Numerical analysis of dams

ICOLD-BW
9th-11th September 2019
MILANO

CIGB ICOLD

10th September 2019

Theme B:
Seismic analyses of Menta Embankment dam

Introduction to Theme B

Giacomo Russo

Department of Earth Science, Environment and Resources, University of Napoli Federico II

(formerly Department of Civil and Mechanical Engineering, University of Cassino and Southern Lazio)

DiSTAR Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse

DICM

Theme B Formulators: G. Russo, A. Vecchietti, M. Cecconi, V. Pane, S. De Marco, A. Fiorino

Team of Formulators of Theme B

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Dept. of Earth Science, Environment and Resources

Giacomo Russo

Program of the Session

8:30 – 9:00 Presentation of Theme B

Sergio De Marco – SoRiCal – Menta Hydroelectric power plant

Giacomo Russo – UniNa – Menta Embankment Dam

Manuela Cecconi – UniPg – Overview of contributions

9:00 – 11:30 Presentation of contributions from Participants

12:00 – 13:00 Synthesis of results

Alessia Vecchietti – UniPg – Results

Manuela Cecconi – UniPg – Remarks

Giacomo Russo – UniNa – Closure

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Menta Embankment Dam

Giacomo Russo

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DICeM

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Menta Dam

Main features

Giacomo Russo
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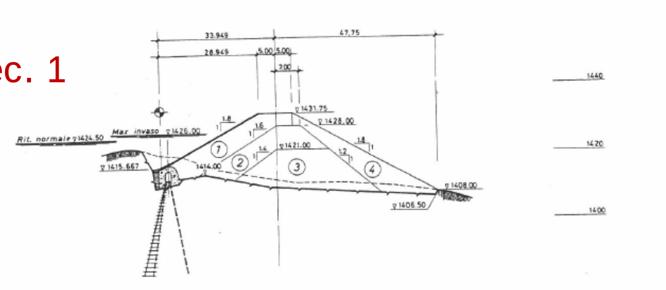
Menta Dam

Main features

Sec. 1



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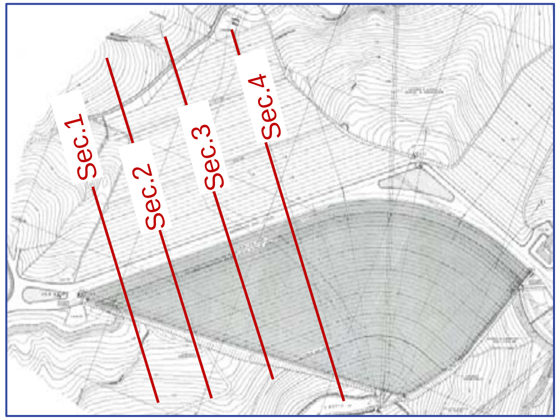

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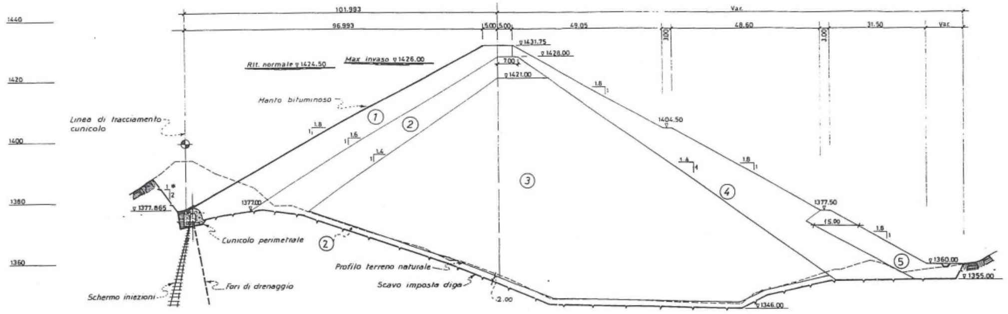

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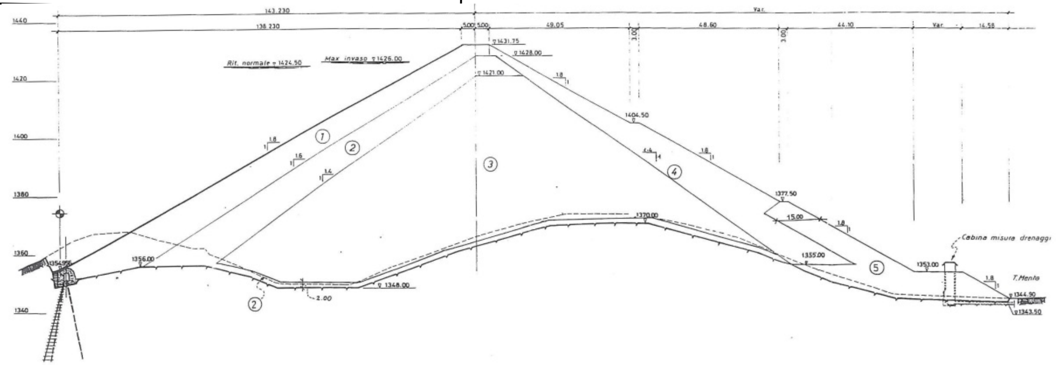

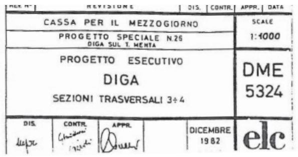

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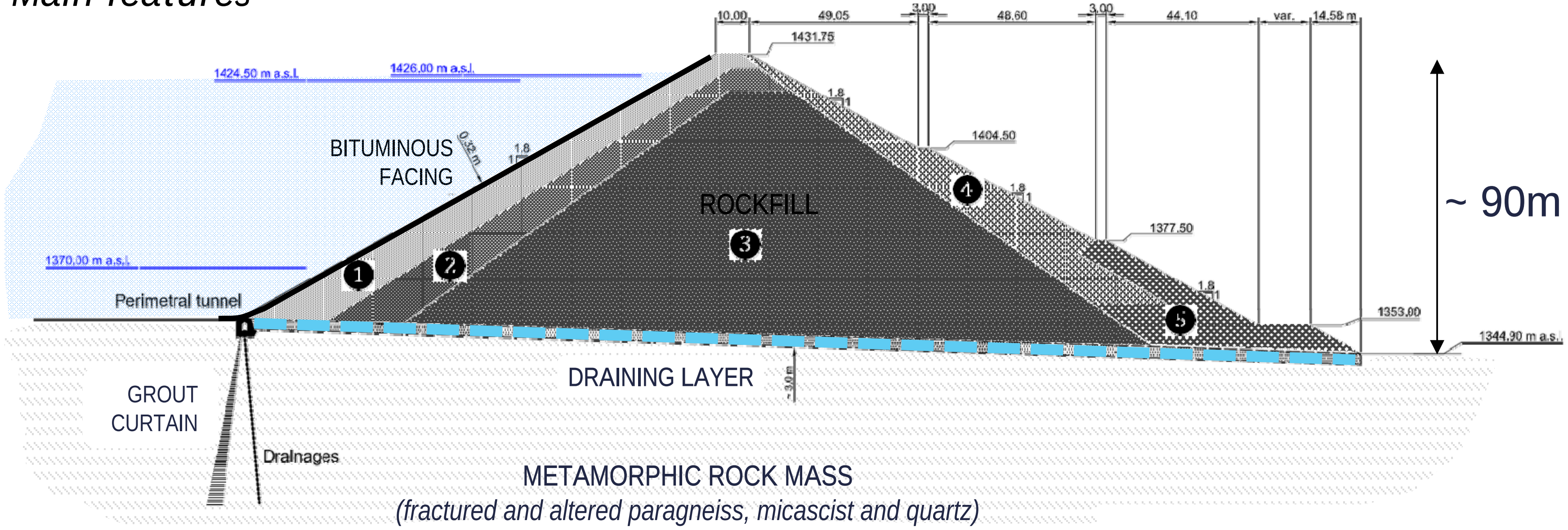
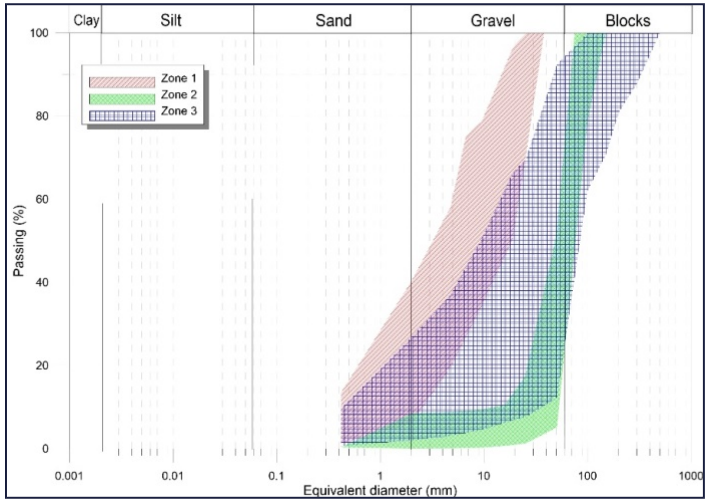
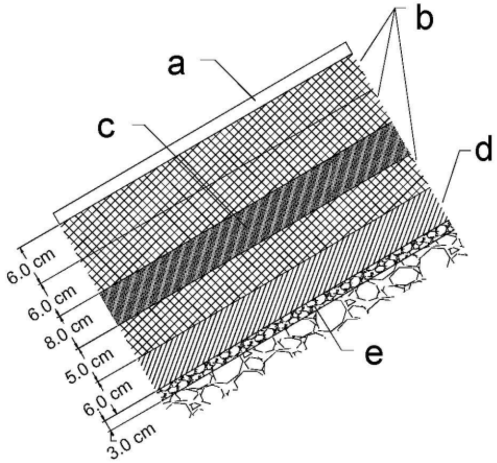
Menta Dam

