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INTERNATIONAL COMMISSION ON LARGE DAMS

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Numerical analysis of 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

Seismic Analysis and Damage Evaluation of Pine Flat Concrete Dam

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Contents

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  - Modelling specifications
  - Results and Interpretation

Absorbing Boundary Conditions (ABC)

- Needed when an infinite domain like the foundation of a dam is modeled using a finite portion of it.
  - main role is to absorb the outgoing propagated waves without any reflection
- Two categories:
  - Global ABCs: quite time consuming due to the coupling characteristics of spatial and time domains
  - Local ABCs: can easily be implemented even in commercial finite element software.
    - Lysmer and Kuhlemeyer (1969) proposed the simplest ABC for scattering problems.

$$f_n = -\rho c_p \frac{\partial u_n}{\partial t}$$

$$f_t = -\rho c_s \frac{\partial u_t}{\partial t}$$

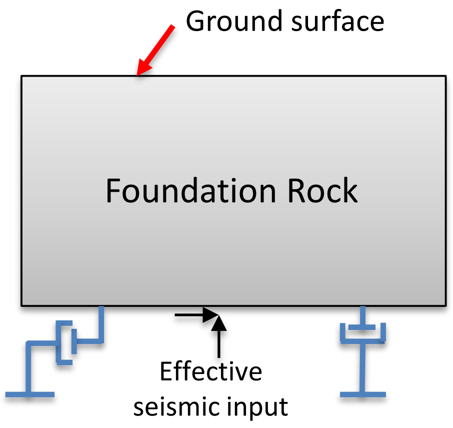
  - Can readily be implemented by normal and tangential dashpots in FE software.

Effective Seismic Input

- When excitation originates from outside of the model such as incoming seismic waves, the ABCs must absorb only the outgoing waves.
- The incoming waves are entered by applying effective tractions which are calculated based on the incoming waves.
  - @ bottom of the model:

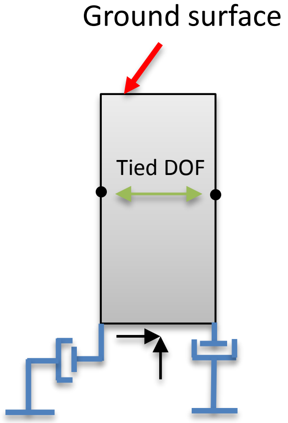
$$\left.\begin{aligned} f_n &= 2\rho c_p \frac{\partial u_n^{\text{in.}}}{\partial t} \\ f_t &= 2\rho c_s \frac{\partial u_t^{\text{in.}}}{\partial t} \end{aligned}\right\} \xrightarrow[\mathbf{u}^{\text{in.}} = \frac{1}{2}\mathbf{u}^{\text{ff}}]{\text{Tractions are zeroes at ground surface in free-field motion}} \left\{\begin{aligned} f_n &= \rho c_p \frac{\partial u_n^{\text{ff}}}{\partial t} \\ f_t &= \rho c_s \frac{\partial u_t^{\text{ff}}}{\partial t} \end{aligned}\right.$$

(Joyner and Chen 1975) (Mejia and Dawson 2006)



Free-field Column Model

- In the lateral wall of the foundation the movements surplus to free-field must be absorbed.
- Free-field column model is used for generating FF motion at each elevation.



