Cyclic behaviour of cohesionless soils under seismic loading

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February 2012

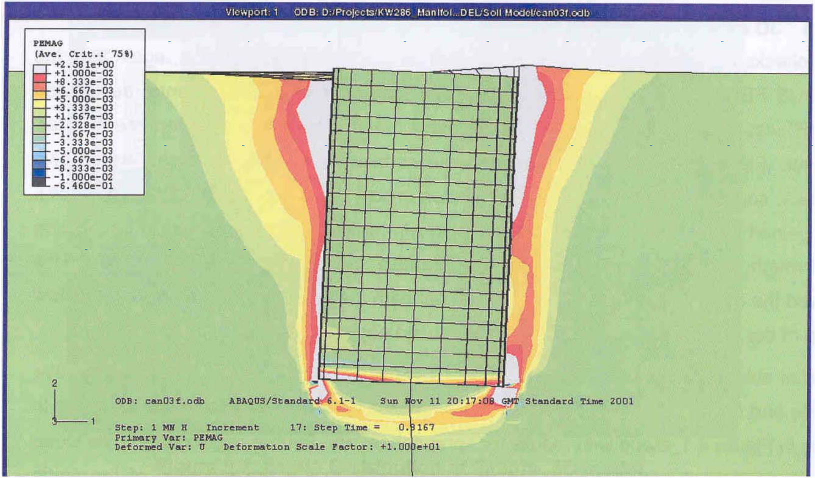
Outline

Nigata, 1964

Kobe, 1995

San Fernando dam, 1971

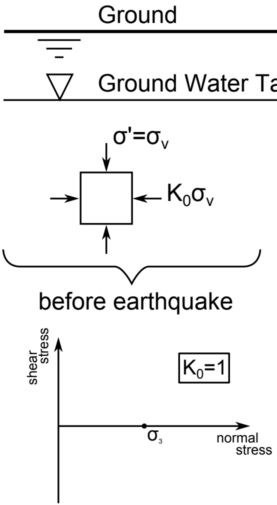
Soil-structure interaction



Outline

1. Context
   - Don't forget the soil !
2. From reality to laboratory
   - Equivalence in-situ/triaxial test
   - Monotonic behaviour charaterization
   - Cyclic behaviour characterization
3. From laboratory to numerical modelling
   - Summary
   - Prevost's model
4. Conclusion

Stress state in the soil



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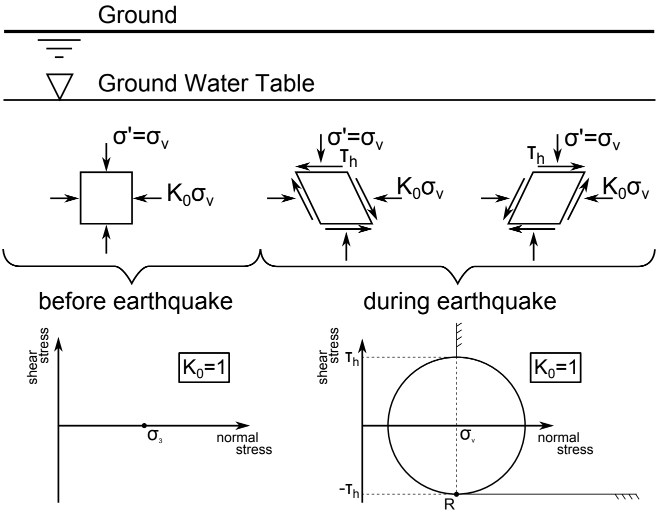
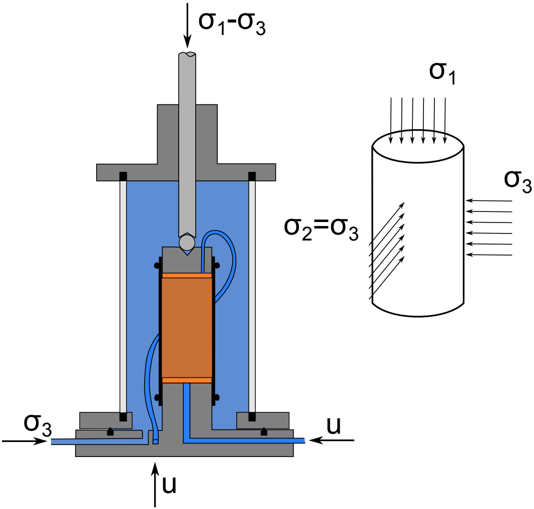


Stress state in laboratory

Essai triaxial :

