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Users Day

1D site effects including spatial variability of soil properties

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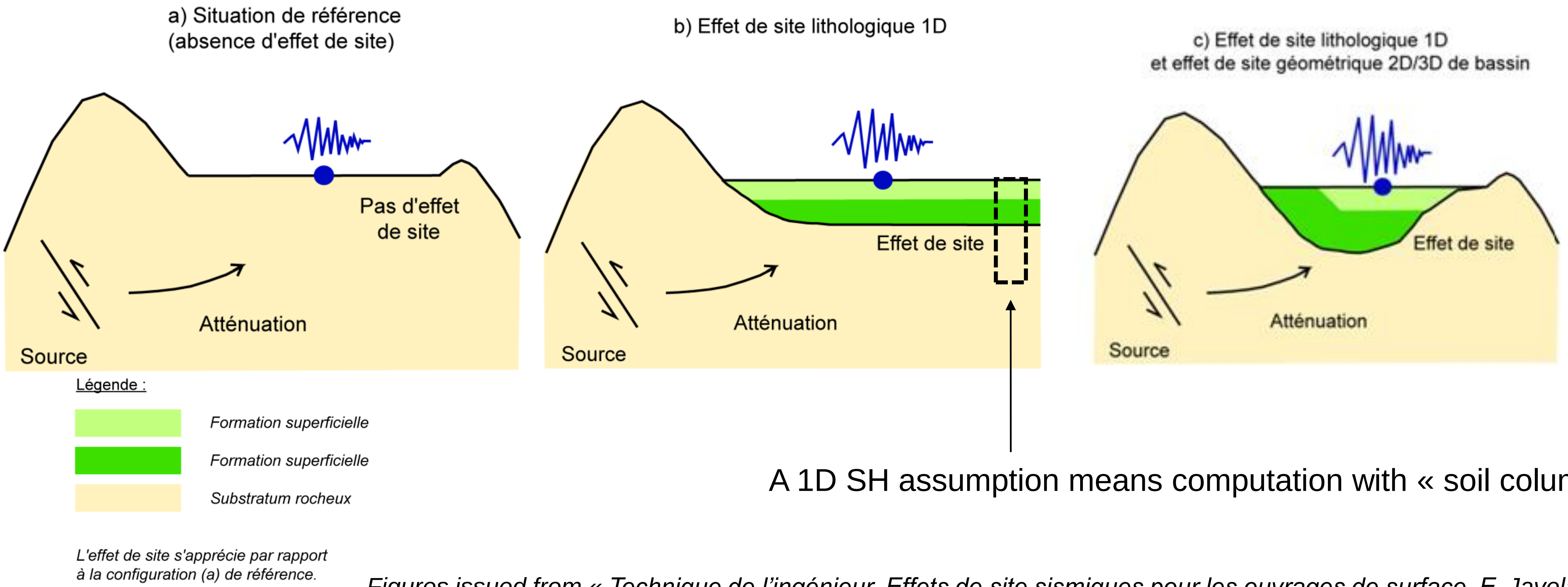
EDF

SOMMAIRE

1. Motivation – Evaluation of 1D seismic site effects (1/2)

A 1D seismic site effects' study consists in ***computing the modification of seismic waves*** (modification in terms of ***amplitude*** (amplification or attenuation), ***frequency*** and ***duration***) in superficial geological layers (typ. first 500m depth) without any geometrical effect.



A 1D SH assumption means computation with « soil columns »

Figures issued from « Technique de l'ingénieur, Effets de site sismiques pour les ouvrages de surface, E. Javelaud »

1. Motivation – Evaluation of 1D seismic site effects (1/2)

The study of local site effects is an important part of the assessment of seismic hazard since damage due to an earthquake may thus aggravated (e.g. 1985 Mexico City earthquake). The knowledge of ***superficial geological layer*** with their ***dynamic characteristics*** are then ***factors of prime importance*** in the evaluation of seismic site effects.

The assessment of a reliable seismic site effects should be not only based on ***laboratory and on-site measurements*** but also should integrate ***uncertainties carried by the measures/models***.

2. Sources and classification of uncertainties (1/2)

The three main sources of uncertainties identified in geotechnics are (guideline PEER 2002-16, guideline EPRI 1050):

- the ***natural variability*** of the soil;
- the ***uncertainties of the measure***;
- the ***uncertainties related to the modelling***;

The three main sources of uncertainties could be grouped into two categories:

- the ***aleatoric uncertainty***: natural variability of phenomena;
- the ***epistemic uncertainty***: lack of knowledge or simplification of the reality;

=> In real life, not so easy to quantify both types of uncertainty separately!
=> In the current study, only the total uncertainties are evaluated.

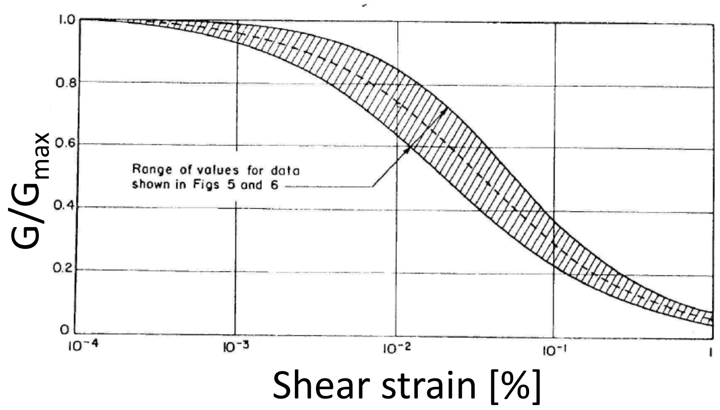
2. Sources and classification of uncertainties (2/2)

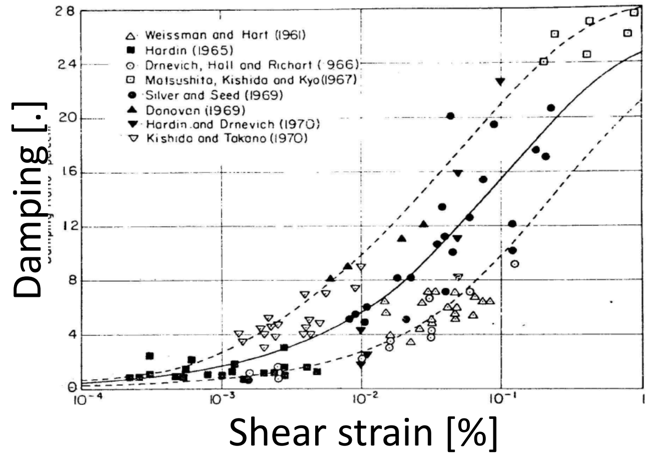
A model of soil column is a mechanical system, characterized by:

- **mass** = density + height of geological layers,
- **stiffness** = initial shear modulus (G_{max}) ;
- **damping** = material (D) and radiative damping.

