UPLIFT PRESSURES FOR SEISMIC AND POST-SEISMIC SAFETY ASSESSMENT OF GRAVITY DAMS

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UPLIFT PRESSURES FOR SEISMIC AND POST-SEISMIC SAFETY ASSESSMENT OF GRAVITY DAMS

1. **Computational tools to investigate seismic (post-seismic) gravity dam stability and uplift pressure assumptions (Pr. *Chopra*)**

2. **Seismic uplift pressures during earthquakes**

3. **Post-seismic uplift pressures**

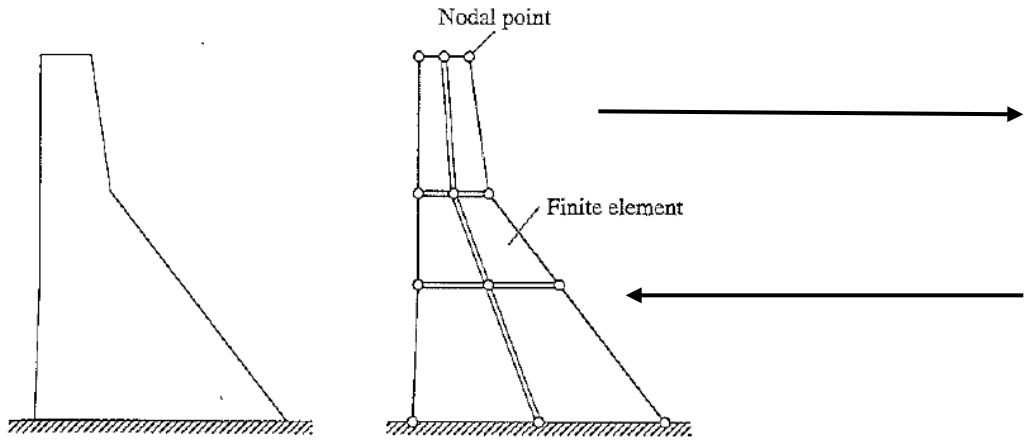
4. **R&D Perspectives**

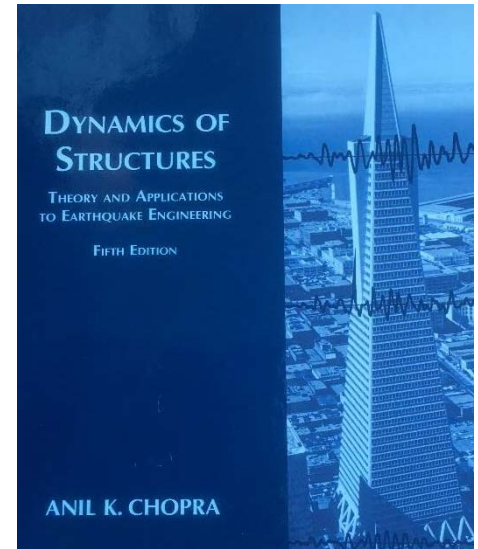
SEISMIC ……. DAMS …….. Contributions

Google (21/09/2017)

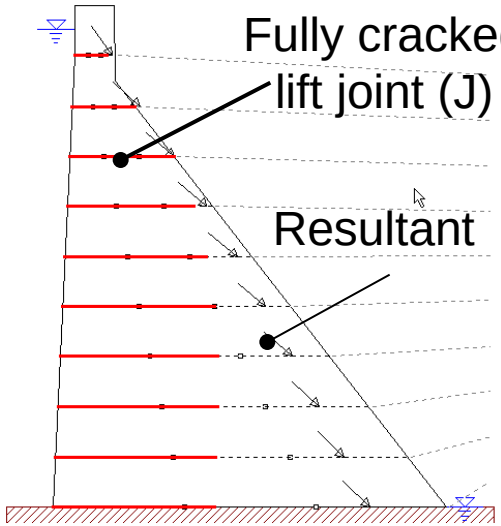
- Seismic+Dams = 908 000 results
- A.K. Chopra+Dams = 336 000 results
- A.K. Chopra+Dam+Koyna = 153 000 results
- A.K. Chopra+Dam+Koyna+Seismic 3 790 results
- A.K. Chopra+Dam+Koyna+Seismic+ 1 result

Dynamic of Structures (5th Ed) ….

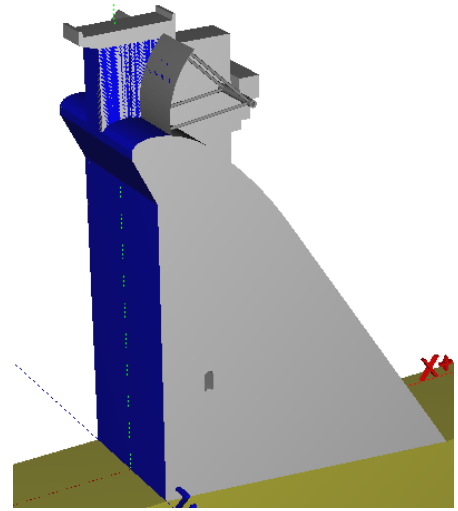




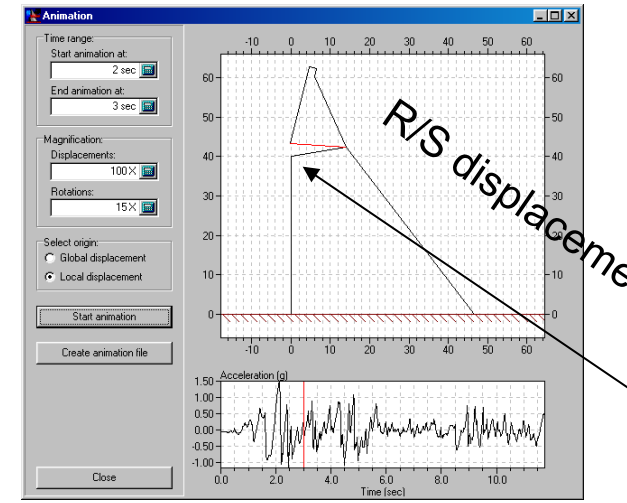
«USER FRIENDLY» COMPUTATIONAL TOOLS TO STUDY MODELLING ASSUMPTIONS



Pseudo-dynamic RSA - (CADAM2D)



Pseudo-dynamic RSA - (CADAM3D)