Main features





Crest elevation	**1431.75 m a.s.l.**
Max. height	**85.75 m** (us) , 89.75 m (ds)
Crest length	325 m (main valley) + 125 m («selletta»)
Impoundment level	**1370.0 m a.s.l.** (min. impoundment) **1424.5 m a.s.l. (normal imp.)** **1426.0 m a.s.l.** (max. impoundment)



a. bituminous sealing
b. sealing layer
c. drainage layer
d. leveling layer
e. bituminous primer

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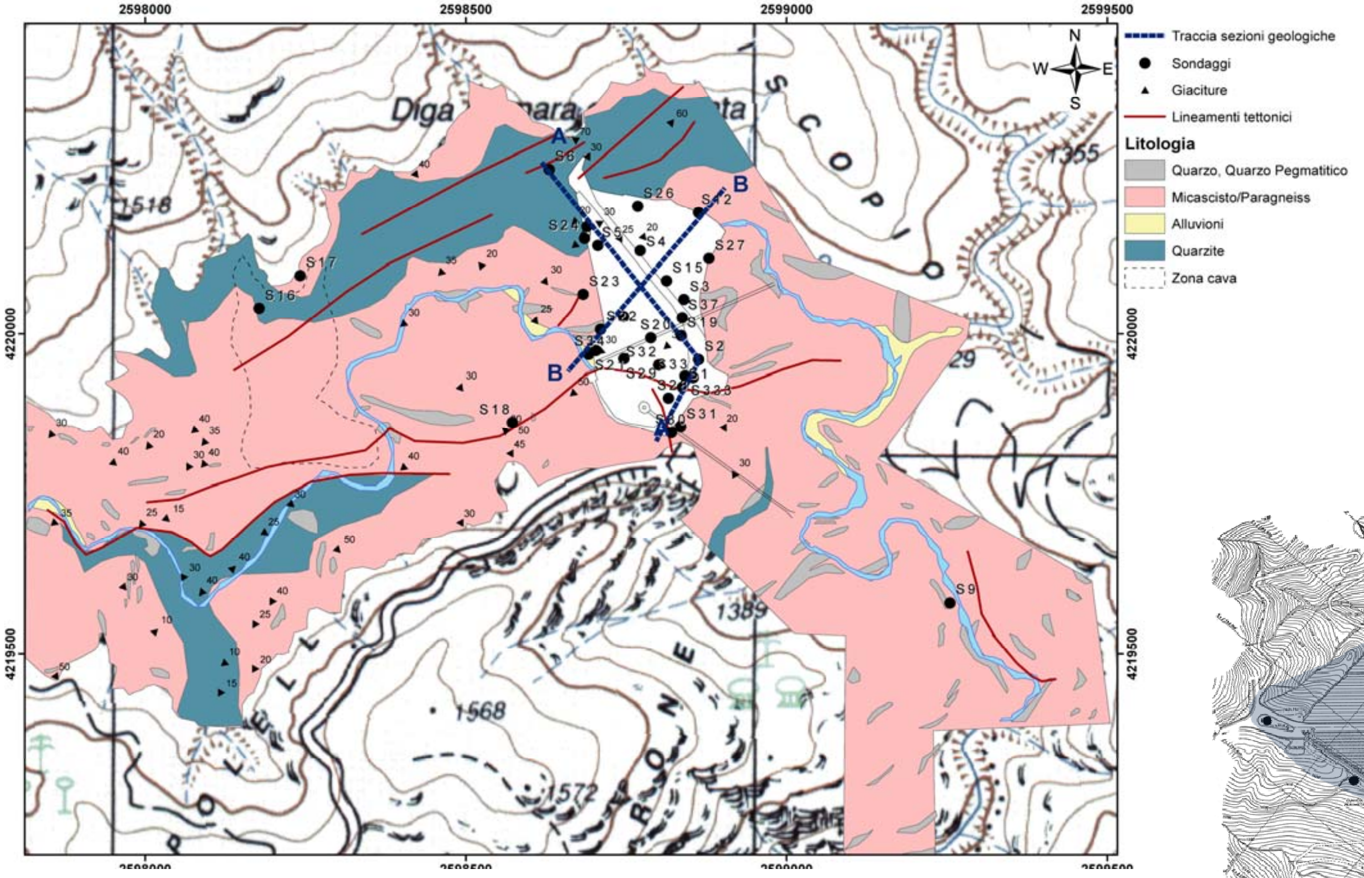
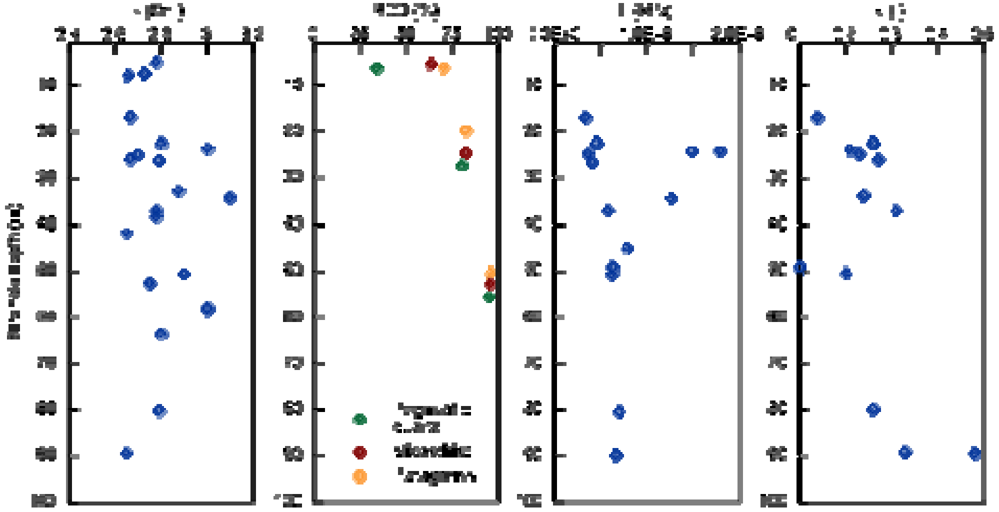
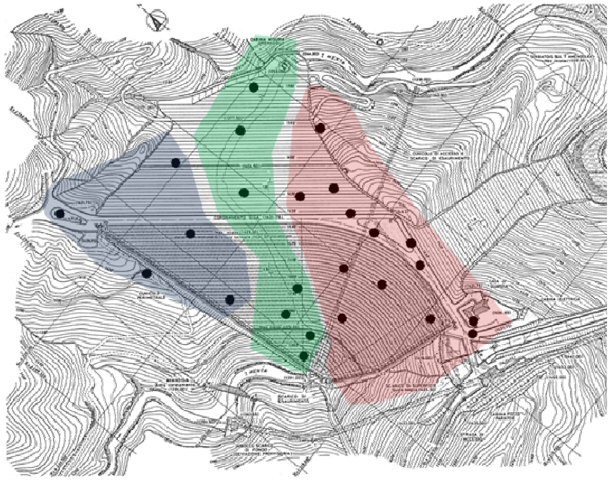
Menta Dam