- compresssion/extension
- monotonic/cyclic
- drained/undrained



Stress state in laboratory

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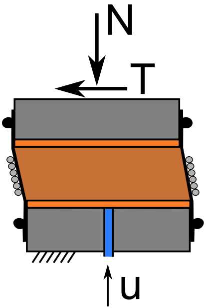
And also :

- simple shear



Stress state in laboratory

Essai triaxial :

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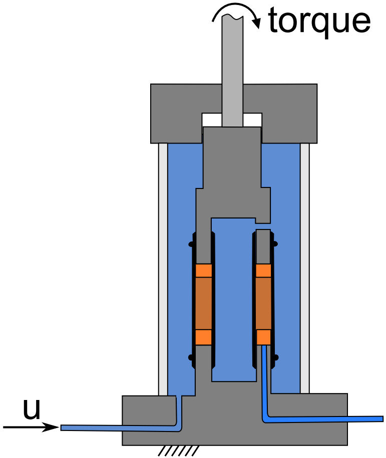
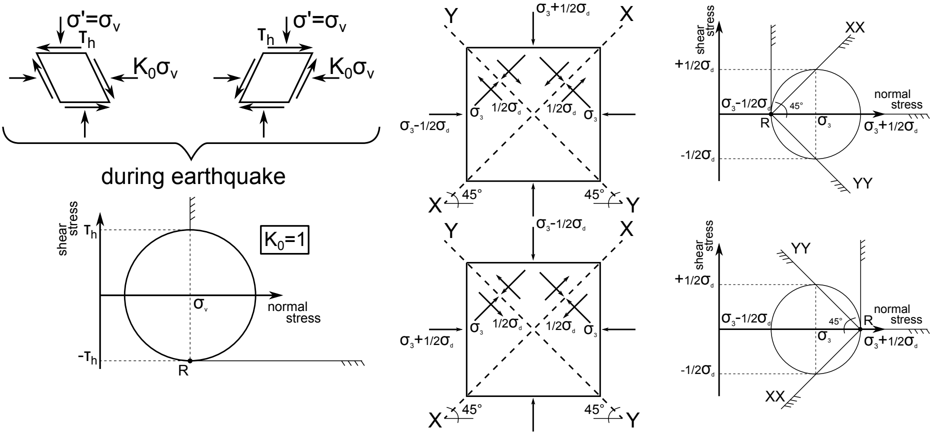
- monotonic/cyclic
- drained/undrained

And also :

- simple shear
- torsional shear test



Stress state in a triaxial test



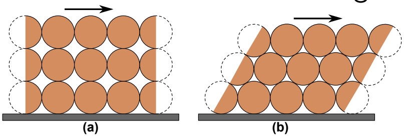
Outline

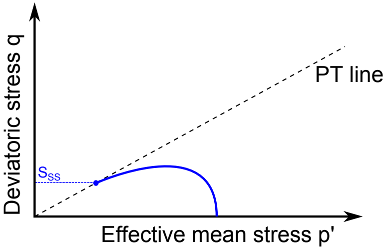
Monotonic undrained test

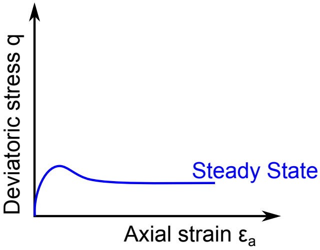
Steady State :

- continuous deformation
- constant p'
- constant q
- constant velocity

Contractancy : $\Delta V < 0$ under shearing





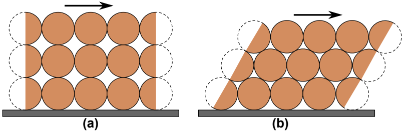


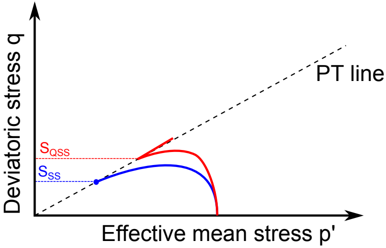
Monotonic undrained test

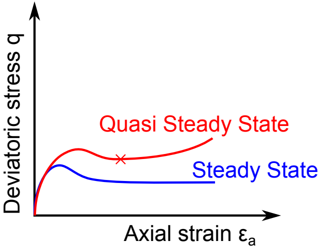
Quasi Steady State :