Rigid body dynamics (RS-DAM) Rocking-Sliding

SIMPLIFIED ANALYSIS FOR EARTHQUAKE RESISTANT DESIGN OF CONCRETE GRAVITY DAMS

REPORT NO. UCB/EERC-85/10
JUNE 1986

GREGORY FENVES
ANIL K. CHOPRA

TECHNICAL REPORT SL-89-4

SIMPLIFIED EARTHQUAKE ANALYSIS OF GATED SPILLWAY MONOLITHS OF CONCRETE GRAVITY DAMS

by

Anil K. Chopra, Hanchen Tan

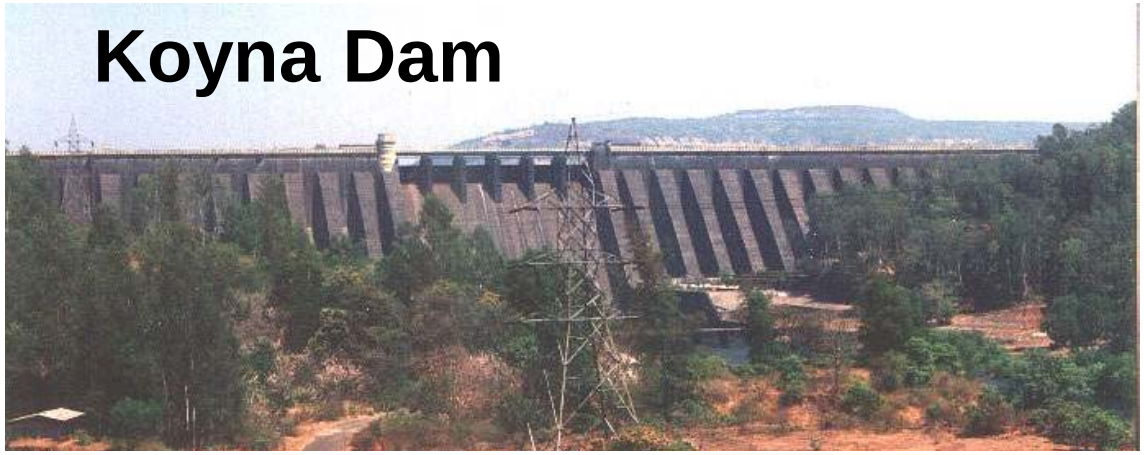
University of California at Berkeley
Berkeley, California 94720

BASE SLIDING RESPONSE OF CONCRETE GRAVITY DAMS TO EARTHQUAKES

REPORT NO. UCB/EERC-91/05
MAY 1991

ANIL K. CHOPRA
LIPING ZHANG

KOYNA DAM – 1967 Earthquake (M6.2)



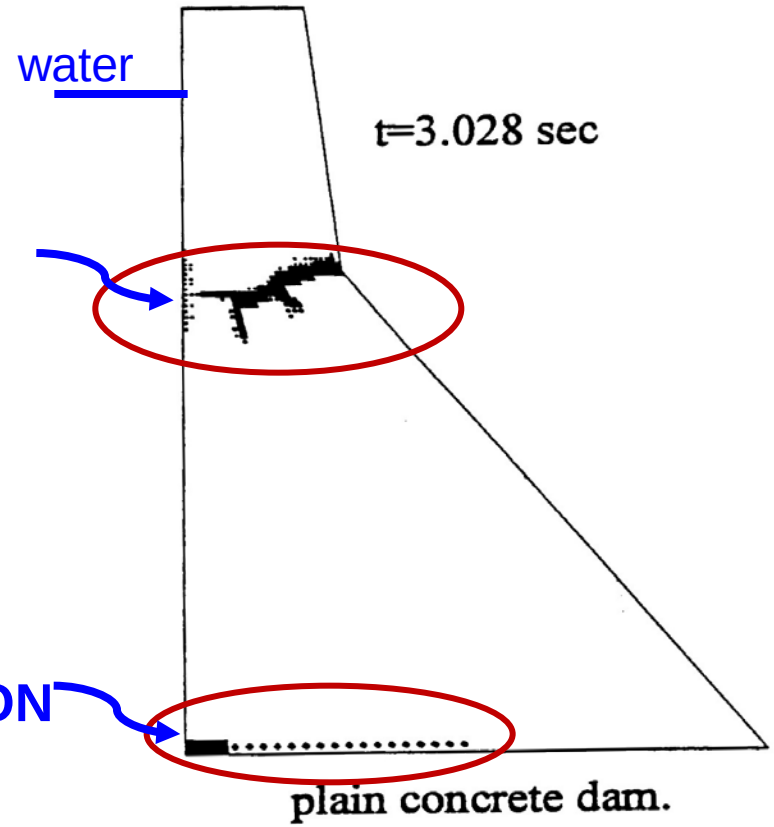
Bulletin of the Seismological Society of America. Vol. 63, No. 2, pp. 381–397. April 1973