Geological and geotechnical rock mass properties

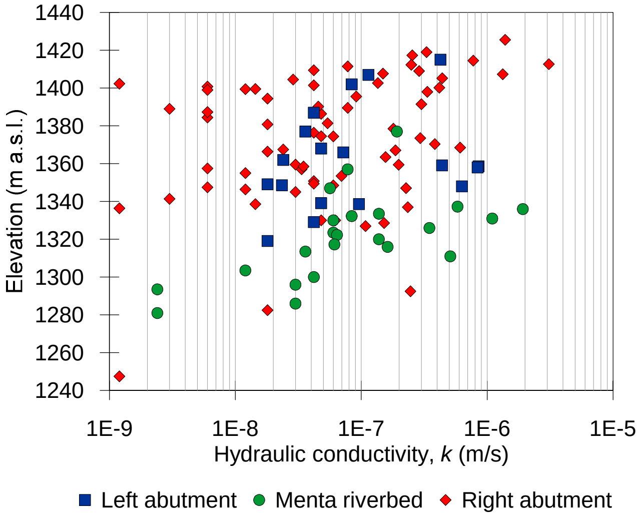






upstream

Hydraulic conductivity in-situ tests



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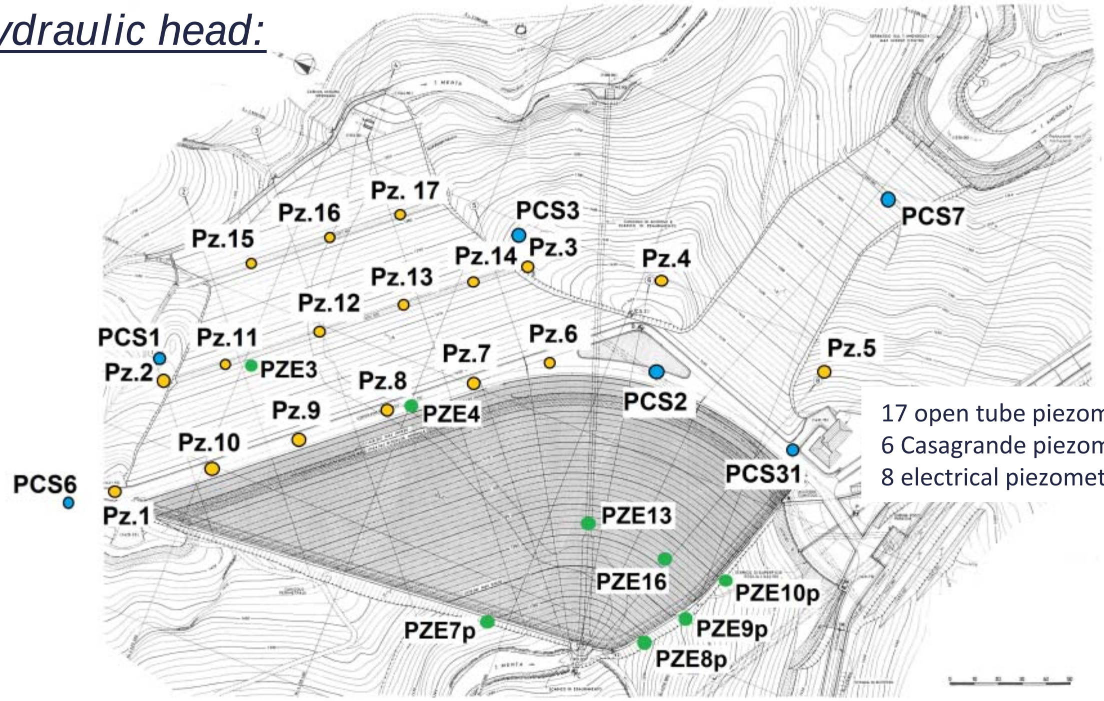
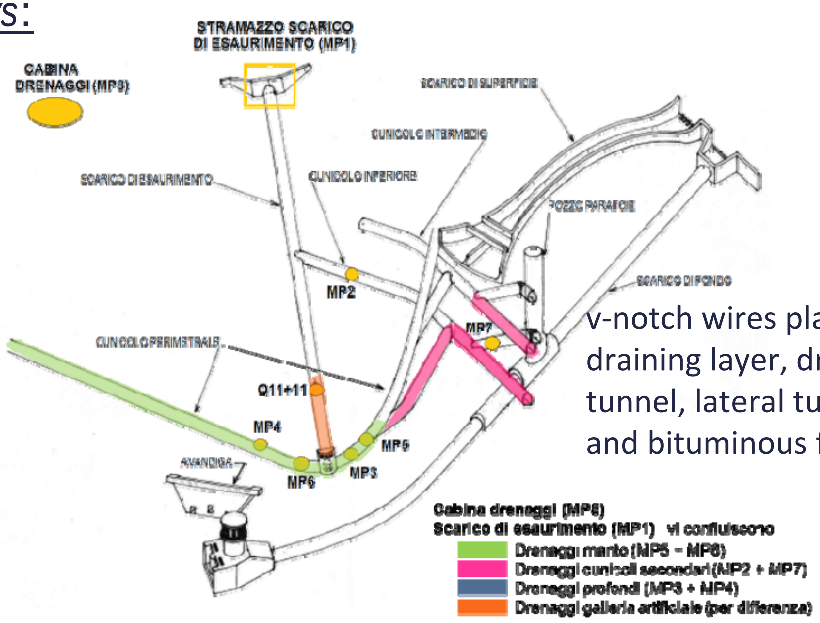
Menta Dam – Monitoring system

Hydraulic head:



17 open tube piezometers
6 Casagrande piezometres
8 electrical piezometers

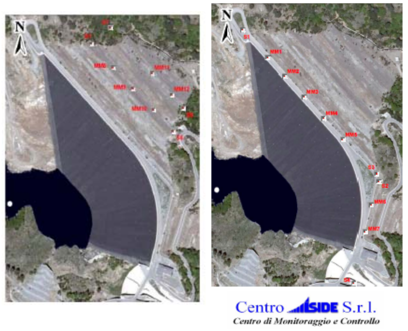
Water flows:

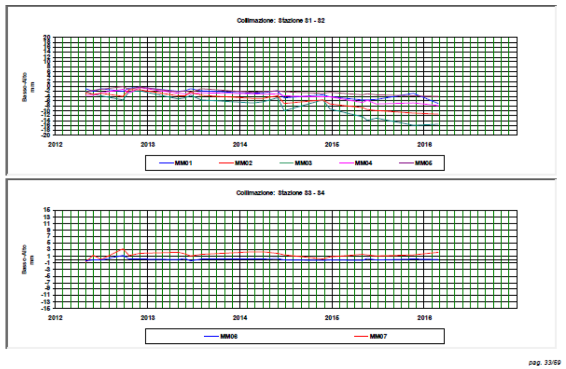


v-notch wires placed at draining layer, draw-off tunnel, lateral tunnels and bituminous facing

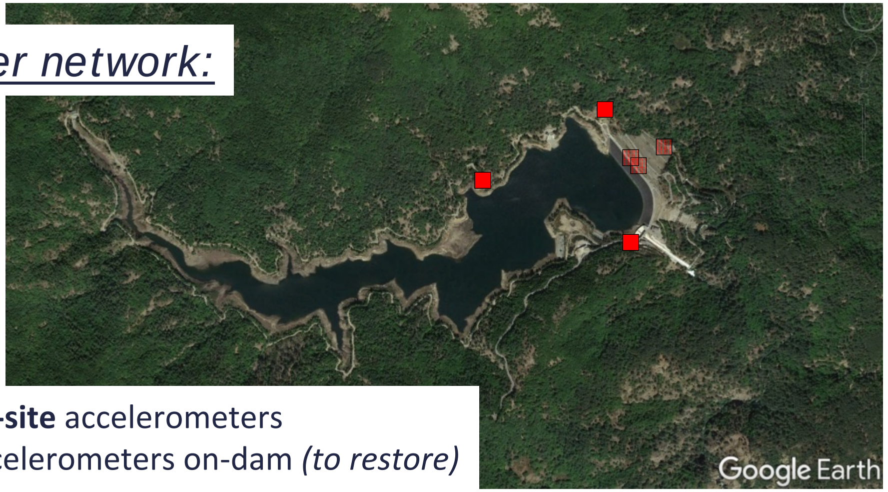
Horizontal and vertical displacements:

exstensimeters, inclinometers, topographic network (settlement plates and benchmarks)





Accelerometer network:



3 **on-site** accelerometers
3 accelerometers on-dam *(to restore)*

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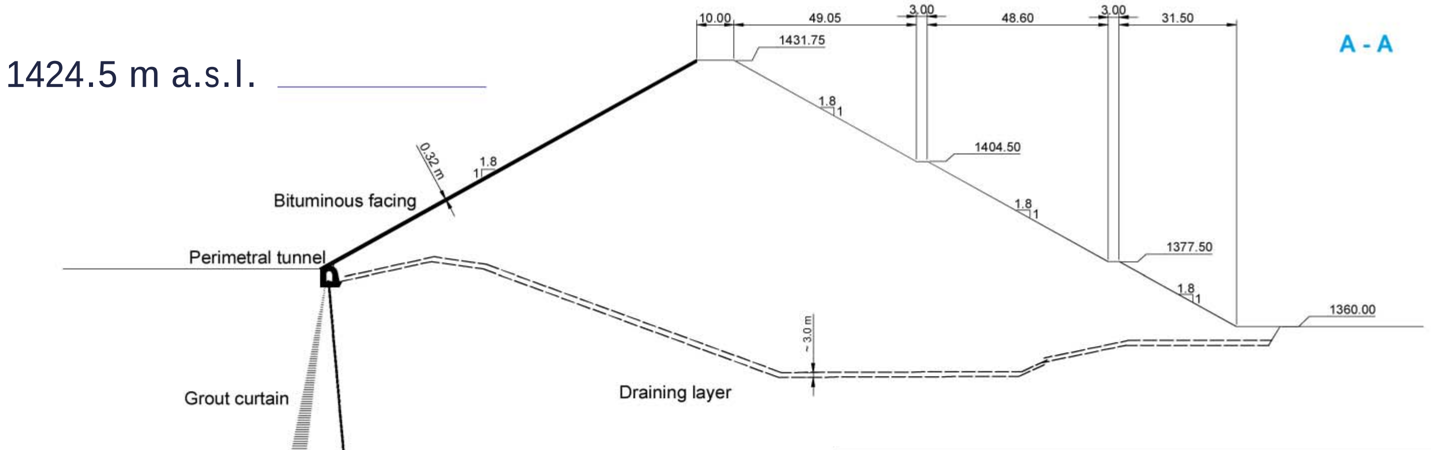
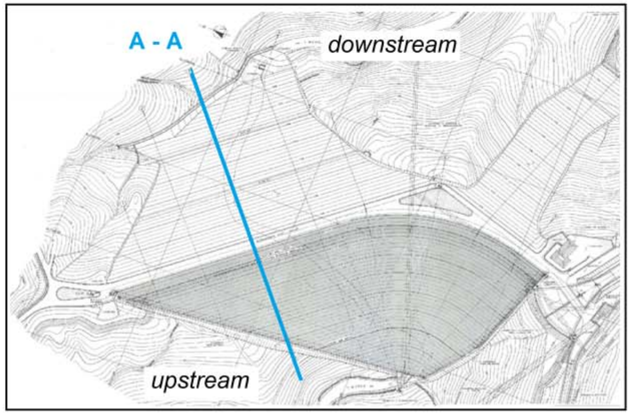
Formulation of Theme B

