Numerical evaluation of fragility curves for earthquake-liquefaction-induced settlements of an embankment

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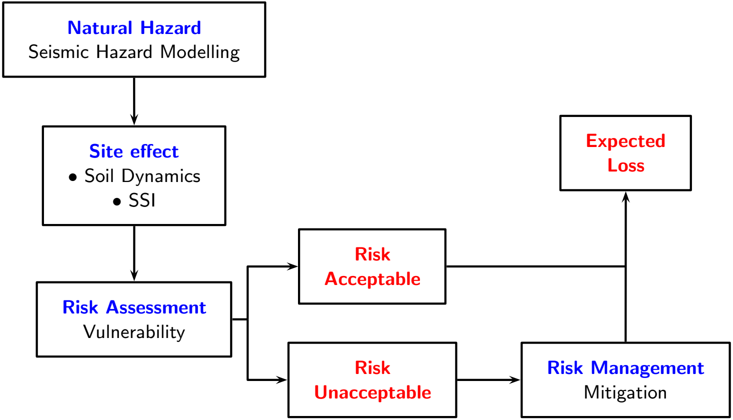
Context

Earthquake loss estimation



Global approach

- Need for understanding mechanisms controlling induced damage in earthquake loss estimation (e.g. soil foundation, structures, dams, . . .) ;
- Improve and validate traditional approaches and evaluation methods ;
- Use of numerical methods in order to facilitate the comprehension of the global problem via parametric analyses ;

- *Various uncertainties on the material properties, loading parameters and scenarios will be considered ;*
- *Probabilistic analyses as a complement of conventional deterministic analyses will be used.*

Outline

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1. Liquefaction simulation

2. Liquefaction seismic risk analysis

GEFDyn - ECP's numerical tool

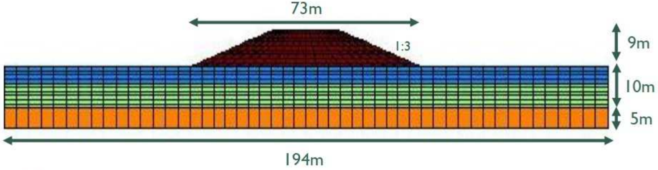
The ECP's elastoplastic multi-mechanism model [Aubry et al., 1982, Hujeux, 1985]

- The model is written in terms of effective stress,
- Coulomb type failure criterion,
- Critical state concept,
- Deviatoric primary yield surface of the k plane : $f_k(\sigma, \varepsilon_v^p, r_k) = q_k - \sin\phi'_{pp} \cdot p'_k \cdot F_k \cdot r_k$
  $F_k = 1 - b \ln\left(\frac{p'_k}{p_c}\right)$ and $p_c = p_{co} \exp(\beta\, \varepsilon_v^p)$
- Progressive friction mobilization with shear : $r_k = r_k^{el} + \frac{\int_0^t \overline{\dot{\varepsilon^p}}\, dt}{a + \int_0^t \overline{\dot{\varepsilon^p}}\, dt}$
  $a = a_1 + (a_2 - a_1)\, \alpha_k(r_k)$
- Roscoe's dilatancy law
- Isotropic yield surface : $f_{iso} = |p'| - d\ p_c\ r_{iso}$

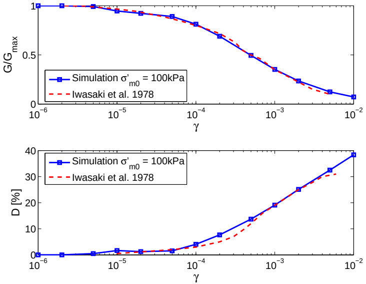
Studied case

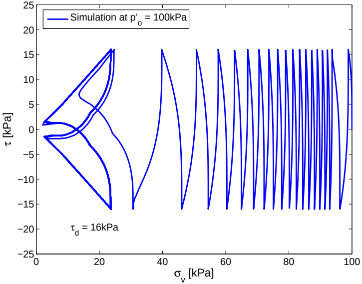
Height of the dam = 9m

Loose sand = 4m
Dense sand = 6m
Water table = 1m
(dam is kept dry)