THE KOYNA EARTHQUAKE AND THE DAMAGE TO KOYNA DAM

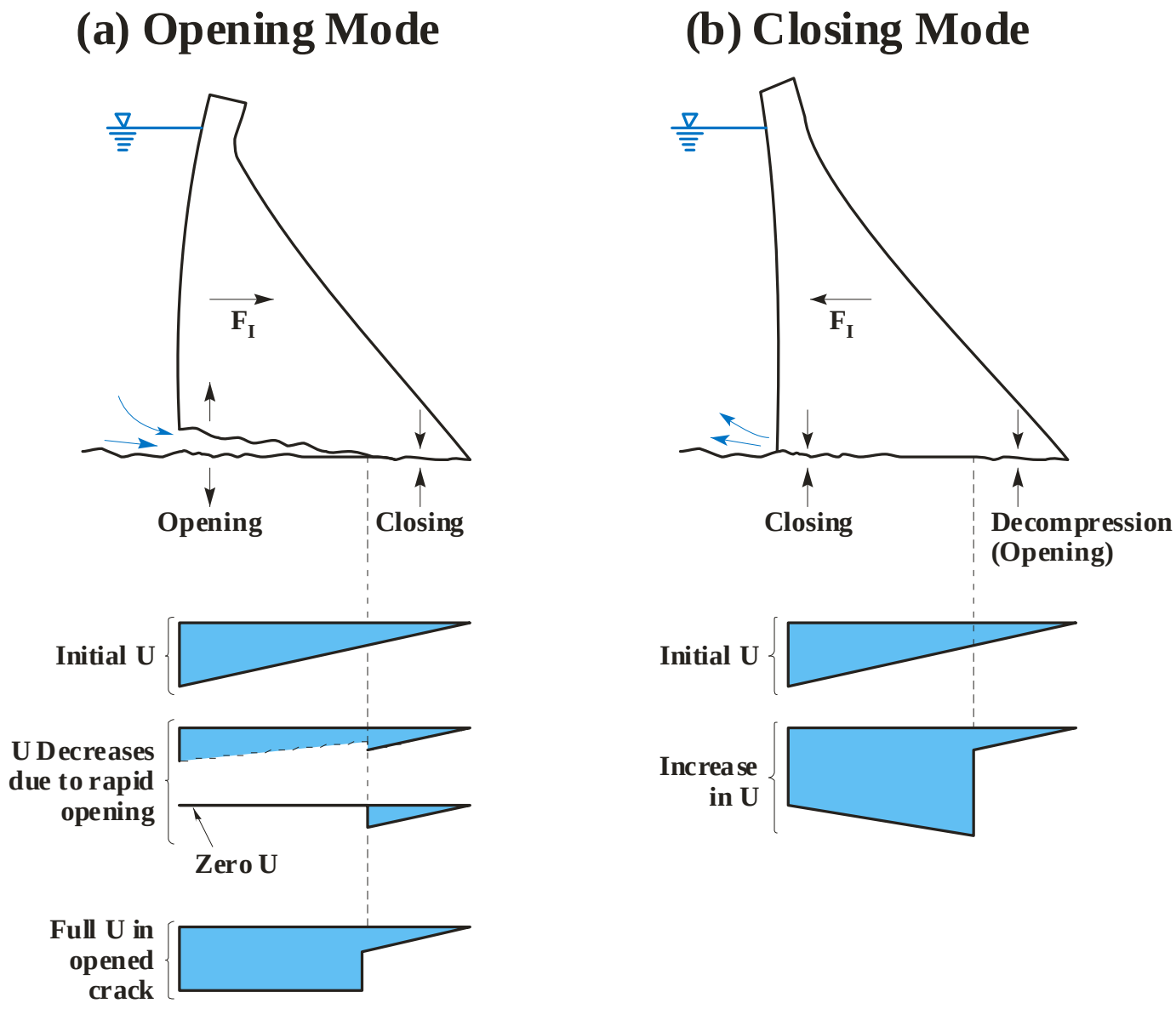
BY ANIL K. CHOPRA AND P. CHAKRABARTI

- **DAM-FOUNDATION-RESERVOIR INTERACTION MECHANISMS**
  - **PRESSURISED WATER PENETRATION IN SEISMIC CRACKS (?)**

FE Seismic cracking analysis 1967 Earthquake

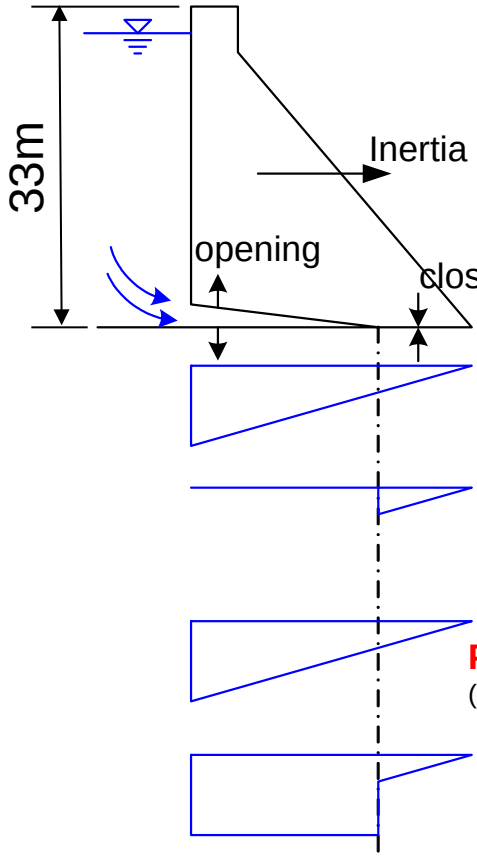


TRANSIENT UPLIFT PRESSURES DURING EARTHQUAKES



UPLIFT PRESSURES IN SEISMIC CRACKS

DAM SAFETY GUIDELINES



Initial uplift distribution

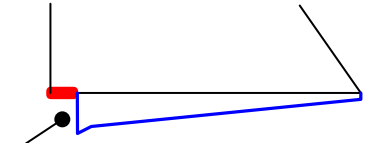
Zero uplift pressure in crack
(USBR 1995, CDSA 1997 (high seismicity))

Pre-earthquake uplift pressures in crack
(USACE 1995, FERC 1991, CDSA 1997 (low seismicity))

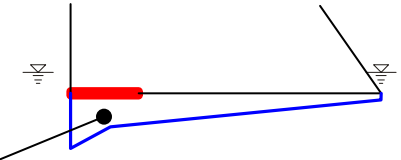
Full uplift pressures in crack
(ICOLD 1986)

CADAM SEISMIC ANALYSES

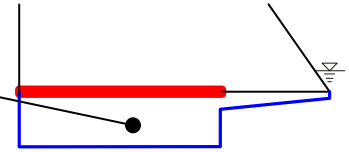
CRACKING: 7.6% of base
UPLIFT: 2237 kN
SSF: 3.70



CRACKING: 21.9% of base
UPLIFT: 2663 kN
SSF: 3.30

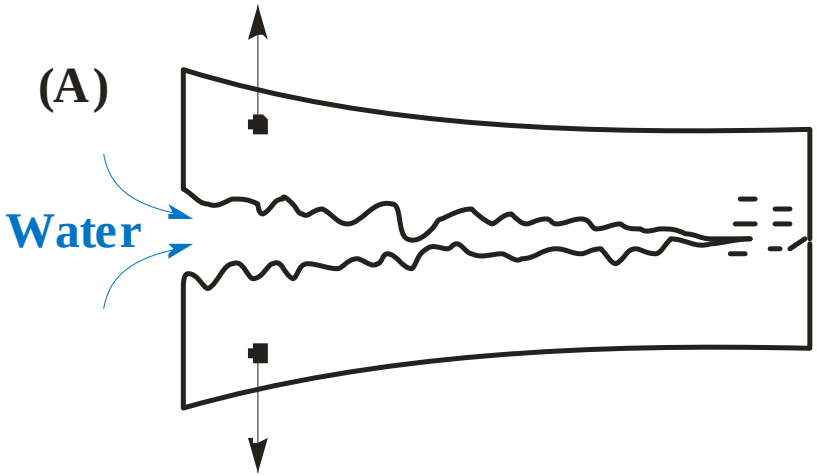


CRACKING: 65.4% of base
UPLIFT: 4413 kN
SSF: 1.95

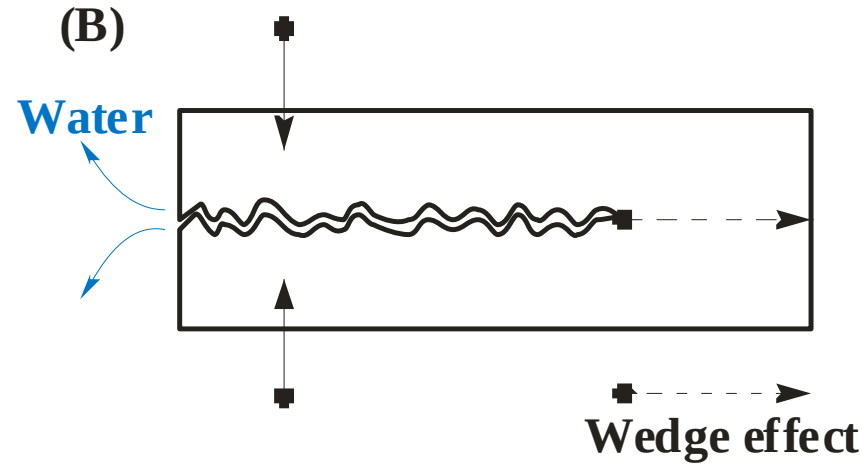


NEED HYDRO MECHANICAL MODELS + VV (Experimental Data Needed)