- transient state
- p' minimum
- q minimum

Contractancy : $\Delta V < 0$ under shearing





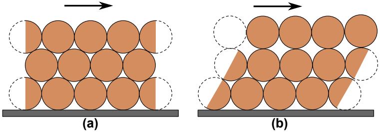


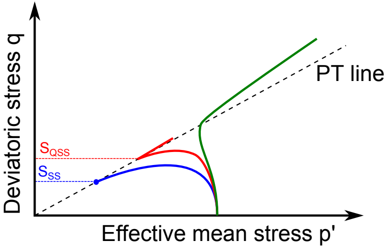
Monotonic undrained test

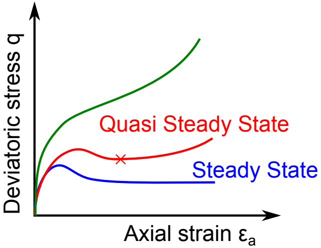
Dilative state

- strain hardening
- no instability

Dilatancy : $\Delta V > 0$ under shearing

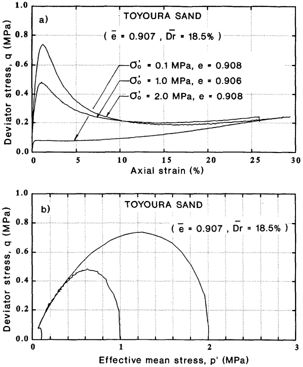






Triaxial undrained test examples (1)

Deformation controlled triaxial undrained tests : Toyoura sand [Verdugo and Ishihara, 1996]
Dr = 18.5%



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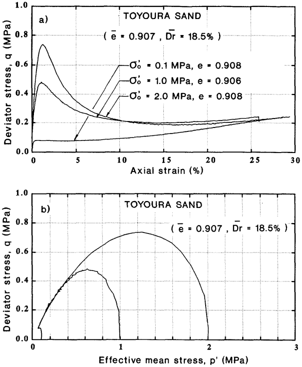
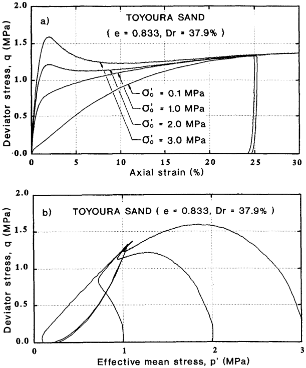


Dr = 37.9%



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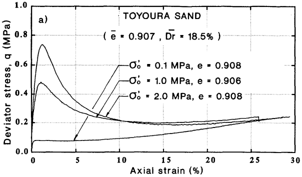
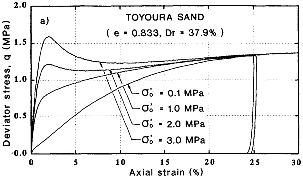
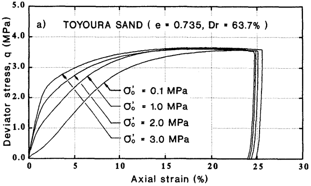
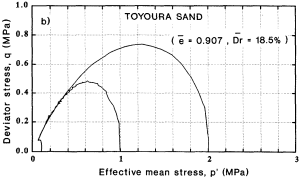
Deformation controlled triaxial undrained tests : Toyoura sand [Verdugo and Ishihara, 1996]

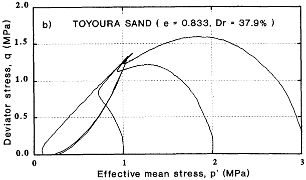
Dr = 18.5% Dr = 37.9% Dr = 63.7%

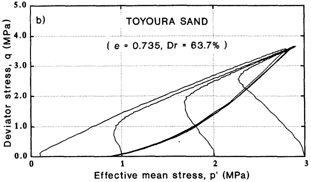




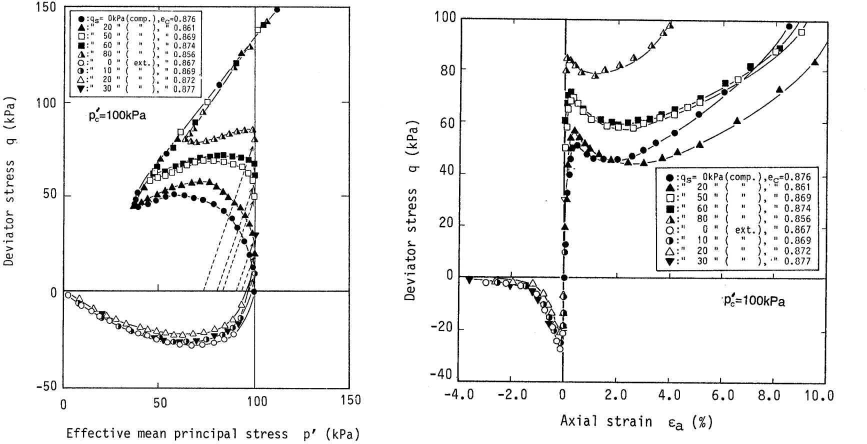








Triaxial undrained test examples (2)

