ICOLD

INTERNATIONAL COMMISSION ON LARGE DAMS

ICOLD COMMITTEE ON COMPUTATIONAL ASPECTS OF ANALYSIS AND DESIGN OF DAMS

15th INTERNATIONAL BENCHMARK WORKSHOP ON NUMERICAL ANALYSIS OF DAMS

Theme A - Formulation

SEISMIC ANALYSIS OF PINE FLAT CONCRETE DAM

9 September 2019, Milan, Italy

Analysis of Pine Flat Dam considering Fluid-Soil-Structure Interaction and a linear-equivalent model

André Stabile, Pierre Labbé, Anh Nguyen

Damping introduced by absorbing boundaries

- Equivalent damping determined to be of the order of 2% (Formulation document)
- Log-decrement method applied to the EMVG case:

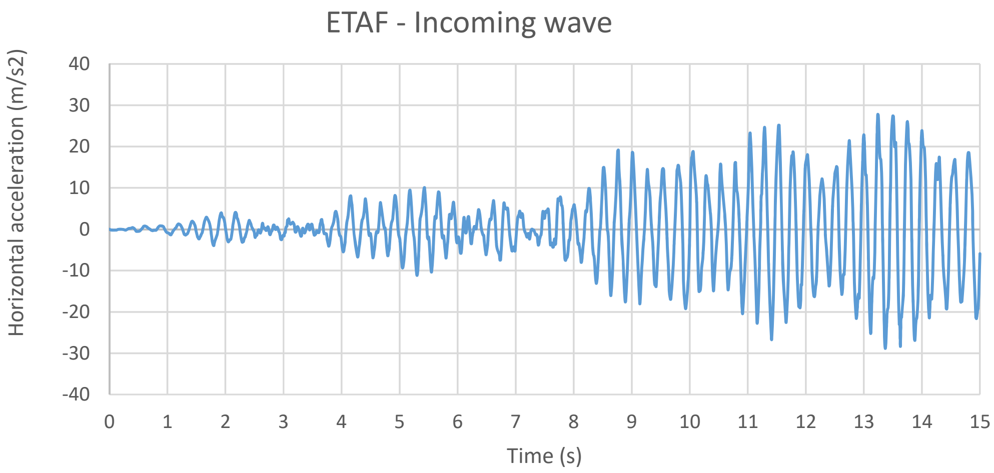
- ξ of the order of 11% for the model with Rayleigh damping and absorbing boundaries (α=0,0005 et β=0,75)

- ξ of the order of 9% for the model with absorbing boundaries but without material damping (α=β=0)

- We see that the damping is, indeed, of the order of 2%
- The total damping is, however, much superior
- How to model for it then?