Seismic Crack-Water Interaction Mechanisms + Cyclic Damage

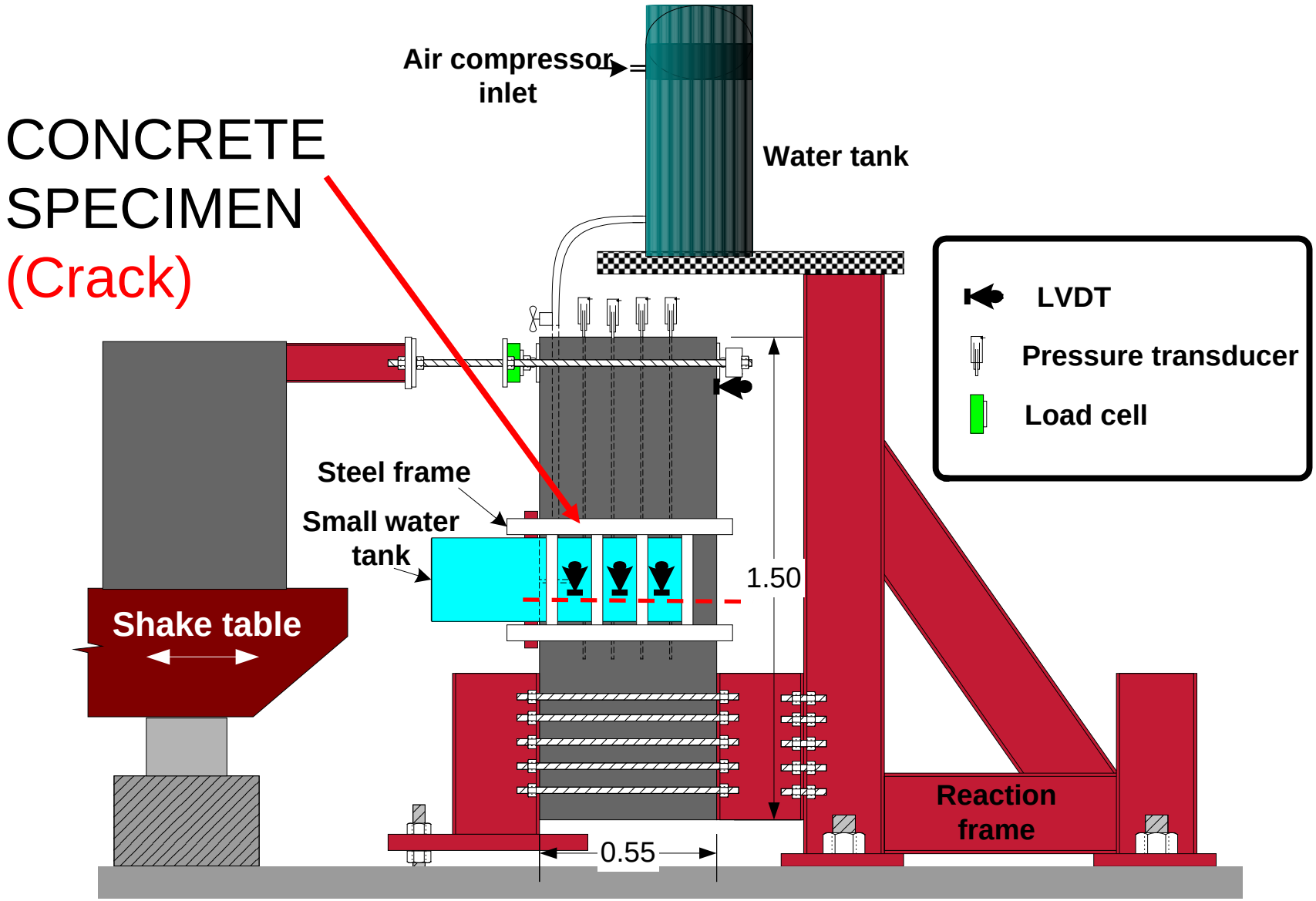


- Opening mode:
- Velocity of water front vs crack front
- Water in tension can vaporize (cavitation)



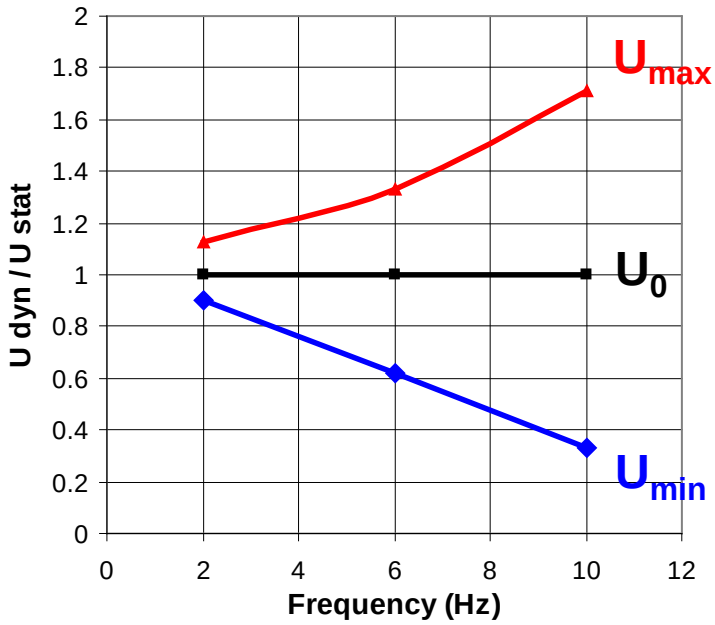
- Cosing mode:
- Impact and crushing of wall asperities
- Expulsion of water

