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Seismic response and numerical modelling of earthfill dams

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Nicholas Ambraseys memorial symposium, 19th of March 2014

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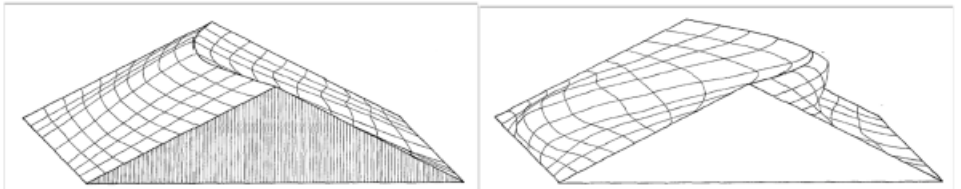
Seismic response of earthfill dams

The "Ambraseys legacy" in seismic response of dams

- *Established analytically the transverse dynamic response of homogeneous dams*
- *Extended the shear beam method to account for truncated wedge shape, rectangular canyon and underlying elastic layer*
- *Sliding block analysis to calculate permanent seismically induced displacements*
- *Detailed investigation of numerous case studies of dam performance during earthquakes*



First 2 natural transverse modes of vibration (Ambraseys 1960a, BBSA, Vol.50)

Ambraseys & Sarma (1967)

Ambraseys & Menu (1988)

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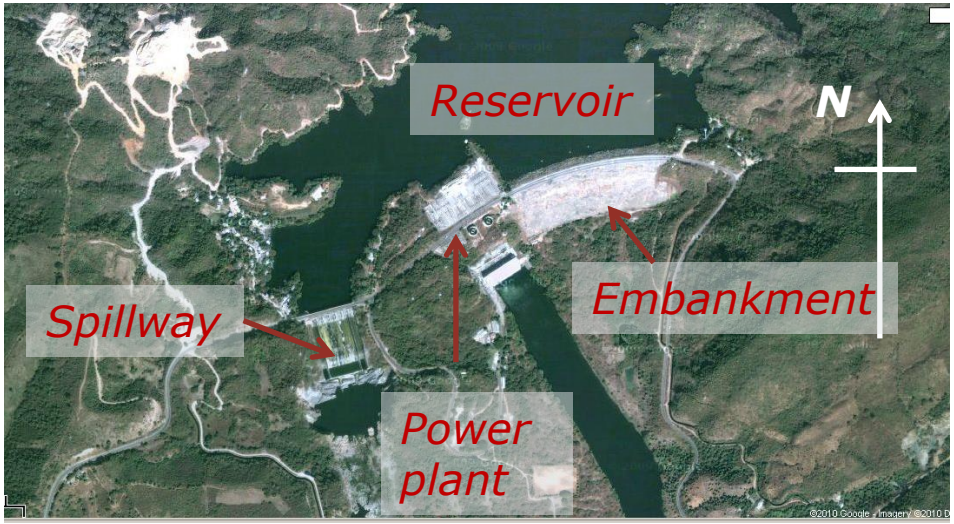
Case study: La Villita dam, Mexico

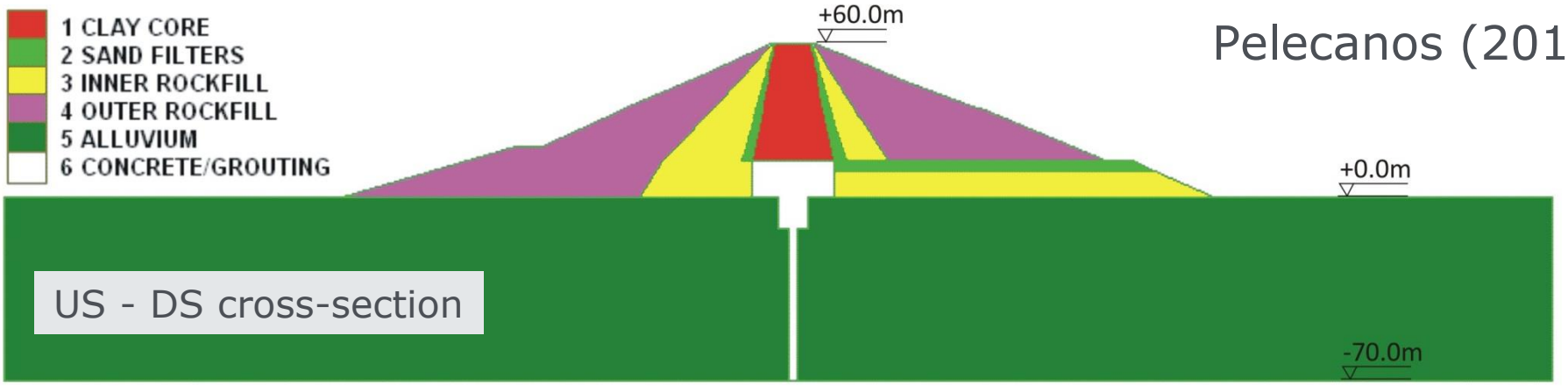
Project construction: 1964-1968

Embankment construction: 1967

Reservoir Impounding: 1968



(Google Earth, 2010)



US - DS cross-section

Pelecanos (2013)

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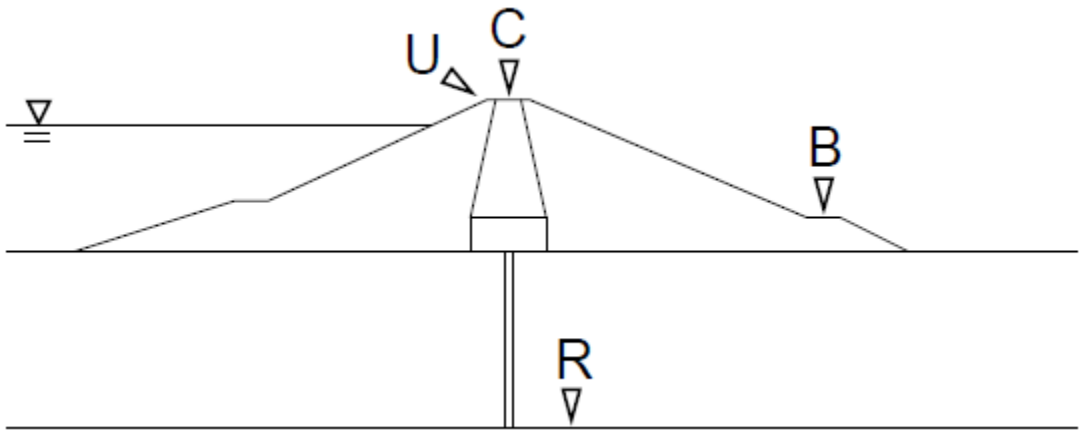
Case study: La Villita dam, Mexico

- Experienced a number of seismic events of varying intensity
- No severe damage, but suffered significant deformations
  - Crest settlement
  - Slope movements
- Available measurements:
  - settlement history
  - acceleration recordings



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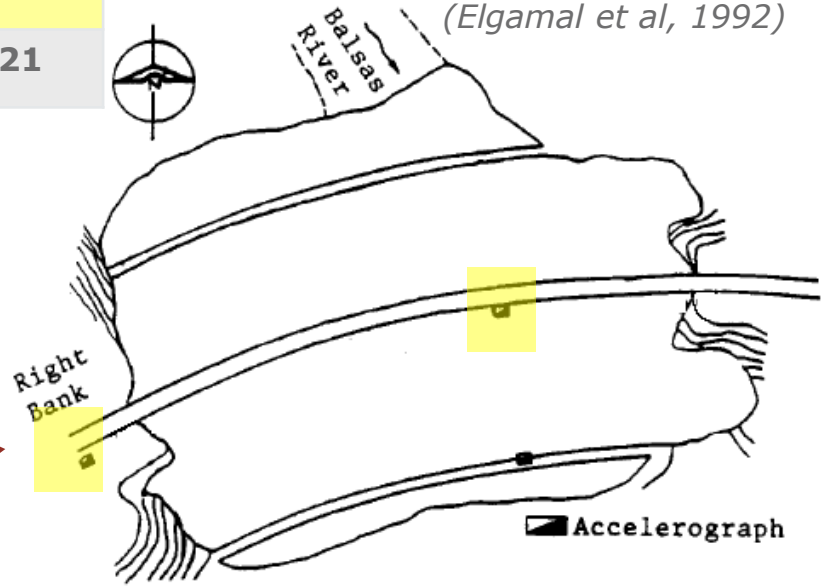
Case study: La Villita dam, Mexico

	Date	Ms	Epicentral Distance (km)	PGA (g) (rock)	PGA (g) (crest)
EQ1	11/10/1975	4.5	52	0.07	0.36
EQ2	15/11/1975	5.9	10	0.04	0.21
EQ3	14/3/1979	7.6	121	0.02	0.4
EQ4	25/10/1981	7.3	31	0.09	0.43
EQ5	19/11/1985	8.1	58	0.12	0.76
EQ6	21/11/1985	7.5	61	0.04	0.21