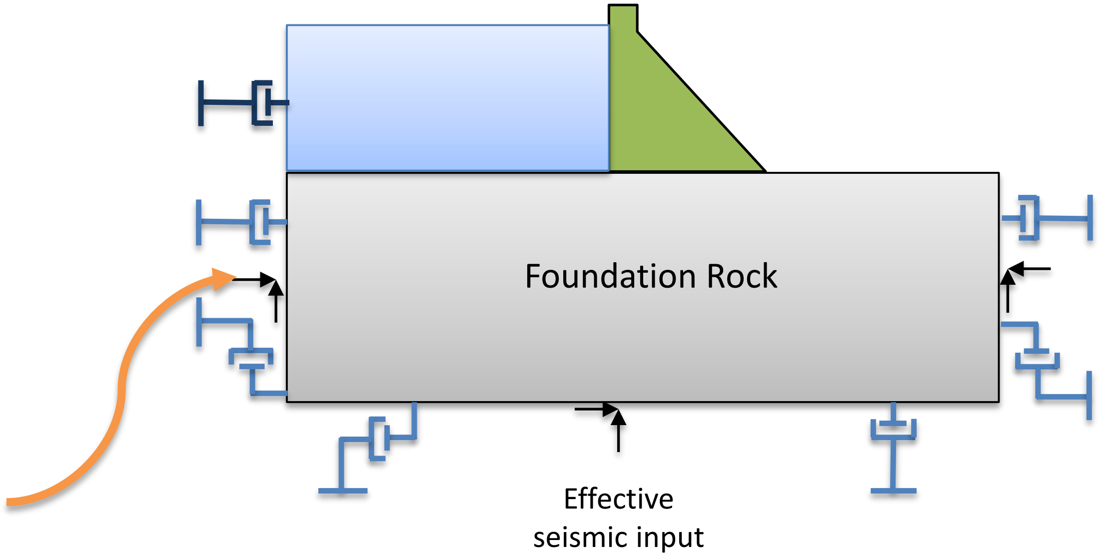
Free-field Column Model
(Zienkiewicz, Bicanic, and Shen 1989)

$$f_n = -\rho c_p\left(u_n^{\mathrm{m}} - u_n^{\mathrm{ff}}\right) + \sigma_n^{\mathrm{ff}}$$
$$f_t = -\rho c_s\left(u_t^{\mathrm{m}} - u_t^{\mathrm{ff}}\right) + \tau_{nt}^{\mathrm{ff}}$$

(Løkke and Chopra 2017)

$$f_n = \underbrace{-\rho c_p u_n^{\mathrm{m}}}_{\text{Dashpots}} + \underbrace{\rho c_p u_n^{\mathrm{ff}} + \sigma_n^{\mathrm{ff}}}_{\text{Tractions calculated from FF motion (Nielsen 2006)}}$$

$$f_t = \overbrace{-\rho c_s u_t^{\mathrm{m}}} + \overbrace{\rho c_s u_t^{\mathrm{ff}} + \tau_{nt}^{\mathrm{ff}}}$$