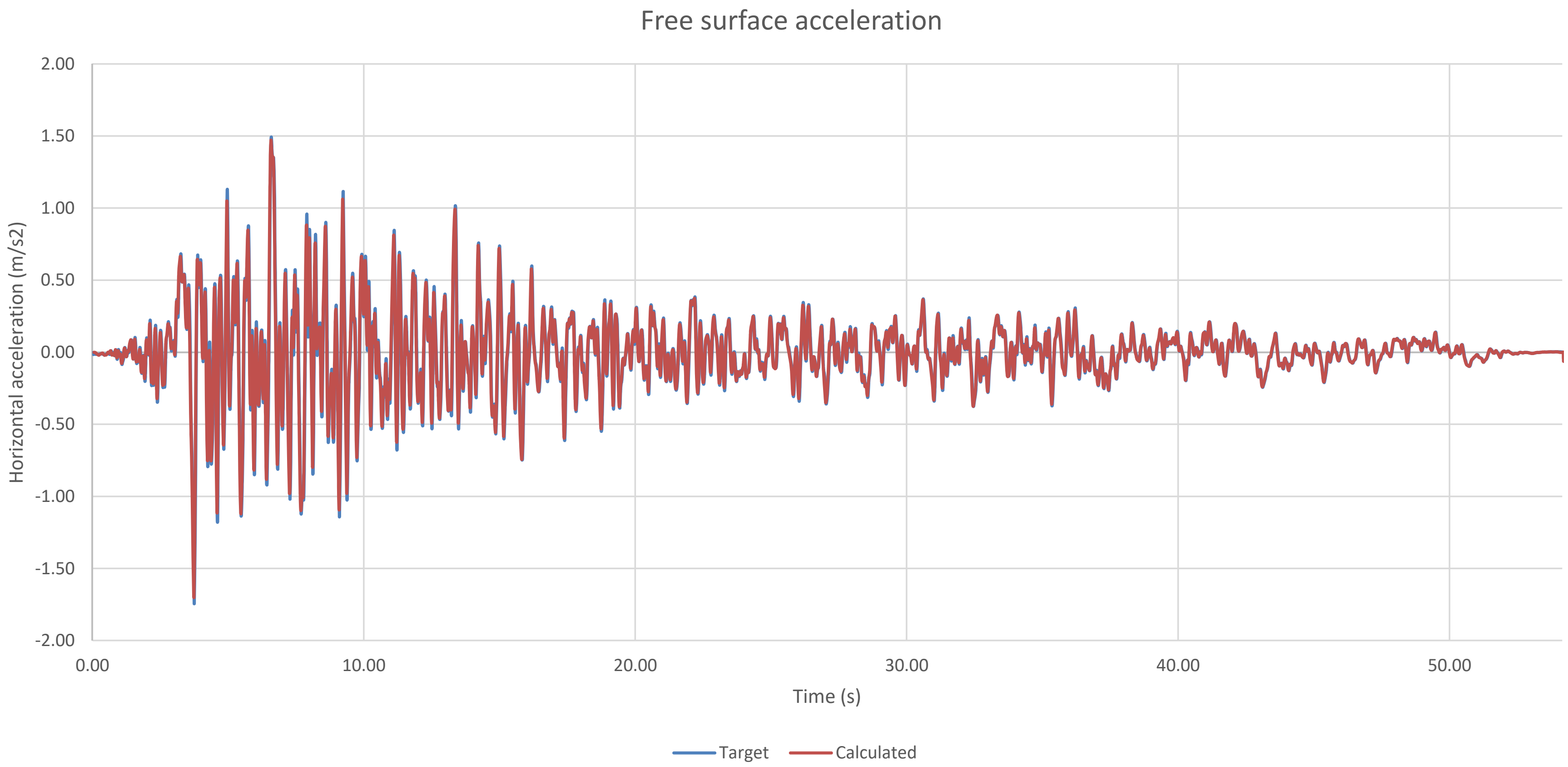
ETAF’s incoming wave

- Specific need of the incoming wave, not the deconvolved signal, from Code_Aster
- The deconvolved wave at time t is the sum of the incoming wave and the reflected wave
- The reflected wave at time t is the incoming wave at time t - 2T, where T is the wave propagation time on the foundation
- Therefore, the incoming wave can be found
- In the above procedure damping in the foundation is neglected



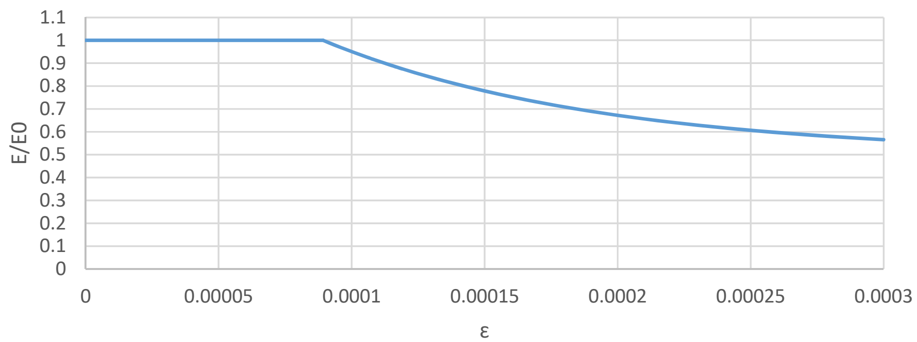
ETAF's incoming wave

- Taft's signal used for comparison. Good agreement between the calculated incoming wave and the one provided by the Organizers



Linear equivalent model

- Non-linear analyses are complex and time consuming
- A linear model allows for a modal analysis, which is not possible for a non-linear one – better understanding of the dam's behavior
- Proposed iterative method :
  - Displacement based approach
  - Maximum principal strain throughout time considered at each element - $\varepsilon_1^{\max}$
  - No damage if $\varepsilon_1^{\max}$ < 0,00009
  - In case it is exceeded a reduced Young's module is considered :



$$\frac{E(\varepsilon)}{E_0} = \begin{cases} 1 \ if \ \varepsilon \leq 0{,}00009 \\ 0.5 + 0.5e^{-9629{,}27\varepsilon + 0.8594} \ \ if \ \varepsilon \geq 0{,}00009 \end{cases}$$

