GRADUAL MODELING OF ARATOZAWA DAM UNDER STRONG EARTHQUAKE

Centre d'Ingénierie Hydraulique

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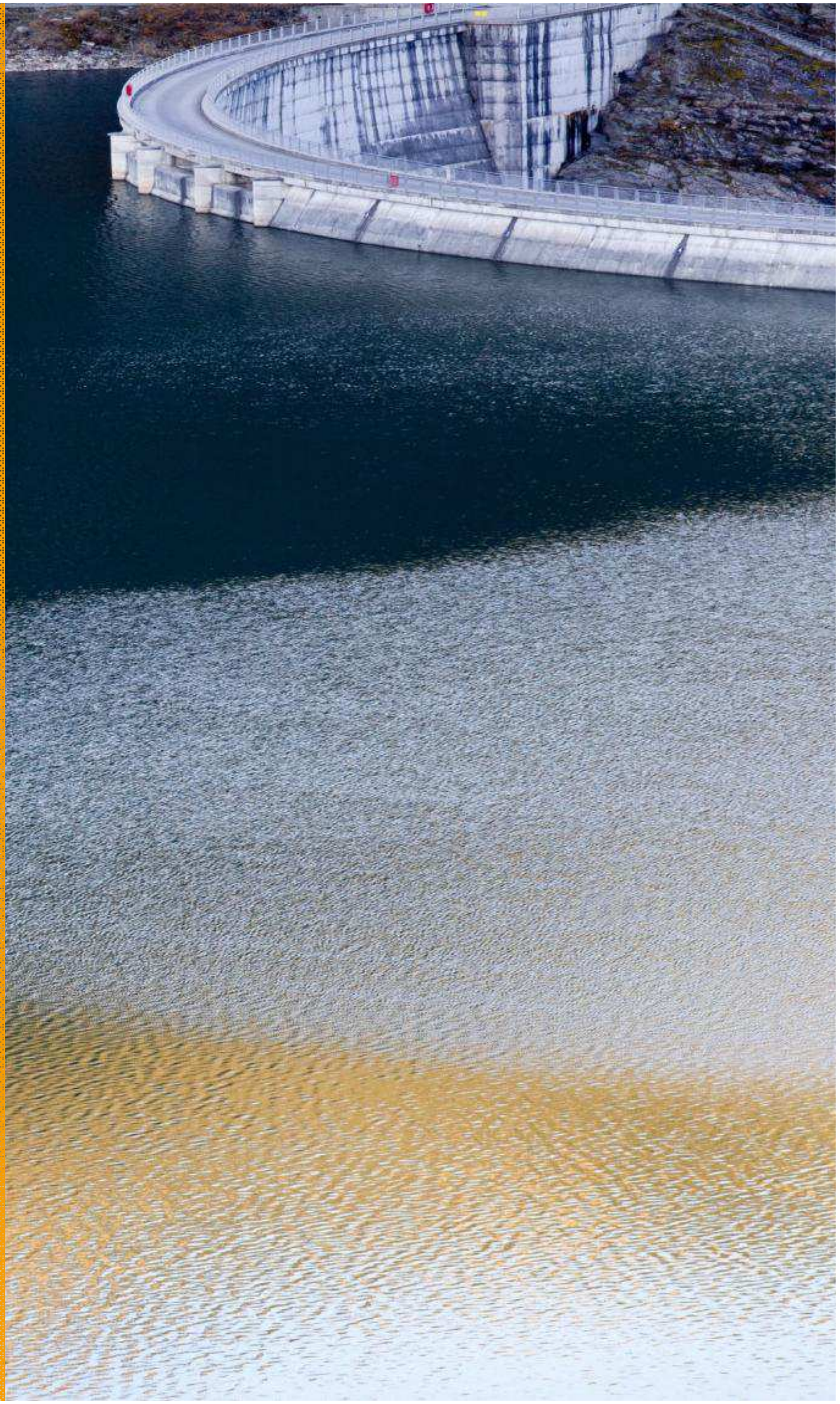
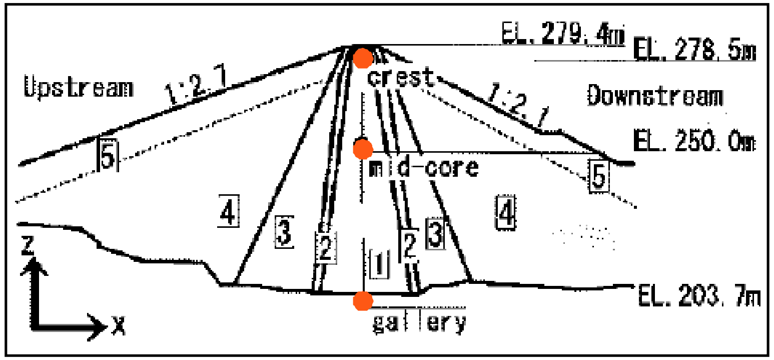
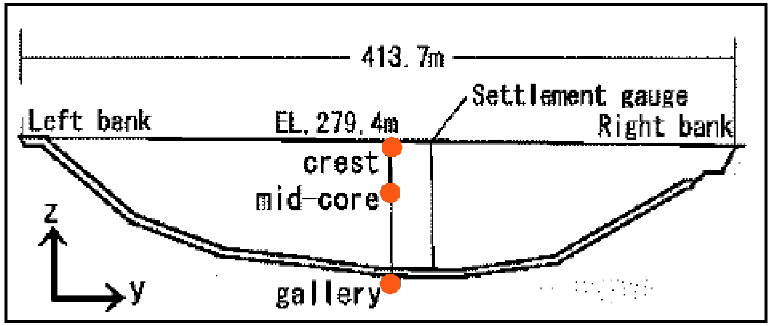


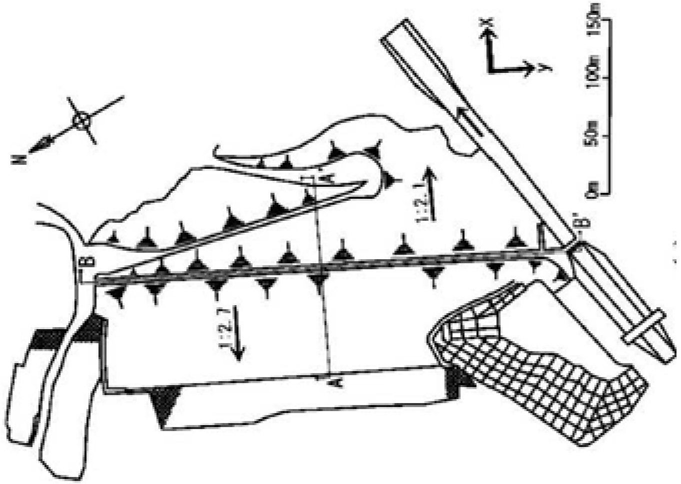
SUMMARY

1. **ARATOZAWA DAM**
2. **MAIN ASSUMPTIONS OF THE MODEL**
3. **RESULTS**
   - UNCOUPLED APPROACH
   - COUPLED APPROACH
   - UNSATURATED APPROACH

