International Symposium
Qualification of dynamic analyses of dams and their equipments
and of probabilistic assessment seismic hazard in Europe
31th August – 2nd September 2016 – Saint-Malo

Coupled elasto-plastic dynamic response of dams

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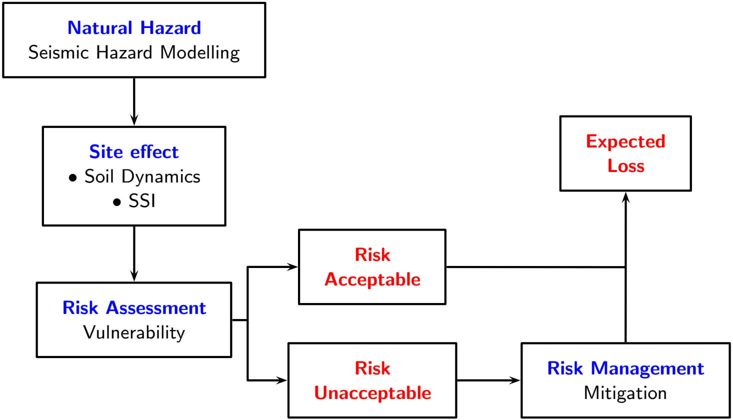
Saint-Malo © Yannick LE GAL

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;
- Take into account the non linear soil behaviour;
- 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

Recorded signals

ECP's numerical tool

Numerical model

Conclusions

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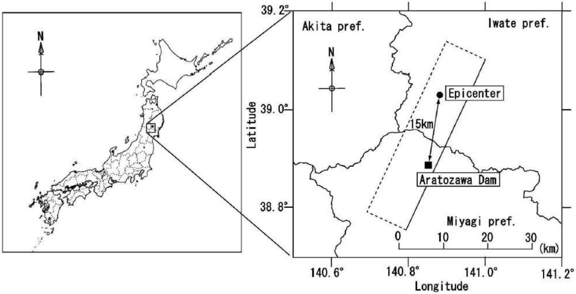
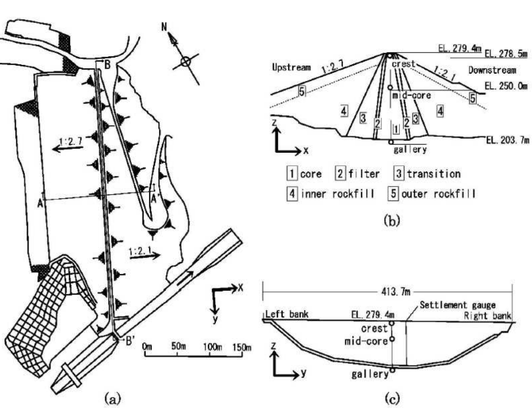
Aratozawa Dam



The 2008 Iwate-Miyagi Nairiku earthquake [Ohmachi and Taharz, 2011]

Aratozawa Dam



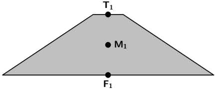
Plan and cross sections of the Aratozawa dam [Ohmachi and Taharz, 2011]

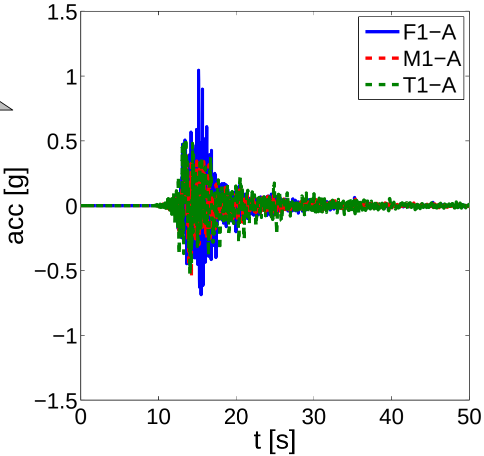
Recorded signals

Event	Year	Location	PGA [cm/s^2]
Southern Akita Pref	1996	F1-A	**28**
		T1-A	**105**
Northern Miyagi Pref	1996	F1-A	33
		T1-A	114
Northern Miyagi Pref	1996	F1-A	30
		T1-A	87
Northern Miyagi Pref	2003	F1-A	113.5
		T1-A	365
Southern Iwate Pref	**2008**	F1-A	**1023.8**
		T1-A	**525.3**
Far E Off Miyagi Pref	2011	F1-A	102
		T1-A	290.3

