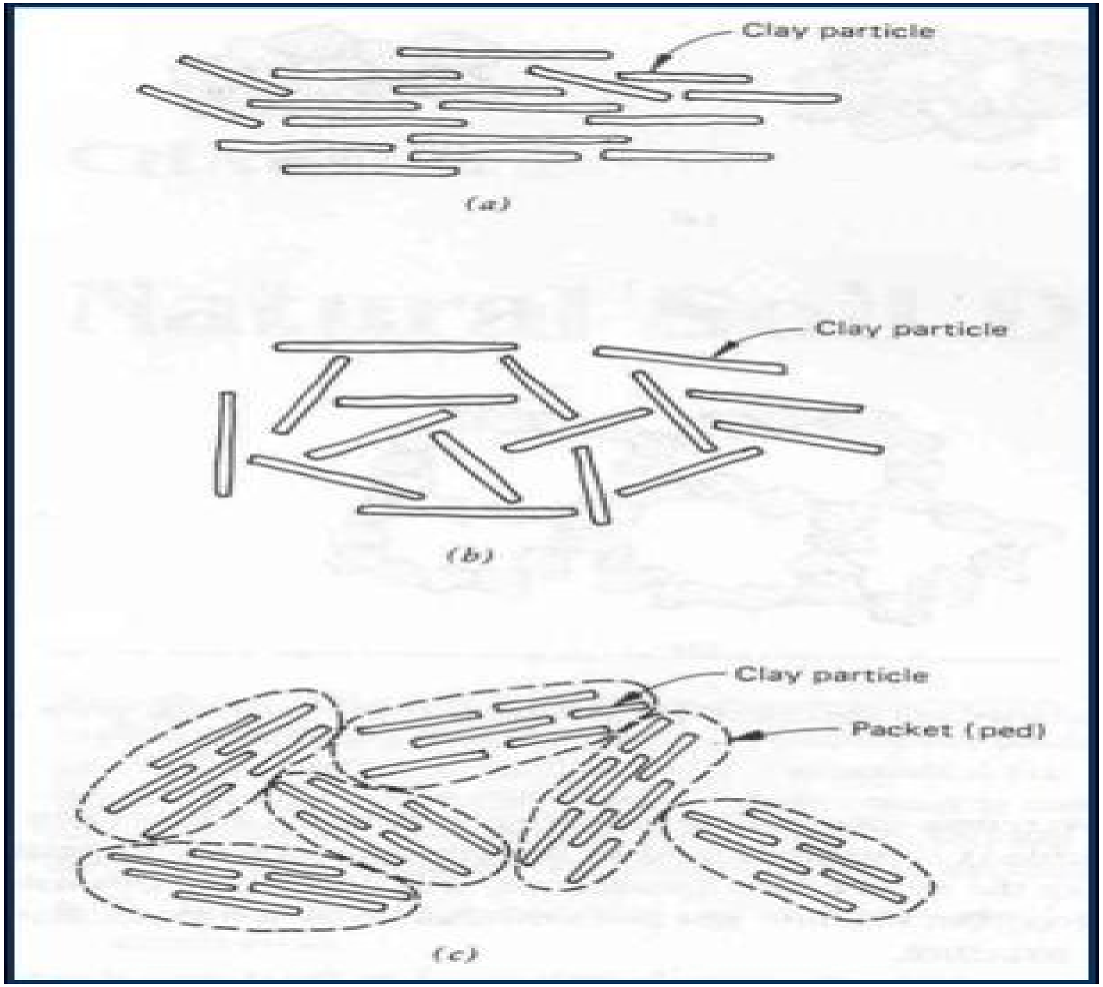
Flocculated arrangement of plates forming a "Ped"

Structure of clay plates and particles

IILITE



“PEDS”



KAOLIN PIPE BOWLS

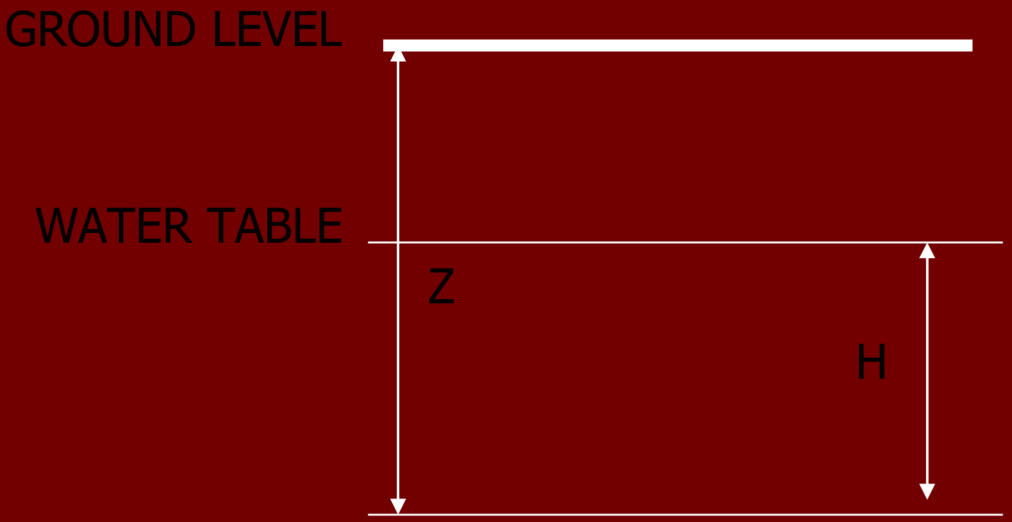
CLAY v SAND

- CLAY CAN BE REGARDED AS A FINE GRAIN MATERIAL, WHOSE GRAINS HAVE LOW STIFFNESS AND ARE DUCTILE -THEY CAN ALSO ABSORB WATER.
- SAND IS A COURSE GRAIN MATERIAL, WHOSE GRAINS ARE STIFF AND BRITTLE.

GEOSTATICS

STRESS IN THE GROUND

$$n = \frac{\Delta V_v}{\Delta V}$$



$$u = \rho_W g H$$

$$\sigma = n\rho_W g H + (1-n)\rho_s g Z$$

$$\sigma' = (1-n)g(\rho_S Z - \rho_W H)$$

$$\text{Note: } \sigma' \downarrow \text{ as } H \uparrow$$

QUICKSAND

"Sherlock Holmes"

- If the water table is higher than the local free surface as by a retaining wall, or in a natural depression, the effective pressure can be zero

