



CFMS Jeunes et groupe jeunes de l'AFPS  
Journée Technique du 3 avril 2019

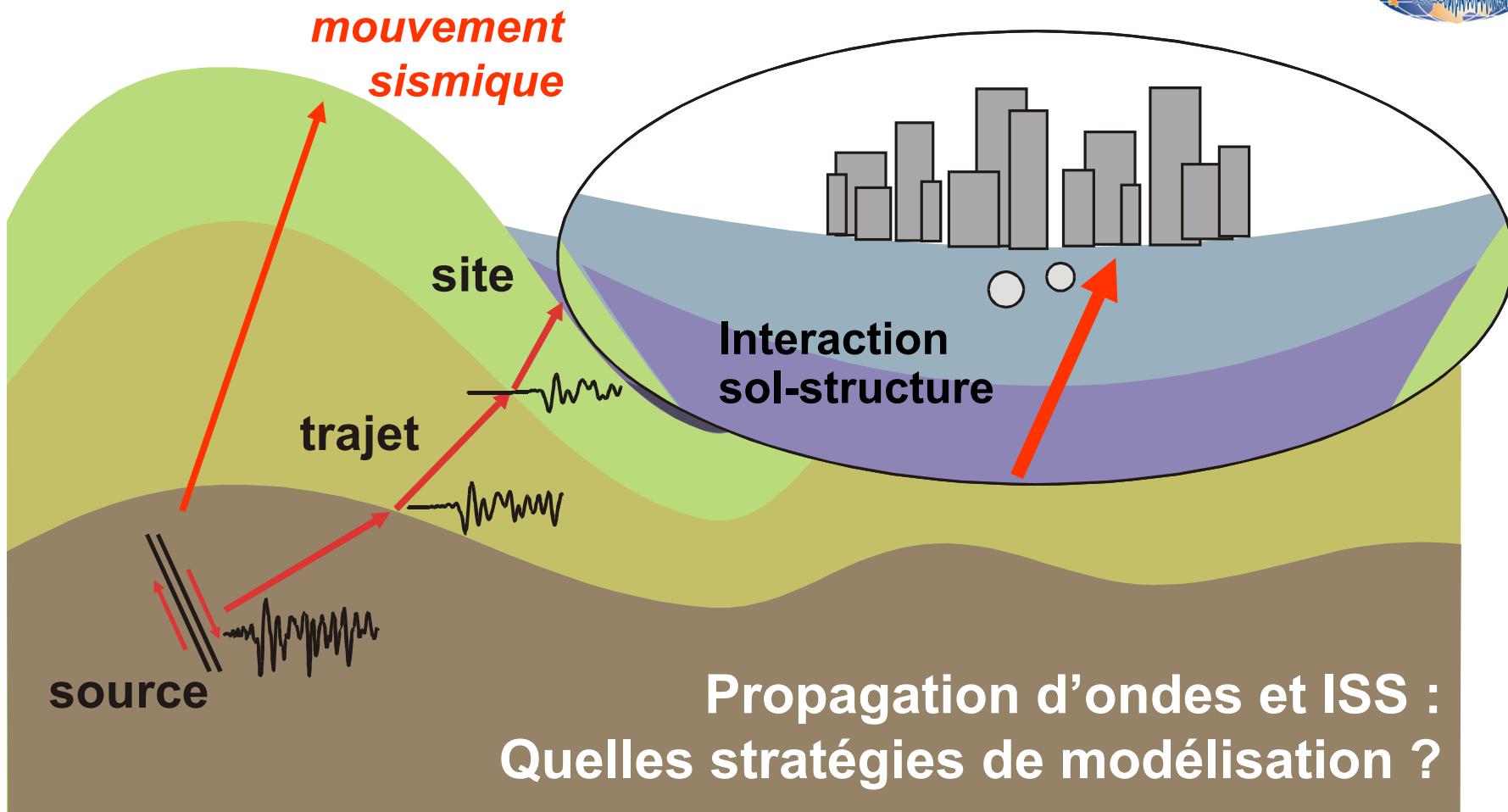
**« A la frontière entre géotechnique et parasismique »**

## **Modéliser la propagation des ondes sismiques dans les sols : *FEM, BEM, SEM et Cie***

J.F.Semblat<sup>(1)</sup>, Y.Abboud<sup>(2)</sup>, M.P.Santisi<sup>(3)</sup>, C.Varone<sup>(4)</sup>, S.Chaillat<sup>(1)</sup> et al.

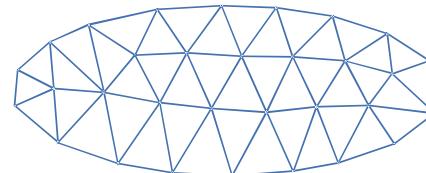
<sup>(1)</sup> ENSTA-ParisTech , <sup>(2)</sup> Terrasol , <sup>(3)</sup> Univ. Côte d'Azur, <sup>(4)</sup> ESITC-Paris/IFSTTAR