(Elgamal et al, 1992)



Bedrock motion

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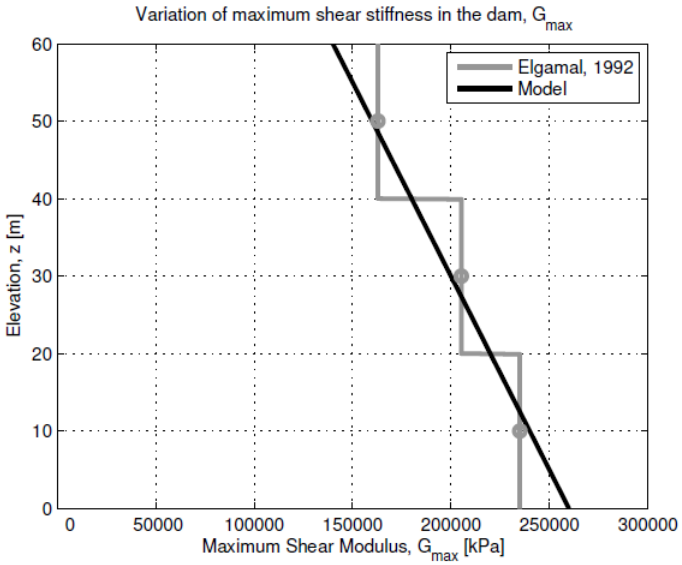
Case study: La Villita dam, Mexico

Material	Cohesion	Angle of shearing resistance	Shear modulus	Stiffness degradation/ damping curves
	c` (kPa)	φ` (degrees)	G_{max} (MPa)	
Clay Core	5	25	spatially varying	Vucetic & Dobry (1991)
Sand Filters	0	35	spatially varying	Seed et al. (1986)
Rockfill	5	45	spatially varying	Rollins et al. (1998)
Alluvium	5	35	200	Rollins et al. (1998)

Material properties based on Elgamal (1992)

Stiffness variation for the clay core



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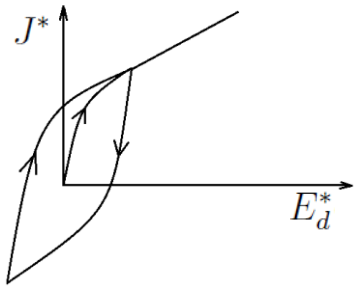
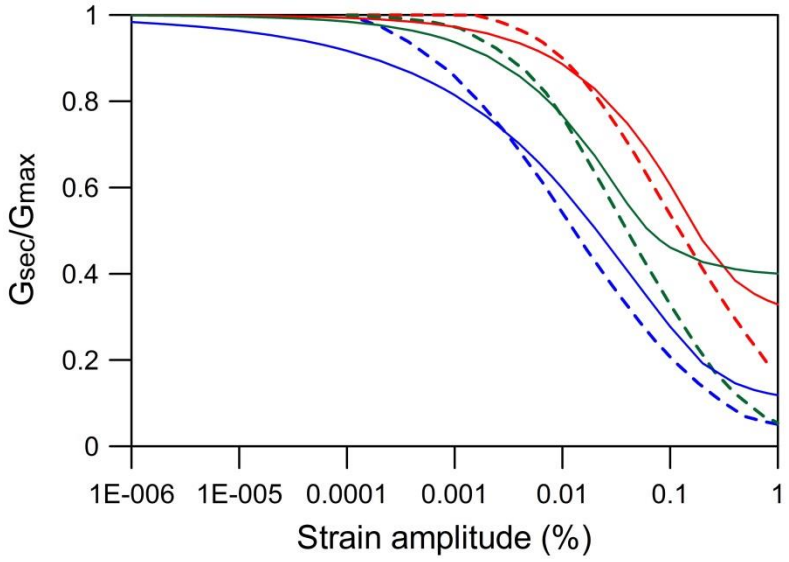
Case study: La Villita dam, Mexico

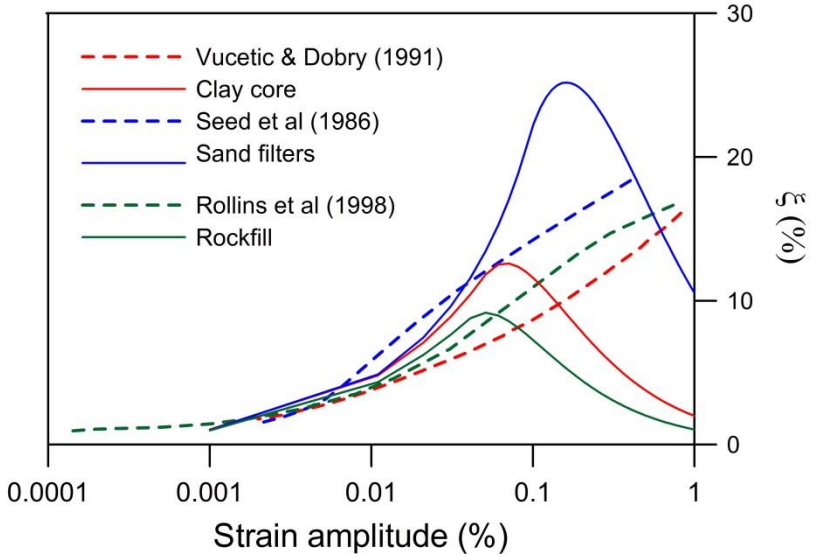
Cyclic nonlinear model combined with a Mohr-Coulomb failure criterion

$$J = E_d G_{max} \left[1 - \alpha ln\left(1 + \frac{G_{max}\,|E_d|}{J_L}\right)^R\right]$$

Taborda (2011)
(Puzrin & Burland 2000)







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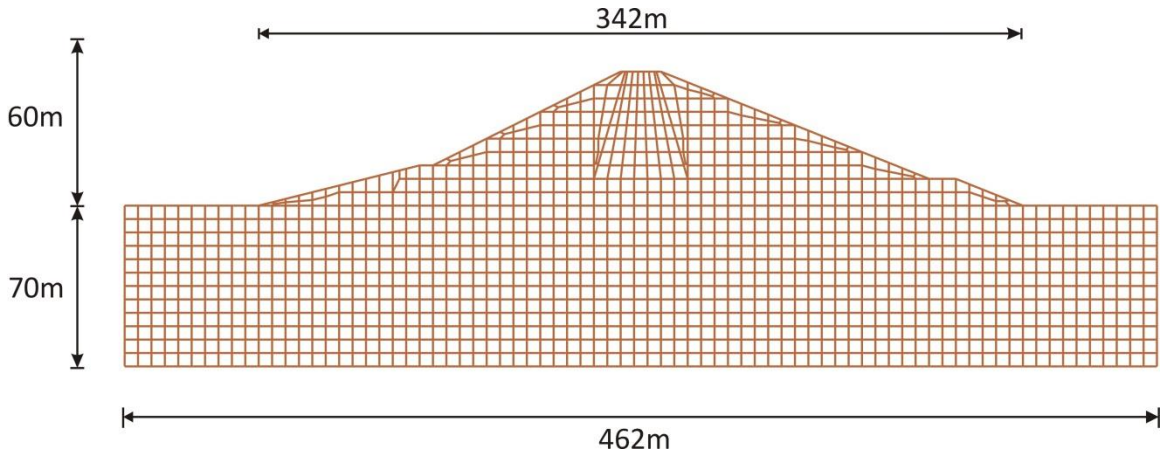
Case study: La Villita dam, Mexico

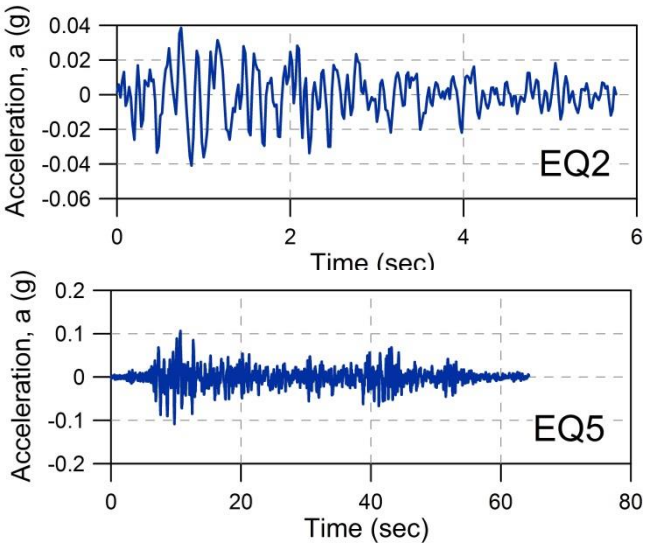
Coupled consolidation, plane strain analyses with **ICFEP**