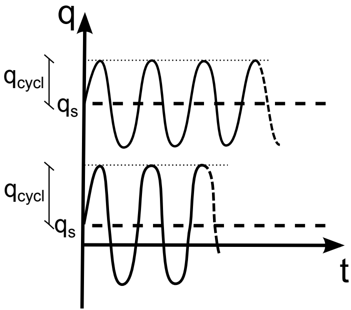


Loose Toyoura sand [Hyodo and al., 1994]

Outline

The cyclic triaxial test

- **load**/deformation controlled



The cyclic triaxial test

- **load**/deformation controlled
- drained/**undrained**

The cyclic triaxial test

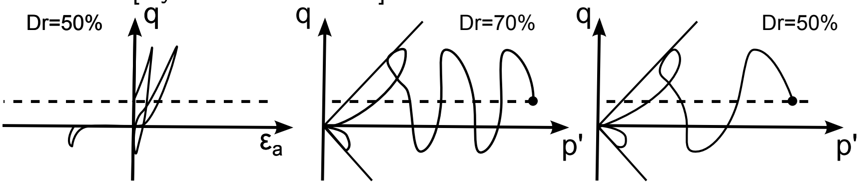
- **load**/deformation controlled
- drained/**undrained**
- until failure : liquefaction **or not**

Liquefaction failure (general term)

Liquefaction and liquefaction failures encompass all phenomena involving excessive deformations of saturated cohesionless soils.

Cyclic behaviour

after [Hyodo and al. 1994]



Initial liquefaction

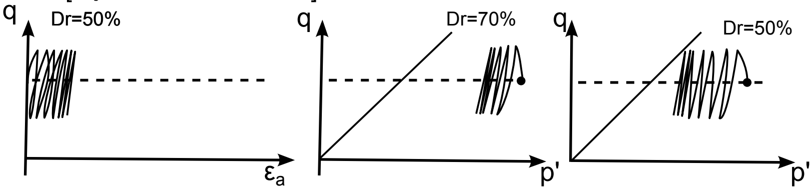
Transient state when the soil sample is submitted to zero mean effective stress ($u = p_{conf}$) and zero deviatoric stress for the first time. This phenomenon involves very large deformations.

Liquefaction (specific term)

True liquefaction occurs when the soil reaches the steady state and deforms continuously.

Cyclic behaviour

after [Hyodo and al. 1994]

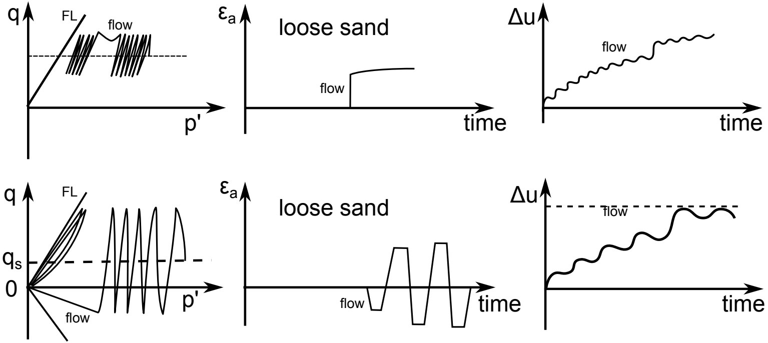


Cyclic mobility

The cyclic mobility denotes the undrained cyclic soil response where the soil undergoes strain softening which is mainly a consequence of the build up of pore water pressure.

Cyclic behaviour

after [Hyodo and al. 1994]



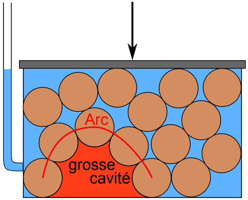
Flow deformation

Flow deformation is an instability characterized by a quick development of strain and pore pressure. If after this phenomenon, the strain increases slowly again, this behaviour is called limited deformation.

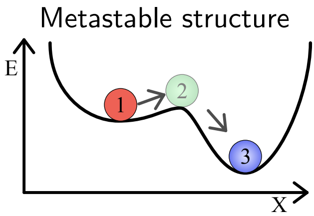
Flow deformation

Structural collapse

In a loose sand in undrained conditions, the structural collapse is the specific response of the loose structure which is exhibited as vigorous pore pressure generation.