# Introduction

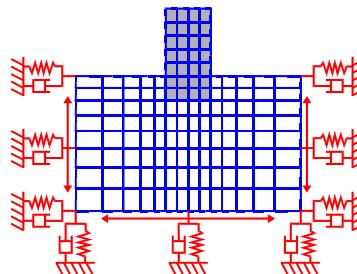


# Méthodes et mise en oeuvre

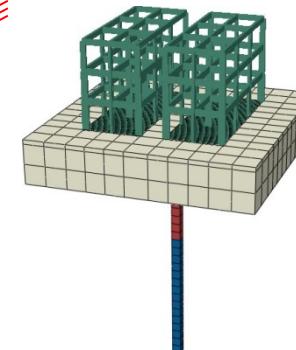
## 1. Bestiaire des méthodes



## 2. Modéliser l'infini



## 3. Couplages et ISS

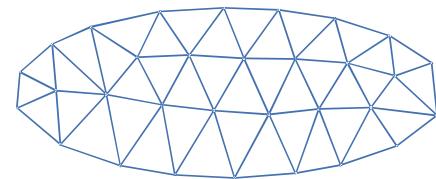


## 4. Perspectives

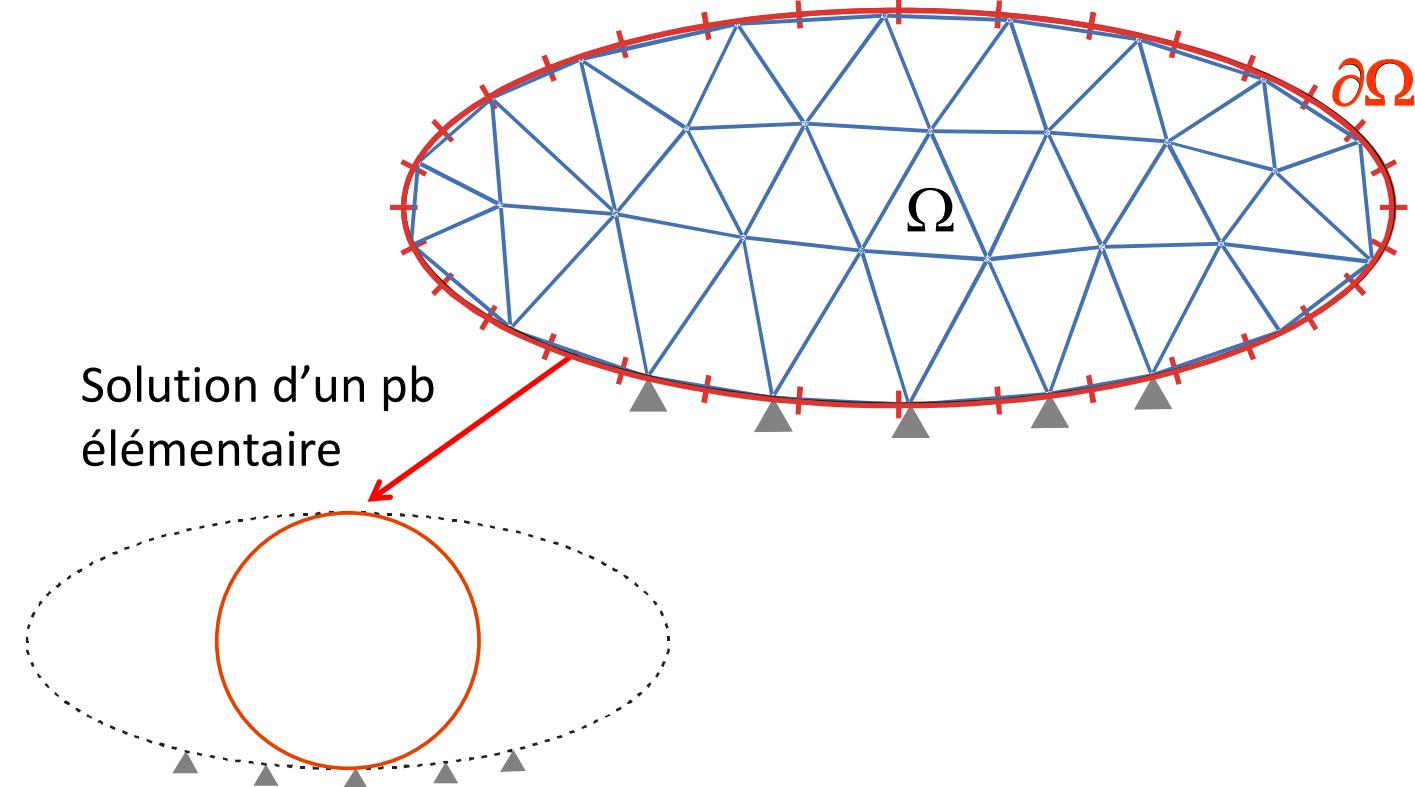




# 1/ Bestiaire des méthodes

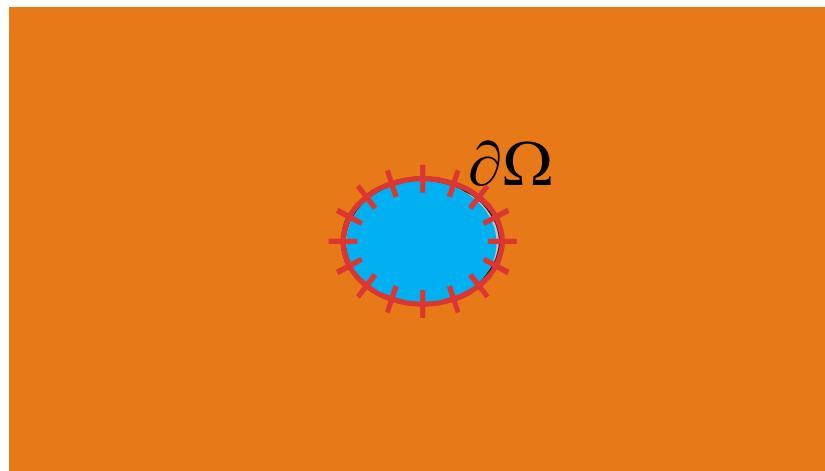


# FEM/BEM : principes



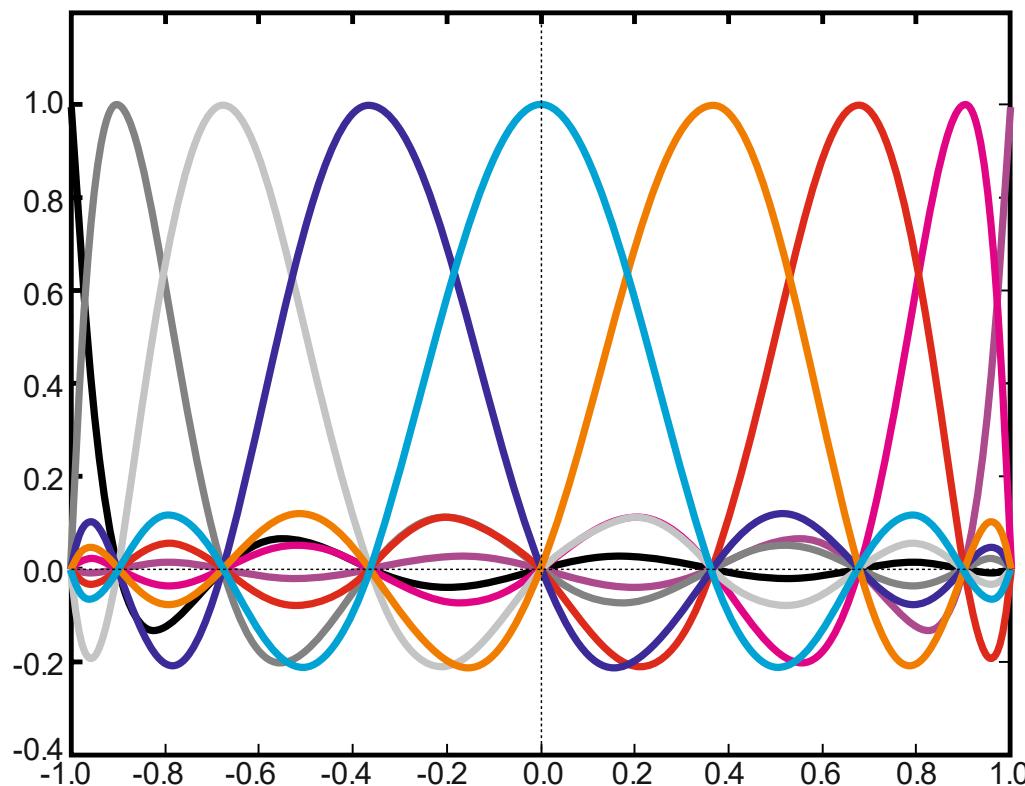
# BEM : milieu infini

- Réduction de la dimension du problème à résoudre : 3D → 2D ; 2D → 1D
- Avantages pour les problèmes en milieu infini ou semi-infini. Ex.: *cavité dans massif de sol*



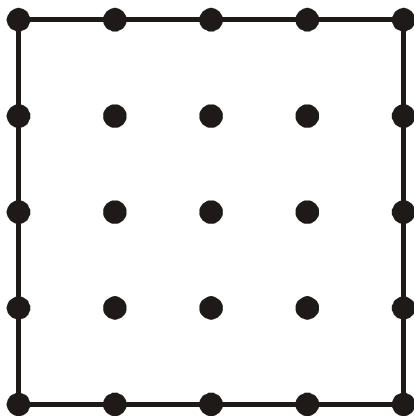
# FEM/SEM : différences

- SEM : interpolation Legendre/Tchebychev

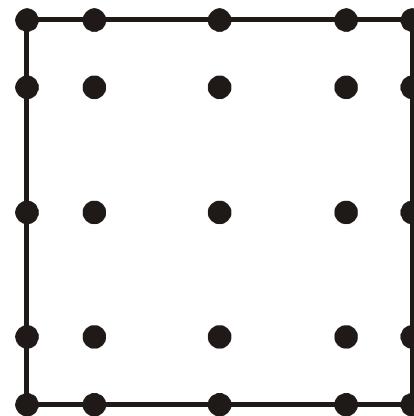


# FEM, SEM ou BEM ?

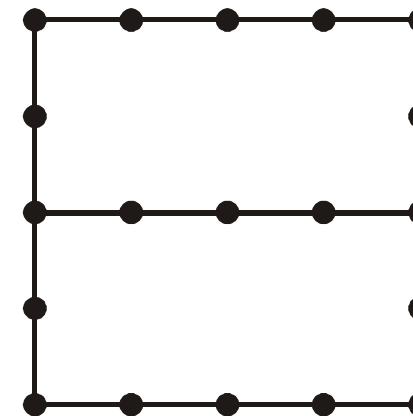
Éléments finis



Éléments spectraux



Éléments frontière



## FEM/SEM:

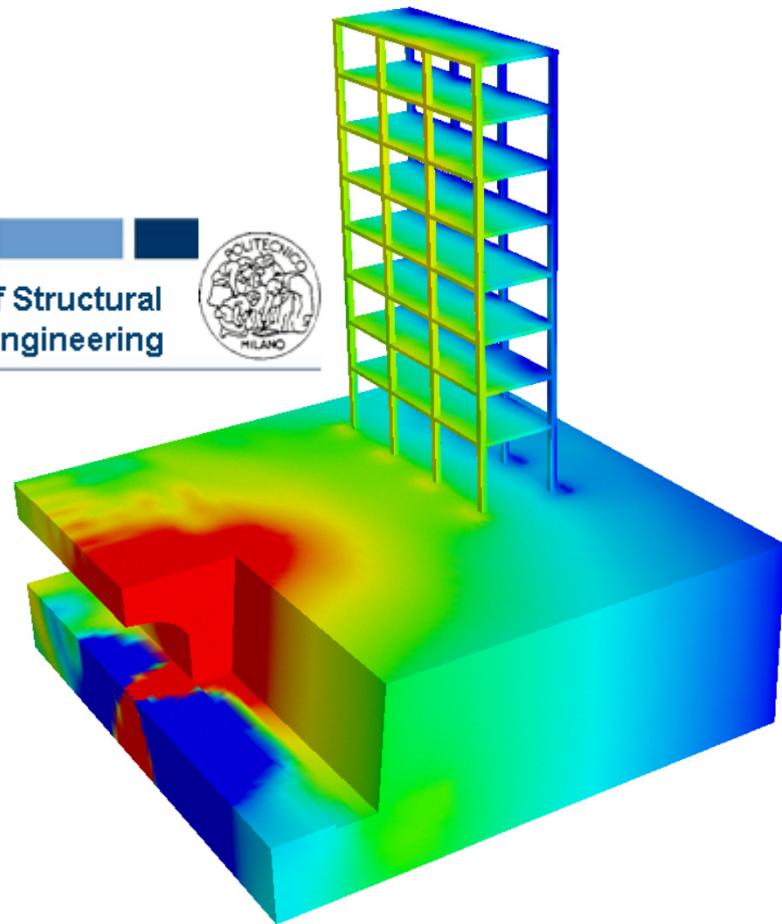
- Fortes hétérog.
- Comportements diff.
- Erreur cumulative
- Réflexions parasites