Static analysis

- Layered construction
- Water impoundment
- Consolidation up to the 1st seismic event (6.5 years)



Dynamic analysis



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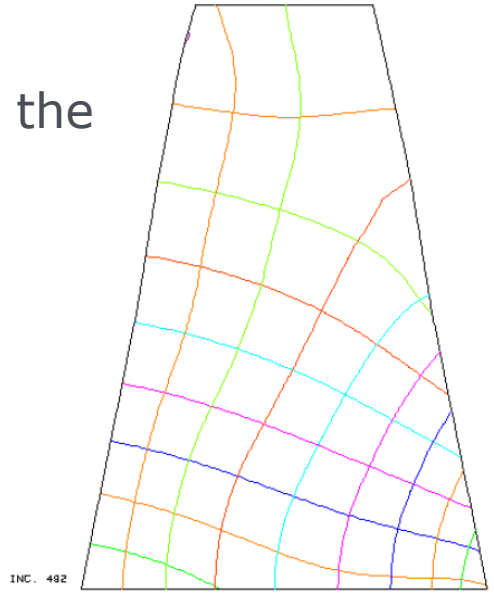
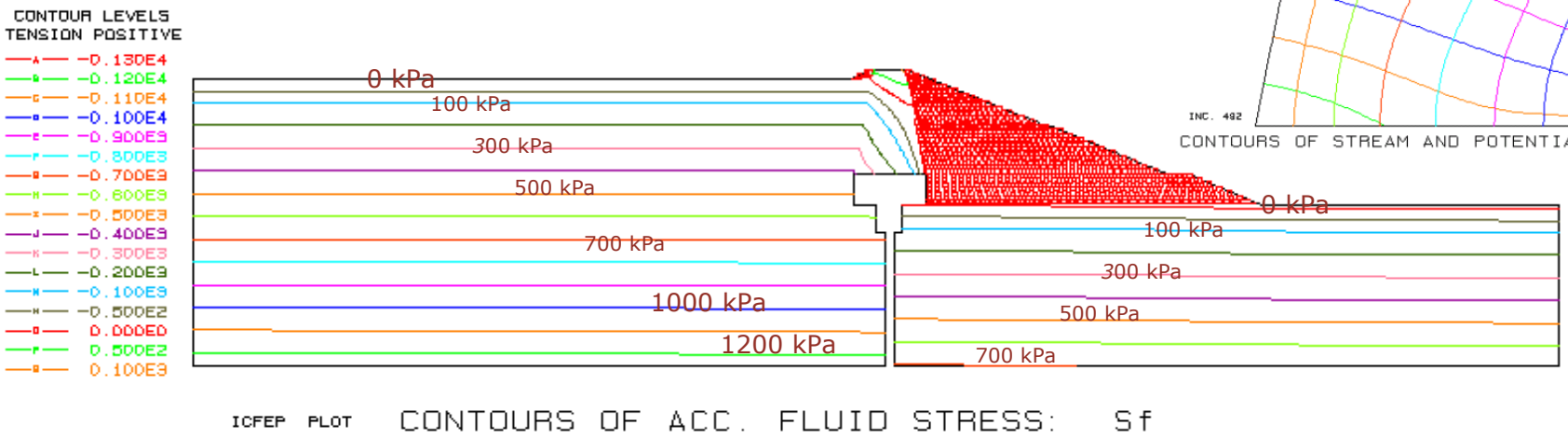
Case study: La Villita dam, Mexico