19 earthquake records tested

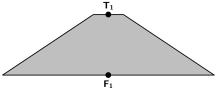
Recorded signals

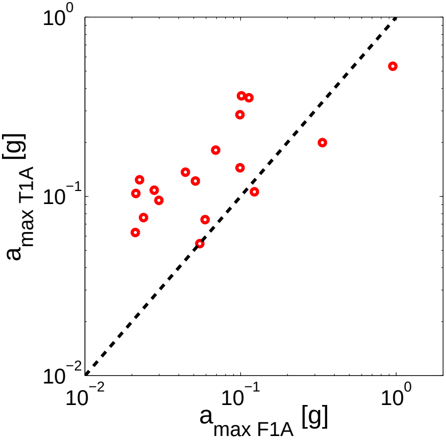




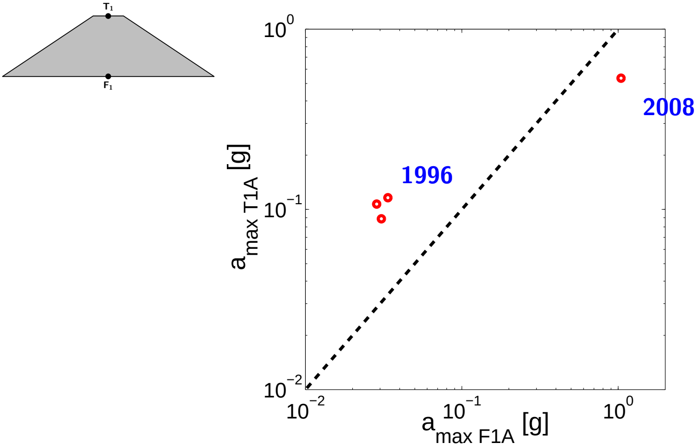
signals in A direction - 2008 Iwate-Miyagi Nairiku Earthquake

Recorded signals

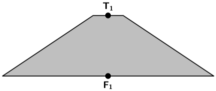


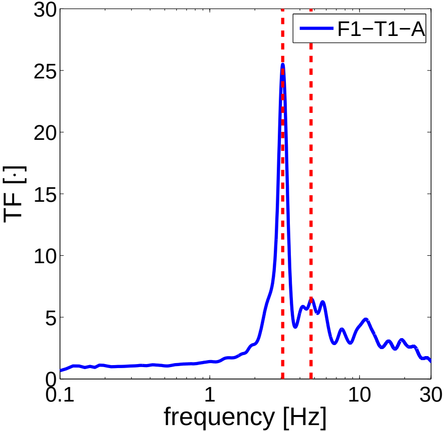


Recorded signals



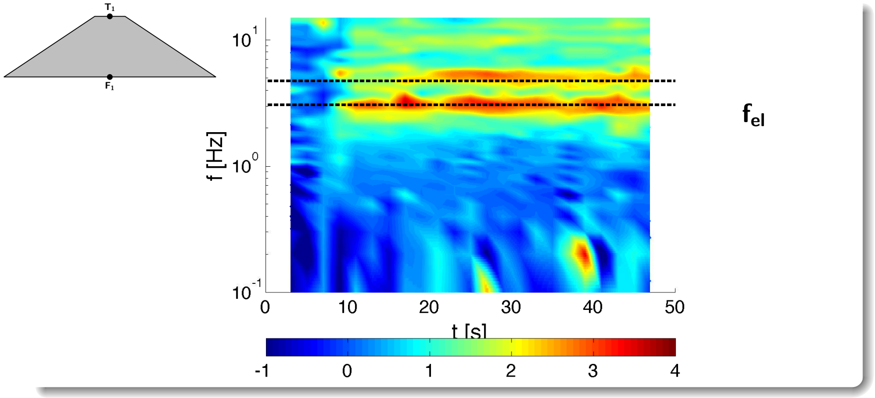
Recorded signals





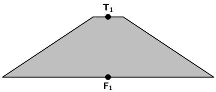
spectral ratio F1-T1- PGA $= 30\text{cm/s}^2$ - 1996 Northern Miyagi Pref
$f = 3.06$ and 4.74 Hz