**couplage,  
méthodes  
hybrides**

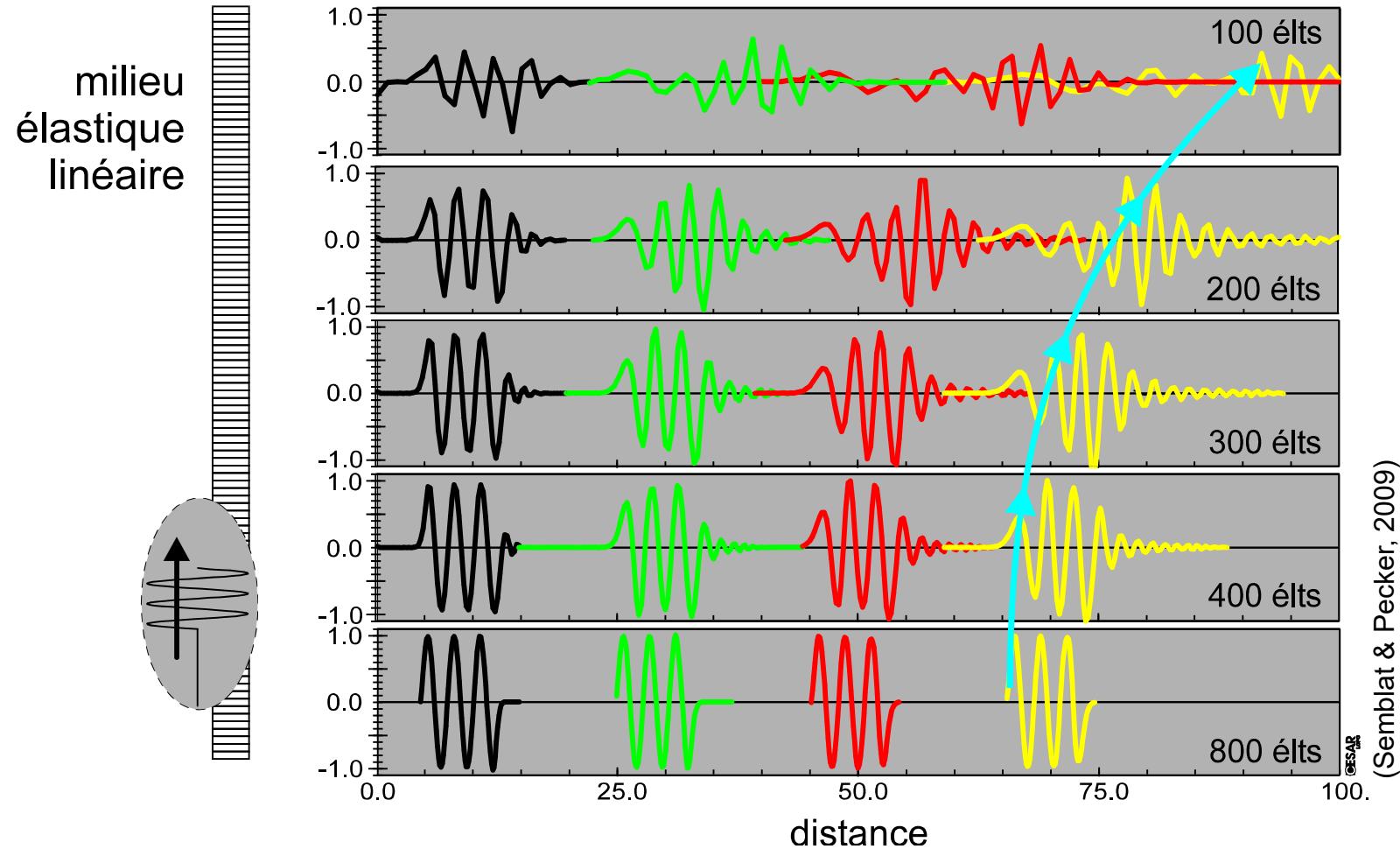
## BEM:

- Faibles hétérog.
- Comportem<sup>t</sup> linéaire
- Pas d'erreur cumulative
- Milieux infinis

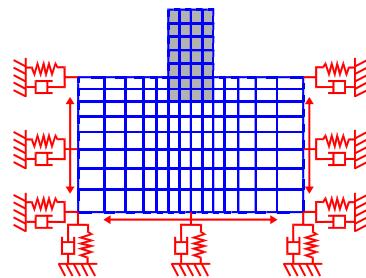
# SEM : exemple 1



# FEM/SEM : erreurs numériques



## 2/ Modéliser l'infini



# FEM/SEM : troncature

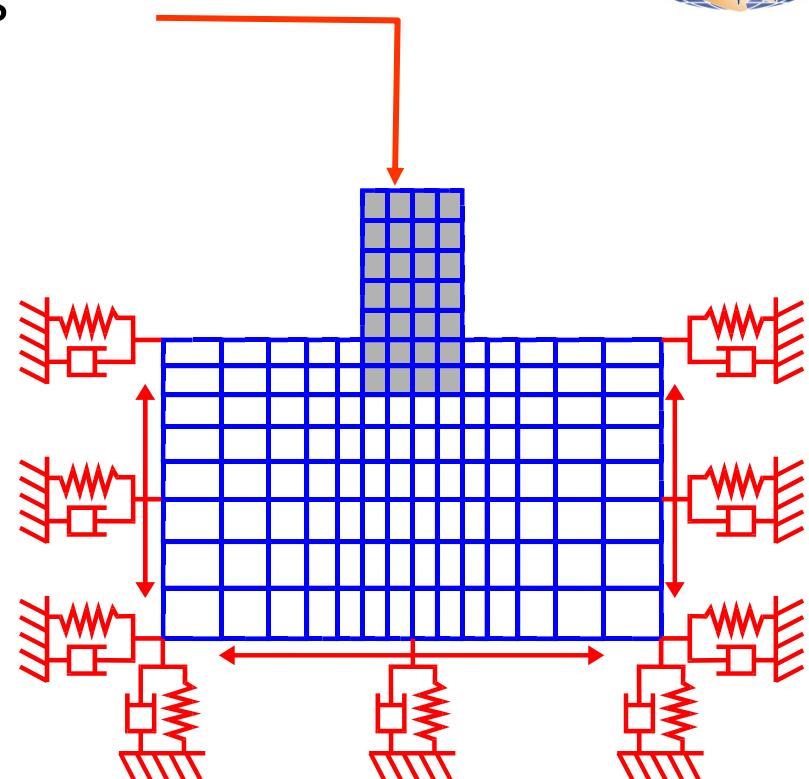
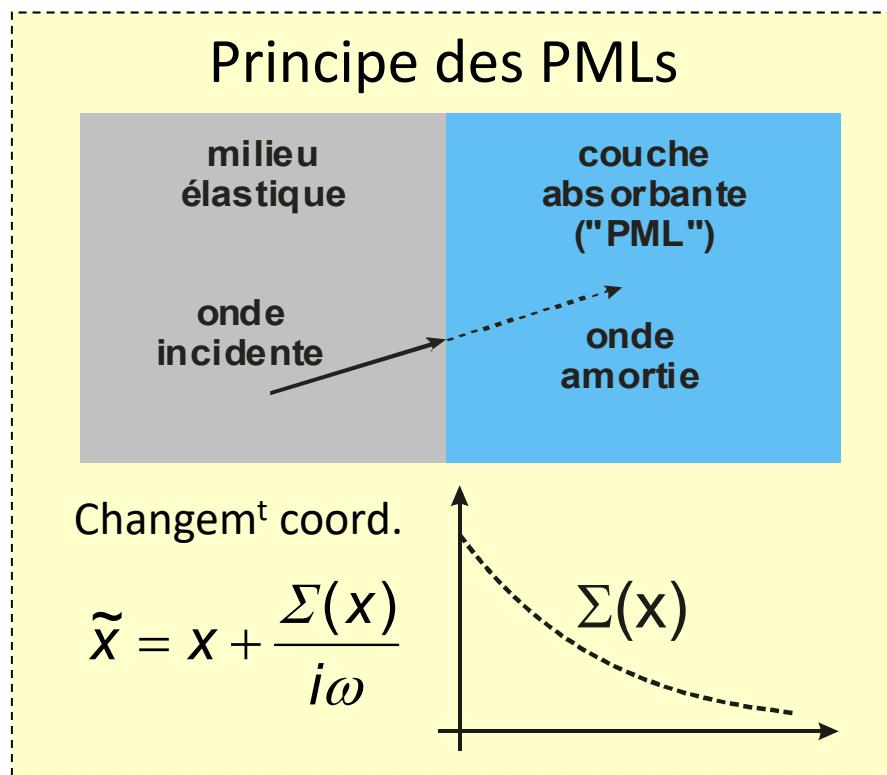


