

*Departamento de Ingeniería del
Terreno, Cartográfica y Geofísica*
**UNIVERSITAT POLITÈCNICA DE
CATALUNYA**



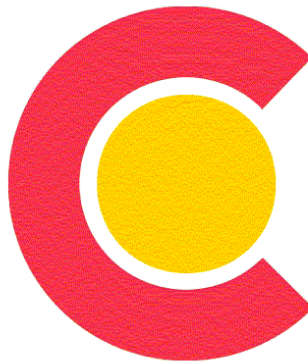
*Instituto de Investigaciones
Antisísmicas "Ing Aldo Bruschi"*
**UNIVERSIDAD NACIONAL DE
SAN JUAN**



Laboratorio de Geotecnia
**UNIVERSIDAD NACIONAL DE
CÓRDOBA**

Geotecnia e Ingeniería Sísmica aplicadas a la Minería

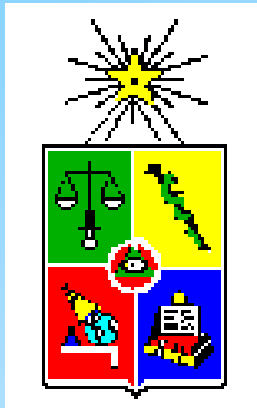
San Juan, Argentina, 16 de Octubre de 2007



**AGENCIA
ESPAÑOLA DE
COOPERACIÓN
INTERNACIONAL**



DISEÑO SISMICO DE PRESAS DE RELAVES



Prof. Ramón Verdugo A.

**DEPARTAMENTO DE INGENIERIA CIVIL
UNIVERSIDAD DE CHILE**

- PRESAS DE RESIDUOS MINEROS (TAILINGS DAMS) HAN MOSTRADO SER SENSIBLES AL FENÓMENO DE LICUACIÓN, O LICUEFACCIÓN.

- EN EL CASO DE CHILE, LAS MINAS DE COBRE TIENEN LEYES DEL ORDEN DEL 1%. ESTO SIGNIFICA QUE POR CADA TONELADA DE ROCA EXTRAÍDA, SE PRODUCEN 10 kg DE COBRE Y 990 kg DE RESIDUOS.

- POR RAZONES DE ESPACIO Y DISTANCIA, ES NORMAL QUE RESULTE ATRACTIVO Y ECONÓMICO EL DESARROLLO DE GRANDES PRESAS. POR EJEMPLO, EN CHILE YA EXISTEN PRESAS DE RESIDUOS DE MAS DE 150m DE ALTURA.

- PROBLEMA COMÚN EN EL CONTEXTO ANDINO

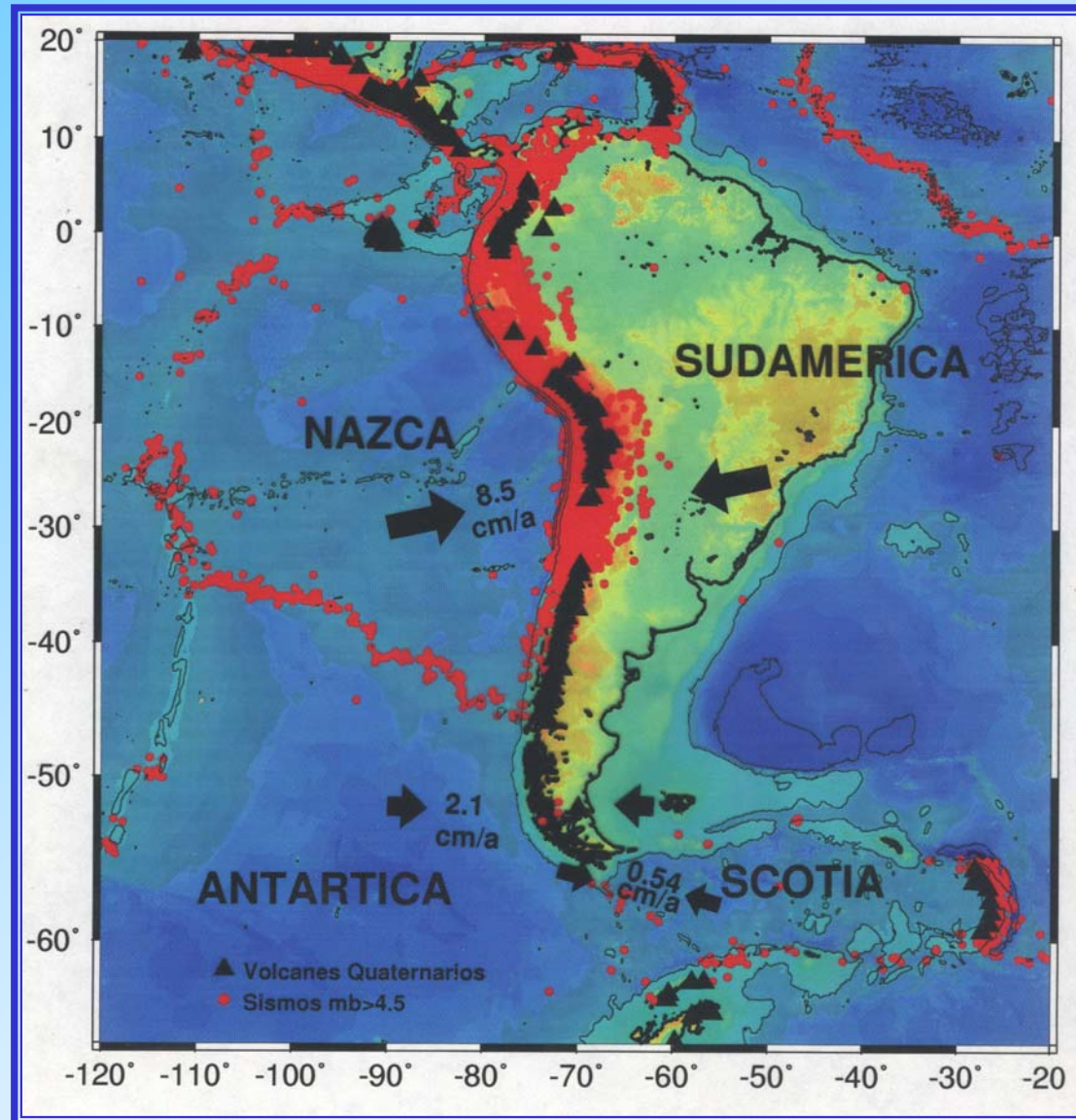
- ALTA SISMICIDAD**

- IMPORTANTE PROYECCION MINERA
METÁLICA Y NO-METÁLICA**

- VARIEDAD DE SUELOS COMPLEJOS
CENIZAS VOLCÁNICAS
SUELOS DE GRANDES PARTÍCULAS
DEPÓSITOS DE DIATOMEAS
SUELOS RESIDUALES**

- GEOLOGÍA VIVA**

SISMICIDAD EN SUDAMERICA



- LAS FALLAS MAS CATASTRÓFICAS DE PRESAS DE RESIDUOS MINEROS HAN SIDO CAUSADAS POR LA OCURRENCIA DEL FENOMENO DE LICUACION.

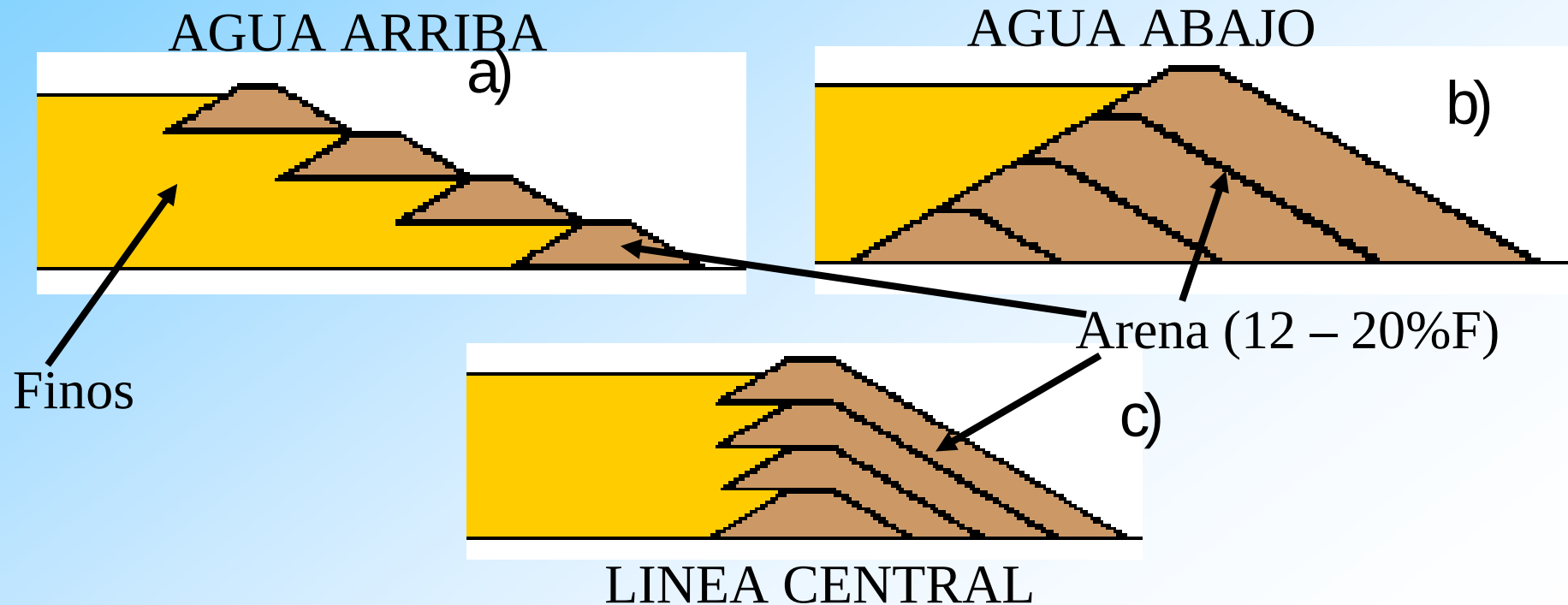
- LO COMÚN HA SIDO LA OCURRENCIA DE FALLA DE FLUJO, GATILLADA POR EVENTOS SÍSMICOS MEDIANOS A FUERTES.

TRANQUE CONVENCIONAL
(Relaves cicloneados)

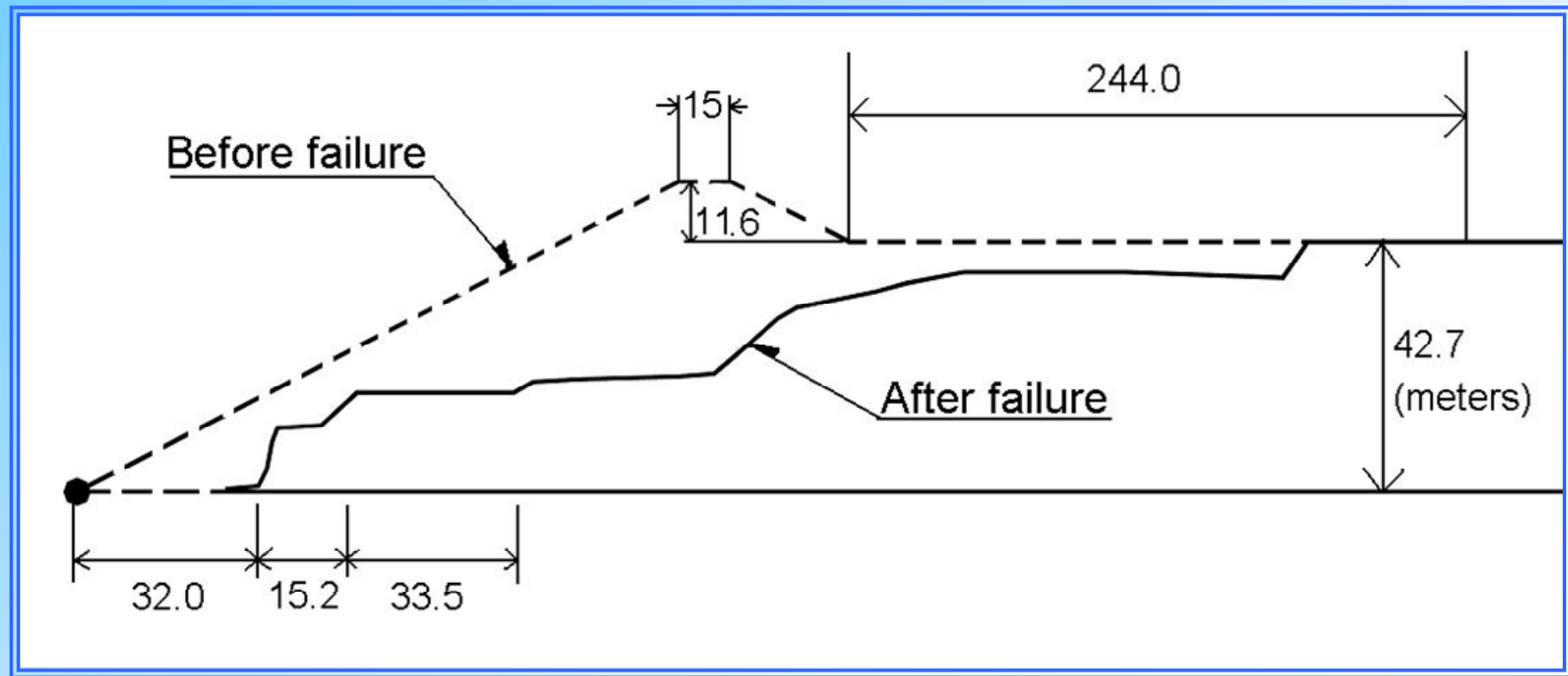
RELAVES ESPESADOS:
(Relave integral)

TRANQUE CONVENCIONAL

SISTEMA DE CICLONES → **ARENA**
→ **FINOS (LAMAS)**

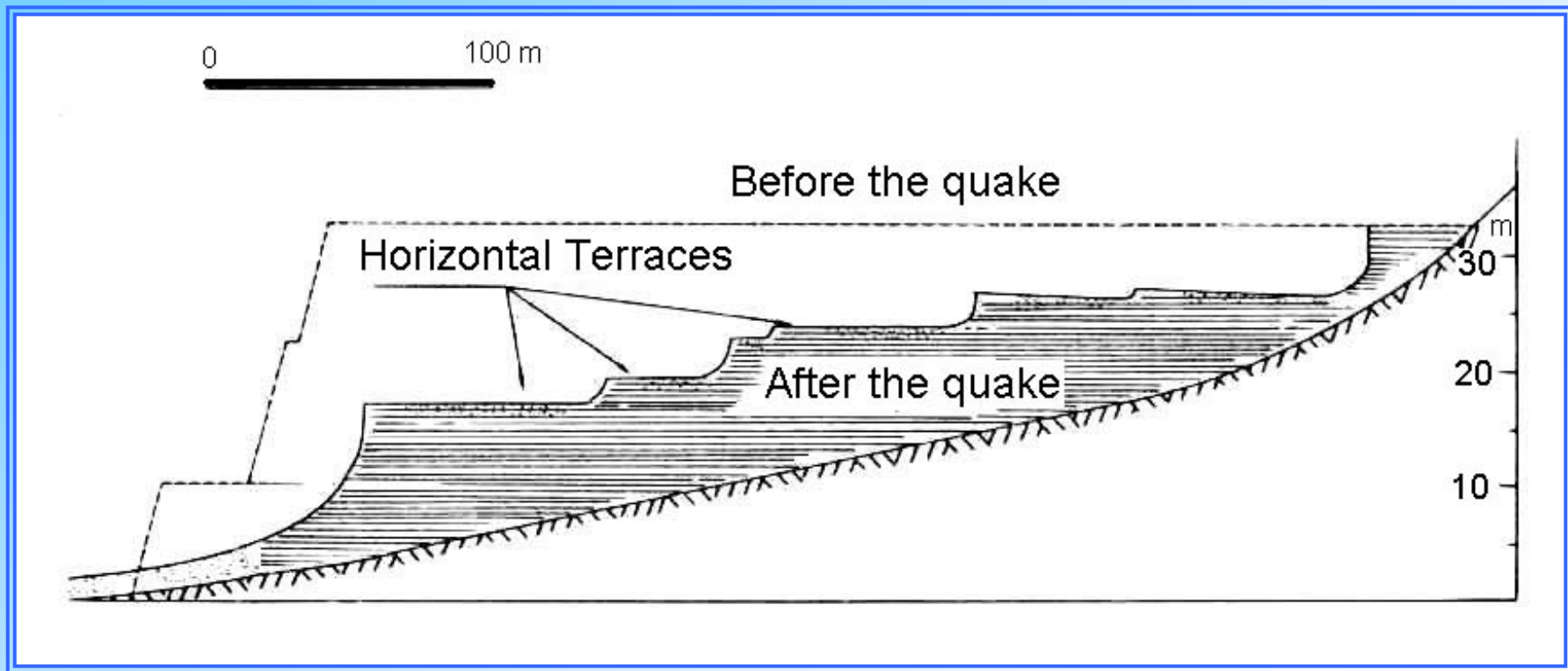


FAILURE OF BARAHONA TAILINGS DAM OCTOBER, 1, 1928



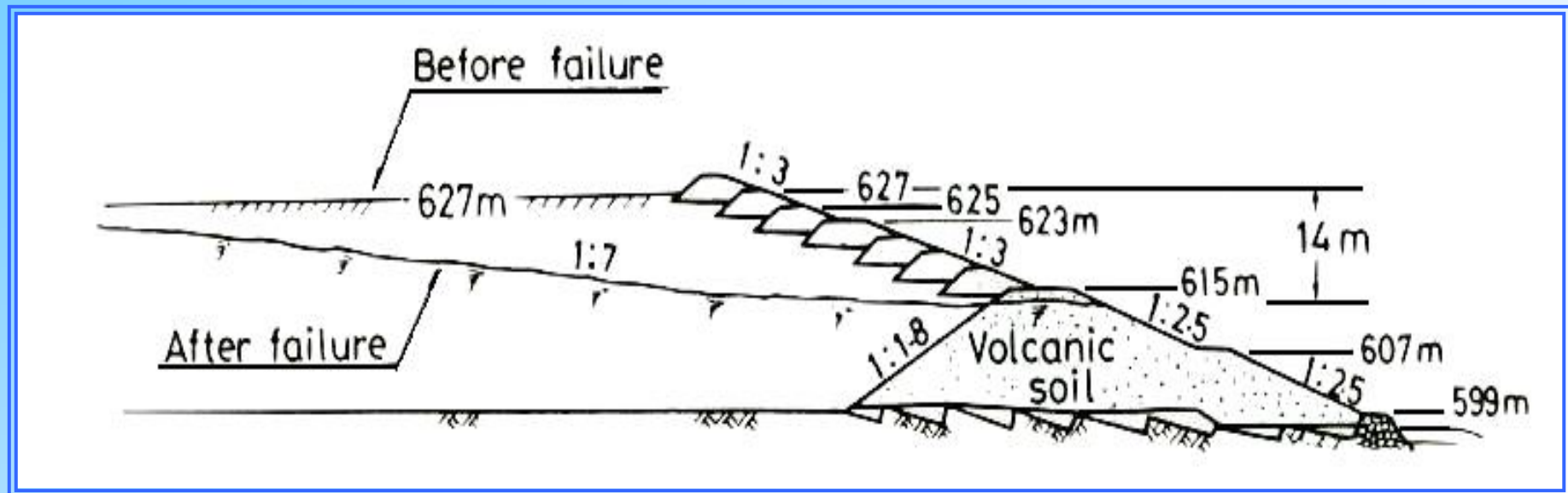
(Agüero, 1929)

FAILURE OF EL COBRE TAILINGS DAM MARCH, 28, 1965



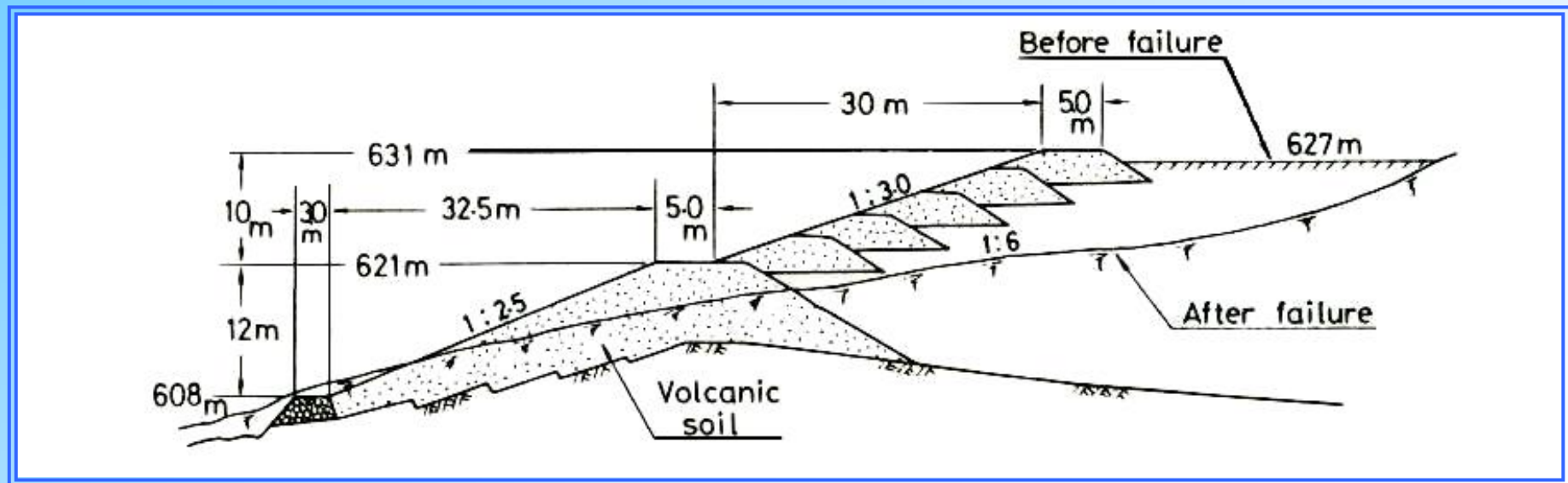
(Dobry et al, 1967)

FAILURE OF MOCHIKOSHI TAILINGS DAM DIKE No. 1, JANUARY 14, 1978



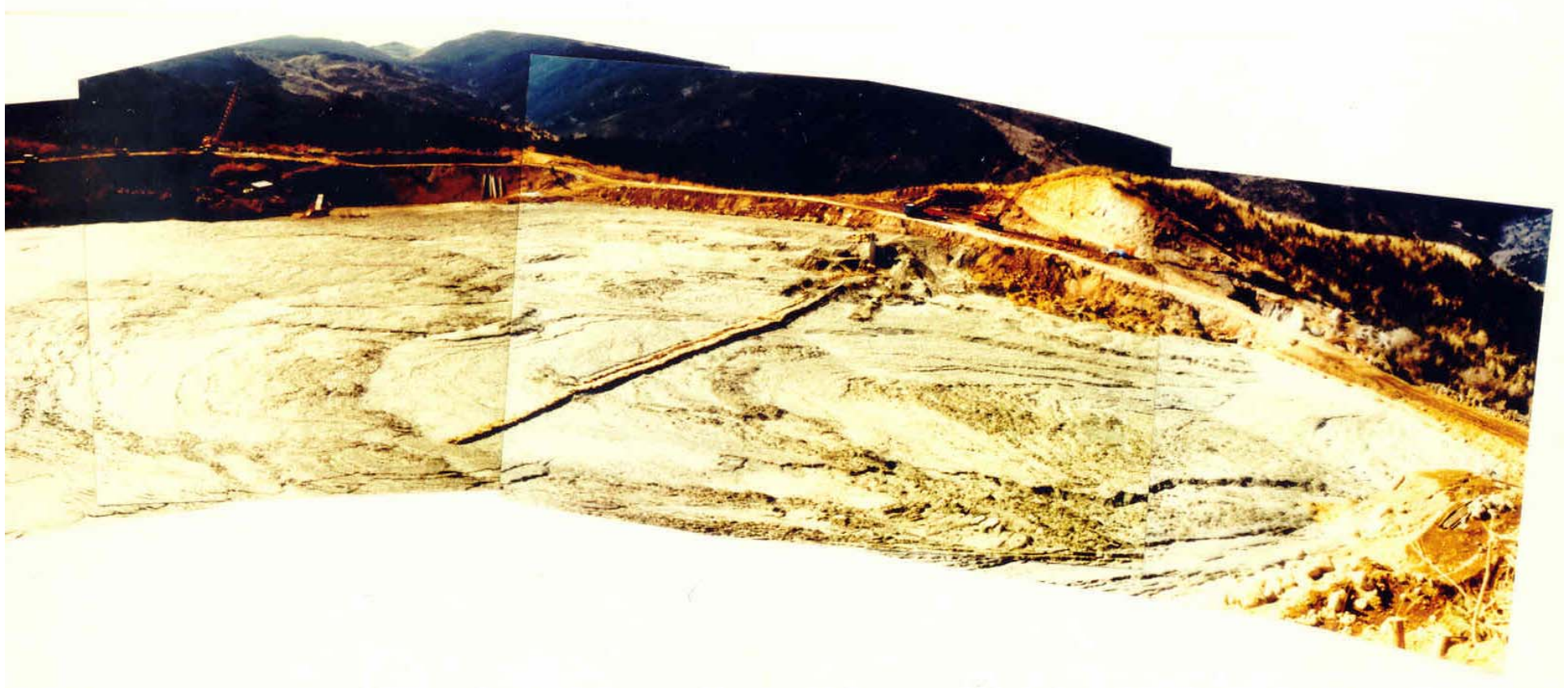
(Ishihara, 1984)