Bedrock = 5m (Vs = 1000 m/s)

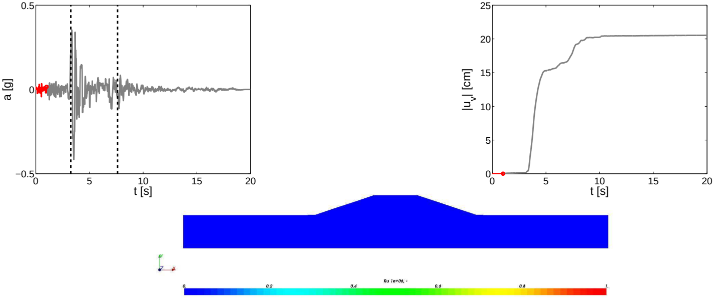




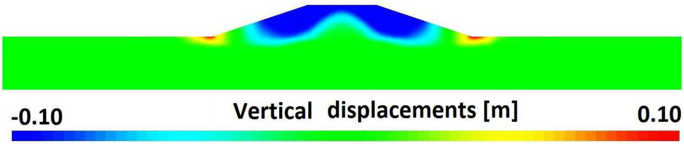
Excess pore water pressure ratio generation

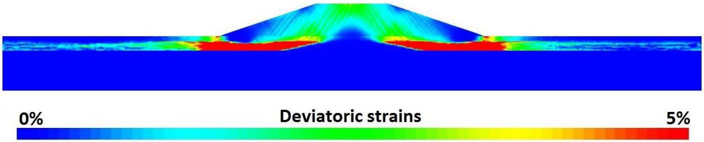
Crest settlement and $r_u = \Delta p_w / \sigma'_{v,0}$ time evolution

EQ3 : a_{max}=0.42g, t_{595}=4.3s, N_{cycles}=5



Studied case





Liquefaction risk assessment

Questions that need to be answered :

- Is the soil susceptible to liquefaction ?
- If yes, Is the apparition of soil liquefaction possible ?

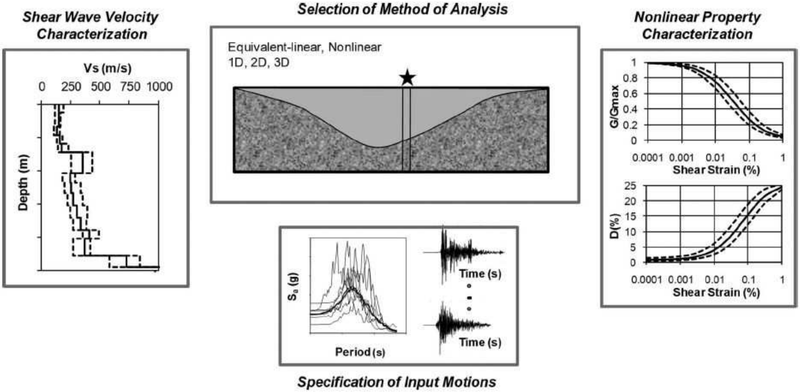
  $\Rightarrow$ For what hazard level ?
- If yes, Can damage occur ?

  $\Rightarrow$ What kind of damages ?
- Are those damages acceptable ?

  $\Rightarrow$ If no, How to minimize the damage ?

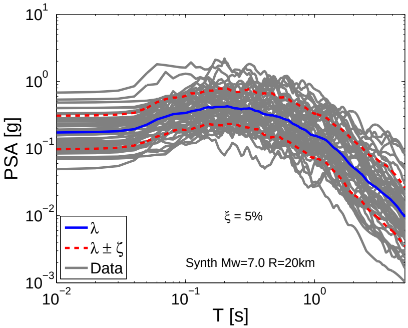
Sources of uncertainty

Sources of uncertainty in a seismic analysis

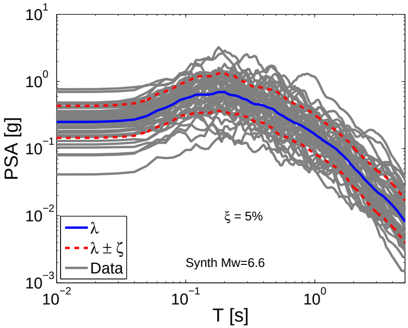


(Rathje et al 2010)