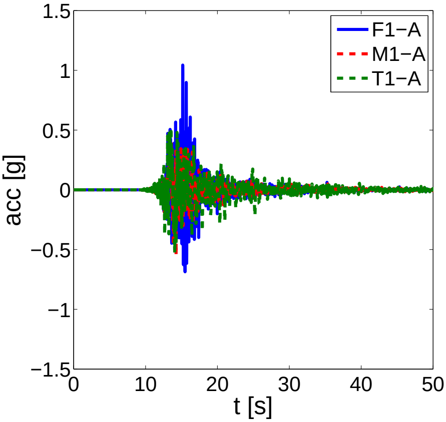
Recorded signals



Short Time Fourier Transform (STFT) spectral ratio F1-T1
3.1 and 4.7 Hz - 1996 Northern Miyagi Pref.

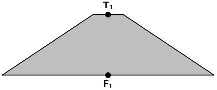
Recorded signals

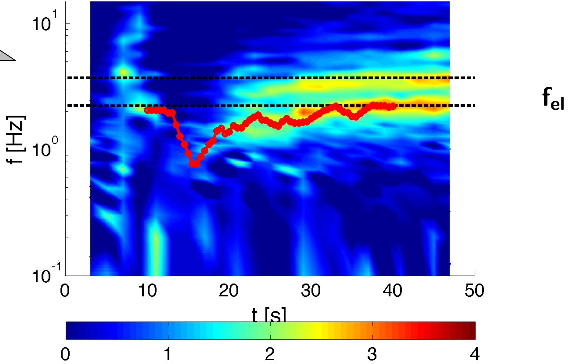




Short Time Fourier Transform (STFT) spectral ratio F1-T1
2008 Southern Iwate Pref

Recorded signals





Short Time Fourier Transform (STFT) spectral ratio F1-T1
(≈ **0.8**) 2.2 and 3.7 Hz - 2008 Southern Iwate Pref

Recorded signals

Event	PGA [cm/s²]	f_1 [Hz]	f_2 [Hz]
Southern Akita Pref	28	2.91	4.71
Northern Miyagi Pref	33	3.01	5.21
Northern Miyagi Pref	30	3.06	4.74
Southern Iwate Pref	1023.8	2.22*	3.70*

* Computed between 35-50s.

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JCOLD

Outline

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ECP's numerical tool

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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: $f_{iso} = |p'| - d\ p_c\ r_{iso}$

GEFDyn & Code_Aster - ECP's numerical tool

Classification of the Elastoplastic model parameters

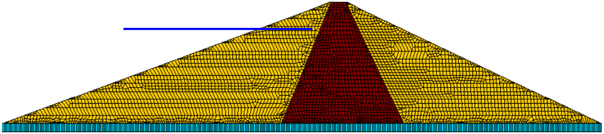
[Lopez-Caballero et al., 2003]

	Directly measured *	Not-Directly measured
Elastic	K_{ref}, G_{ref} n_e, p_{ref}	
Critical State and Plasticity	ϕ'_{pp}, β p_{co}, d	b
Flow Rule and Isotropic hardening	ψ	a_1, a_2, α_ψ, m, c_{mon}
Threshold domains		r^{ela}, r^{hys} r^{mob}, r^{ela}_{iso}

* From : Triaxial, Resonant column, CPT, oedometric tests among others

Outline

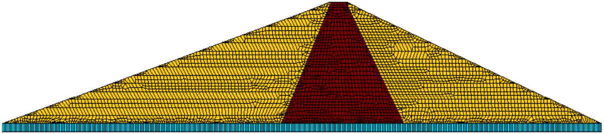
Numerical model



- Construction stage of the dam and seismic loading,
- Two approaches for Pore-water pressure generation in this study,*
  - Decoupled behaviour for the core and the upstream rockfill (effective stress),
  - Coupled behaviour for the core and the upstream rockfill,
- Dry condition is supposed for the downstream rockfill (total stress),