Static analysis results: after impoundment

Flow net in the clay core

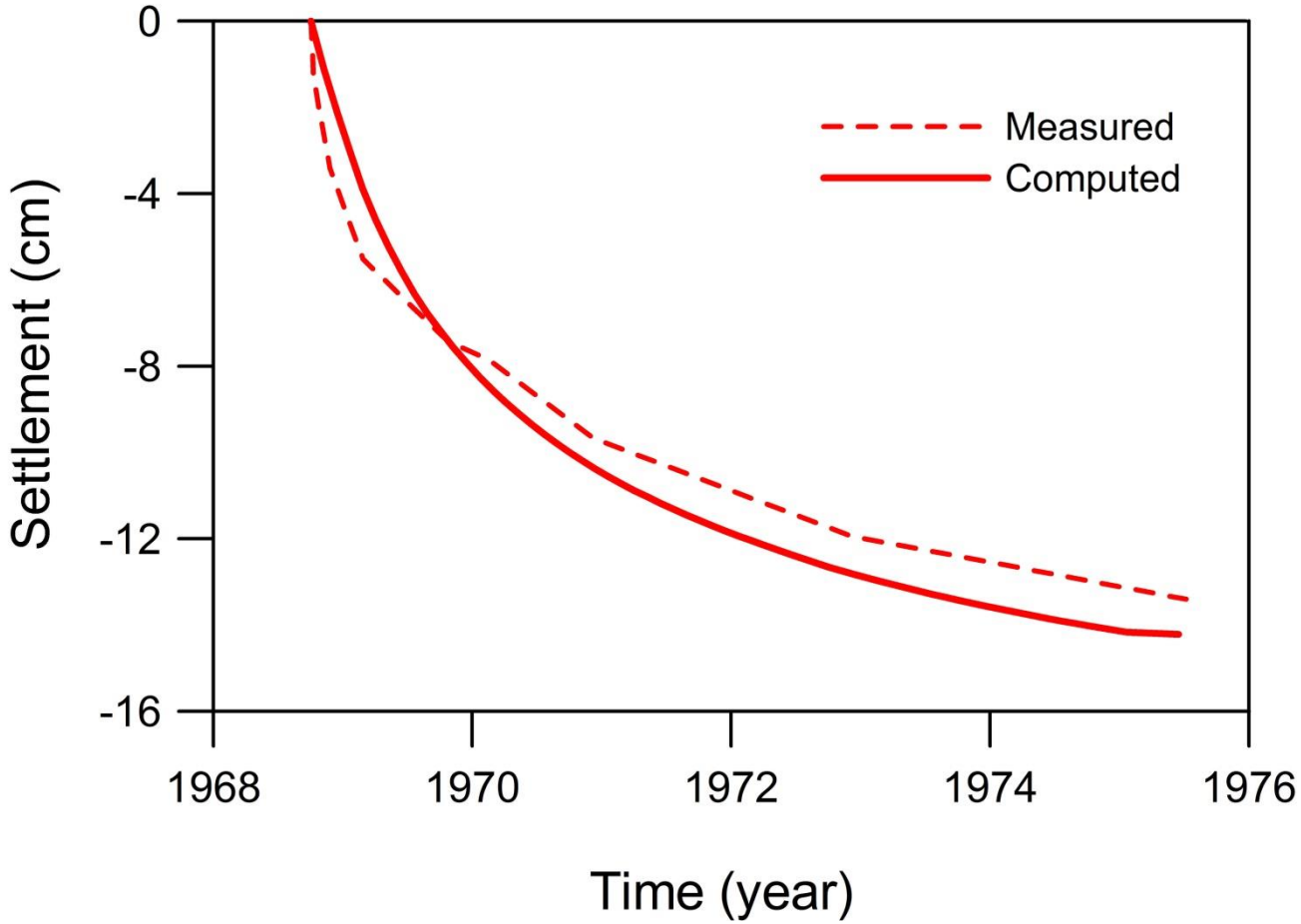


Pore water pressure distribution



Case study: La Villita dam, Mexico

Static analysis results: Crest settlement during impoundment and consolidation



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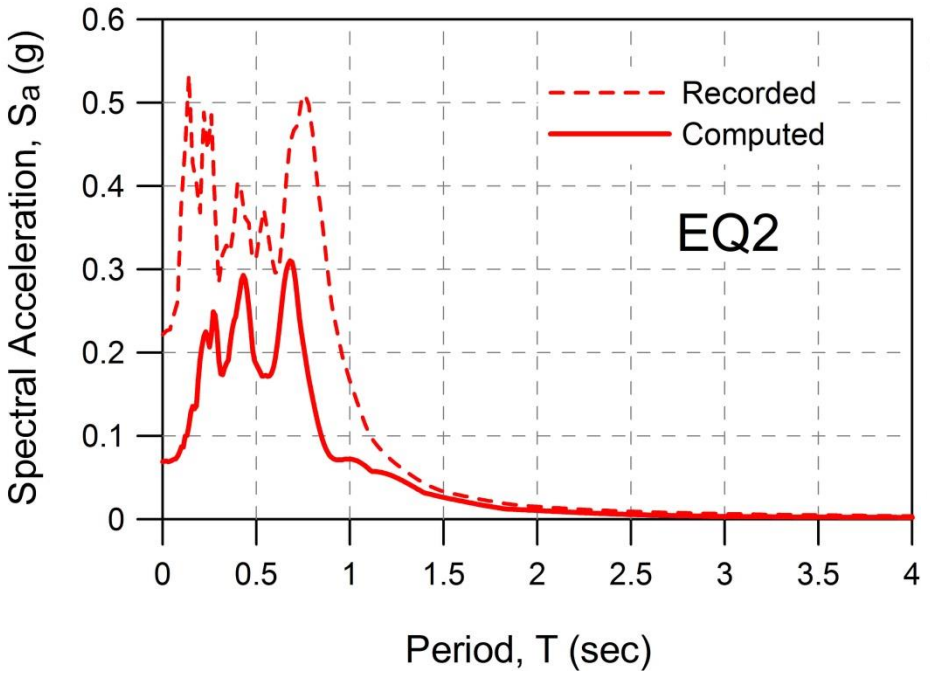
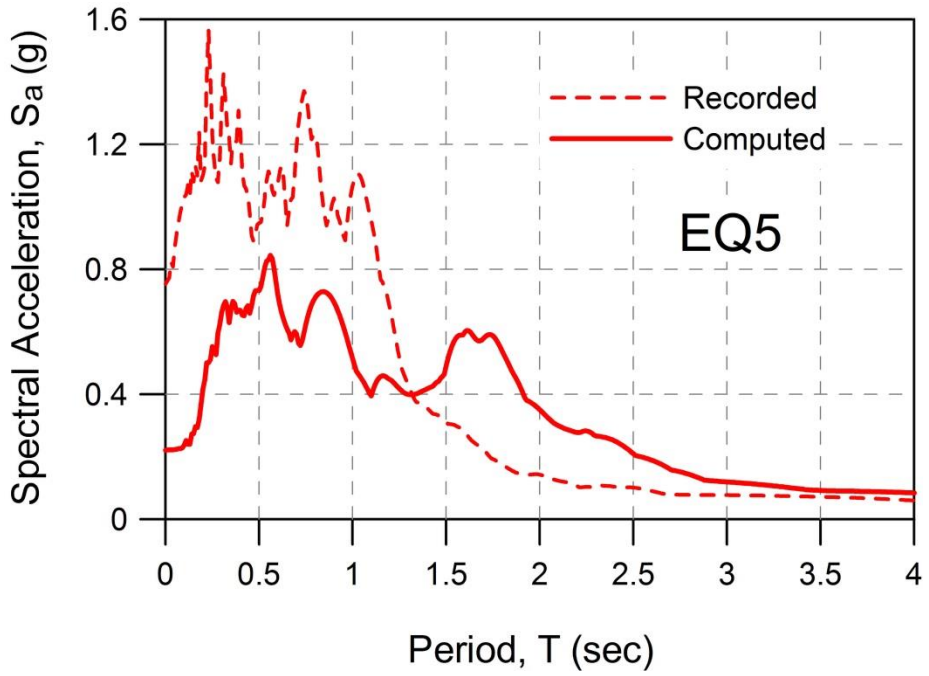
Case study: La Villita dam, Mexico

Dynamic analysis results: Response spectra (ξ=5%) at the crest





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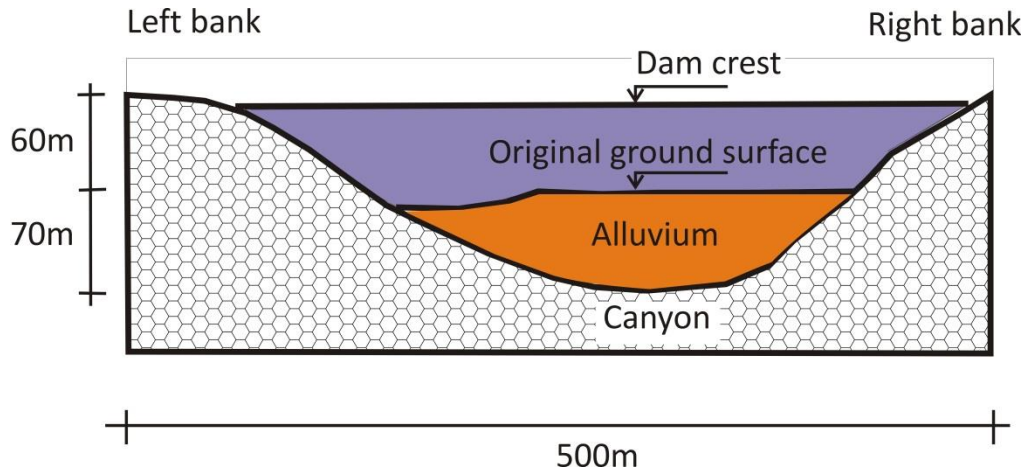
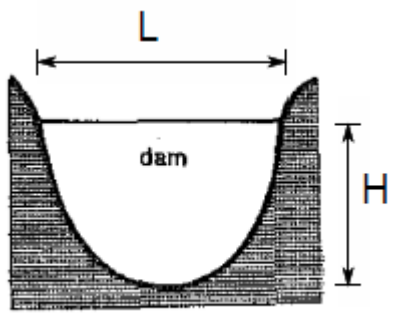
Case study: La Villita dam, Mexico

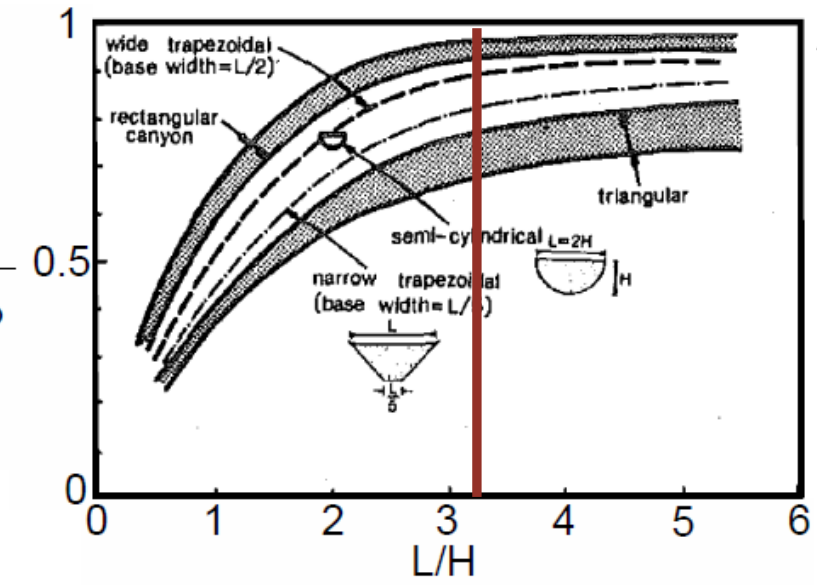
Canyon effects?

Hatanaka (1952), ***Ambraseys (1960)***

Dams built in narrow canyons have a stiffer response than dams built in wide canyons







Dakoulas & Gazetas (1987)

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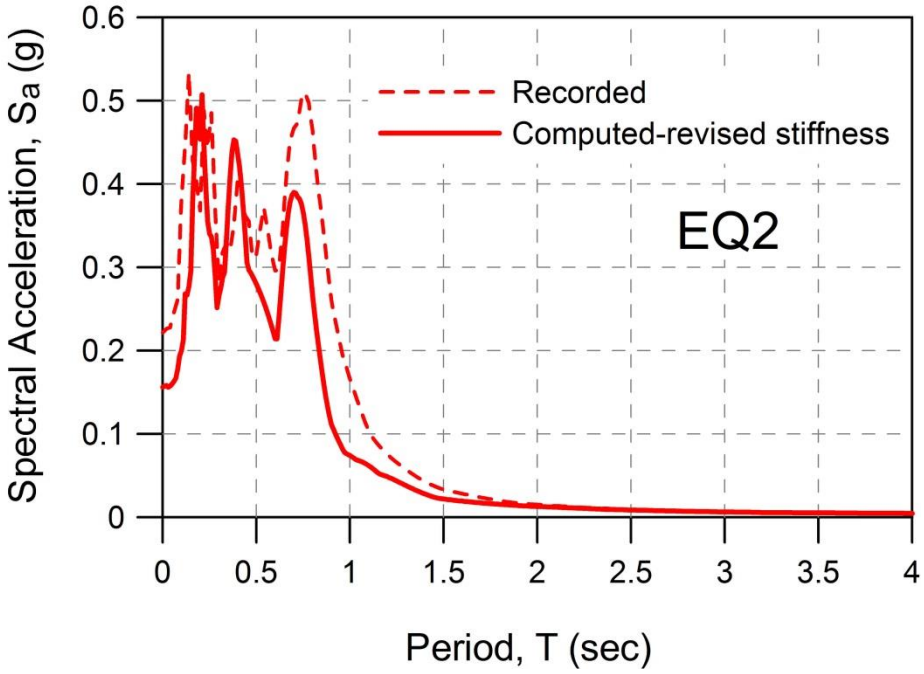
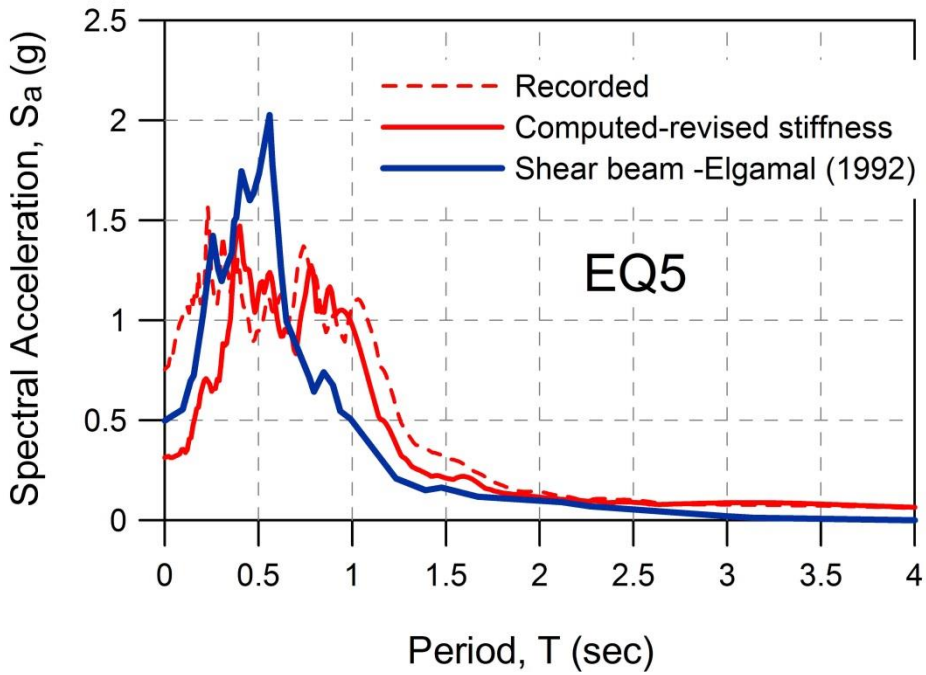
Case study: La Villita dam, Mexico

