XVII European Conference on Soil Mechanics and Geotechnical Engineering
ECSMGE 2019 Reykjavik

SIMSG ISSMGE

XVII ECSMGE-2019
Geotechnical Engineering foundation of the future

TC210 Embankment Dams
Workshop on Embankment Dams

Effects on earth dams of drawdown scenarios imposed after a strong earthquake

Stefania Sica, Federica Rotili
(University of Sannio, Italy)

Luca Pagano
(University of Naples Federico II, Italy)

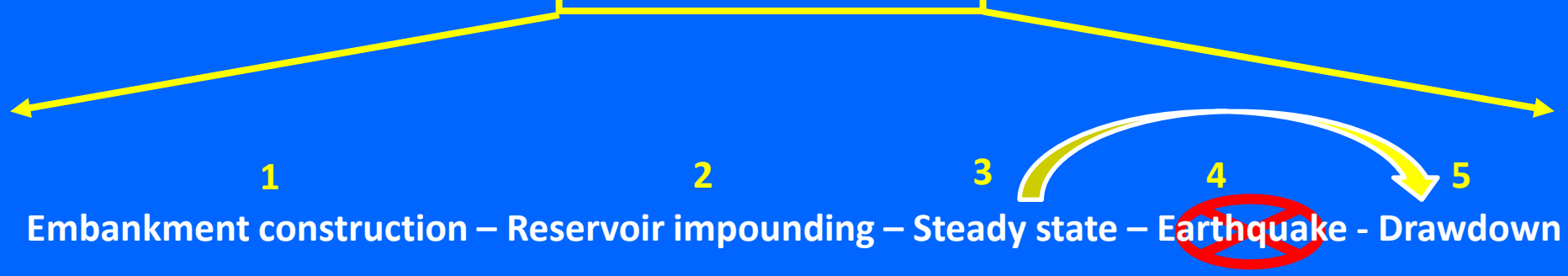
Reykjavik, 1 September 2019

OVERVIEW

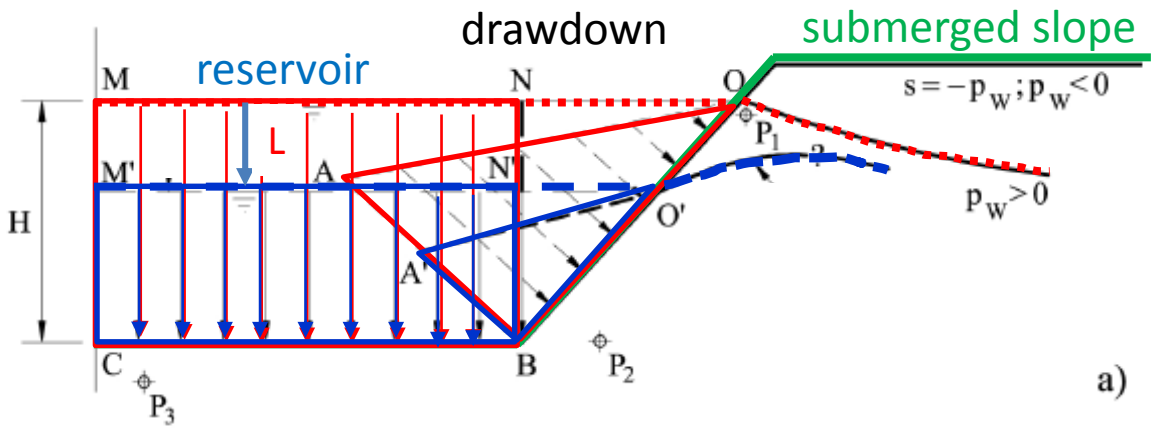
- Lowering the water level of a reservoir may be critical for the **stability** of earth dams. In literature, several cases of slope failures caused by rapid drawdown were described (Sherard et al. 1963; Morgenstern 1963, etc.). An iconic case-history is **San Luis Dam in California** in 1981.

- To date the combined effects of an **earthquake** first and a **rapid drawdown** later have never been investigated.