FAILURE OF MOCHIKOSHI TAILINGS DAM DIKE No. 2, JANUARY 14, 1978



(Ishihara, 1984)

FALLA PRESA MOCHIKOSHI, 1979

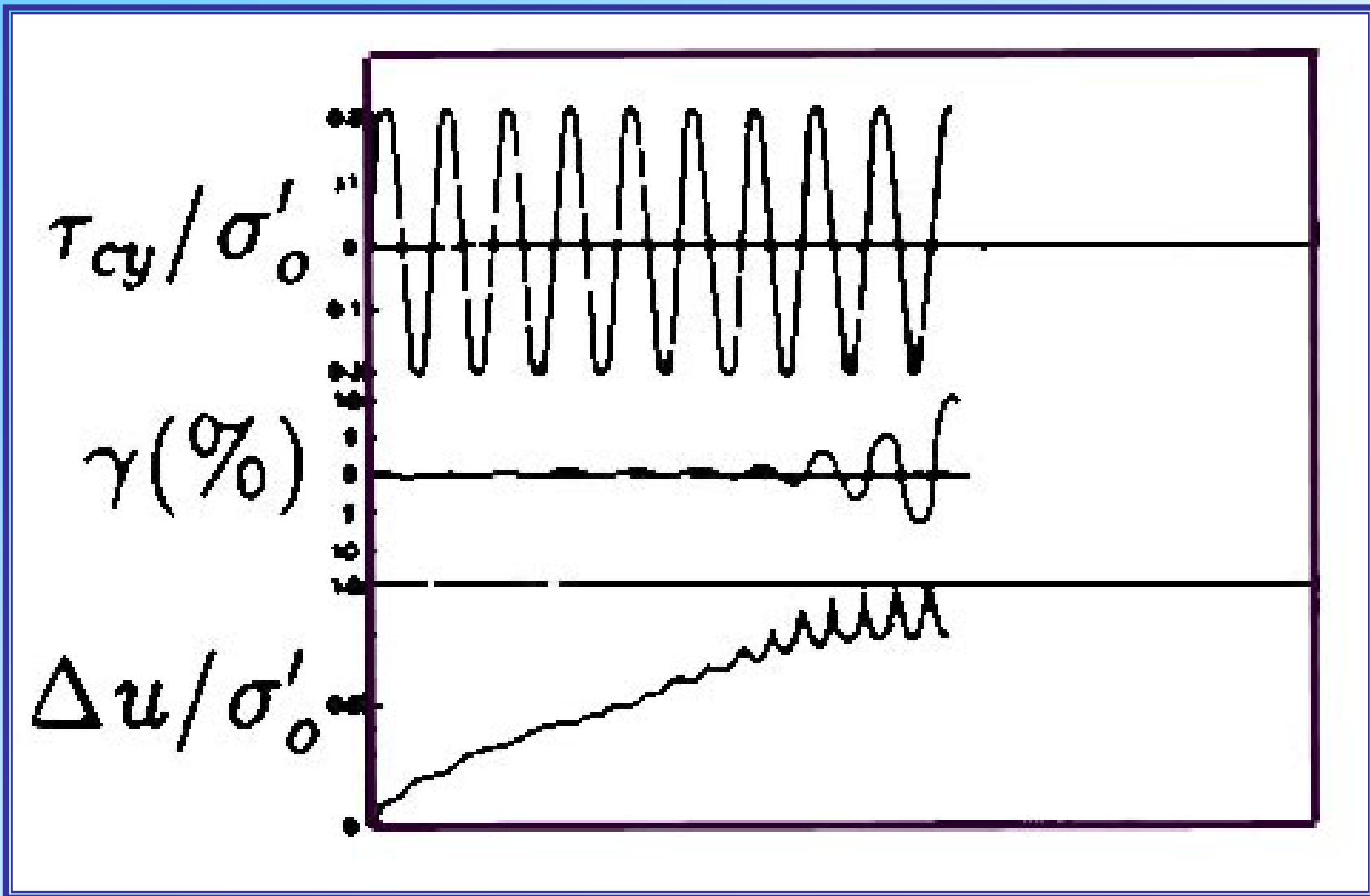


(Cortesía Prof. Ishihara)

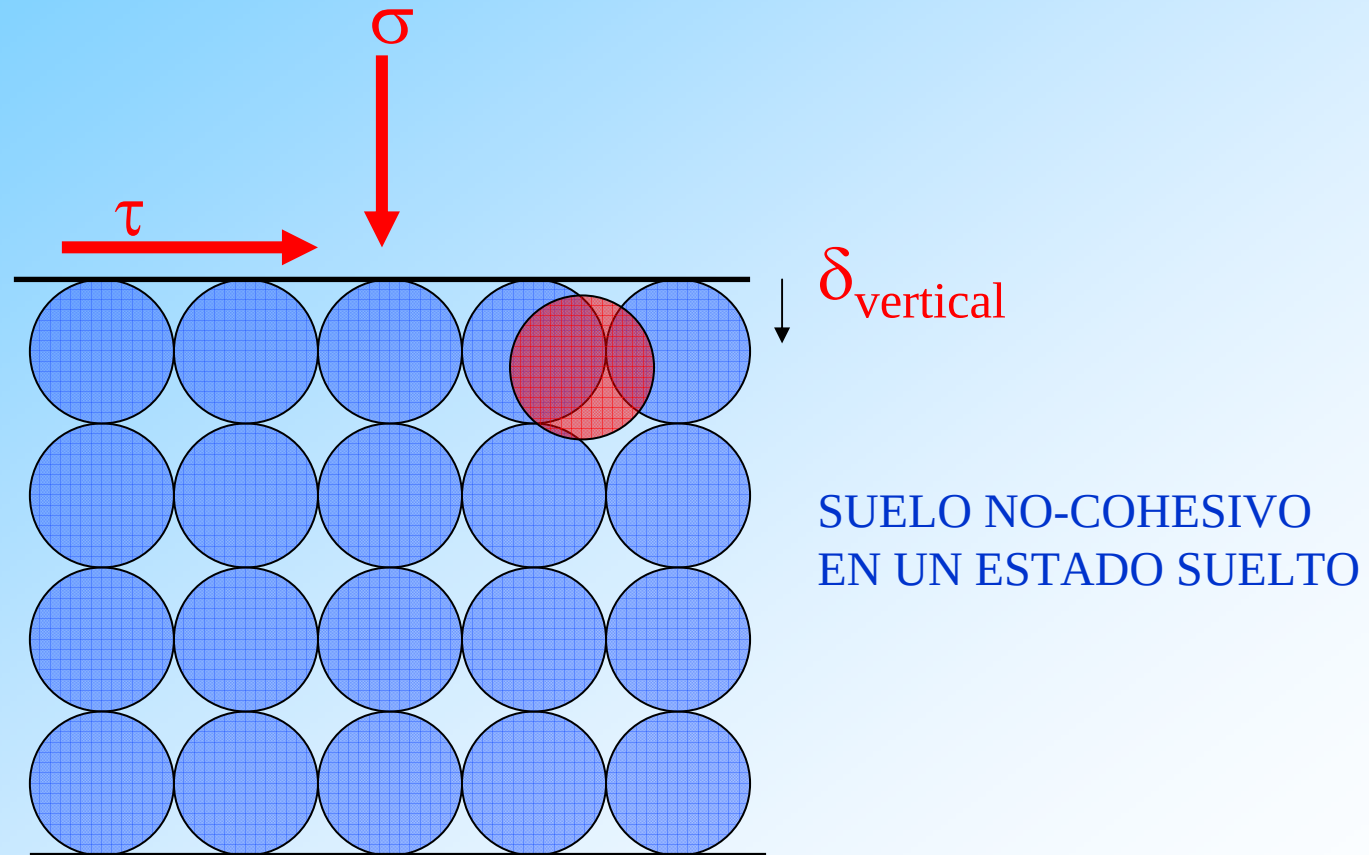
LICUEFACCION

- Movilidad cíclica
 - Pérdida de rigidez
- Falla de flujo
 - Pérdida de resistencia

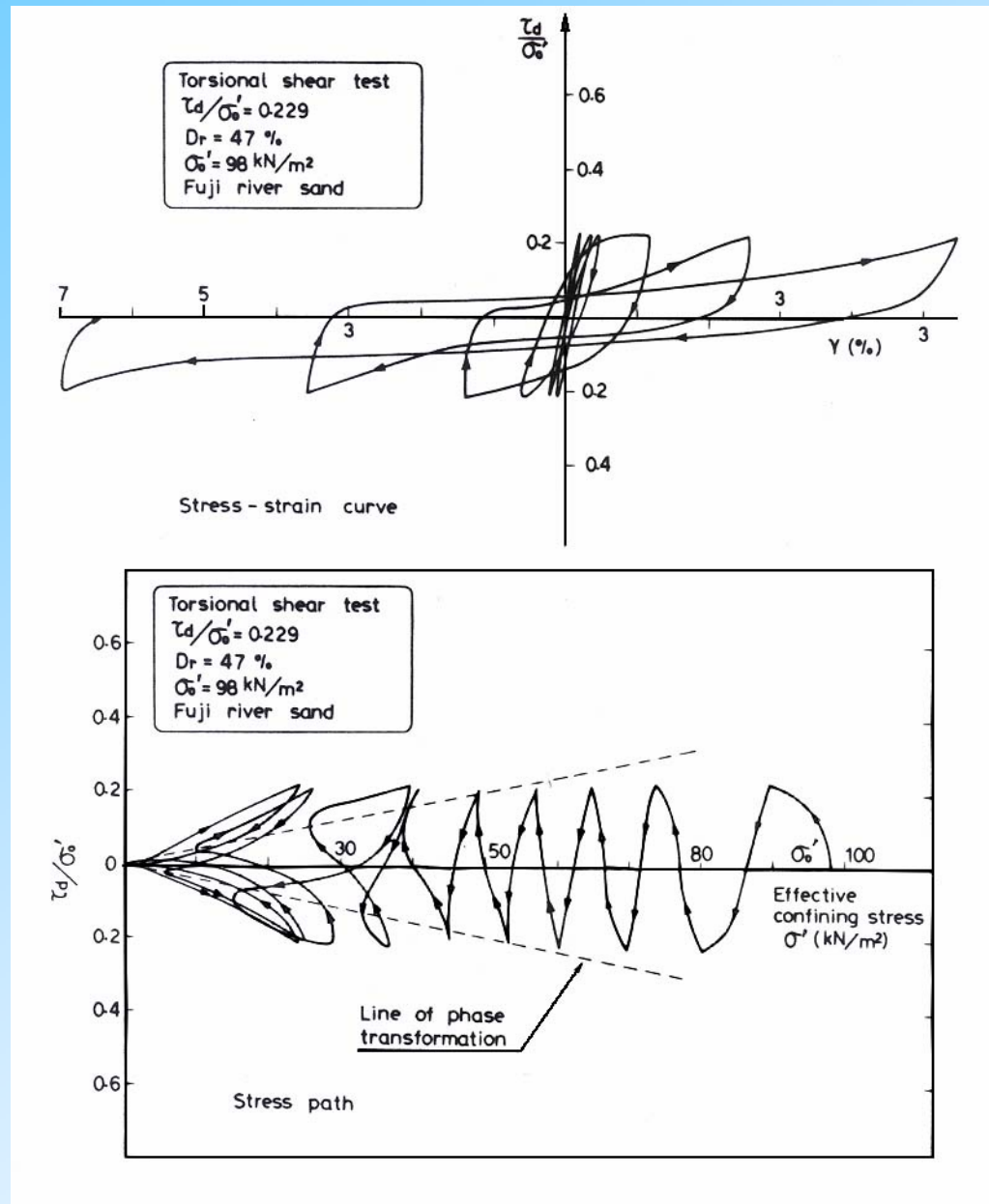
MOVILIDAD CICLICA



CONCEPTO DE CAMBIO DE VOLUMEN EN UN SISTEMA PARTICULADO

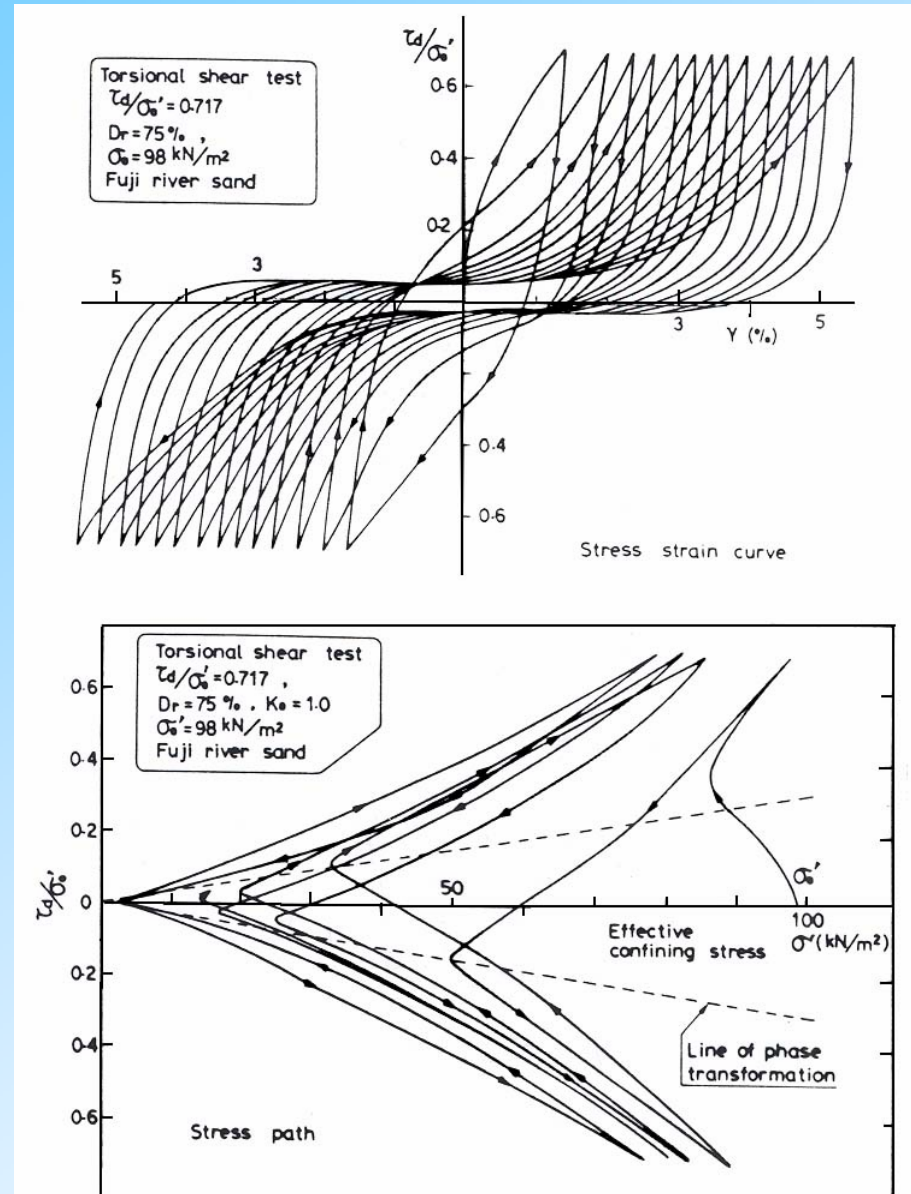


MOVILIDAD CICLICA EN ARENA SUELTA



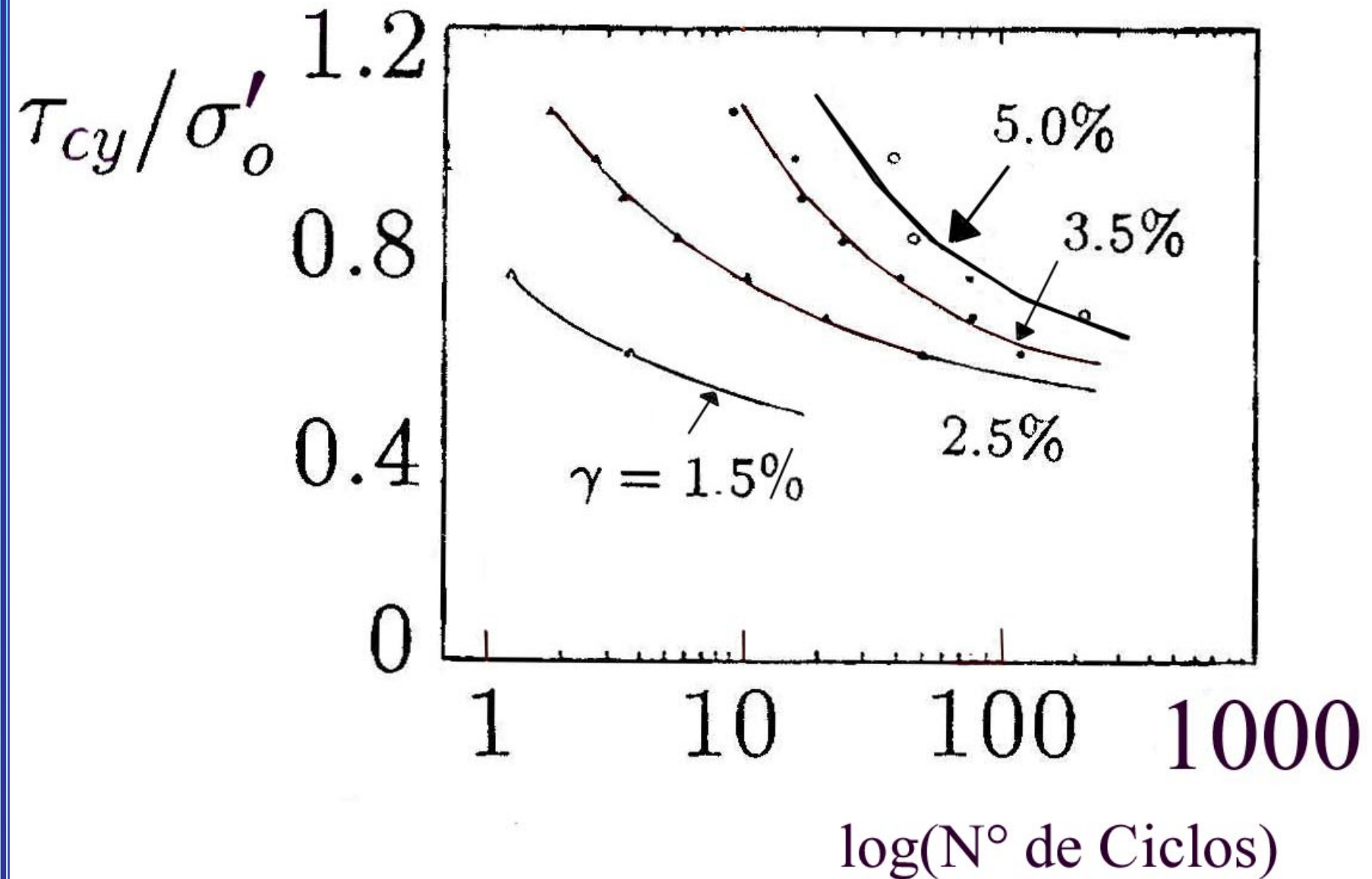
(Ishihara, 1985)

MOVILIDAD CICLICA EN ARENA DENSA



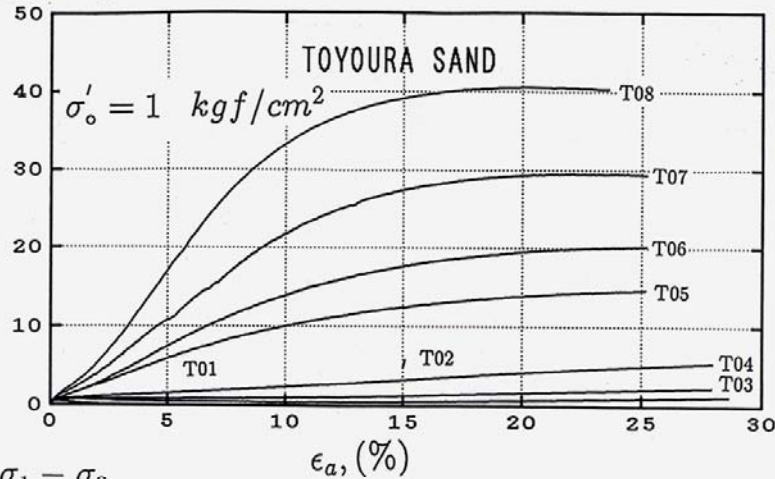
(Ishihara, 1985)

RESISTENCIA CICLICA

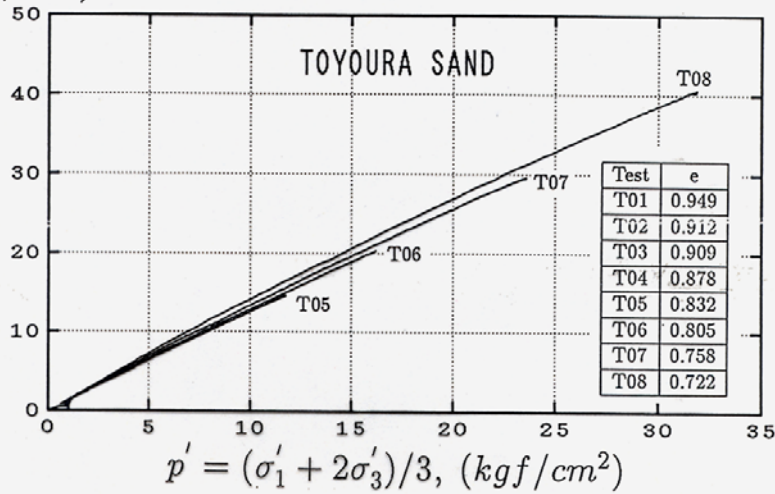


RESPUESTA NO DRENADA EN ENSAYOS CIU

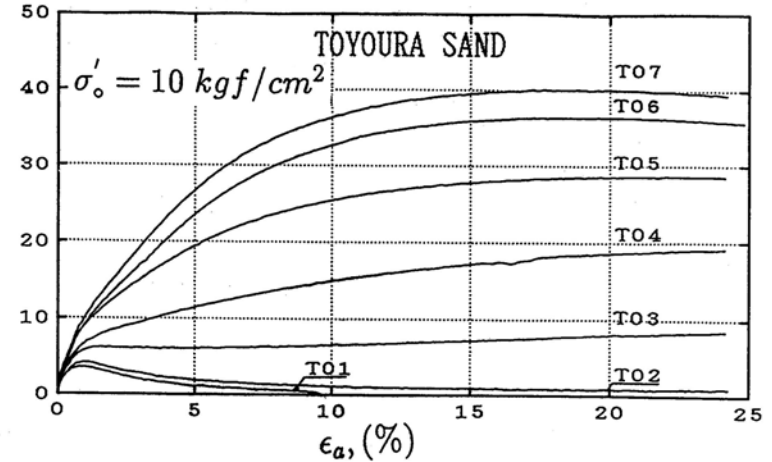
$$q = \sigma_1 - \sigma_3, \\ (\text{kgf/cm}^2)$$