EXPERIMENTAL TESTING PROCEDURE

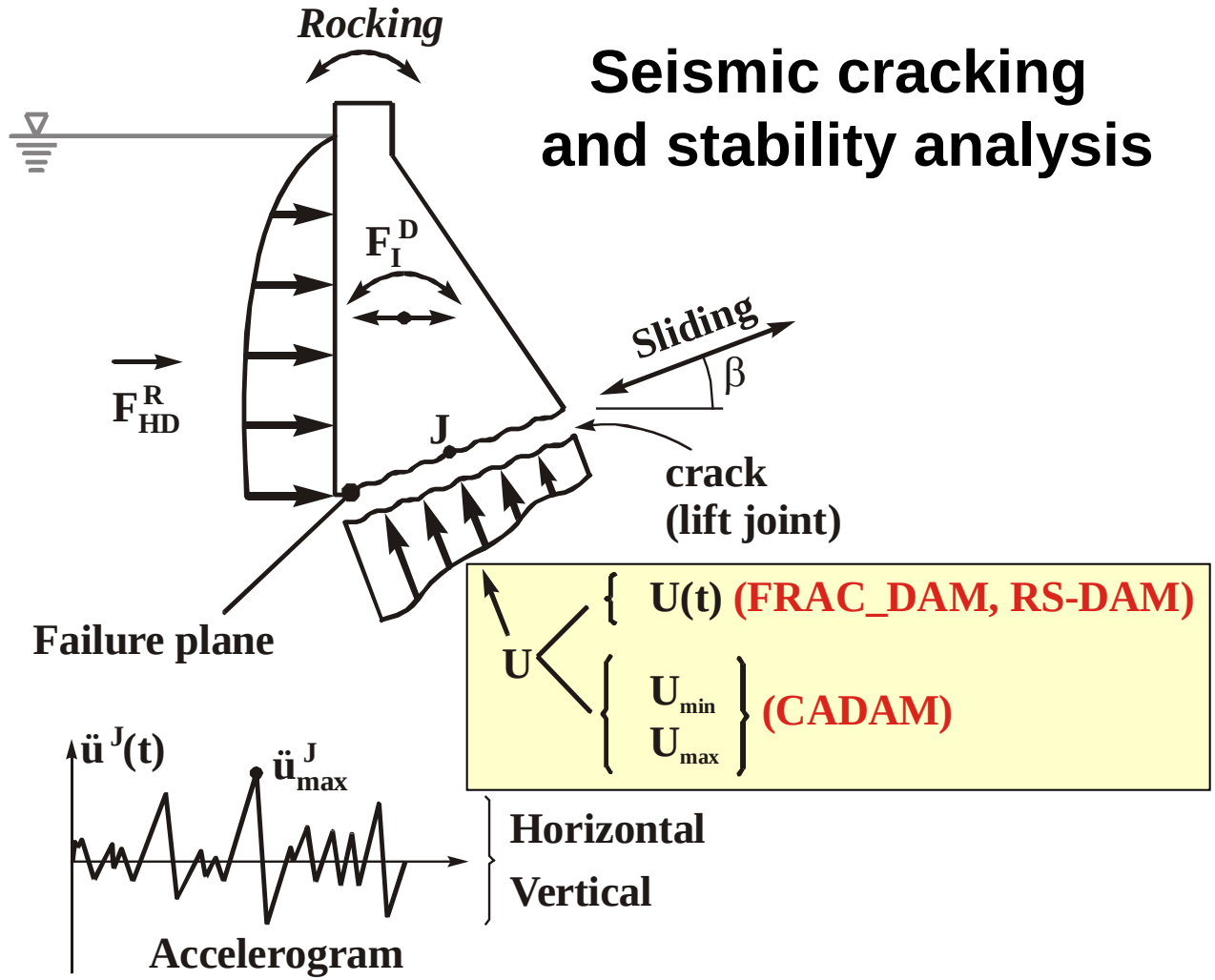


TRANSIENT SEISMIC UPLIFT PRESSURES

Dynamic amplification (reduction) of U_0 vs Crack Walls Opening / Closing Frequency



Seismic cracking and stability analysis



SEISMIC UPLIFT PRESSURES DURING EARTHQUAKES

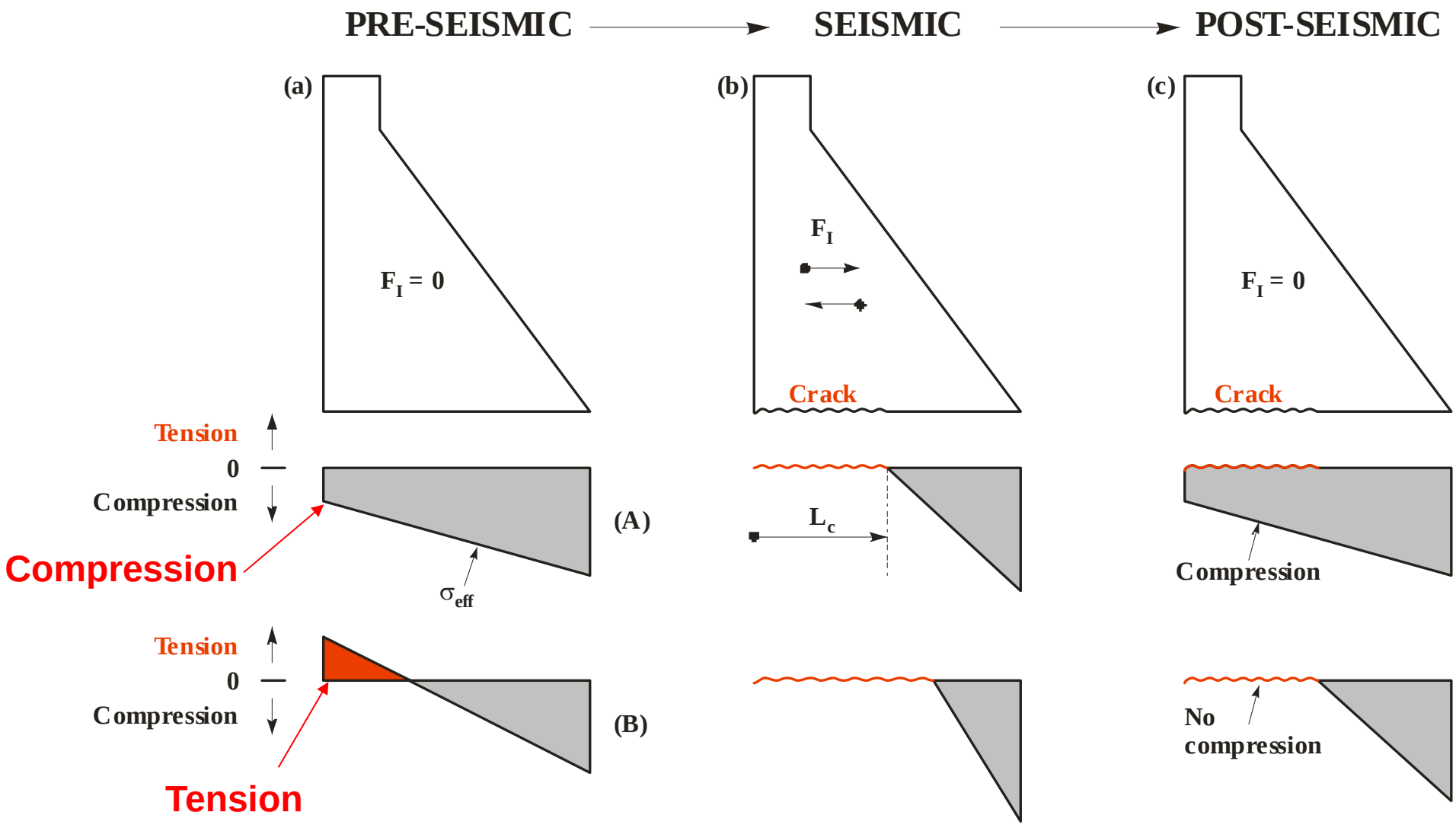
- **New crack** in opening mode: U(t) close to zero near the propagating tip, some pressure build-up along the crack walls.