EXPERIMENTAL TECHNIQUES

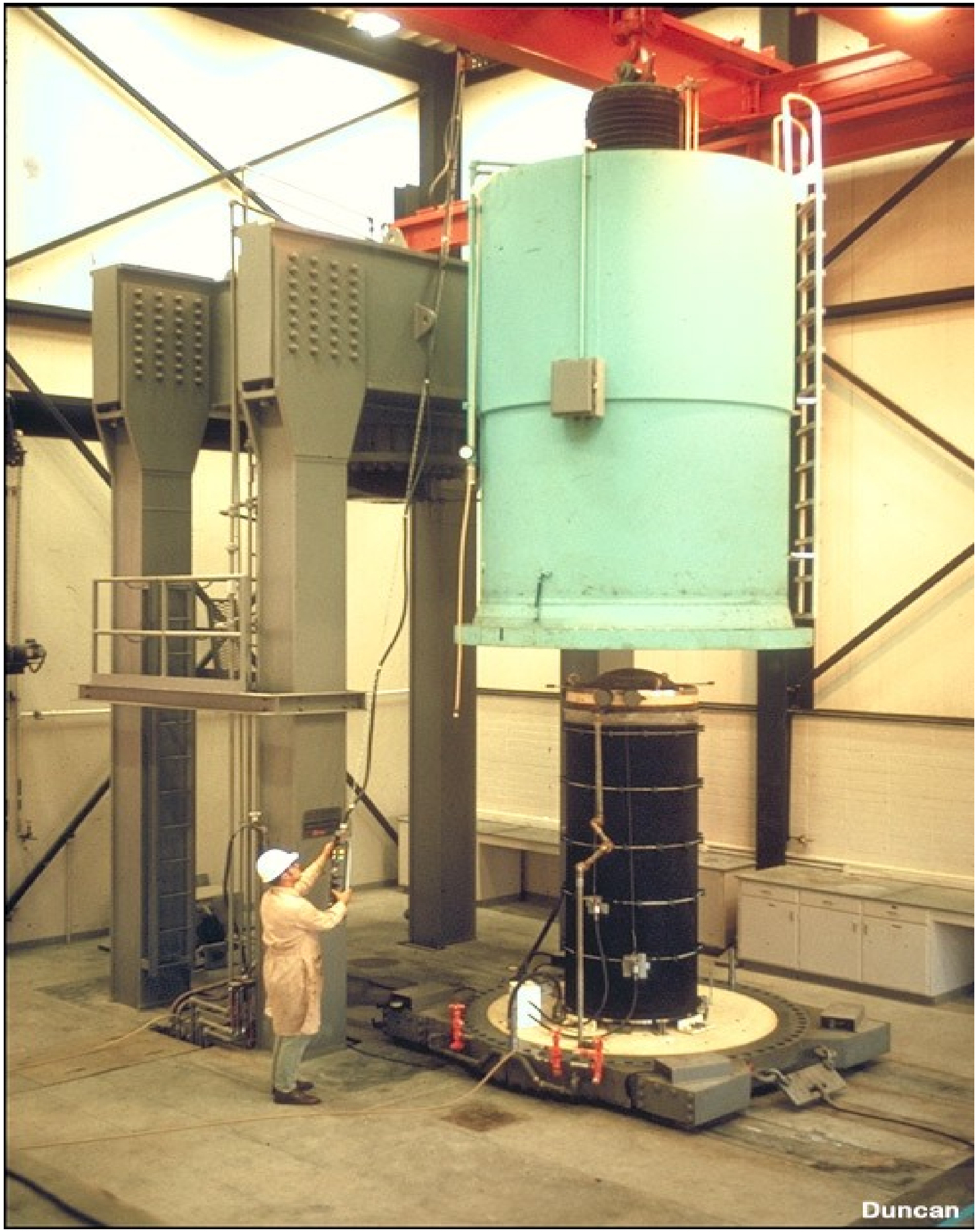
LIMITED NUMBER OF POSSIBLE EXPERIMENTS

- TRIAXIAL
- TRUE-TRIAXIAL
- SHEAR BOX
- SIMPLE SHEAR
- RING SHEAR

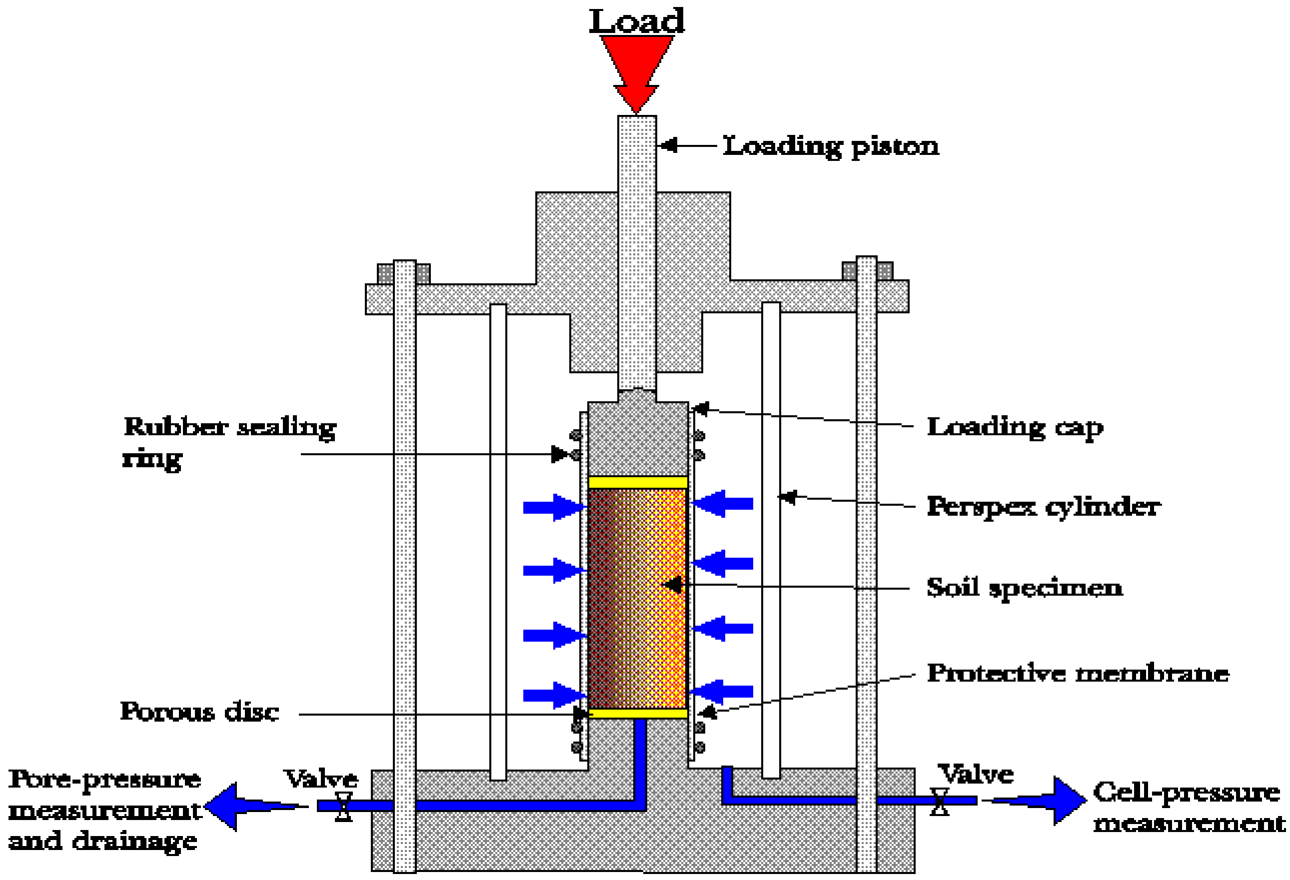
- DRAINED
- UNDRAINED
- (CENTRIFUGE)
- (DISCRETE ELEMENT SIMULATION)