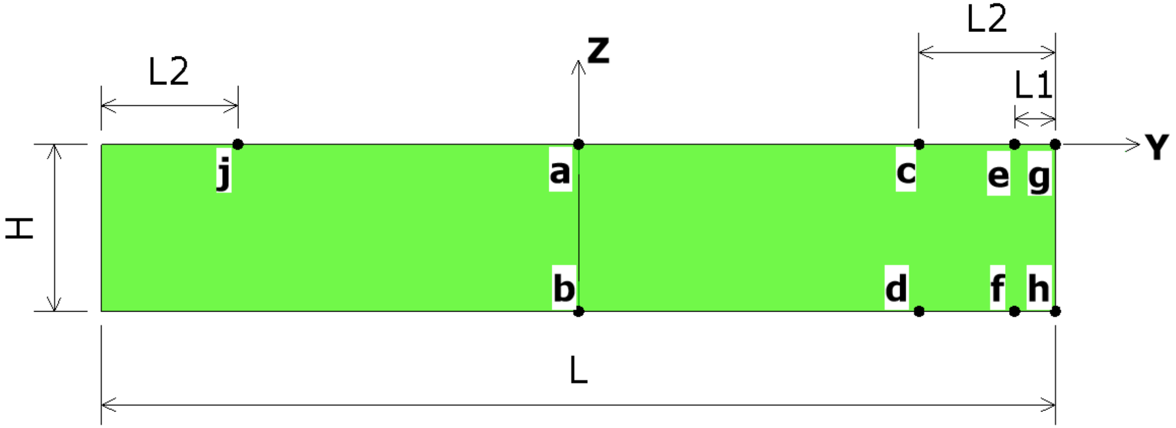


Main Model

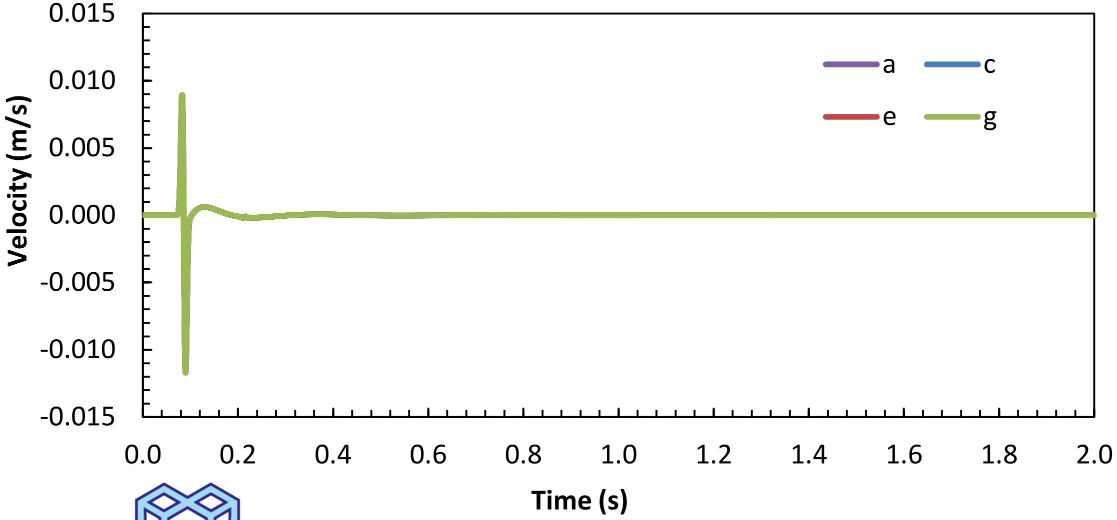
Implementation

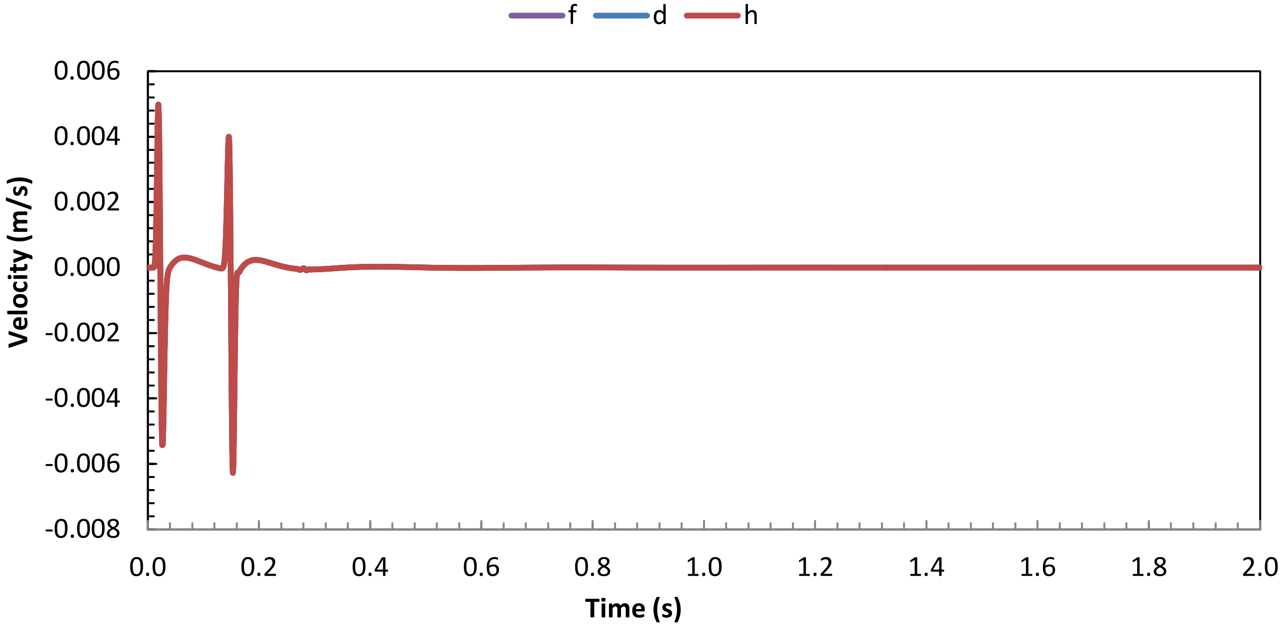
- The method can be implemented in any software that enjoys dashpot elements.
  - Free-field column model should be analyzed separately.
  - Huge data transmission is needed between FF column model and the main model.
- Some software such as **PLAXIS**, **3DEC**, and **FLAC** have built-in free-field column element for their standard users.
  - All of the operations are handled in a single model.
- **ABAQUS** software:
  - Infinite continuum elements can be used instead of the dashpots (no need lumped parameters for dashpots)
  - Thanks to UEL capability in ABAQUS, one can utilize this element by adopting the subroutine developed by Nielsen (2006, 2014).