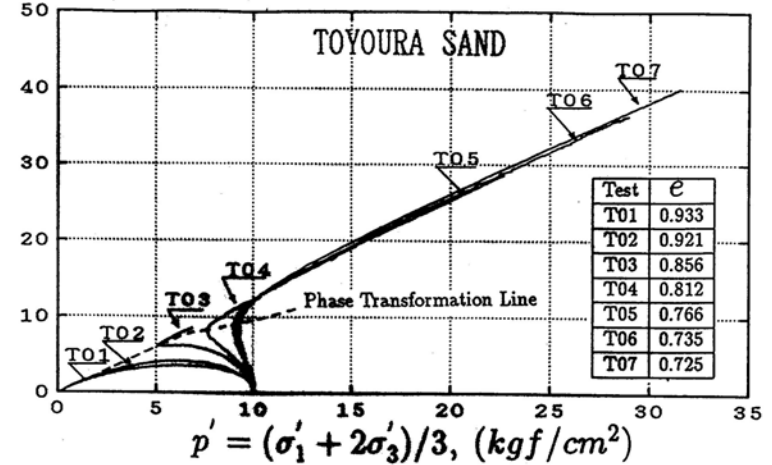
$$q = \sigma_1 - \sigma_3 \\ (\text{kgf/cm}^2)$$



$$q = \sigma_1 - \sigma_3 \\ (\text{kgf/cm}^2)$$

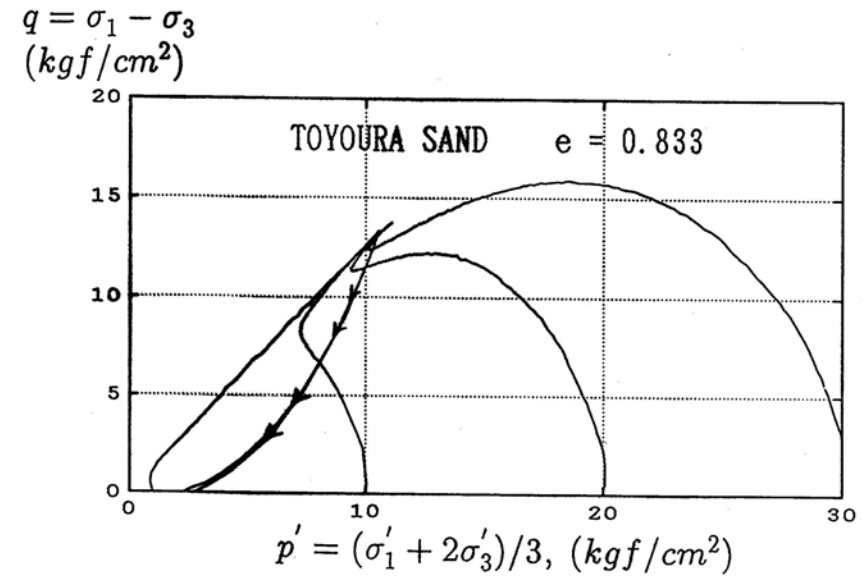
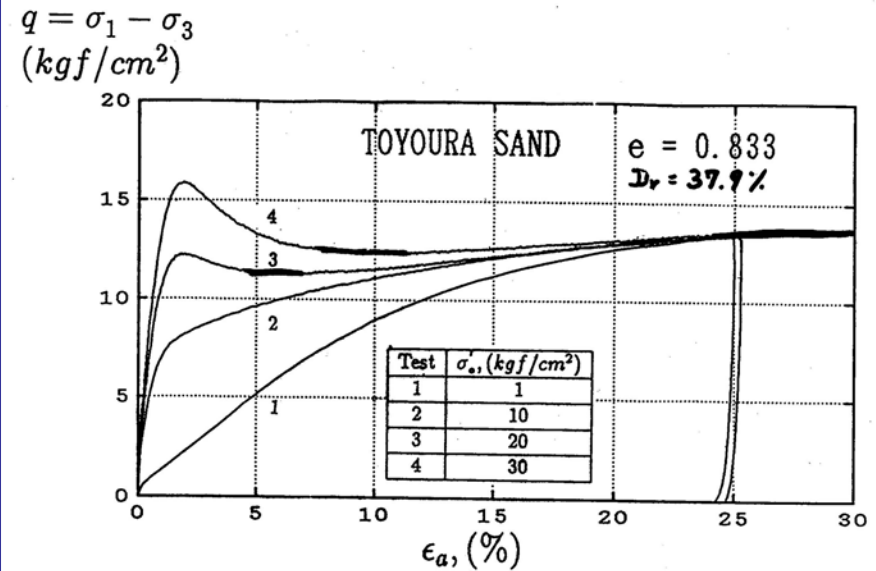
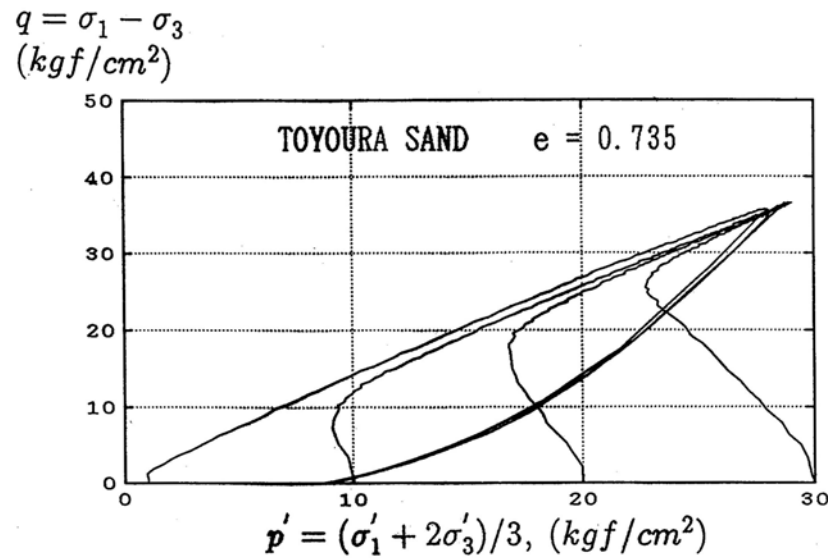
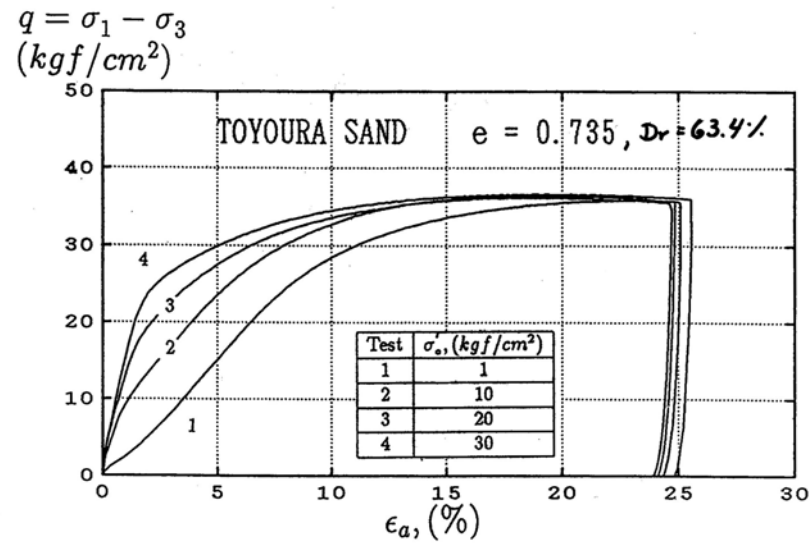


$$q = \sigma_1 - \sigma_3 \\ (\text{kgf/cm}^2)$$



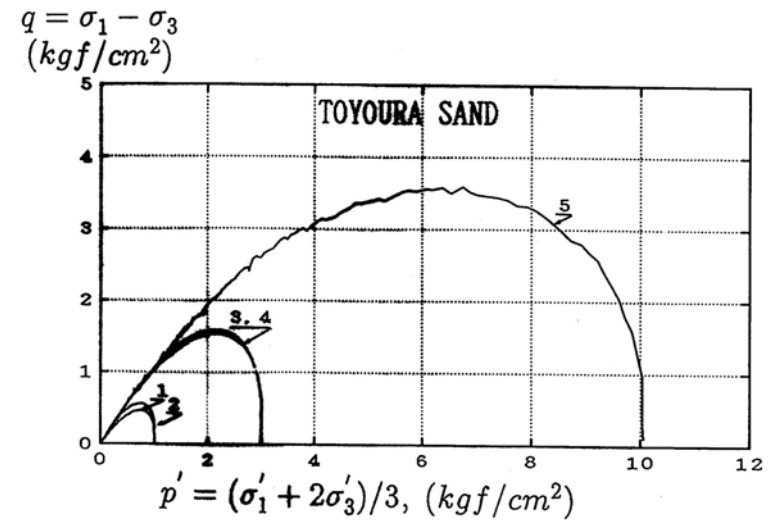
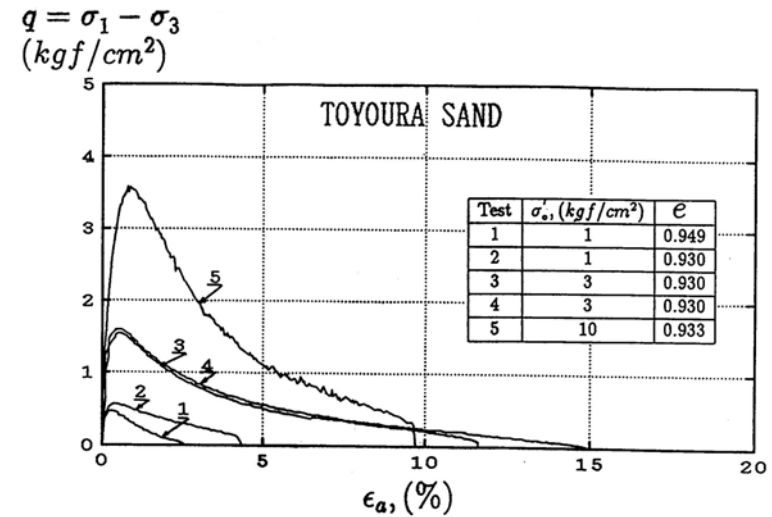
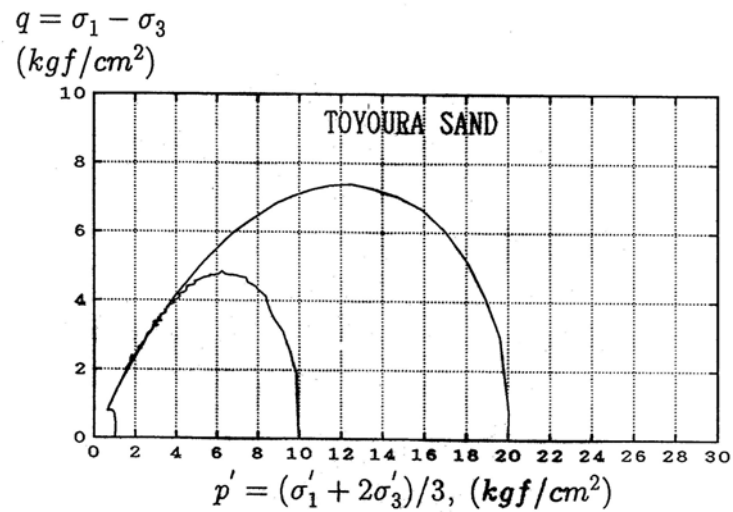
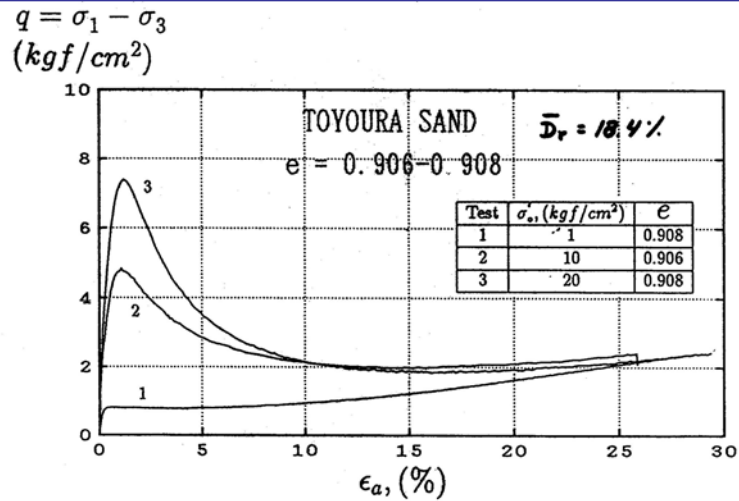
(Verdugo, 1992)

RESPUESTA NO DRENADA EN ENSAYOS CIU



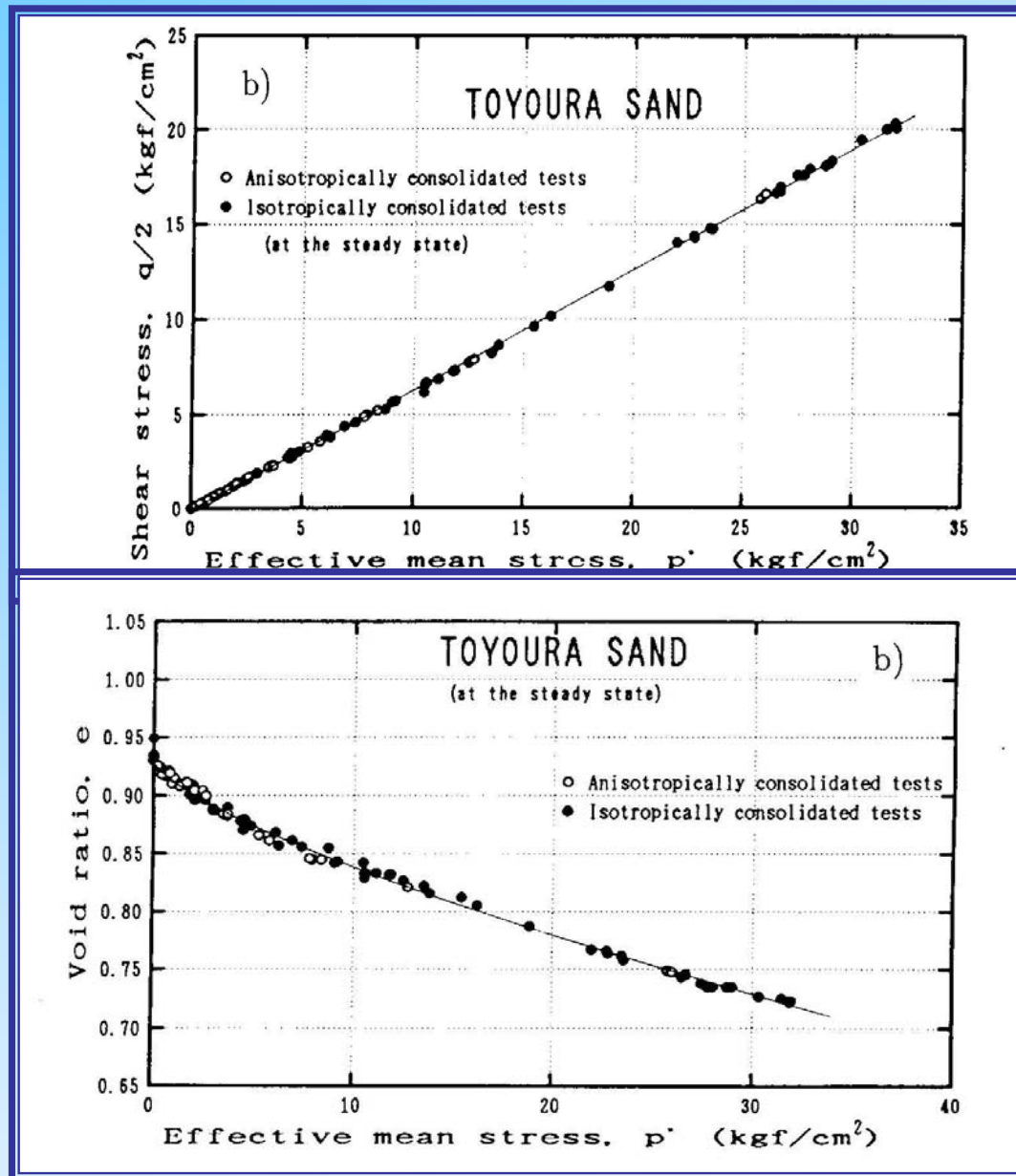
(Verdugo, 1992)

RESPUESTA NO DRENADA EN ENSAYOS CIU



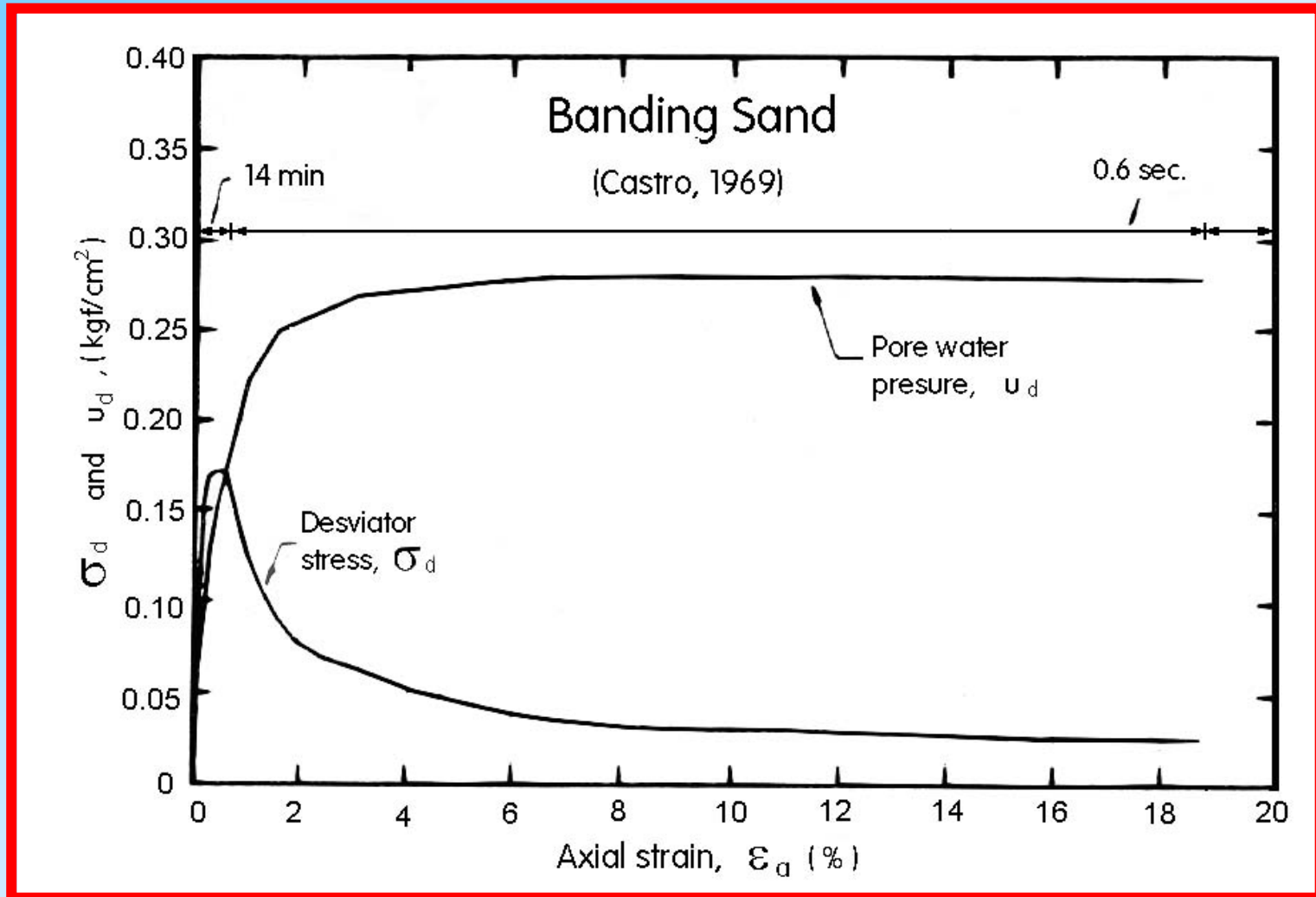
(Verdugo, 1992)

LÍNEA DE ESTADO ÚLTIMO (STEADY STATE)

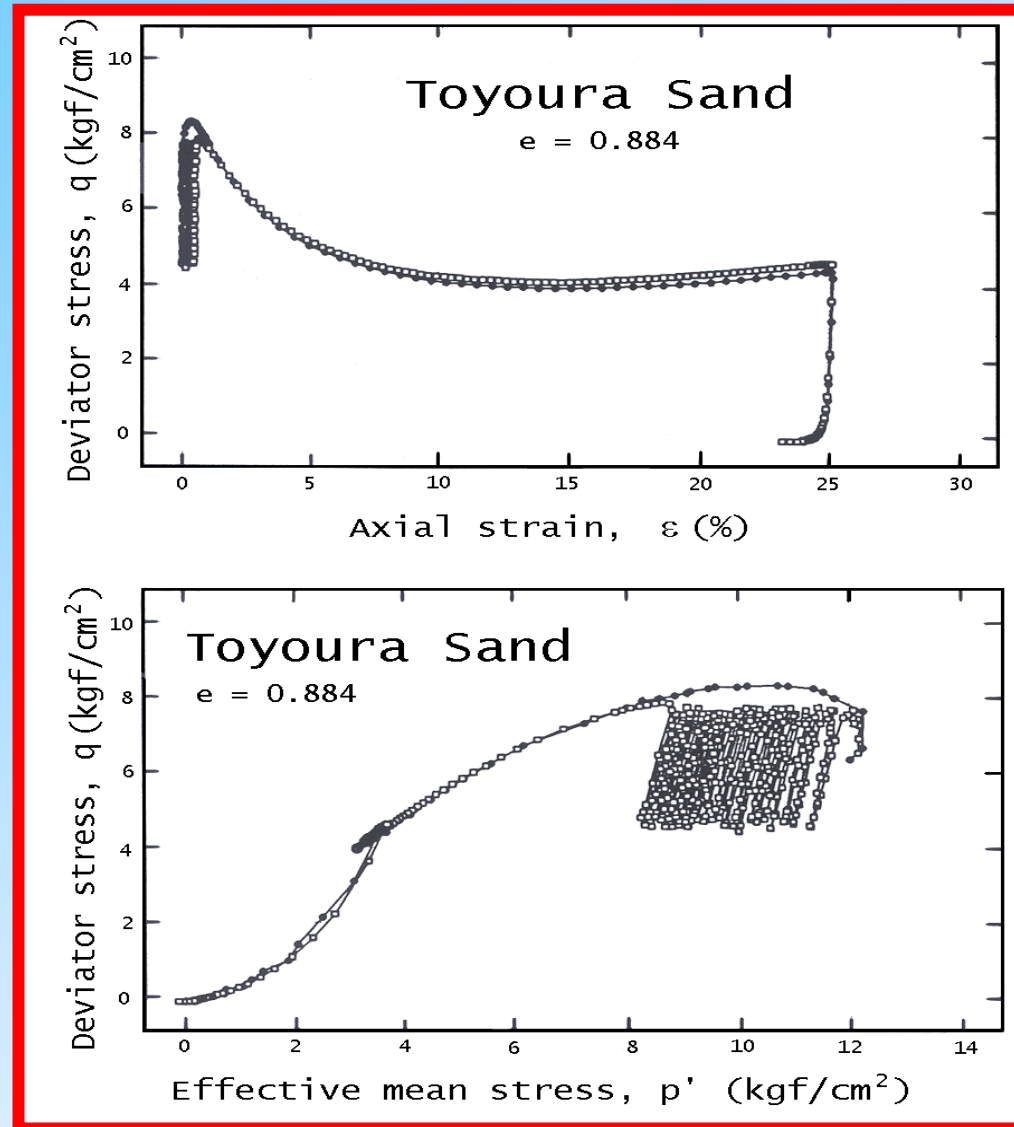


(Verdugo, 1992)