- **Existing pressurised crack** with cyclic opening / closing : U(t) oscillate around the average initial uplift pressure U_0 that remained constant.

- Magnitudes of **pressure** drops during **crack opening** (cavitation) and pressure increases during **crack closing** depend **on loading frequency**.

- If we do not recognise explicitly the dynamic variation of U(t), it appears **reasonable**, with our current knowledge, to assume that during the earthquake the **uplift pressure remains unchanged** from its pre-seismic value.

POST-SEISMIC CRACKS – EFFECTIVE STRESSES



Uplift pressures in cracks (?)

POST-SEISMIC UPLIFT PRESSURES

- **Post-Seismic Uplift Pressures Depend on:**
  - **Post-seismic stress and displacement conditions along the crack plane (compression or tension)**
  - **Post-Seismic seepage path; (crack hydraulic conductivity, aperture… boundary conditions)**
  - **Presence of drains, pressure relief at crack boundaries (water stops damaged or not)**
  - **Post-earthquake drain efficiency**

Historical Evidences : Post-Seismic Uplift Pressures

- **Kobe M7.2 EQ Japan 1995 – Several dams affected**

  Yuzuruha Gravity Dam (42m high) 43 km from epicentre (minor damage)

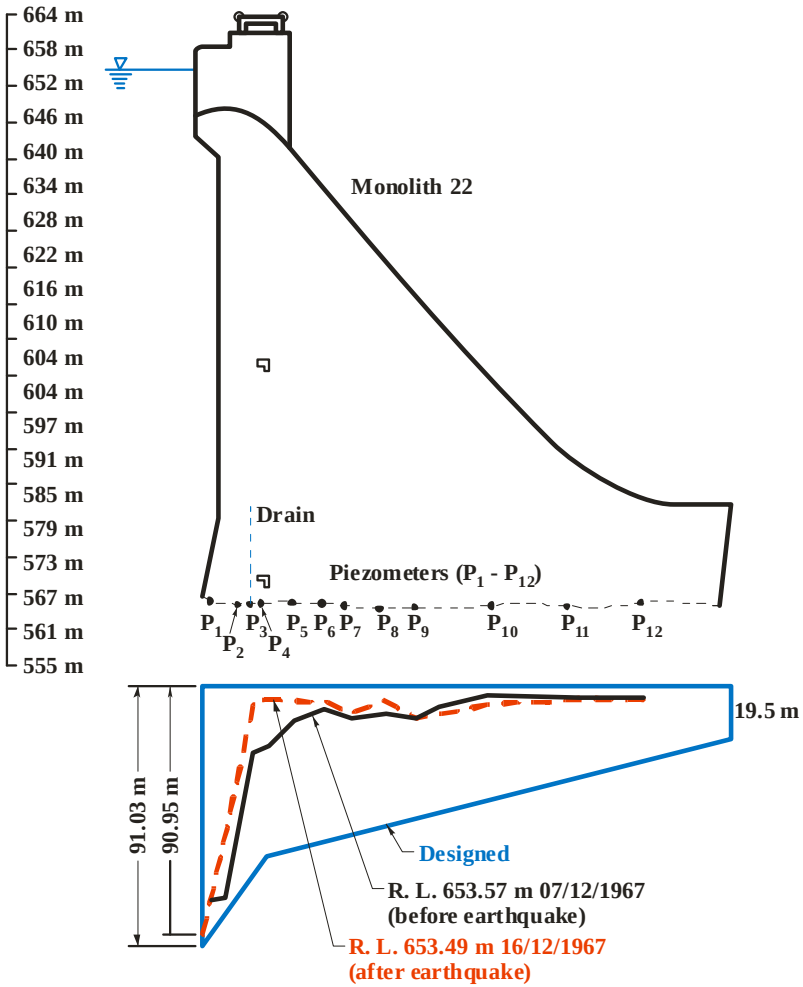
  «Drainage water and uplift both slightly increased after the quake, but stabilized later » (Matsumoto et al. 1996)