CESAR

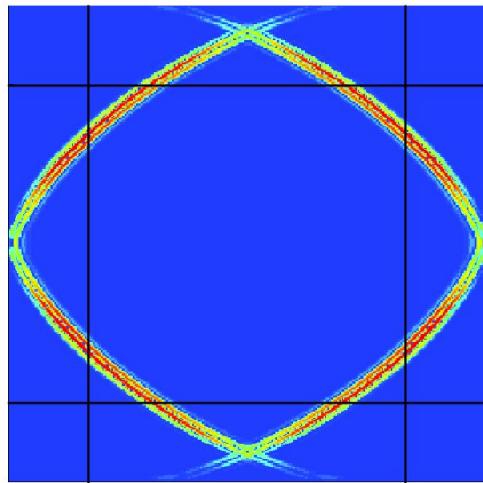
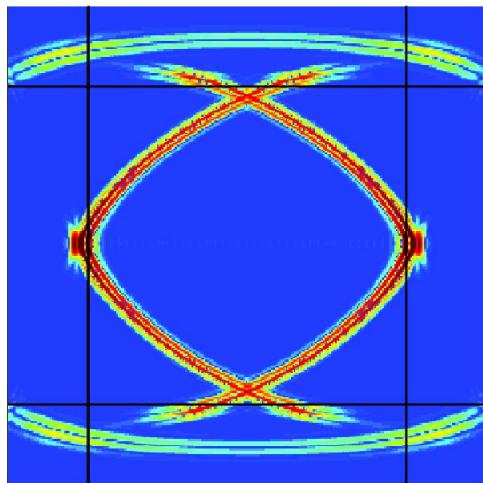


# FEM/SEM : frontière/couches abs.

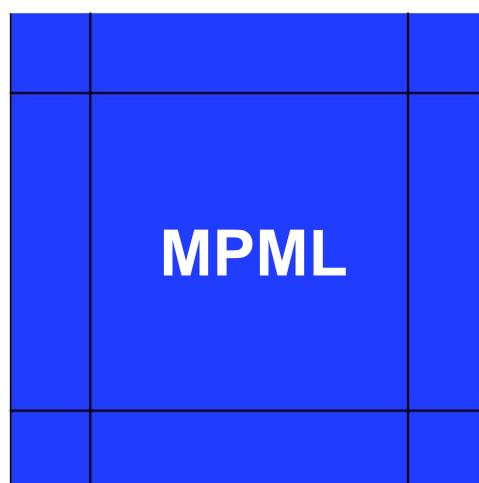
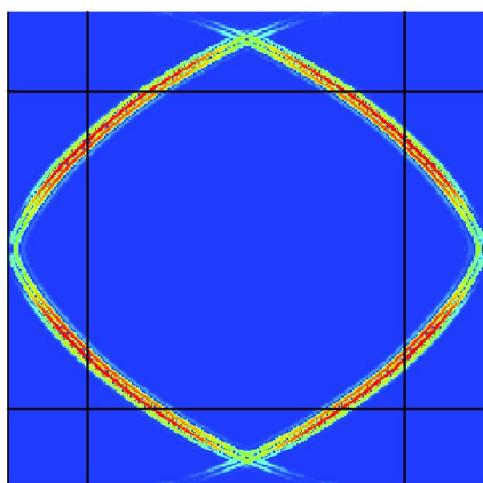
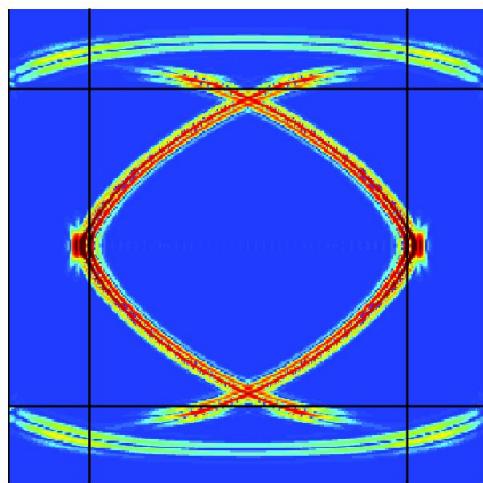
- Frontières absorbantes classiques
- Éléments infinis
- Couches absorbantes ("PML")



# FEM/SEM : PML multiaxiales



**PML  
classique**

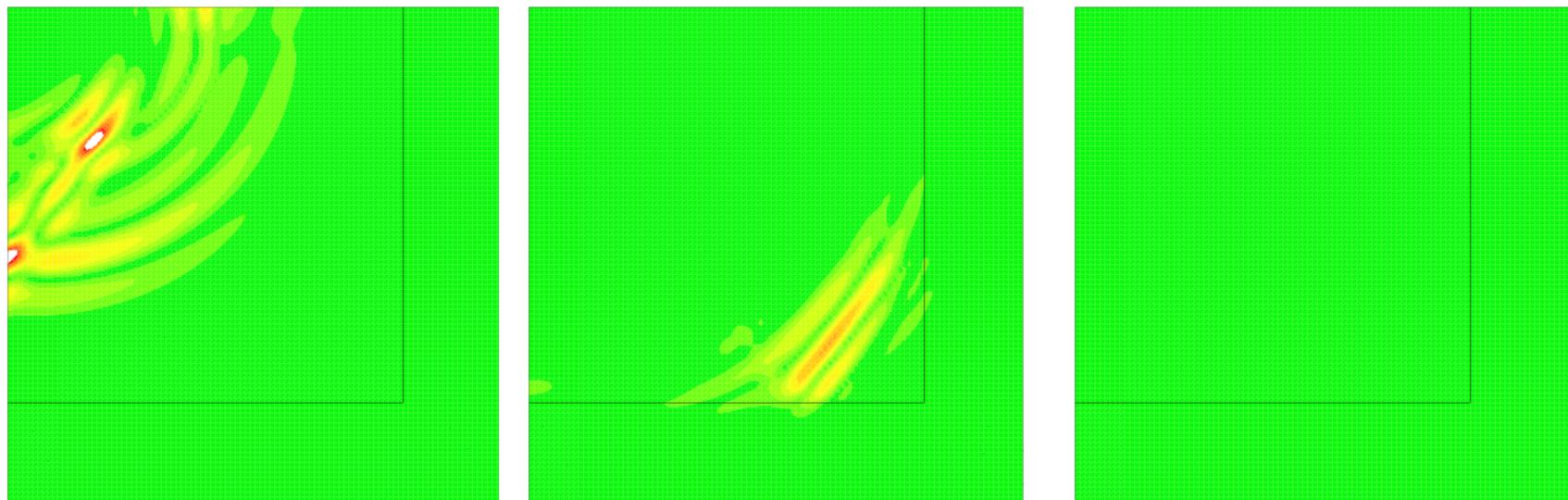


**MPML**

(Meza-Fajardo & Papageorgiou, 2008)