PRESENTATION OF THE DAM (1/2)

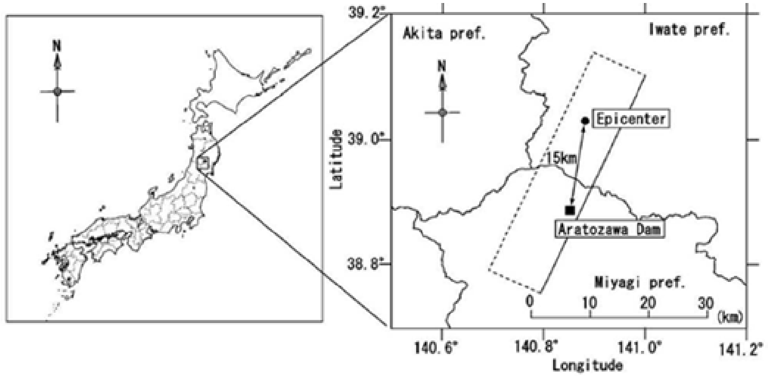




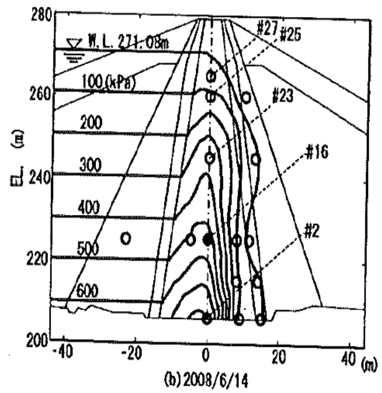


PRESENTATION OF THE DAM (2/2)

- **Iwate-Miyagi Nairiku Earthquake:**
  - 2008
  - Mw=7.2
  - PGA at the bottom= 10.24 m/s2
- **Response of the dam :**
  - Strong disamplification at the crest
  - Roof settlement about 40 cm
  - pp measures in the core

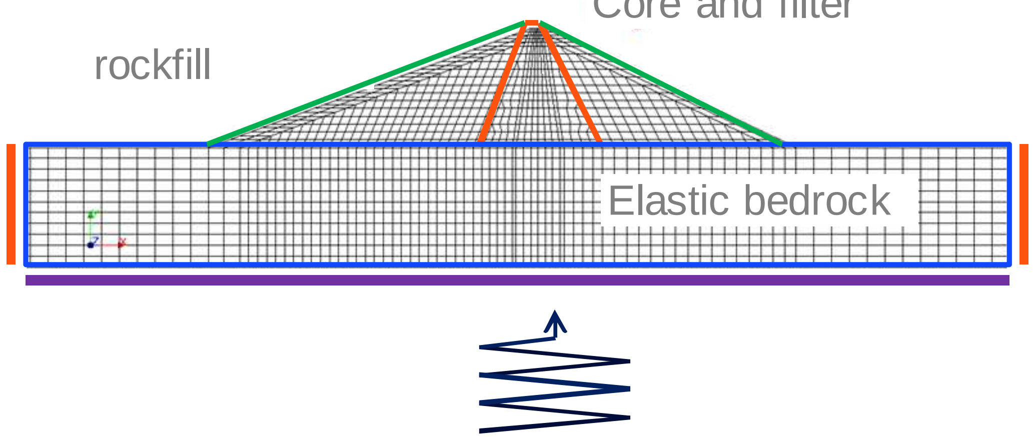


Position	Direction		
	Stream	Dam Axis	Vertical
Crest	5,25	4,55	6,22
Core Centre	5,35	4,78	4,70
Base Galery	10,24	8,99	6,91



AVALAIBLE TOOL AND METHOD AT EDF

Code_Aster : a Finite Element Code adapted for dynamic hydromechanical problems:



An adapted constitutive model :

Hujeux's Model [Aubry et al. 1982, Hujeux 1985]

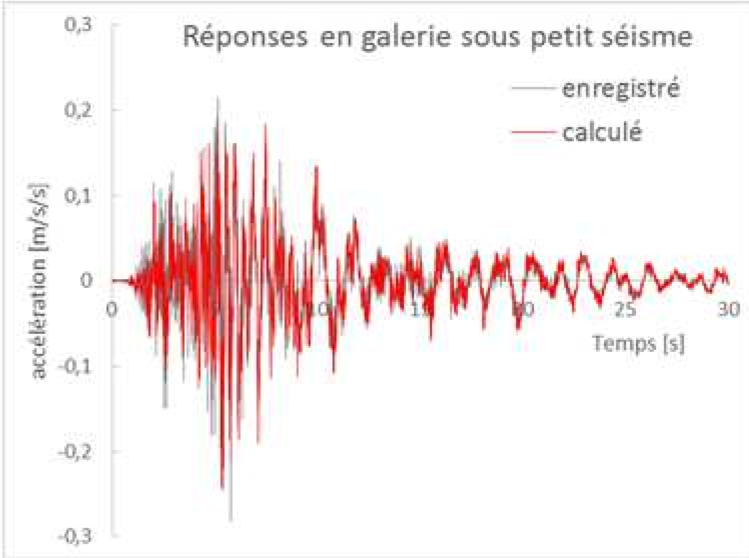
- Effective stress
- Coulomb to Camclay type failure criterion
- 4 coupled mechanisms:
  - 3 deviatoric yield surfaces
  - 1 isotropic yield surface
- 4 coupled cyclic mechanisms
- Critical state concept