… Except that the stiffness (G) and the damping (D) evolve according to the shear strains of the geological layers:

➔ Need to get degradation curves ***G/G_{max}-gamma*** et ***D-gamma*** of each geological layer.





The identified sources of uncertainties taken into account in the evaluation of 1D site effects are :

- Uncertainties on the **shear wave velocity profile**,
- Uncertainties on the **stratigraphy** (top of the geological layers),
- Uncertainties on GG-g (stiffness) and D-g (damping) **degradation curves**.

3. Uncertainty quantification

Objective :

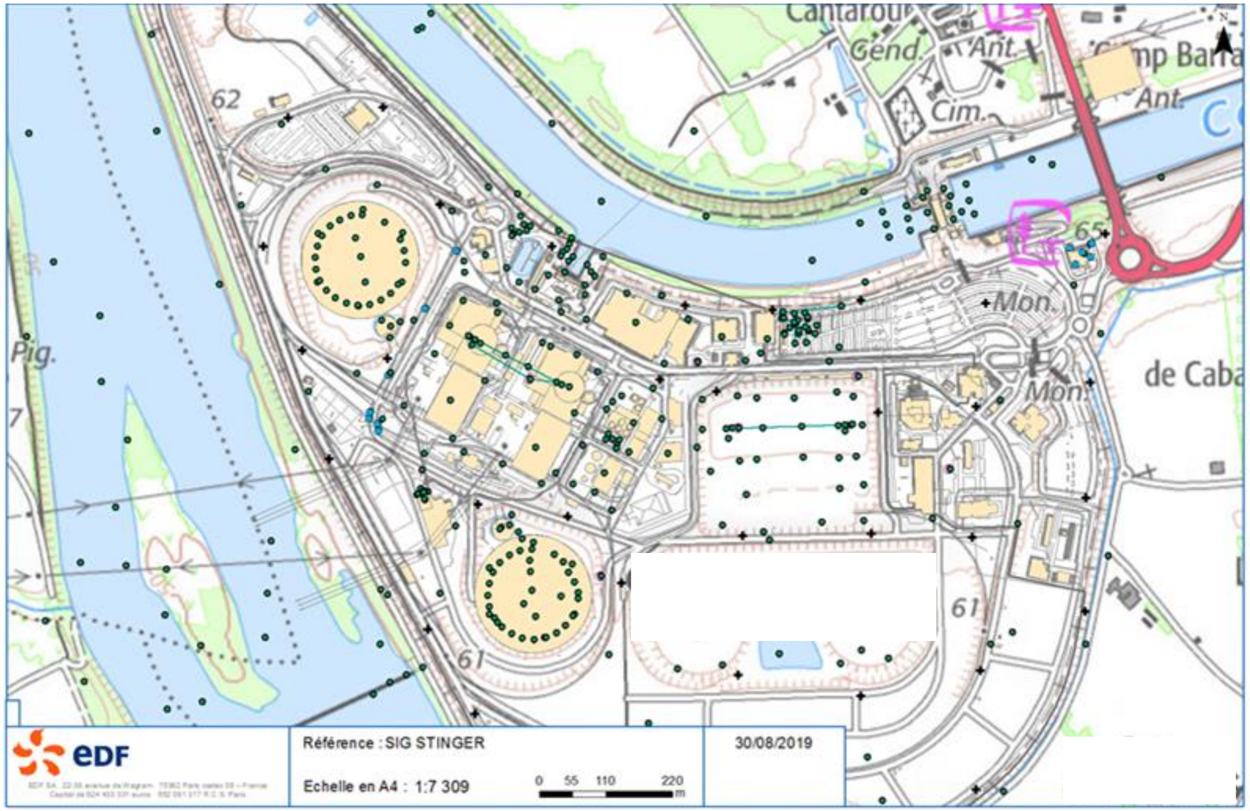
- **N** (integer) **numerical evaluations** of the 1D SH wave propagation from the seismic bedrock to the free field with variabilities allowing to **cover uncertainties** of soil properties.

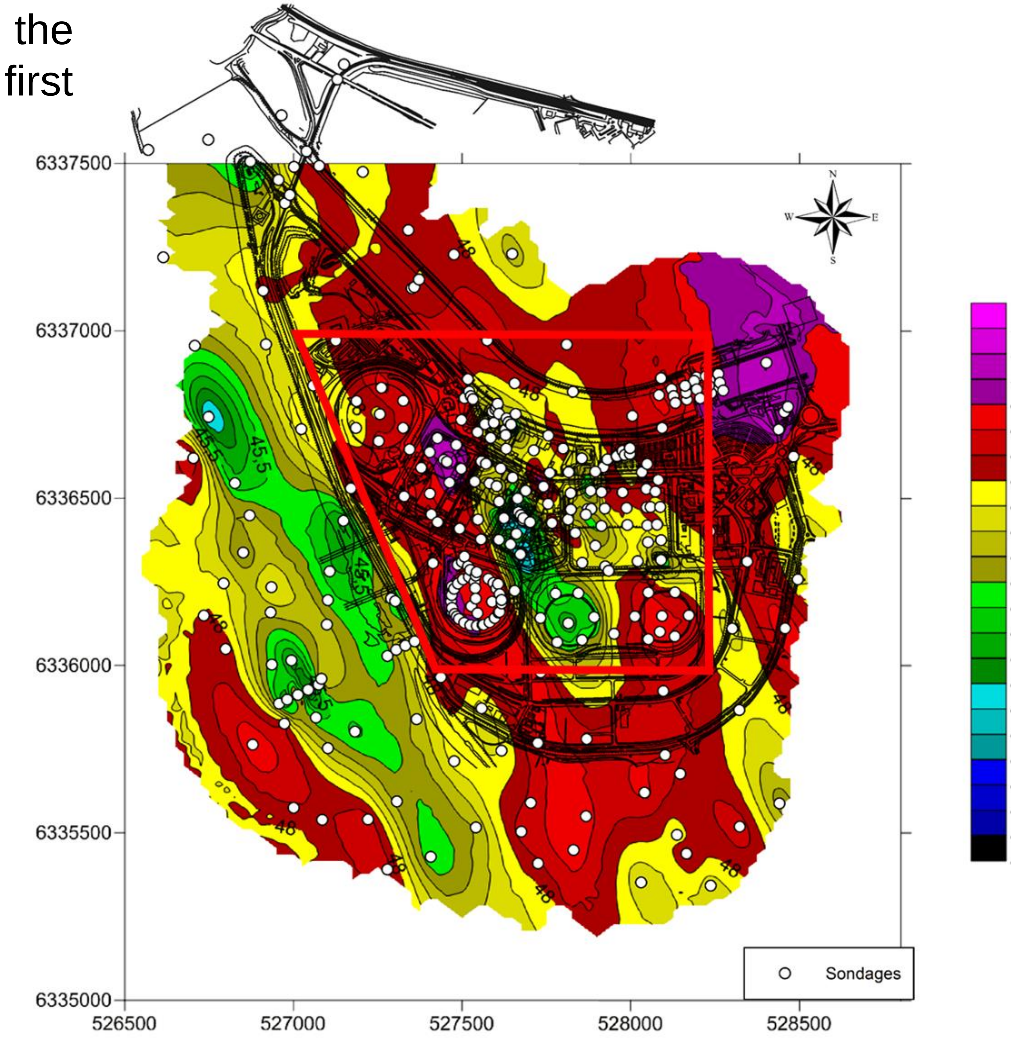
General probabilistic framework:

