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Seismic behavior of Pine Flat concrete gravity dam using microplane damage-plasticity model

EPFL
Samuel Vorlet, Giovanni De Cesare, Pedro Manso
Platform of Hydraulic Constructions (PL-LCH), Ecole Polytechnique Fédérale de Lausanne (EPFL)
LCH
PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

Introduction

The response of gravity dams under seismic loads is a major concern of dam safety assessment in earthquake-prone areas. The dynamic response of the dam body depends to some extent on the binding foundation conditions as well as on the interaction with the reservoir. During earthquakes, gravity dams are subject to strong horizontal and vertical motions inducing stresses with peaks that may be greater than the maximal strength and consequently lead to damage in the dam body, mainly in tension state. Currently, most dam safety evaluations with finite elements (FE) analysis of reservoir-dam-foundation systems consider a linear elastic model for mass concrete with failure criteria based on maximal tensile strength [1,2], in particular for the non-extreme load combinations. First assessments of extreme load combinations using linear analyses allow preliminary estimates of the location and extent of tensile stress peaks greater than the maximal concrete tensile strength but cannot inform on stress and stiffness redistribution during an earthquake (damage time evolution). This study concerns linear and nonlinear analyses with damage model in order to assess the dam safety under seismic loads resulting with stress peaks leading to damage in the dam body. It presents the seismic analysis of Pine Flat Dam for the 15th International Benchmark Workshop on Numerical Analysis of Dams to be held in Milan in September 2019. It focuses on the tallest non-overflow monolith of Pine Flat concrete gravity dam located on King's River, east of Fresno, California (USA).

Methods

Numerical simulations were performed using the finite element code ANSYS (M-APDL) to discretize the governing equations on the computational domain. A two-dimensional finite elements (FE) model of the reservoir-dam-foundation system is considered. The dam is composed of 37 monoliths and its crest is 561 m long. The tallest non-overflow monolith is 121.91 m high with a 95.8 m base length. The dam body and rock foundation (700 m x 122 m) are modeled with quadrilateral structural plane strain elements. The reservoir is modeled using acoustic elements with inviscid and compressible.

