ICOLD
INTERNATIONAL
COMMISSION ON
LARGE DAMS

ICOLD-BW 2019
9th-11th September
MILANO
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 of Pine Flat Concrete Dam

Tsinghua University

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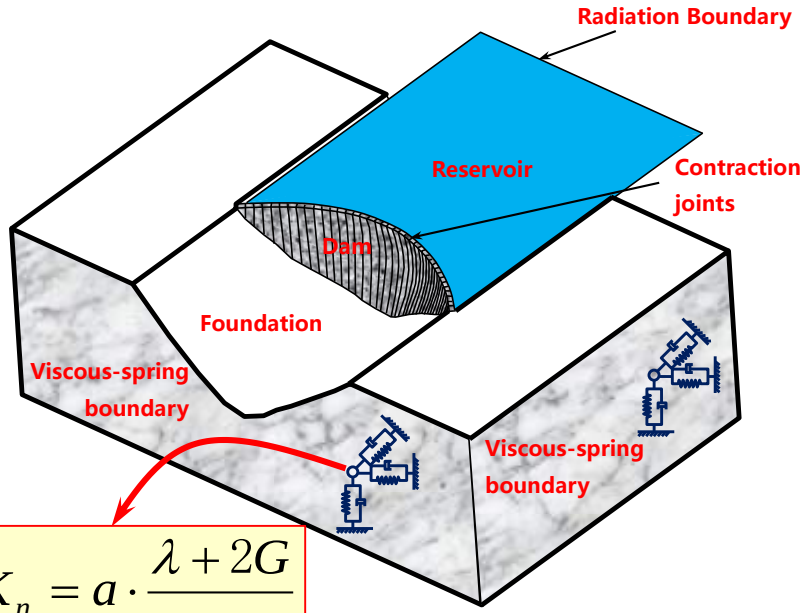
Computational Model at Tsinghua University

The Research Group on Earthquake Resistance of High Dams at Tsinghua University developed a comprehensive analysis model of dam-water-foundation system.



