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# Cyclic behaviour of cohesionless soils under seismic loading

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Context ●0000	From reality to laboratory	From laboratory to numerical modelling	Conclusion
Don't forget the soil!			
Outline			

Don't forget the soil !

#### Prom 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

Context 0●000

From reality to laboratory

From laboratory to numerical modelling

Conclusion

Don't forget the soil !

## Nigata, 1964



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From reality to laboratory

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Don't forget the soil !

## Kobe, 1995



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## San Fernando dam, 1971



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Don't forget the soil !

## Soil-structure interaction



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From reality to laboratory

From laboratory to numerical modelling

Equivalence in-situ/triaxial test

## Outline



• Don't forget the soil !

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Equivalence in-s	itu/triaxial test		
Stress s	state in the soil		
	Ground $\overline{-}$ $\nabla$ Ground Water Ta	able	
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	Set K <sub>0</sub> =1 σ, normal stress		
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From reality to laboratory

From laboratory to numerical modelling 00000

Conclusion

Equivalence in-situ/triaxial test

## Stress state in laboratory

Essai triaxial :

- compression/extension
- monotonic/cyclic
- drained/undrained



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## Stress state in laboratory

Essai triaxial :

- compresssion/extension
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And also :

• simple shear



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## Stress state in laboratory

Essai triaxial :

- compression/extension
- monotonic/cyclic
- drained/undrained

And also :

- simple shear
- torsional shear test



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### Stress state in a triaxial test



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## 2 From reality to laboratory

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#### • Monotonic behaviour charaterization

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From reality to laboratory 

Monotonic behaviour charaterization

## Monotonic undrained test

Steady State :

- continuous deformation
- constant p'
- constant q

σ

**Deviatoric stress** 

constant velocity



From reality to laboratory

From laboratory to numerical modelling

Conclusion

Monotonic behaviour charaterization

## Monotonic undrained test

Quasi Steady State :

- transient state
- p' minimum
- q minimum

σ

**Deviatoric stress** 



From reality to laboratory 

Monotonic behaviour charaterization

## Monotonic undrained test

Dilative state

σ

Deviatoric stress

- strain hardening
- no instability



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## Triaxial undrained test examples (1)

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



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## Triaxial undrained test examples (1)

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



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## Triaxial undrained test examples (1)

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



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Image: A matrix and a matrix

Conclusion

Monotonic behaviour charaterization

## Triaxial undrained test examples (2)



Loose Toyoura sand [Hyodo and al., 1994]

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## The cyclic triaxial test

• **load**/deformation controlled



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## The cyclic triaxial test

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



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## 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.



#### 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 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.



#### 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.

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## 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.





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Flow d	eformation		

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## Flow deformation

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#### Structural collapse

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Image: A matched black

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## Flow deformation examples



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#### Summary

## 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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From laboratory to numerical modelling 0000

#### Summary

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[Alarcon-Guzman and al.,1988]

#### Summary

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Prevost's model			
Character	rization		

- 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, ...



<sub>23/26</sub> after [Yang ,Elgamal and Parra, 2003]

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Charac	terization		

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ight)^n$$
 ,  $\mathcal{K} &= \mathcal{K}_0 \cdot \left(rac{p'}{p_{ref}}
ight)^n$  ,  $\mathcal{G} &= \mathcal{G}_0 \cdot \left(rac{p'}{p_{ref}}
ight)^n \end{split}$ 



after [Yang and Elgamal, 2008]

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## Numerical examples



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Prevost's model

## Numerical examples



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## To conclude



- pore pressure buildup
- different modes of failure
- contractive/dilative transition
- instability
- Prevost model : qualitatively OK...

BUT has to be modified quantitatively