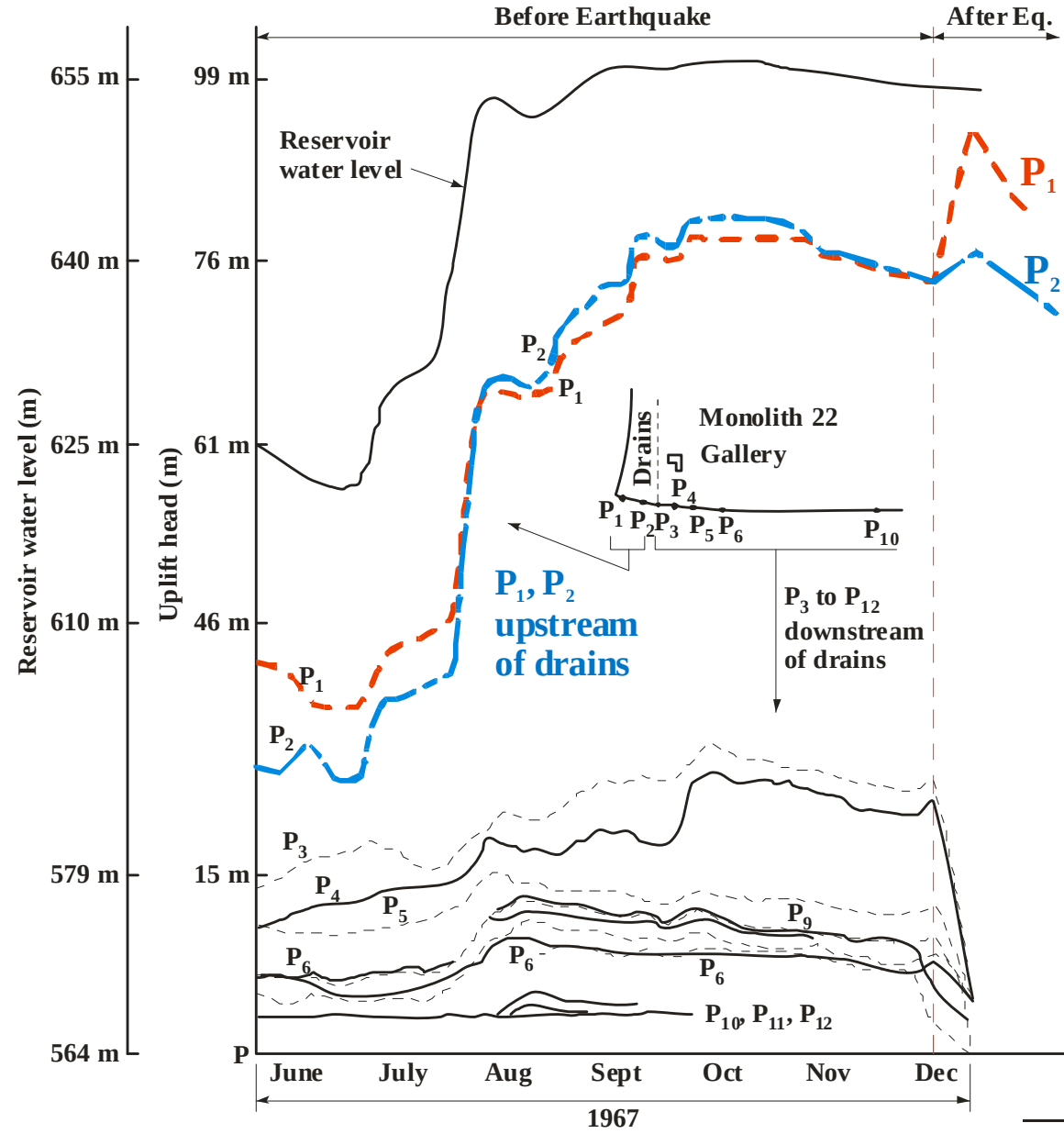
- **Sefid Rud Buttress Dam, Iran (106m high), M7.3 EQ in 1990, very close**

  « Uplift water pressures were found to have strongly decrease after the earthquakes, perhaps as a result of the closure of joints or of increased compressive forces across the seepage paths » (ICOLD 2001)

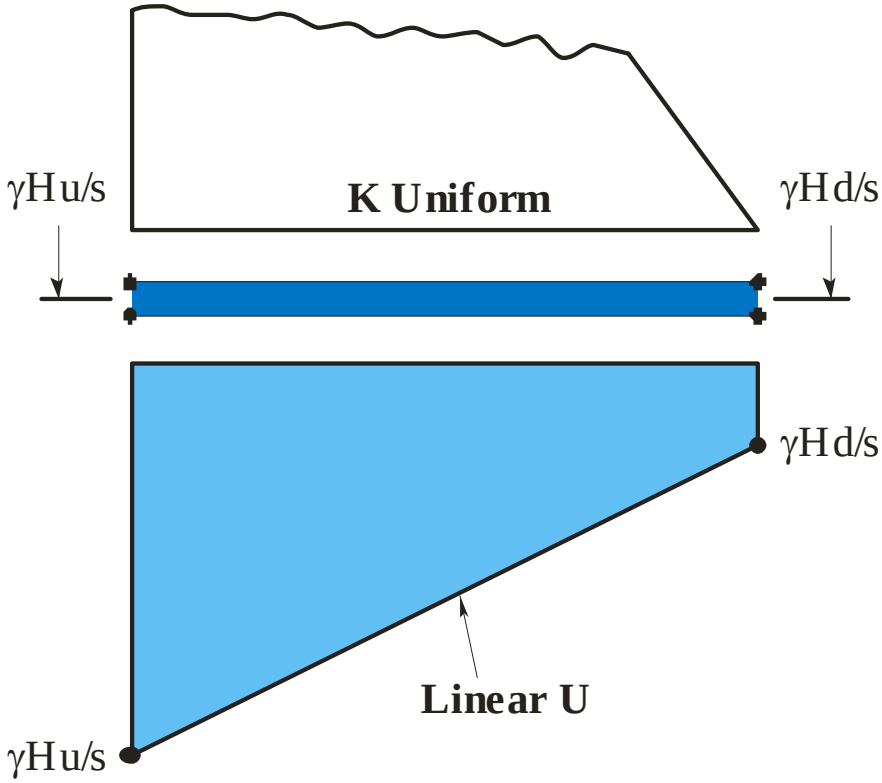
- **Koyna Dam, India (103m high), M6.2 EQ in 1967, 3km from epicentre**

KOYNA DAM – POST-SEISMIC UPLIFT PRESSURES (Pant 1990)