- Individual uncertainties on material properties are combined in order to quantify variability of the overall system,
- In practice, uncertainty of each quantity of interest are described by one or several random variables defined by a normal, log-normal or uniform distribution,
- A Latin Hypercube sampling is then considered for generating a near-random sample of parameter values from the defined multidimensional distribution,
- If any, correlation are introduced after Latin Hypercube sampling.

3.1. Uncertainties of the top of the geological layers

The EDF DI-TEGG' in-house software **STINGER** contains a database of the overall geophysical surveys performed on nuclear sites from the first preliminary geotechnical reconnaissance to present day.

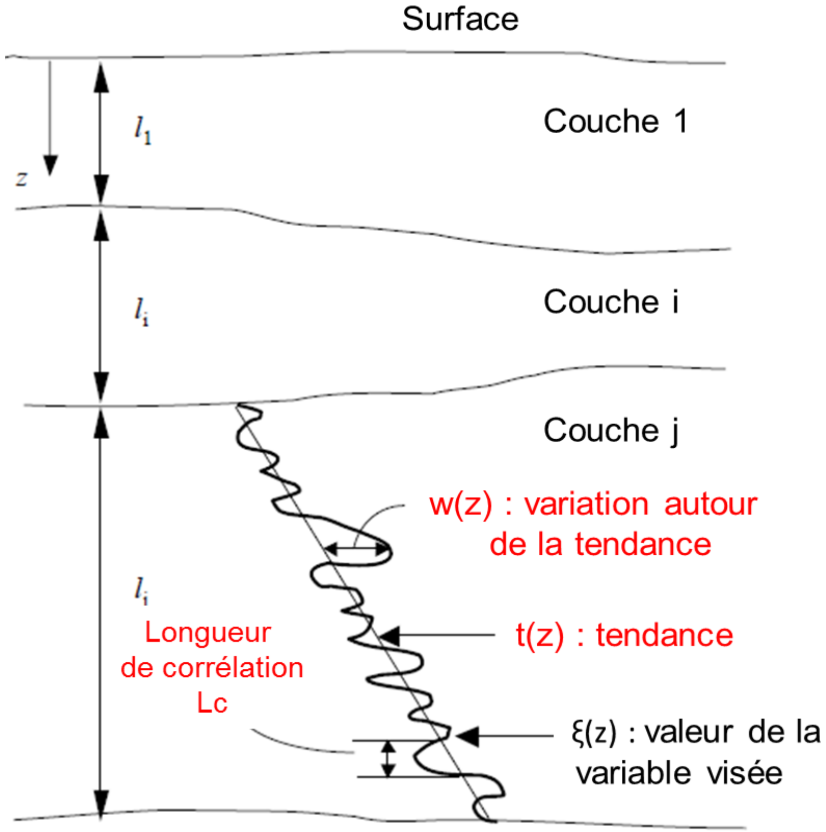




Example of a top of geological layer

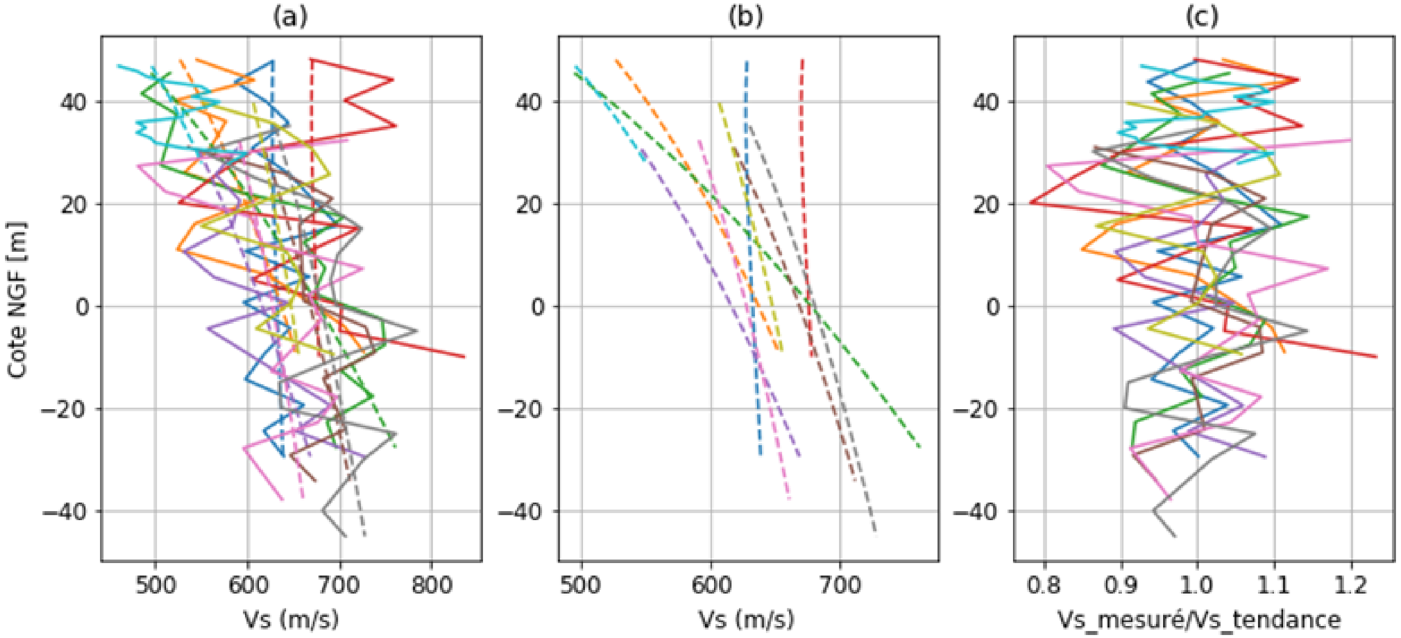
3.2. Uncertainties on shear wave velocity profile (1/4)