(a)



Flow deformation

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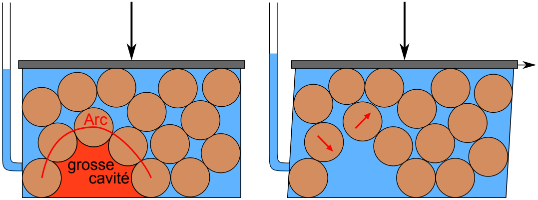

(a) (b)

Flow deformation

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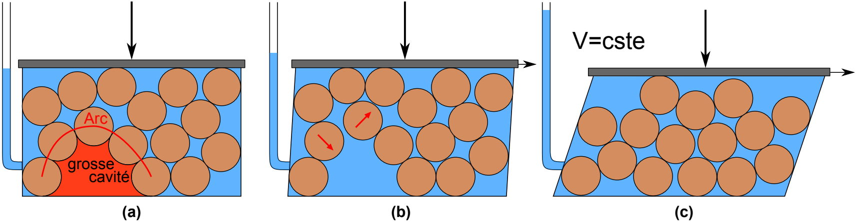

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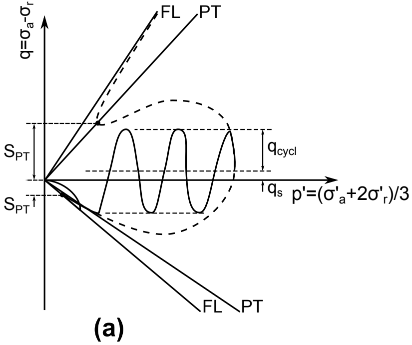
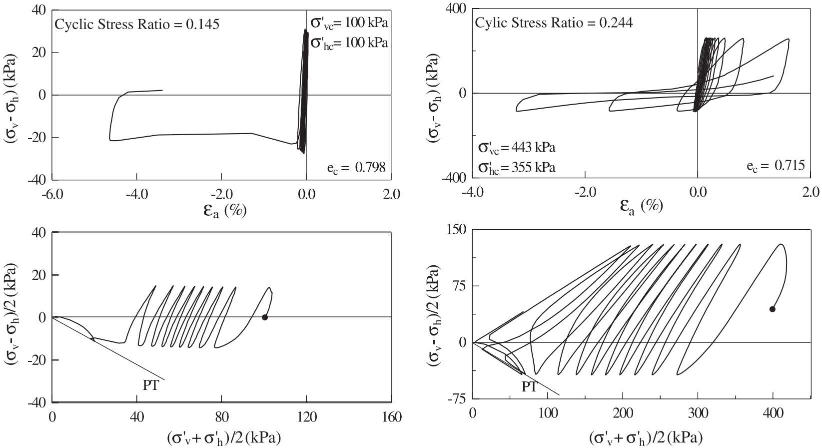


after [Hyodo and al., 1994]

Flow deformation examples

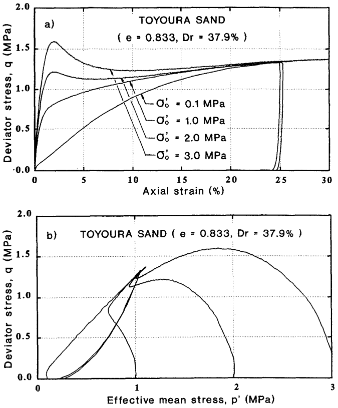


[Vaid and al., 2001]

Outline

The model has to take into account :

- the contractive/dilative transition and softening ;
- the pore pressure build up ;
- the different modes of failure ;
- the failure anisotropy ;



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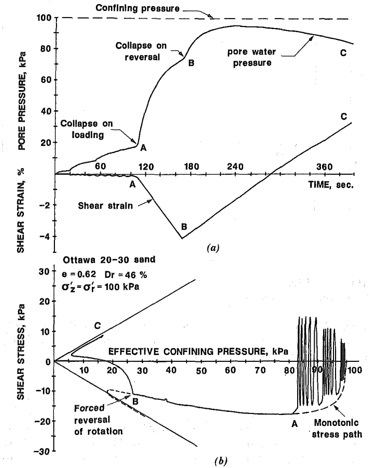

[Alarcon-Guzman and al.,1988]

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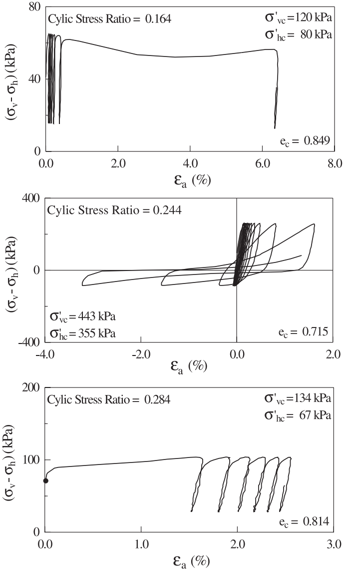