Canyon effects?

Analyses with stiffer properties





Dynamic analysis results: Response spectra (ξ=5%) at the crest

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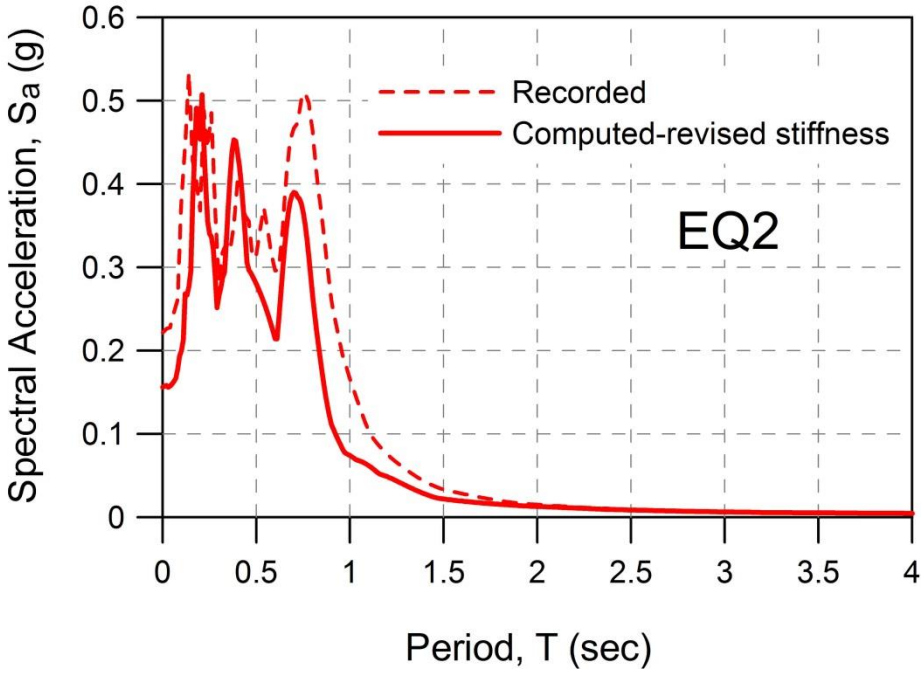
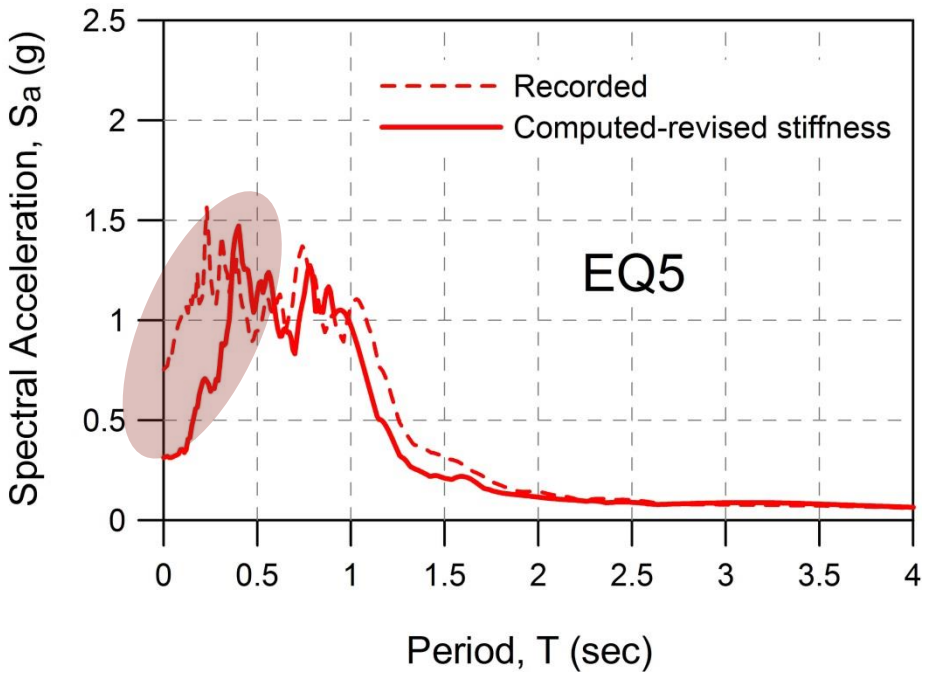
Case study: La Villita dam, Mexico

Canyon effects?

Analyses with stiffer properties





Dynamic analysis results: Response spectra (ξ=5%) at the crest

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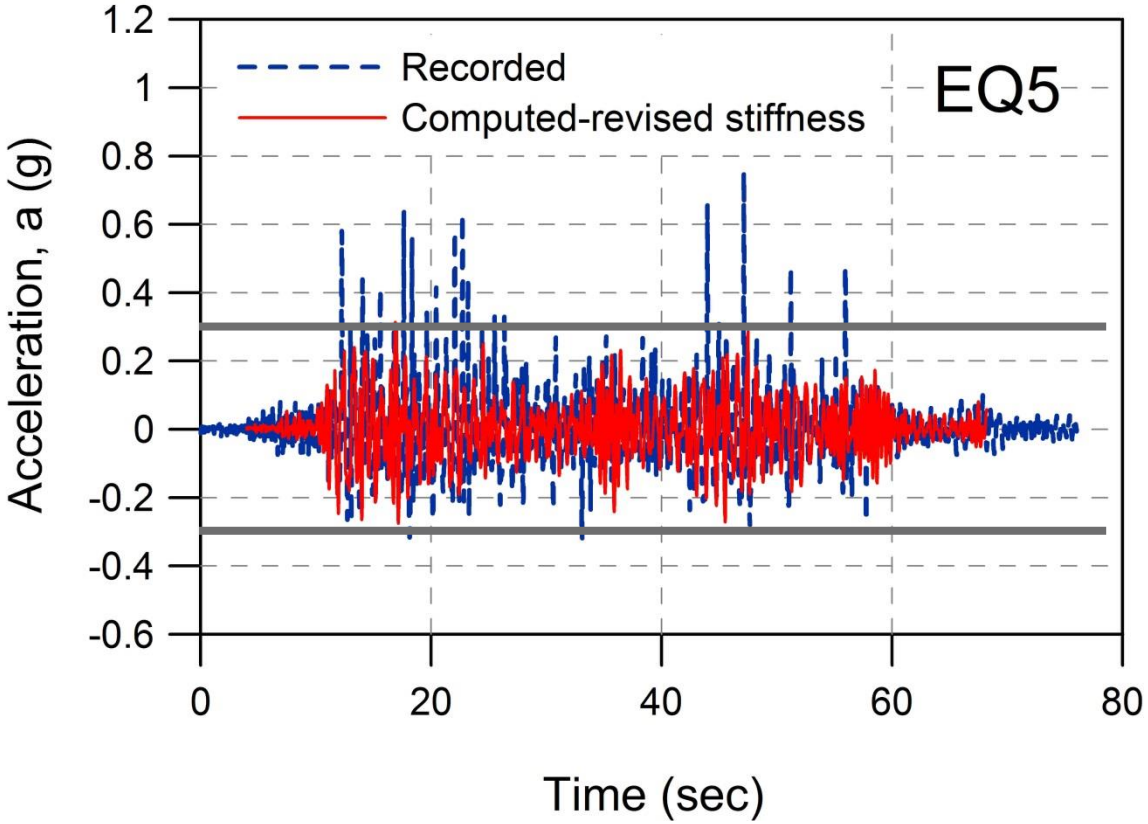
Case study: La Villita dam, Mexico