$$K_n = a \cdot \frac{\lambda + 2G}{r}$$

$$K_s = a \cdot \frac{G}{r}$$

$$C_n = b\rho V_P$$

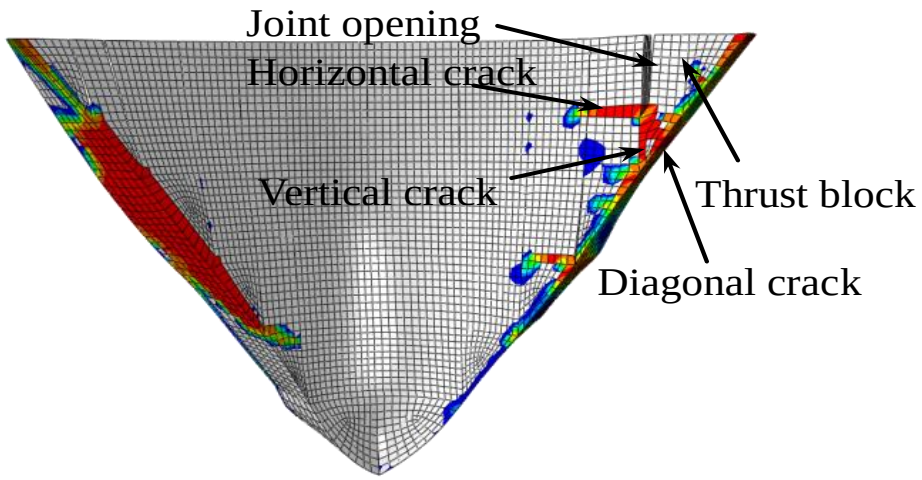
$$C_s = b\rho V_S$$

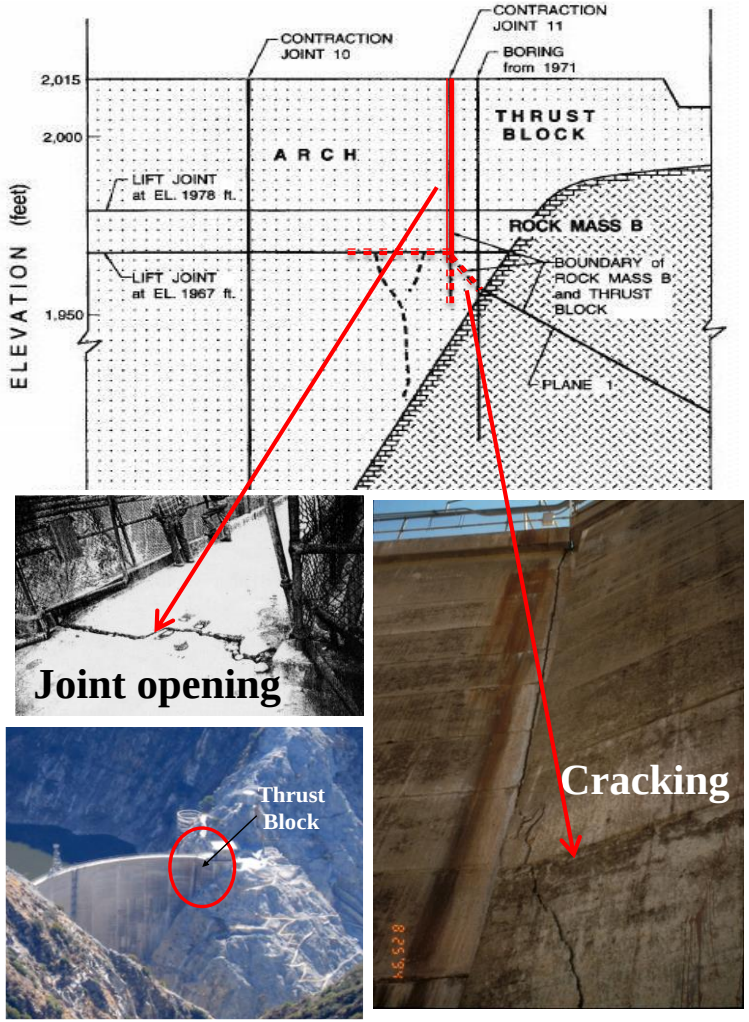
- Dam-foundation interaction
- Dam-water interaction
- Compressible water
- Opening of contraction joints
- Damage cracking of concrete
- Strengthening measures
- Nonlinearity of foundation rock

Zhang CH, Pan JW, Wang JT (2009); Pan JW, Zhang CH, Wang JT, Xu YJ (2009; Wang JT, Zhang CH, Jin F (2012); Wang JT, Lv DD, Jin F, Zhang CH (2013);

Pacoima Dam in Northridge EQ

Damage of the Pacoima dam in 1994 Northridge Earthquake





- Some of the joints opened during the earthquake and the thrust block joint remained open after earthquake
- A diagonal crack on the downstream face
- A permanent horizontal offset along the horizontal joint

Wang JT, Lv DD, Jin F, Zhang CH (2003)