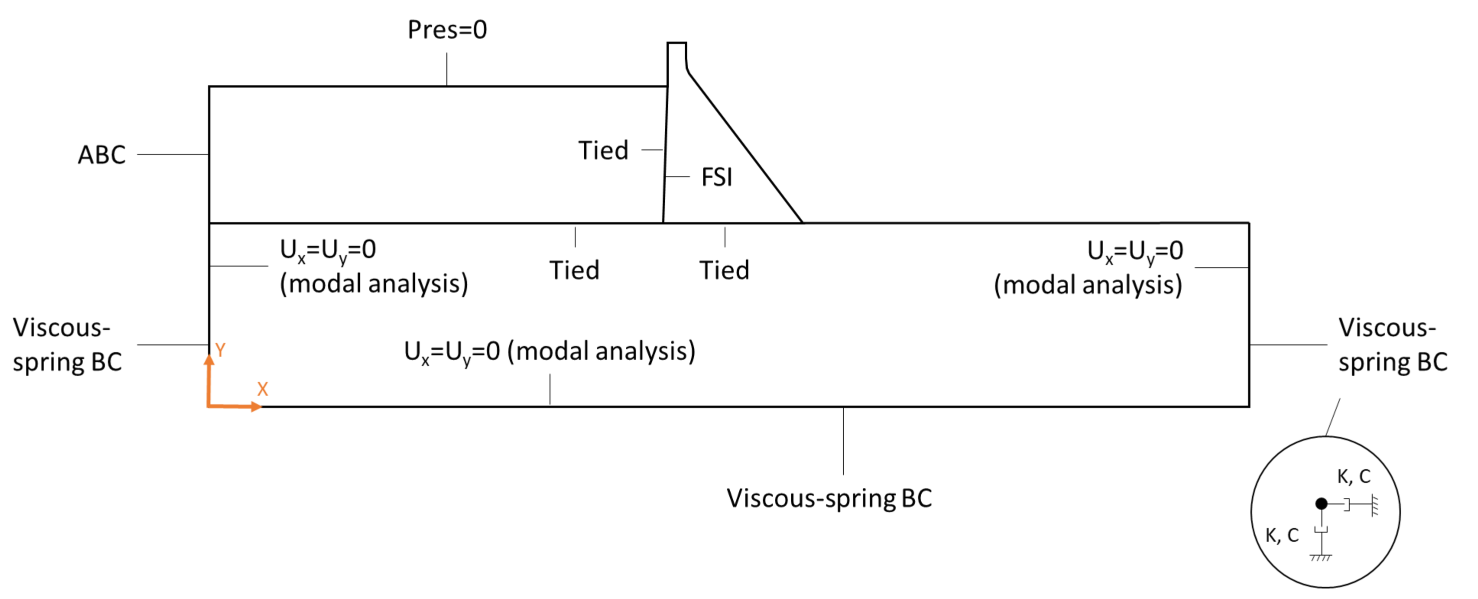

***Figure 1:** Reservoir-dam-foundation FE model boundary conditions and interfaces*

For damage modeling in the dam body, a coupled damage-plasticity model for concrete [3] based on microplane formulation [4, 5] is used. The model has the ability to define different damage initiation criteria and damage evolution laws between tension and compression states. The model can additionally represent cyclic loading conditions, where stiffness lost during cracking is recovered due to crack closure during transition from tension to compression state, while damage sustained under compression remains upon transition to tension state [3].

Dynamic properties

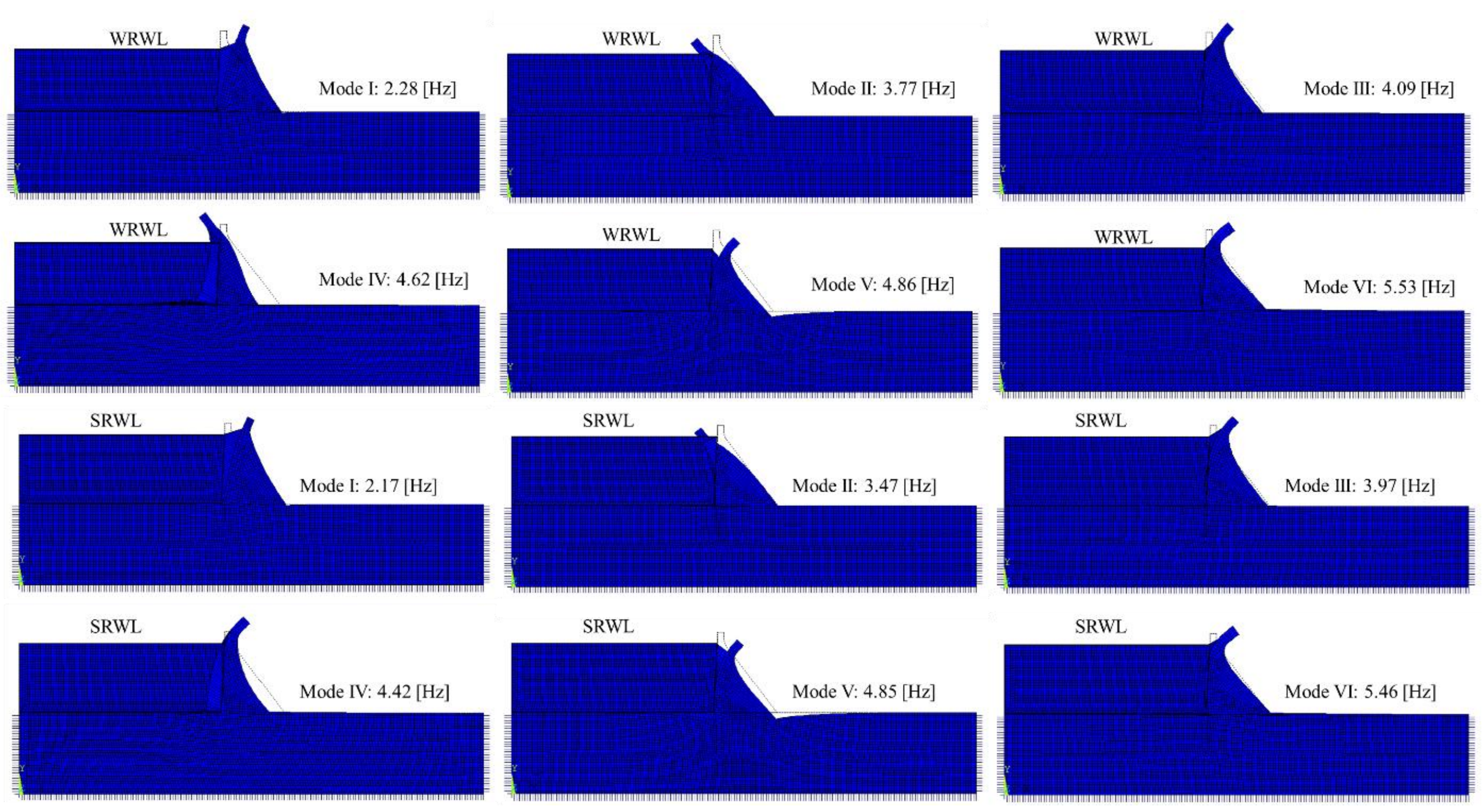

***Figure 2:** Natural frequencies and mode shapes; Winter Reservoir Water Level (WRWL); Summer Reservoir Water Level (SRWL)*