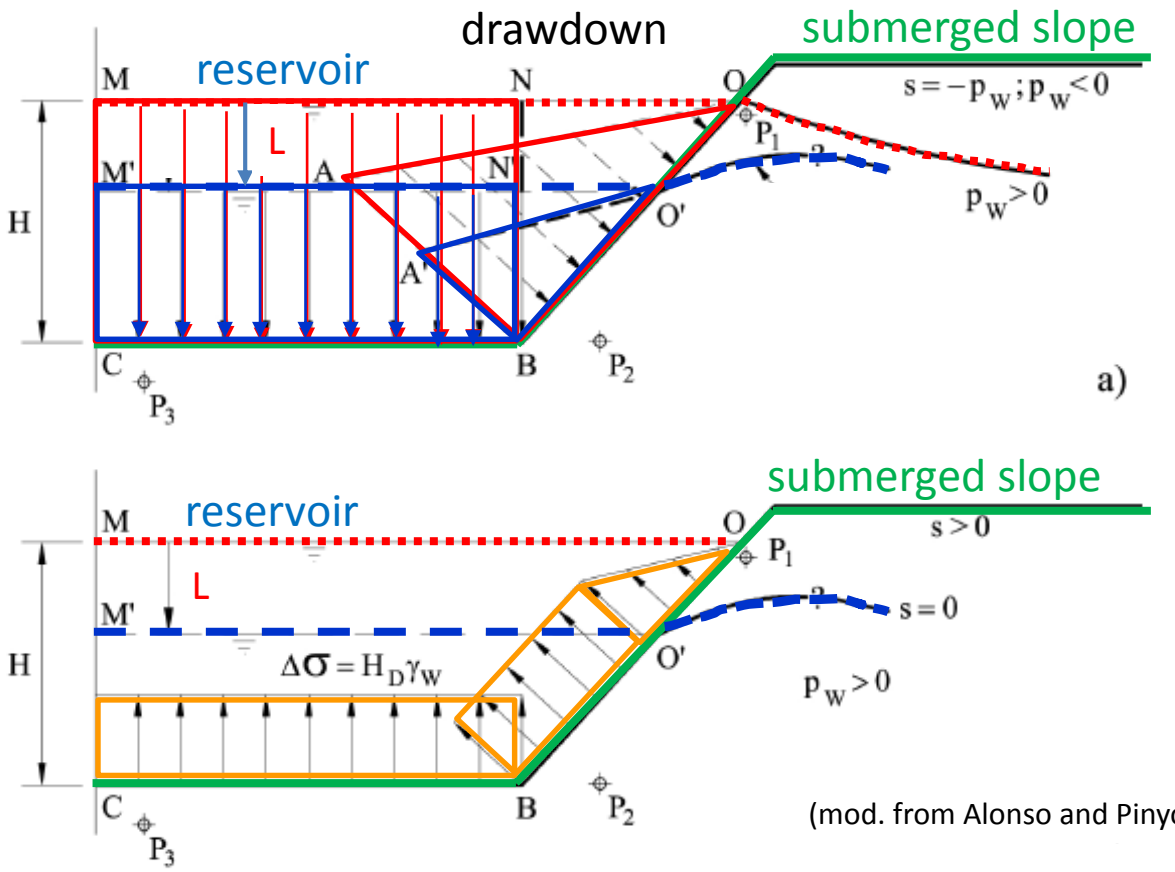
Numerical study



DRAWDOWN EFFECTS: HYDROSTATIC PRESSURES ALONG THE SLOPE SURFACE



DRAWDOWN EFFECTS: HYDROSTATIC PRESSURES ALONG THE SLOPE SURFACE



(mod. from Alonso and Pinyol, 2009)

The external stabilizing hydrostatic pressures reduce but the internal-to-slope pore water pressures could delay their decrease to the steady-state values associated to the new reservoir level.

DRAWDOWN EFFECTS: CHANGES IN TOTAL STRESS AND PORE PRESSURE INSIDE THE SLOPE

The change in **hydrostatic pressures along the slope** surface induces a change in **total stress and pore water pressures** inside the slope.

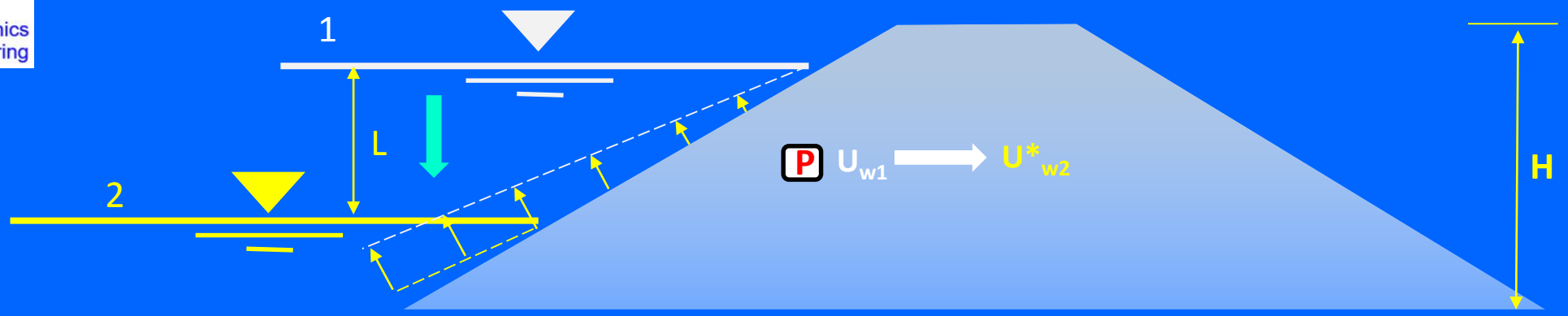
The resulting pore water pressures will not be in equilibrium with the new boundary conditions and a transient regime will develop.