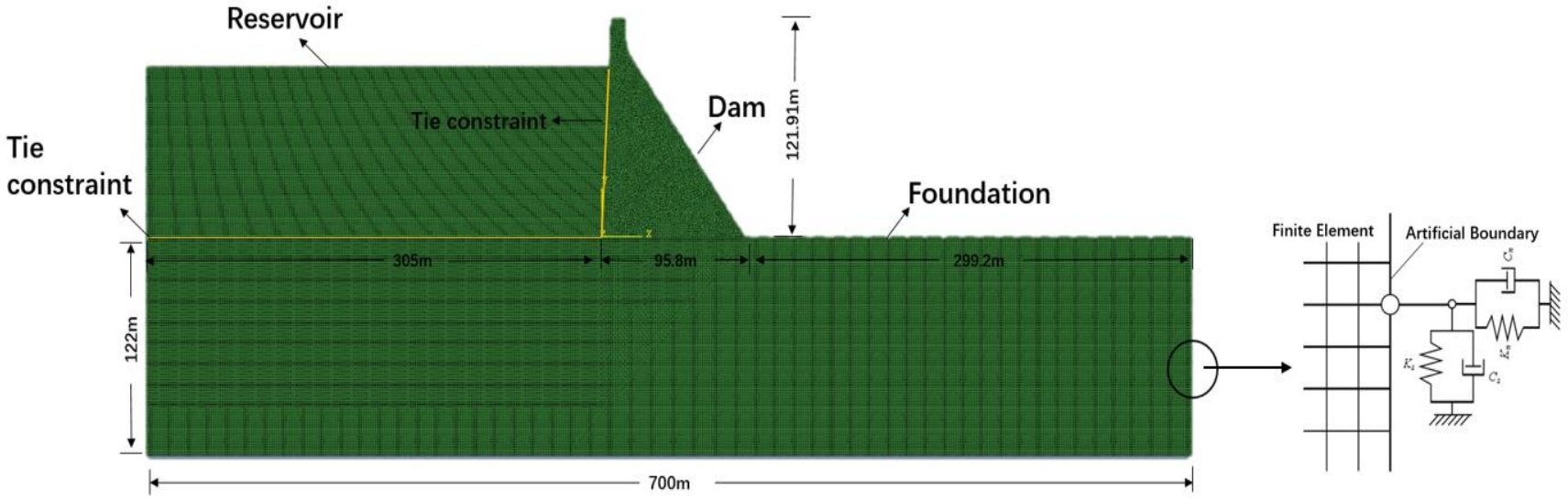
Analysis Model

Model features

- Dam: Plane stress elements
- Foundation: Plane strain elements
- Reservoir water: acoustic fluid elements

Analysis conditions

- The mass of dam, foundation and reservoir
- Rayleigh damping for dam and foundation
- Artificial boundary at bottom and sides of foundation



Viscous-spring boundary

Radiation damping of semi-unbounded foundation

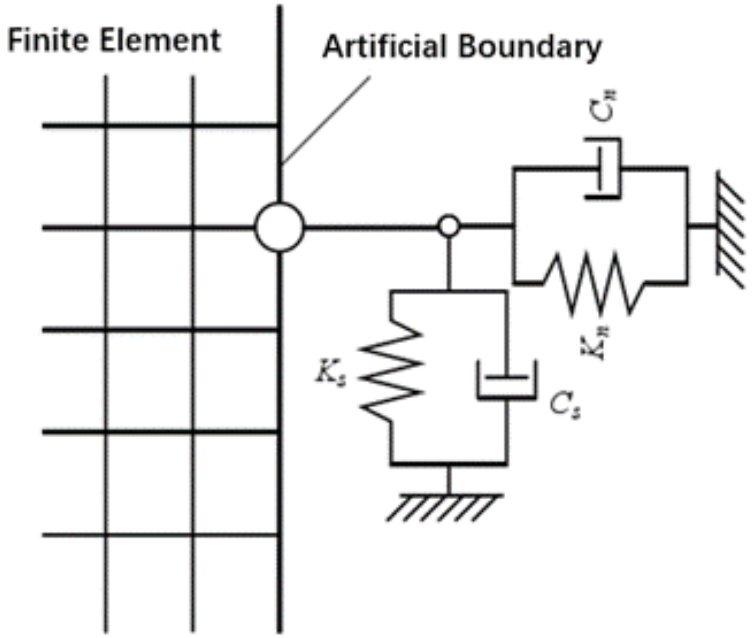
The viscous–spring condition is applied to the truncated foundation boundaries to simulate the radiation damping

- Normal

$$K_n = a \cdot \frac{\lambda + 2G}{r} \qquad C_n = b\rho V_P$$

- Tangential

$$K_s = a \cdot \frac{G}{r} \qquad C_s = b\rho V_S$$

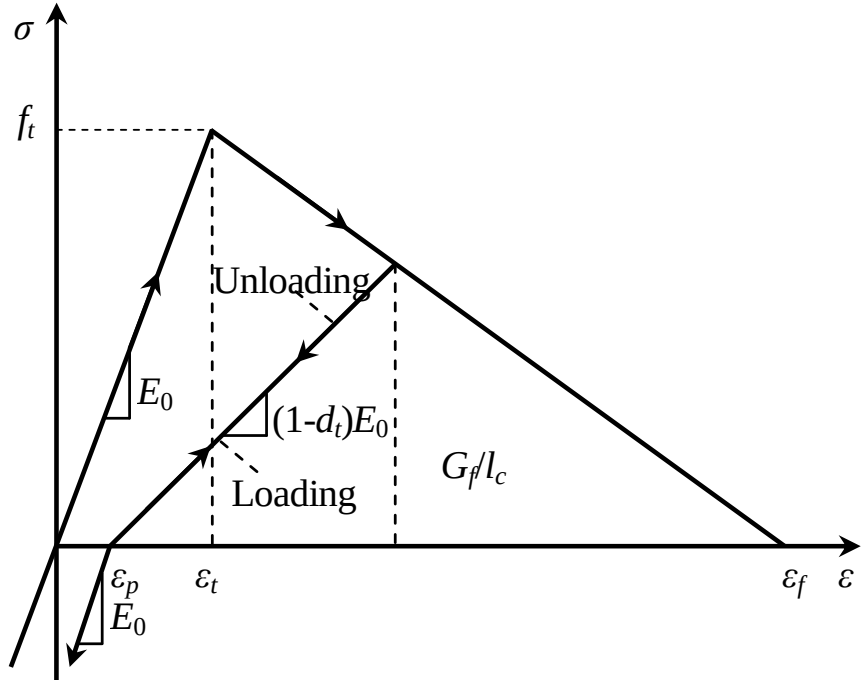


Zhang C, Pan J, Wang J. Influence of seismic input mechanisms and radiation on arch dam response. Soil Dynamics and Earthquake Engineering, 2009, 29:1282-1293.