Evaluation of the embankment stress-strain behaviour under seismic conditions





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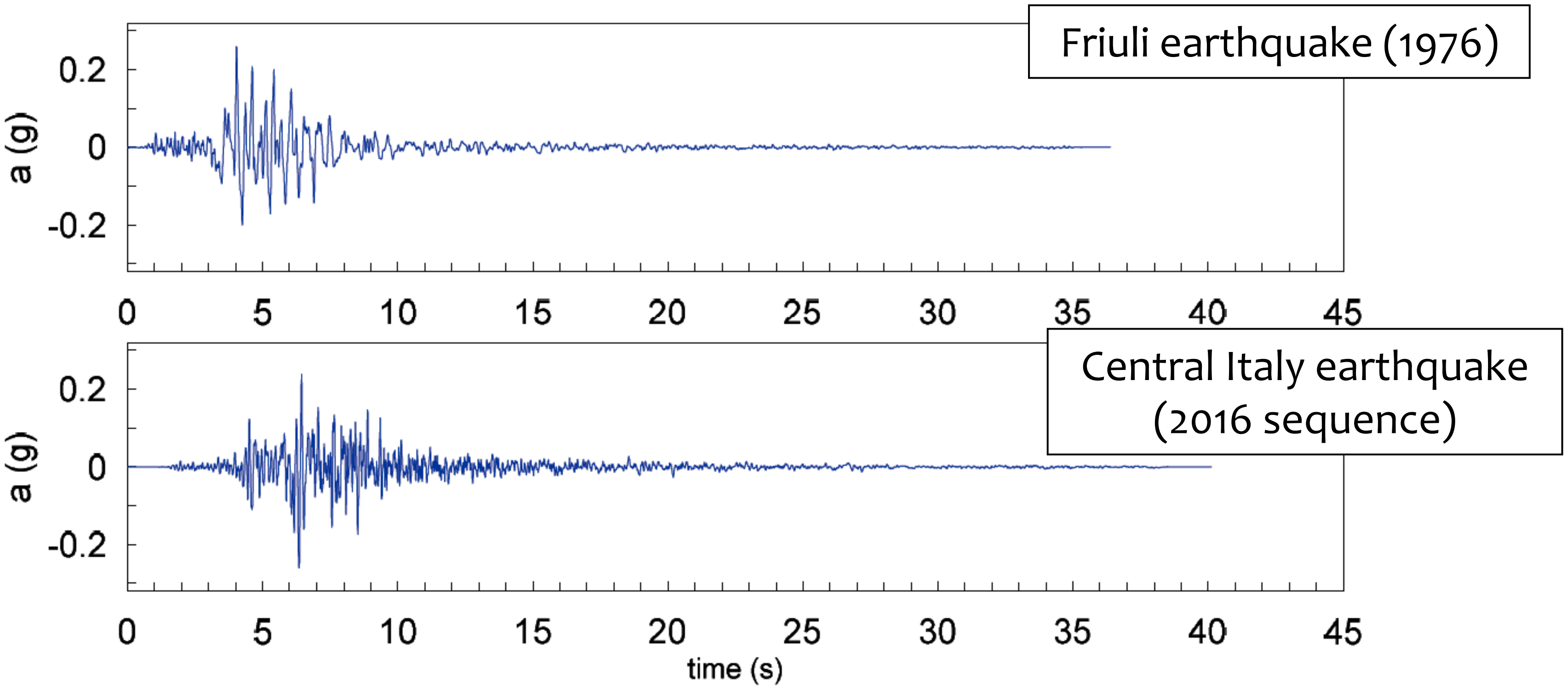
Formulation of Theme B

Evaluation of the embankment stress-strain behaviour under seismic conditions

Seismic scenario: a_g = 0.26 g, n.2 time series recording as input



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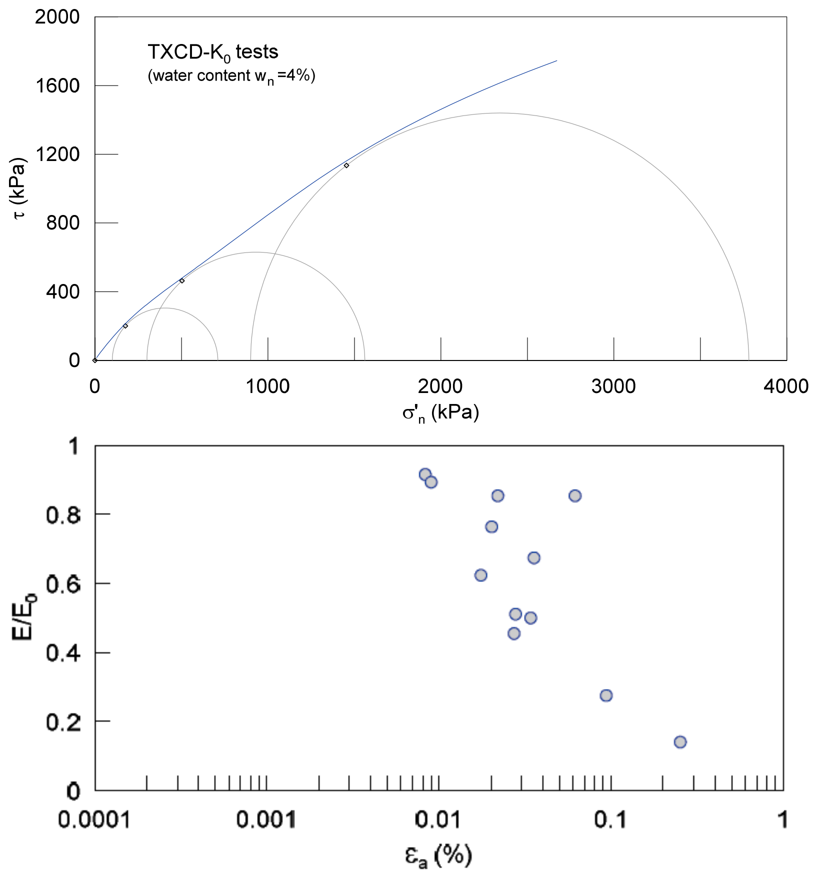
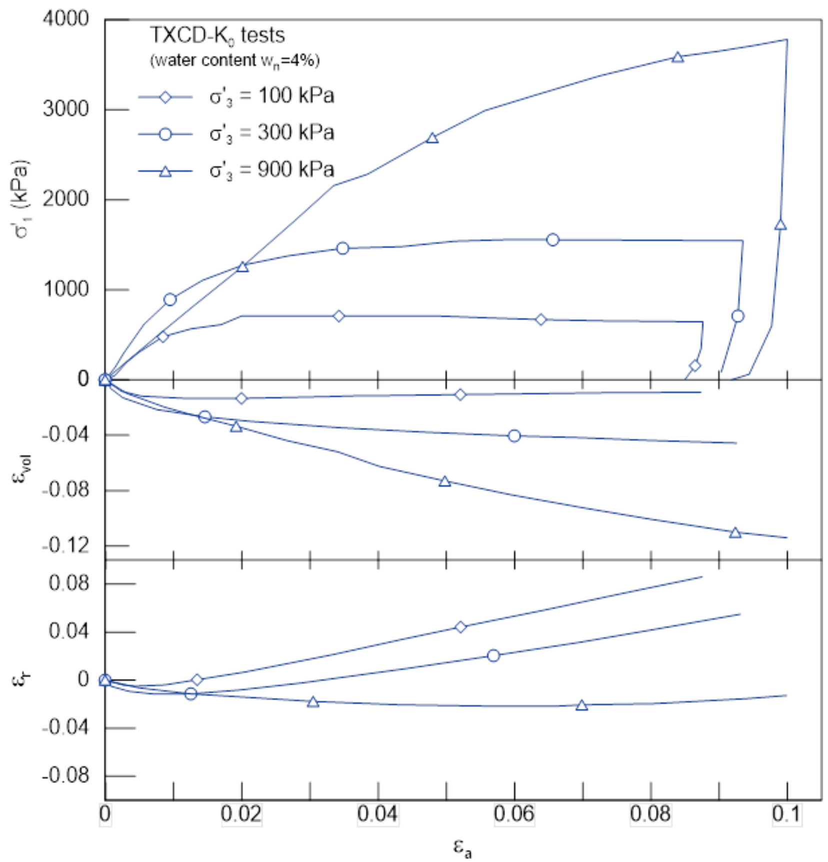
Formulation of Theme B