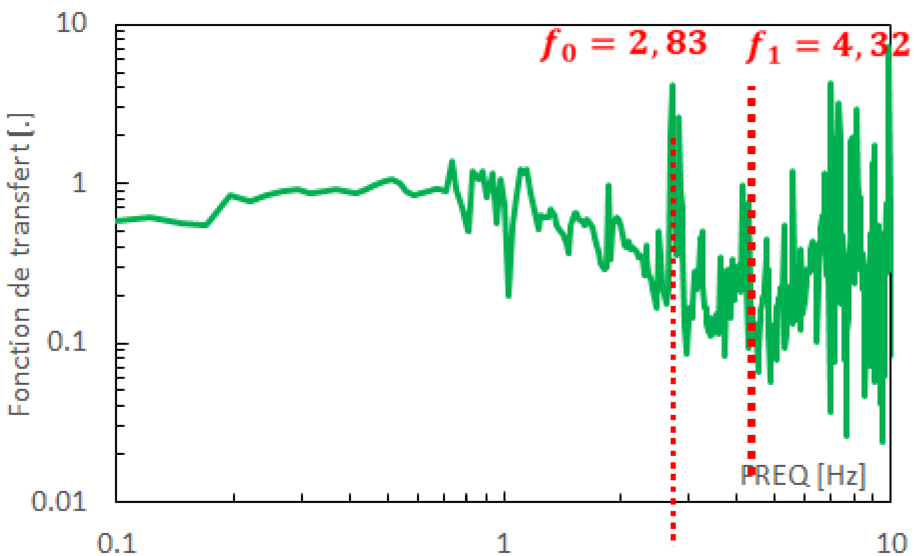
SCALING OF THE ELASTIC RESPONSE

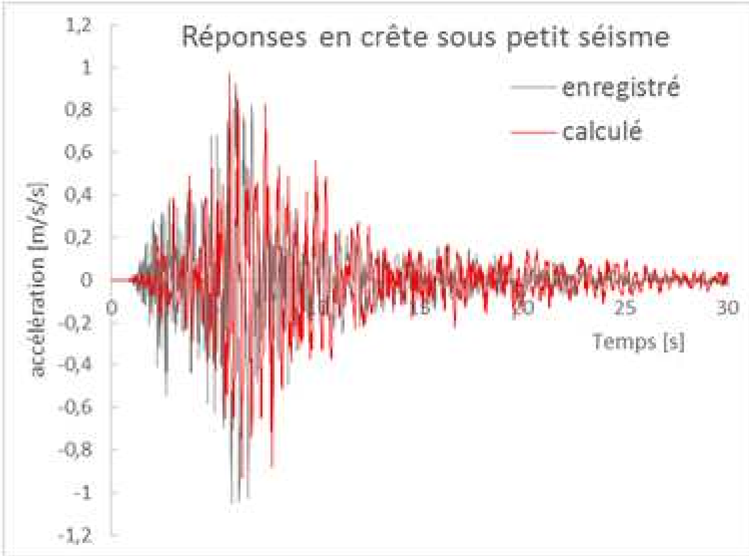
- **Under a small earthquake (1996)**

  Vs Profile (Sawada)

  $Vs(z)=180\ z^{0.35}$







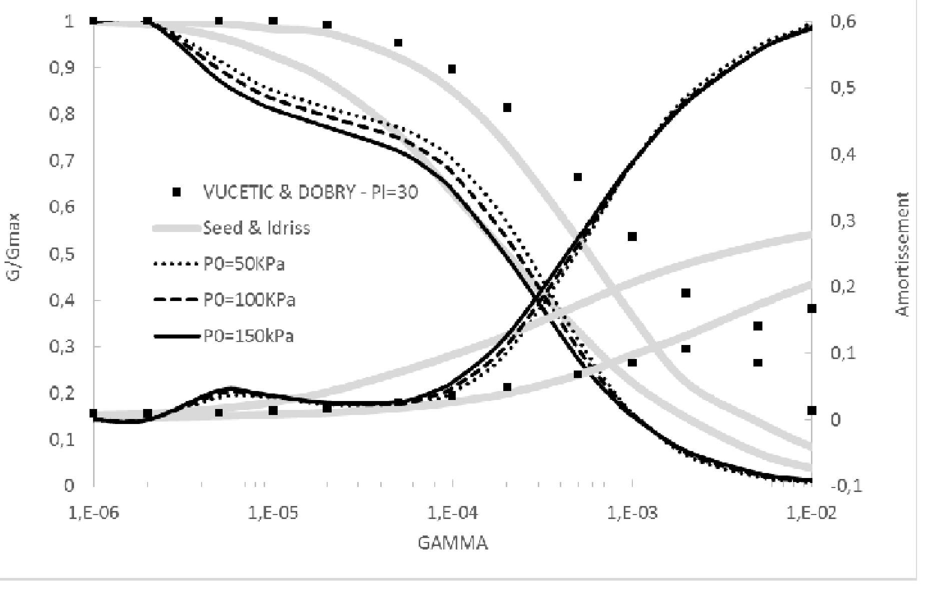
NON LINEAR SHEAR BEHAVIOUR

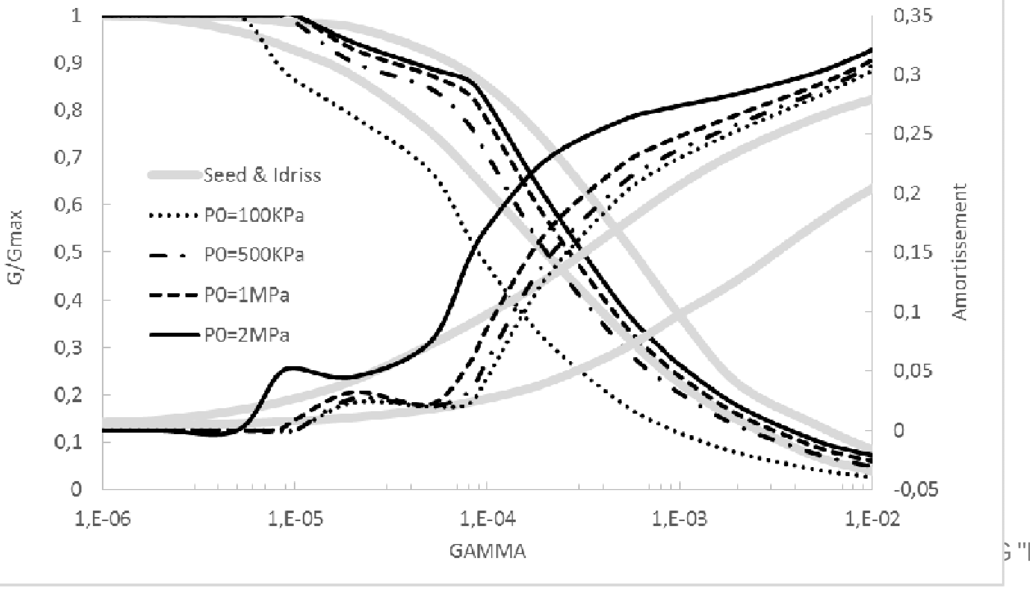
Calibration of all parameters of deviatoric mechanisms

by using G-γ and D-γ curves

(Vucetic and Dobry or

Seed and Idriss)





COMPRESSIBILITY

Calibration of all parameters affecting compressibility:

No data except very high densities of materials

Reasonnable set of parameters

1) Fixed pore pressure (uncoupled approach)

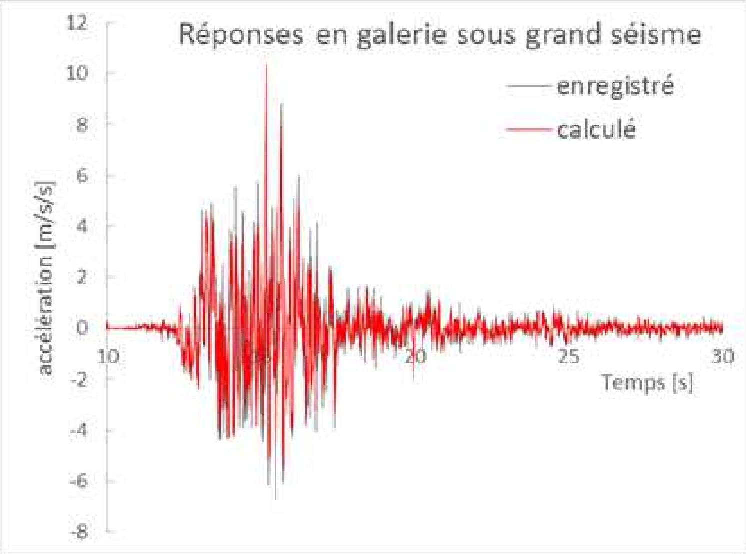
2) Free pore pressure (fully coupled approach)