UoA Standard Triaxial

A large Triaxial

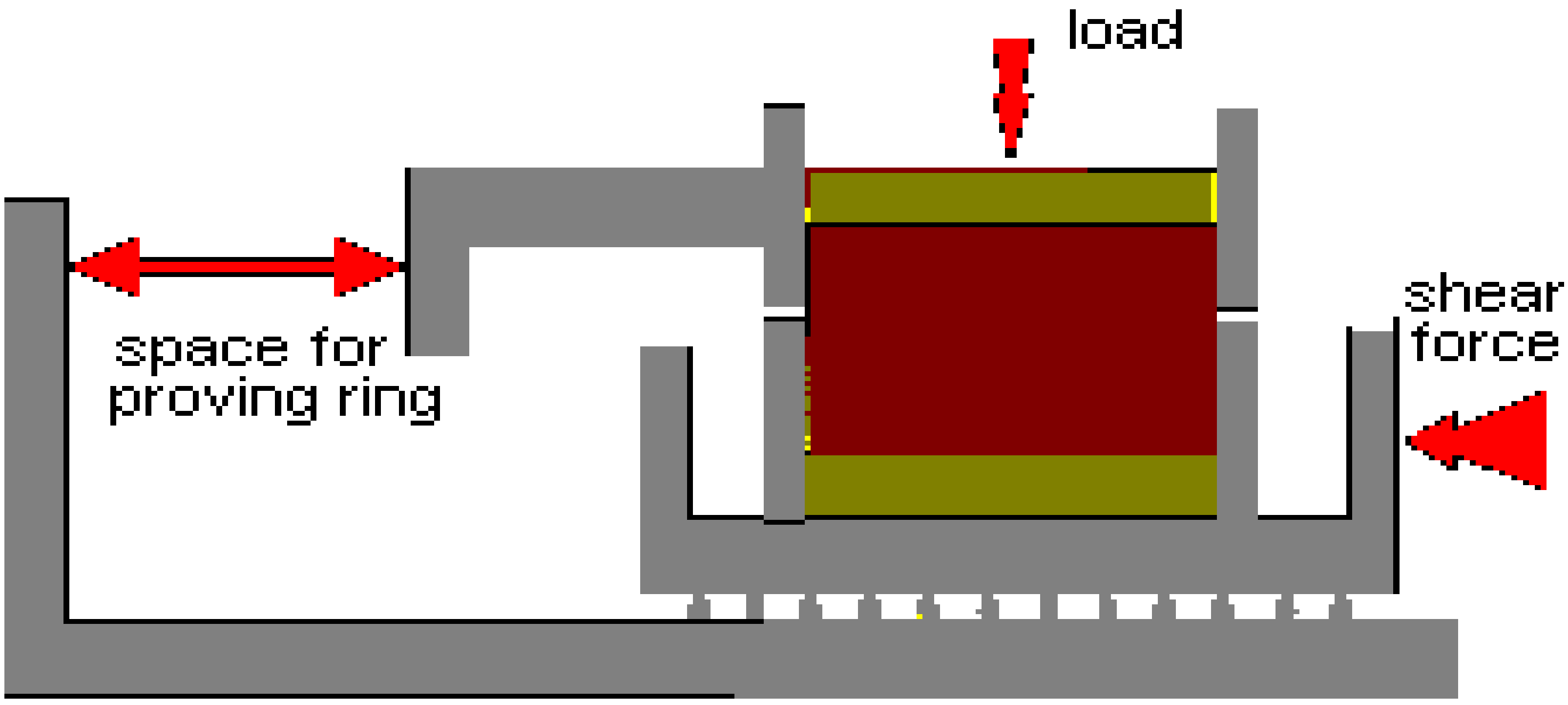


STANDARD TRIAXIAL CELL



Triaxial apparatus

SHEAR BOX



A CENTRIFUGE

NOTATION

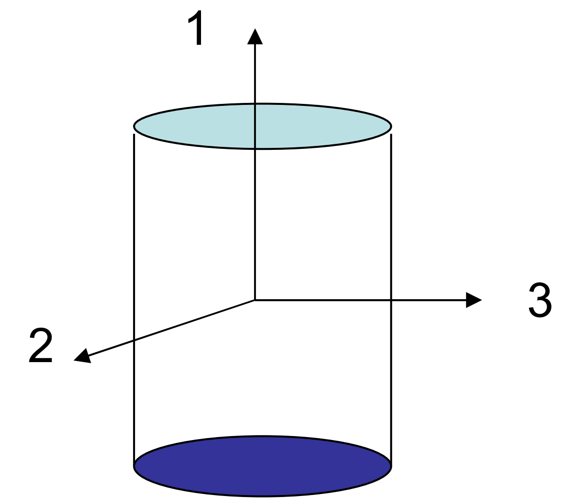
- IN THIS LECTURE WE WILL USE THE STANDARD NOTATION OF TRIAXIAL TESTS –
- ALL STRESSES ARE EFFECTIVE STRESSES.

$$p = \frac{1}{3}(\sigma_1 + 2\sigma_3) \text{ and } q = (\sigma_1 - \sigma_3)$$

$$e_v = (e_1 + 2e_3) \text{ and } e_\gamma = \frac{2}{3}(e_1 - e_3)$$

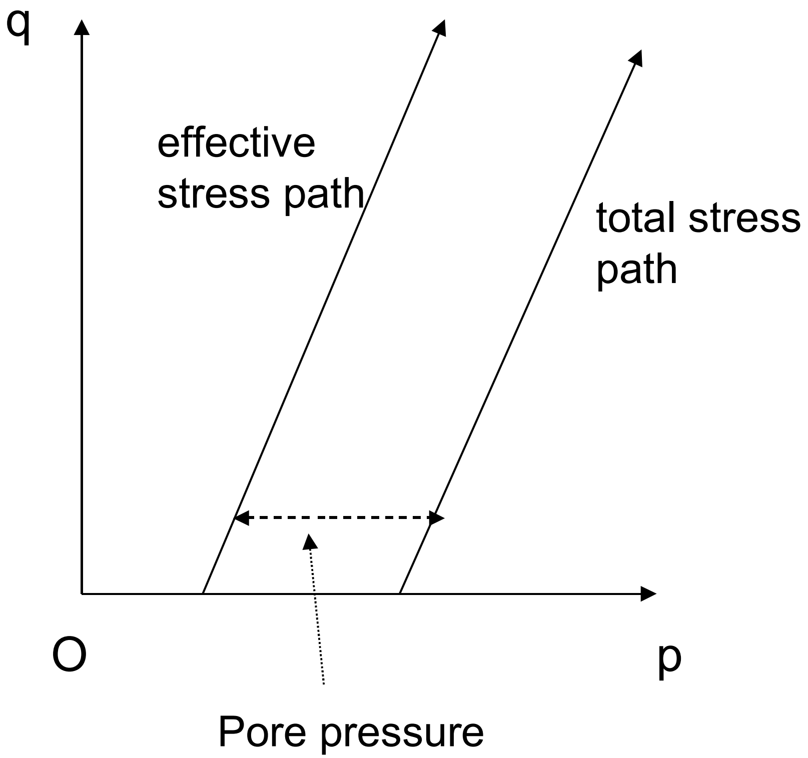
volume strain

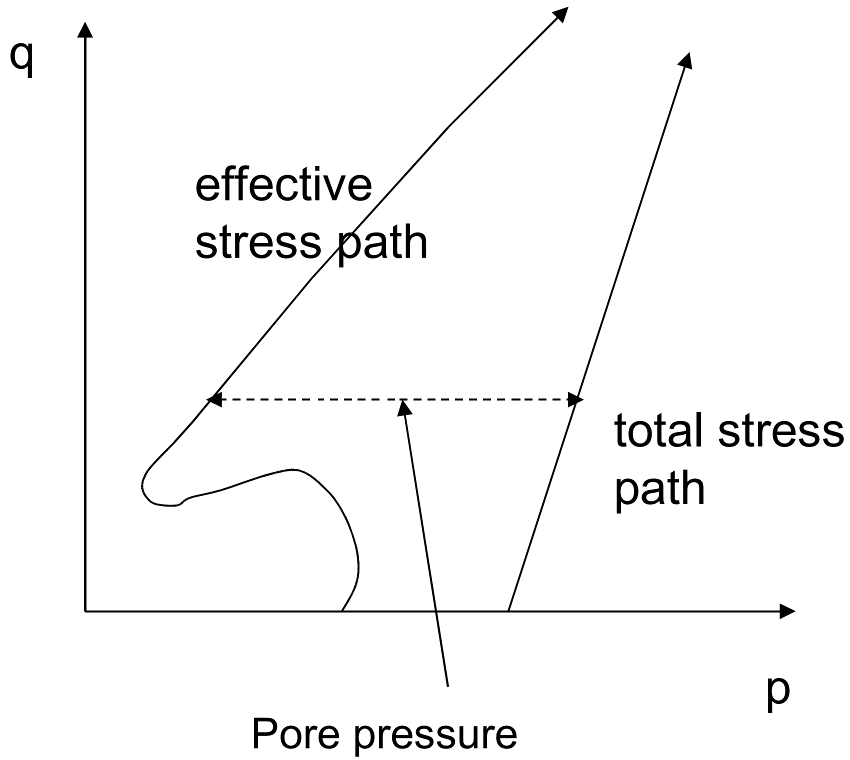
shear strain



STANDARD “TRIAXIAL” TESTS

- DRAINED TESTS (slow)
- UNDRAINED TESTS (fast)