Asymmetry in the crest response



***Asymmetry observed**:*

- *Only in the crest response (not at bedrock or toe records)*
- *More pronounced in the strong events, i.e. EQ3, EQ4, EQ5*

Postulation:
The high positive peaks are a consequence of a localised slip
(Elgamal et al 1990)

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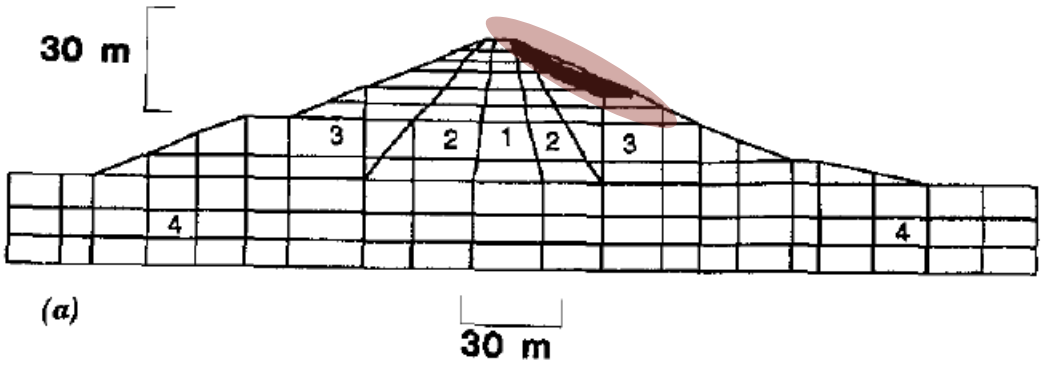
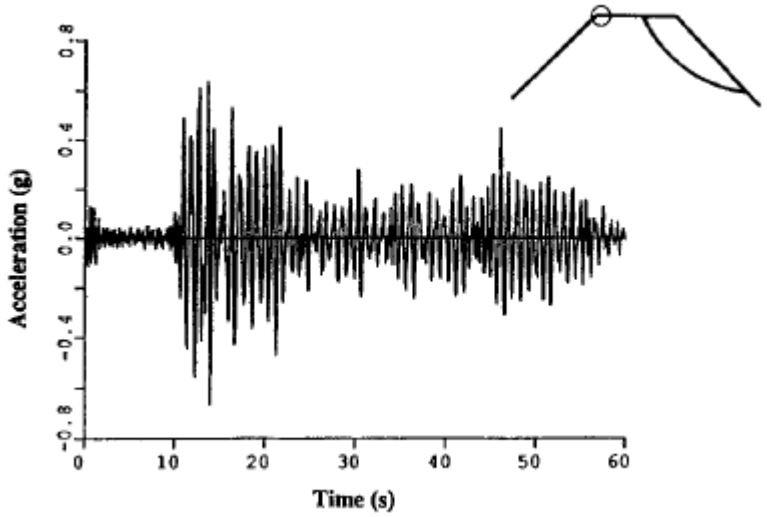
Case study: La Villita dam, Mexico

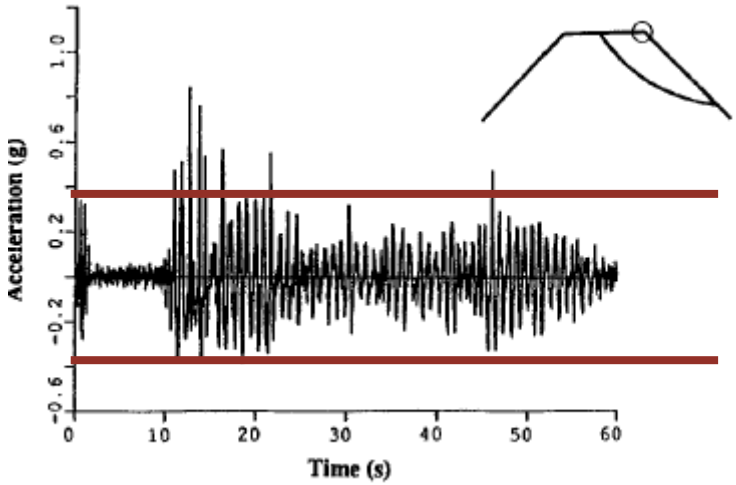
Asymmetry in the crest response



Gazetas & Uddin (1994)

Equivalent linear FE analysis with pre-defined slip surface using interface elements





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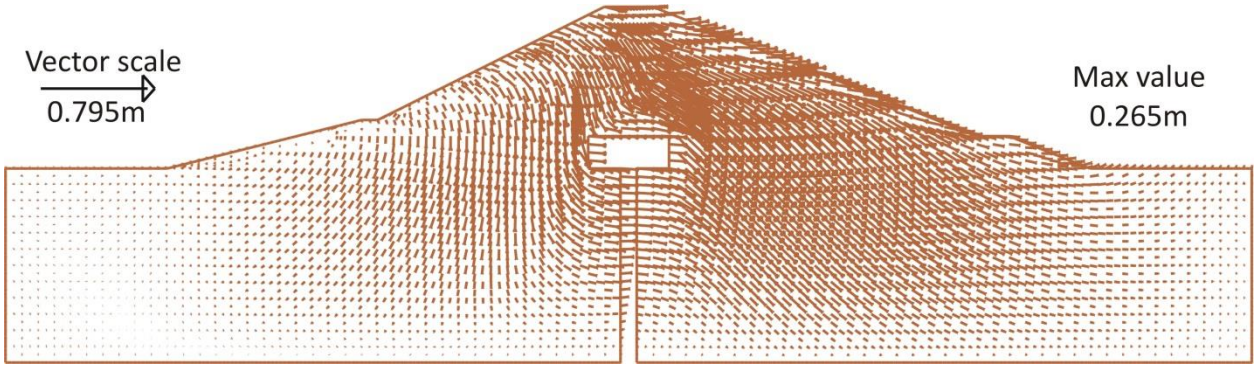
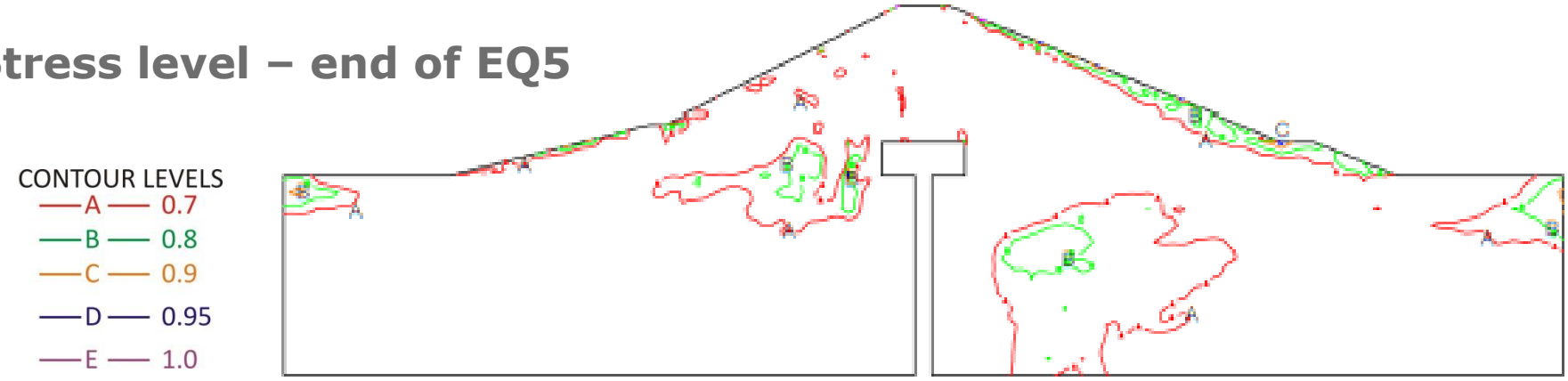
Case study: La Villita dam, Mexico