* details in [Montoya-Noguera and Lopez-Caballero, 2016]

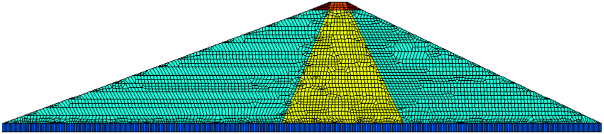
Numerical model



- Core → non-linear elasto plastic model (ECP model)
- Core filter → non-linear elasto plastic model (ECP model)
- Rockfill → non-linear elasto plastic model (ECP model)
- Bedrock → infinitely rigid with absorbing elements *

* details in [Montoya-Noguera, 2016]

Numerical model

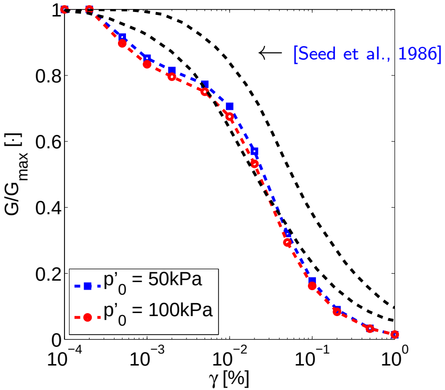


- Core → $V_s = 220 \cdot z^{0.35}$ *
- Core filter → $V_s = 220 \cdot z^{0.35}$ *
- Rockfill → $V_s = 250 \cdot z^{0.2}$ *
- Bedrock → infinitely rigid with absorbing elements

* adapted from [Ohmachi and Taharz, 2011]

Numerical model

Core and Core filter behaviour :

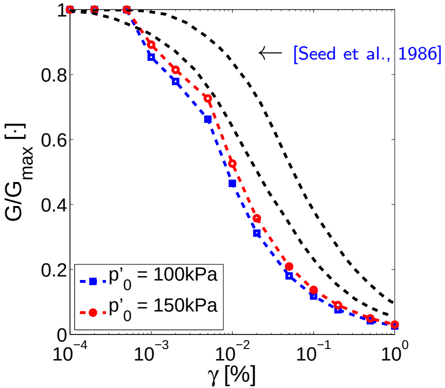


Simulated $G/G_{max} - \gamma$ curves

Remark : These curves are not an input of the model.

Numerical model

Rockfill behaviour :

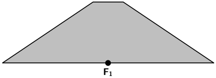


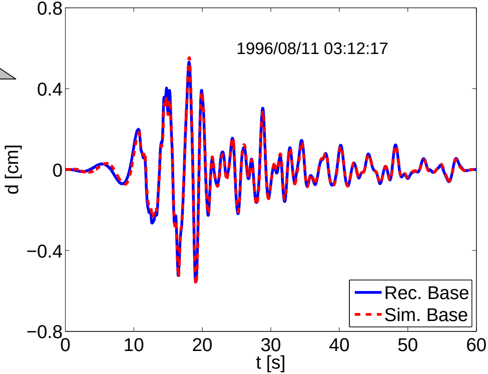
Simulated $G/G_{max} - \gamma$ curves

Remark : These curves are not an input of the model.