The shear wave velocity (Vs) or the shear modulus profile can be assessed by the following simple model (Phoon et Kulhawy (1999), guidelines PEER 2002-16 and EPRI (1995)):



$$G(z)=t(z).w(z) \quad \begin{cases} t(z)=K.(OCR)^k.P_a.\left(\frac{\sigma'_m}{P_a}\right)^m & \text{Hardin et Drnevich (1972)} \\ t(z) = a.z + b \\ t(z) = a.z^b \\ t(z) = b \end{cases}$$

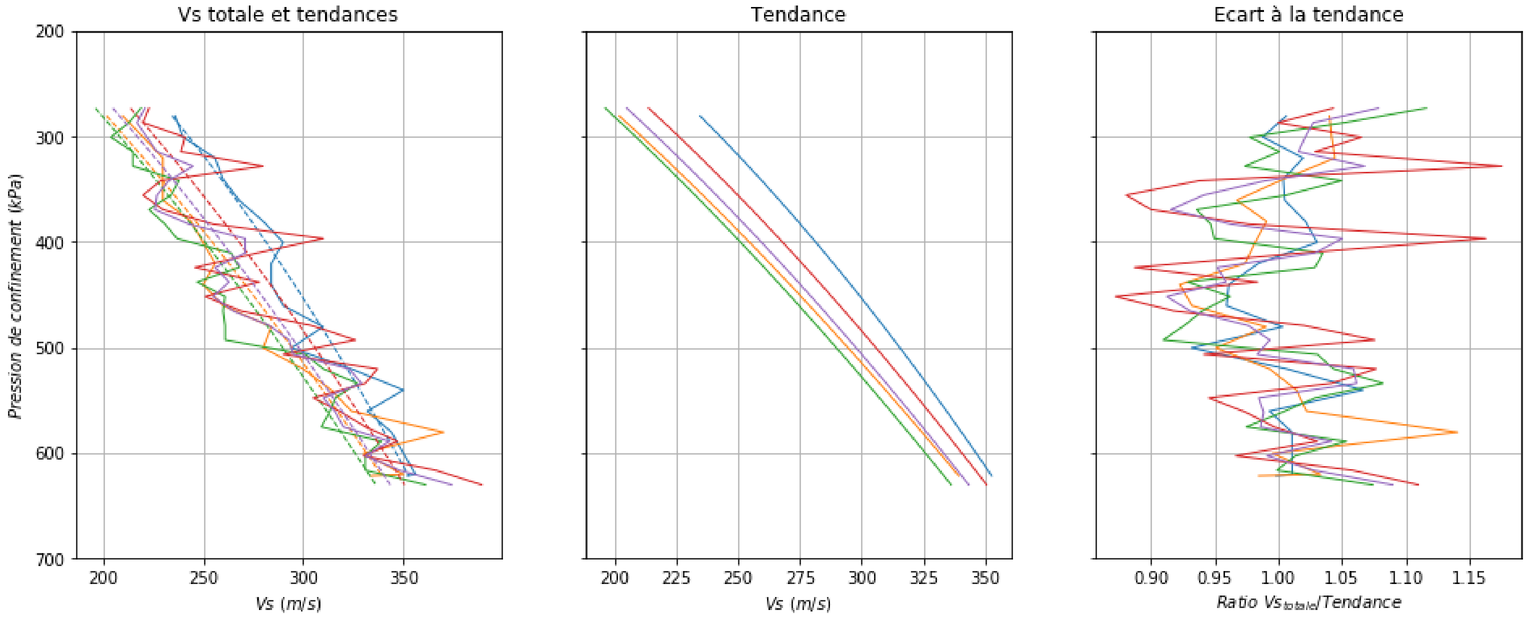
<u>Example of a shear wave velocity profile decomposition from invasive measurement</u>