Damage model

Nonlinearity of dam concrete

The plastic damage model is used to model the material nonlinearity of dam concrete

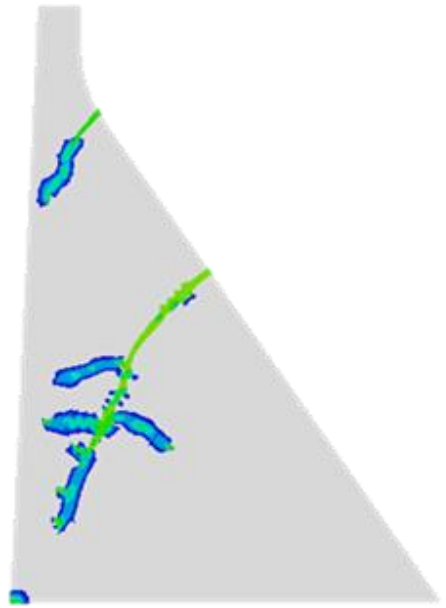


Pan J, Zhang C, Wang J, Xu Y. Seismic damage-cracking analysis of arch dams using different earthquake input mechanisms. Science in China Series E: Technological Sciences, 2009, 52:518-529.

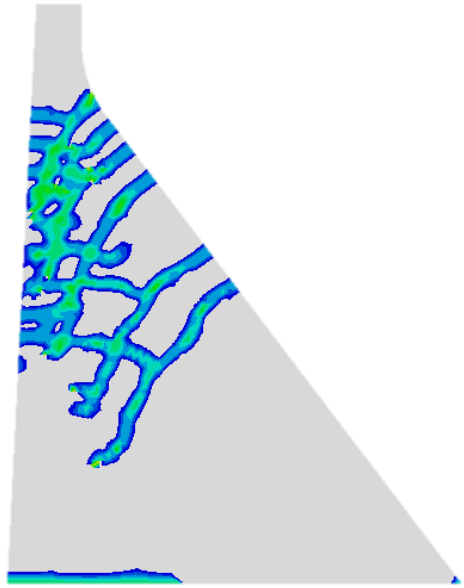
Case studies

Case	Analysis type			
	1	2	3	4
A	√	√	√	√
B	√	√	√	√
C	√	√	√	√
D	√	√	√	
E	√	√		
F	√	√	√	

Case	Loads	Tensile strength (MPa)	Concrete (GPa)
1	**ETA**	**2.4**	**33.62**
2	**ETA**	**2.0**	**22.41**