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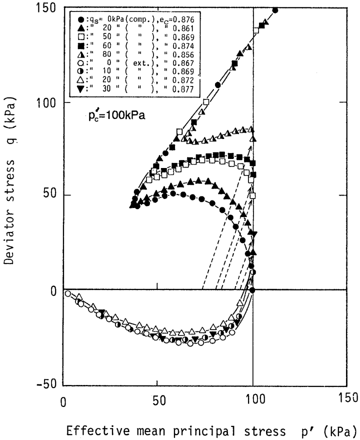
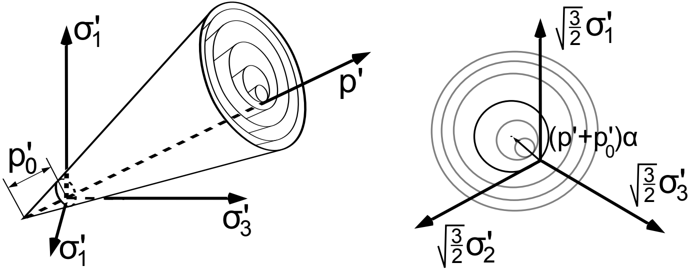


Outline

Characterization

- N nested conical yield surfaces associated with H', M, $\underline{\alpha}$;
- Kinematic hardening in the stress-space ;
- Calibration using monotonic triaxial tests ;
- Non-associative volumic plastic potential
- Sophistication : p' dependency, Lode angle dependency, ...



after [Yang ,Elgamal and Parra, 2003]

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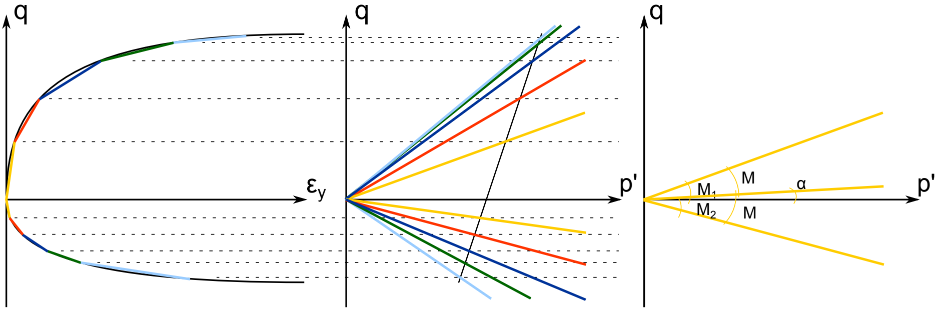

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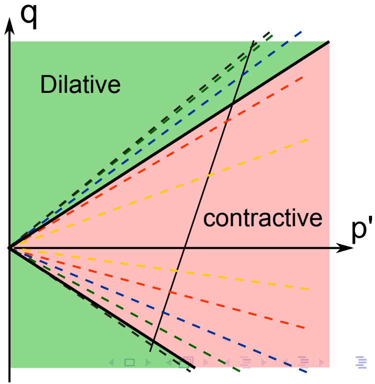
$$P'' = \frac{1 - \left(\frac{\eta}{\bar{\eta}}\right)^2}{1 + \left(\frac{\eta}{\bar{\eta}}\right)^2}$$

$$\eta = \frac{q}{p'}$$



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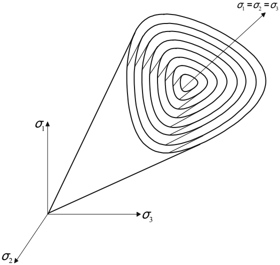
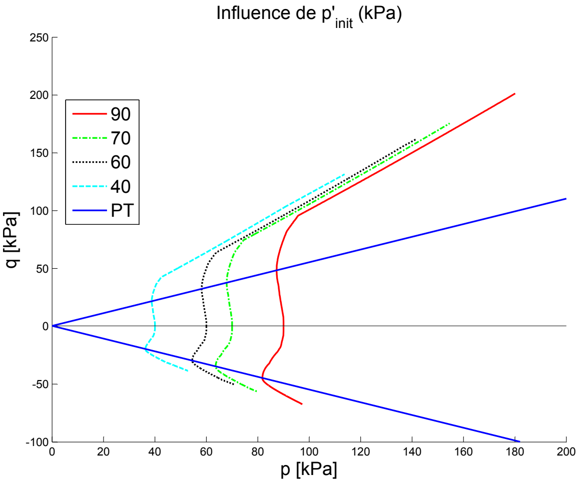
$$H' = H'_0 \cdot \left(\frac{p'}{p_{ref}}\right)^n, K = K_0 \cdot \left(\frac{p'}{p_{ref}}\right)^n,$$
$$G = G_0 \cdot \left(\frac{p'}{p_{ref}}\right)^n$$



after [Yang and Elgamal, 2008]