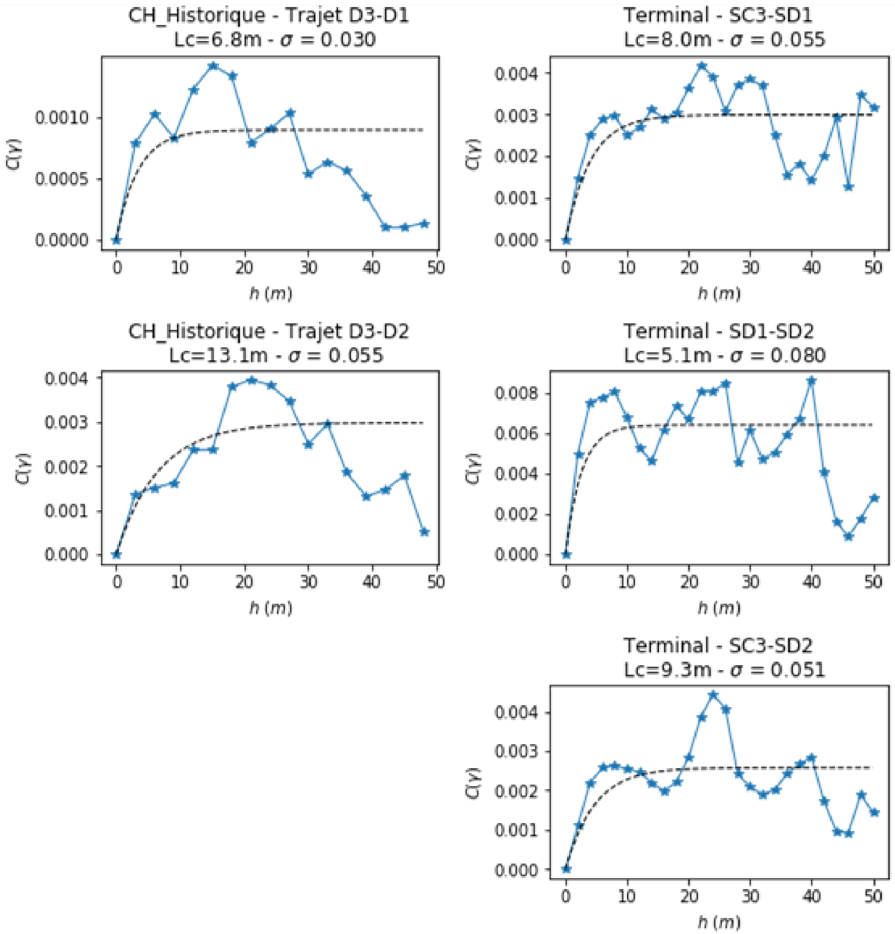


3.2. Uncertainties on shear wave velocity profile (2/4)

(1) **Quantification of the trend line t(z) and its variability,**

(2) **Variation w(z) around the trend line and its variability: estimation of correlation length Lc and standard deviation.**



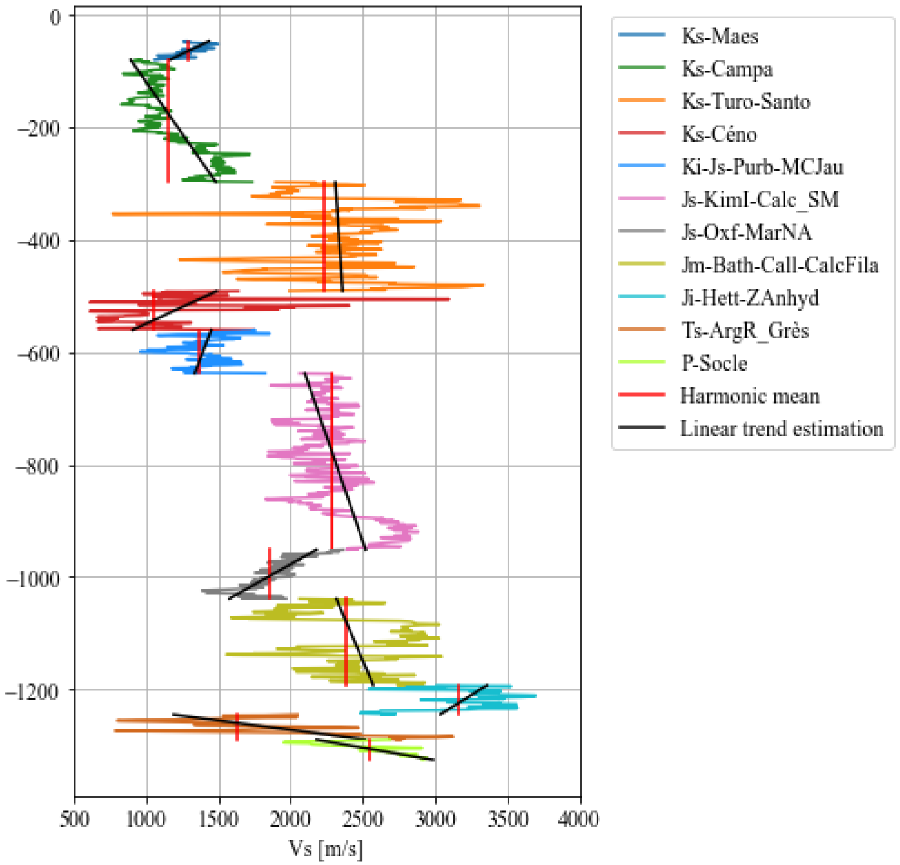


3.2. Uncertainties on shear wave velocity profile (3/4)

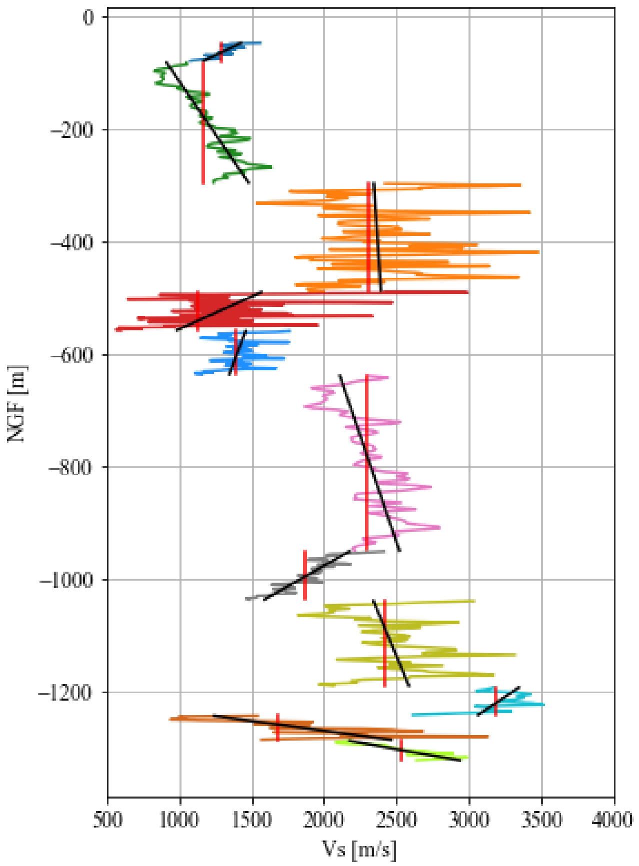
Measure vs. random field computation: comparison to Petroleum Geophysical Surveys (P-Sonic)

The variation w(z) around the trend line is model by **a random field** directly obtained through the *code_aster operator* `DEFI_PROP_ALEA`.