Seismic Hazard



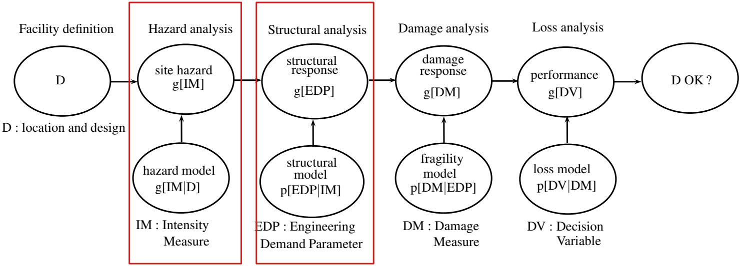
Synthetic signals M=7.0 - R=20km



Synthetic signals M=6.6 - R=16km

Outline

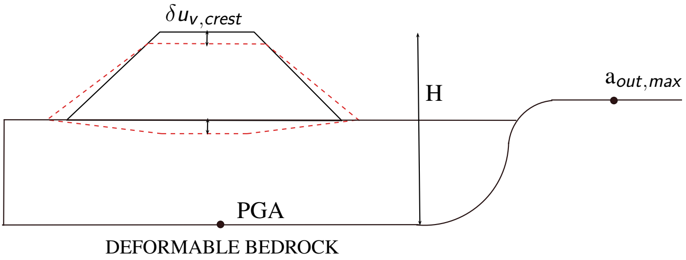
PEER's Performance-Based Earthquake Engineering Methodology



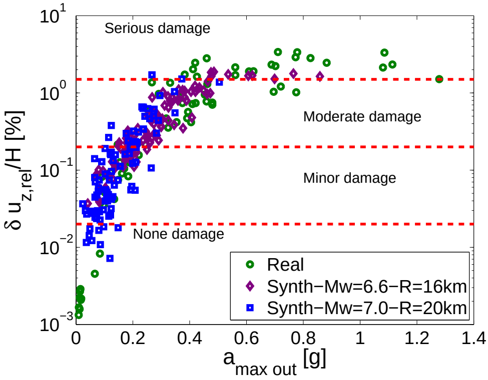
Liquefaction vulnerability analysis : identify the EDP of interest and IM for the seismic hazard

IM : maximum amplitude $a_{bed,max}$, Arias intensity (I_{Arias}), equivalent predominant period $T_{V/A}$, duration of mainshock t_{595}, number of cycles N_{cycles}
EDP of interest : settlements, excess pore water pressure ratio r_u, horizontal displacements, ...

Damage level evaluation

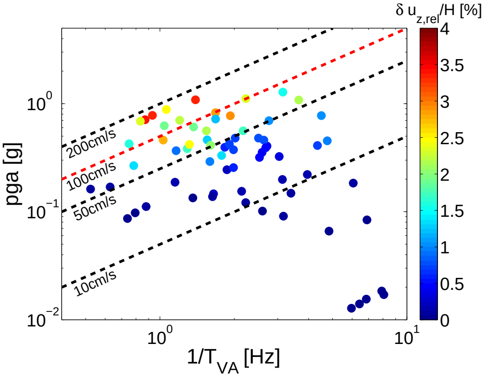


Vulnerability



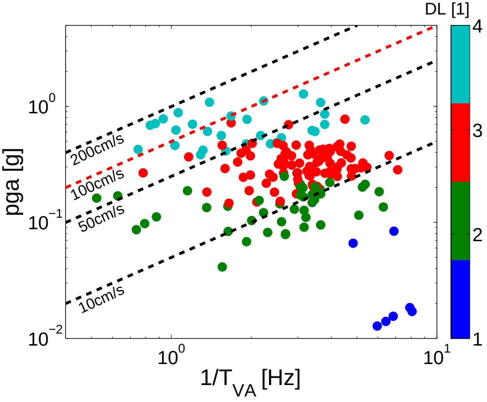
EDP : Crest settlement - IM : $a_{max\ out}$