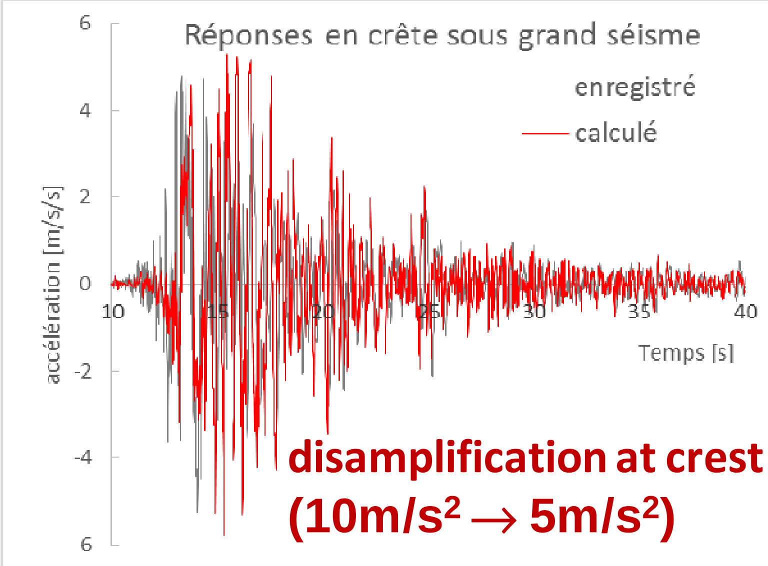
uniform fluid compressibility : Kw~ 2.10^{e}9 Pa or 2.10^{e}7 Pa

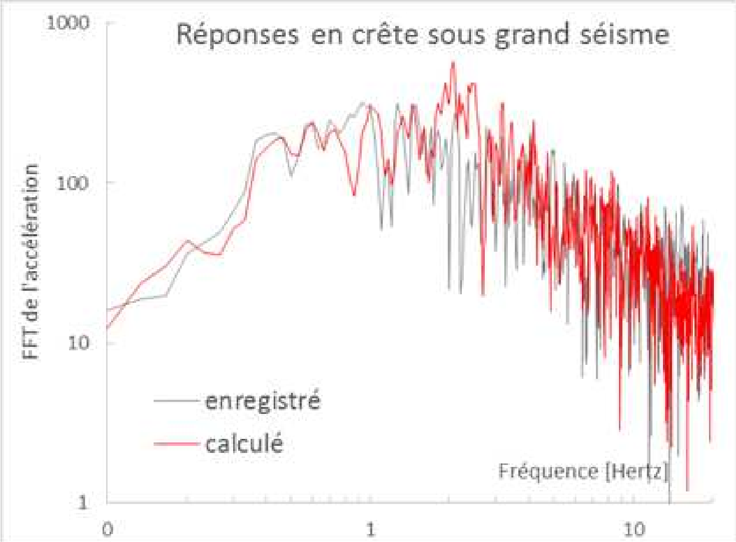
3) Free pore pressure (fully coupled approach)

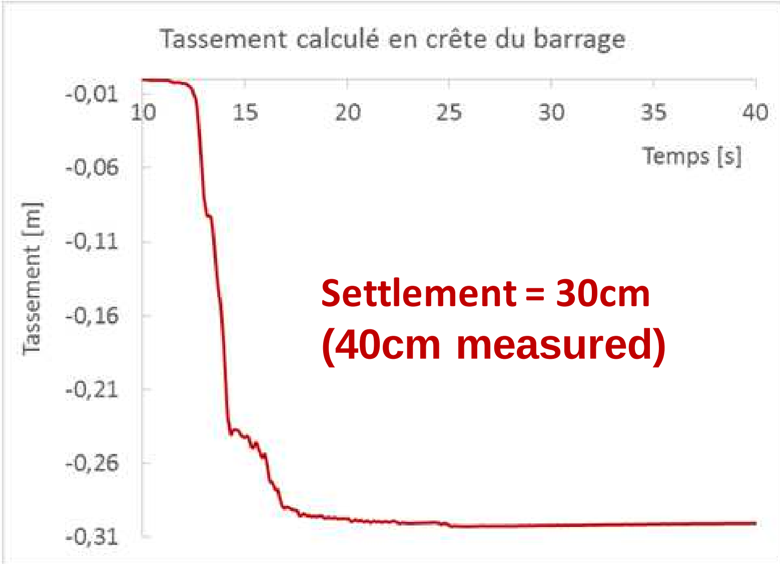
justify the variability of fluid compressibility by an unsaturated approach: 2^{e}7 to 2^{e}9 Pa

RESULTS OF THE UNCOUPLED APPROACH





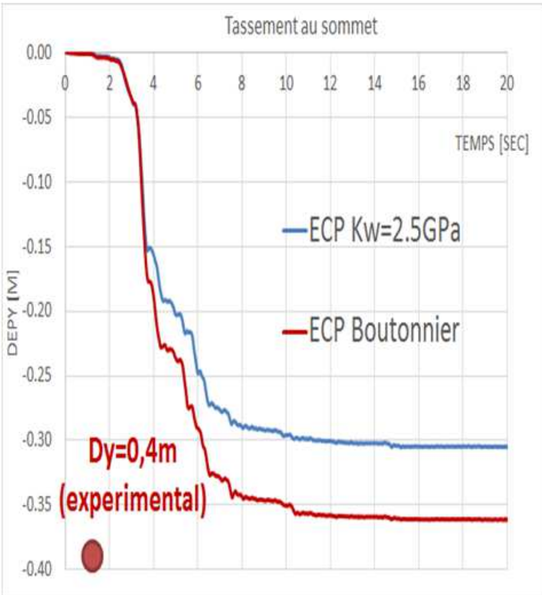


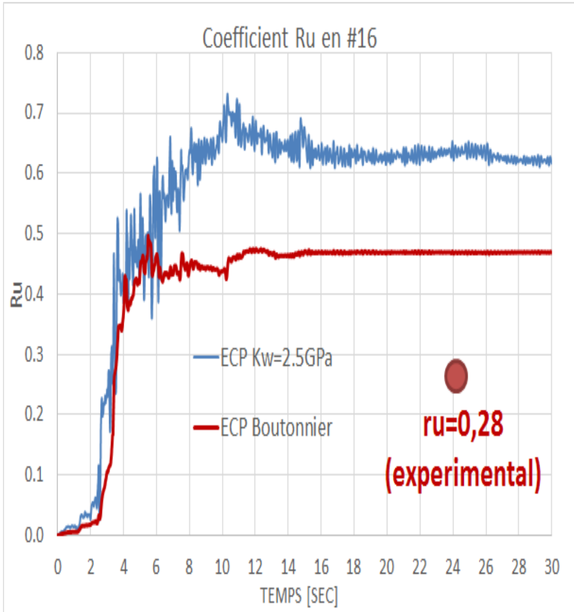


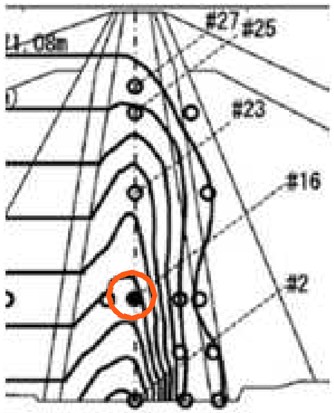
RESULTS OF THE COUPLED APPROACH

Additional assumptions: permeabilities of the materials

Water compressibility k_w ~2 GPa or 20 MPa (Boutonnier)