RESPUESTA CONTRACTIVA CARGA CONTROLADA

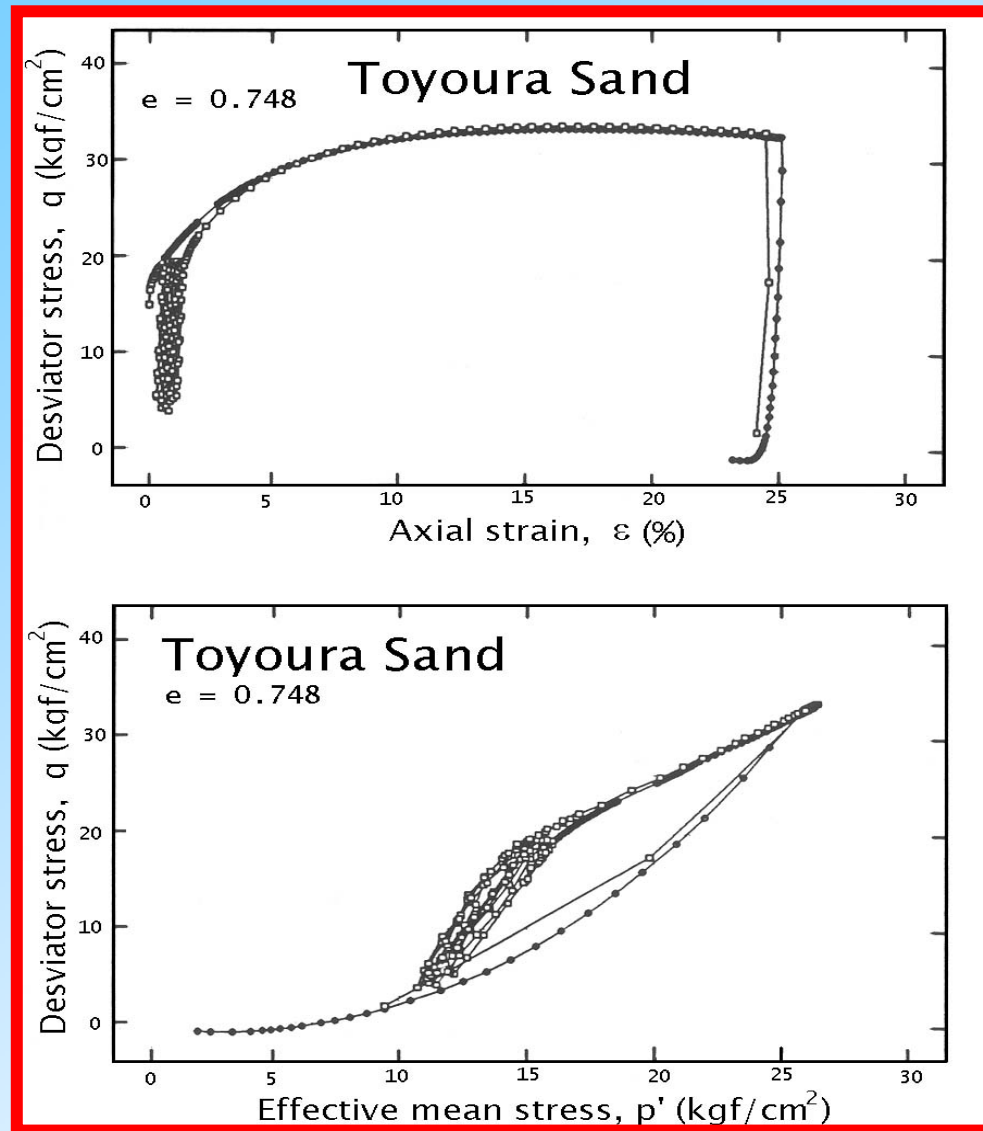


STRESS HISTORY AND STEADY STATE STRENGTH



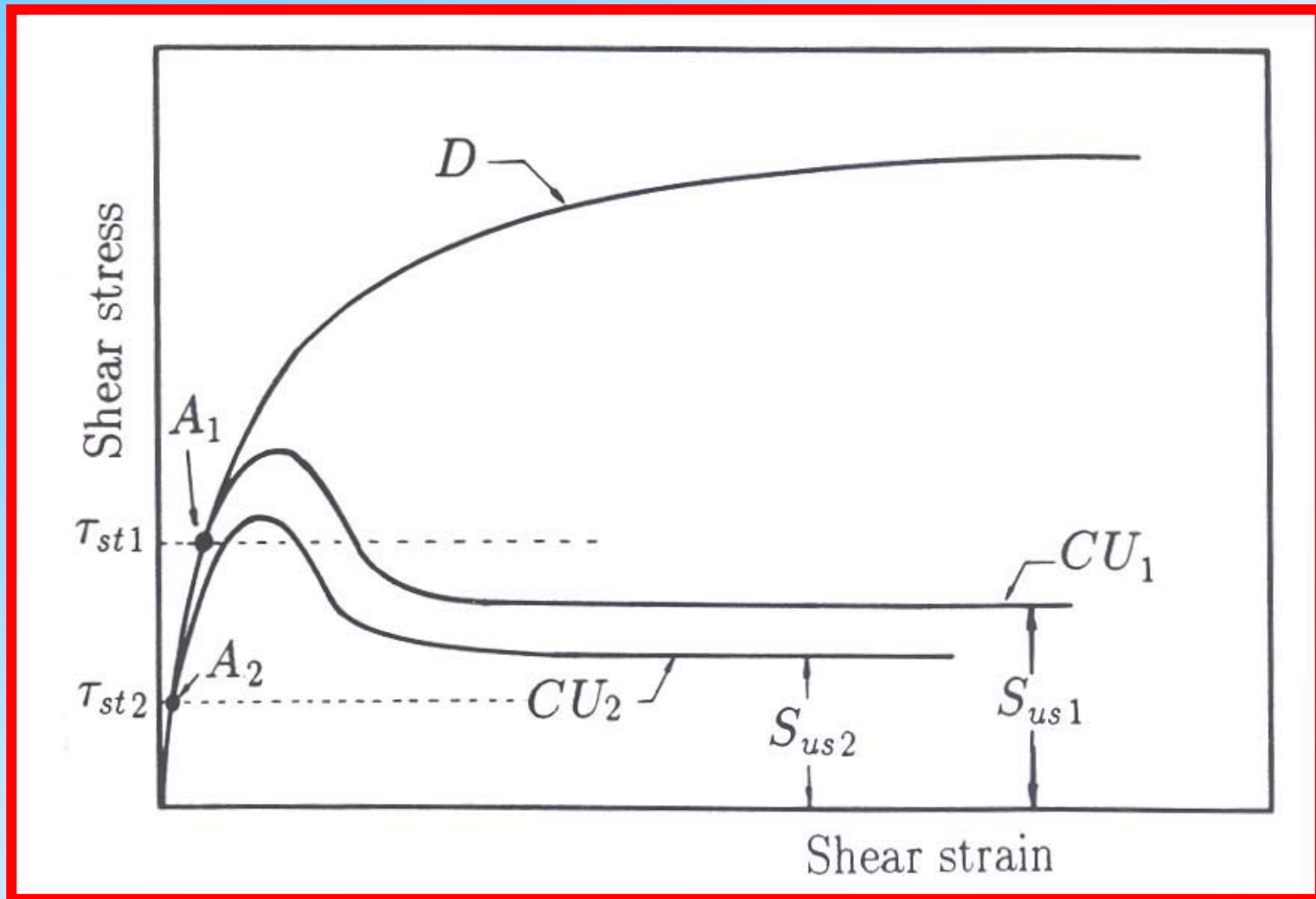
(Verdugo, 1992)

STRESS HISTORY AND STEADY STATE STRENGTH



(Verdugo, 1992)

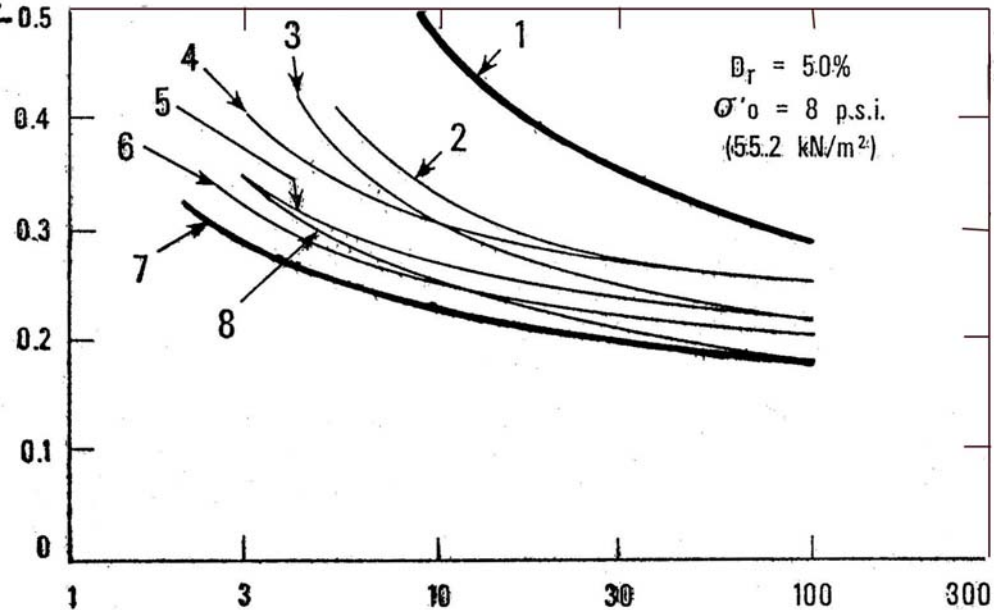
CONCEPT OF A FLOW FAILURE



FACTORES QUE CONTROLAN LA RESISTENCIA CICLICA

STRESS RATIO,

$$R = \frac{\sigma_{dc}}{2 \sigma'_3}$$



NUMBER OF CYCLES TO CAUSE PEAK CYCLIC PORE PRESSURE RATIO OF 100% and $\pm 2.5\%$ AXIAL STRAIN, n

Curva N°

- ①
- 2
- 3
- 4
- 5
- 6
- ⑦
- 8

Método de Compactación

- High frequency vibrations on moist samples
- Moist tamping
- Moist rodding
- Low frequency vibrations on dry samples
- High frequency vibrations on dry samples
- Pluviated-water
- Pluviated-air
- Dry rodding

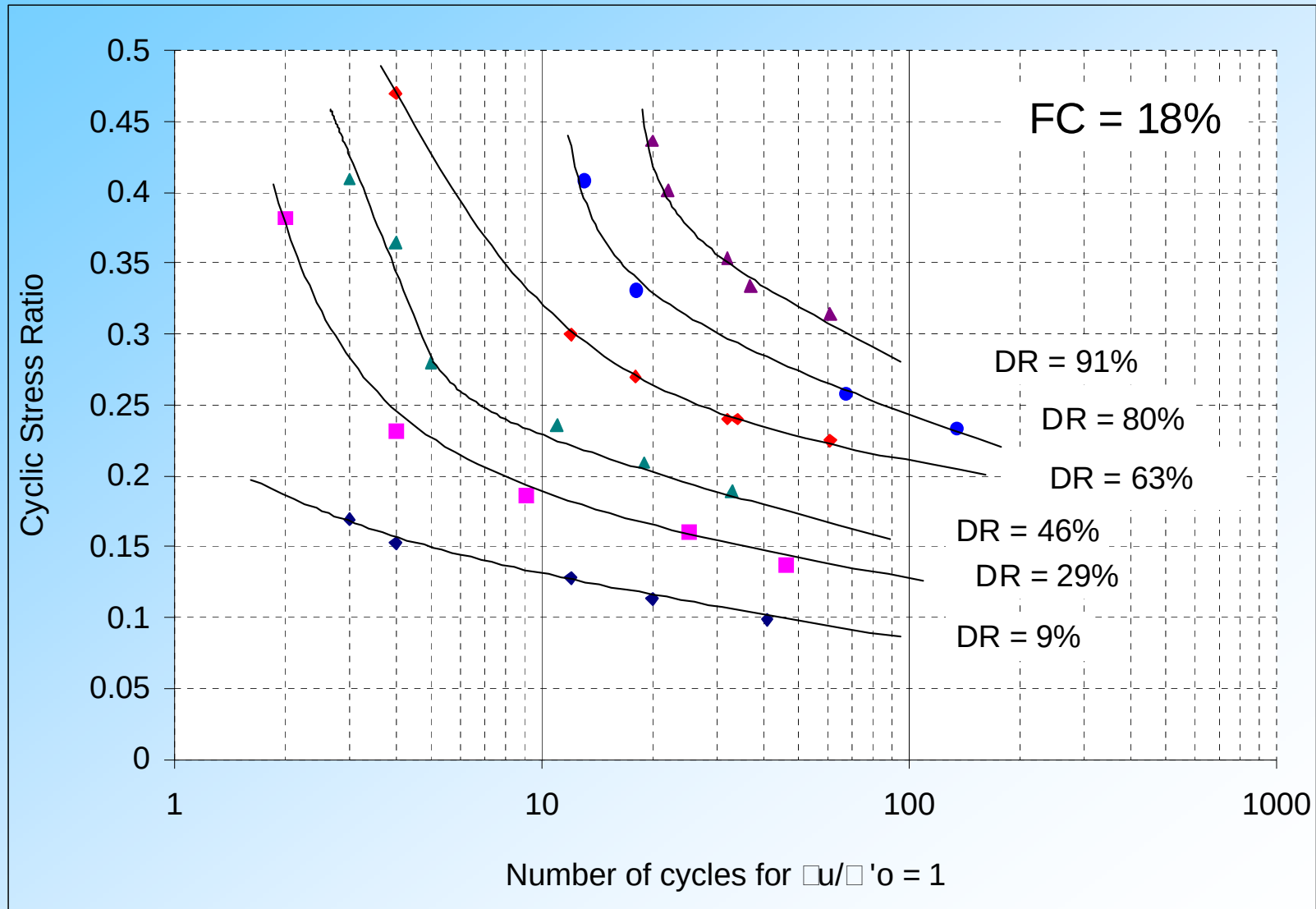
TRANQUE CONVENCIONAL:

- Método constructivo
- Grado de densificación
- Contenido de finos

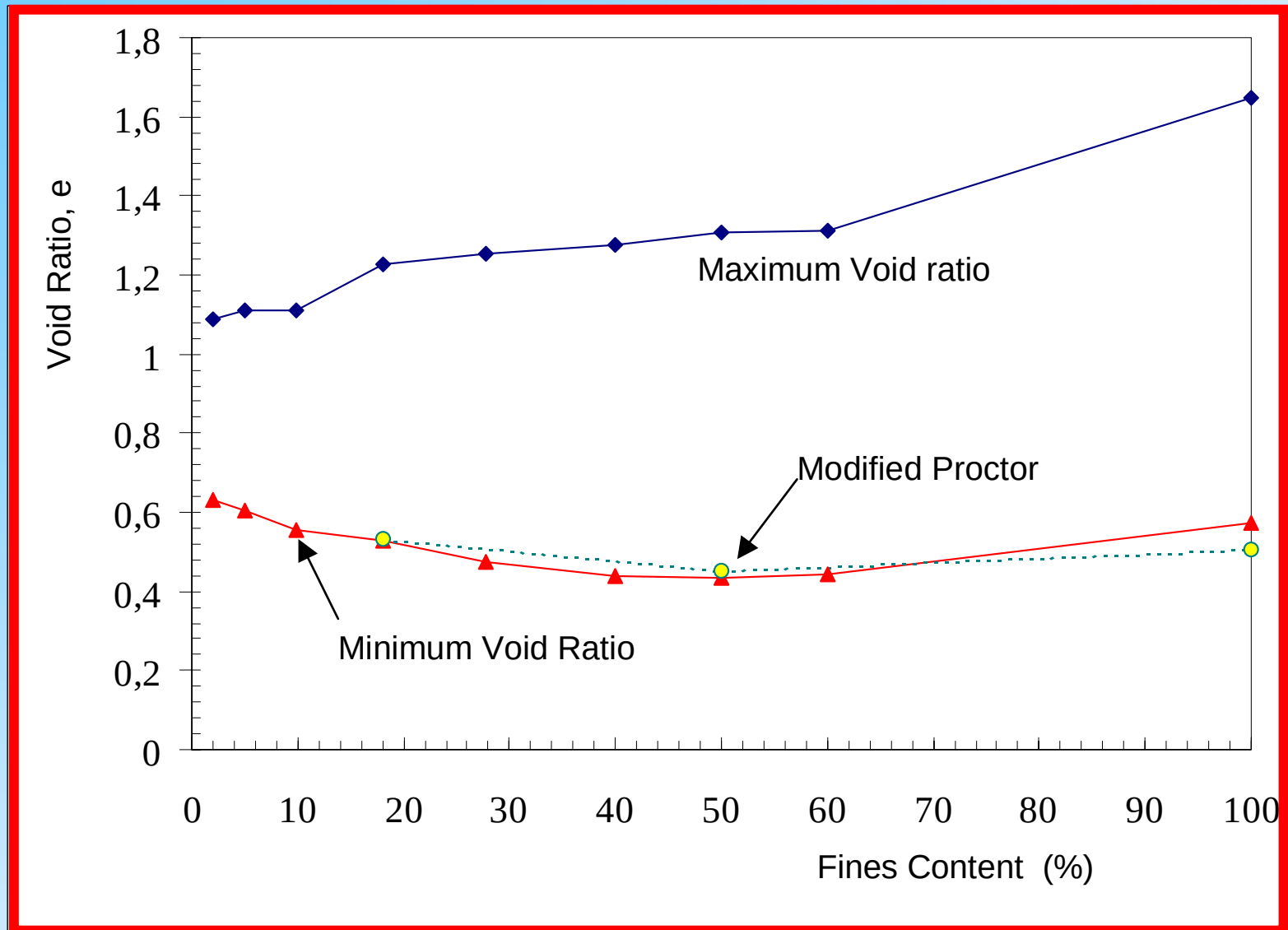
RELAVES ESPESADOS:

- Segregación mínima
- Secamiento
- Densidad

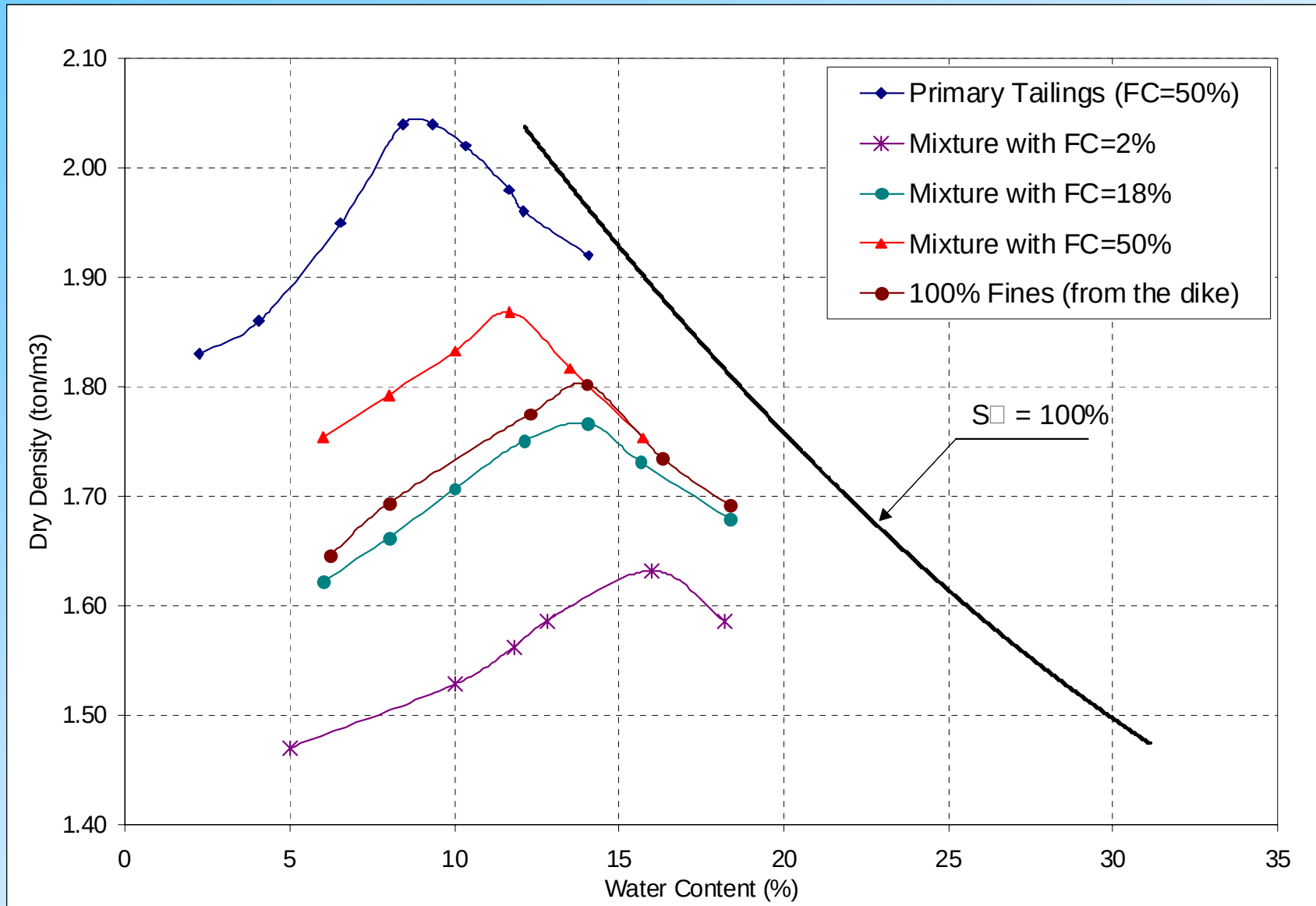
EFFECT OF RELATIVE DENSITY ON THE CYCLIC STRENGTH



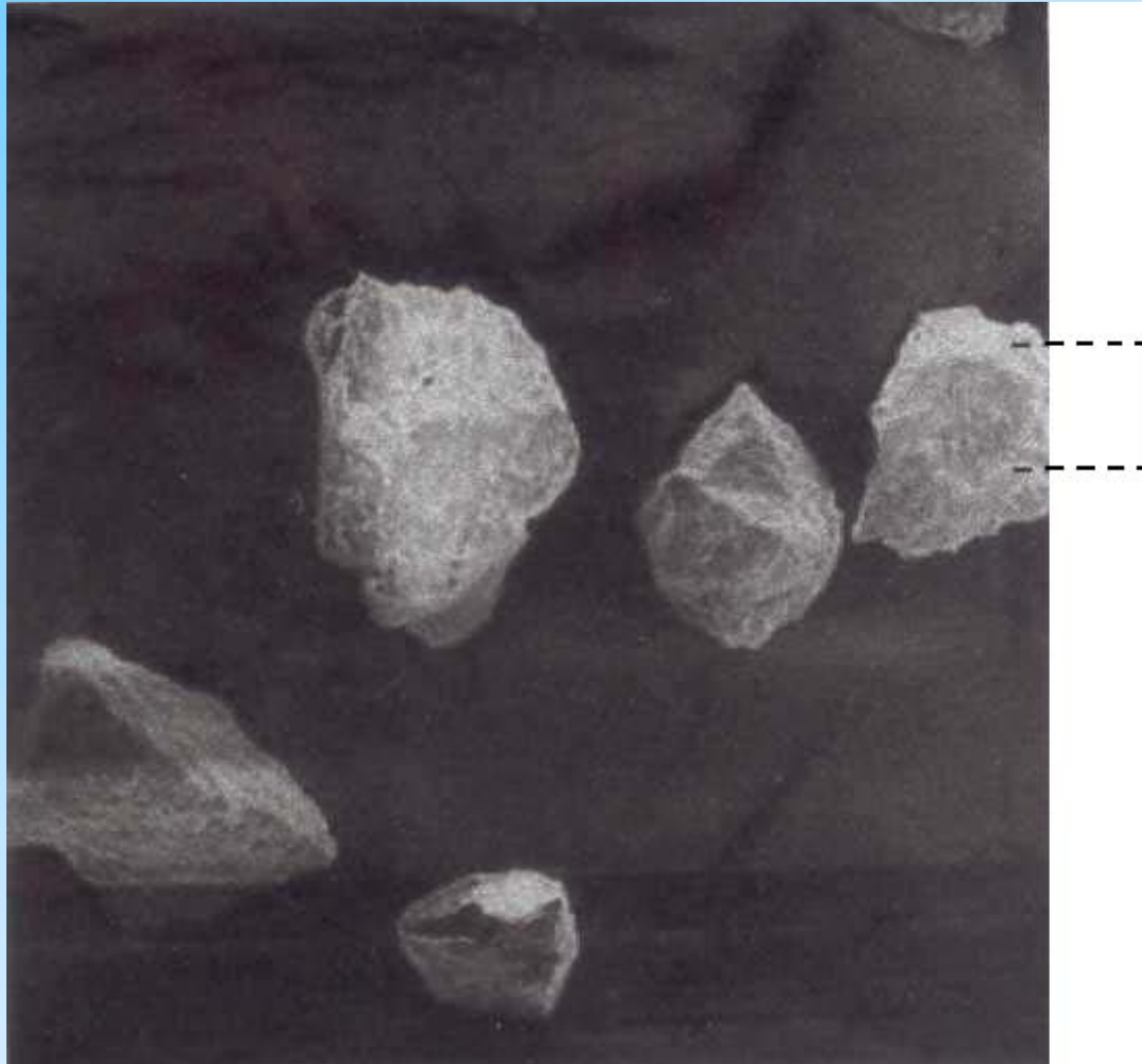
MAXIMUM AND MINIMUM DENSITIES



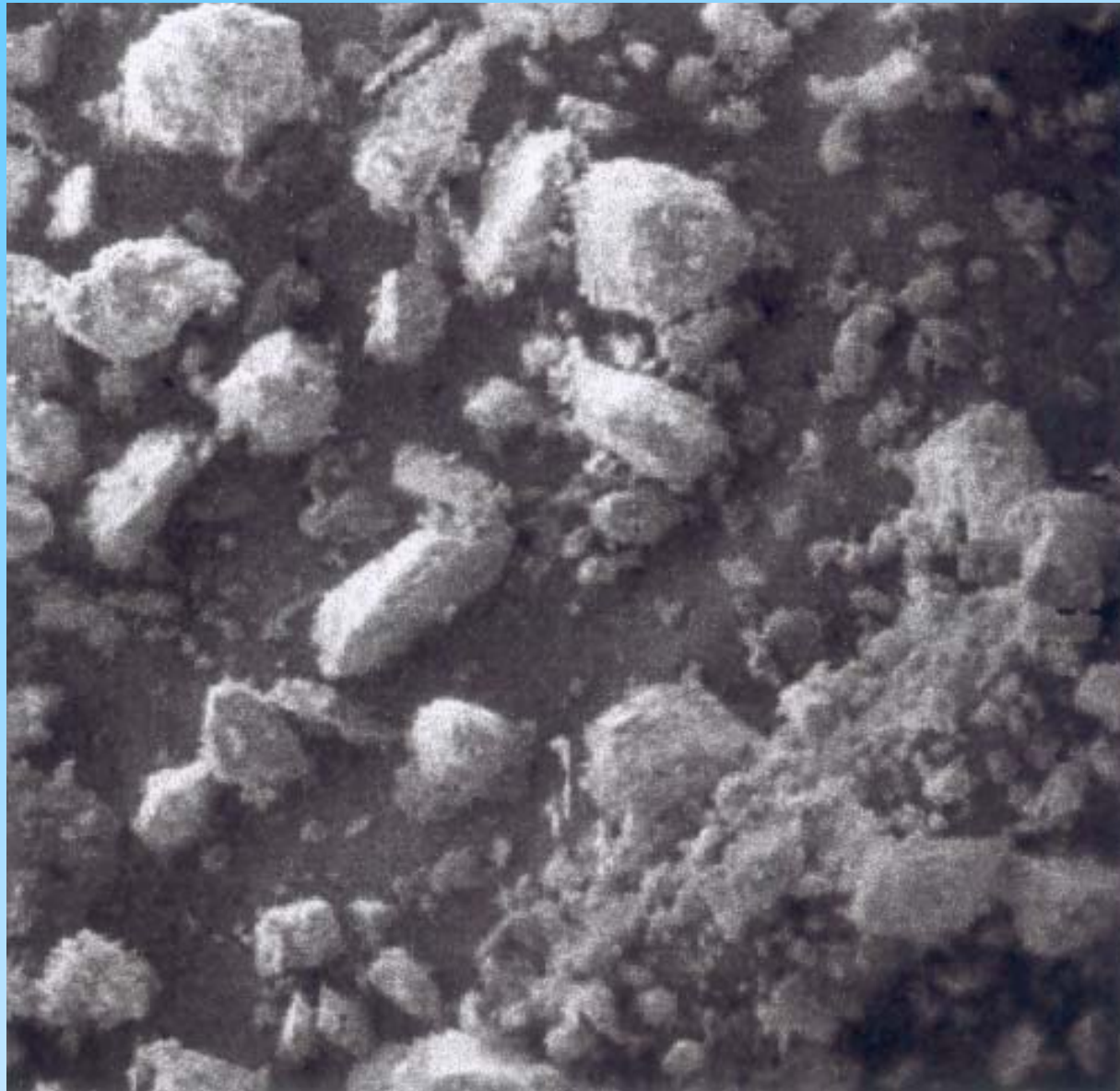
MAXIMUM DENSITY



SANDY PARTICLES

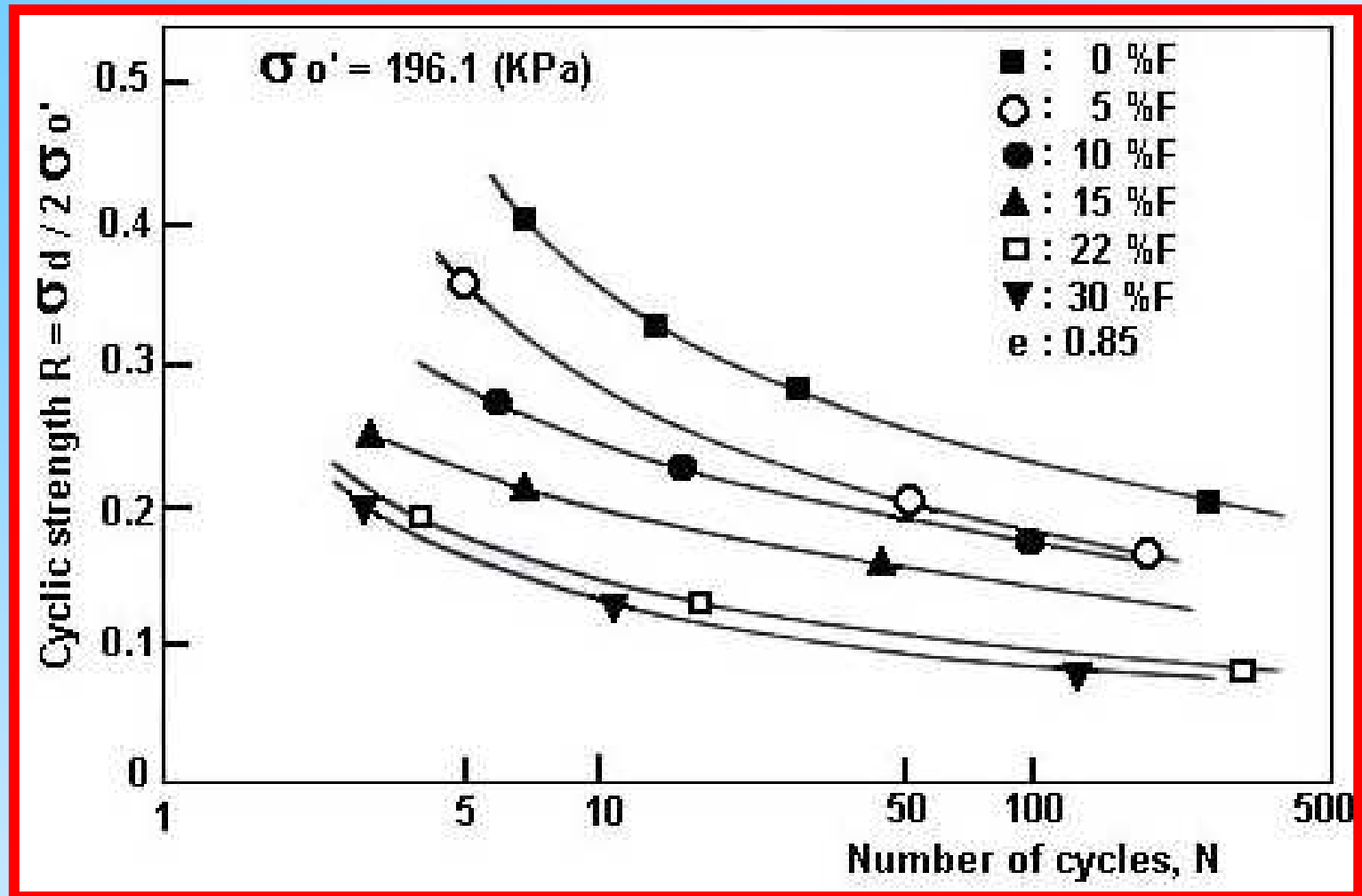


0.074mm



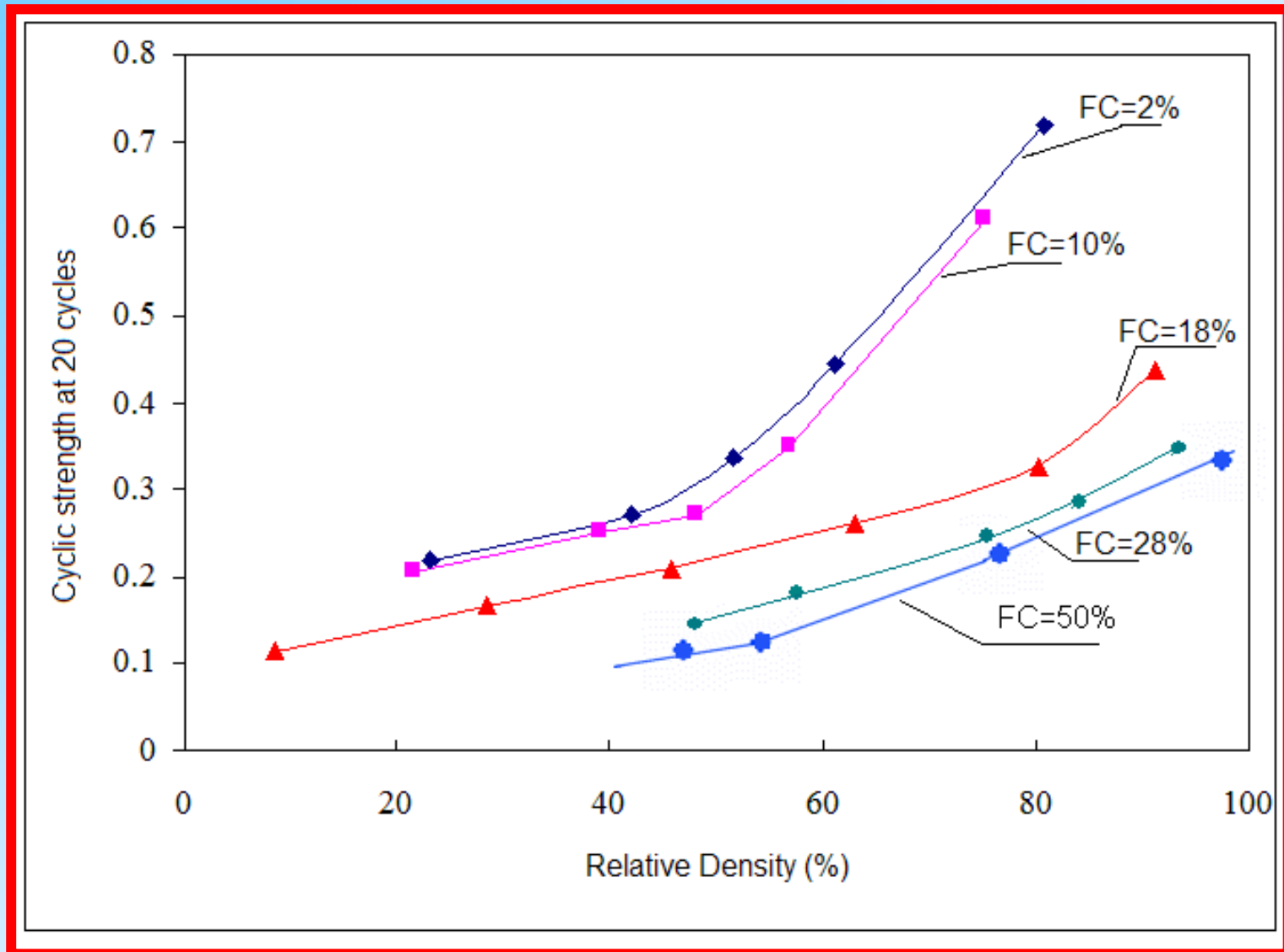
0.054 mm

EFFECT OF LOW PLASTIC FINES ON THE CYCLIC STRENGTH OF TAILINGS SAND

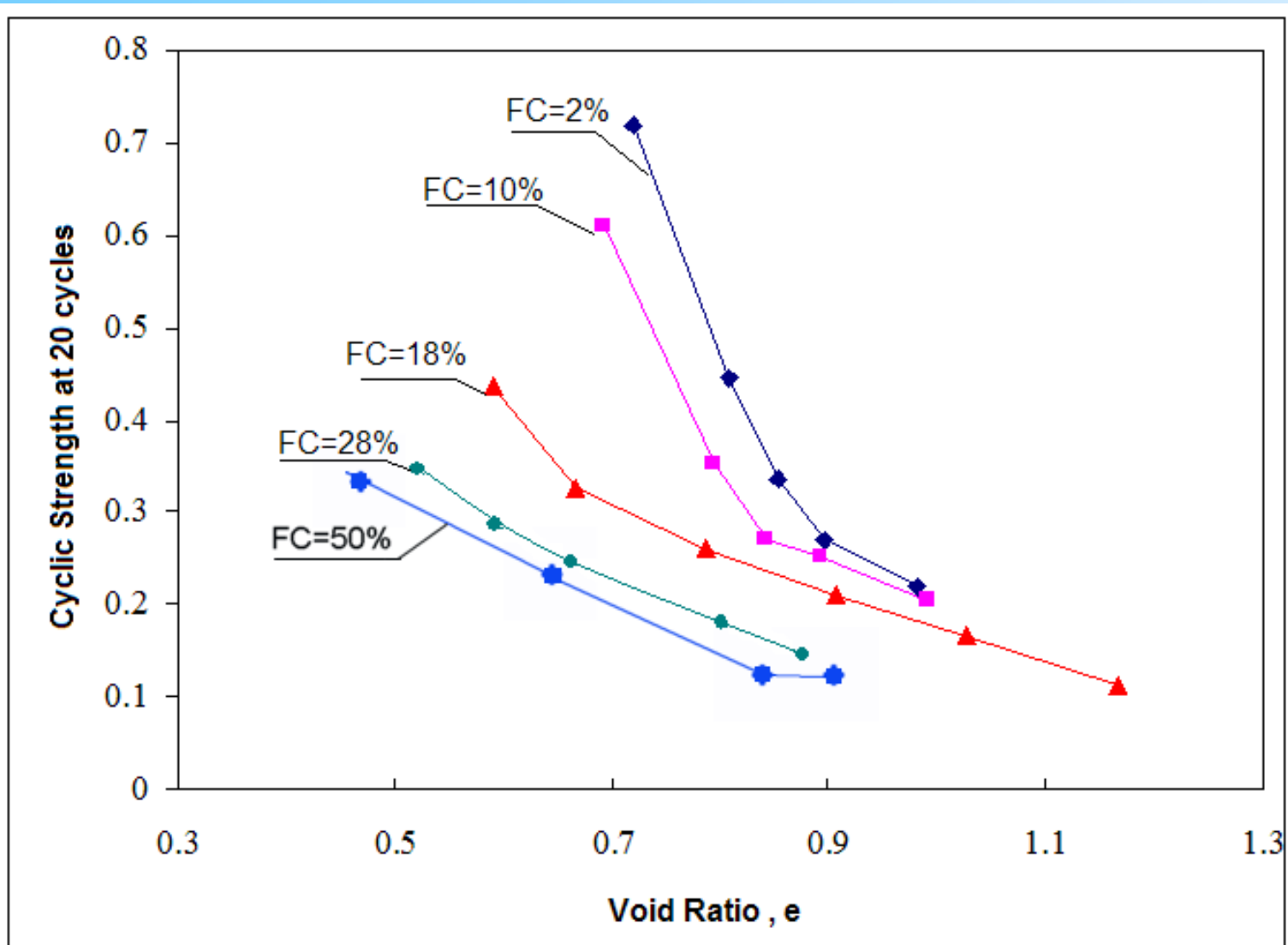


(Verdugo, 1982)

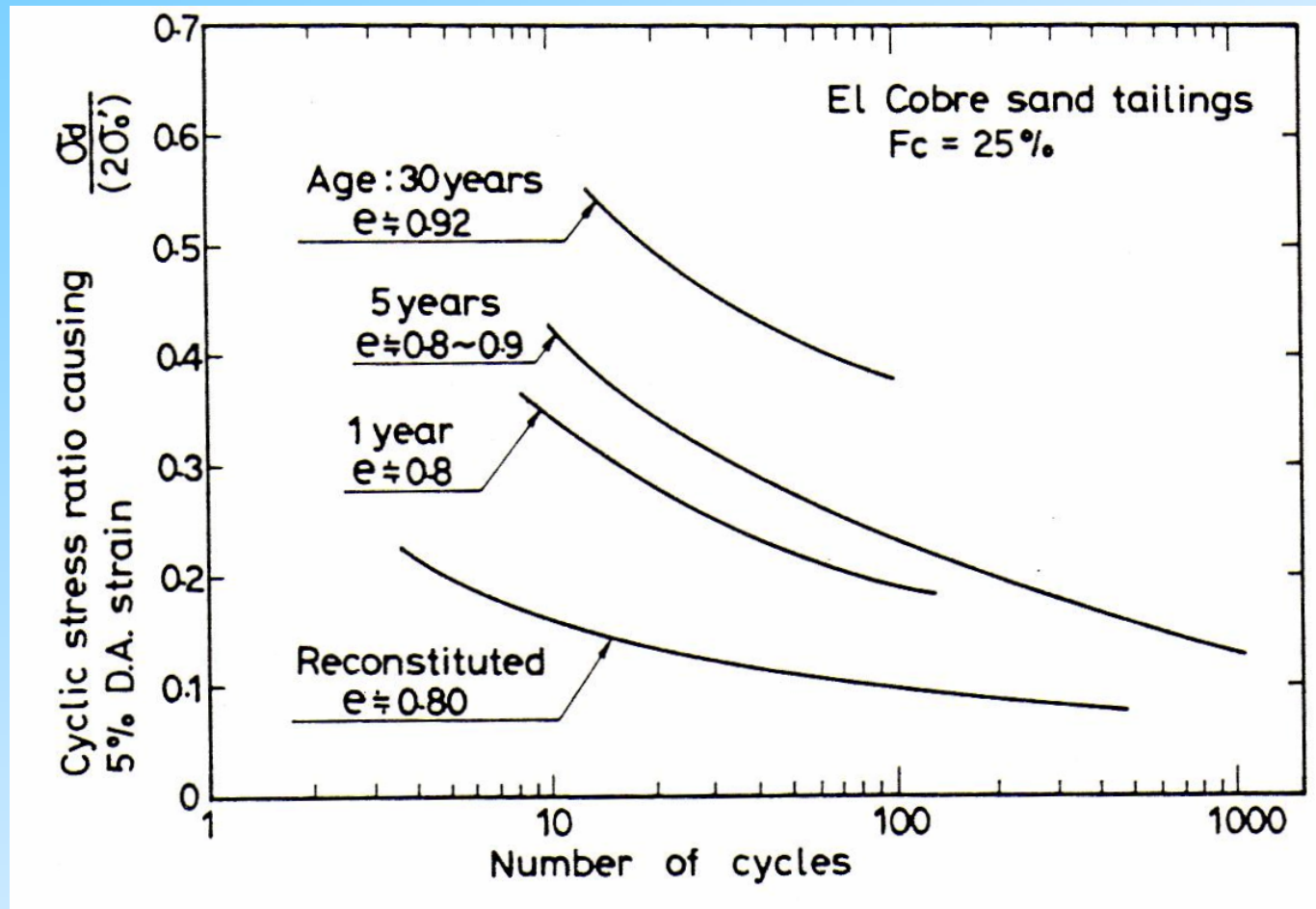
CYCLIC STRENGTH AS FUNCTION OF DENSITY AND FINES CONTENT



EFFECT OF NON-PLASTIC FINES IN THE CYCLIC STRENGTH OF TAILINGS SAND

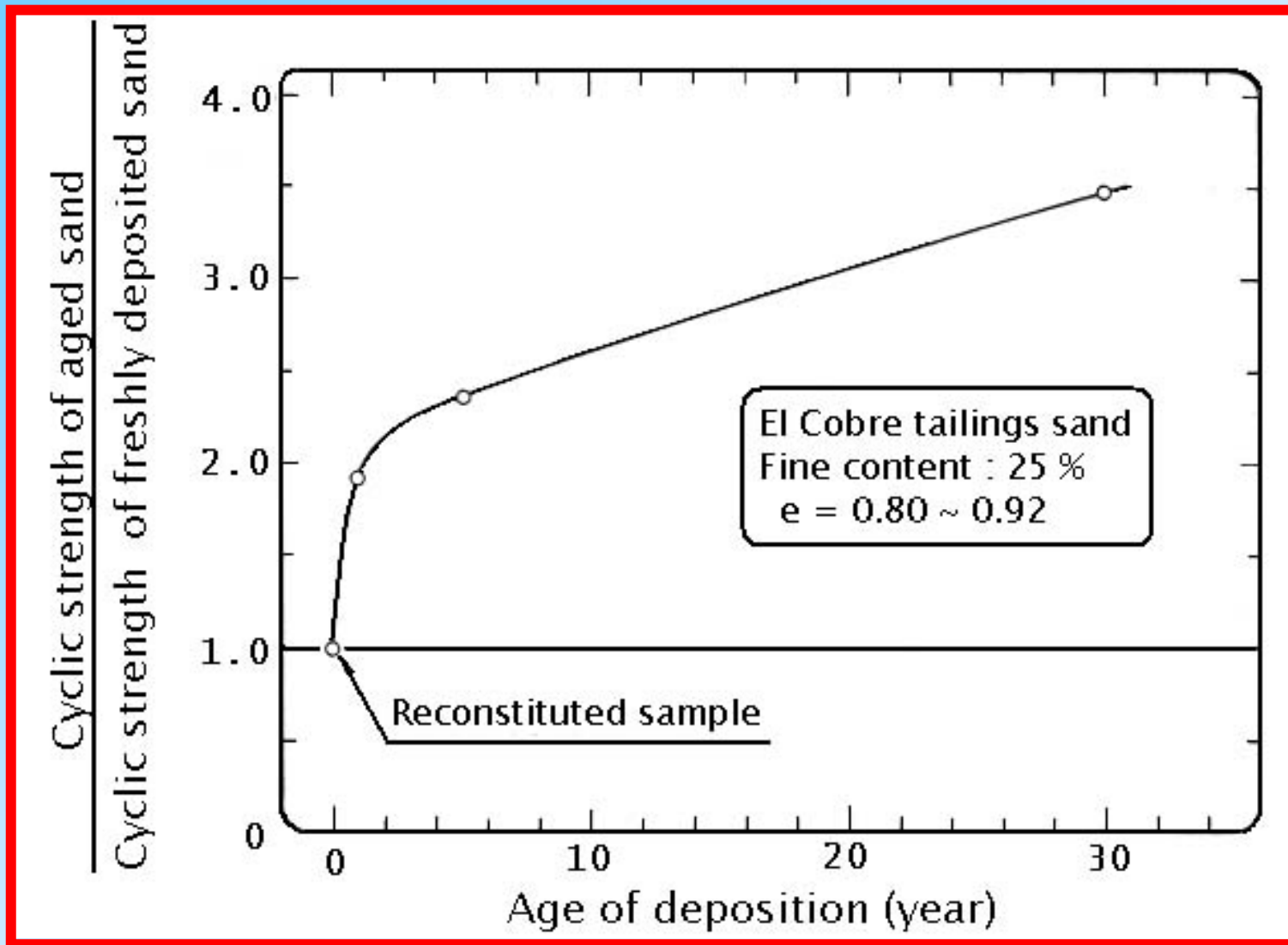


AUMENTO DE LA RESISTENCIA CICLICA EN EL TIEMPO



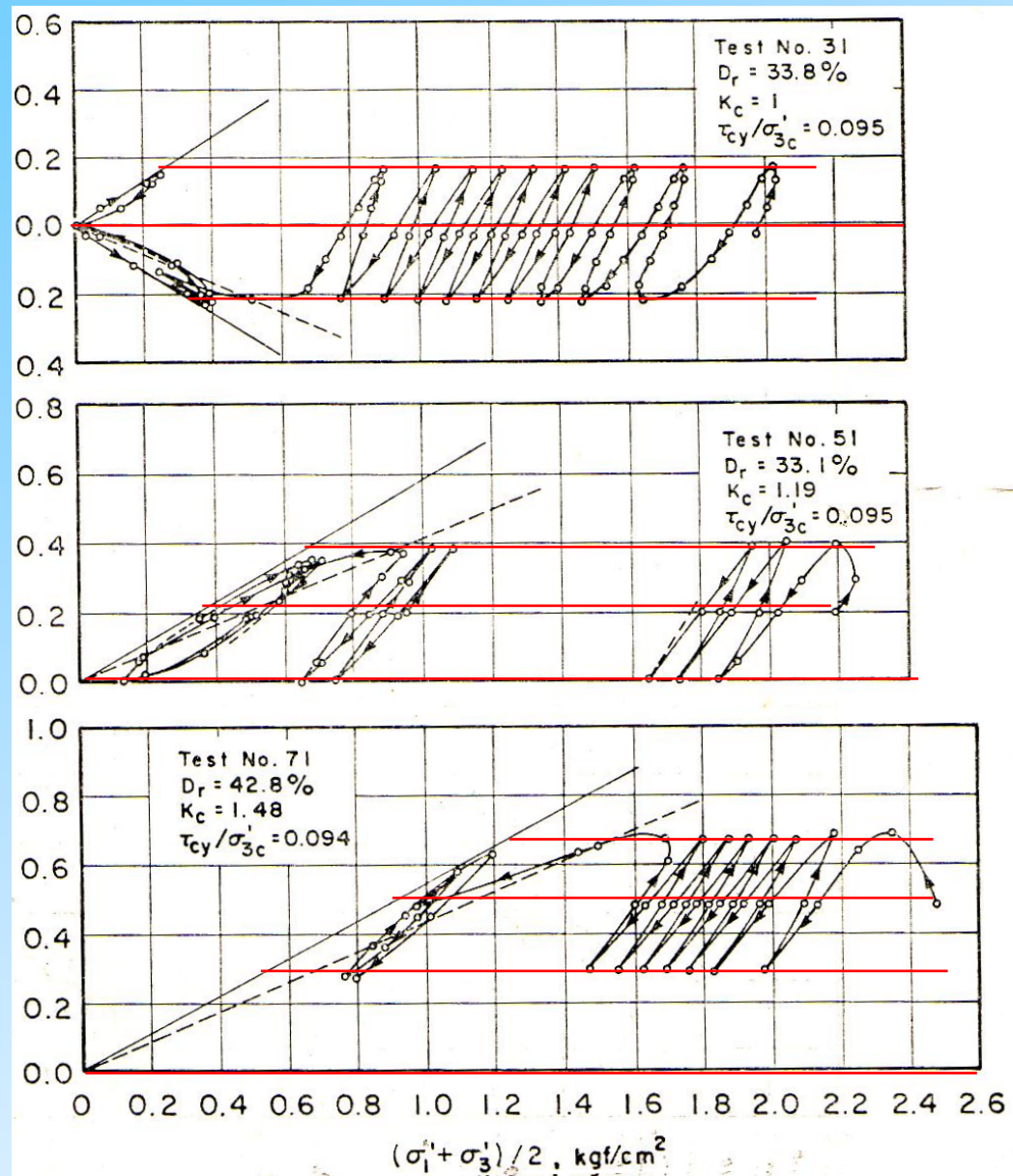
(Troncoso, Ishihara & Verdugo, 1988)