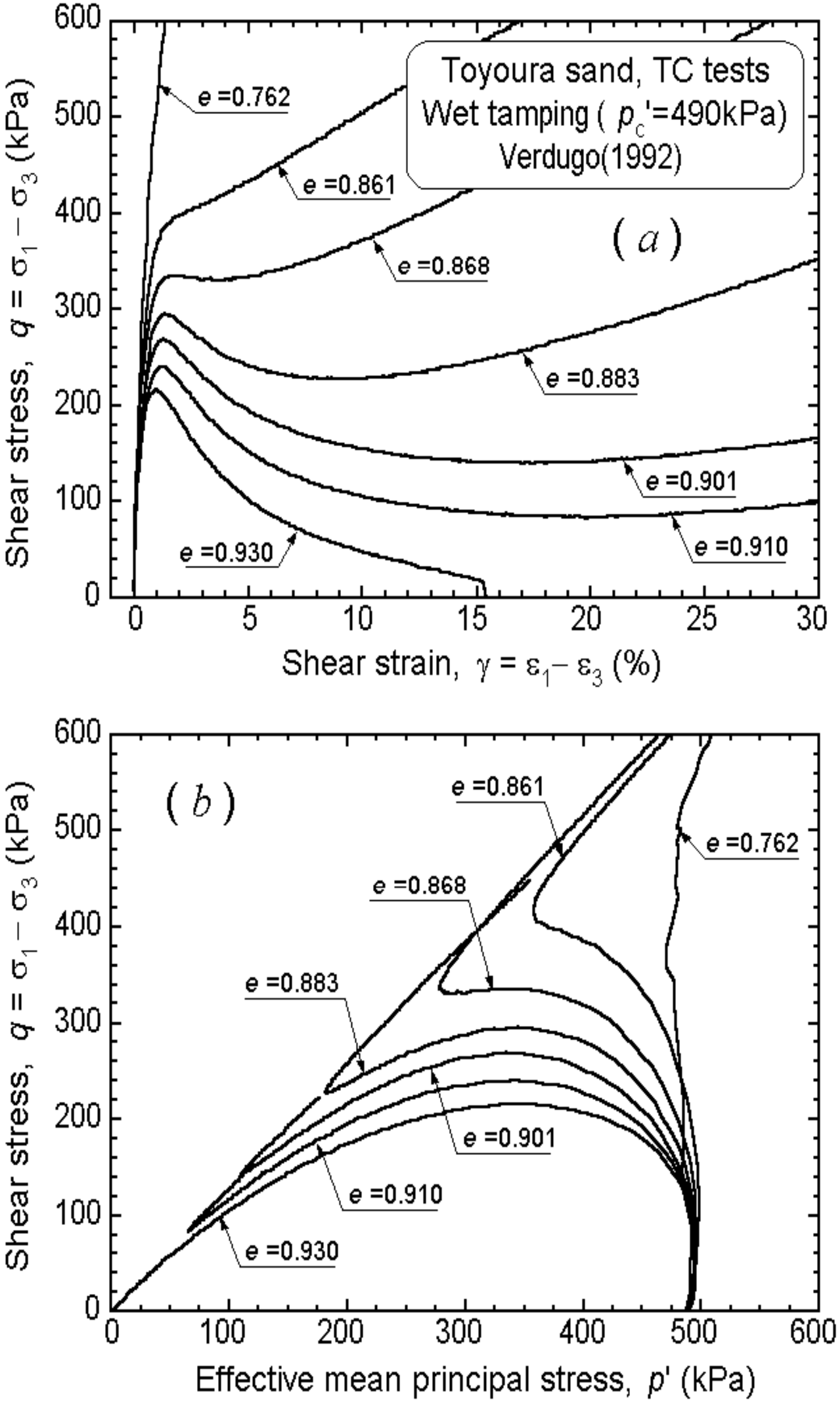


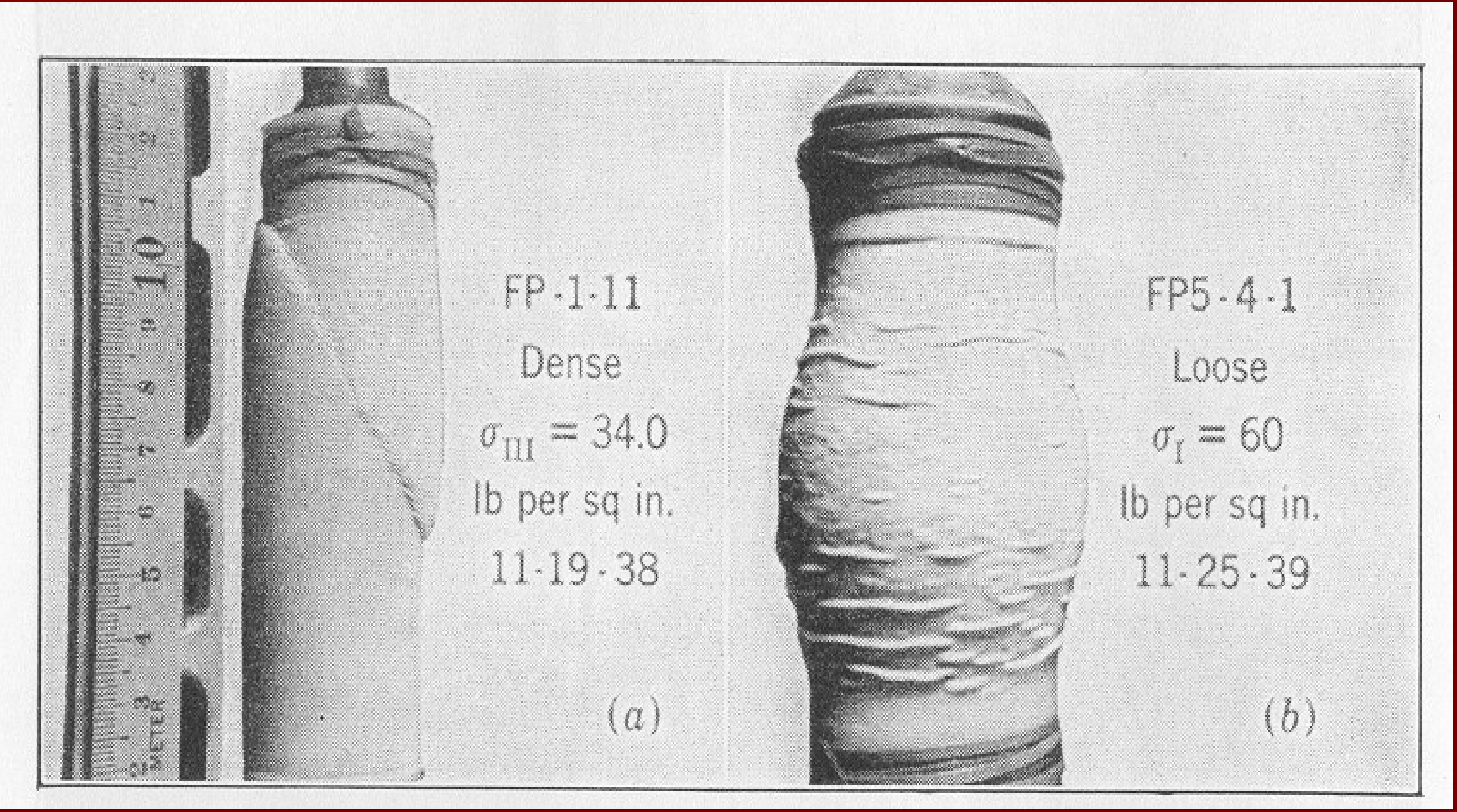


UNDRAINED TESTS ON SAND

USING MOIST TAMPING

“STATIC LIQUEFACTION??”





BIFURCATIONS IN DENSE AND LOOSE SAND

THREE PREPARATION PROCEDURES

- MOIST TAMPING

- WATER PLUVIATION

- AIR PLUVIATION

(Experiments by Vaid)

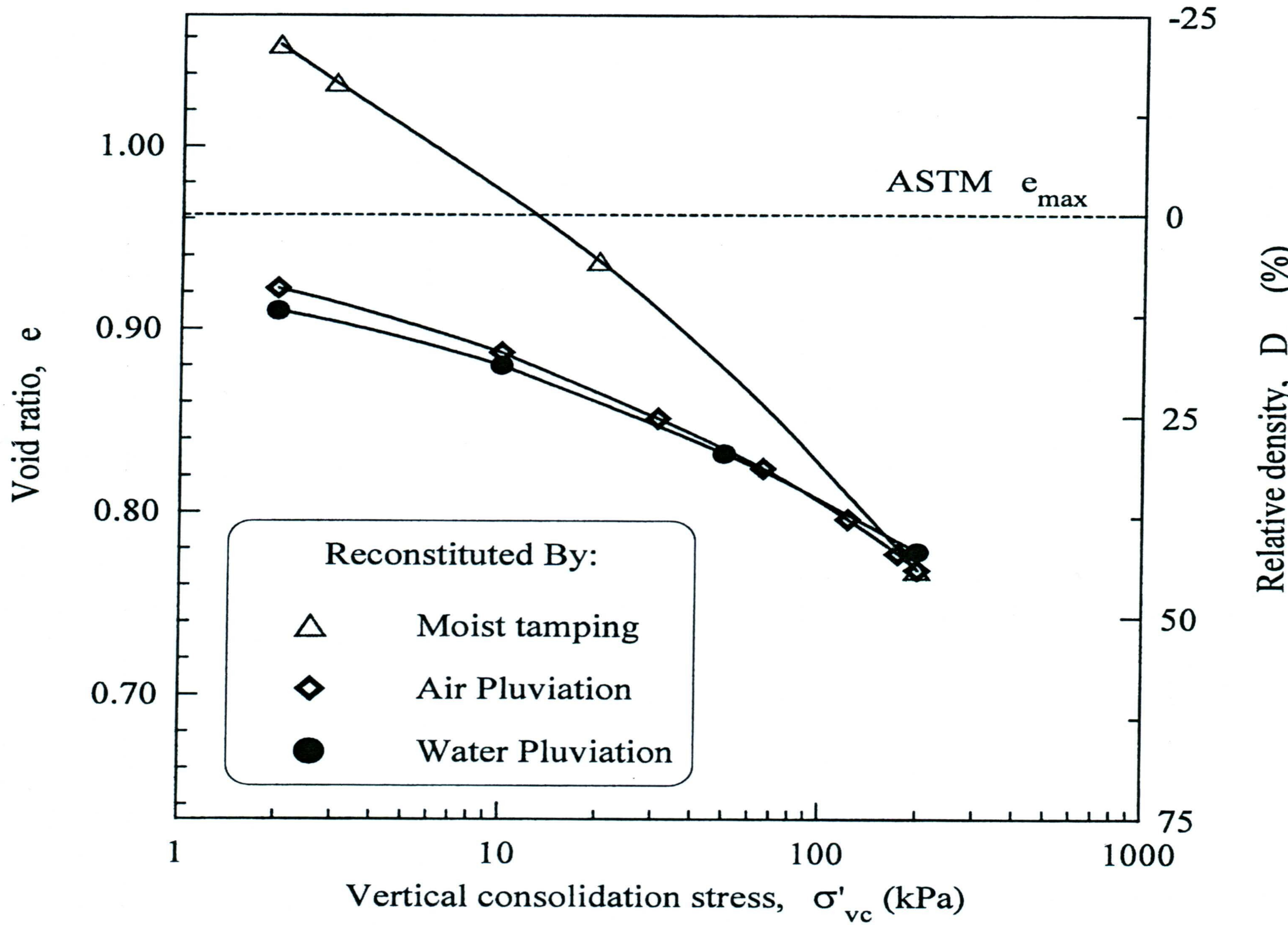


FIG. 3—*One-dimensional compressibility of Syncrude sand specimens reconstituted by different methods.*