Validation

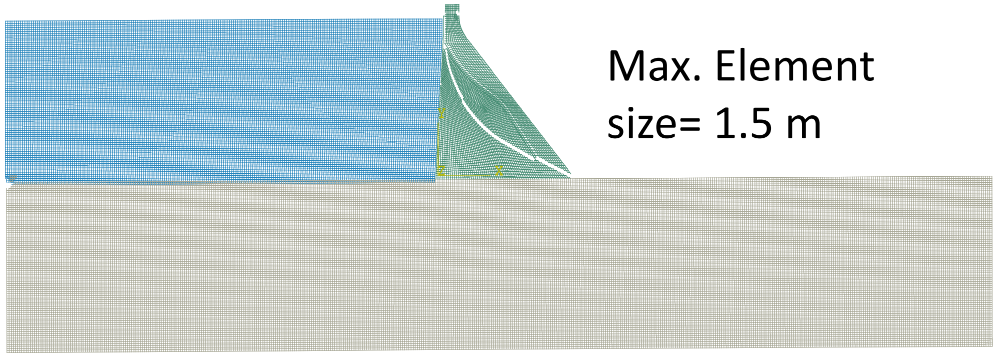


History of Velocities – High frequency Pulse signal

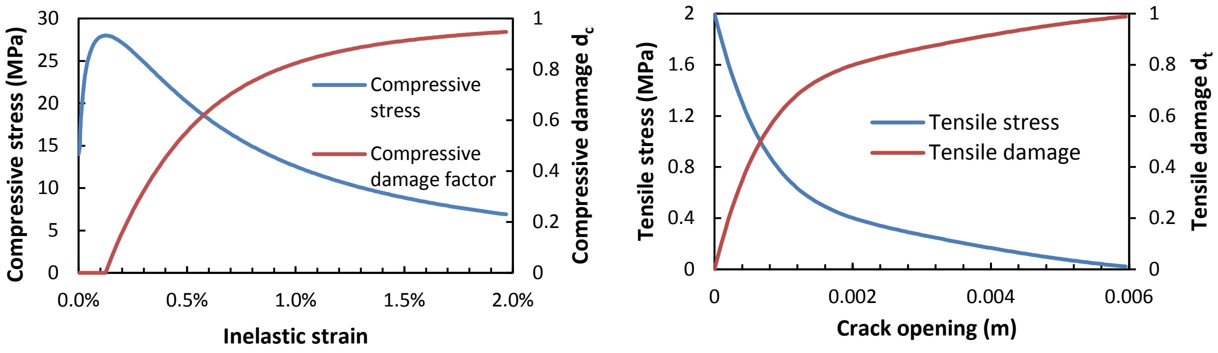




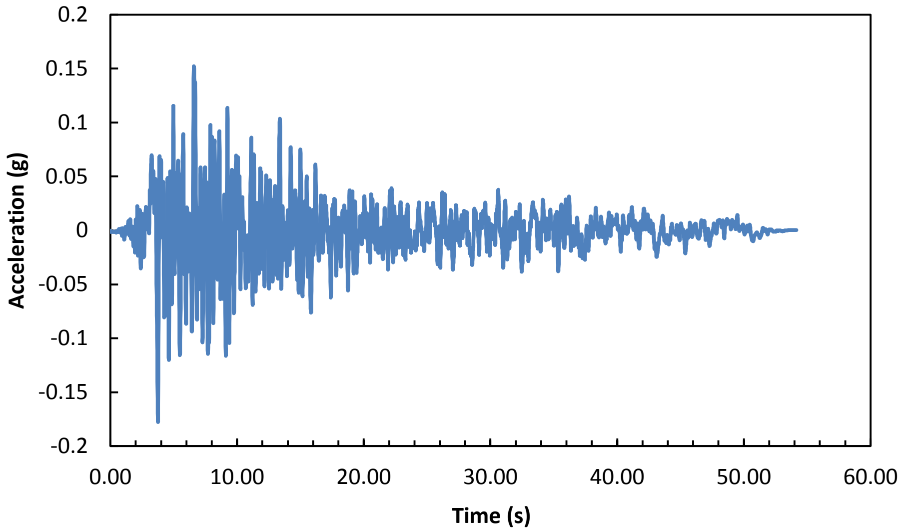
Pine Flat concrete Dam



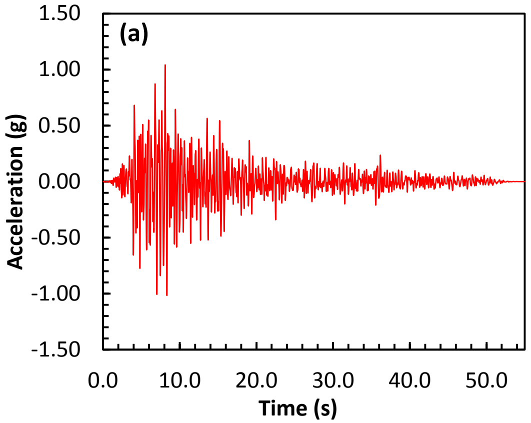