Evaluation of the embankment stress-strain behaviour under seismic conditions

Seismic scenario: a_g = 0.26 g, n.2 time series recording as input

Rockfill behaviour: stiffness dependence on strain levels and hysteretic damping





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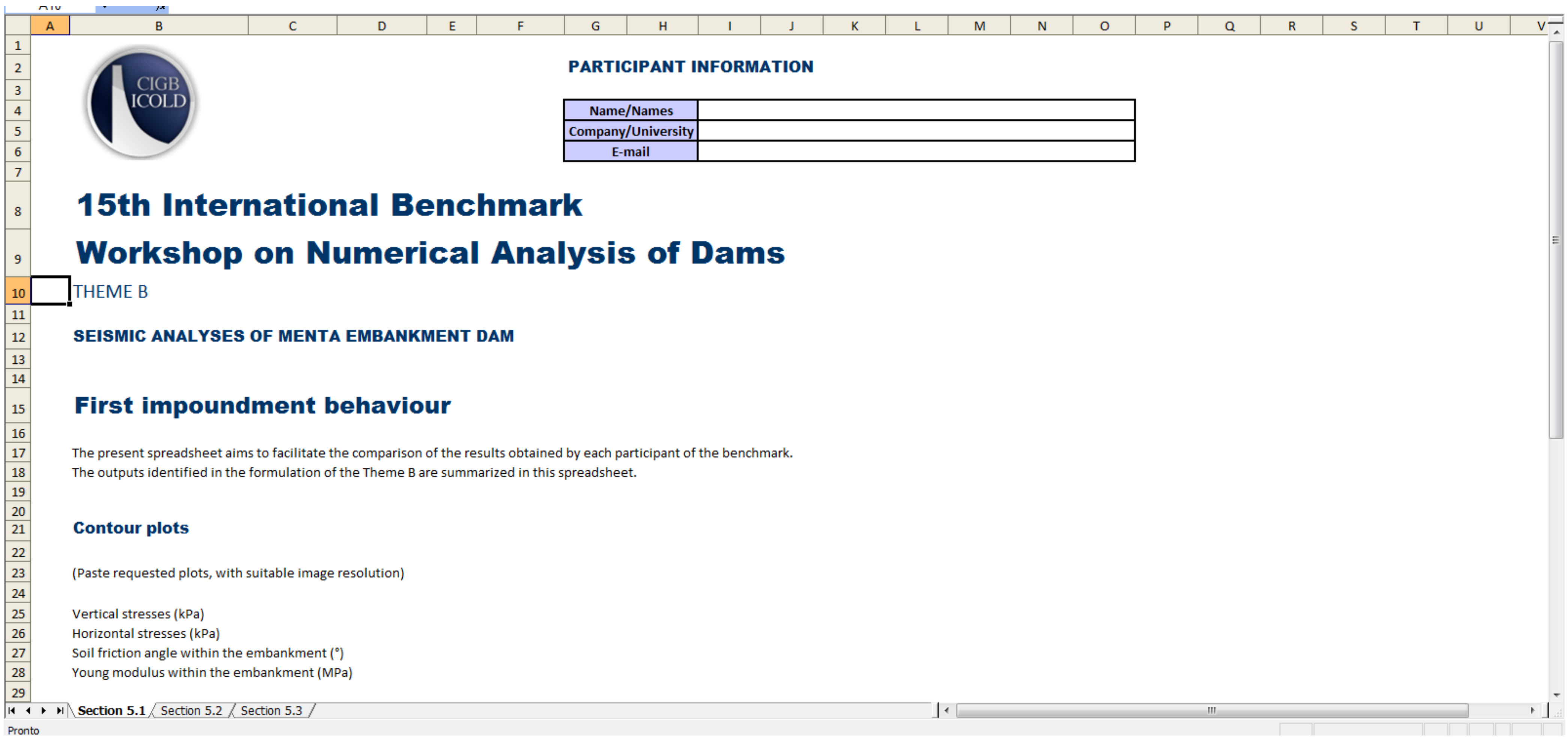
Formulation of Theme B

Evaluation of the embankment stress-strain behaviour under seismic conditions

Expected results



PARTICIPANT INFORMATION

Name/Names	
Company/University	
E-mail	

15th International Benchmark

Workshop on Numerical Analysis of Dams

THEME B

SEISMIC ANALYSES OF MENTA EMBANKMENT DAM

First impoundment behaviour

The present spreadsheet aims to facilitate the comparison of the results obtained by each participant of the benchmark.
The outputs identified in the formulation of the Theme B are summarized in this spreadsheet.

Contour plots

(Paste requested plots, with suitable image resolution)

Vertical stresses (kPa)
Horizontal stresses (kPa)
Soil friction angle within the embankment (°)
Young modulus within the embankment (MPa)

Section 5.1 | Section 5.2 | Section 5.3

Pronto

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Formulation of Theme B

Evaluation of the embankment stress-strain behaviour under seismic conditions

Expected results

A15

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U

Seismic behaviour

The present spreadsheet aims to facilitate the comparison of the results obtained by each participant of the benchmark.
The outputs identified in the formulation of the Theme B are summarized in this spreadsheet.

Fundamental frequency

	Hz	Comments
Empty reservoir		
Full reservoir		

Embankment acceleration

	input #1	input #2
Crest-to-base max. acceleration ratio		

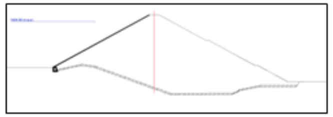
Embankment displacements

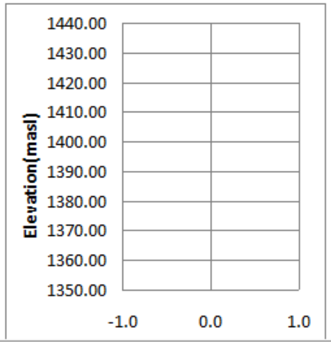
	m
Max. Crest displacement	
Max. Crest settlement	

Time	Crest acceleration	Crest acceleration
(s)	(g)	(g)
0.000	...	...
0.005	...	....
0.010	...	...
0.015		
0.020		
0.025		
0.030		
0.035		
0.040		
0.045		

Crest displacemnt	Crest settlement
(m)	(m)
...	...
....	....
...	...

Elevation	Horizontal displacements of central axis	Horizontal displacements of central axis
(m.a.s.l.)	(m)	(m)
1431.75		
....		
1352.60		





Section 5.1 | Section 5.2 | Section 5.3

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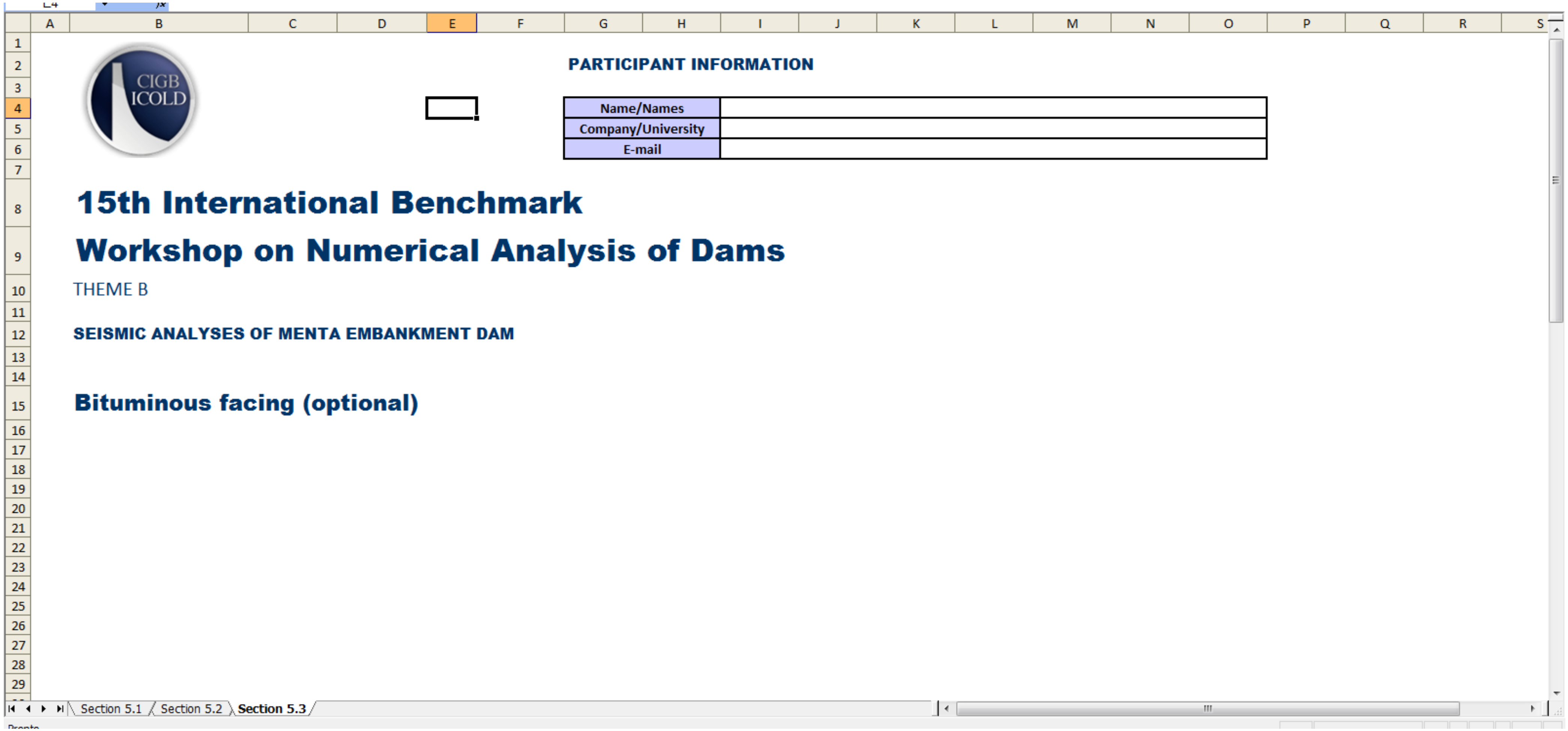
Formulation of Theme B