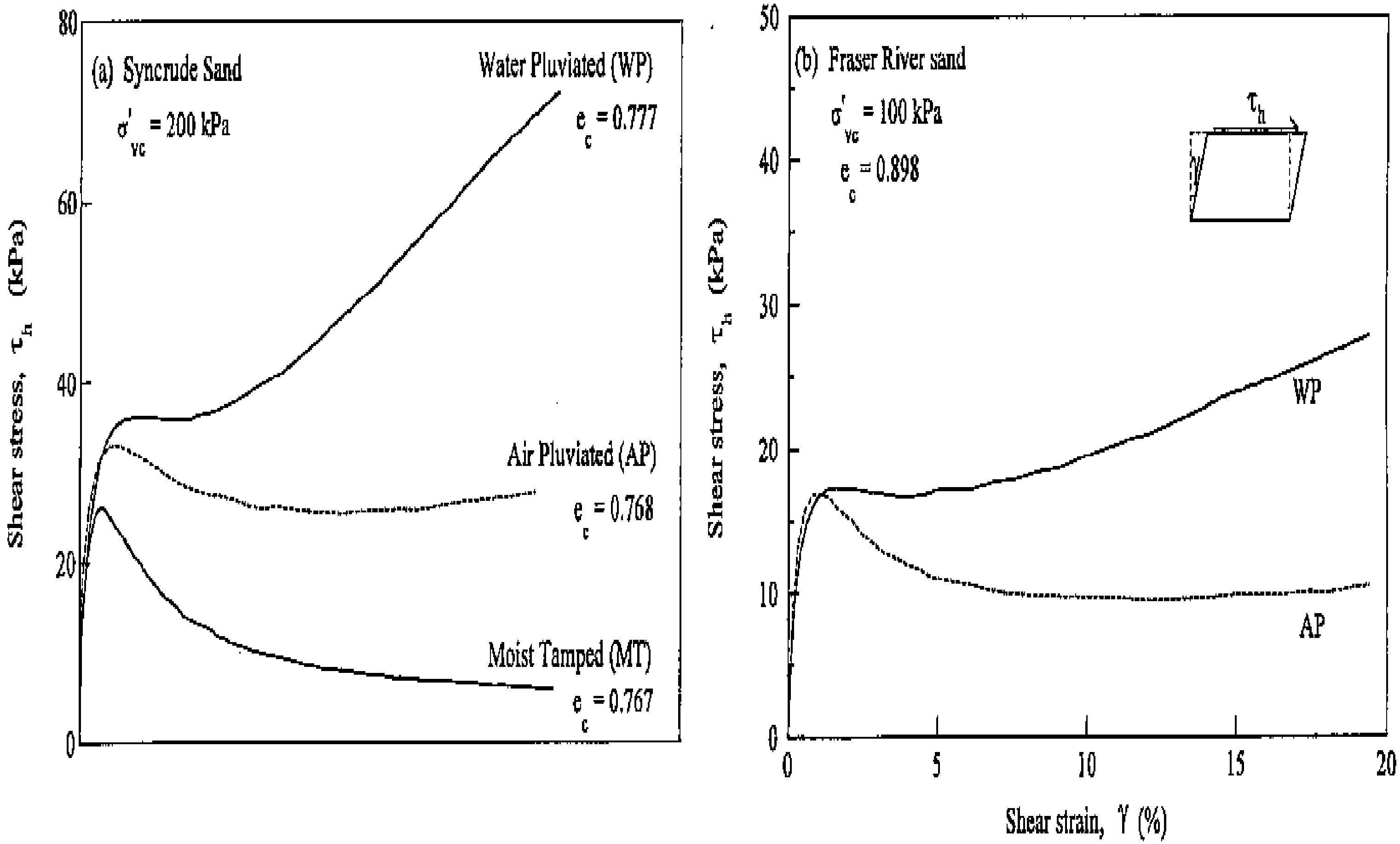
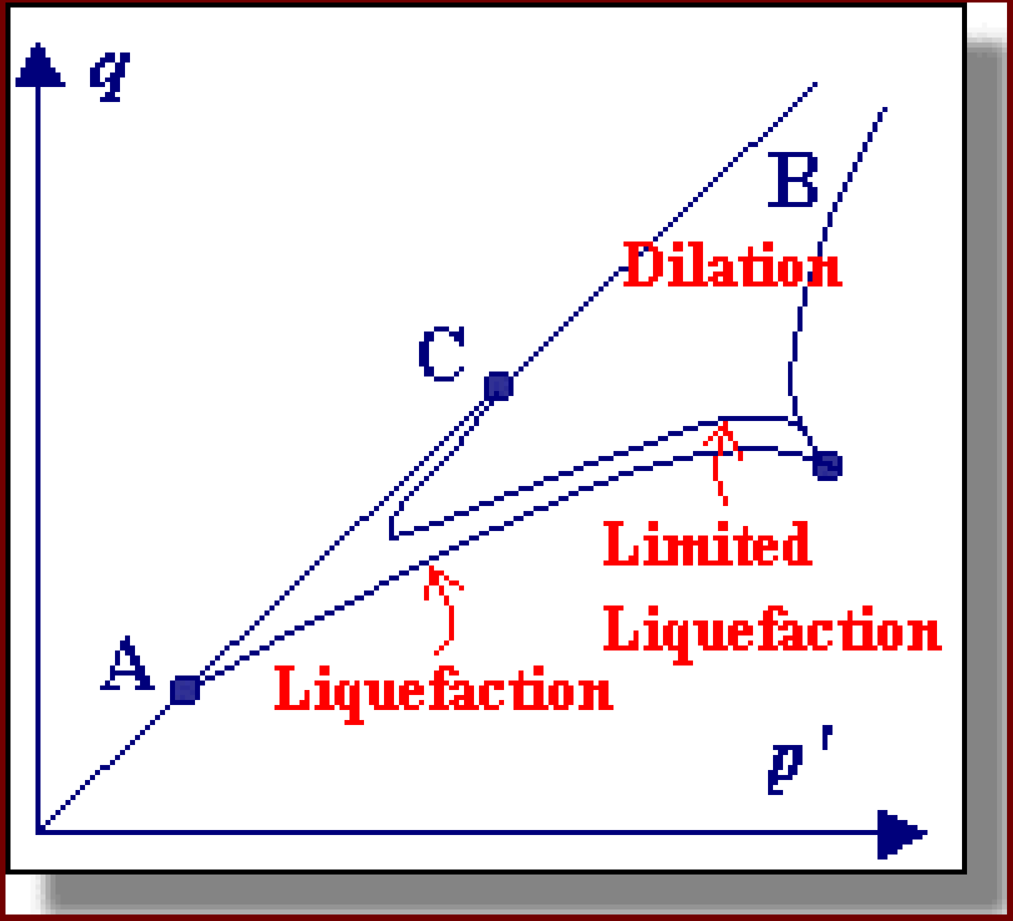


FIG. 4—*Undrained simple shear response of specimens reconstituted by different techniques:* (a) *Syncrude sand,* (b) *Fraser River sand.*