Numerical model

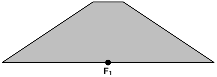
Southern Akita Pref - 1996

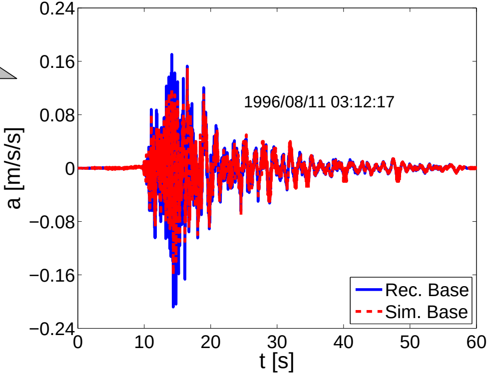




Numerical model

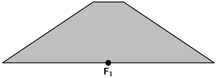
Southern Akita Pref - 1996

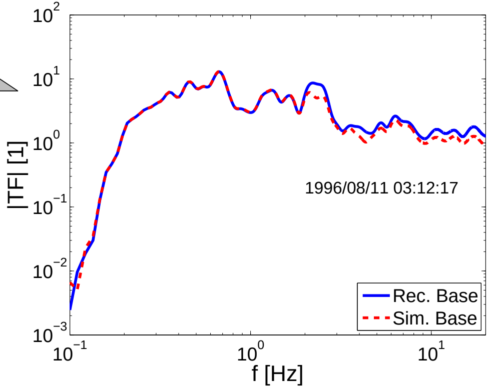




Numerical model

Southern Akita Pref - 1996





Numerical model

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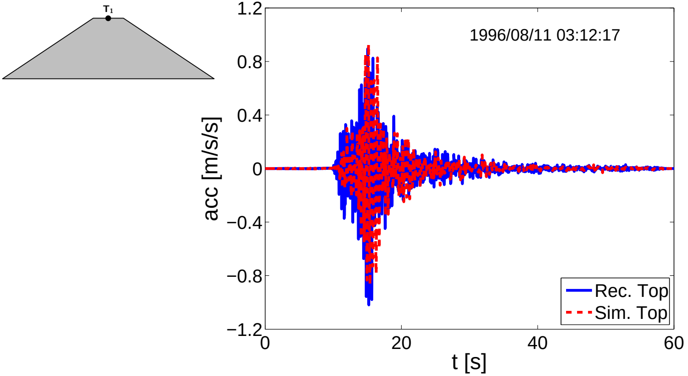
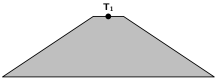
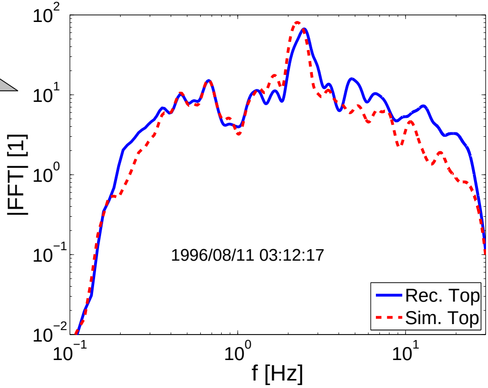