AGING EFFECT MEASURED ON TAILINGS SAND

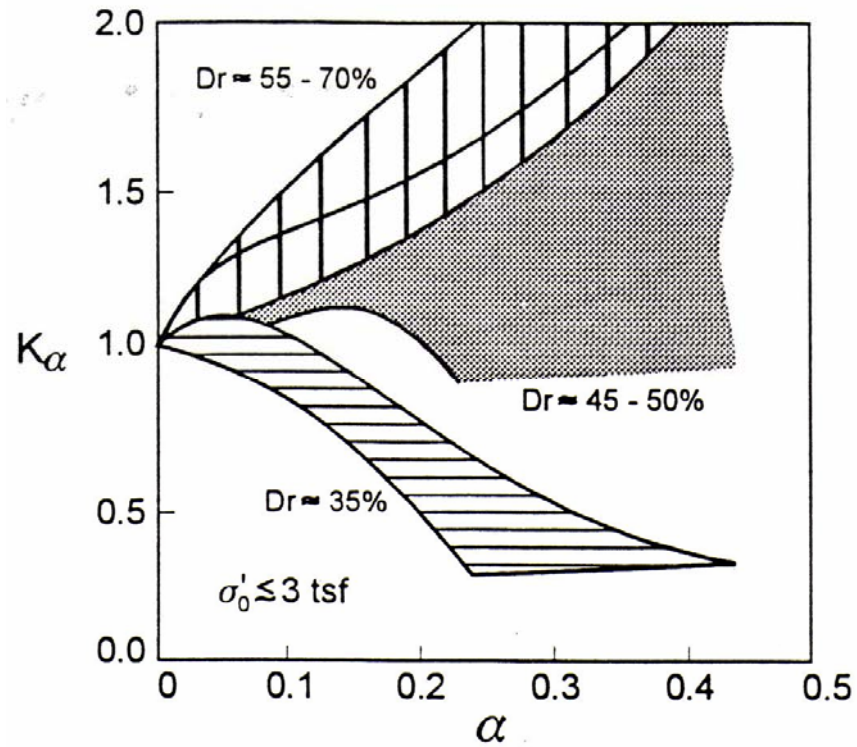


(Troncoso, Ishihara & Verdugo, 1986)

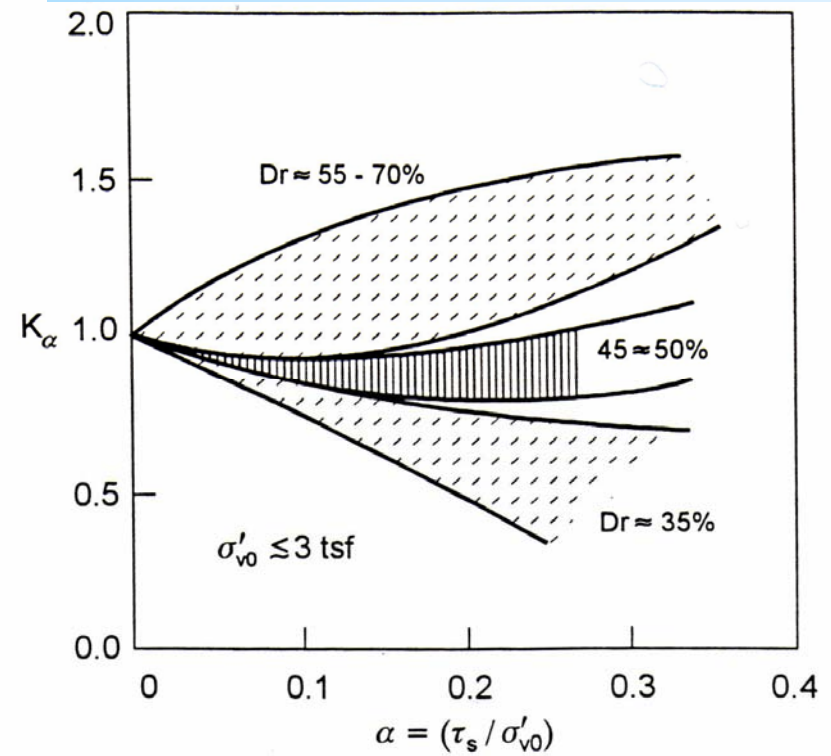
τ_{cy}



FACTOR DE CORRECCION POR CORTE ESTATICO INICIAL

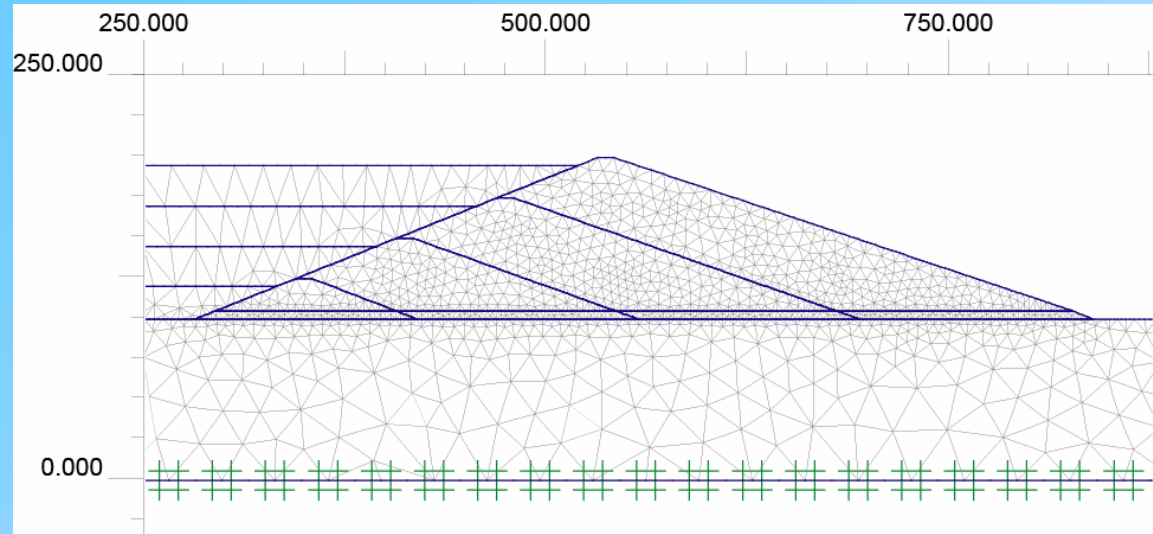


(Seed & Harder, 1990)

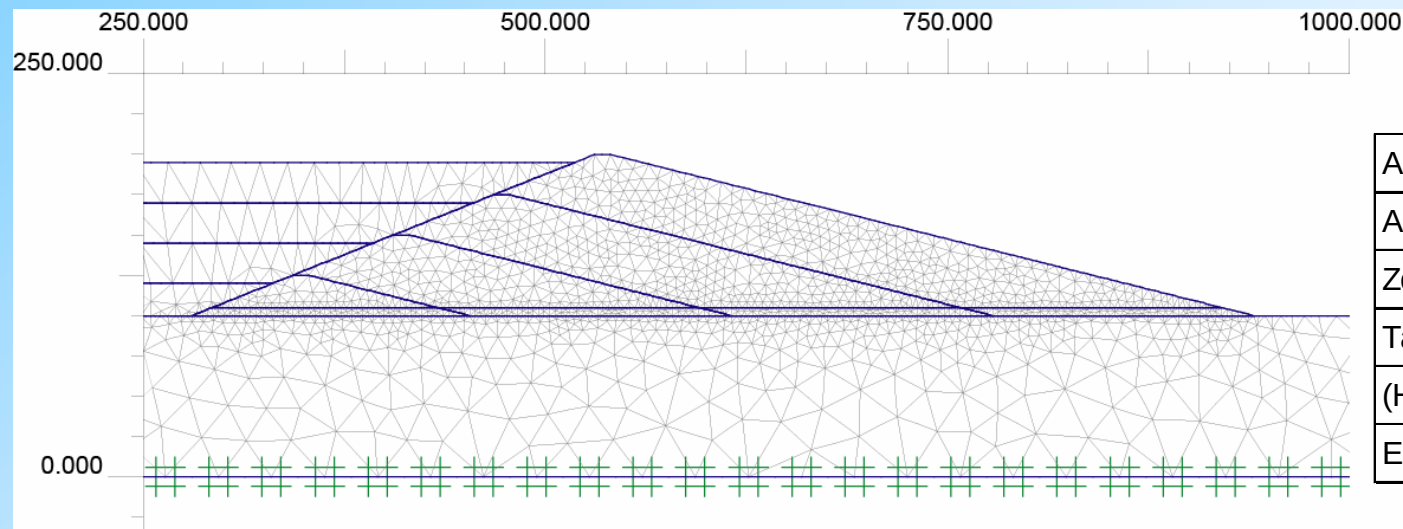


(Boulanger et al., 1991)

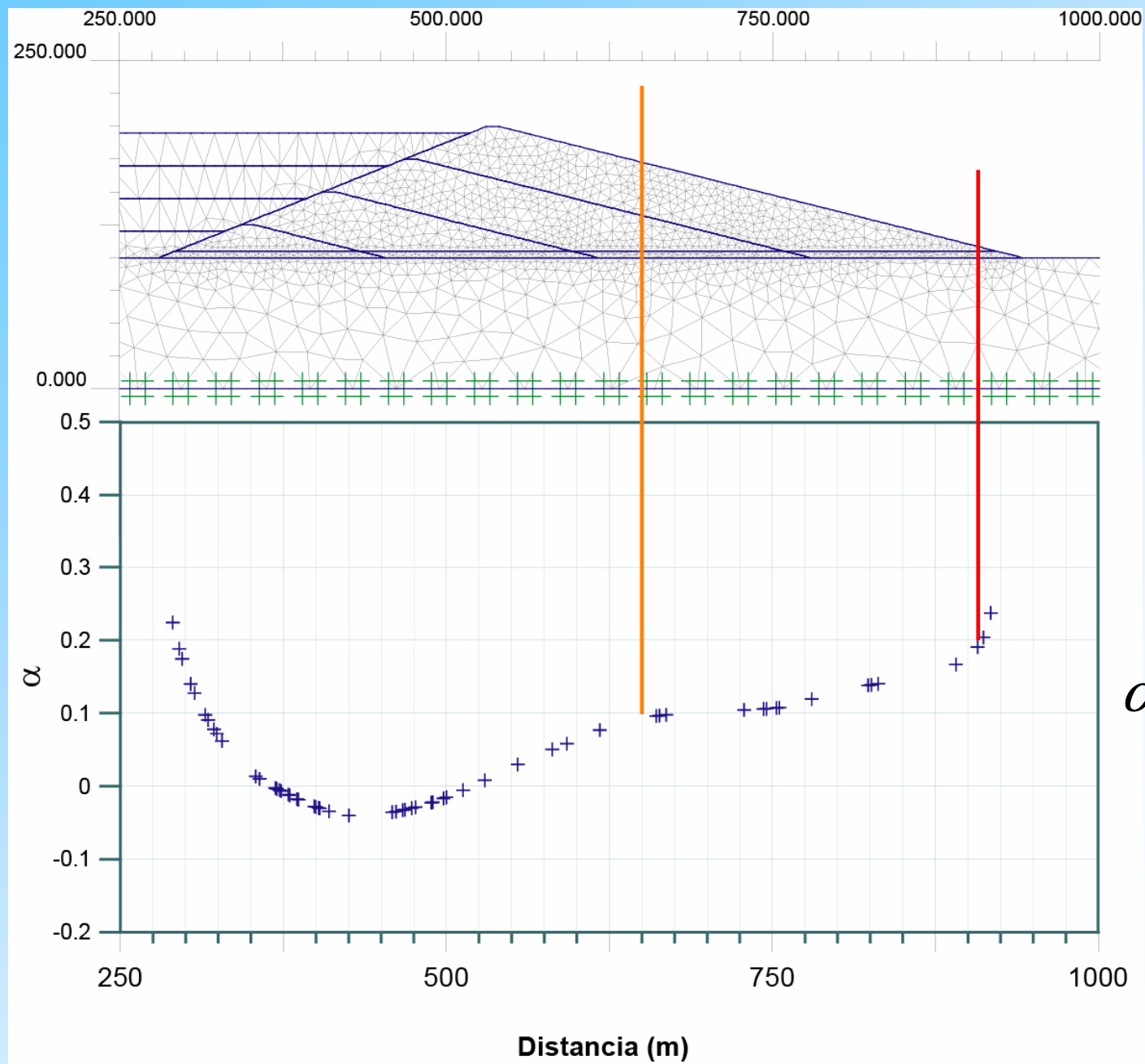
Modelación Numérica



Altura	(m)	100
Ancho Coron.	(m)	10
Zona saturada	(m)	5
Talud	A. Arriba	2.5 : 1.0
(H:V)	A. Abajo	3.0 : 1.0
Etapas		4

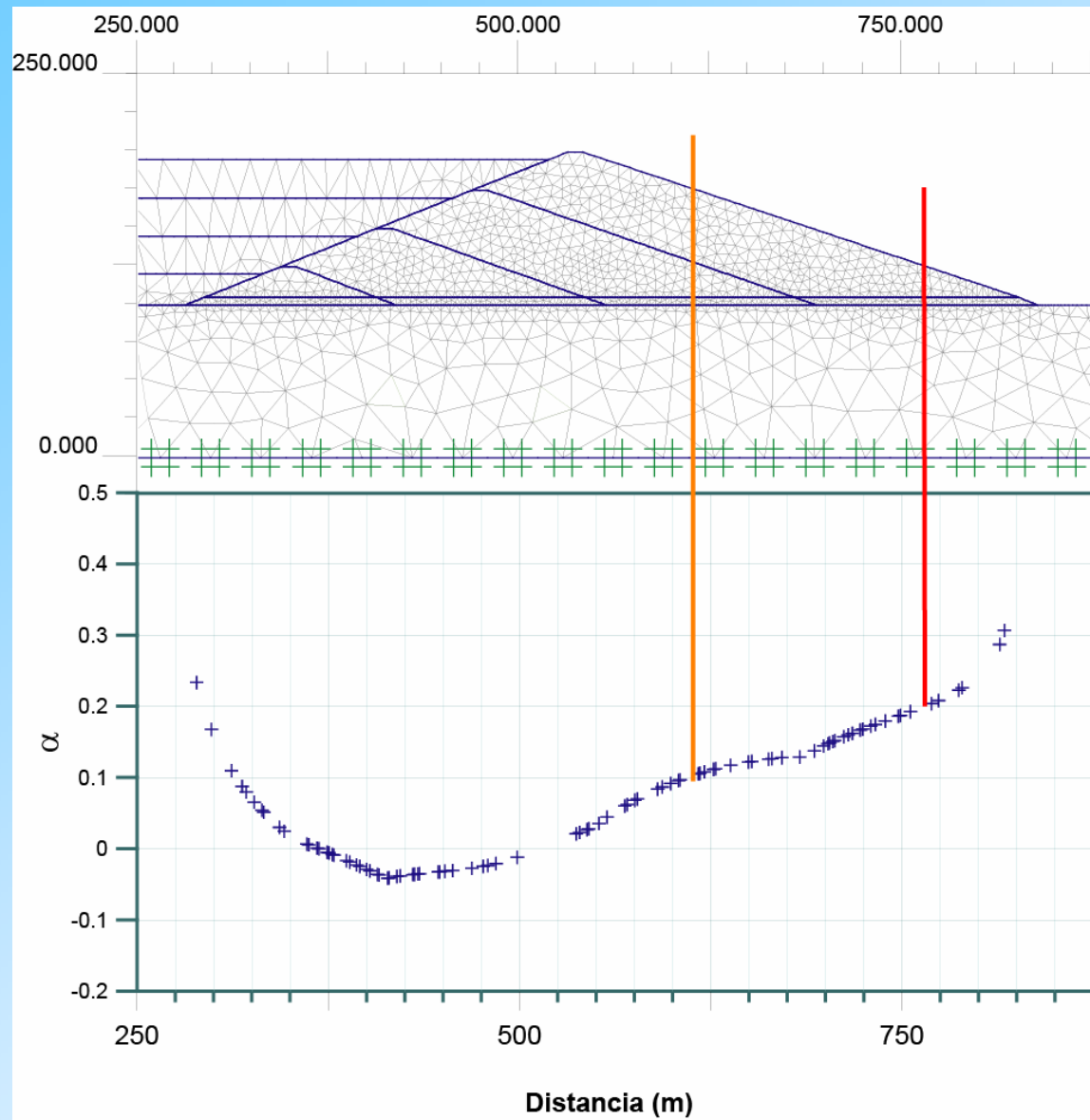


Altura	(m)	100
Ancho Coron.	(m)	10
Zona saturada	(m)	5
Talud	A. Arriba	2.5 : 1.0
(H:V)	A. Abajo	4.0 : 1.0
Etapas		4



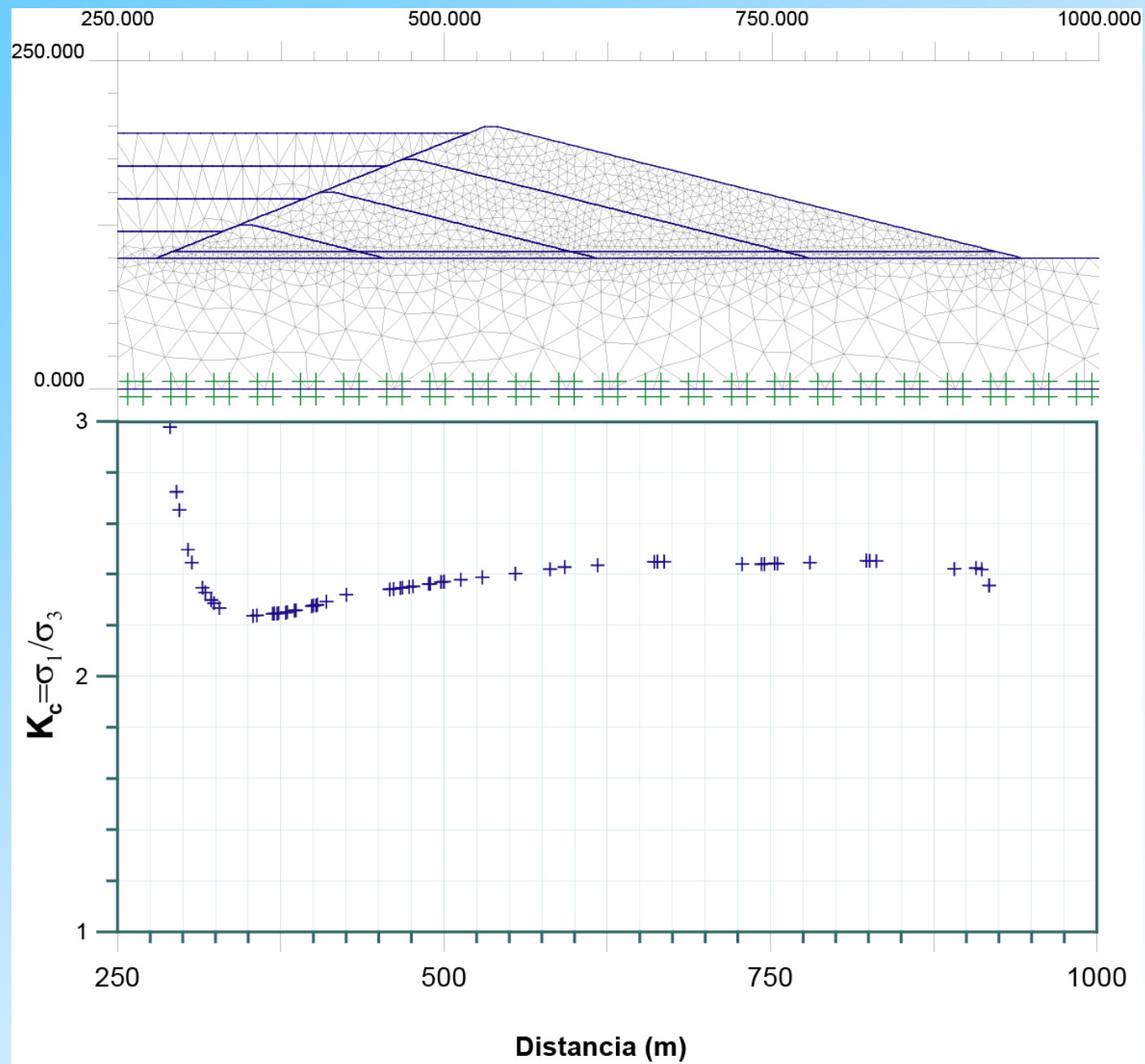
$$\alpha = \frac{\tau_{estático}}{\sigma_v}$$