Evaluation of the embankment stress-strain behaviour under seismic conditions

Expected results



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15th International Benchmark

Workshop on Numerical Analysis of Dams

THEME B

SEISMIC ANALYSES OF MENTA EMBANKMENT DAM

Bituminous facing (optional)

Section 5.1 Section 5.2 Section 5.3

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Menta Embankment Dam

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Brief overview of adopted models, analyses and results

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Dipartimento di Ingegneria
Department of Engineering

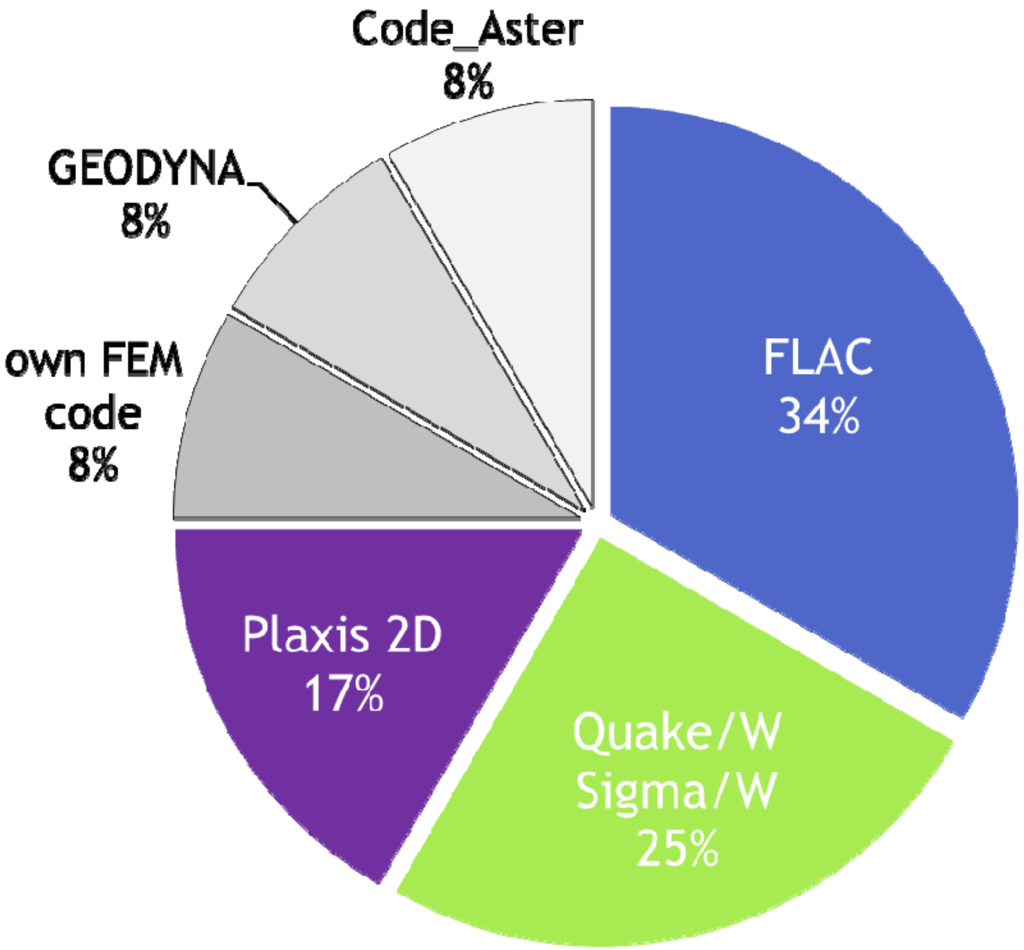
Theme B Formulators: G. Russo, A. Vecchietti, M. Cecconi, V. Pane, S. De Marco, A. Fiorino

CONTRIBUTORS

#	Research_Group	Affiliations	Country
1	Aliberti Vecchiotti, Cascone	Università degli Studi di Messina, Italy	Italy
2	Catalano, Stucchi, Agosti, Crapp	Lombardi Engineering Ltd, Minusio, CH	Switzerland
3	Chugh	US Bureau of Reclamation, Denver (CO), USA	Colorado (USA)
4	Freius, Kainrath, Krstic, Smesnik	Poyry Austria Gmbh, Tschernutter Consulting Ltd.	Austria
5	Fu, Mi, Wei	Nanjing Hydraulic Research Institute, China	China
6	Glagovski, Gibyanskaya	Vedeneev Research Institute (VNIIG), St. Petersburg, Russia	Russia
7	Liu J., Zou, Liu H., Wang	Dalian University of Technology, China Chengdu Eng. Corporation limited	China
8	Lu, Athanasiu	Multiconsult, Oslo	Norway
9	Mészaros, Minarik, Bakes	Vodohospodarska Vystavba, Bratislava, Slovakia	Slovakia
10	Mondoloni, Kolmayer, Alves-Fernandes	Hydraulic Engineering Center (EDF), France Electricitè de France R&D	France
11	Petkovski, Mitovski, Panovska	University Sts Cyril and Methodius, Civil Eng Faculty Skopje, Rep. of Macedonia	Rep. of Macedonia
12	Raggi	ELC Electroconsult SpA, Milano, Italy	Italy

Numerical Methods/Codes

#	Research _Group	Numerical Method	Numerical Code
1	Aliberti, Vecchiotti, Cascone	FDM	FLAC v. 7
2	Catalano, Stucchi, Agosti, Crapp	FDM	FLAC v. 8
3	Chugh	FDM	FLAC
4	Freius, Kainrath, Krstic, Smesnik	FEM	QUAKE/W + SIGMA/W
5	Fu, Mi, Wei	FEM	PERSONAL CODE
6	Glagovski, Gibyanskaya	FEM	PLAXIS 2D (2018)
7	Liu J., Zou, Liu H., Wang	FEM	GEODYNA
8	Lu, Athanasiu	FEM	PLAXIS 2D(2019)
9	Mészaros, Minarik, Bakes	FEM	QUAKE/W + SIGMA/W
10	Mondoloni, Kolmayer, Alves-Fernandes	FEM	Code_ASTER (EdF. Lab.)
11	Petkovski, Mitovski, Panovska	FEM	QUAKE/W + SIGMA/W
12	Raggi	FDM	FLAC



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Numerical Code and seismic input

#	Research _Group	Numerical Method	Numerical Code	Seismic Input Friuli 1976_F Central Italy 2016_CI (H, V)	First natural frequency (Hz) empty, full	max. crest horiz. acceleration (g)
1	Aliberti, Vecchiotti, Cascone	FDM	FLAC v. 7	H + V	2.32, 2.44	0.532
2	Catalano, Stucchi, Agosti, Crapp	FDM	FLAC v. 8	H + V	1.85, 1.90	0.62
3	Chugh	FDM	FLAC	H	1.3 (with specific procedure)	0.234
4	Freius, Kainrath, Krstic, Smesnik	FEM	QUAKE/W + SIGMA/W	H + V	1.8 - 2 (F) 3.7 (CI)	1.48
5	Fu, Mi, Wei	FEM	PERSONAL CODE	H	2.07 – 2.35 2.15 – 2.43	0.83
6	Glagovski, Gibyanskaya	FEM	PLAXIS 2D (2018)	H + V	1.09, 1.0	0.44
7	Liu J., Zou, Liu H., Wang	FEM	GEODYNA	H + V	2.18, 2.25	0.52
8	Lu, Athanasiu	FEM	PLAXIS 2D(2019)	H + V	2.0, 2.0 (F) 0.7, 0.44 (CI)	0.714
9	Mészaros, Minarik, Bakes	FEM	QUAKE/W + SIGMA/W	H + V	1.6 – 2.0 (F) 1.6 – 2.0 (F) 6.7 – 5.3 (CI) 6.7 – 2.1 (CI)	0.296
10	Mondoloni, Kolmayer, Alves-Fernandes	FEM	Code_ASTER (EdF. Lab.)	H	1.82, 1.86	6.79
11	Petkovski, Mitovski, Panovska	FEM	QUAKE/W + SIGMA/W	H + V	3.03, 3.03 – 2.7	0.782
12	Raggi	FDM	FLAC	H	1.7, 1.4	