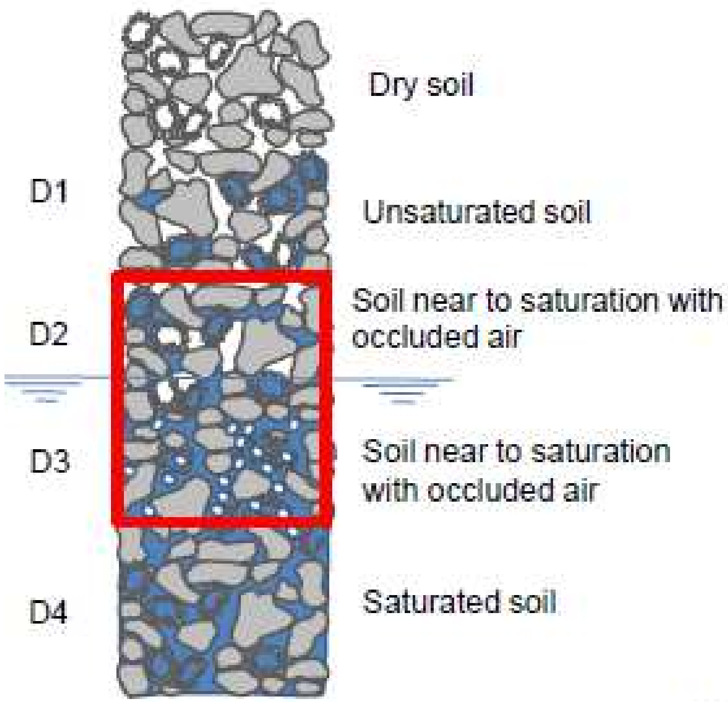
Water compressibility influences the settlement and the pore pressure increase.

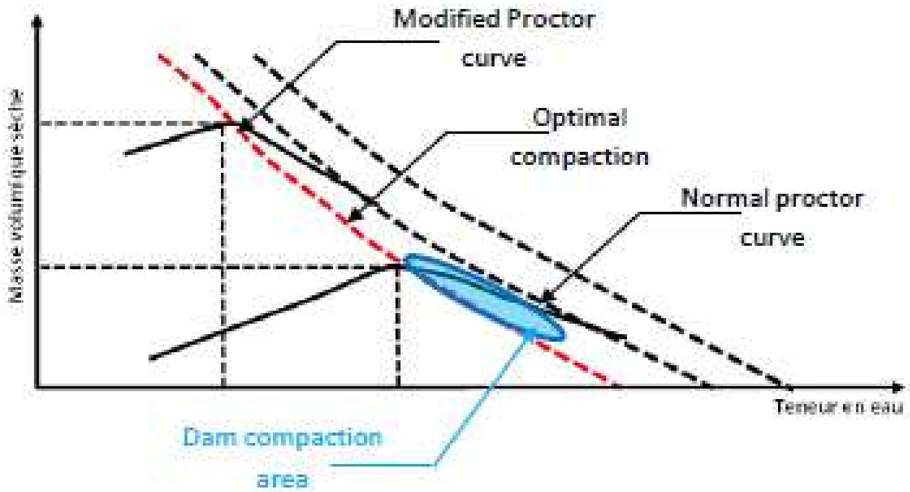
How to choose the real fluid compressibility?

UNSATURATED APPROACH: THE BOUTONNIER MODEL

- Fluid compressiblity based on Boutonnier’s model [Boutonnier, 2007]
  - $\Rightarrow$ Take into account occluded air into water

Fluid compressibility



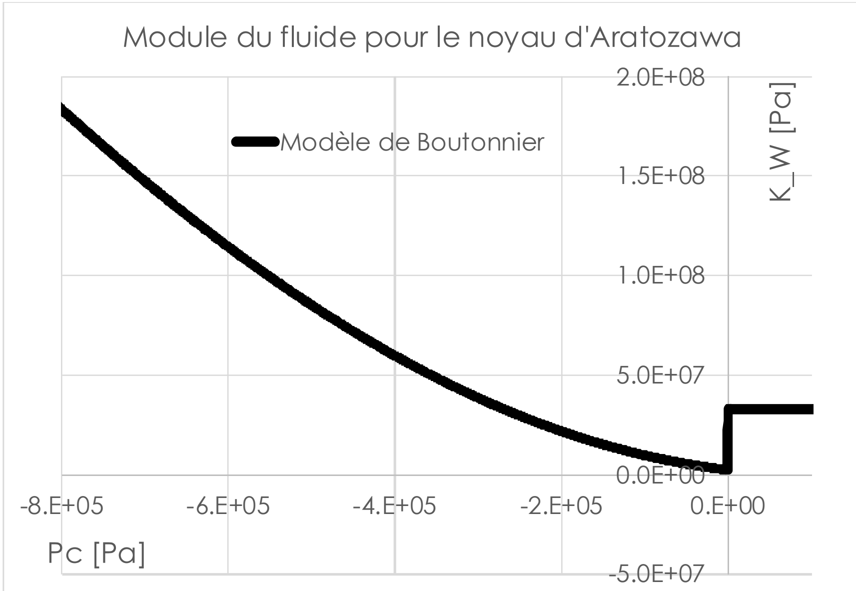


$$c_f = \frac{1}{S_r} \cdot \frac{dS_r}{du_w} + c_w \qquad B = \frac{1}{1 + n\, c_f\, E}$$

➔ Prediction of pore pressure build-up in the core

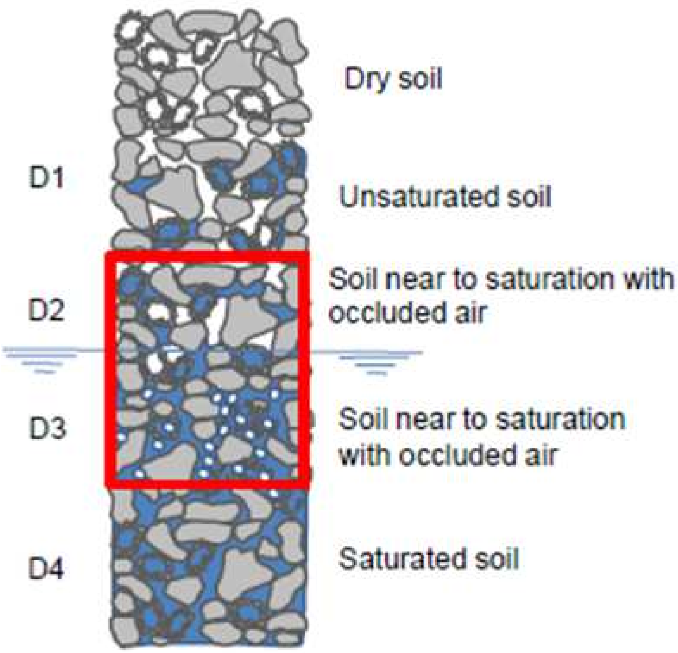
AN UNSATURATED APPROACH: THE BOUTONNIER MODEL

- Fluid compressiblity based on Boutonnier's model [Boutonnier, 2007]