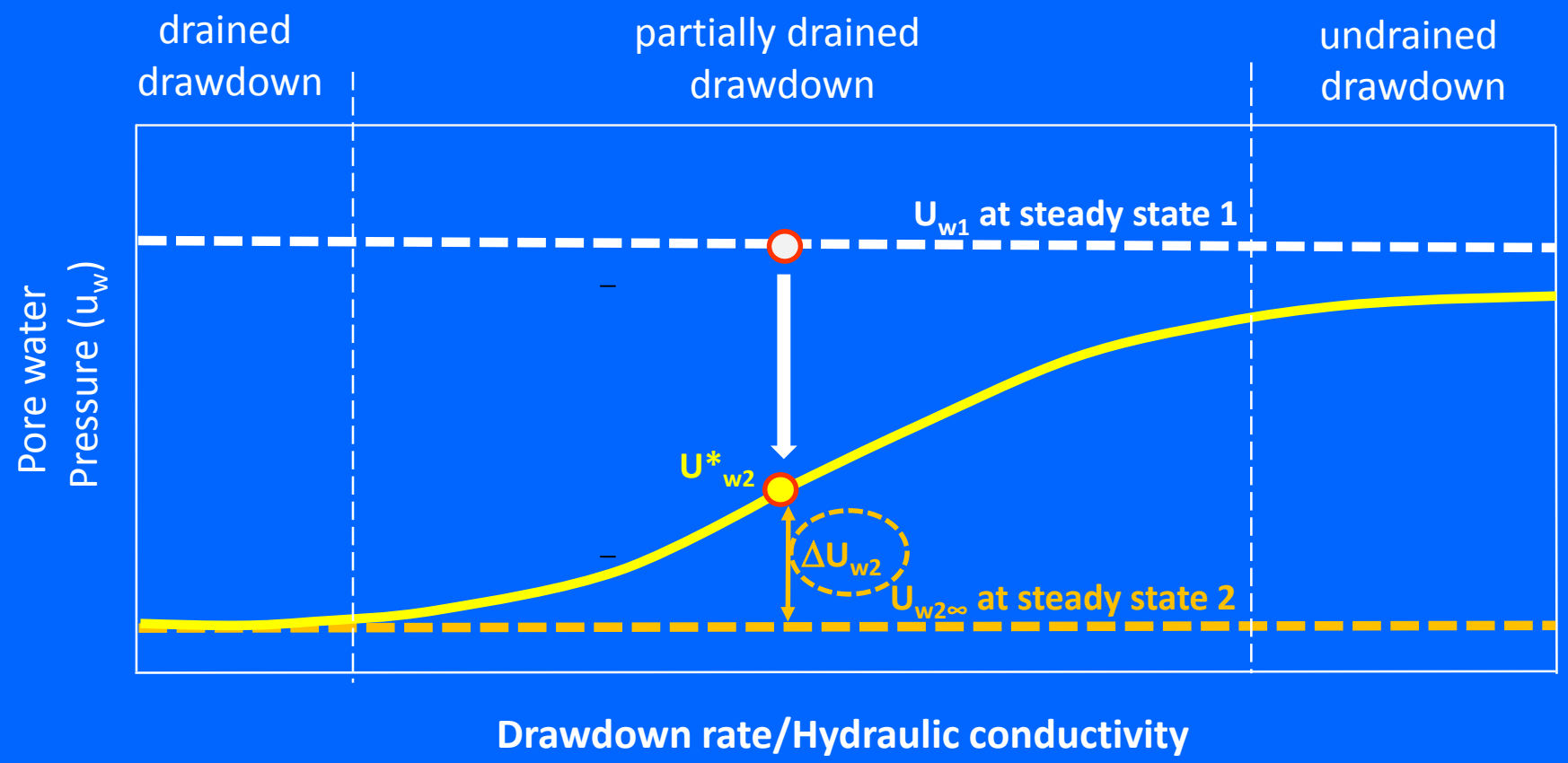
R/k = Rate of drawdown/Hydraulic conductivity

During the drawdown, the resulting pore pressures will be affected by:

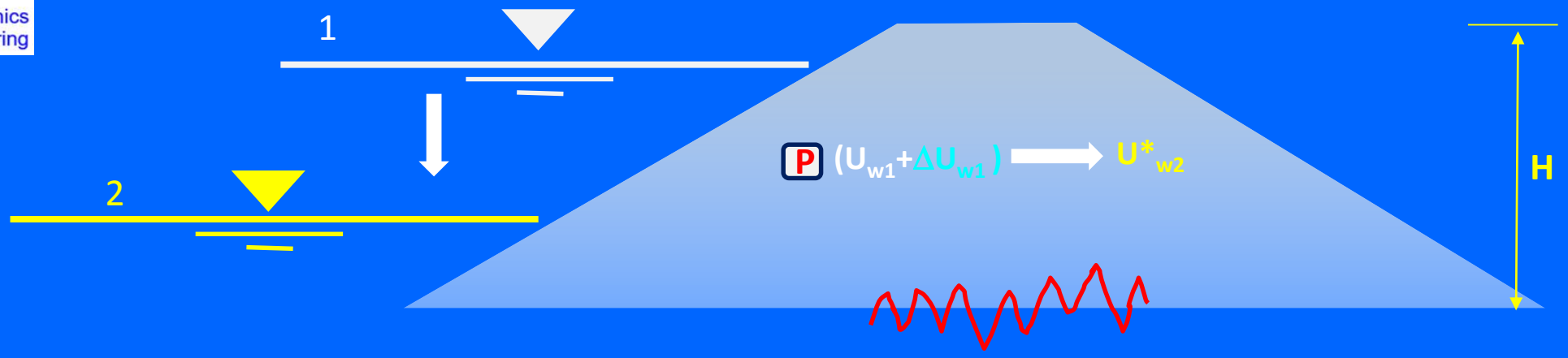
- **soil permeability**
- **rate of water level lowering**
- **initial pore pressures** (and initial stress field),
- **soil skeleton behavior** (controlled by soil stiffness and change in saturation).