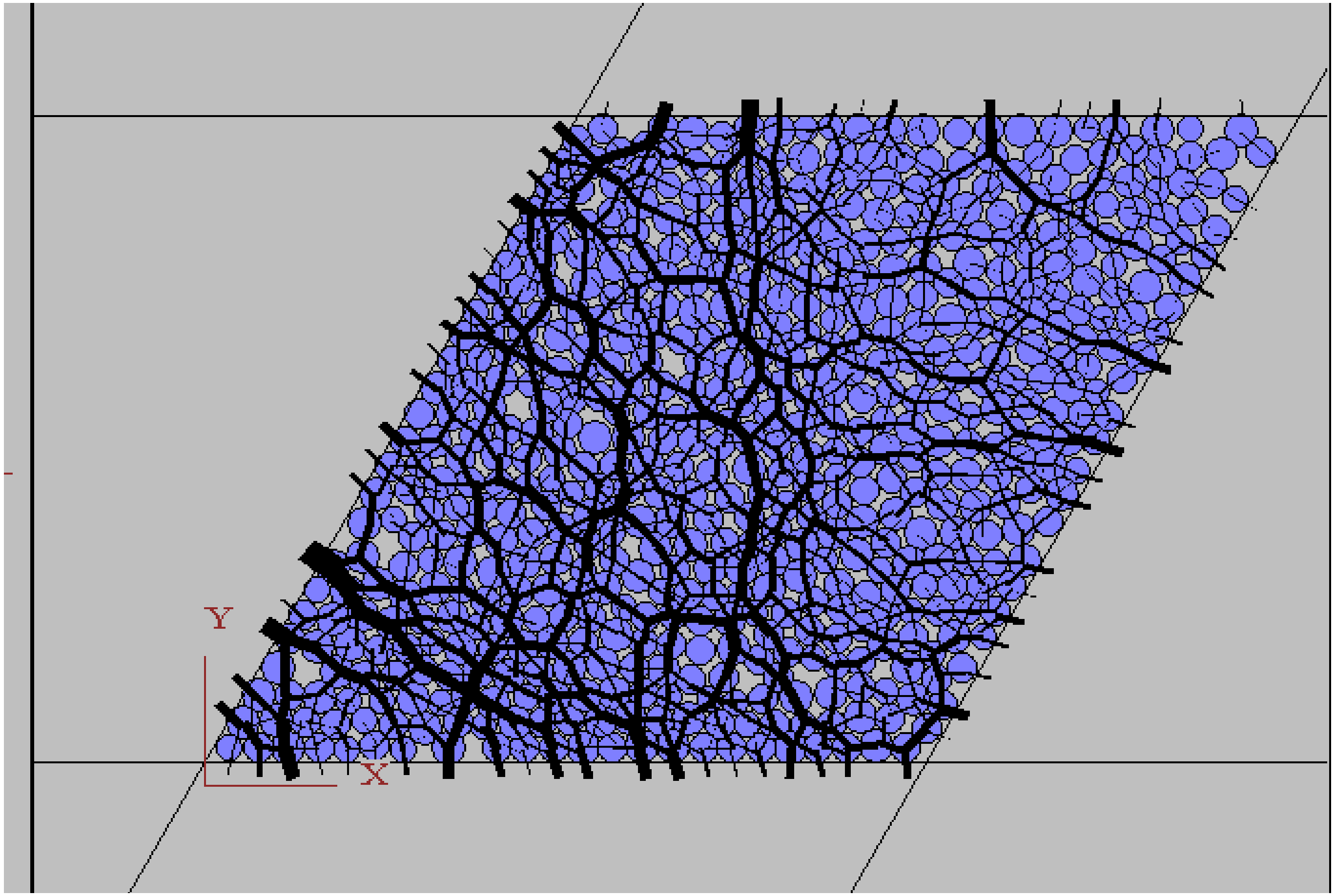
THE RESPONSE IS DEPENDENT ON PREPARATION PROCEDURE

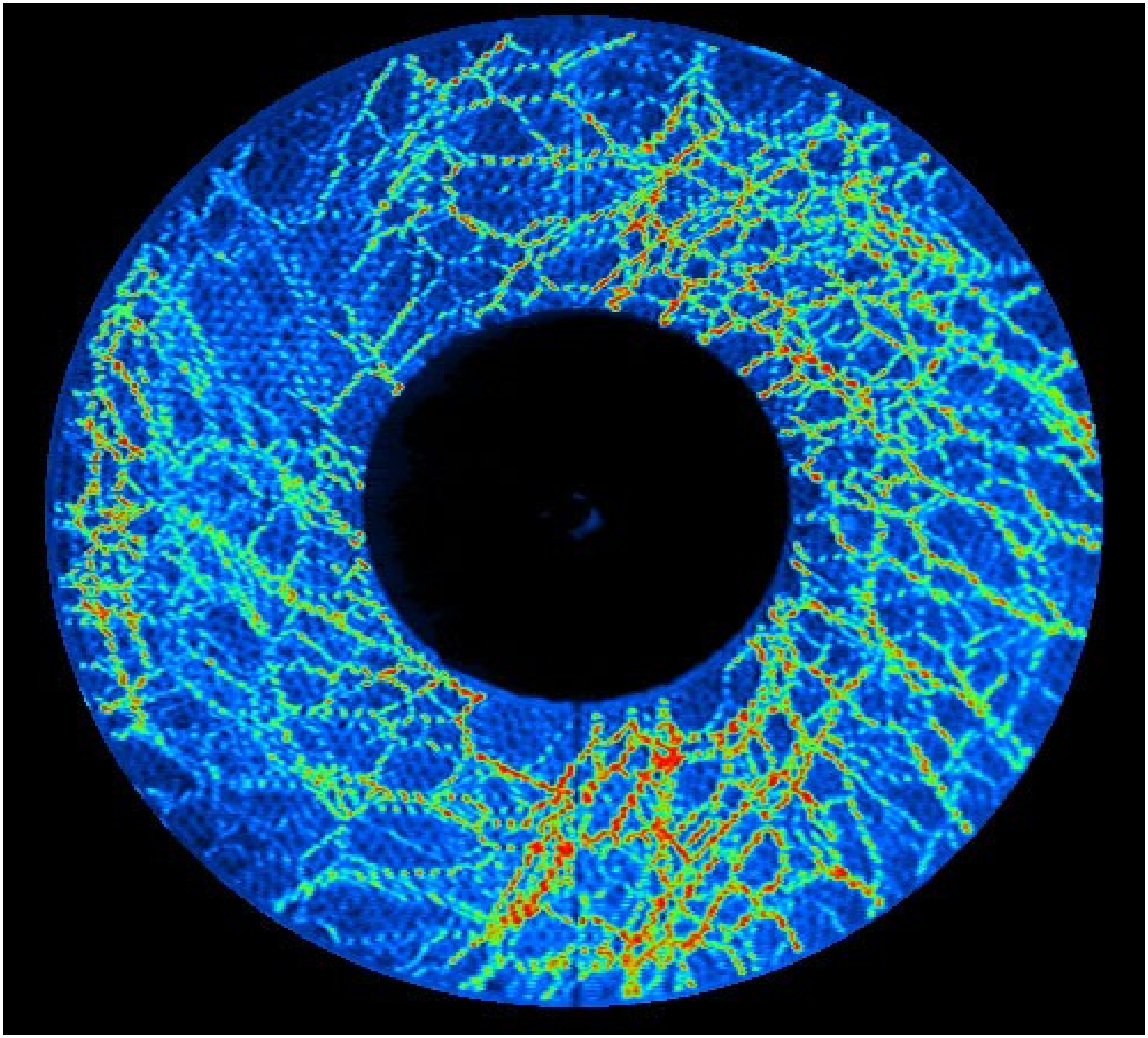
- In undrained tests, static liquifaction is only obtained using moist tamping



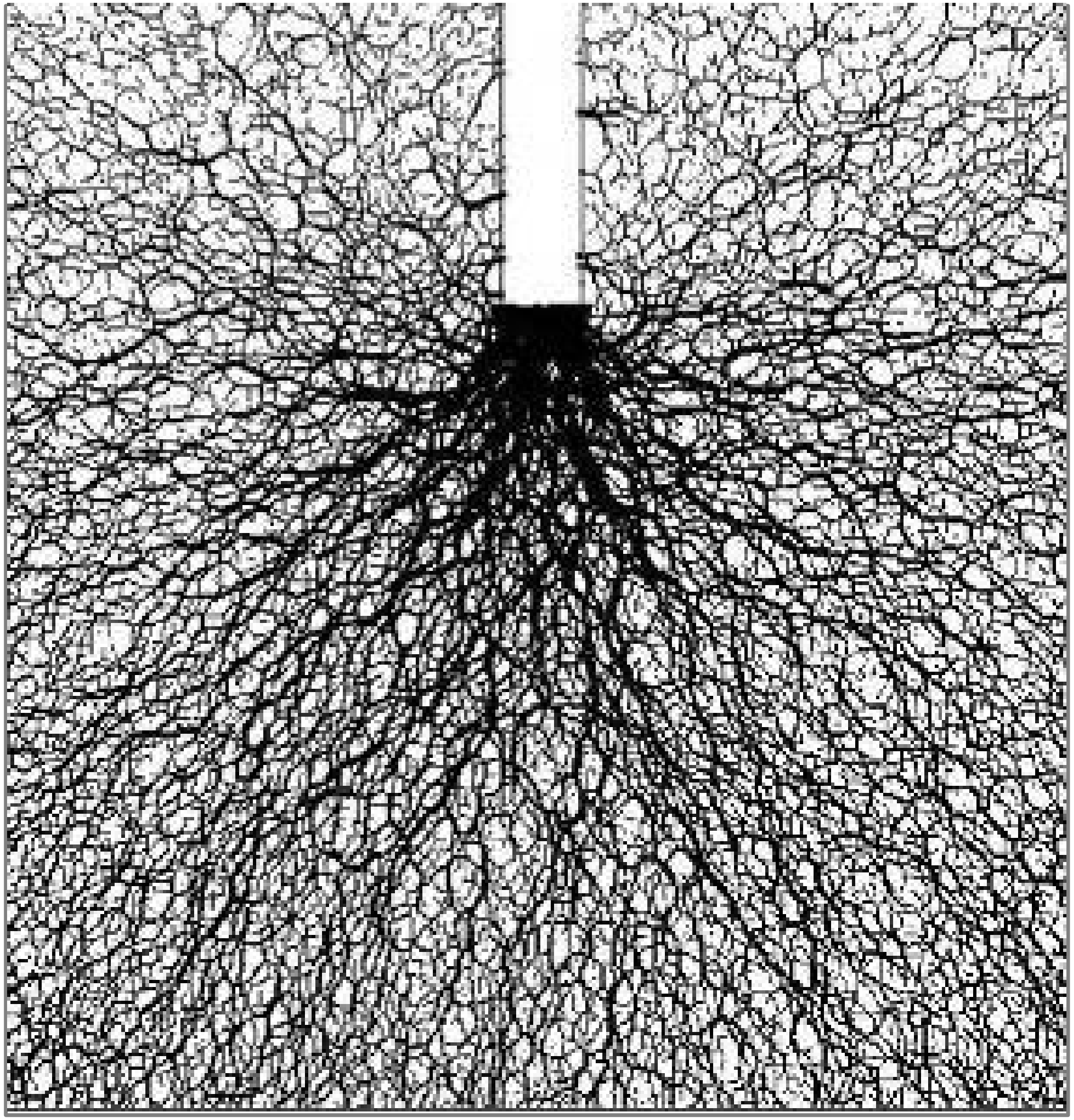
DISCRETE ELEMENT SIMULATIONS (DEM)