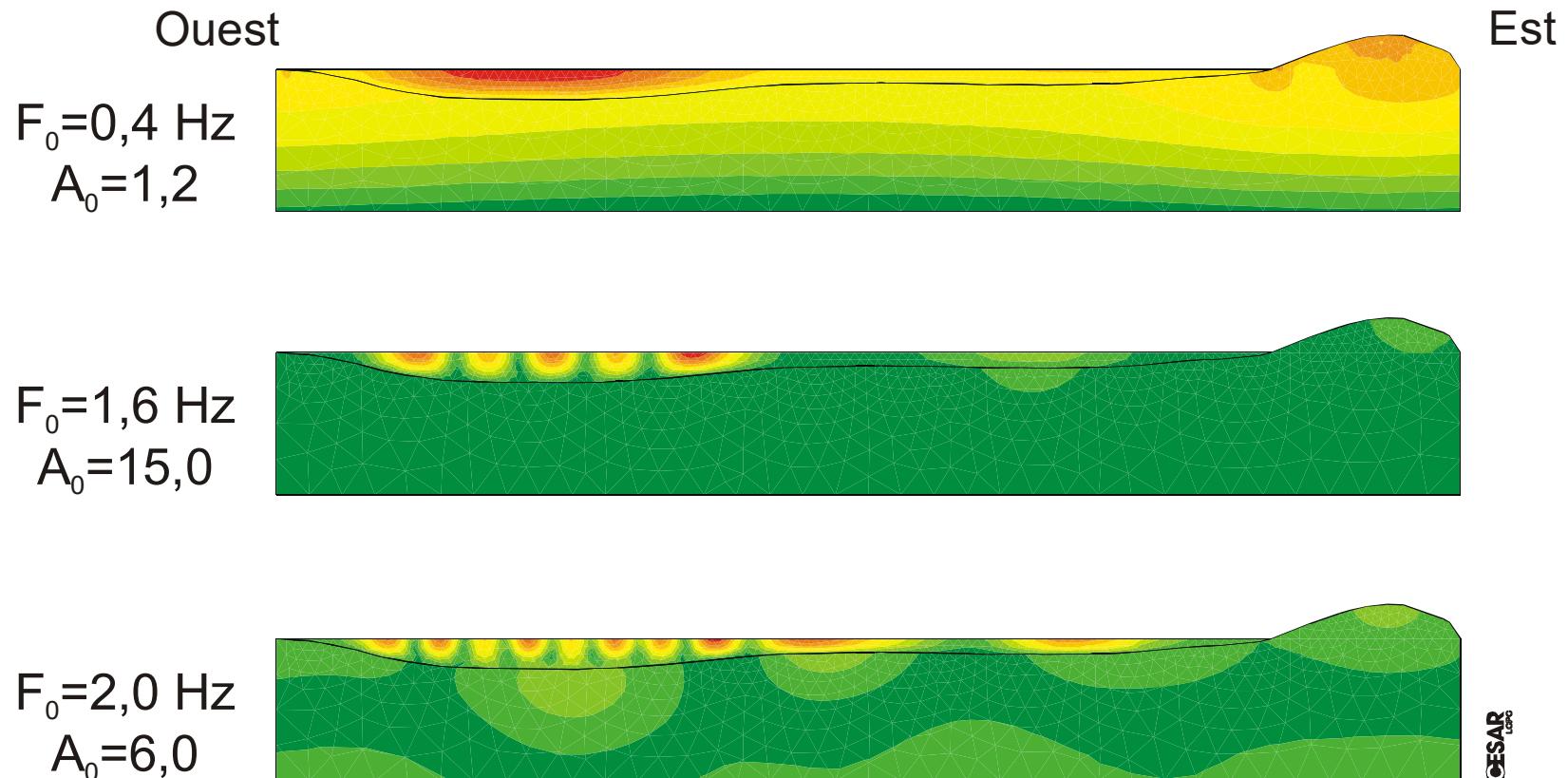
# FEM/SEM : couches absorbantes

- Couches absorbantes « simples » :
  - Couches avec amortissement de Rayleigh,
  - Amortissement homogène ou variable (« CALM »)

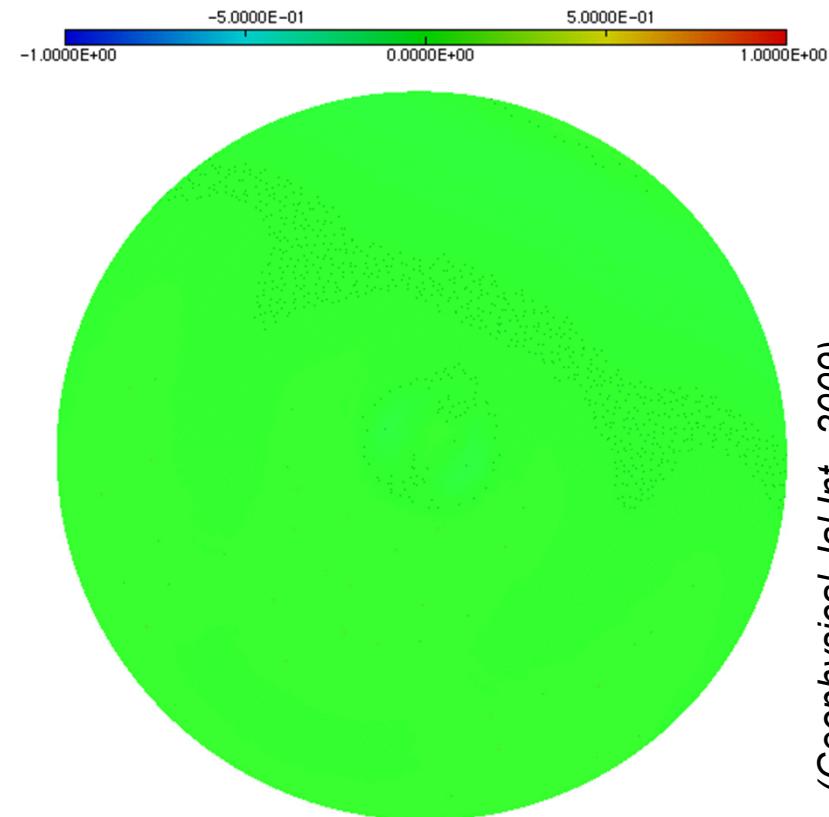


(Semblat, Lenti, Gandomzadeh, 2011)

# BEM : exemple 1



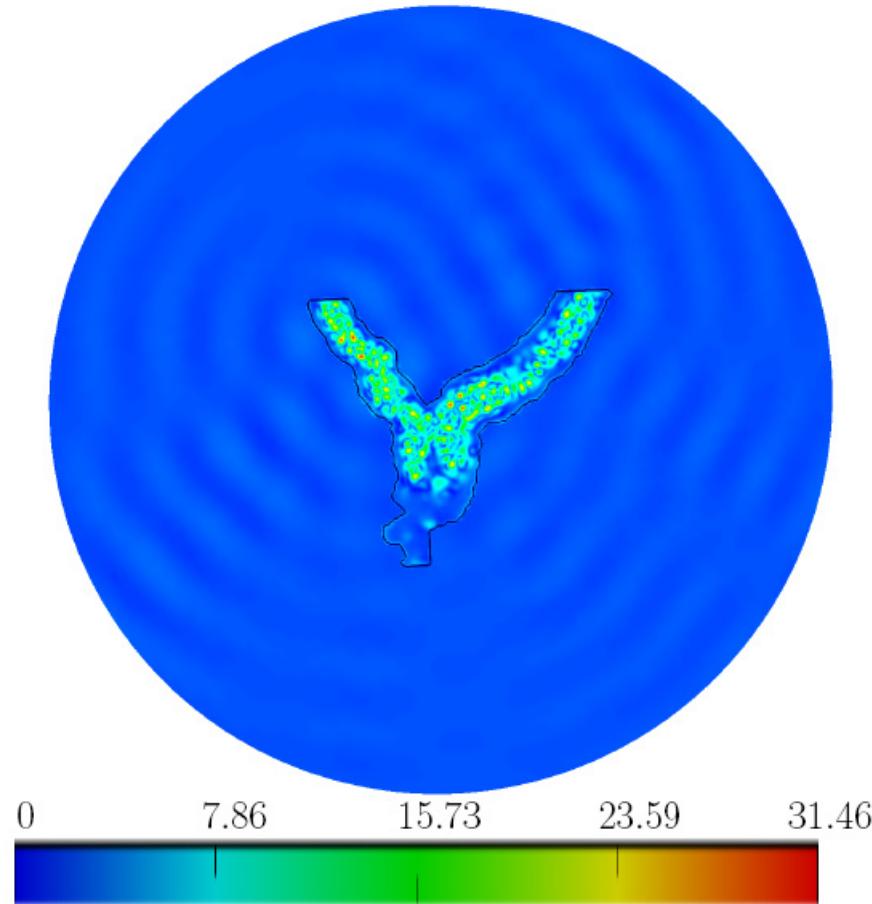
# BEM : exemples 3D



(Geophysical Jnl Int., 2009)

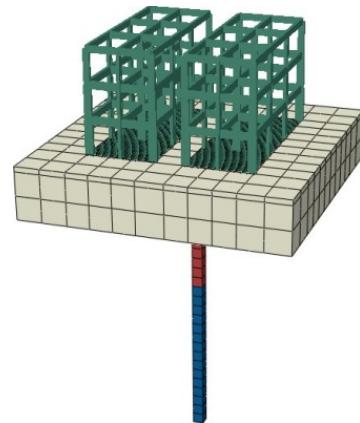
# BEM : exemples 3D

- Bassin Grenoble
- Onde plane
- Module du déplacement vertical à  $f=0.6\text{Hz}$
- Calcul :  
 $N=141288$   
747 itérat. avec précondition.