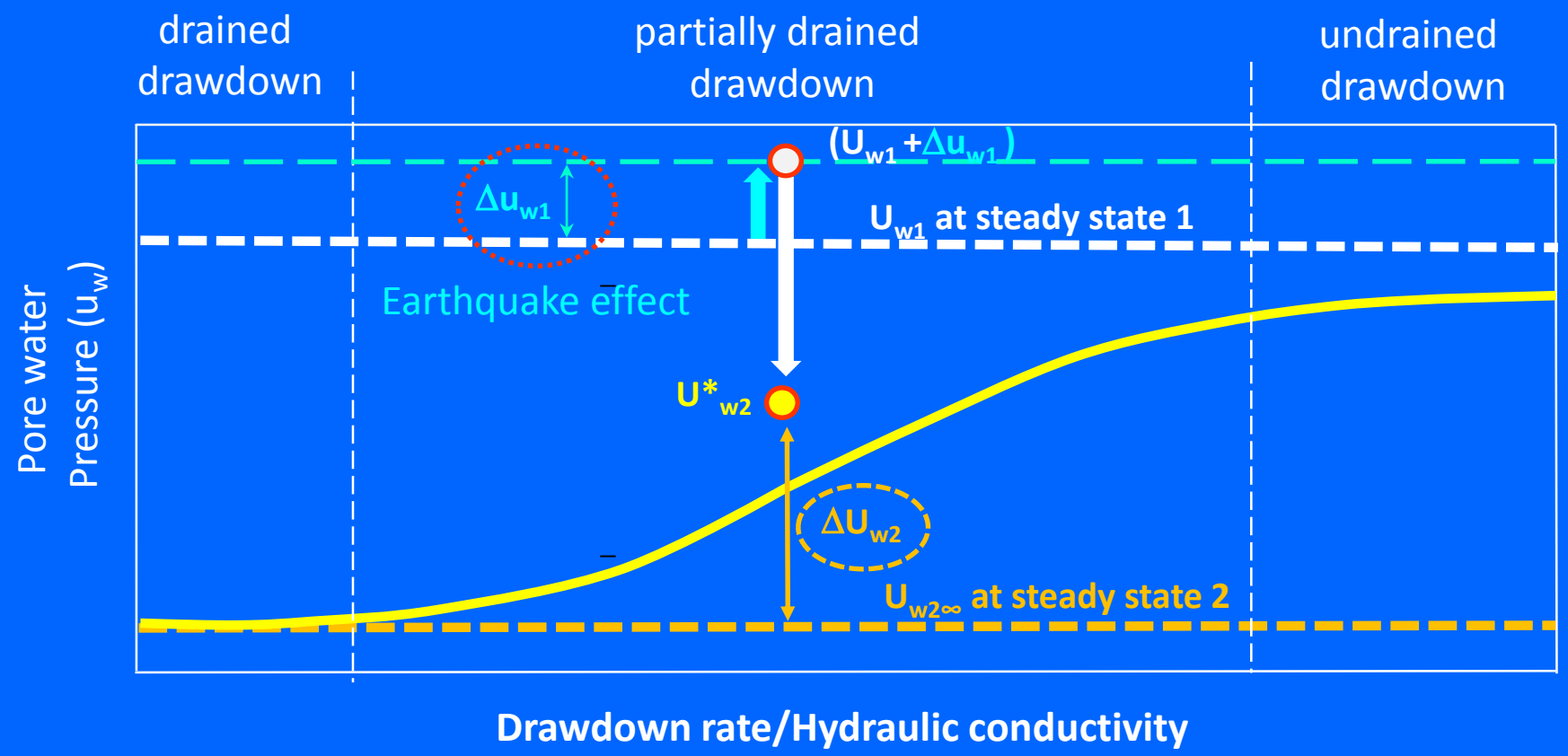
GLOBAL INSTABILITY – DRAWDOWN





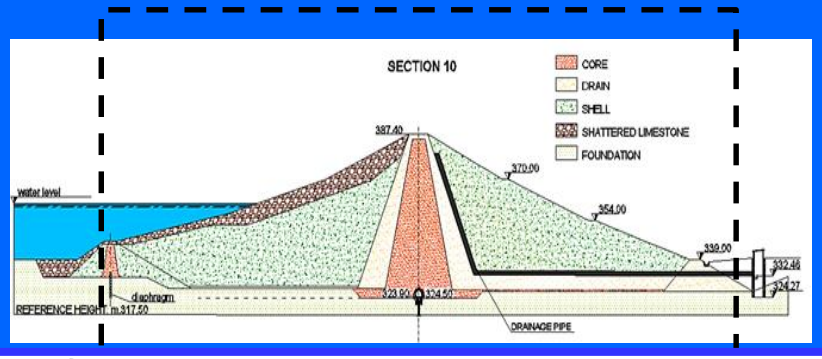
GLOBAL INSTABILITY – DRAWDOWN AFTER AN EARTHQUAKE

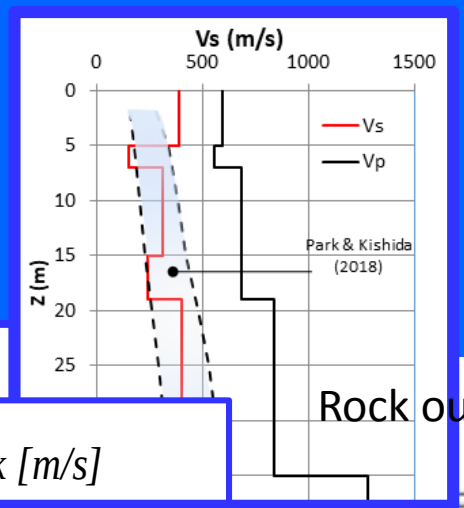




THE CAMPOLATTARO DAM (ITALY)