Talud 3:1

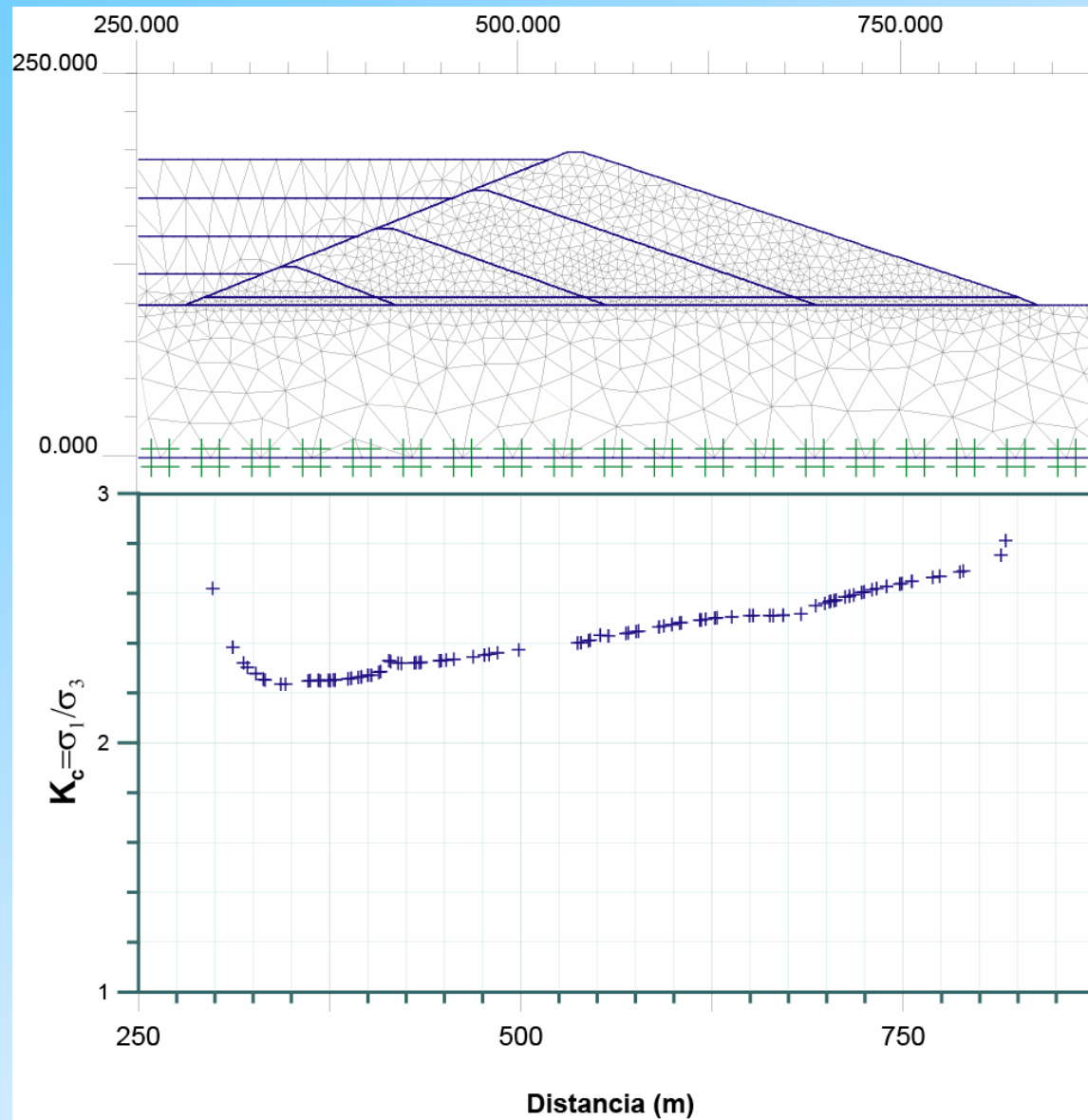


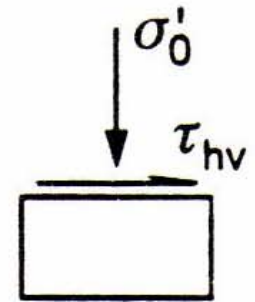
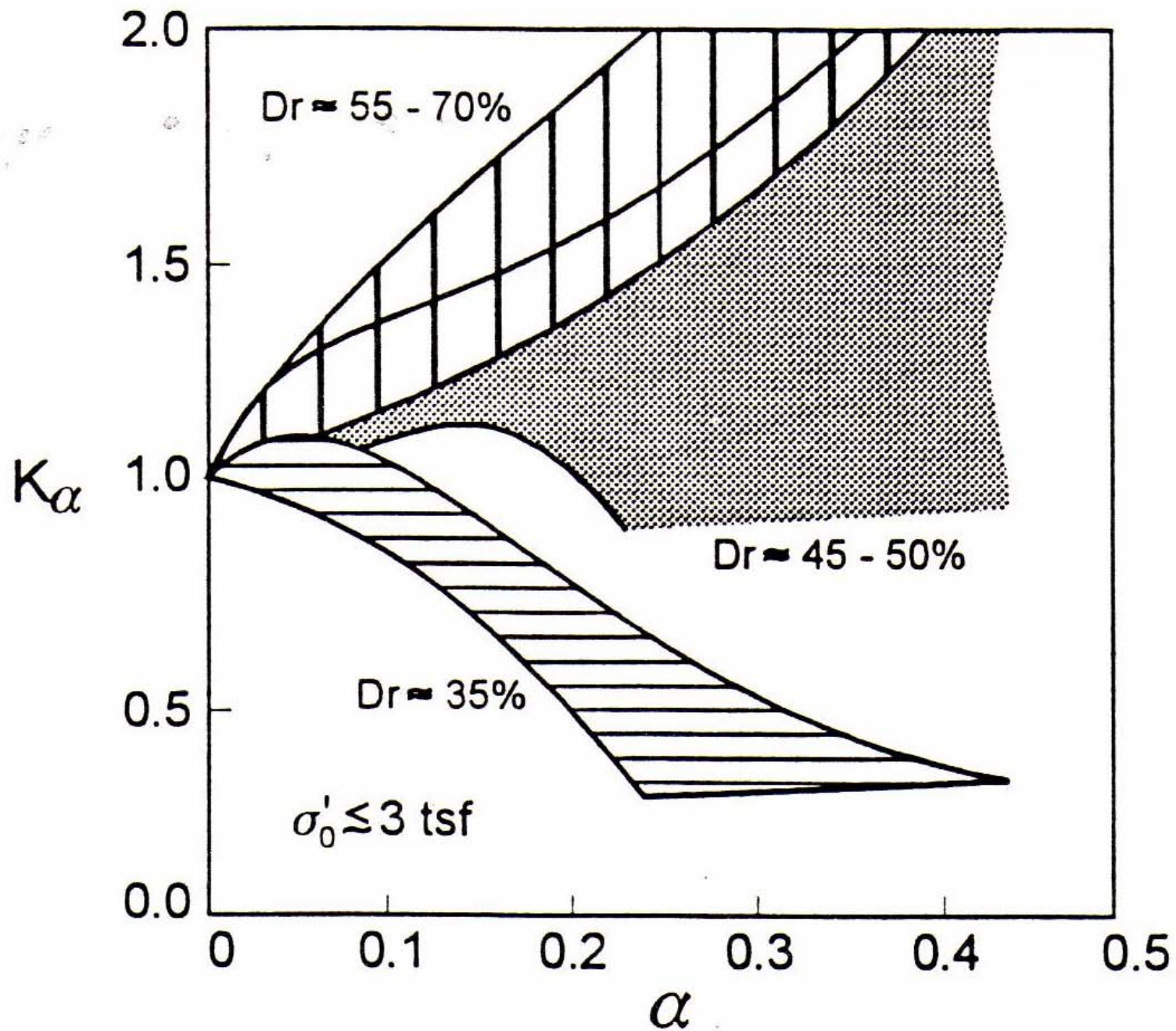
$$\alpha = \frac{\tau_{estático}}{\sigma_v}$$

Talud 4:1

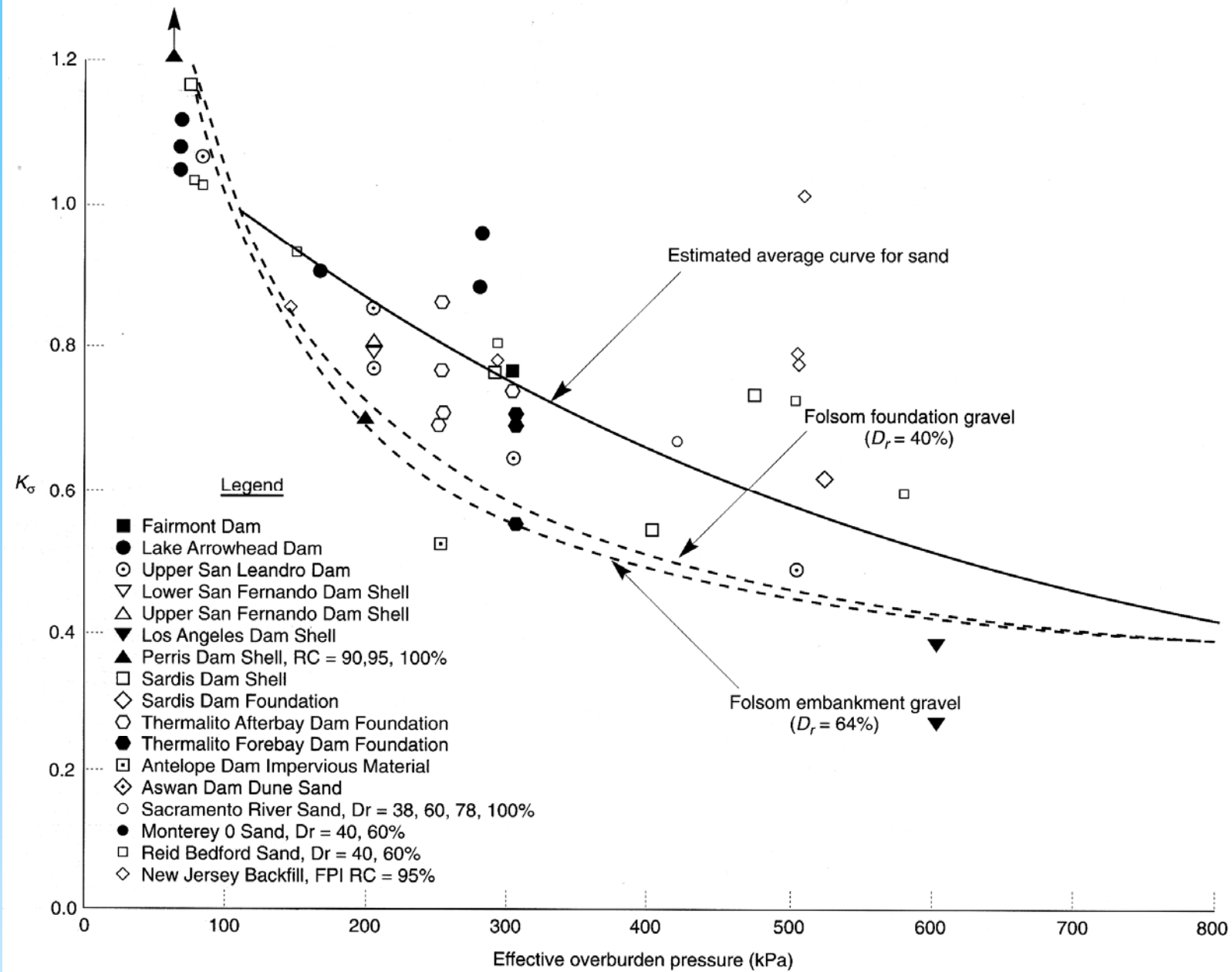


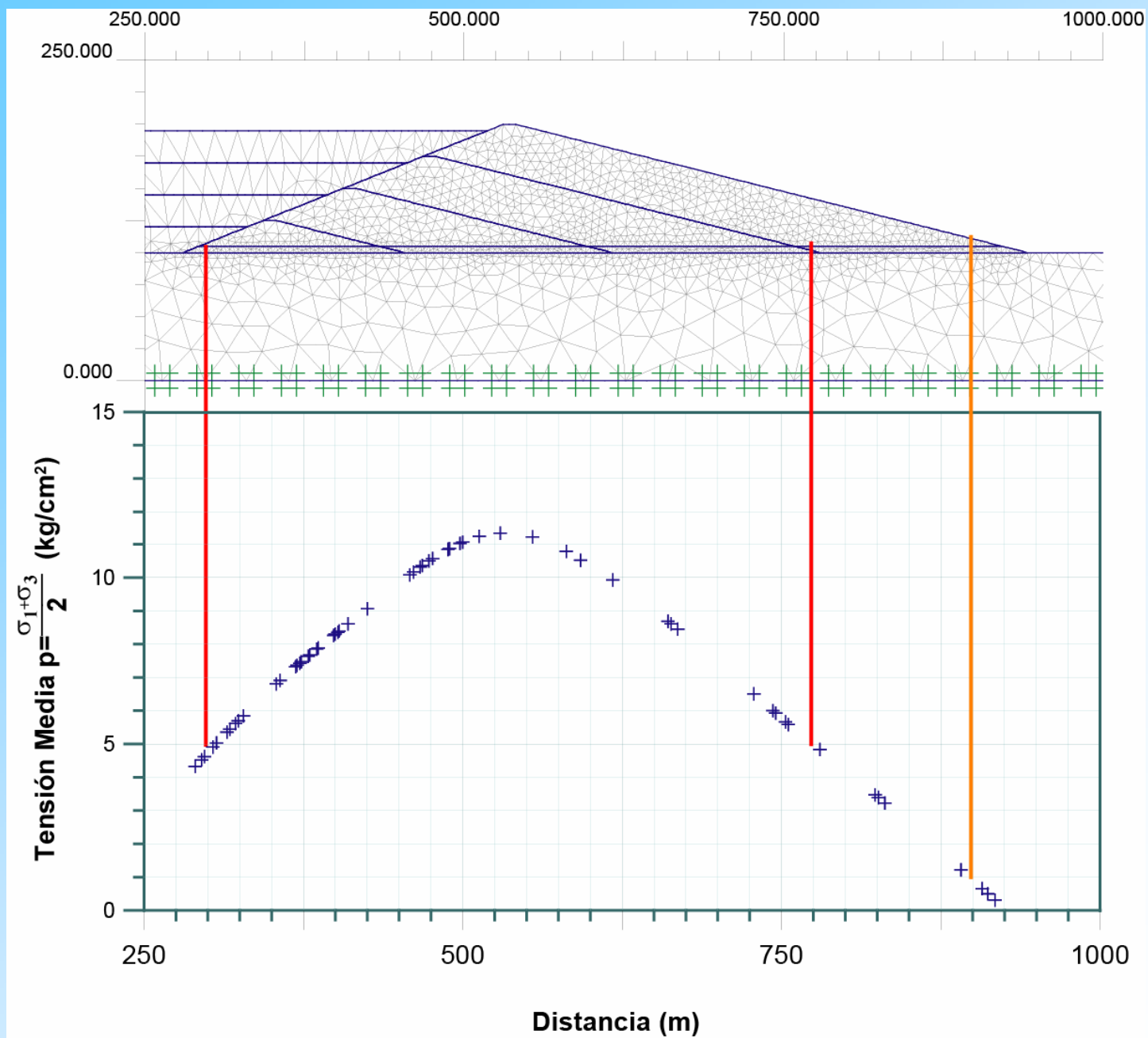
Talud 3:1

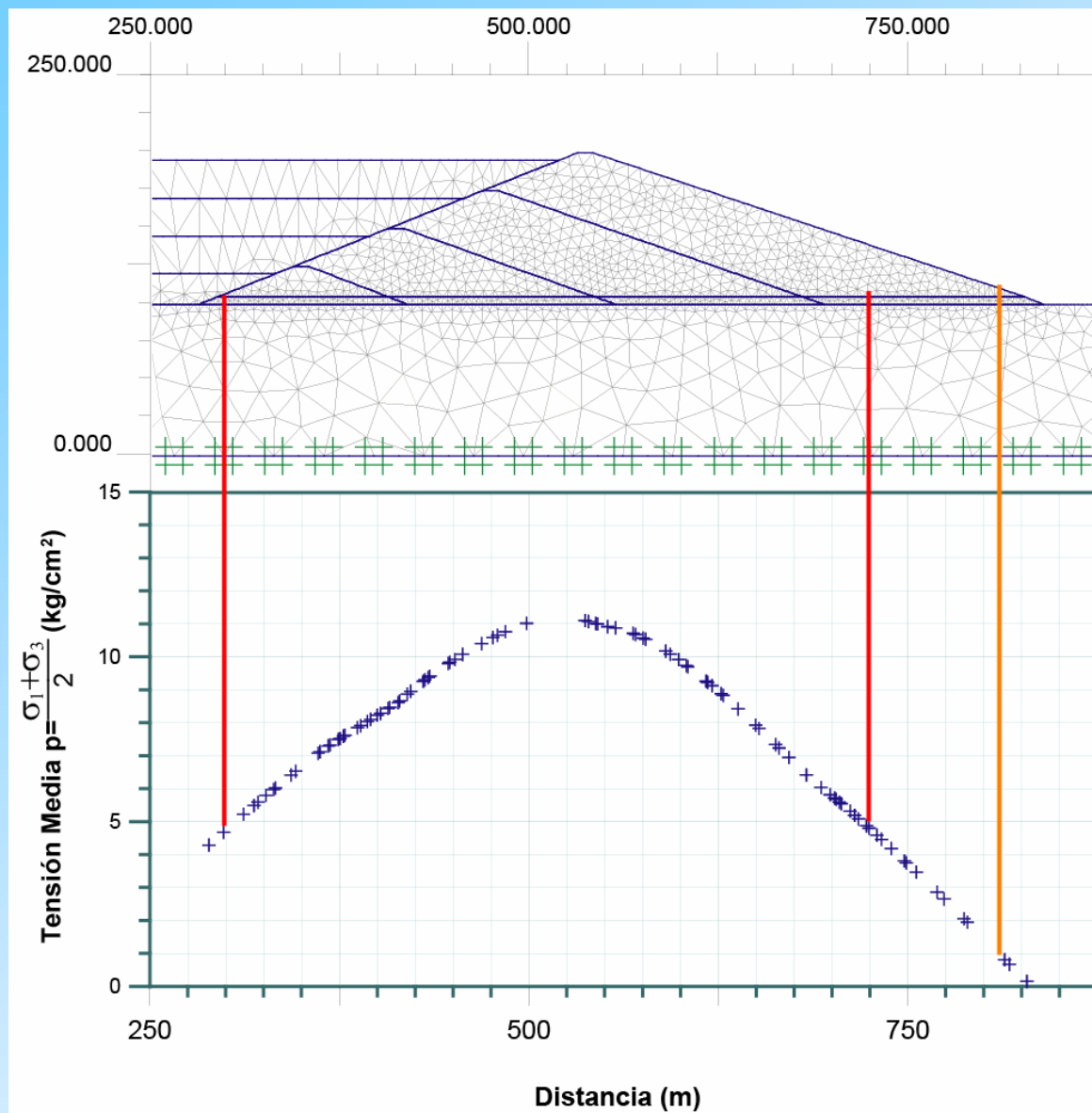




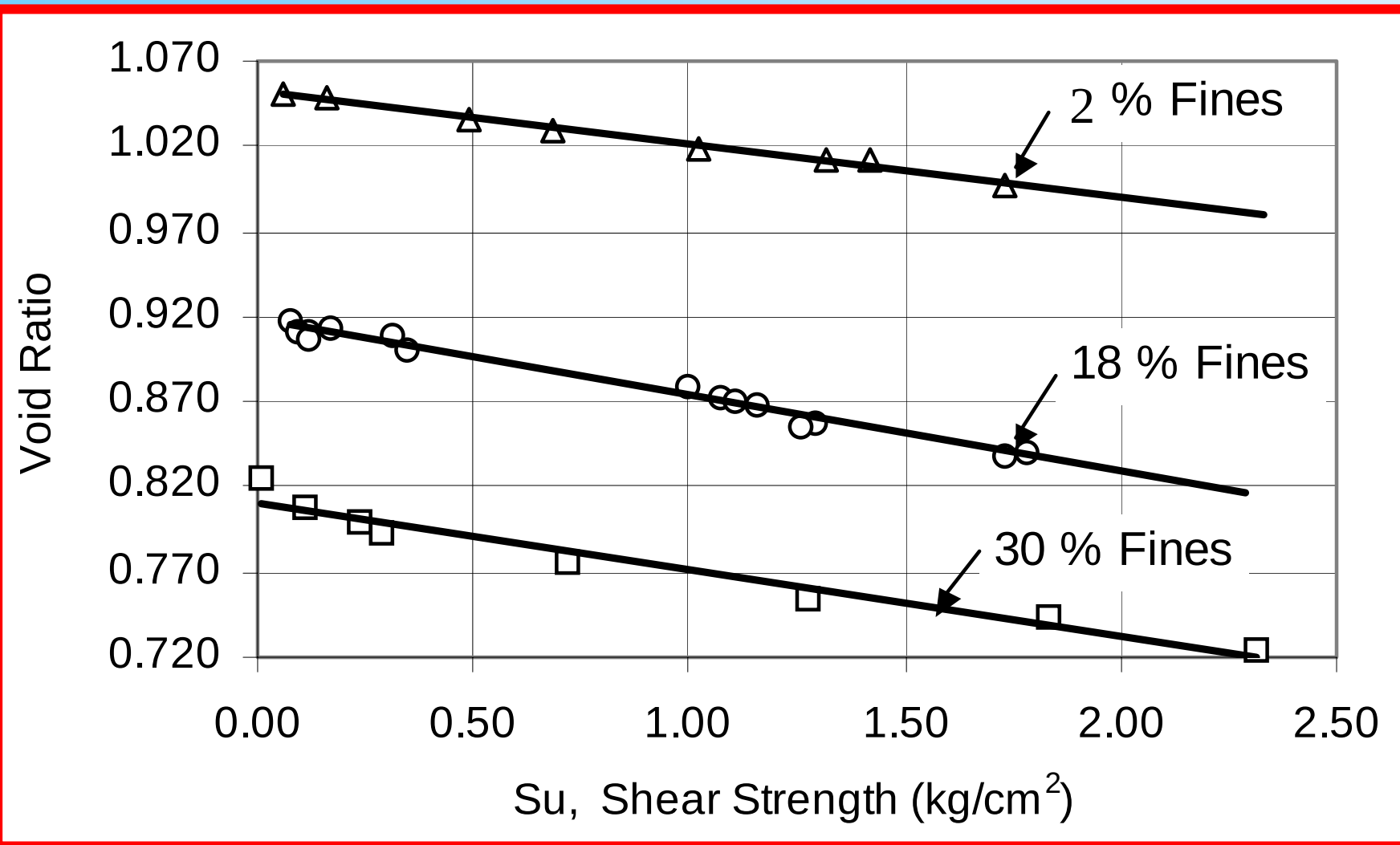
$$\alpha = \left| \frac{\tau_{hv}}{\sigma'_0} \right|$$