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ROCKFILL: Geotechnical properties and Constitutive models

#	Research _Group	Geotechnical properties	Constitutive model	Damping
1	Aliberti, Vecchiotti, Cascone	based on data from proposal + eq.s from the literature	ELASTO-PLASTIC material following non-linear M-C failure criterion	hysteretic, from Rollins et al. (1998)
2	Catalano, Stucchi, Agosti, Crapp	based on data from proposal	ELASTO-PLASTIC material non-linear M-C failure criterion	hysteretic, from data fit
3	Chugh	data derived from other previous studies	ELASTO-PLASTIC material non-linear M-C failure criterion (*) Rock foundation model	hysteretic, from previous data from the literature (Albano, 2013) (*) Deconvolution analysis
4	Freius, Kainrath, Krstic, Smesnik	based on data from proposal + literature/reccomendations (rockfill/ICOLD)	HYPERBOLIC E-B in static conditions, EQUIVALENT LINEAR for dynamic + DYNAMIC DEFORMATION ANALYSIS (DDA)	hysteretic, from Rollins et al. (1998), Seed et al., (1984)
5	Fu, Mi, Wei	based on data from proposal	Specific Elasto-plastic in static conditions + Hardin-type for dynamic (Fu et al., 2014, 2017, 2019)	hysteretic
6	Glagovski, Gibyanskaya	based on data from proposal + previous experience	ELASTO-PLASTIC with HARDENING SMALL STRAIN (HS small)	constant (10%)
7	Liu J., Zou, Liu H., Wang	based on data from proposal	Specific ELASTO-PLASTIC model (Liu et al. 2018)	viscous damping (Rayleigh)
8	Lu, Athanasiu	based on data from proposal + PLAXIS Manual + engineering practice	HARDENING SMALL STRAIN	viscous damping (Rayleigh)
9	Mészaros, Minarik, Bakes	based on available data (derived from ?)	HYPERBOLIC E-B in static conditions, non-linear dynamic + DYNAMIC DEFORMATION ANALYSIS. Newmark stability analyses	damping ratio varying from 6 to 15%
10	Mondoloni, Kolmayer, Alves-Fernandes	from data calibration, based on proposal	Hujeux ELASTO-PLASTIC constitutive model	hysteretic
11	Petkovski, Mitovski, Panovska	based on data from proposal	ELASTO-PLASTIC non-linear M-C in static conditions EQUIVALENT LINEAR for dynamic + DYNAMIC DEFORMATION ANALYSIS (DDA	damping ratio varying from 5 to 25%
12	Raggi	based on data from proposal	Double-Yield Model from FLAC library	10% (Rayleigh damping and local damping)

RESULTS (SEISMIC)

#	Research _Group	max acceleration ratio (crest over base)	max horizontal displ. (+ ds, - us) @ crest (m)	max vertical displ. (+ settlement) @ crest (m)	post-seismic horiz. displ. from contour plots (m)	post-seismic vert. displ. from contour plots (m)	strain contour plots
1	Aliberti, Vecchiotti, Cascone	2.64	0.213	0.080	0.31	0.135	Y
2	Catalano, Stucchi, Agosti, Crapp	2.7	0.085	0.023	0.03 – 0.1	0.02 – 0.05	Y
3	Chugh	2.45	-0.091	0.017	0.02	+/- 0.03	Y
4	Freius, Kainrath, Krstic, Smesnik	6.17	-0.116	-0.012	< 0.1	0.01	Y
5	Fu, Mi, Wei	3.25	0.073	0.191	0.08	0.19	Y
6	Glagovski, Gibyanskaya	1.69	0.018	0.012	0.02	0.012	
7	Liu J., Zou, Liu H., Wang	2.00	0.056	0.206	0.50	0.20	Y
8	Lu, Athanasiu	3.11	0.373	0.210	0.37	0.21	Y
9	Mészaros, Minarik, Bakes	1.14	≅ 0.18	0.08	-	-	-
10	Mondoloni, Kolmayer, Alves-Fernandes	3.82	0.033	0.14	0.05	0.14	Y
11	Petkovski, Mitovski, Panovska	3.01	0.36	0.34	0.68	-	-
12	Raggi		0.61	0.55	> 0.60	> 0.60	Y, failure

BITUMINOUS FACING

#	Research _Group	Bituminous facing_ Optional (Y, N)	Assumptions and investigated aspects
1	Aliberti, Vecchiotti, Cascone	Y	Elasto-plastic constitutive model, Temperature effects (T=1°C , 26°C) Cracking evaluation (M, N specific domain)
2	Catalano, Stucchi, Agosti, Crapp	Y	Elastic, Cracking evaluation (strain) Comparison with other available results from the literature
3	Chugh	Y	Elastic, Cracking evaluation (stress, strain patterns, displacements)
4	Freius, Kainrath, Krstic, Smesnik	N	-
5	Fu, Mi, Wei	N	-
6	Glagovski, Gibyanskaya	N	-
7	Liu J., Zou, Liu H., Wang	Y	Focus on the interface model (bituminous facing and rockfill, Liu et al. 2014). Cracking evaluation (stress pattern)
8	Lu, Athanasiu	Y	Elastic, Temperature effects, Cracking evaluation (axial forces)
9	Mészaros, Minarik, Bakes	N	-
10	Mondoloni, Kolmayer, Alves-Fernandes	N	-
11	Petkovski, Mitovski, Panovska	Y	Elastic, Cracking evaluation (stress, strain)
12	Raggi	N	-

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Results

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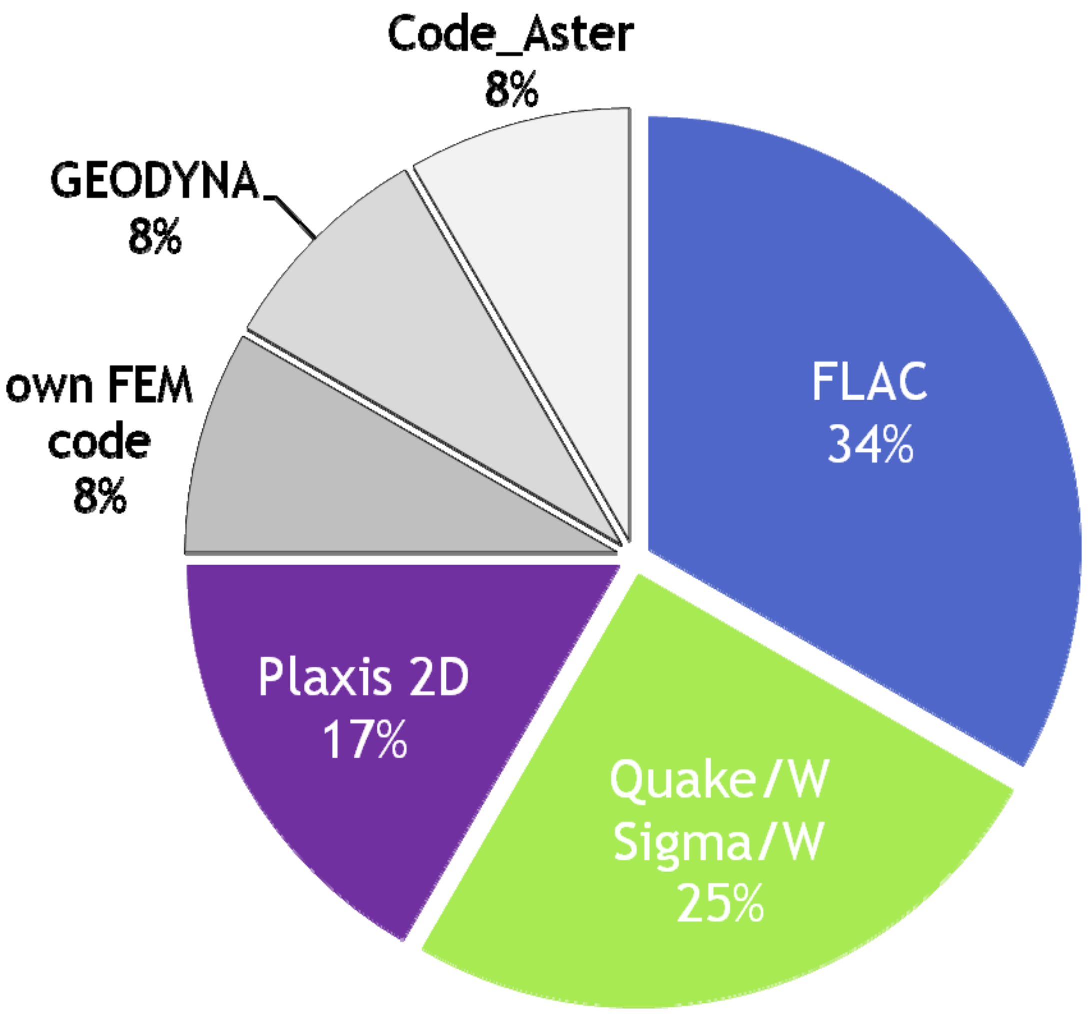
Department of Engineering, University of Perugia