Convergence is reached based on the system's fundamental frequency

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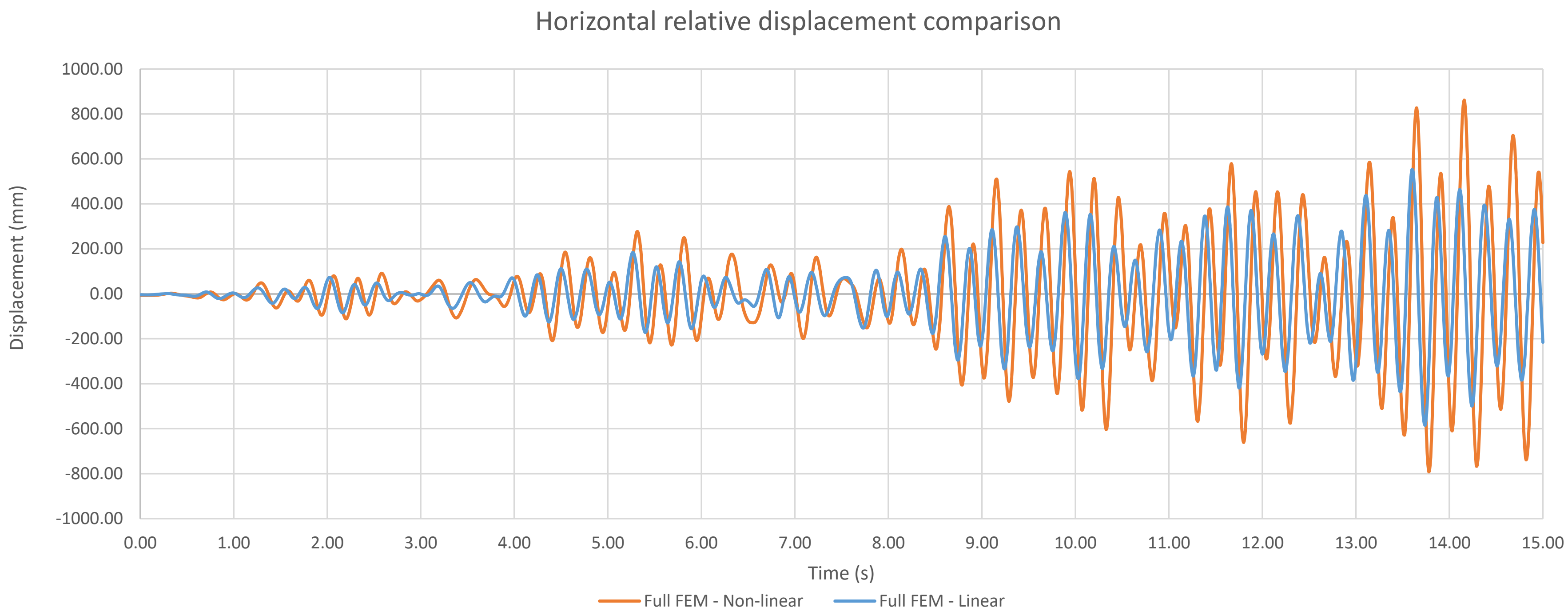
Linear vs linear-equivalent response

- Due to the decrease in the dam's fundamental frequency the linear-equivalent response is placed further away in the time axis



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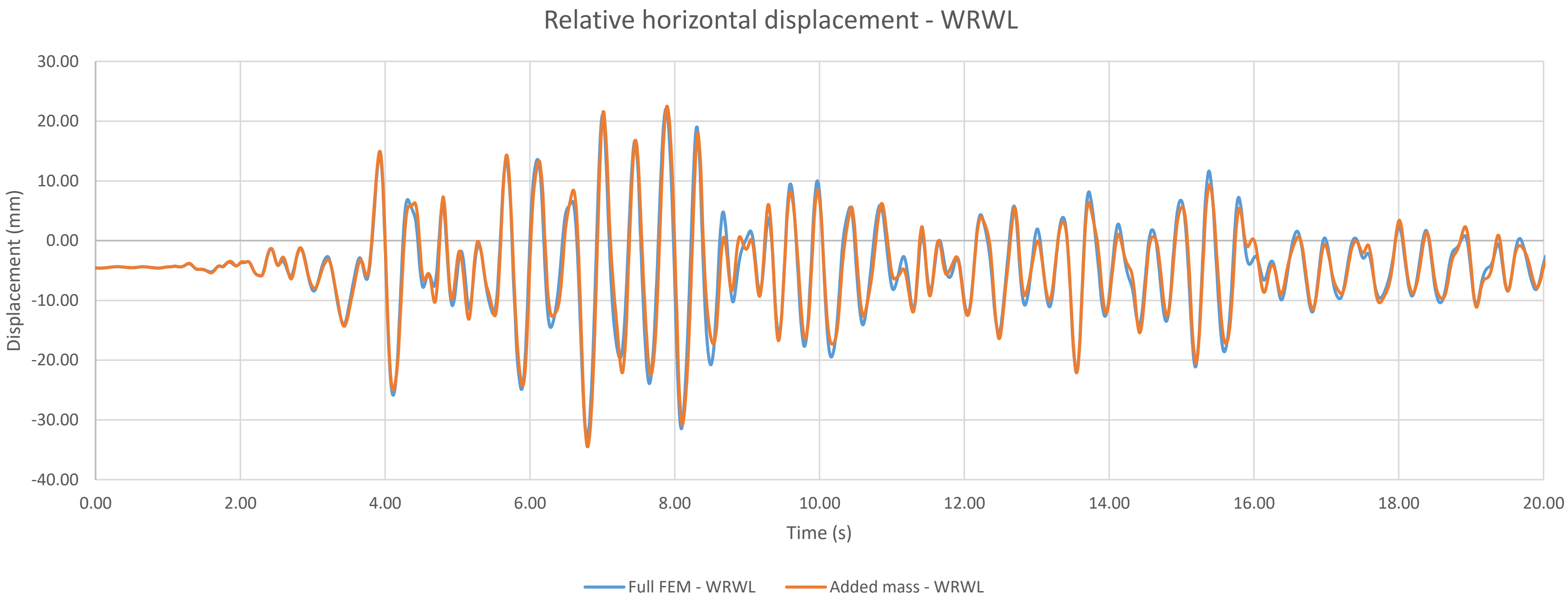
Acoustic elements vs Westergaard's added mass