DEM SIMULATION OF SIMPLE SHEAR

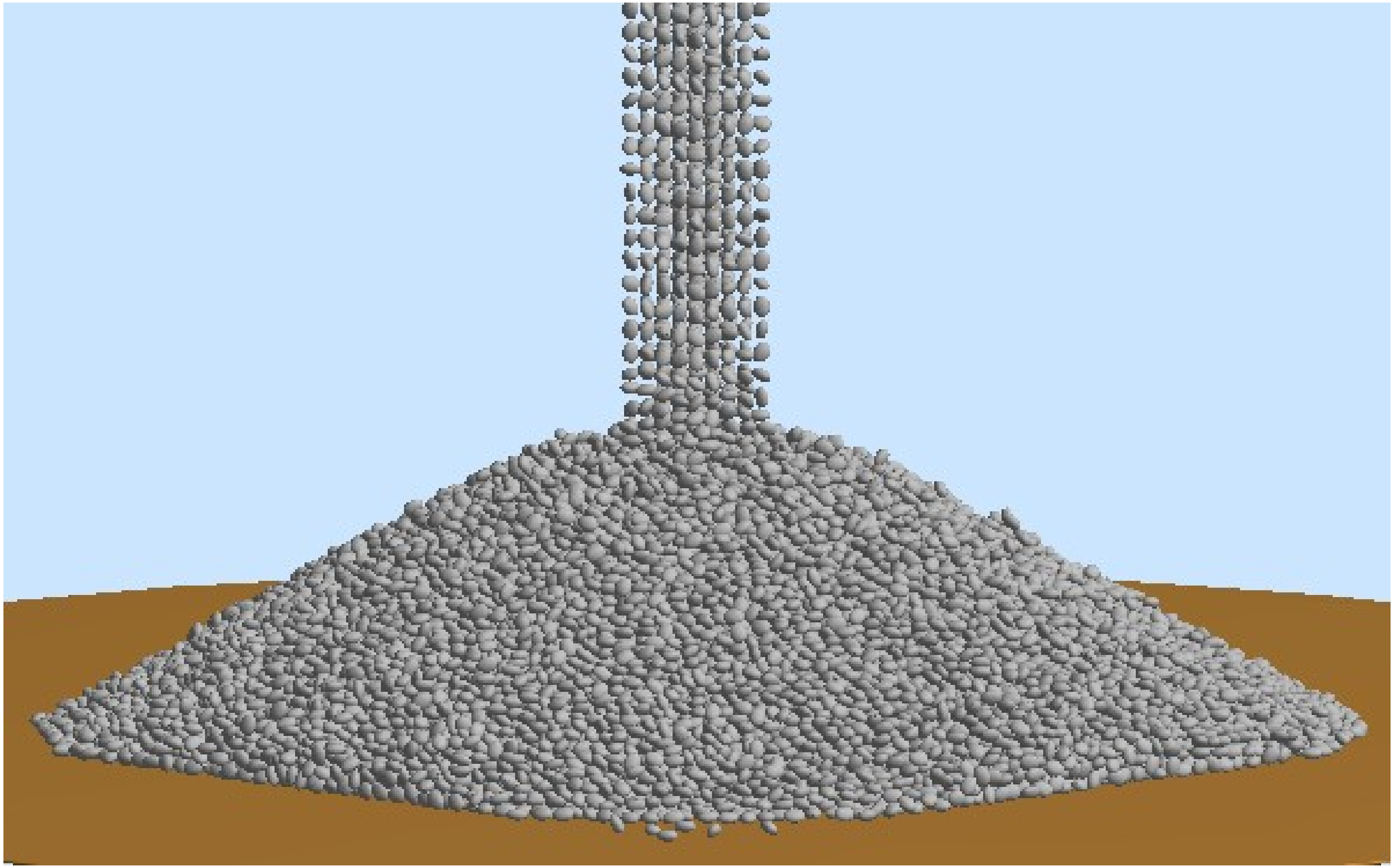




RING SHEAR TEST (Bob Behringer, Duke University)



FORCE CHAIN NETWORK DURING PILE INDENTATION



FORMATION OF SAND HEAPS (Bob Behringer, Duke University)

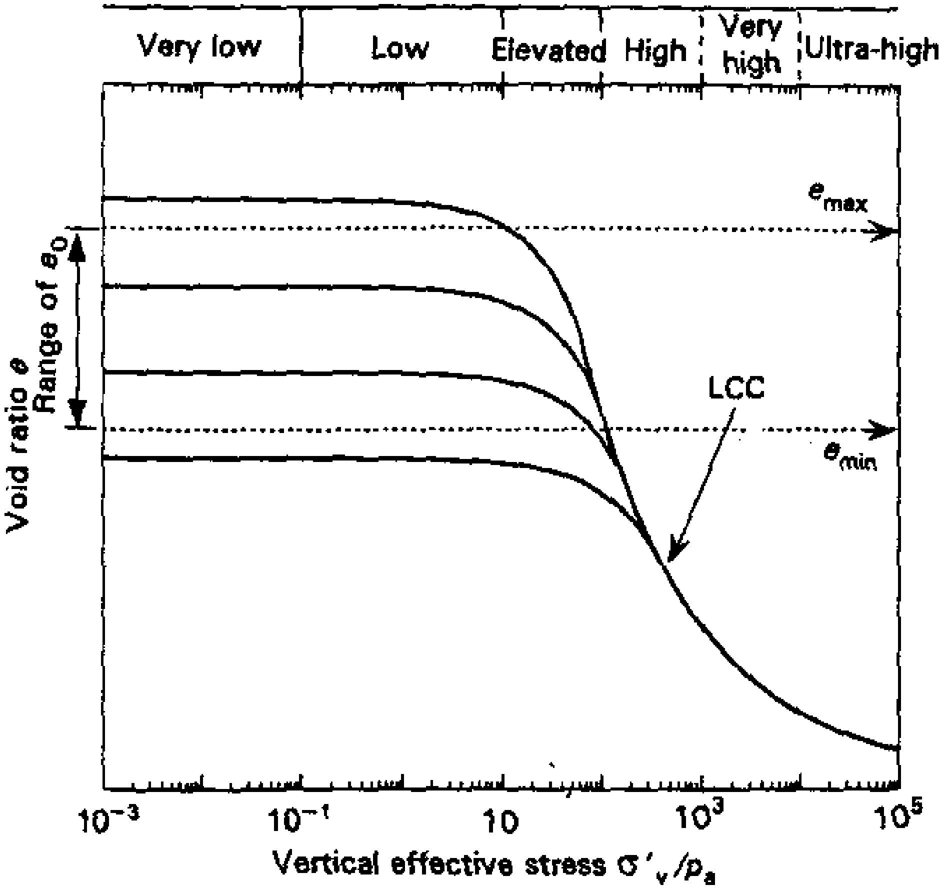
“EXPLODING GRAIN SILO”

PARTICLE CRUSHING

Thin sleeve of crushed particles immediately adjacent to the pile shaft

-Experimental results depicting soil state near the pile - [adapted from Randolph, 2003]