$$c_f = \frac{1}{S_r}.\frac{dS_r}{du_w} + c_w$$

Fluid compressibility

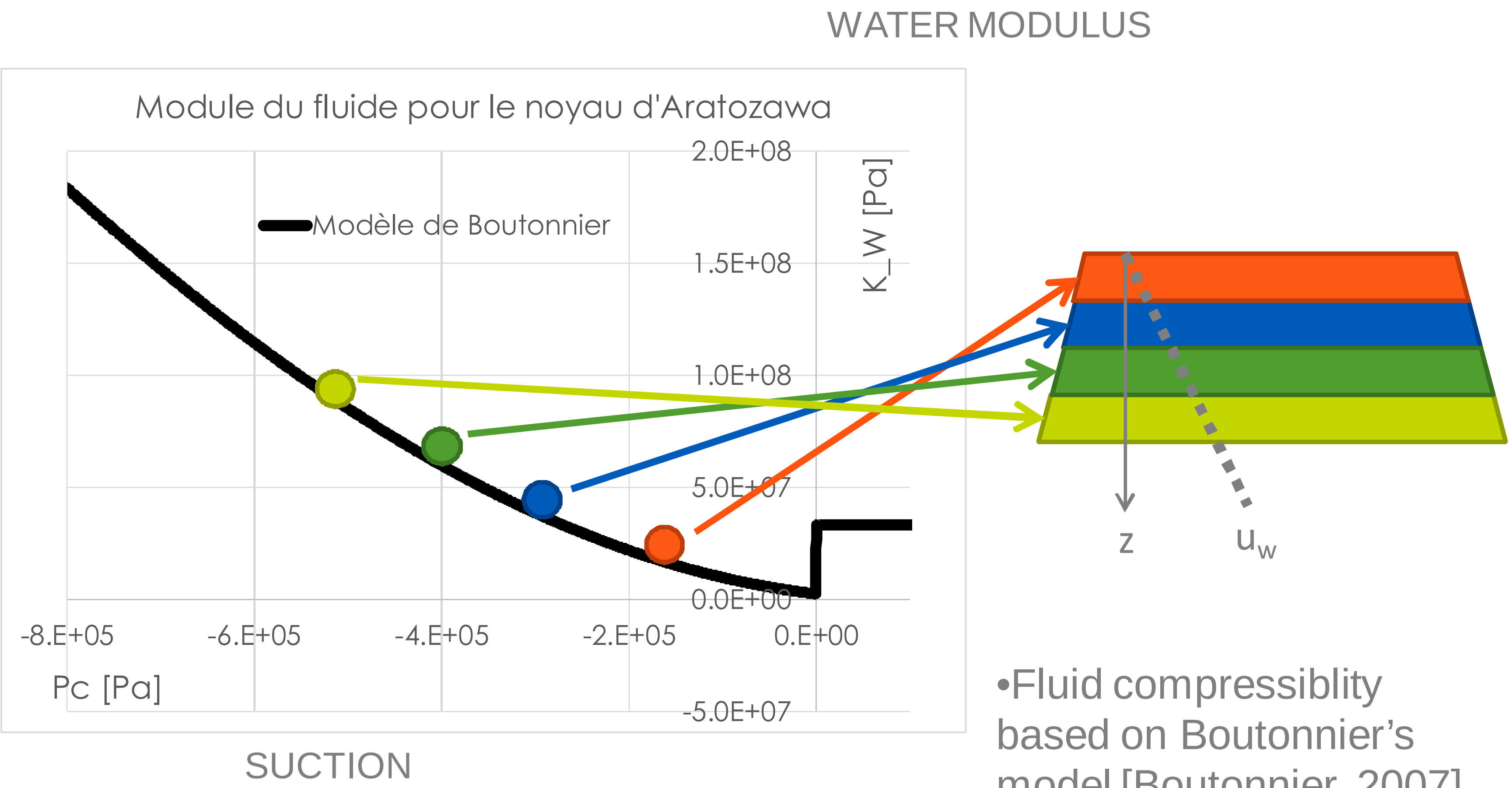


$$S_r = S_{re} - u_w \frac{(S_{re} - S_{rair})}{u_{wair}}$$

$$S_r = \frac{1}{1 - h + \left(\frac{1 - S_{re} + h.S_{re}}{S_{re}}\right).\left(\frac{s_{bm} + p_a - u_{wg}}{u_w + s_{bm} + p_a - u_{wg}}\right)}$$

$$S_r = 1$$

AN UNSATURATED APPROACH:
THE BOUTONNIER MODEL



•Fluid compressiblity based on Boutonnier's model [Boutonnier, 2007]

UNSATURATED APPROCH
WITH 5 SETS OF PARAMETERS

- Sets are based on two kinds of compressibility of the core:
- Isotropic and deviatoric