H = 63 m
Built 1986 -1992
Maximum water storage 125 Mm^3

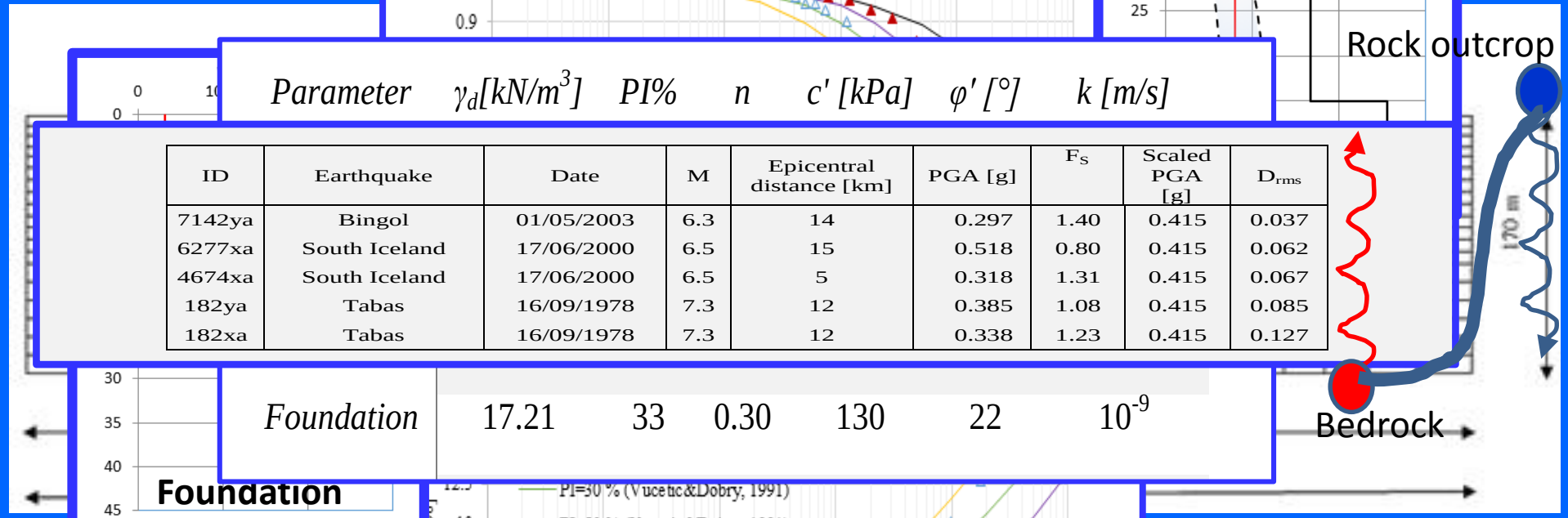


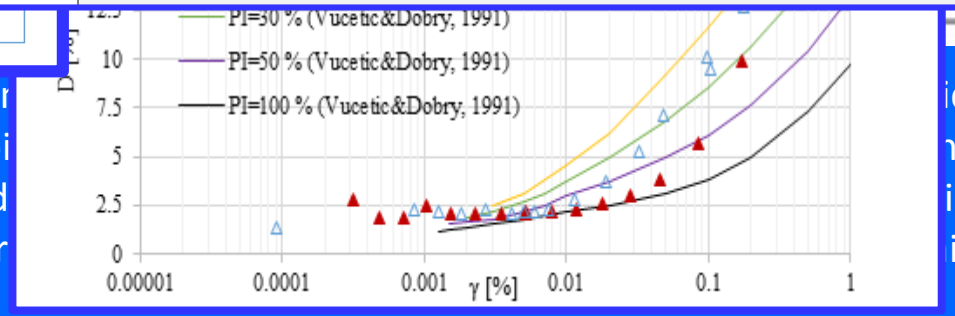


Rock outcrop

Parameter	γ_d[kN/m^3]	PI%	n	c' [kPa]	φ' [°]	k [m/s]
Foundation	17.21	33	0.30	130	22	10^{-9}

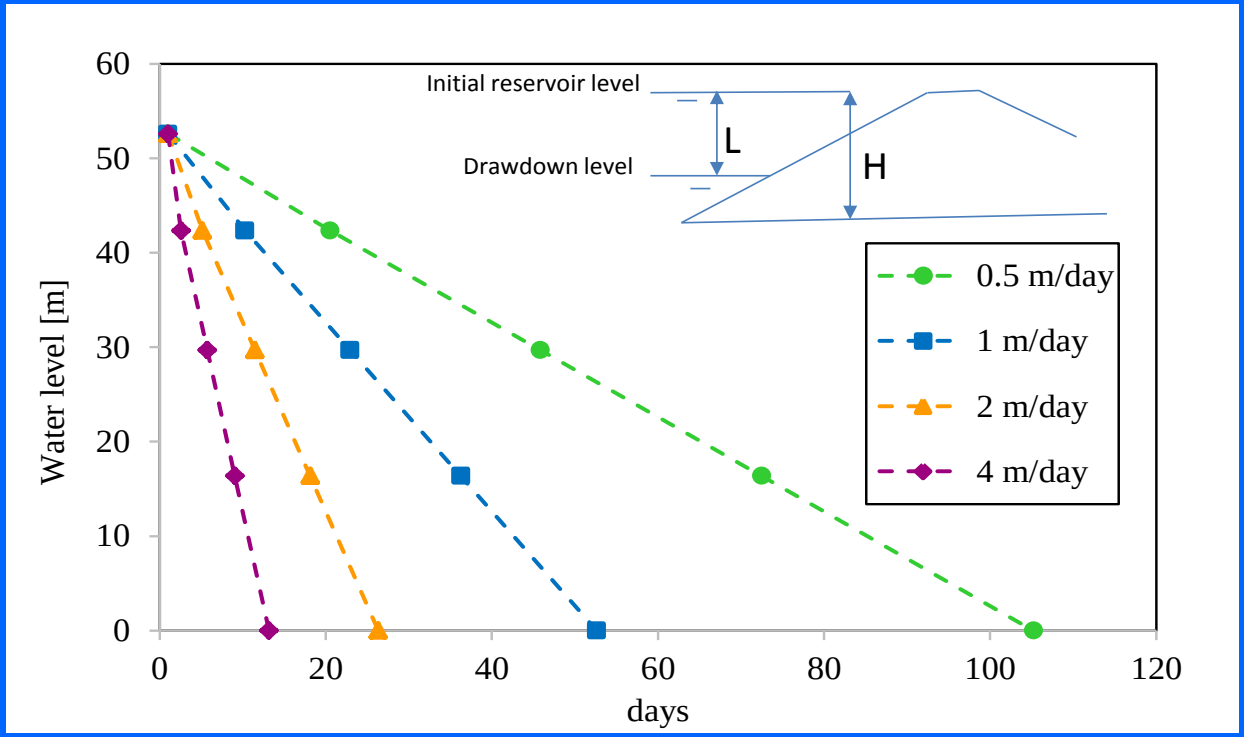
ID	Earthquake	Date	M	Epicentral distance [km]	PGA [g]	F_S	Scaled PGA [g]	D_{rms}
7142ya	Bingol	01/05/2003	6.3	14	0.297	1.40	0.415	0.037
6277xa	South Iceland	17/06/2000	6.5	15	0.518	0.80	0.415	0.062
4674xa	South Iceland	17/06/2000	6.5	5	0.318	1.31	0.415	0.067
182ya	Tabas	16/09/1978	7.3	12	0.385	1.08	0.415	0.085
182xa	Tabas	16/09/1978	7.3	12	0.338	1.23	0.415	0.127