Linear analysis

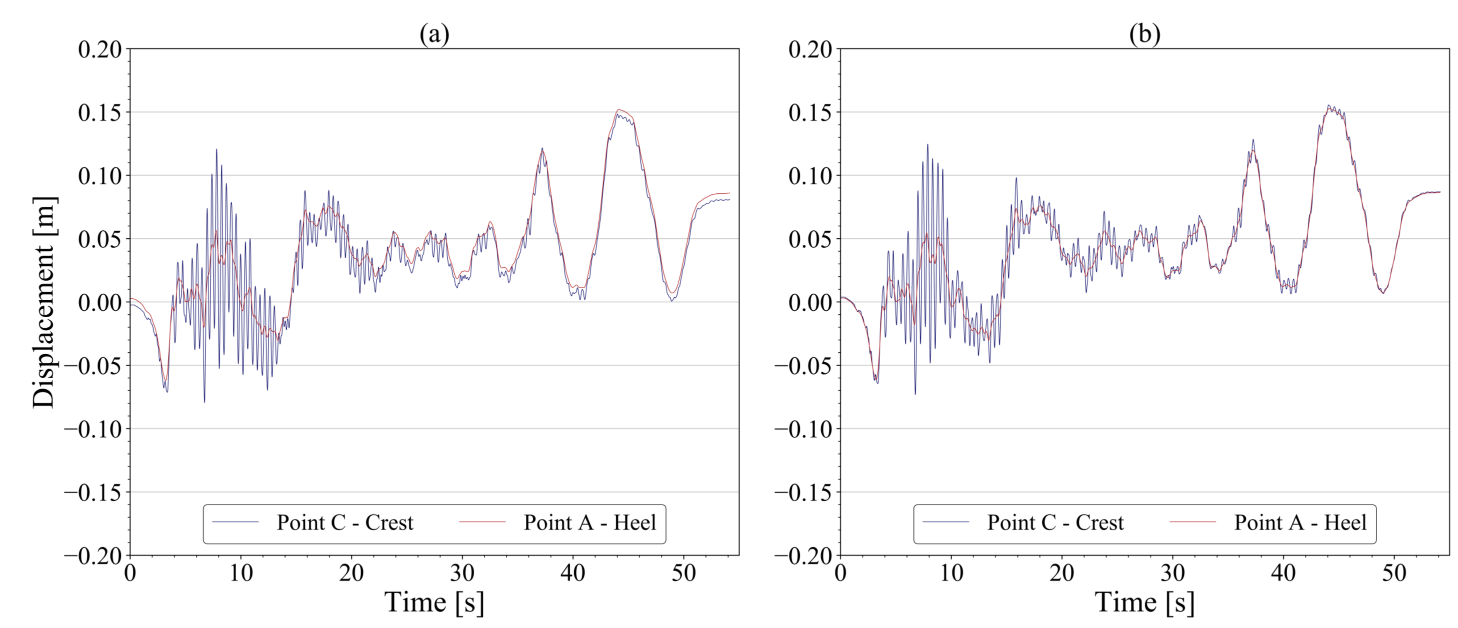

***Figure 3:** Computed horizontal displacements at crest and heel of the dam; (a) WRWL; (b) SRWL; Taft Record acceleration*