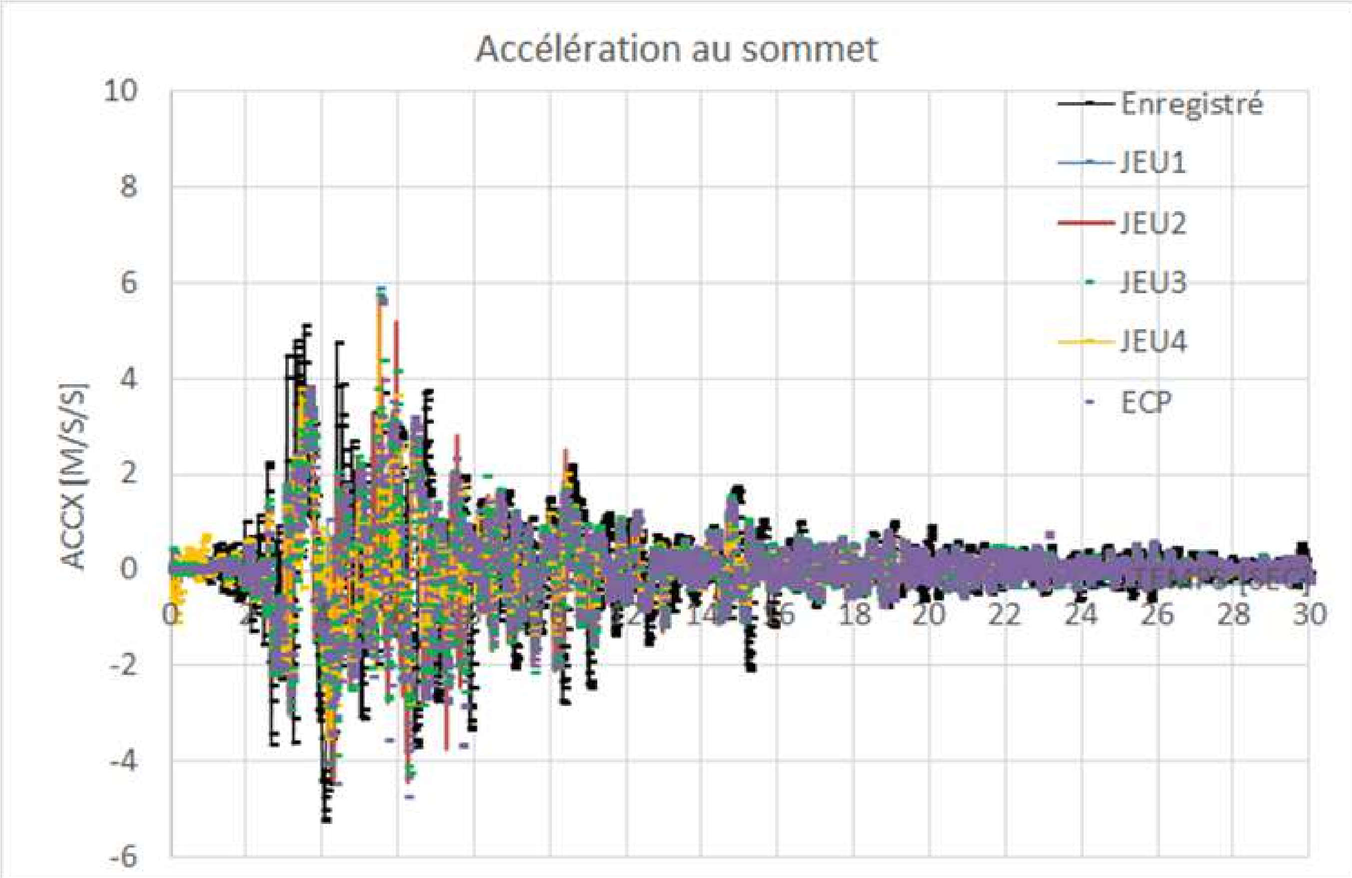
Isotropic Compressibility →

Compressibility under shear cycles ↓

Shear residual Resistance	Low compressibility	Middle compressibility		High Compressibility	
Stronger	ECP (reference)		JEU2	JEU3	
Lower		JEU1			JEU4

RESULTS FOR THE UNSATURATED APPROACH

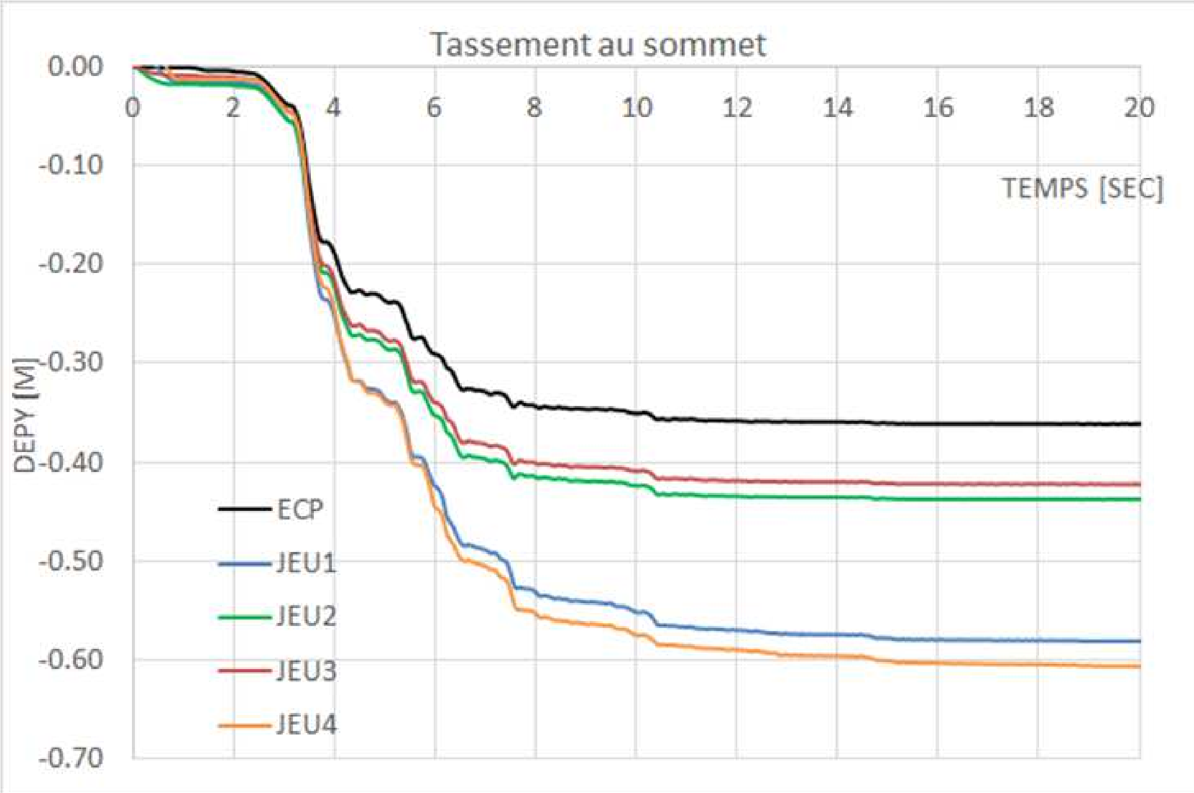
- a_{max} measured ≅ **5,25 m/s²**
- a_{max} calculated: between 5,6m/s² and 5,8m/s²
  - ⇒ major influence of G-γ curves on PCA