(S. Chaillat, J-F Semblat, M. Bonnet, CiCP, 2012)

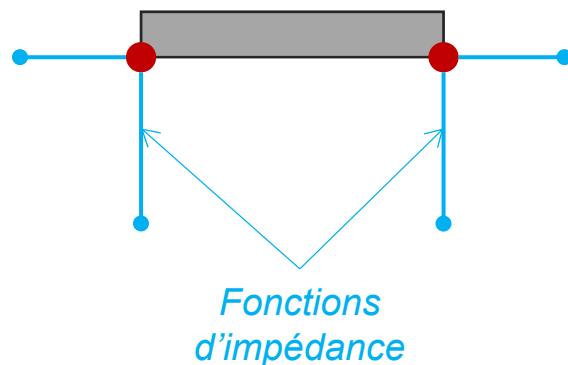
### 3/ Couplages et ISS



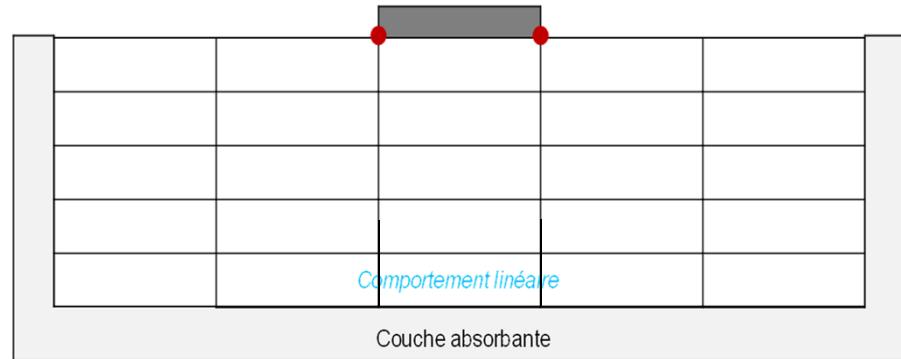
# ISS : modélisation FEM

- Approche « macro-élément » :

Méthode classique (SMM)



Nouvelle approche hybride (HMM)

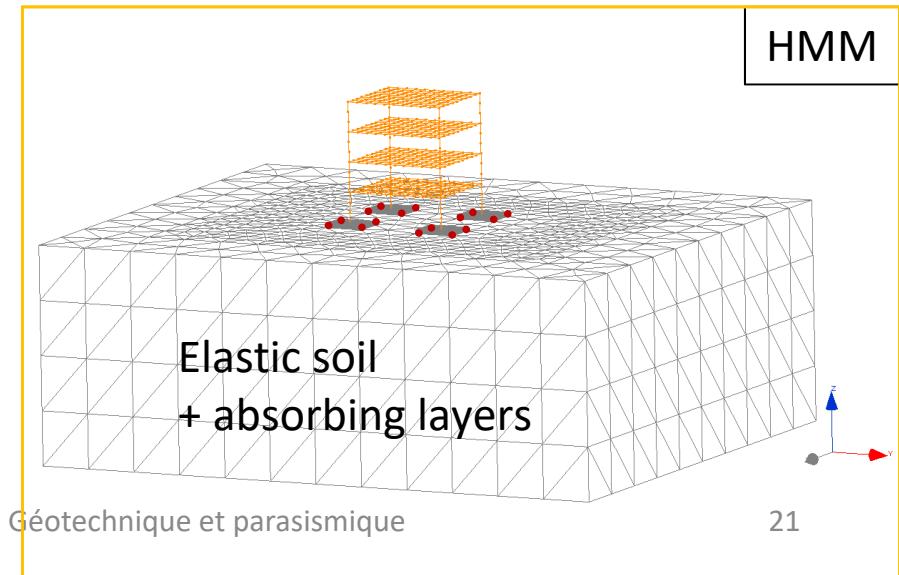
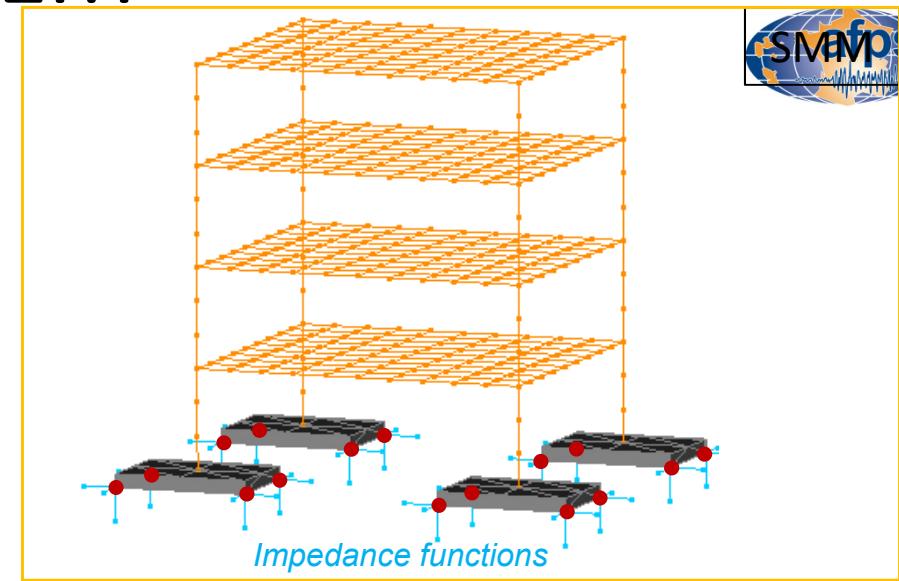
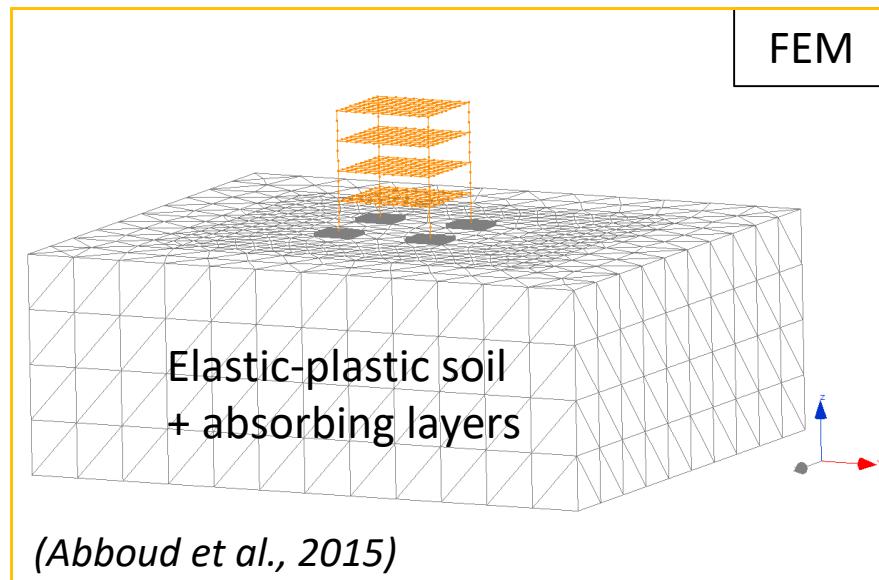


- 3 mécanismes plastiques :
  - glissement,
  - capacité portante,
  - basculement

(Abboud et al., 2015)