Nonlinear analysis

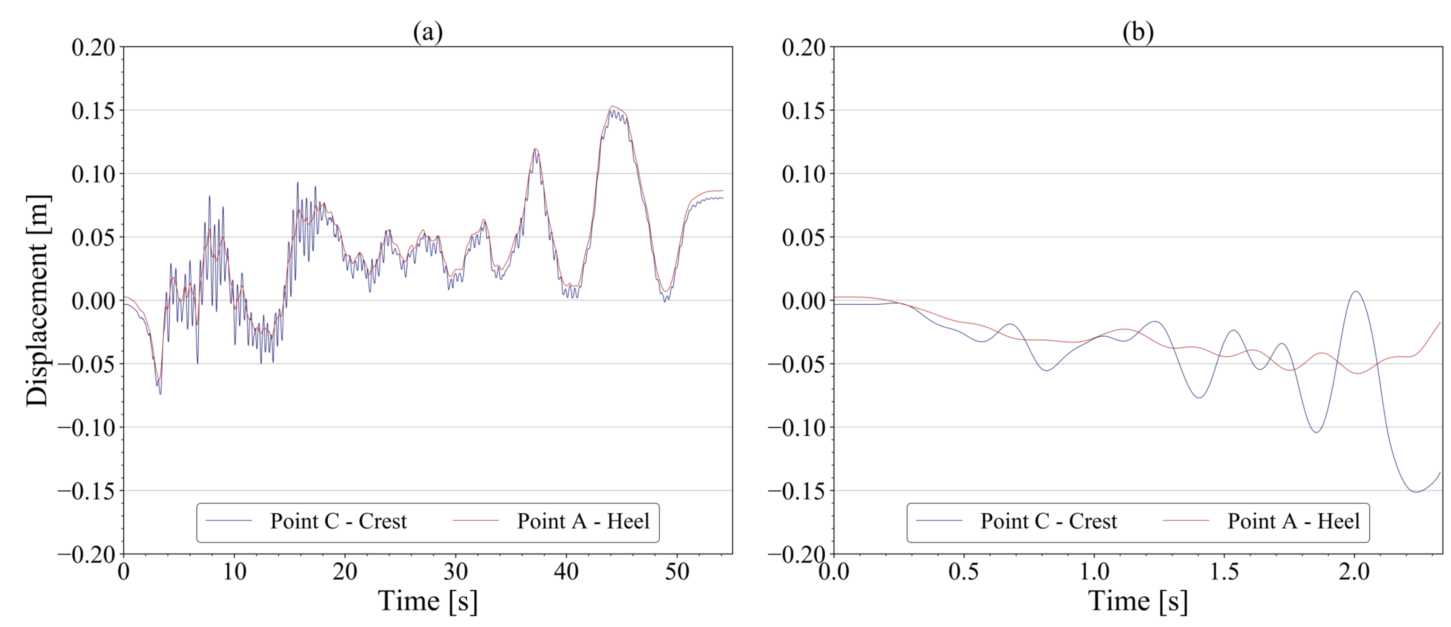

***Figure 4:** Computed horizontal displacements at crest and heel of the dam; (a) Taft Record acceleration, no failure; (b) artificially designed ETAF acceleration, failure*

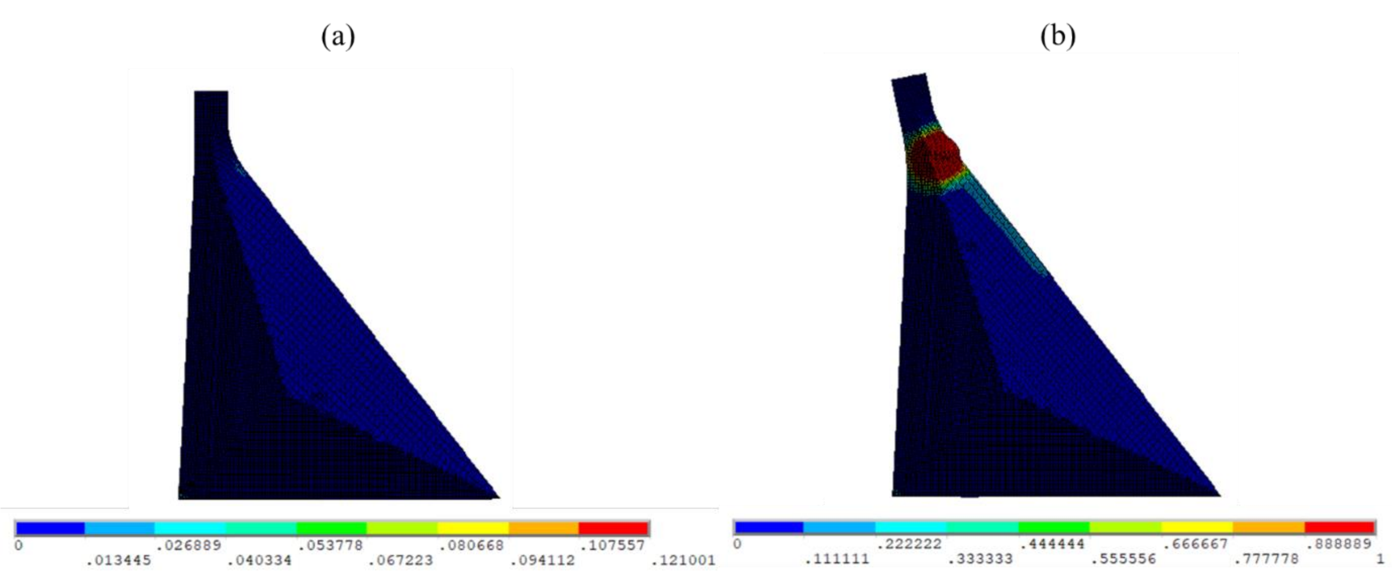

***Figure 5:** Computed damage parameter DMG; (a) Taft Record acceleration, no local dam failure; (b) artificially designed ETAF acceleration, failure of the dam body*

Conclusions

Results show the ability of the numerical models to: (i) reproduce adequately the dynamic properties of the reservoir-dam-foundation system and (ii) conduct dynamic linear and nonlinear analysis. Results of nonlinear analyses show the ability of the model to represent cyclic loading conditions, with recovery of the stiffness lost during cracking in the transition from tension to compression state, and subsequent failure of the dam body near the crest.

References

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