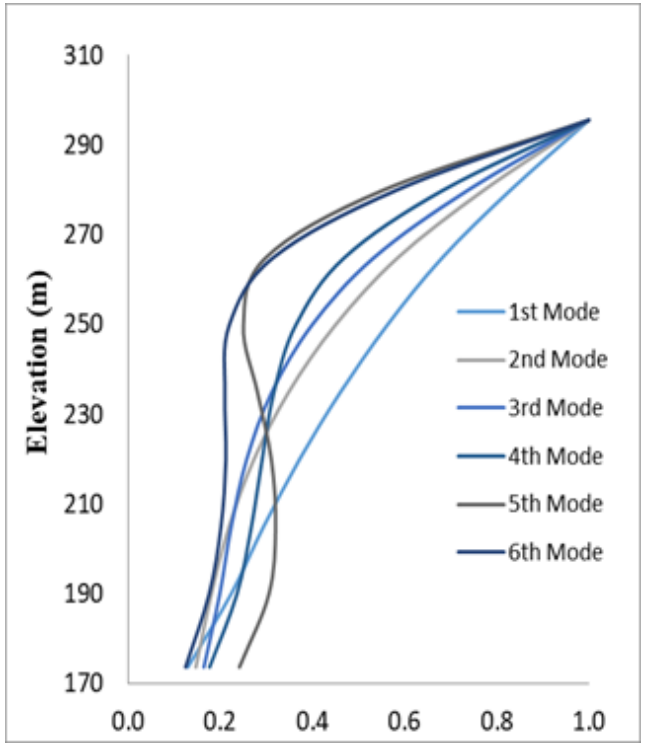


Case 1

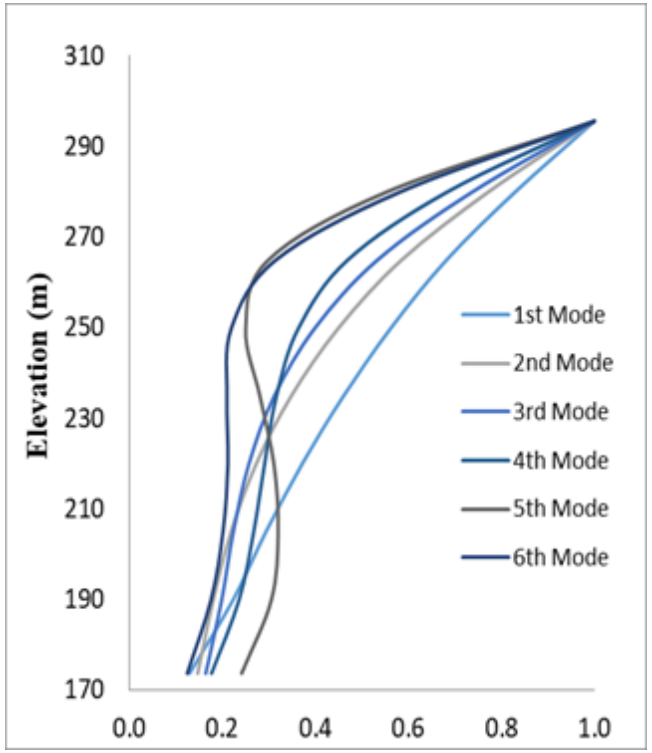


Case 2

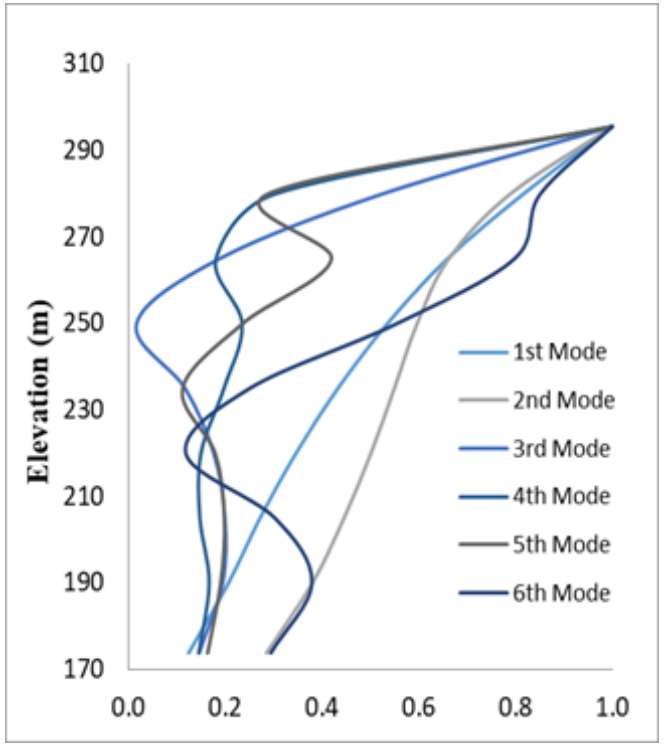
Comparison of normalization modes of models



Winter reservoir water level



Summer reservoir water level



No reservoir

The normalized mode shape of two models with different water are similar, but the mode shape of the model without reservoir is quite different from those of the model with reservoir except for 1st mode.

Conclusions

- In EMVG test simulation, the acceleration in Case A3 (lower reservoir water level) is larger than that in Case A4 (higher reservoir water level). Therefore, the effect of reservoir level is notable in EMVG Test Simulation.
- Viscous-spring artificial boundary is able to absorb the reflected wave efficiently.
- The exist of dam can influence the dynamic response on the top of foundation. However, the effect of reservoir on the seismic response of the foundation is not notable.
- The weak parts of the gravity dam body against seismic are dam heel, dam toe, dam neck, and the upper part of downstream dam body. These parts should be paid more attention during seismic design.
- The exist of reservoir has a notable effect on the mode of model during the frequency analysis
- The amplification effect on the dam crest of the model with massless foundation is clearly larger than that of the model with the viscous-spring artificial boundary. That is to say, the dynamic responses computed in model with massless foundation are overestimated.

Acknowledgements

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Thanks for your attention!