- Coupled 2-phase for ... ic stage.
- Non-linear elastic soi ... n.
- Cyclic soil behavior d ... ing (1926) rules.
- Excess pore water pr ... ic loading.

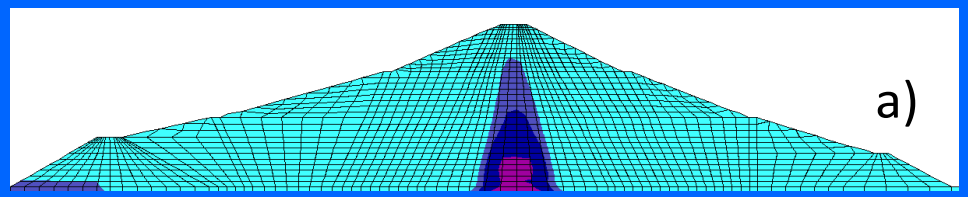
SIMULATED DRAWDOWN SCENARIOS



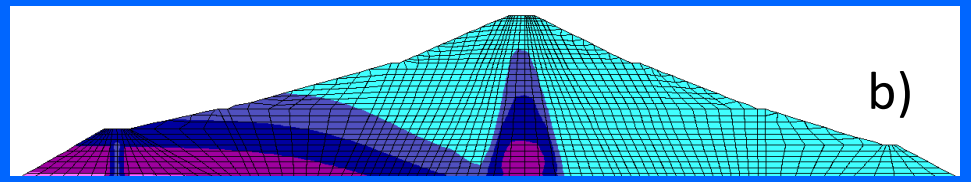
Coupled unsaturated approach (3-phase formulation) during the drawdwon stage.

Soil-water retention curves defined through the Van Genuchten (1980) model.

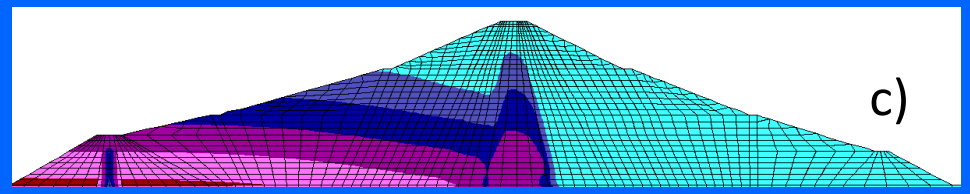
Pore water pressures at different stages of the dam lifetime