Vectors of accumulated displacement- end of EQ5



Stress level – end of EQ5



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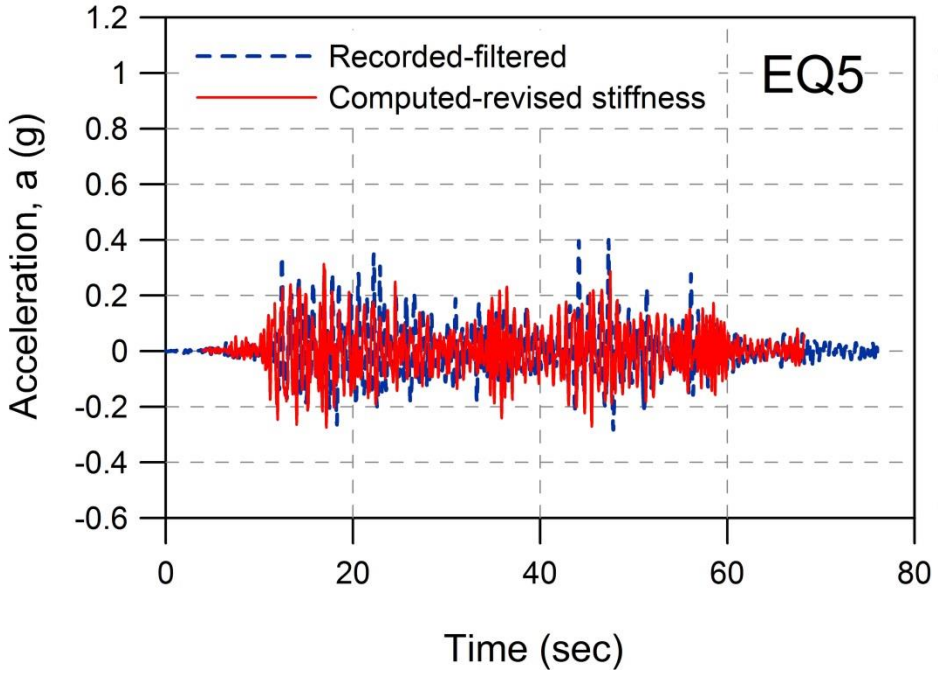
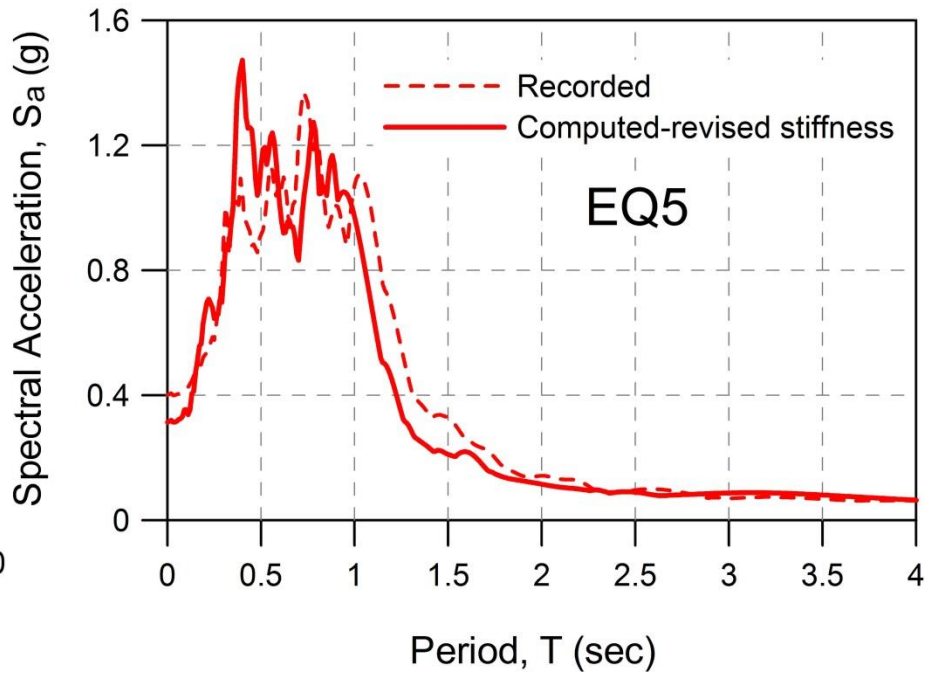
Case study: La Villita dam, Mexico

Filtered recorded motion at crest for f>4HZ





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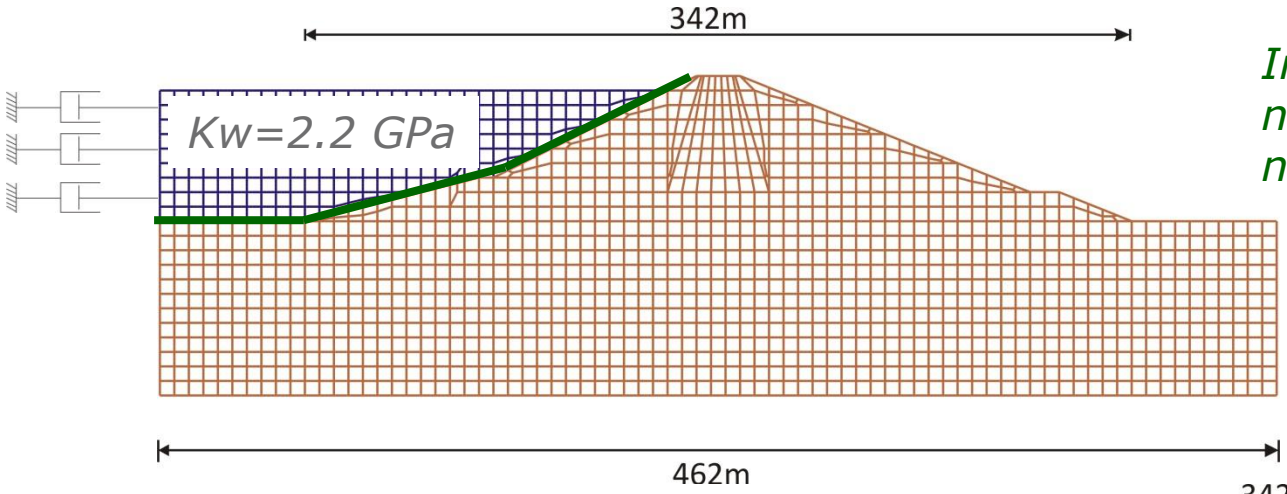
Case study: La Villita dam, Mexico