Vulnerability



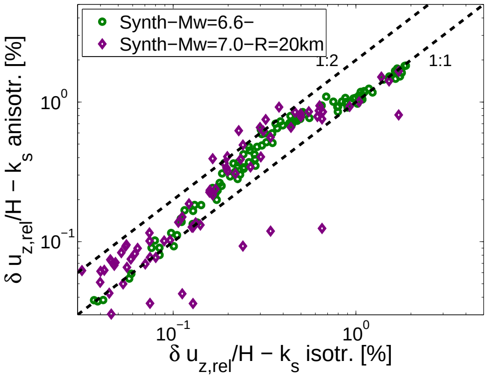
EDP : Crest settlement - IM's : $a_{max\ out}$, pgv and $T_{V,A}$

Vulnerability



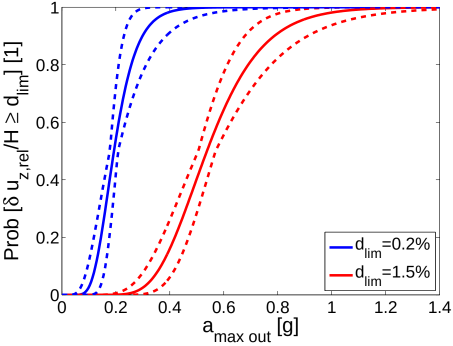
Damage level - IM's : $a_{max\ out}$, pgv and $T_{V,A}$

Vulnerability

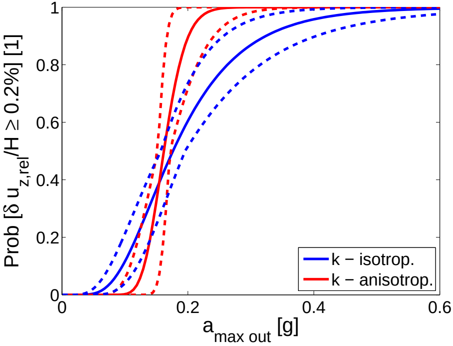


EDP : Crest settlement - Effect of k_s anisotropy - $k_h/k_v = 100$

Vulnerability : Crest settlement



Effect of damage level

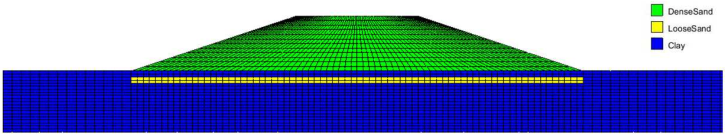


Effect of k_s anisotropy

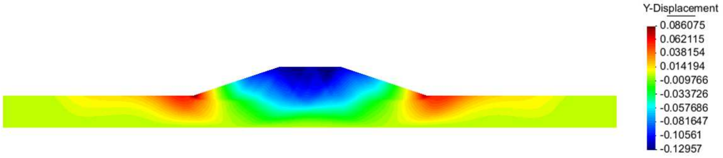
Further works

Liquefaction of soil inside levees :

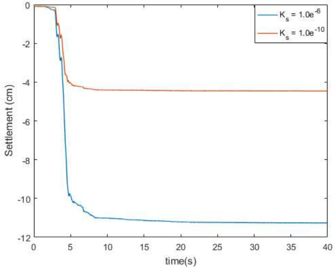
- River levees resting on nonliquefiable foundation
- Soil in the saturated zone liquefies and causes deformation to the levee
  - $\Rightarrow$ effects of the thickness of the saturated zone
  - $\Rightarrow$ effects of drainage at the boundary of the saturated zone



effects of drainage boundary conditions



$k_{s\,clay}/k_{s\,sand} = 1 \times 10^{-2}$ and 1×10^{-6}



Thank you for your attention
Merci de votre attention

Aubry, D., Hujeux, J.-C., Lassoudière, F., and Meimon, Y. (1982).
A double memory model with multiple mechanisms for cyclic soil behaviour.
In *International symposium on numerical models in geomechanics*, pages 3–13. Balkema.

Hujeux, J.-C. (1985).
Une loi de comportement pour le chargement cyclique des sols.
In *Génie Parasismique*, pages 278–302. V. Davidovici, Presses ENPC, France.