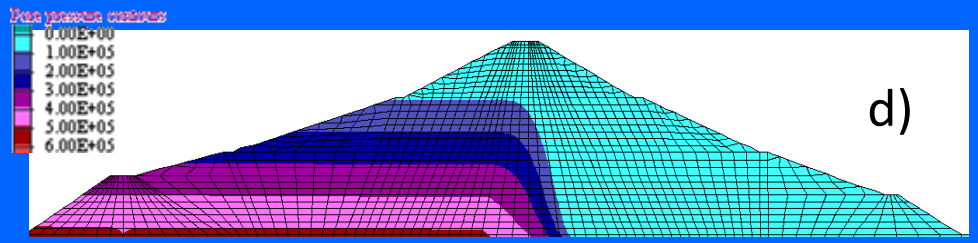
end of the construction stage



water level at +42.36 m

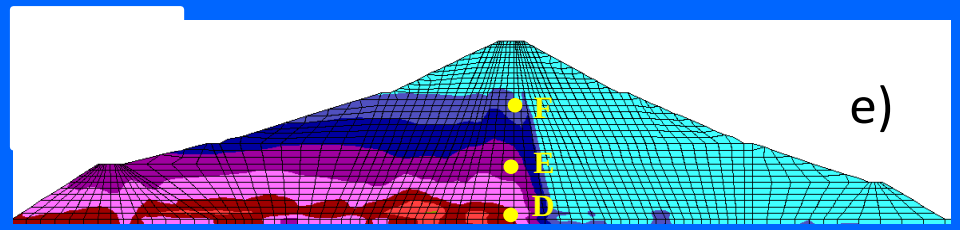


water level +52.62 m



steady-state at the maximum water level

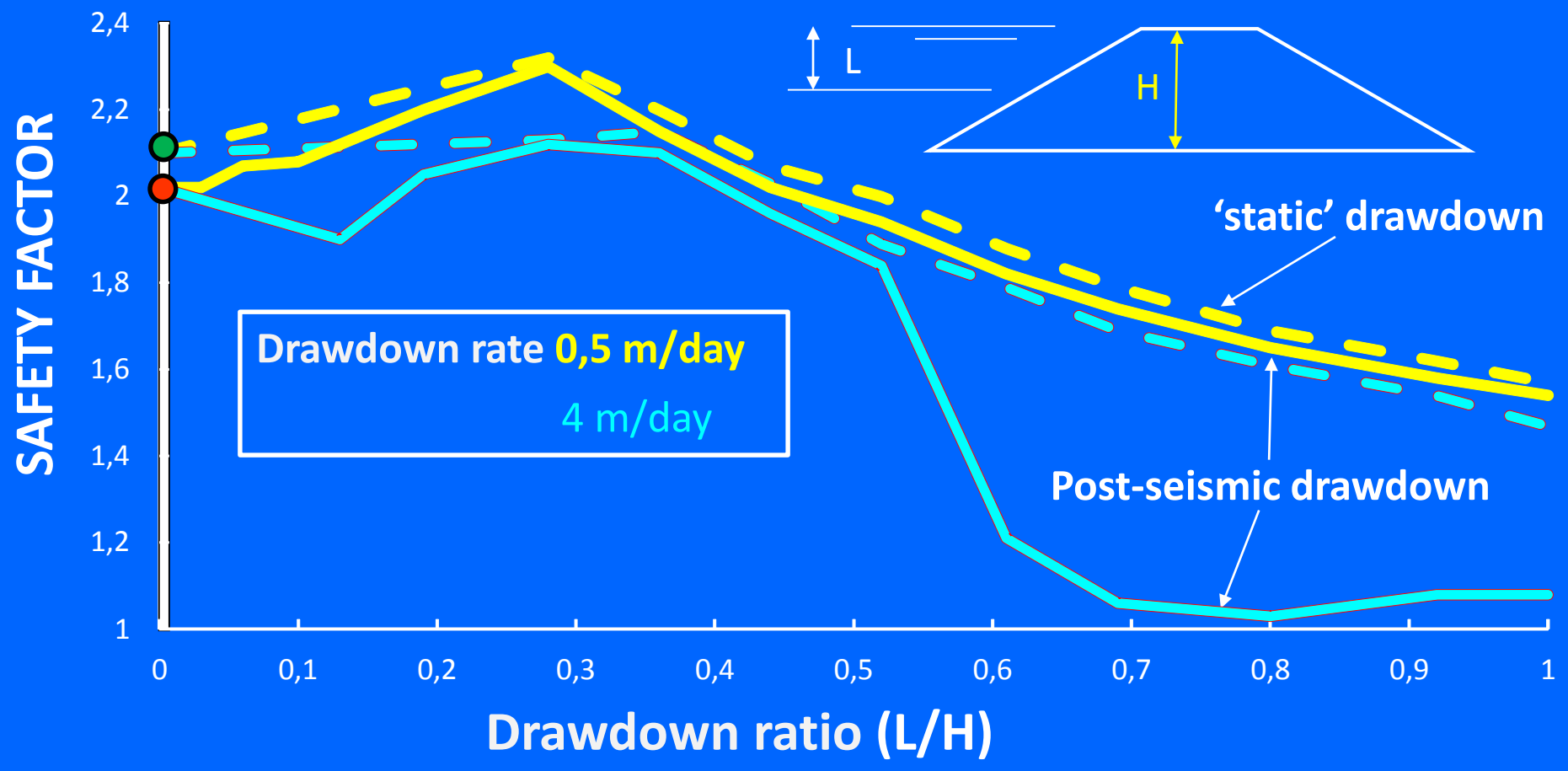
Static drawdown



end of the dynamic stage (4674xa input signal)