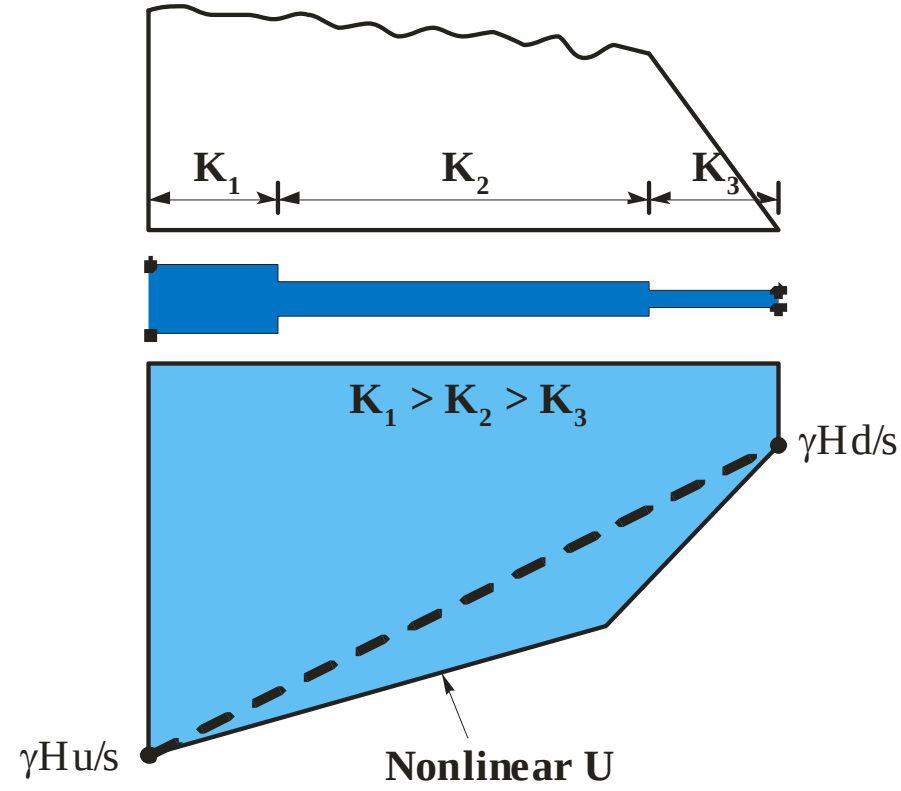




POST-SEISMIC UPLIFT PRESSURES
UNDRAINED (COMPRESSED) CRACK

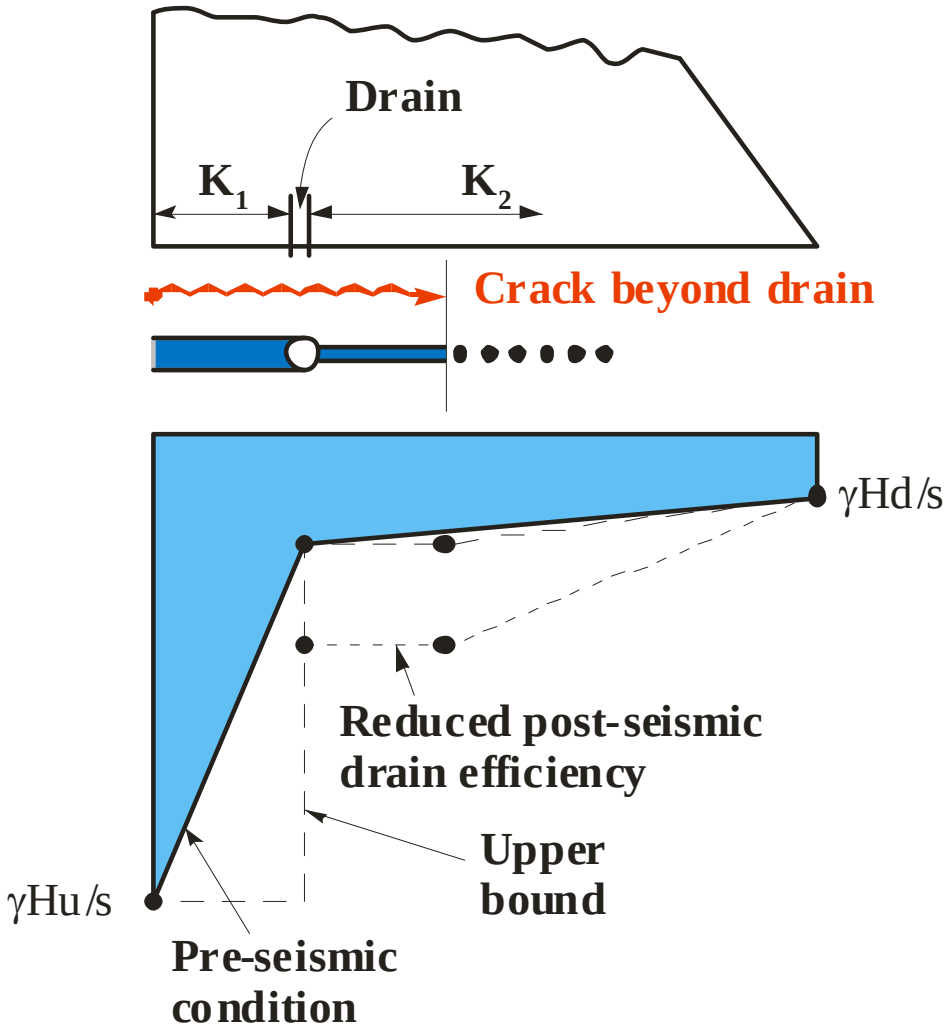


(a) Uniform Aperture

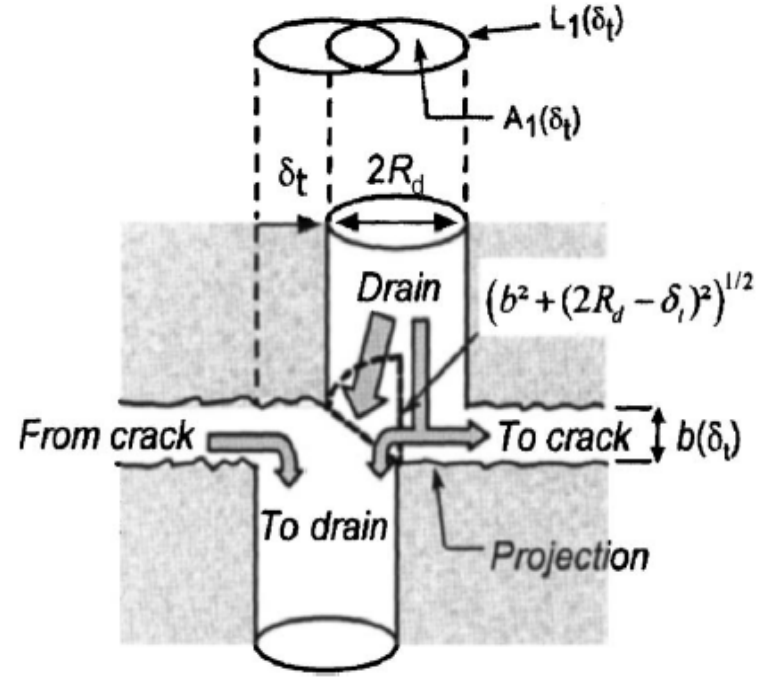


(b) Tapered Aperture

POST-SEISMIC UPLIFT PRESSURES – DRAINED (COMPRESSED) CRACK



(d) Drained Crack



HYDRO-MECHANICAL MODELS – NL Analyses

R&D Perspectives

static/seismic loads

Computational - Experimental

POST-SEISMIC UPLIFT PRESSURES

- **Undrained complete compressed crack: full uplift pressures**
  (too (?) conservative, hydraulic conductivity, Boundary Cond.)

- **Drained Compressed cracks – drains minimal disruption by sliding**
  - **Maintain some drain efficiency**
  - **Possibility (1) : return to pre-seismic uplift pressures**
  - **Possibility (2) : full headwater pressures up to line of drains, significant reduction past the line of drains (e.g. tailwater pressures + 50% of the difference between headwater and tailwater).**

CONCLUSIONS

Analytical/Num. models → **Computational tools** → **Validation/Verification** → **Applications**

- **Anagram**

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Pr. CHOPRA - ***THANK YOU***

ANIL K. CHOPRA ---> KOYNA

VisionarY → **DAM**

ANIL K. **CH**OP**R**A ---> **ARCH**