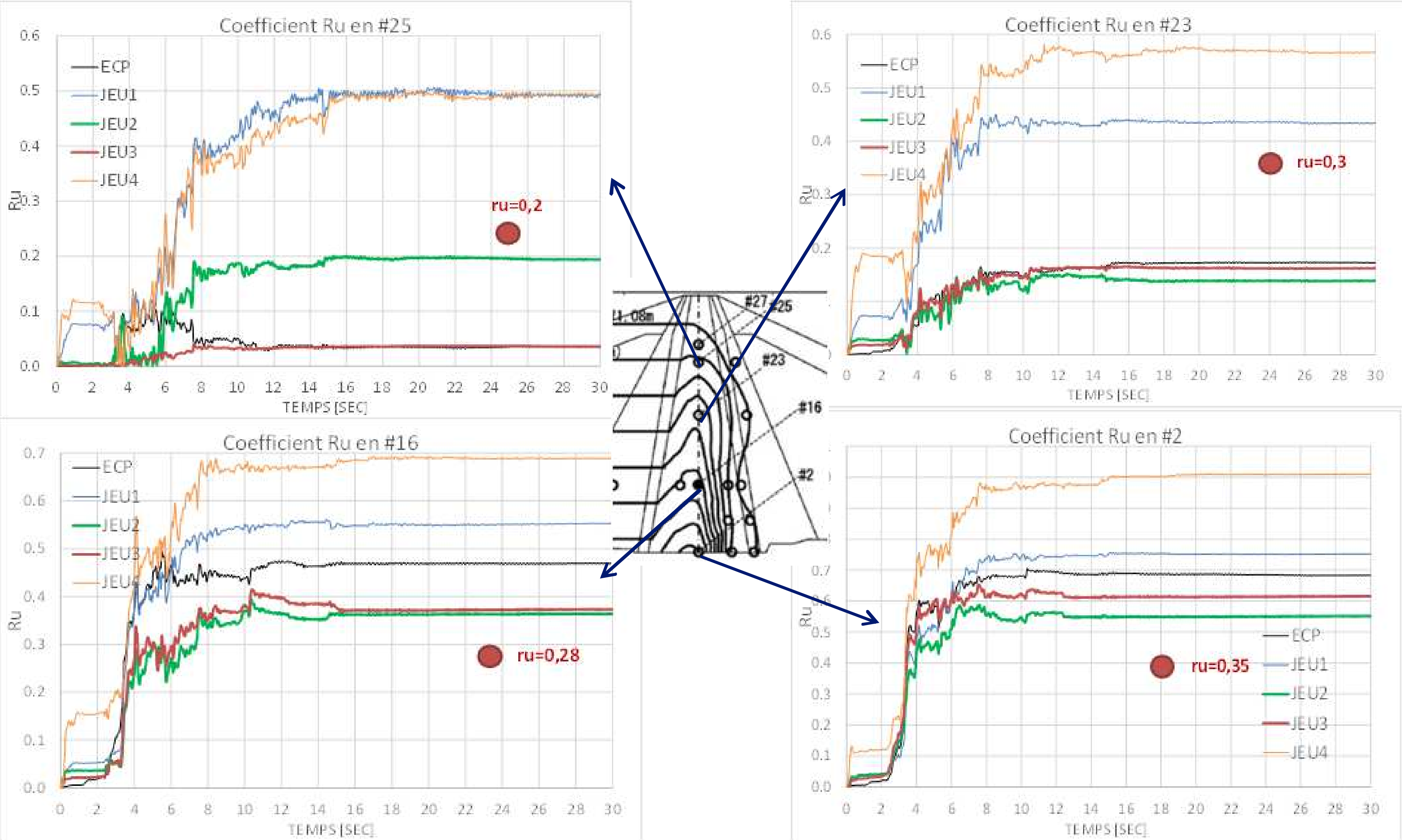
RESULTS FOR THE UNSATURATED APPROACH

- Settlement measured ≅ **40 cm**
- Settlement calculated:

	ECP	36 cm
	JEU1 & JEU4:	58 - 60 cm
☺	**JEU2** & **JEU3**:	42 - 44 cm

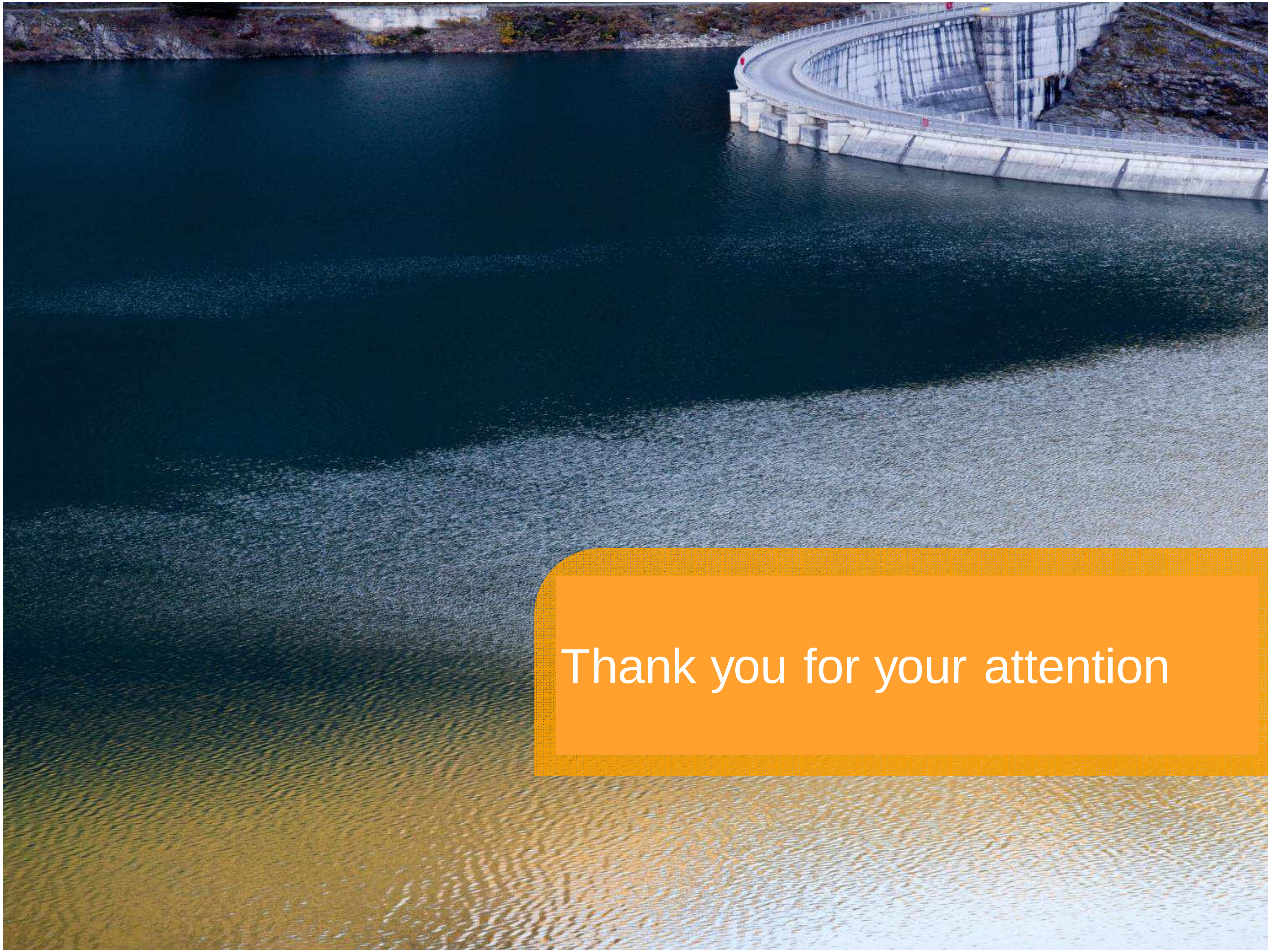


RESULTS FOR THE UNSATURATED APPROACH



CONCLUSION

- **Calibration of the model on the velocity profiles and G-γ curves is sufficient to estimate correctly the time histories of acceleration, PCA and settlement, if the pore pressure built-up remains fair.**
- **In coupled analysis, settlements and pore pressure built-up are related to the compressibilities of the water and of the material.**
- **Taking into account the influence of occluded air on the compressibility of the fluid, even in a simplified way, allows a better prediction of the pore pressure built-up in the whole core.**
- **Boutonnier's model offers a theoretical framework to justify the used values of the compressibility of the water and its dependency on depth.**
- **Future developments:**
  - **In situ investigation of the saturation with geophysical investigations.**
  - **Validation of Boutonnier's model on other case studies of dam.**


Thank you for your attention