Measure



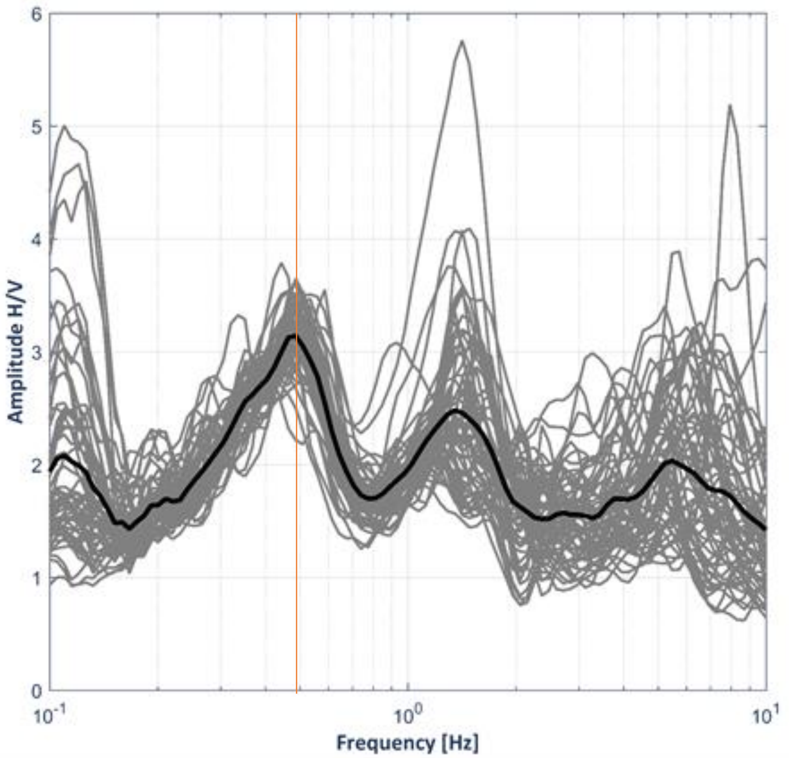
Random field

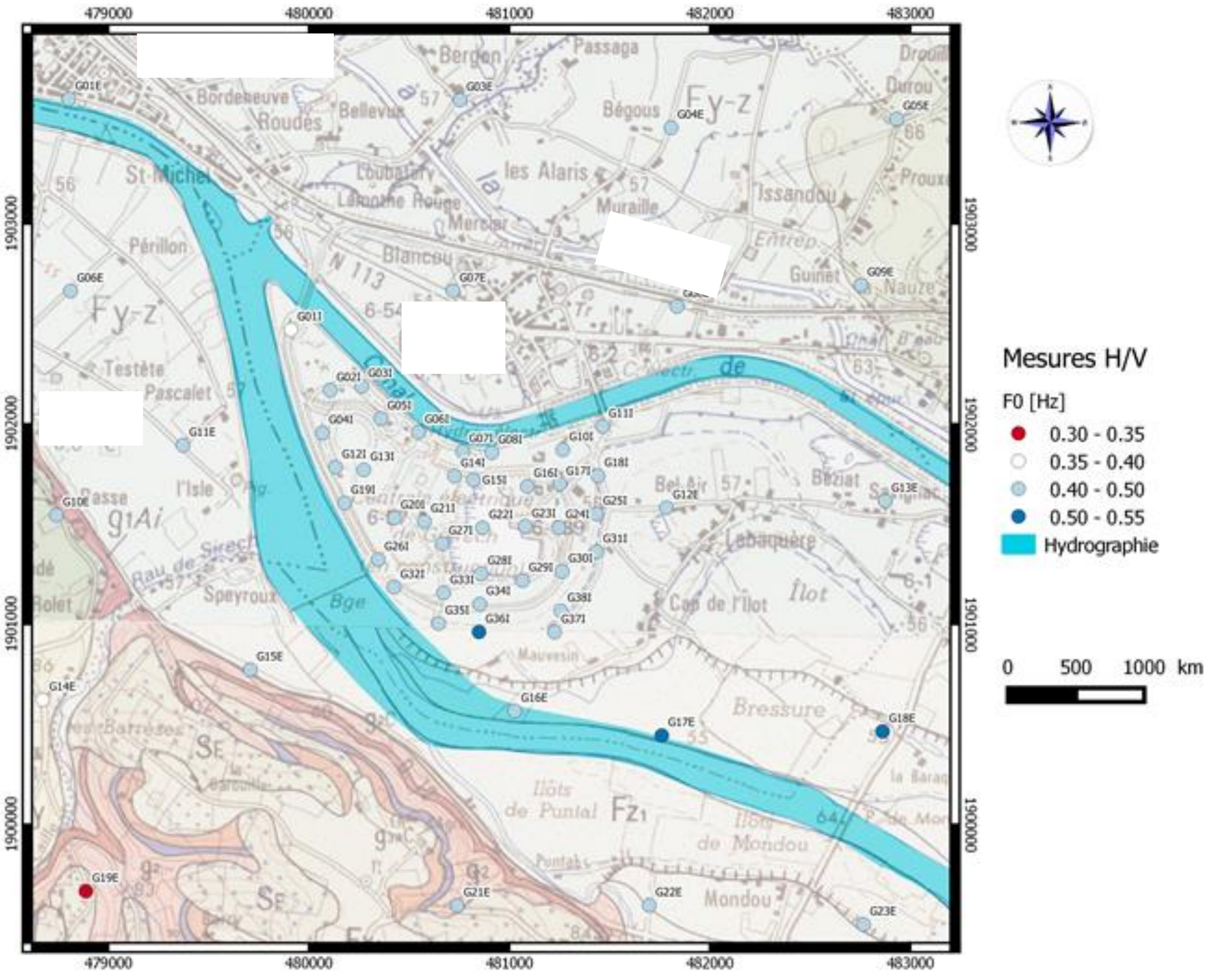


3.2. Uncertainties on shear wave velocity profile (4/4)

Validity of generated Vs profiles:

The first natural frequency of each generated profile should be compatible with one obtained from H/V measurement (measure of the first natural frequency of the site).