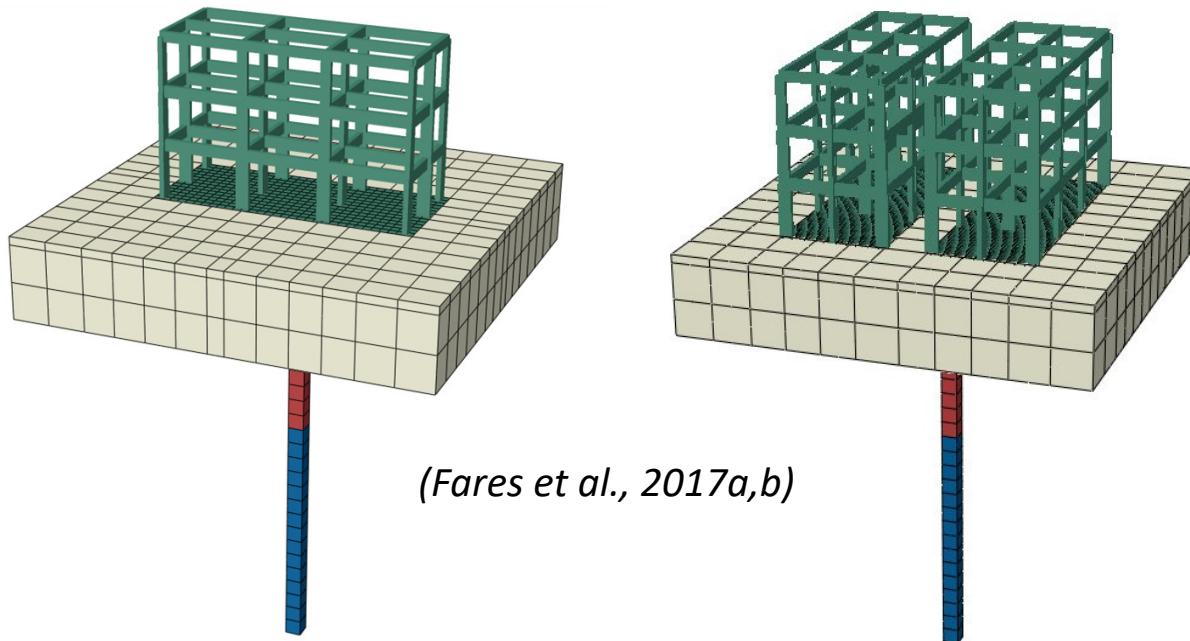
# ISS : modélisation FEM

- Macro-élément : alternatives



# ISS : couplage FEM « 1D-3D »

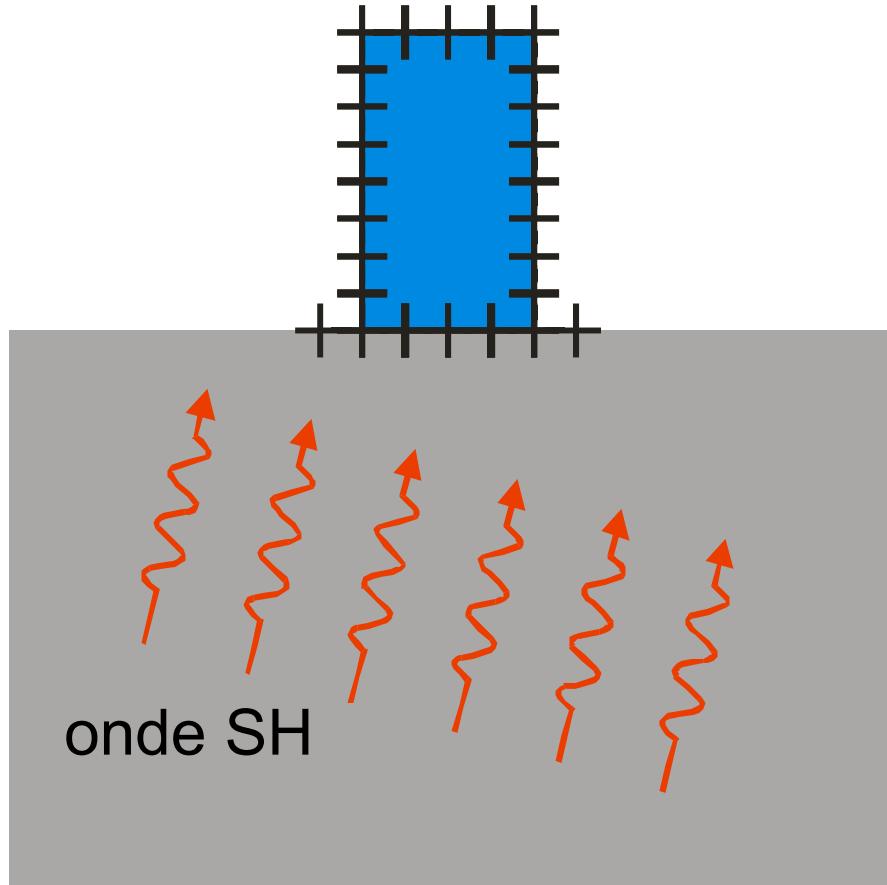
- ISS :  
modèle  
en « T »



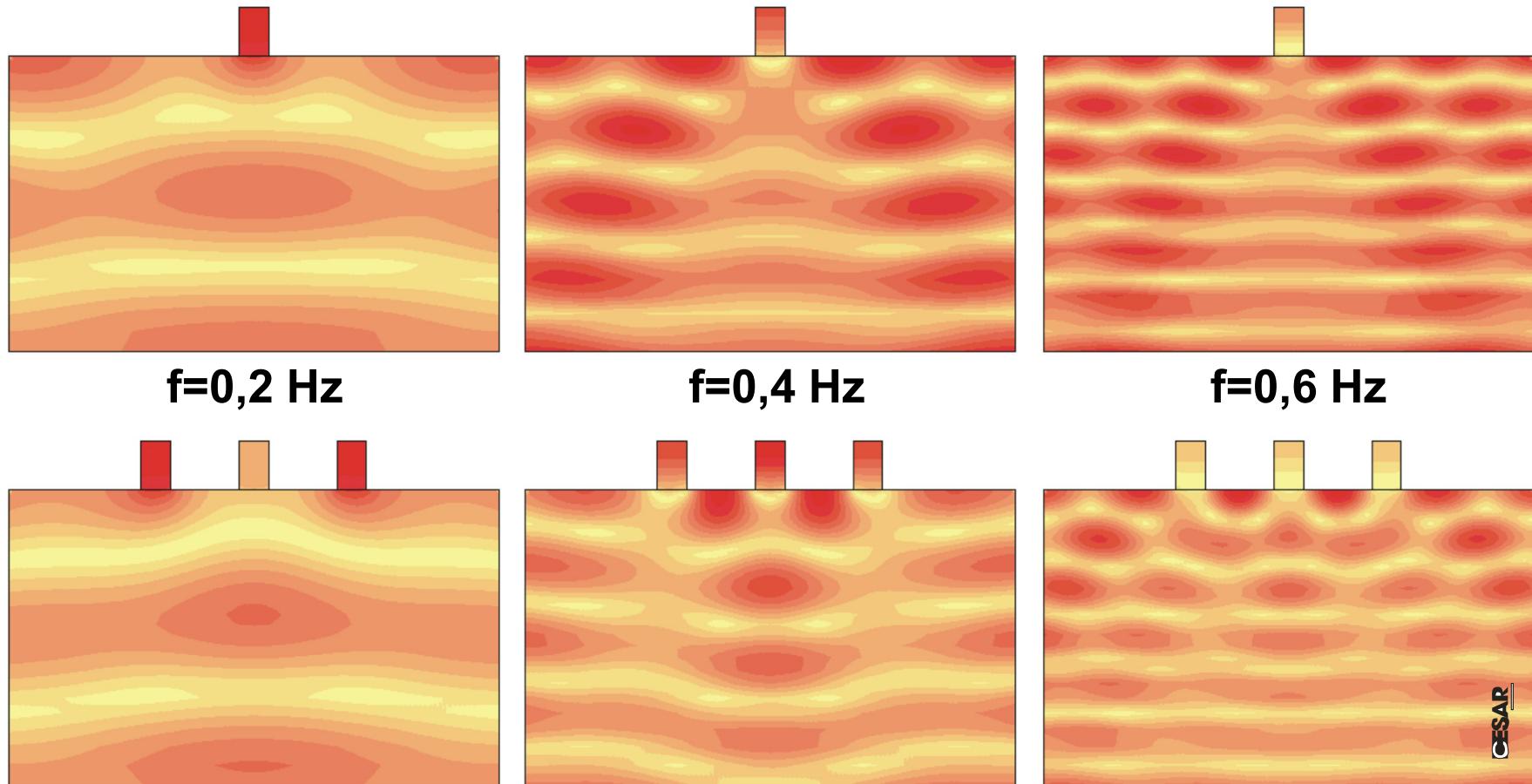
- Réponse de la **fondation superficielle** incluse
- L'interaction **structure-sol-structure** peut être étudiée
- **Réduction du temps de modélisation / calcul** (7 fois plus faible)

# ISS : analyse BEM

- *Problème idéalisé :*  
bâtiment/sol homogènes  
et élastiques + onde plane  
⇒ interaction dynamique  
sol-structure
- Modèle élts frontière:  
analyse en régime  
dynamique stationnaire  
⇒ fréquences