Numerical examples



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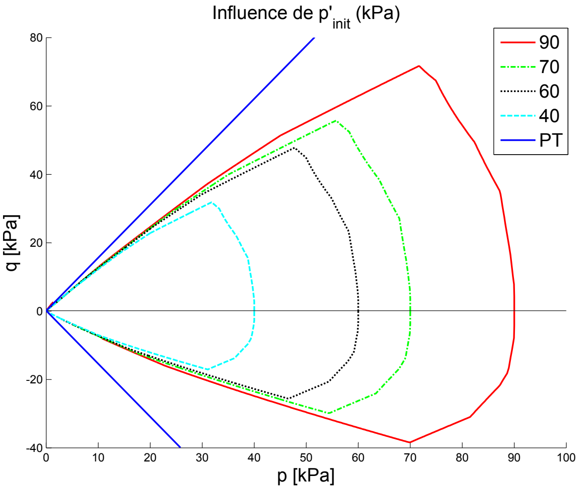

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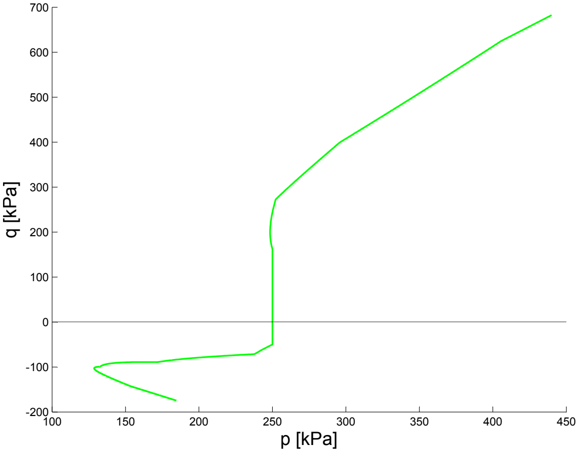

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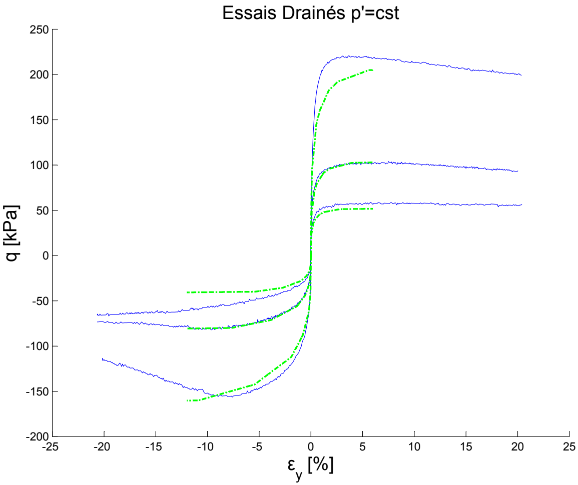

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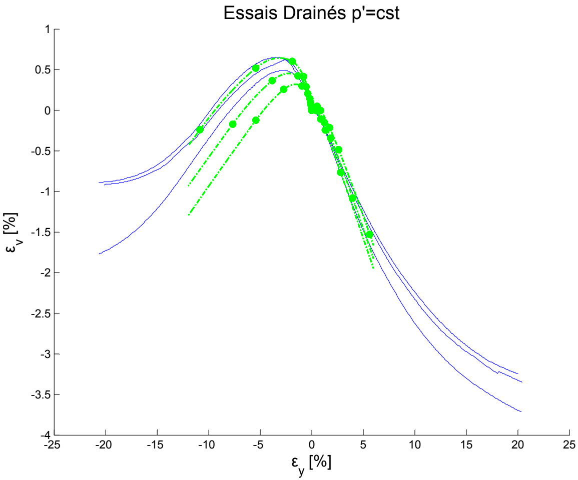