Numerical model

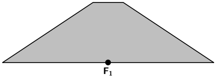
Southern Akita Pref - 1996

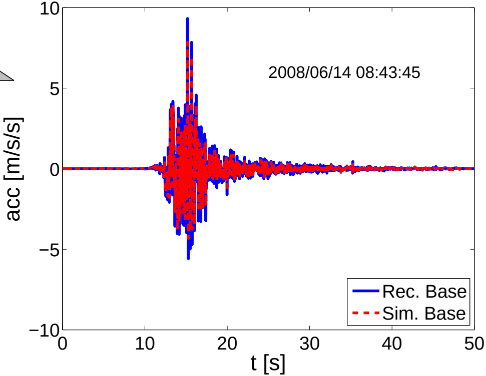




Numerical model

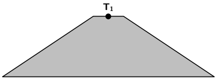
Southern Iwate Pref - 2008

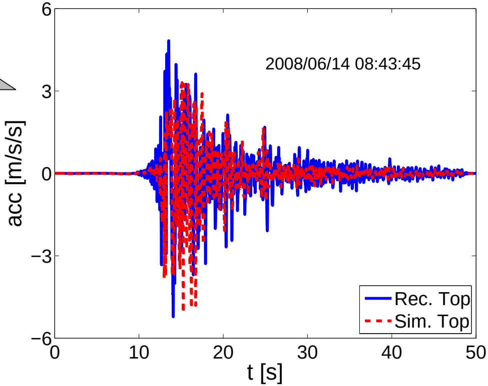




Numerical model

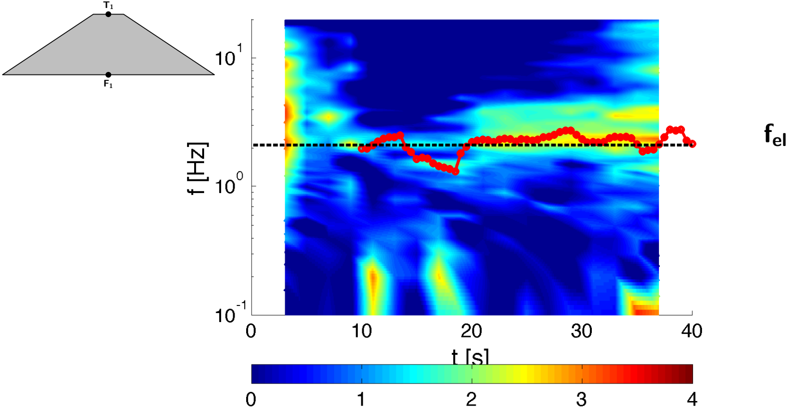
Southern Iwate Pref - 2008





Numerical model

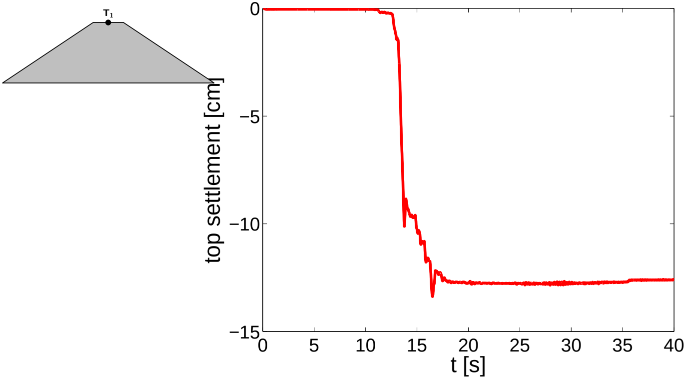
Southern Iwate Pref - 2008



STFT F1-T1- PGA $= 1023.8 cm/s^2$

Numerical model

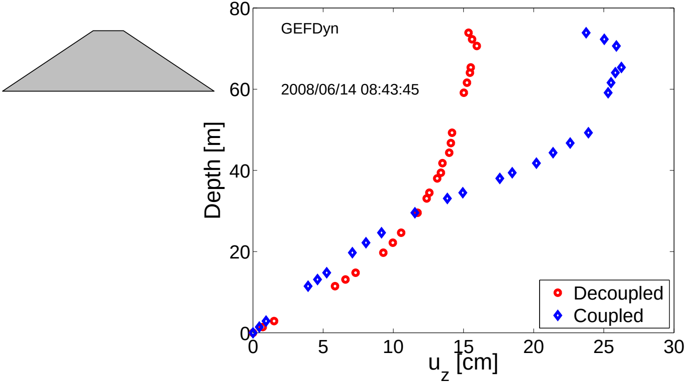
Southern Iwate Pref - 2008



Obtained co-seismic settlement, 13cm - Decoupled behaviour

Numerical model

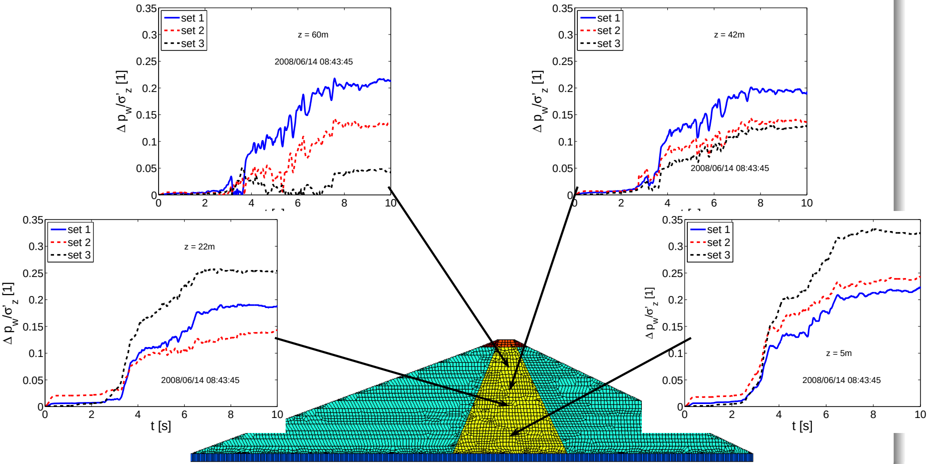
Southern Iwate Pref - 2008



Obtained co-seismic settlement - *GEFDyn*

Numerical model

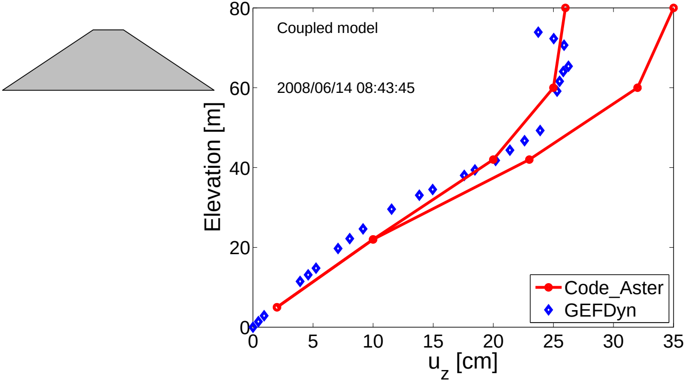
Southern Iwate Pref - 2008



Obtained $\Delta p_w/\sigma'_z$- Coupled behaviour - Code_Aster

Numerical model

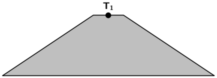
Southern Iwate Pref - 2008

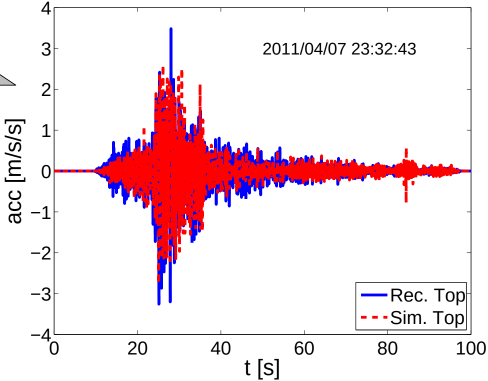


Obtained co-seismic settlement

Numerical model

E Off Miyagi Pref - 2011





Anderson Criteria

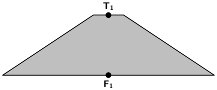
Goodness of fit criteria and Frequency Bands

Number	Symbol	Similarity of:
C1	SDa	Arias duration