Max. Element size= 1.5 m



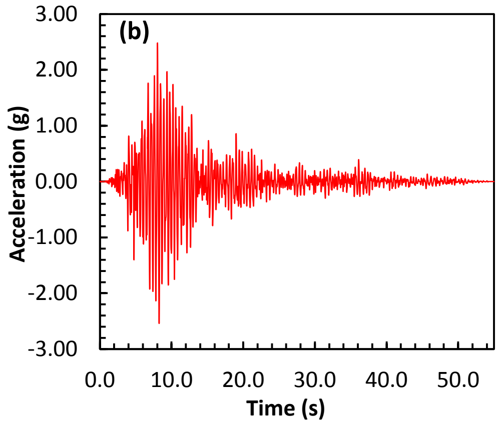
Concrete Damaged Plasticity



Taft Record



Linear model with foundation mass effects



Linear model without foundation mass effects

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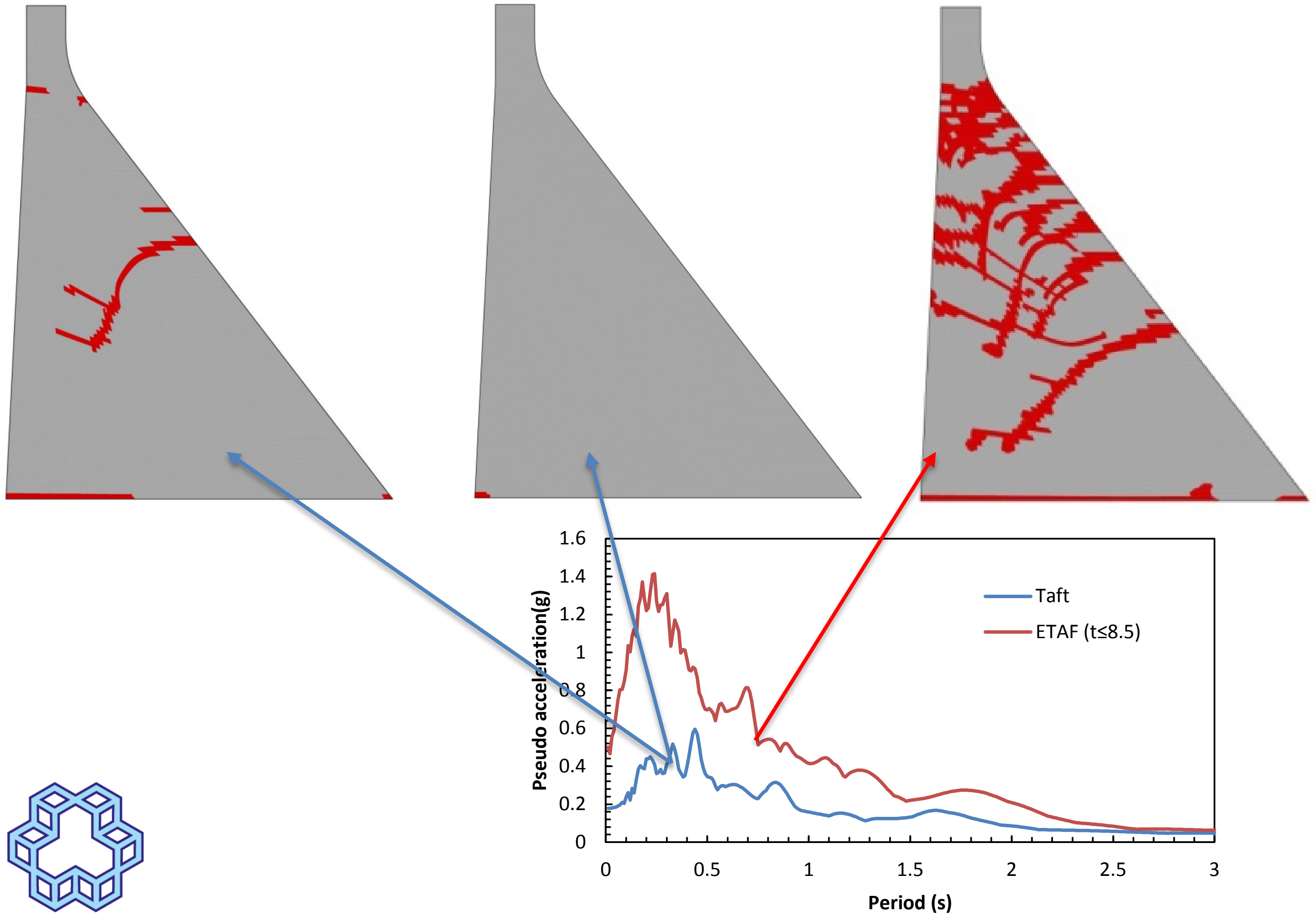
