Theme A: Seismic Analysis of Pine Flat Concrete Dam

S. Valente[1], Q. He[2], C. Capriulo[1]

[1]Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Italy

[2]College of Water Conservancy and Hydropower Engineering, Hohai University, China

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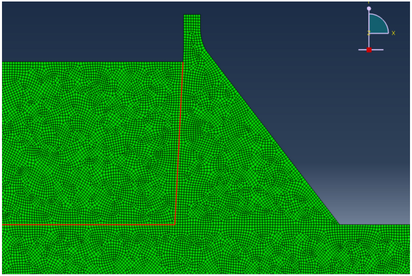
Introduction

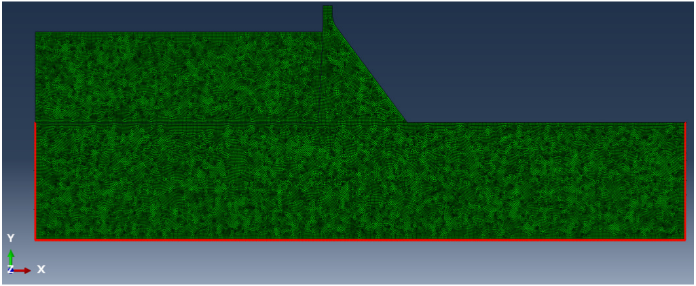
The results obtained are shown in the comparison document prepared by the formulators and are not repeated here. Here we will describe some hypotheses assumed for the numerical calculations.

Mesh used



- maximum element size 1.48 m.
- Dam and foundation structural elements: CPE3 and CPE4R.
- Reservoir acoustic elements: AC2D3 and AC2D4 (Dynamic pressure only).
- red line: Zienkiewicz's acoustic-structural interface elements (ASI).
- The meshes of the four parts are merged.

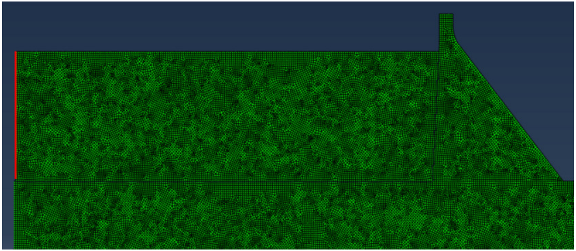
Structural boundary conditions (BC) applied



The BC applied to the red line depends on the phase considered as follows:

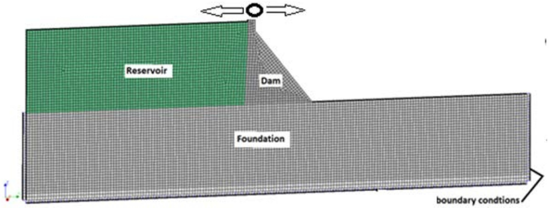
- eigenvectors extraction: $u_1 = u_2 = 0$.
- static reactions induced by dam and reservoir self-weight: $u_1 = u_2 = 0$ along the bottom side; $u_1 = 0$ along the vertical sides. This reactions are used to create a self-equilibrated static loading condition.
- implicit dynamic analysis in time domain: Viscous infinite elements, CINPE4, based on the work of Lysmer and Kuhlemeyer.

Acoustic boundary conditions applied



- zero-pressure applied to the water surface.
- acoustic impedence for incident plane waves applied to the red line.

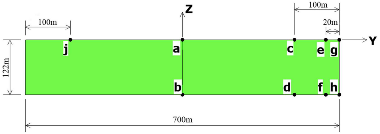
Case A-3: Dynamic force applied to the model



The dynamic force is applied by a eccentic-mass vibration generator (EMVG) positioned at the dam crest.

- The infinite elements offered by the abaqus code (CINPE4) are sufficient to solve this case. No specific code is necessary.
- The elastic waves propagating towards the infinite domain are absorbed by the viscous elements on the boundary.

Case B: Dynamic force applied by vertically propagating SH waves



We call Free Field Motion the dynamic response of the foundation alone, without considering the dam and the reservoir. Ideally, in this condition each column of elements behavies in the same way. As a consequence, the velocity histories evaluated at point A,C,E,G,J have to be the same. At the beginning of this project our focus was on converge issues induced by the softnening behaviour of concrete. So we did’nt applied any appropriated forces on vertical sides.As a consequence the peak velocity at point E was 50% than the same value at point A.

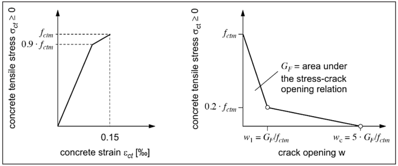
Case B and E : Appropriated forces applied to the vertical sides

After the submission of the final results, we decided to evaluate the impact of an appropriated free field motion on the final damage distribution for case E. The analysis was devided in two steps:

- In a first model, the condition $u_2 = 0$ was applied on both vertical sides. In this model all points in the foundation surfaces moves in the same way. The reaction force histories RF_2 and the displacement histories u_1 were recorded.
- In a second model, the condition $u_2 = 0$ was removed and the force histories RF_2 were applied. Furthermore the CINPE4 elements were added on the vertical sides and the forces necessary to impose the histories u_1 to CINPE4 elements were applied.

A specific python code was written in order to manage the above mentioned histories. This procedure was able to obtain the ideal condition: same velocity histories at points A,C,E,G,J. The same procedure was applied to case E.

Case E: Convergence issues



- The concete damaged plasticityi model was used.
- No water penetration into the crack was assumed.
- The strain softening behaviour of concrete in tension was evaluated according to MC2010.
- It induces loss of uniqness in the implicit dynamic analysis.
- In order to overcome this problem we decided to use the time history for deconvolved acceleration.
- The damage occurs in tension only, and it is localized at the dam-foundation joint.

Case E: Final damage after Taft time history

- Since it is expected that the viscous regularization applied will induce spikes above the tensile strength, the pre-defined value of strength was reduced of 10%.
- Since abaqus code does not reduce the stiffness proportional damping as the damage grows, only for the elements that are expected to be damaged, it was assumed $\beta = 0$ from the beginning.
- without appropriated forces on vertical foundation sides:the damage on dam-foundation joint grows up to 18 m from upstream side.
- with appropriated forces on vertical foundation sides:the damage on dam-foundation joint grows up to 16.5 m from upstream side.
- The 10% pre-defined reduction of tensile strength was unsufficient. Two spikes of 10% above the tensile strength (2 MPa) appears in both cases.