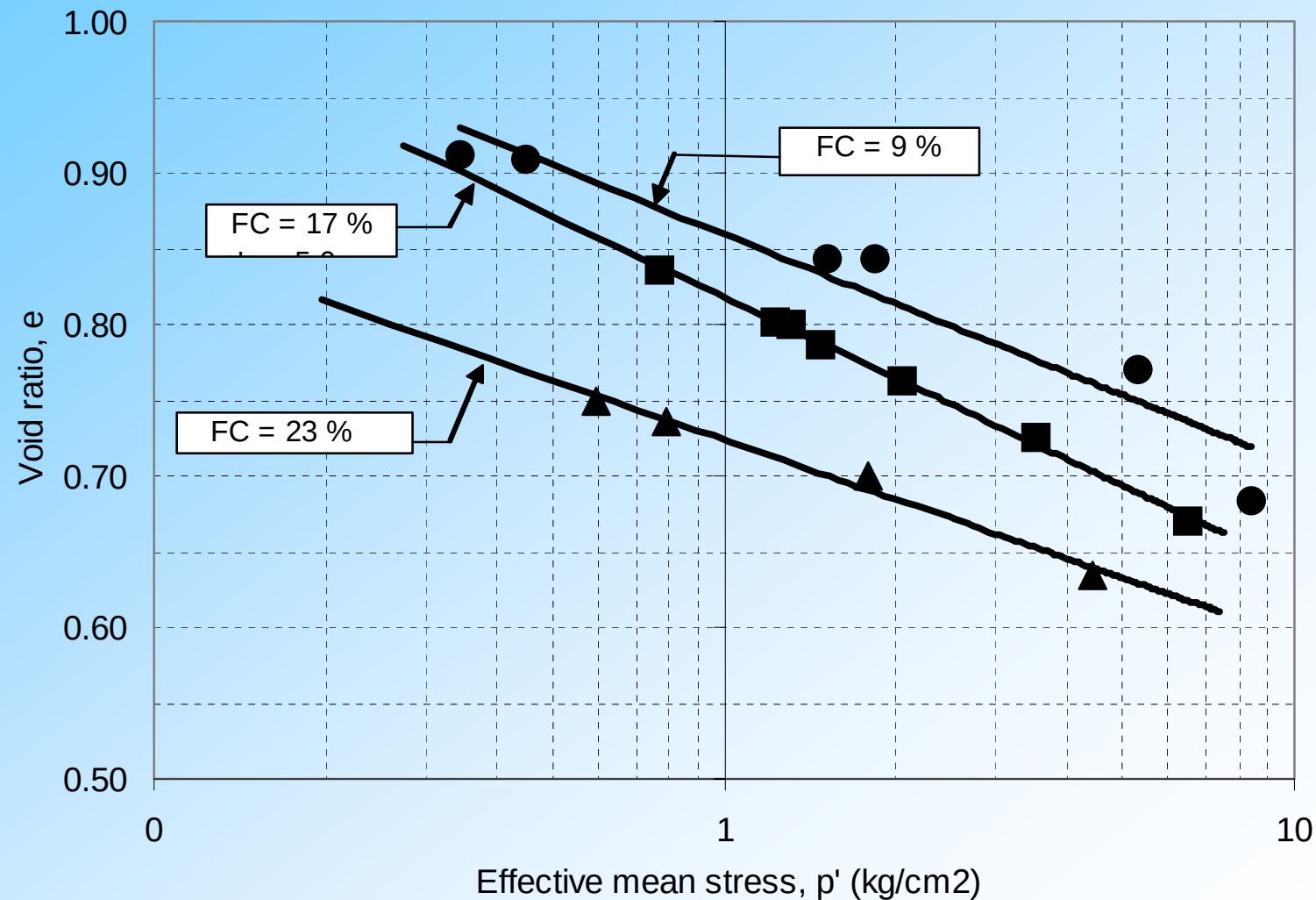




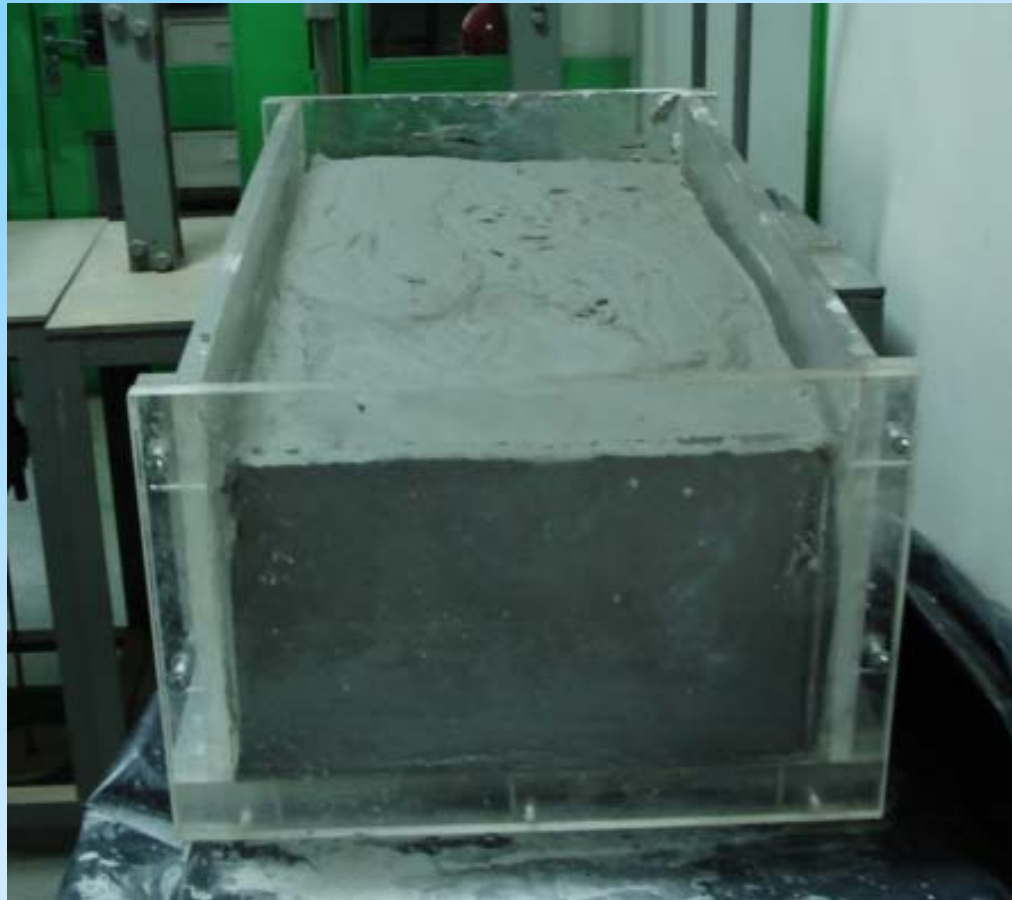
EFFECT OF NON-PLASTIC FINES ON THE STEADY STATE LINES OF EL COBRE TAILINGS SAND



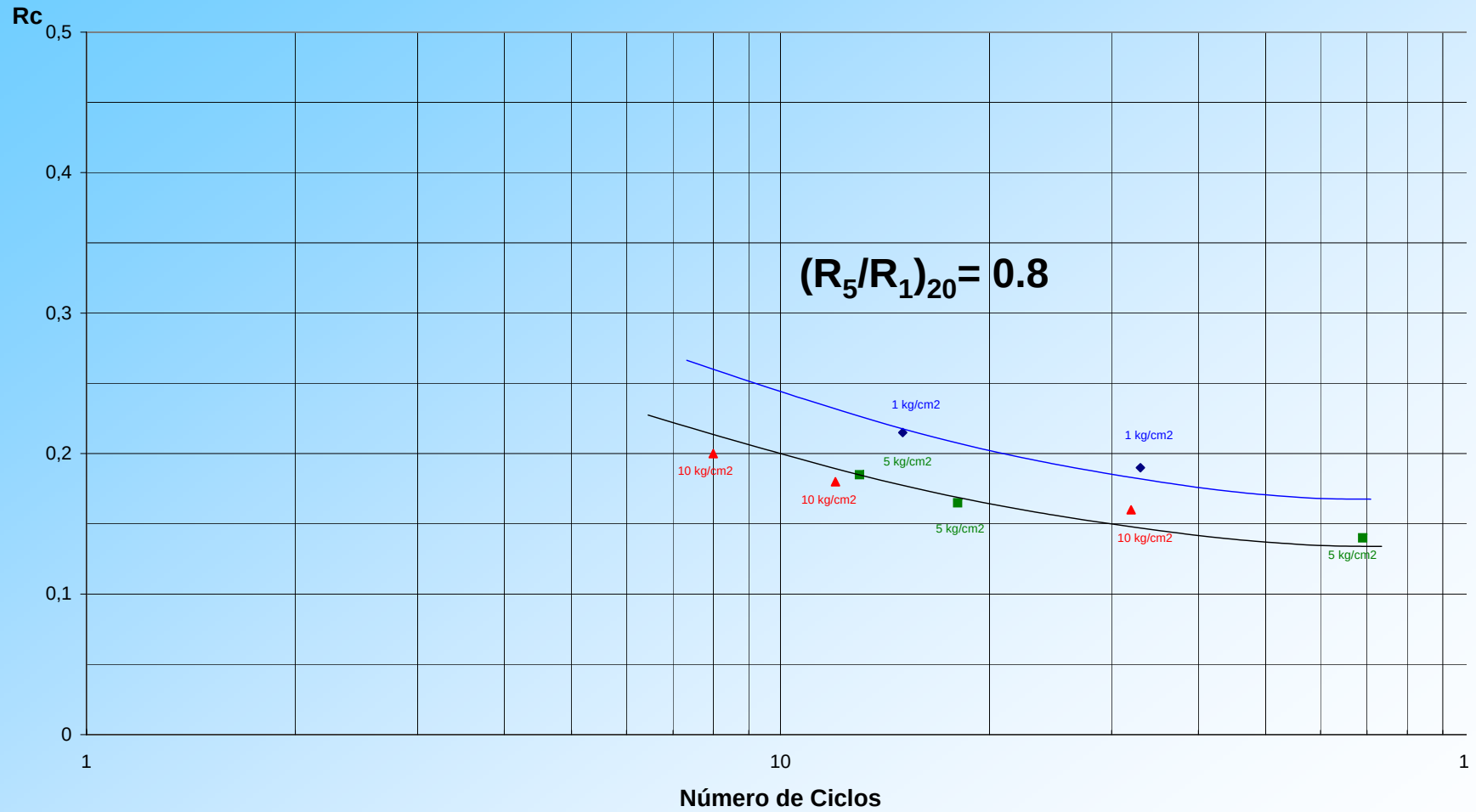
EFFECT OF NON-PLASTIC FINES ON THE STEADY STATE LINES OF OVEJERIA TAILINGS SAND

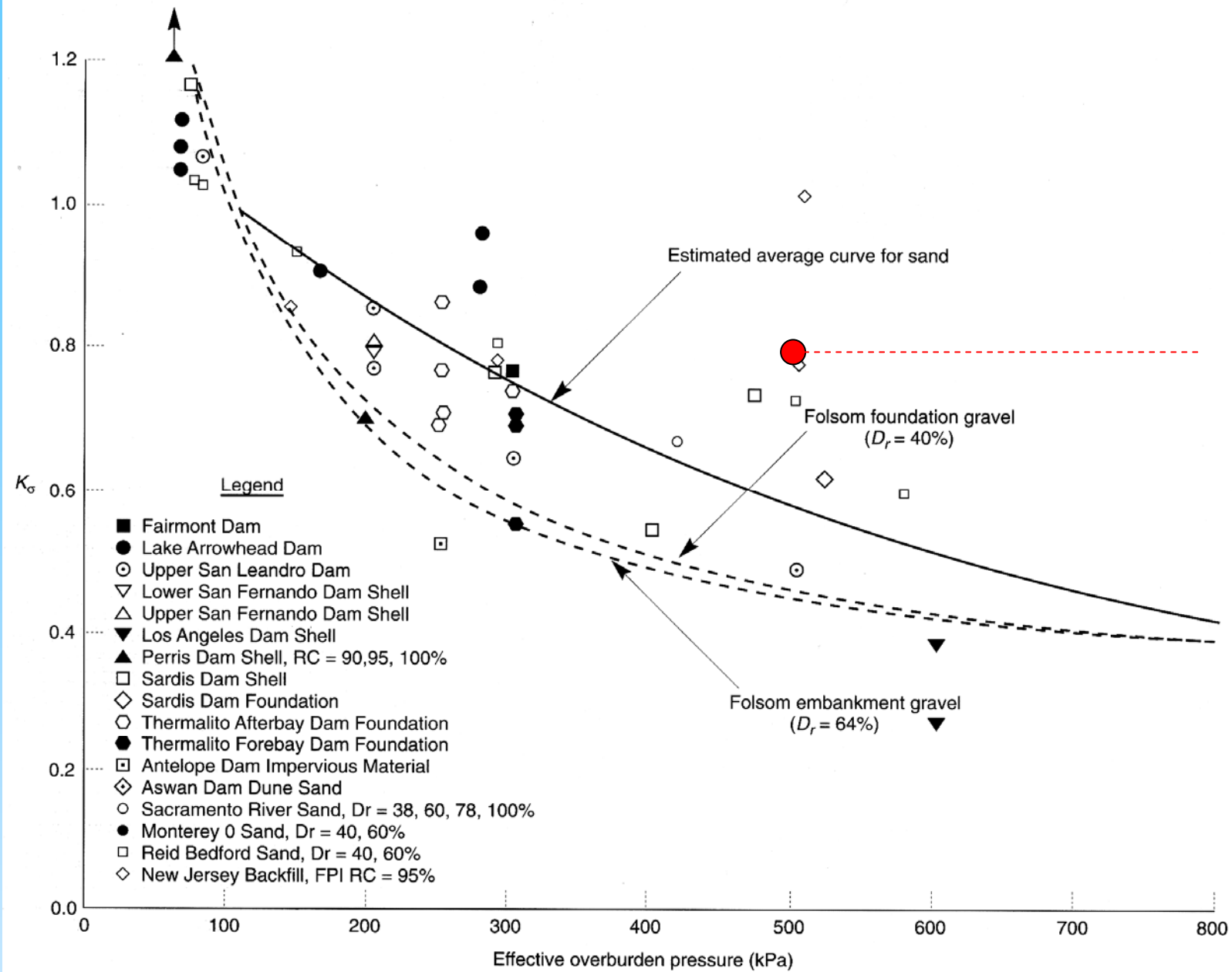


RELAVE INTEGRAL

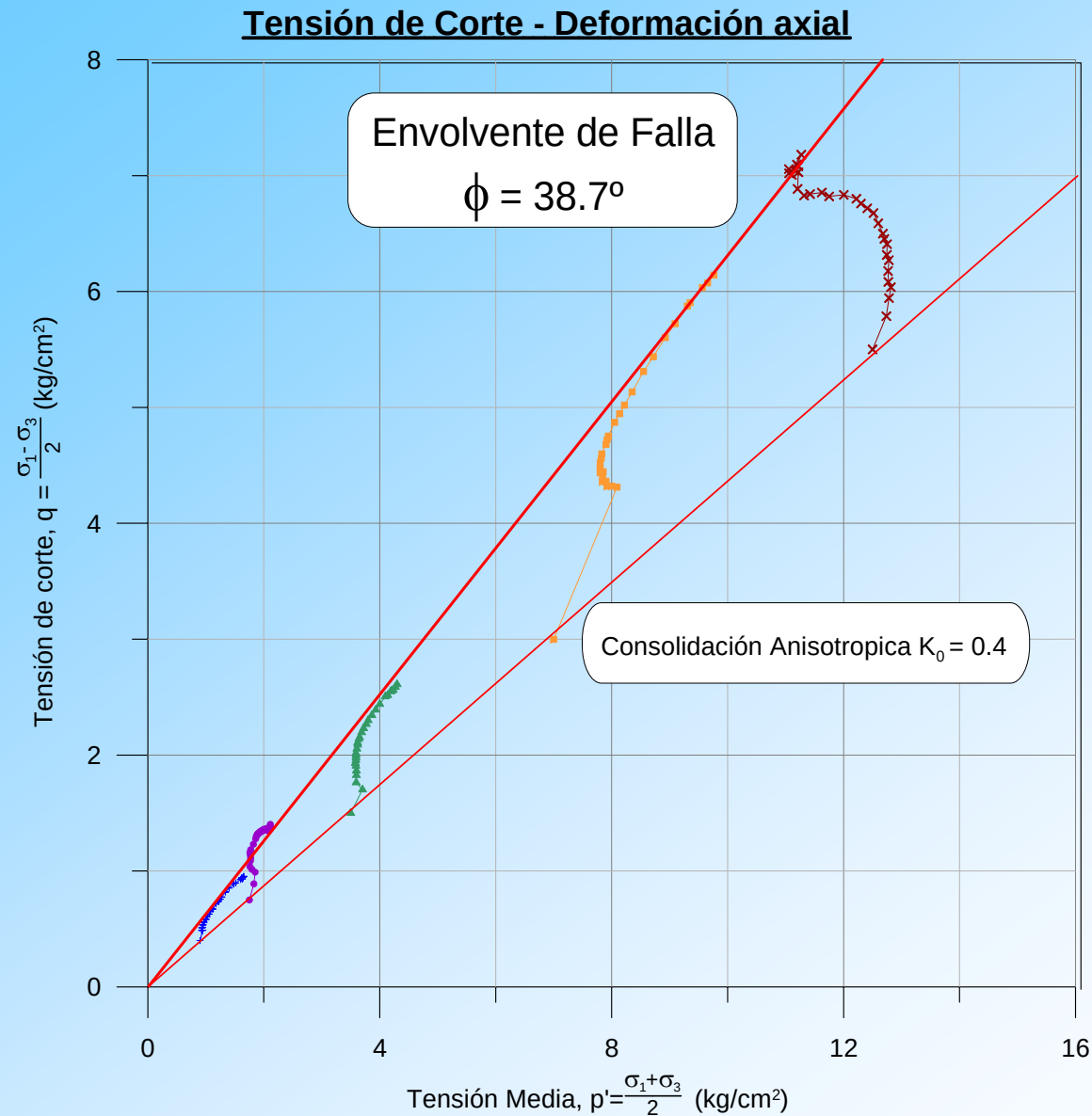


Resistencia Cíclica v/s Número de Ciclos Relave Integral

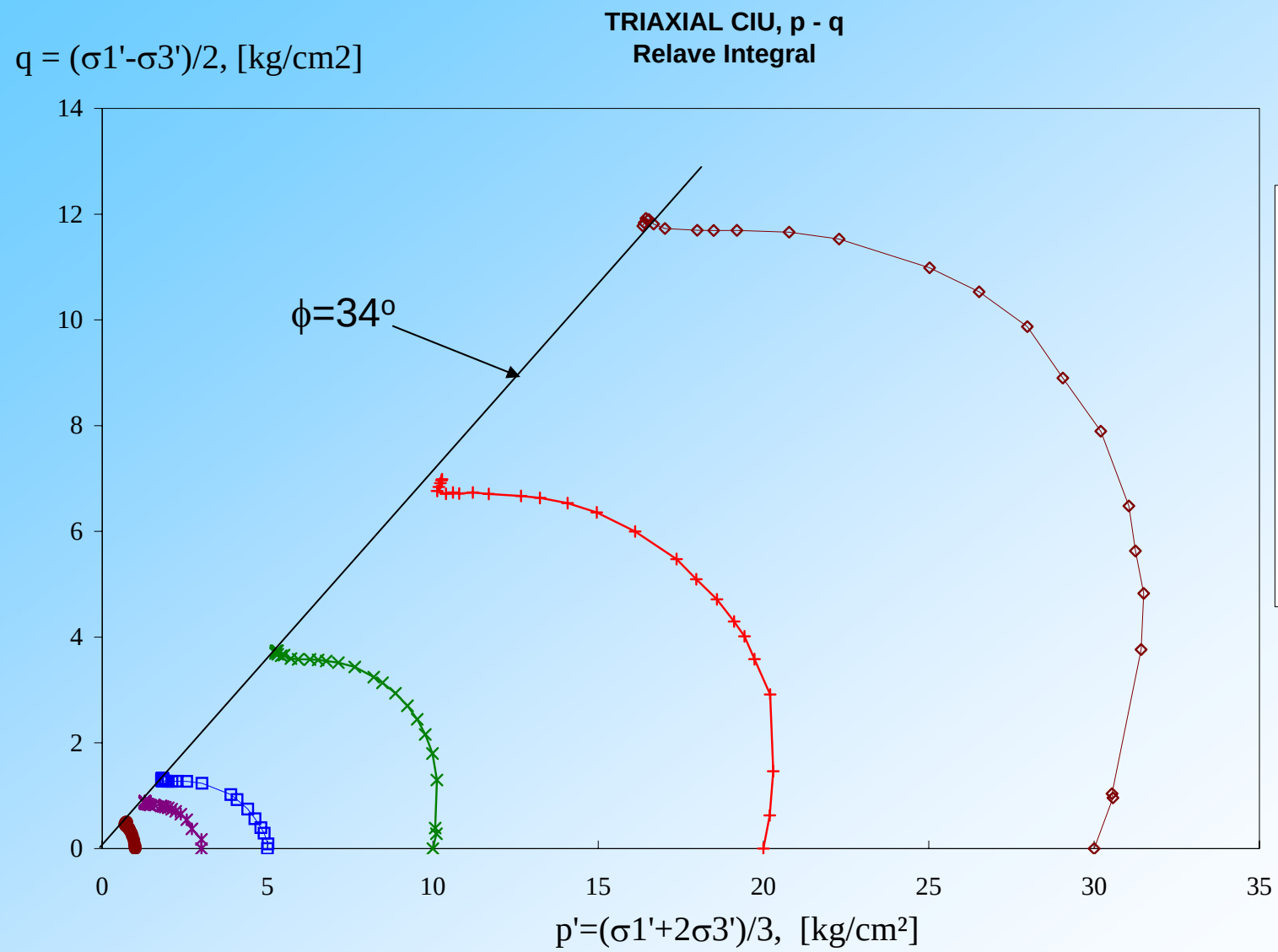




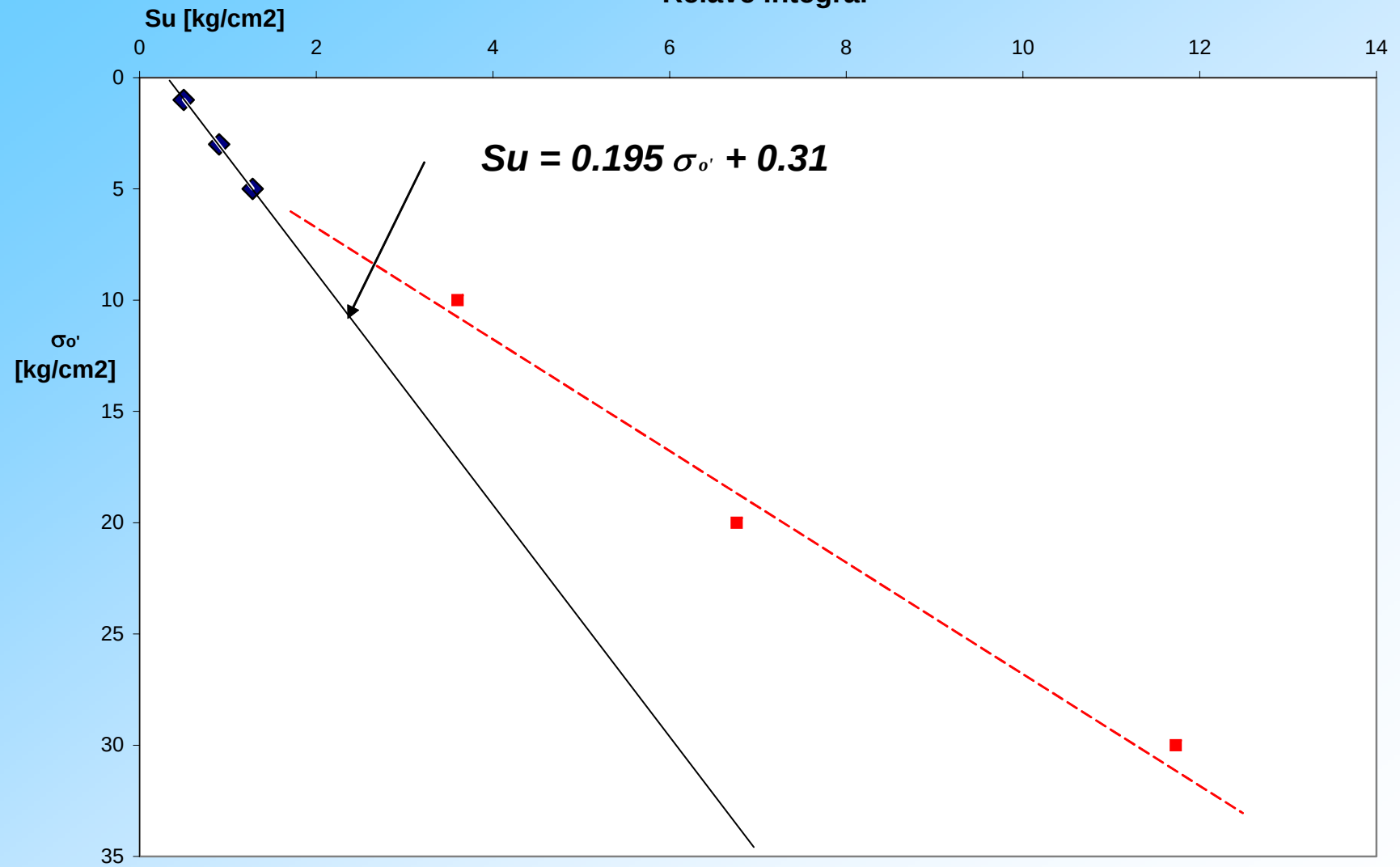
Resultados Triaxial Estático



Muestra inalterada
tomada desde la
cubeta



Resistencia no drenada v/s Presión de Cámara
Relave Integral



GRACIAS