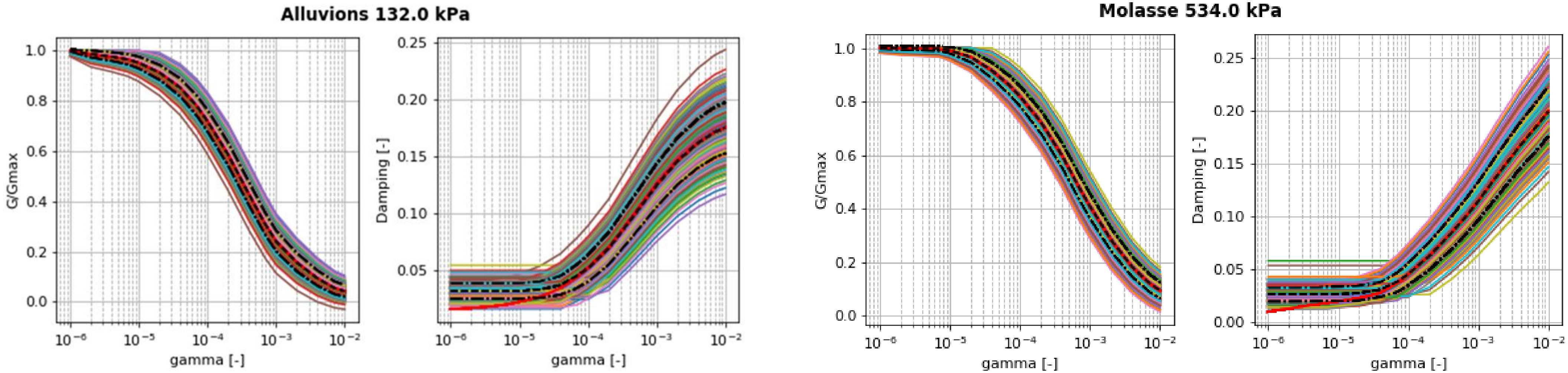
3.3. Uncertainties on degradation curves G/G_{max}–D-gamma

Uncertainties for the degradation curves obtained from two random variables that will be correlated after as:

$$G/G_{max}(\gamma) = [G/G_{max}(\gamma)]_{BE} + \varepsilon_1 . \sigma_{GG}$$

$$D(\gamma) = [D(\gamma)]_{BE} + \rho . \varepsilon_1 . \sigma_D + \sigma_D . \sqrt{1-\rho^2} . \varepsilon_2$$

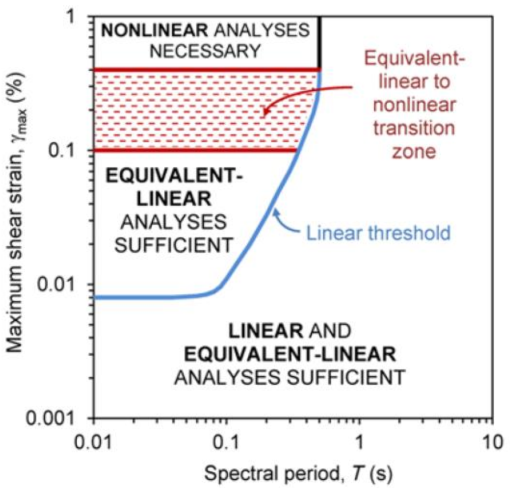
Où ε_1 et ε_2 sont deux variables aléatoires non corrélées suivant une loi normale de moyenne zéro et d'écart-type unitaire, σ_{GG} et σ_D sont les écart-types associés à la dispersion des courbes, et ρ le coefficient de corrélation entre GG-g et D-g.



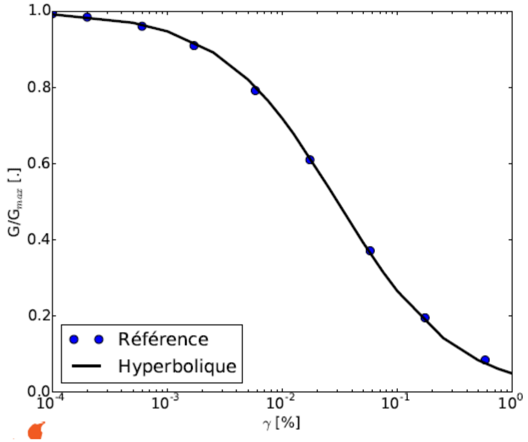
4. Numerical model of the 1D SH soil column

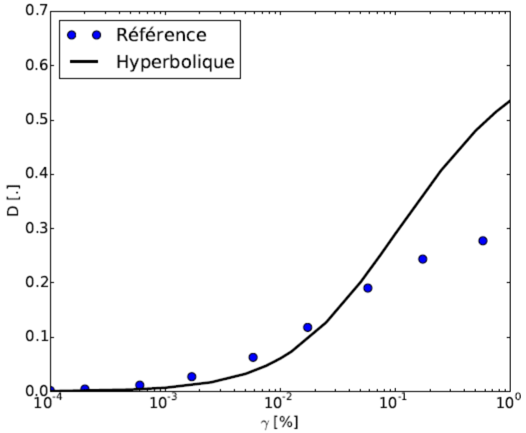
- Equivalent Linear method applicable while maximum shear strains remains low during the earthquake (code_aster operator `DEFI_SOL_EQUI`),

- Iwan non-linear model when shear strains are moderated (multi-mechanism model adapted to cyclic deviatoric behavior of soils).



Kaklamanos et al., (2013)