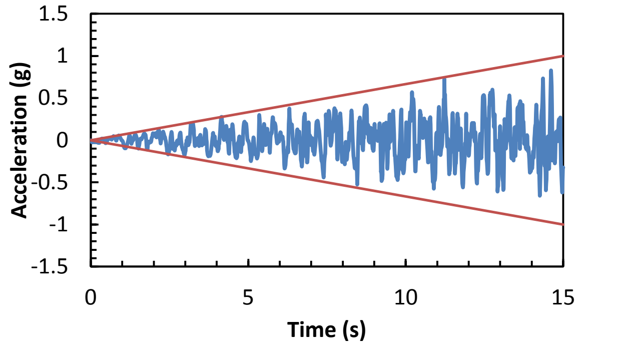
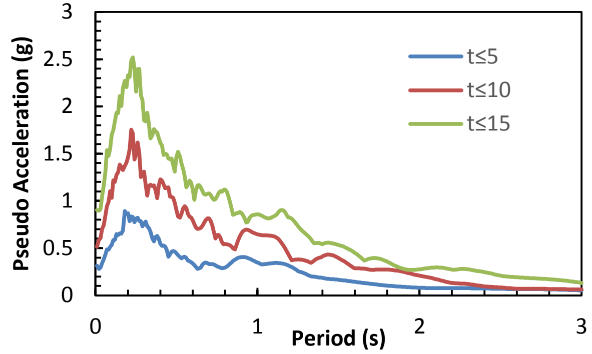
Damage Evaluation

Without foundation mass effects

With foundation mass effects







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