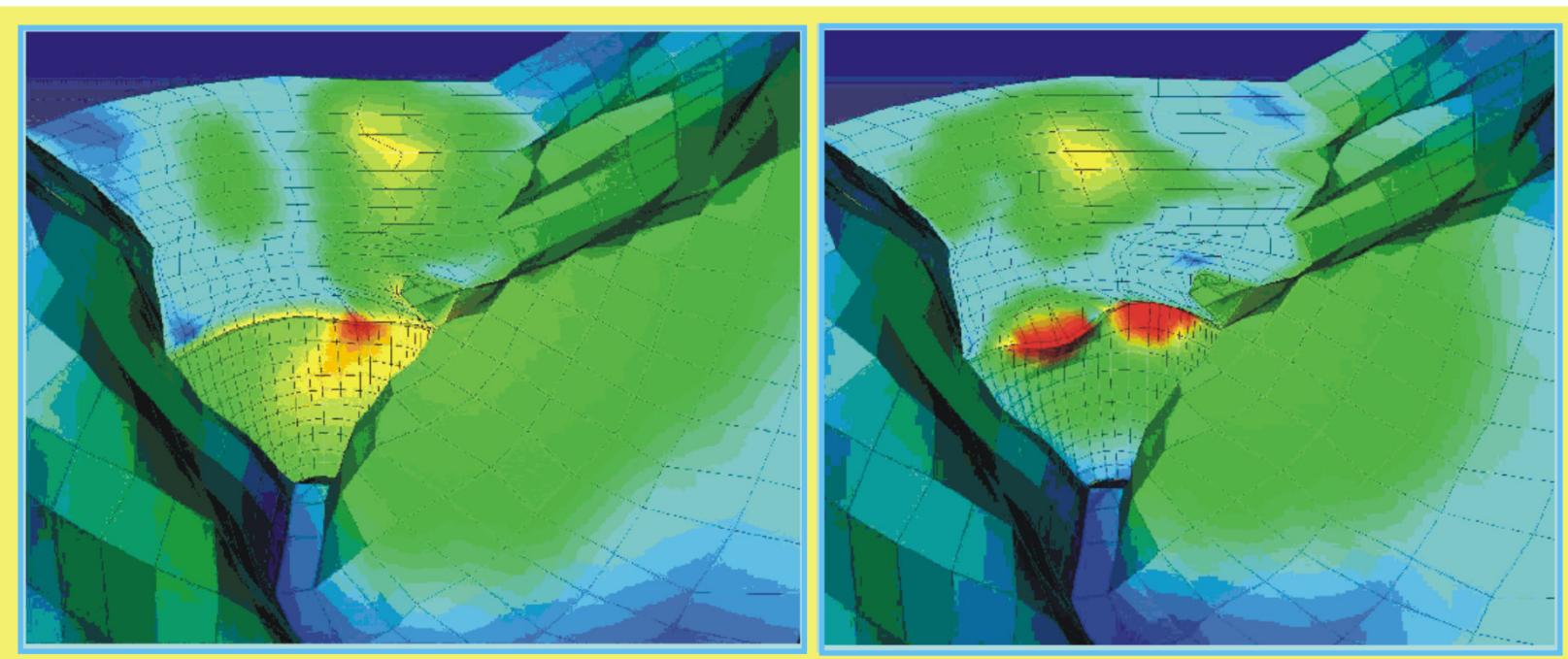
# ISS : analyse BEM



# ISFS : analyse BEM

## Barrage sous séisme

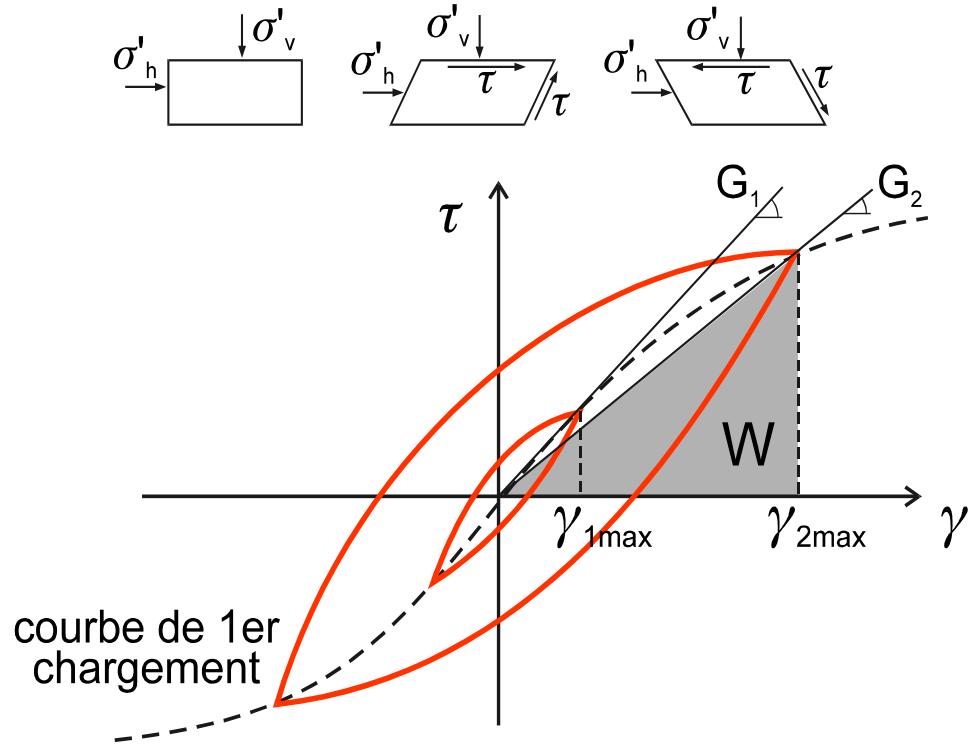
- BEM 3D
- ISS + IFS



## 4/ Perspectives

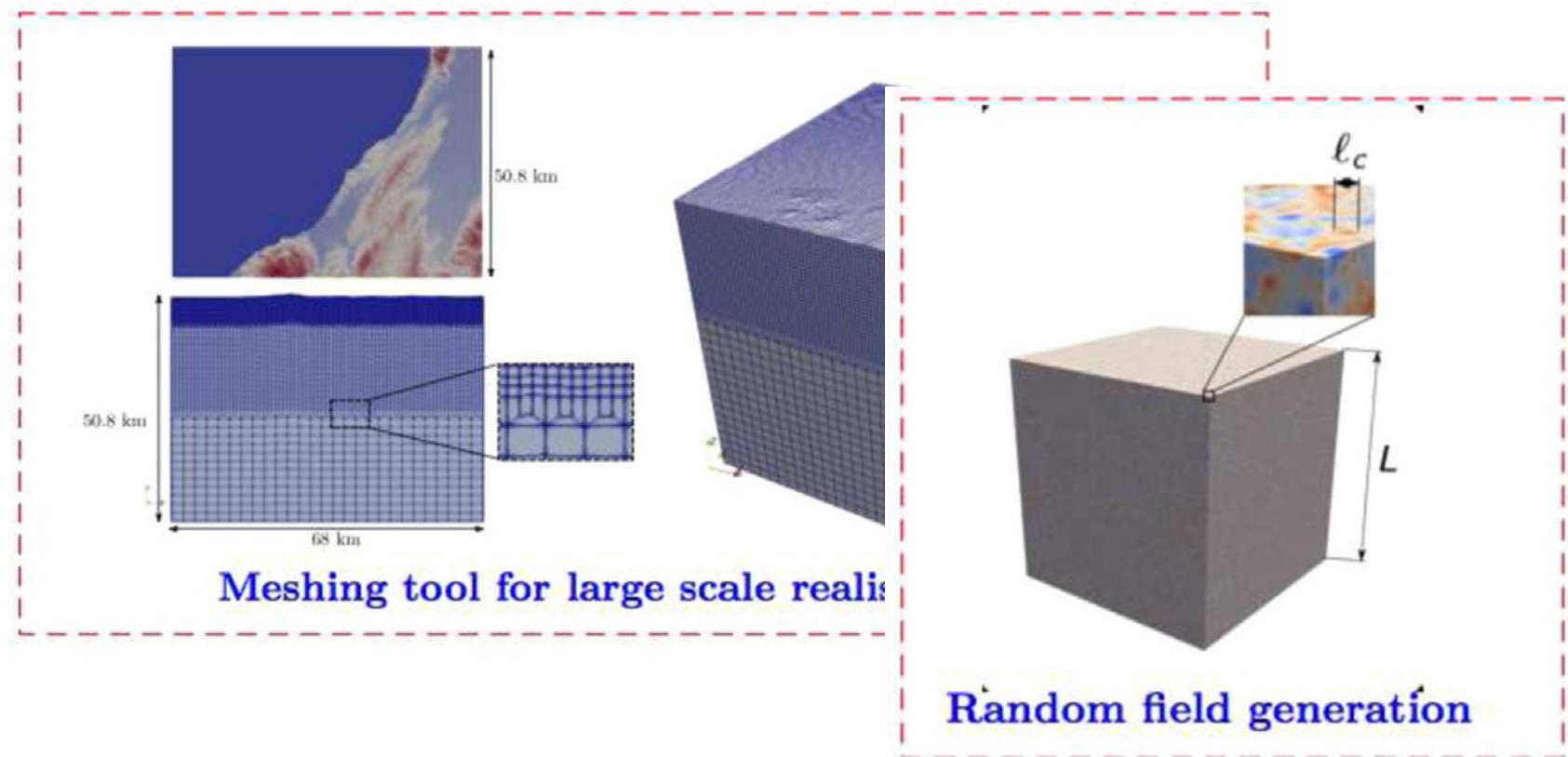


# Séismes forts/sols saturés



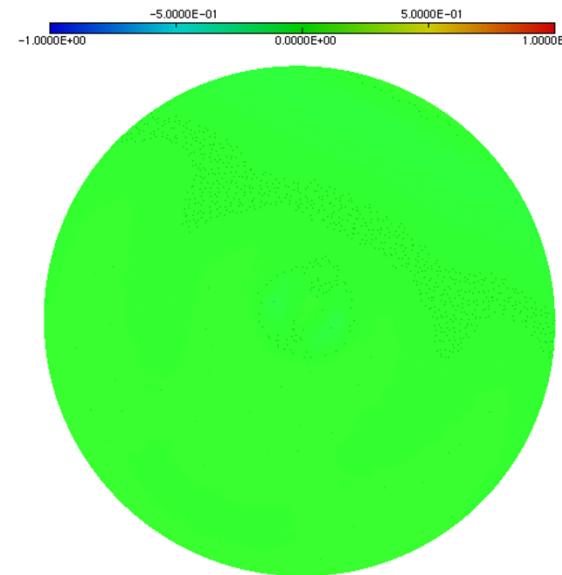
# Variabilité propriétés

- Gatti et al. (SDEE, 2018)



# Questions

[https://www.researchgate.net/profile/Jean-Francois\\_Semblat](https://www.researchgate.net/profile/Jean-Francois_Semblat)



(Meza-Fajardo et al., BSSA, 2016)

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# Références

[https://www.researchgate.net/profile/Jean-Francois\\_Semblat](https://www.researchgate.net/profile/Jean-Francois_Semblat)



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