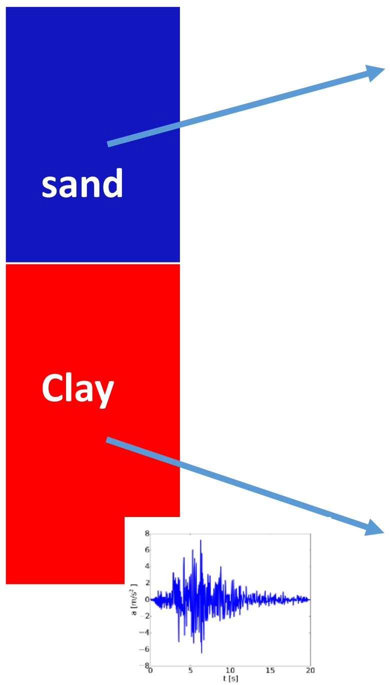


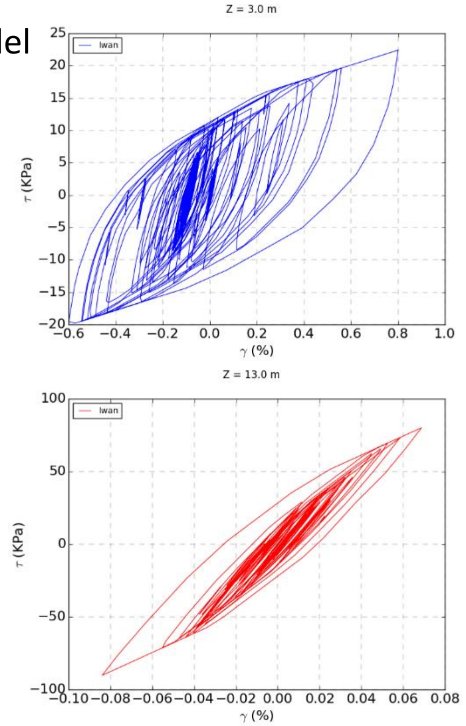


$$\gamma_{ref} = 0.03\%$$
$$n = 0.85$$

$$\tau = \frac{G_{max}\gamma}{1 + \left(\frac{\gamma}{\gamma_{ref}}\right)^n}$$

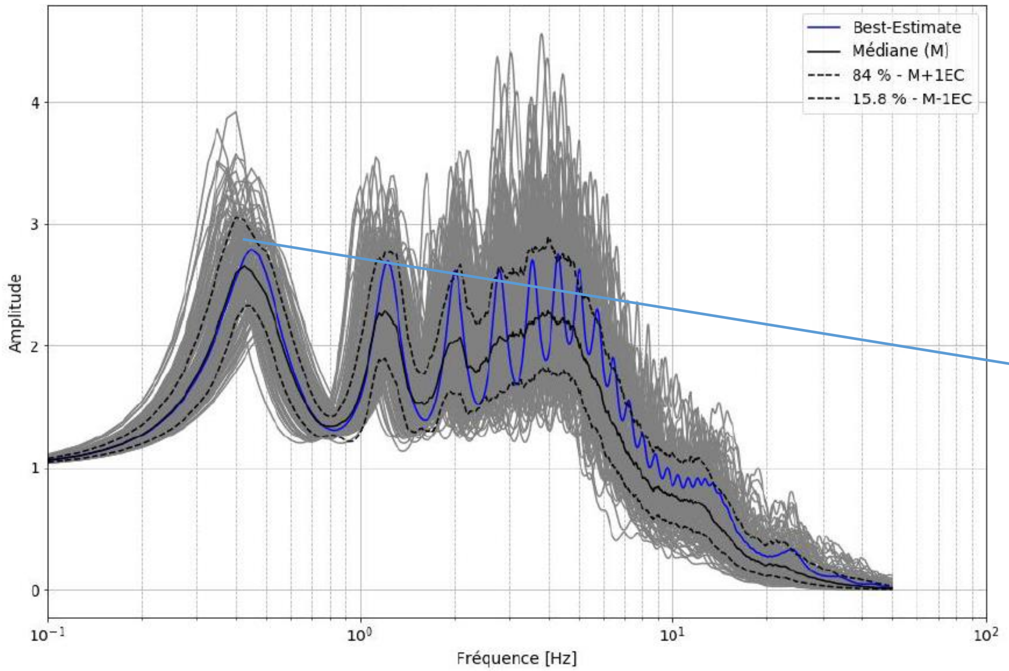
1D SH example with Iwan model

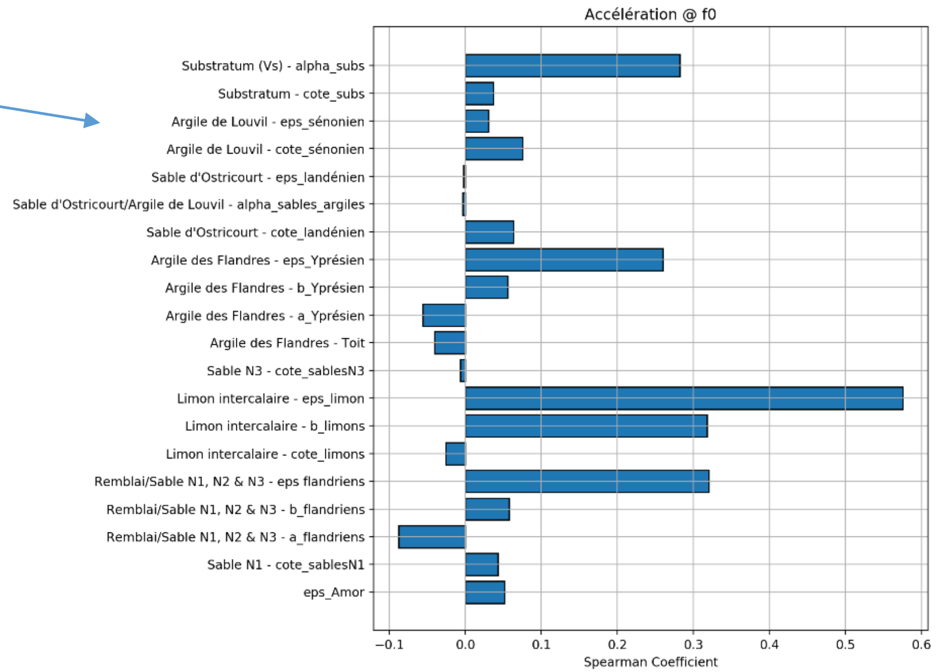




- Panorama of the models of behavior of grounds and rocks, joints available in Code_Aster ; U2.03.09

5. Some results: example of transfer function and weight of parameters





6. Conclusion and perspectives

Conclusion:

- State of the art methodology allowing:
    - To take into account **variabilities** observed **locally** (stratigraphy and velocity profile) and **globally** (variation of natural frequency and degradation curves),
    - To determine main influential parameters affecting 1D site effect,
- **Importance of input data** and the capitalization of historical data to perform relevant evaluations of 1D site effects,
- **Industrial maturity** *of Code_Aster* and *Openturns* for realizing a such study (methodology used for the 1D site effects evaluation on 4 French nuclear sites).

Perspectives:

- Improvement of the methodology in the framework of the European project **METIS** ;
- Exploitation of measures from RAN (Reseau Accélérométrique National) to comfort numerical evaluation of site effects,
- Integration of a Bayesian updating approach for defining shear wave velocity profiles since available measurements become rare when depth increases.

METIS: **ME**thods and **T**ools **I**nnovations for **S**eismic risk assement

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Thank you

Any question

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