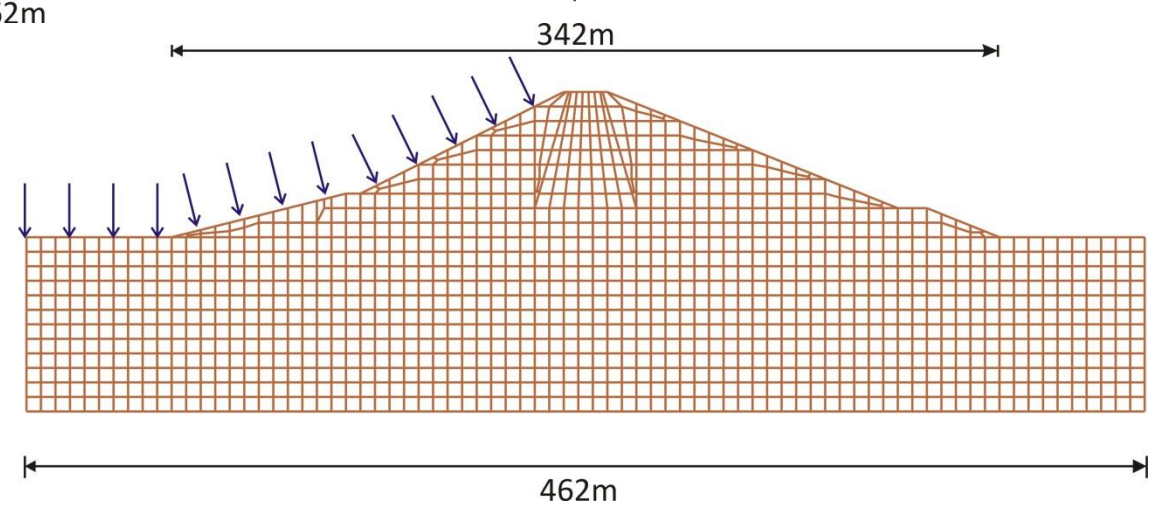
Effects of hydrodynamic pressures



Interface elements with normal stiffness and nominal shear stiffness

Pelecanos et al (2013)
COGE, Vol. 53, pp.68-82

Hydrostatic stress distribution



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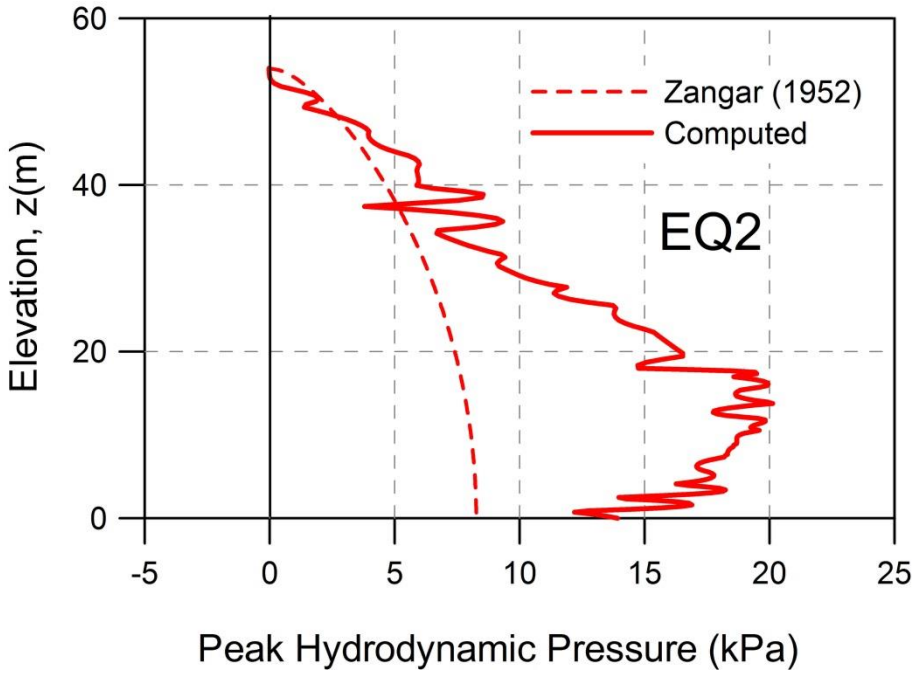
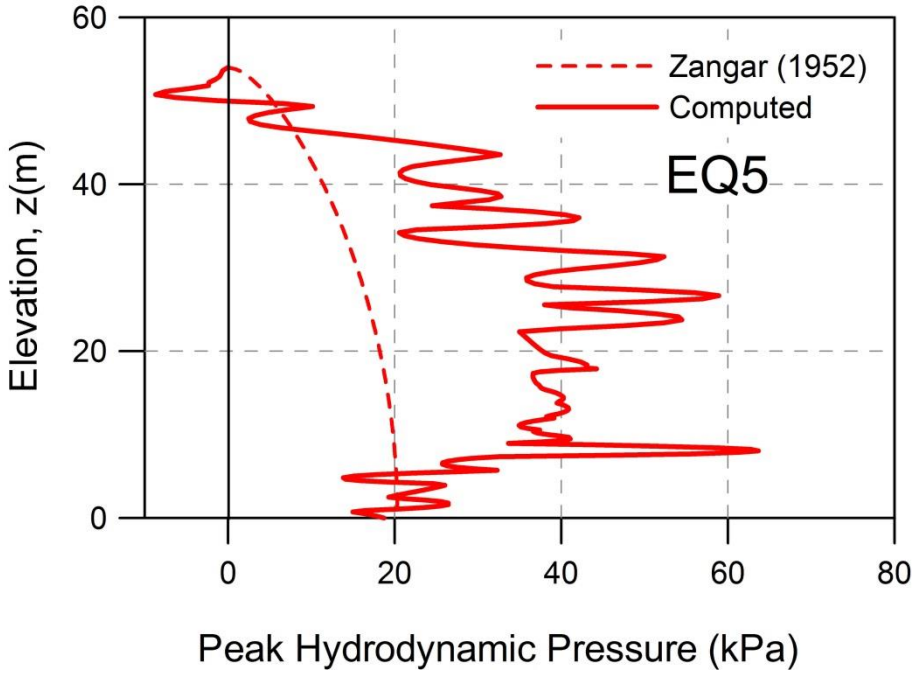
Case study: La Villita dam, Mexico

Effects of hydrodynamic pressures

Distribution of peak hydrodynamic pressure on the upstream face





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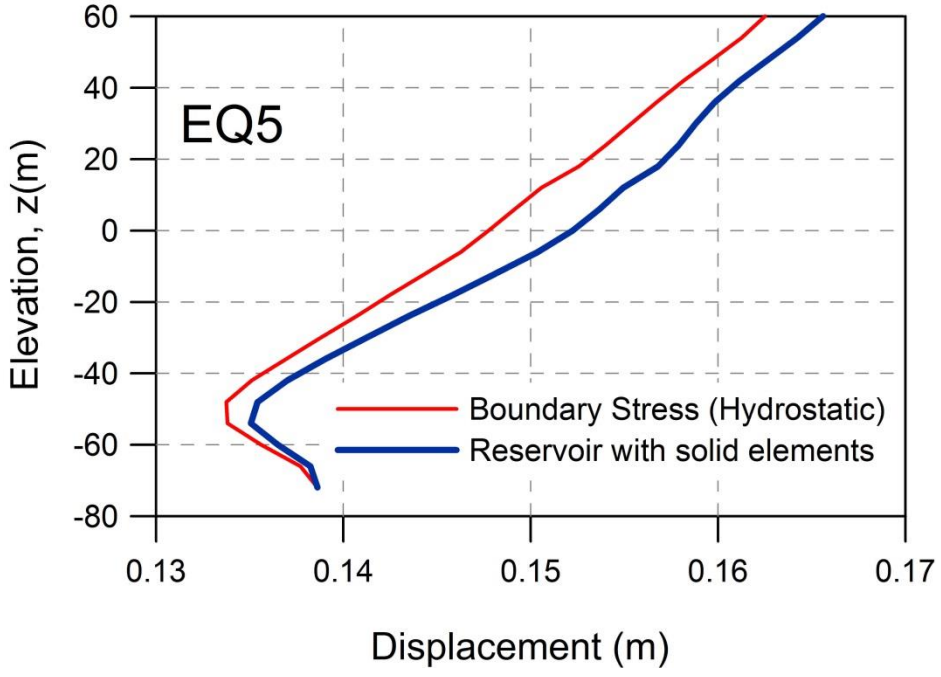
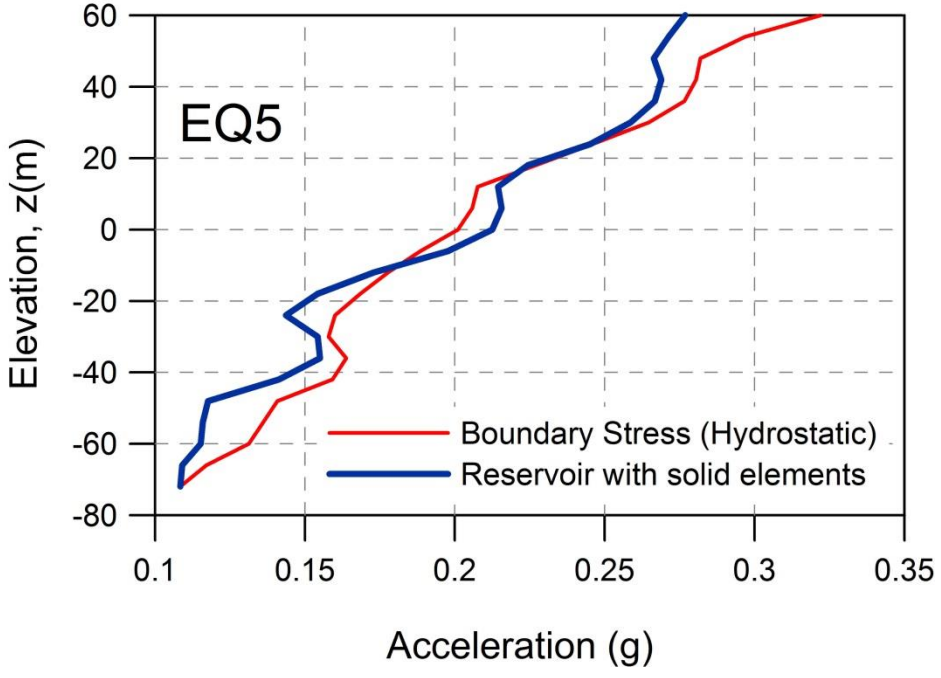
Case study: La Villita dam, Mexico

Effects of hydrodynamic pressures

Earthquake	F_{st}	F_{dyn}	F_{dyn}/F_{st}
	(kN)	(kN)	(%)
EQ2	14303	618	4.3
EQ5	14303	1605	11.2

Vertical profiles of max displacement & acceleration





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Conclusions

- Case studies of recorded ground motion in dams are scarce and are very useful for the validation and improvement of numerical modelling procedures.
- Plane stain analyses can lead to a softer dam response in narrow canyons. In the La Villita case this led to an underestimation of the seismic response.
- The numerical model captured well the acceleration response of the dam, but did not indicate any localised failure for EQ5. This could be due to the existence of a slip surface within the downstream slope as well as the simplicity of the adopted constitutive model.
- A numerical procedure has been developed for the accurate simulation of hydrodynamic pressures. However this study suggests that their impact on the overall response is not significant.

Thank You !