ISOTROPIC COMPRESSION AT LARGE STRESSES



(PESTANA and WHITTLE)

BOLTON-McDOWELL THEORY

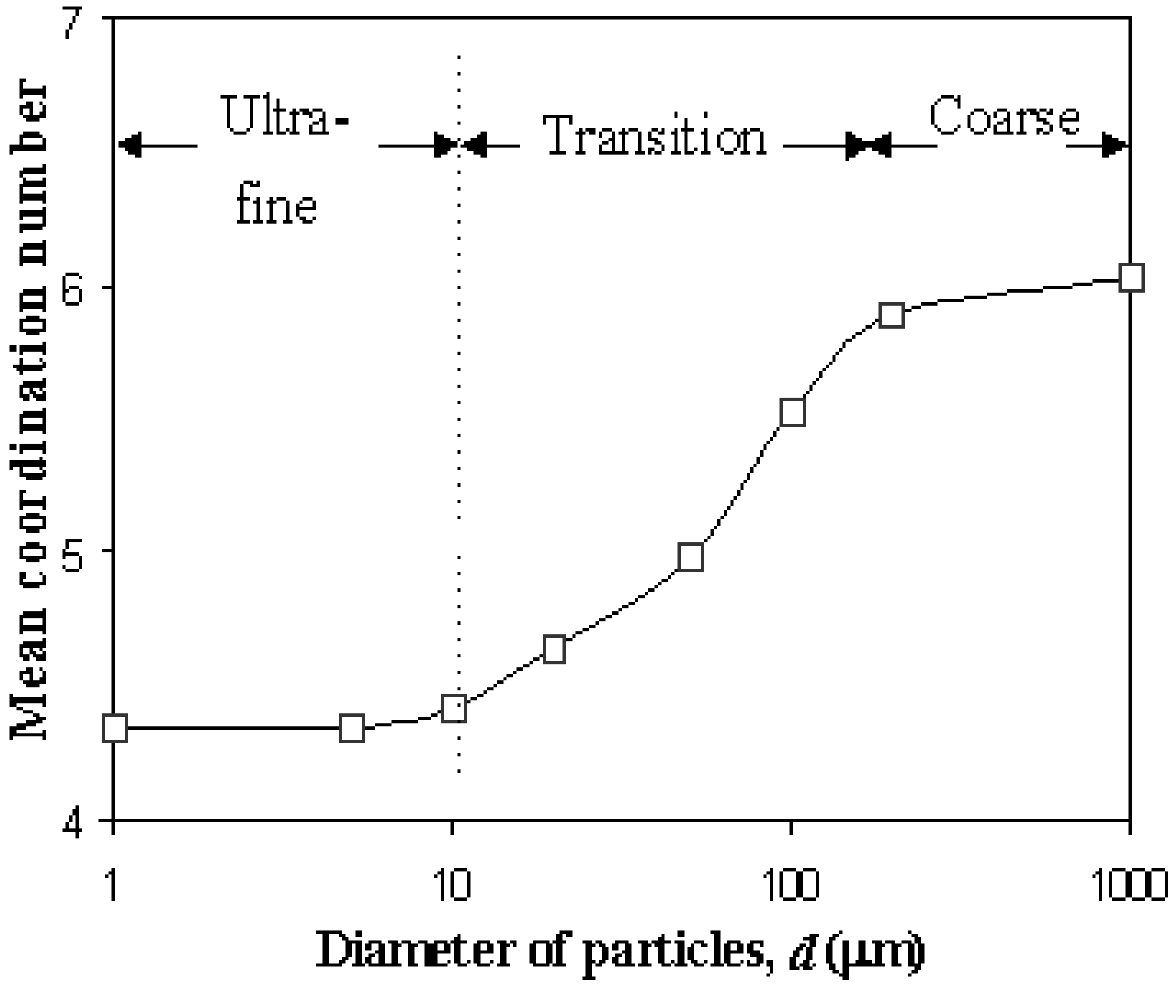
(1) DISTRIBUTION OF GRAIN SIZES IS FRACTAL:

$$N(L > d) = Ad^{-2.5}$$

(3) LARGER PARTICLES "PROTECTED".

(5) "BREAKAGE" STRESS VARIES AS d^{-2}

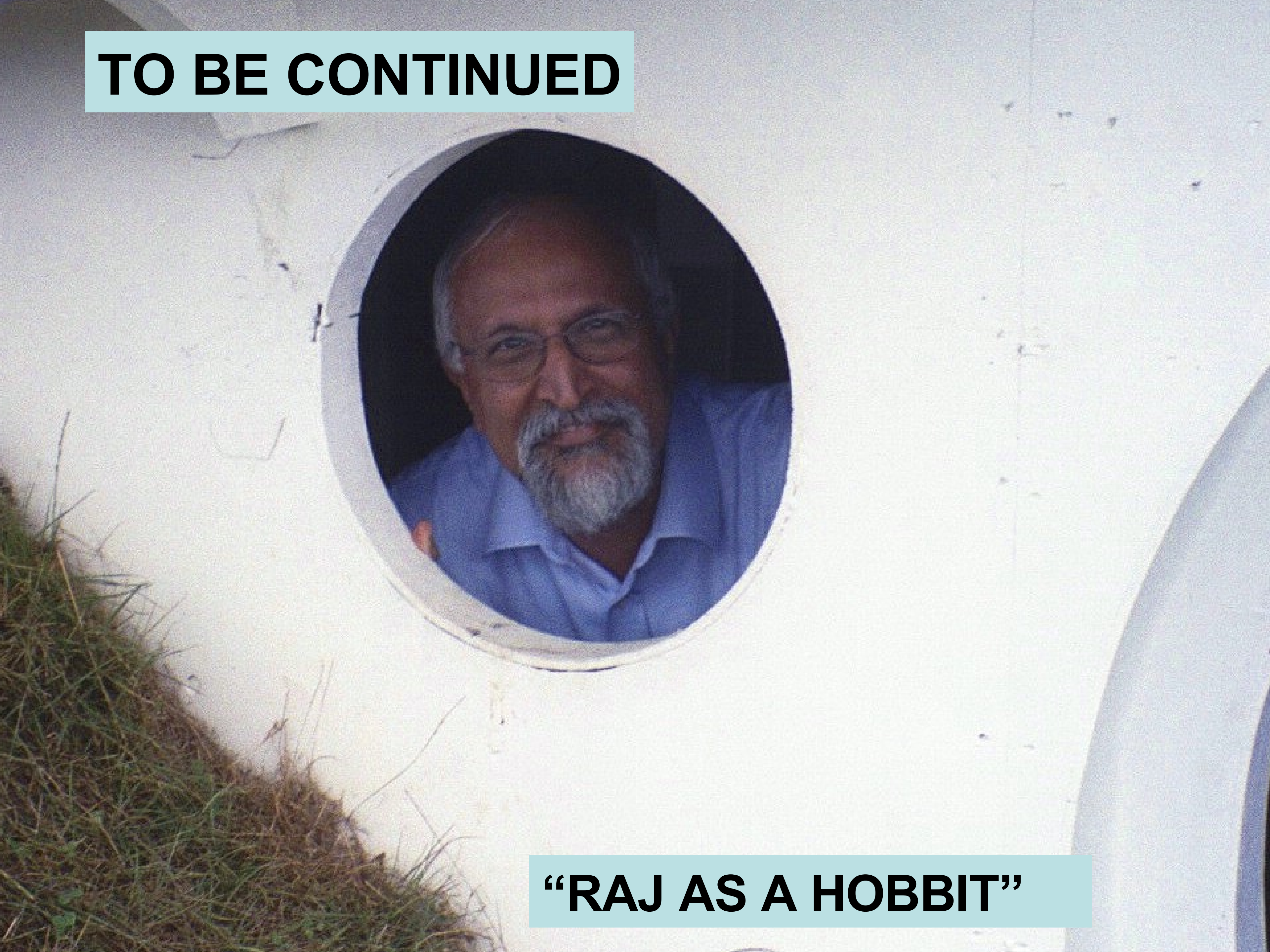
(7) PREDICTS e-Ln(p) LINE



VARIATION OF COORDINATION NUMBER WITH PARTICLE SIZE

CONCLUSIONS

- SOILS ARE 2 OR 3 PHASE MATERIALS
- "STATE VARIABLES" ARE NOT OBVIOUS
- LIMITED RANGE OF EXPERIMENTS
- DILATANCY, CRUSHING, INTERNAL STRUCTURE, INHERENT AND INDUCED ANISOTROPY ARE ALL IMPORTANT
- THESE FACTORS POSE MANY CHALLENGES TO THE MATHEMATICAL MODELLER


TO BE CONTINUED
“RAJ AS A HOBBIT”