C2	SDe	Energy duration
C3	SIa	Arias Intensity
C4	SIv	Energy Integral
C5	Spga	Peak Acceleration
C6	Spgv	Peak Velocity
C7	Spgd	Peak Displacement
C8	Ssa	Response Spectra
C9	Sfs	Fourier Spectra
C10	C*	Cross Correlation

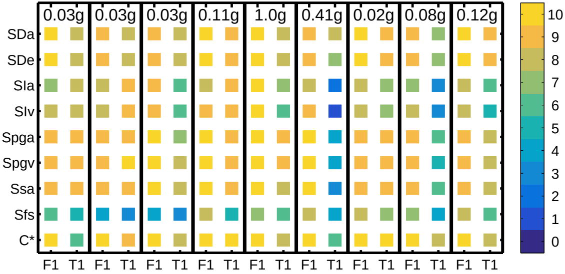
Band	Frequency limits [Hz]
B1	0.05 - 0.1
B2	0.1 - 0.2
B3	0.2 - 0.5
B4	0.5 - 1.0
B5	1.0 - 2.0
B6	2.0 - 5.0
B7	5.0 - 15.0
B8	0.05 - 15.0

$$C_i(p_1, p_2) = 10 \exp\left\{ - \left[\frac{(p_1 - p_2)}{min(p_1, p_2)} \right]^2 \right\} \qquad S = \frac{1}{8} \sum_{B=1}^{8} \left(\frac{1}{10} \sum_{i=1}^{10} C_{i,B} \right)$$

Numerical model



Anderson criteria



Outline

Conclusions

- Used non-linear soil behaviour model is able to represent accurately the recorded behaviour of the dam in the large range of accelerations and frequencies.
- "*Half-space bedrock's boundary condition*" allows to simulate the borehole condition found at the gallery level.
- The condition assumed to define the initial state of all materials could be used as a first approach to simulate the dam behaviour.
- The non-linear behaviour of the dam is concentrated principally at the base of the core material.

Thank you for your attention
Dõmo arigatõ gozaimas[u]

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