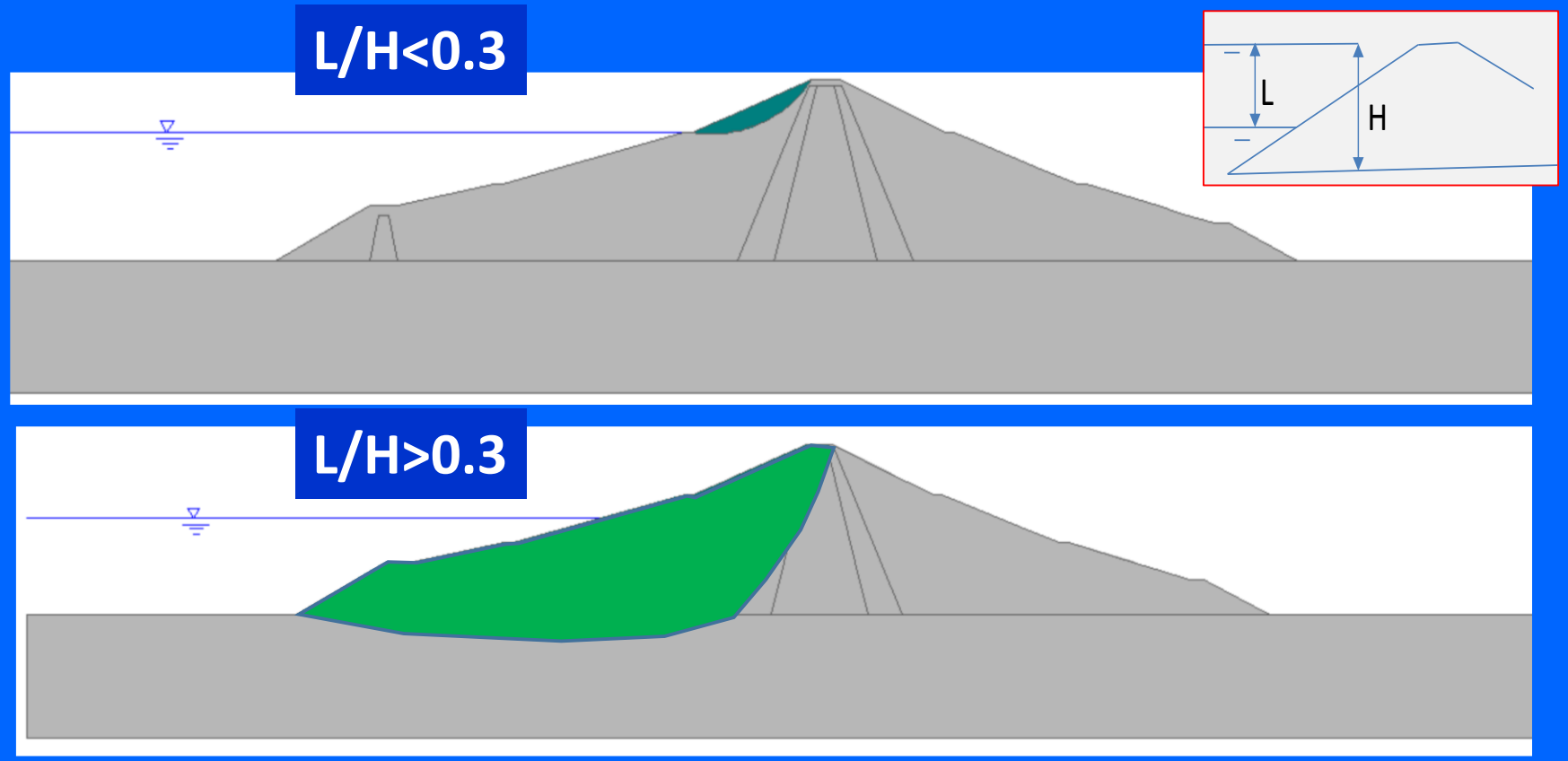
Post-seismic drawdown

DRAWDOWN and GLOBAL INSTABILITY



The shear strength reduction technique proposed by Duncan (1996) was adopted following the specific procedure implemented in FLAC2D.

DRAWDOWN and GLOBAL INSTABILITY



For L/H<0.3, the global instability phenomenon develops entirely within the upstream shell.

With increasing the drawdown ratio, the critical slip surface partly crosses the core where the excess pore water pressures are higher.

CONCLUSIONS

Different drawdown scenarios were simulated on a zoned earth dam considering the combined effects of a strong earthquake first and a drawdown later.

For the case-history considered in this study, the earthquake stage affected dam stability during the reservoir lowering.

The global safety factor (FOS) dropped to one when a very fast drawdown was superimposed to a previous severe seismic stage.

Dam managers should be aware of the risk of rapidly emptying the reservoir immediately after a major earthquake, in the unjustified belief that they are proceeding in the safest way.

Computers and Geotechnics 116 (2019) 103187

Contents lists available at ScienceDirect

Computers and Geotechnics

journal homepage: www.elsevier.com/locate/compgeo

Research Paper

Rapid drawdown on earth dam stability after a strong earthquake

Stefania Sica[a,*], Luca Pagano[b], Federica Rotili[a]

[a] Università degli Studi del Sannio, Italy
[b] Università degli Studi di Napoli "Federico II", Italy

ARTICLE INFO

Keywords:
Earth dam
Earthquake
Drawdown
Stability

ABSTRACT

The paper focuses on the rapid drawdown of earth dams in the hypothesis that a prompt reservoir lowering is needed soon after a strong earthquake. The interest on such a topic comes from the fact that in Italy and worldwide there are many large dams placed very close to active faults. In this case, the dam may be asked to face the earthquake first and the rapid drawdown later to face an emergency state. The problem has been numerically investigated with reference to a zoned earth dam (Campolattaro Dam) placed in a highly seismic area of Southern Italy. To solve the overall boundary value problem, encompassing several stages of the dam lifetime, a 2D finite difference model has been solved through the FLAC2D code, implementing a coupled transient seepage formulation, which accounts for partial saturation of the soil during the drawdown stage. Unlike past literature studies, in which the drawdown stage was modelled without accounting for the past loading history of the dam, in the performed simulation the drawdown stage was placed at the end of a quite real sequence of events, encompassing the embankment construction, the reservoir impounding, and earthquake scenarios compatible with the dam site seismic hazard. The performed analyses pointed out that a seismic stage previously experienced by the dam could further contribute to decreasing dam stability during the drawdown especially during the first stages of reservoir lowering. In addition, the faster the drawdown, the smaller the dam safety factor against stability (FOS) with more prominent effects of the initial (pre-drawdown) soil conditions.