- Good concordance for relatively low acceleration levels (Taft record), but discordance for higher accelerations (ETAF signal).



Acoustic elements vs Westergaard's added mass

ICOLD-BW 2019
9th-11th September
MILANO
Numerical analysis of dams

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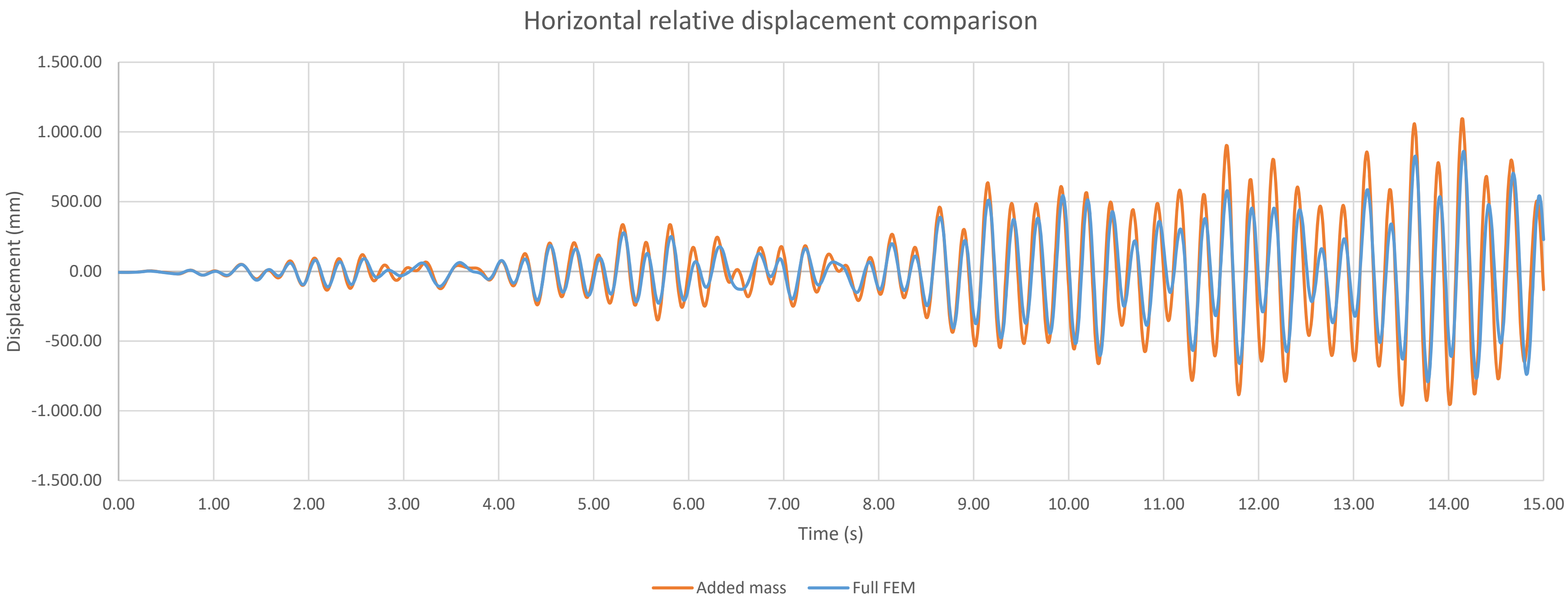

ESTP PARIS
L'ÉCOLE DES GRANDS PROJETS

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Conclusions

- Absorbing boundaries are adequate to represent the infinite domain, however they add additional – unwanted – damping into the system
- Westergaard's added mass model seems to yield results that diverge largely from an acoustic fluid elements model for high levels of seismic input
- A linear-equivalent model is easier to utilize and allows for a better understanding of the response, since a frequency domain analysis is possible, and for the use of the superposition

THANK YOU

FOR YOUR ATTENTION

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