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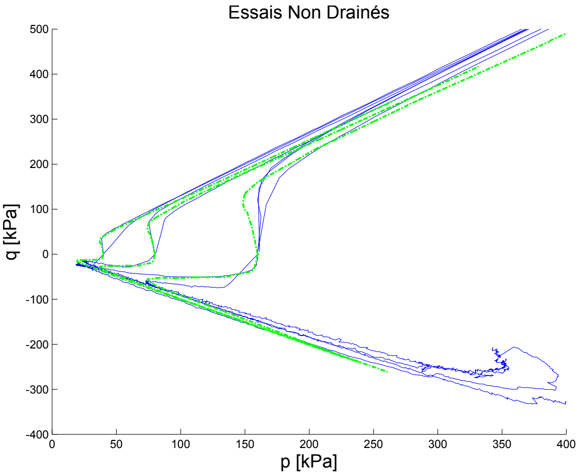

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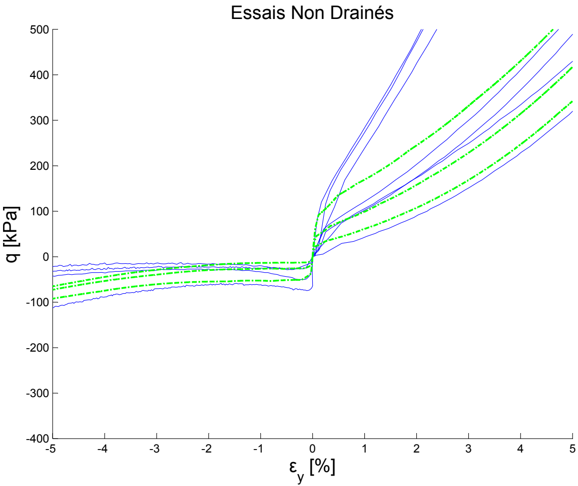

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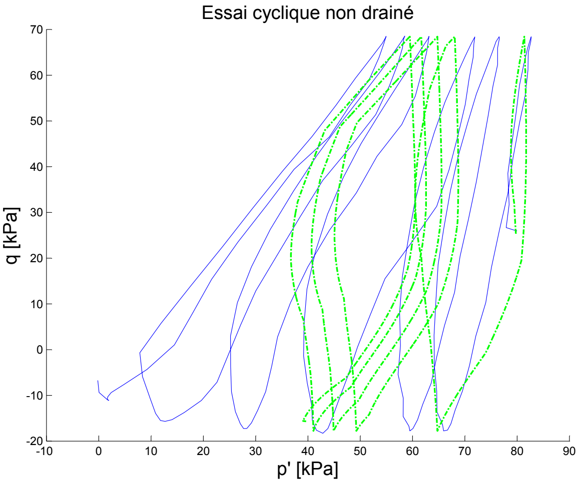
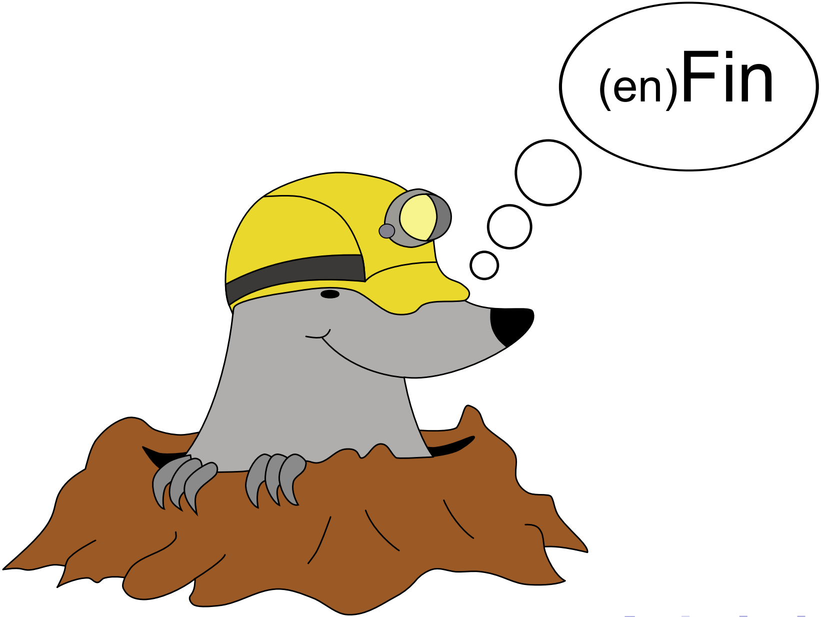


To conclude

1. Very complex actual behaviour
   - pore pressure buildup
   - different modes of failure
   - contractive/dilative transition
   - instability
2. Prevost model : qualitatively OK...

   BUT has to be modified quantitatively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