Presentation of Results: Outline

1. **Static conditions**
    - vertical stresses,
    - horizontal stresses,
    - Initial Young modulus,
    - friction angle

2. **Fundamental frequency**
   Dynamic conditions
    - crest-to-base amplification
    - displacements and settlements

3. **Bituminous facing**



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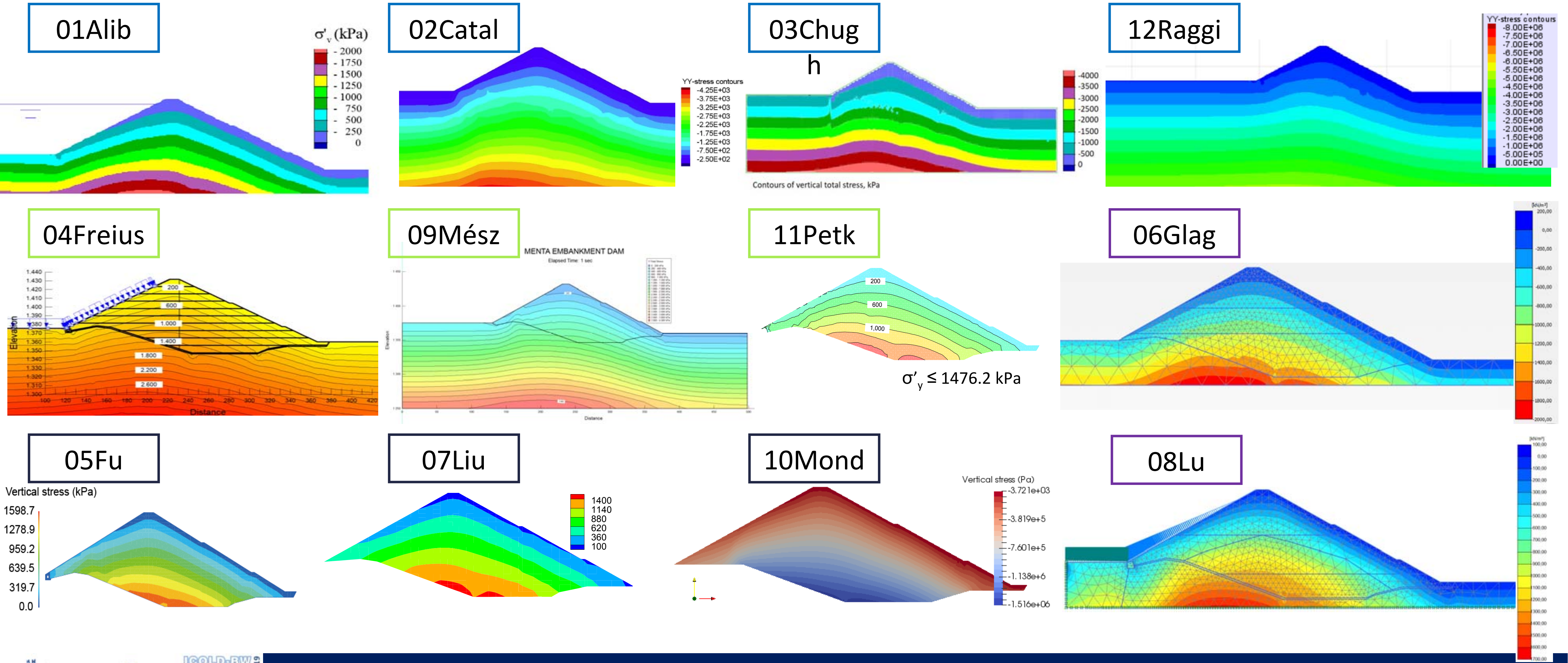
Part 1 _ STATIC CONDITIONS
Vertical stresses (kPa)

FLAC | SIGMA/W | PLAXIS | OWN FEM CODE



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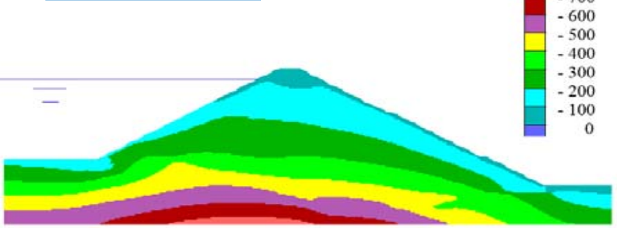
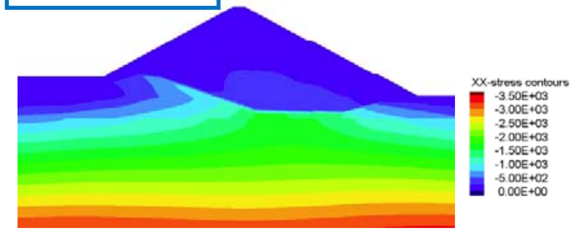
Part 1 _ STATIC CONDITIONS
Horizontal stresses (kPa)

FLAC | SIGMA/W | PLAXIS | OWN FEM CODE

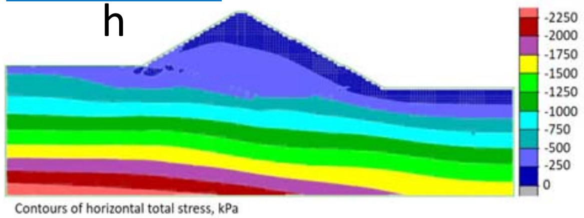
01Alib



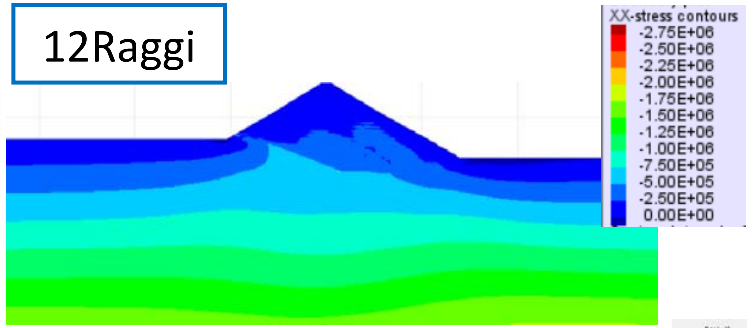
02Catal



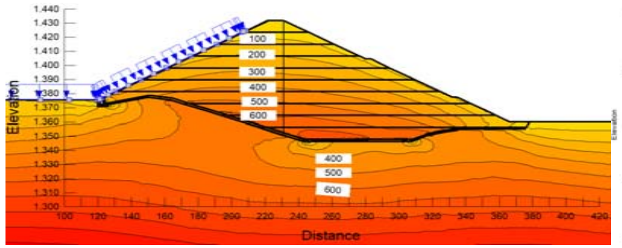
03Chug
h



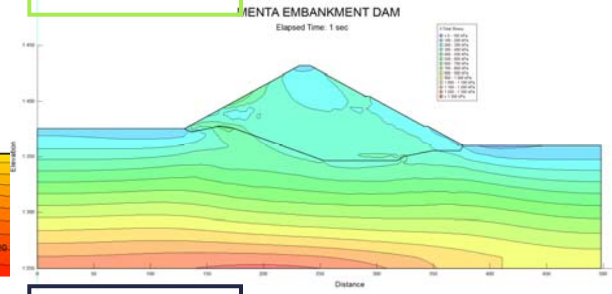
12Raggi



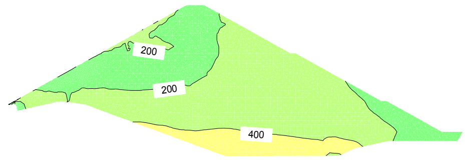
04Freius



09Mész

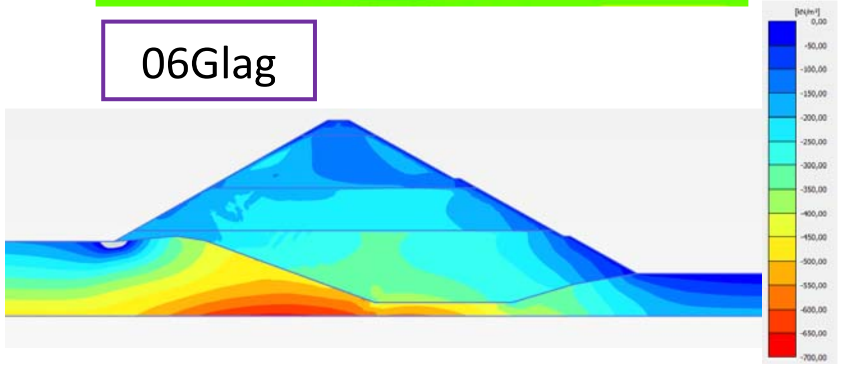


11Petk



σ'x ≤ 922.8 kPa

06Glag



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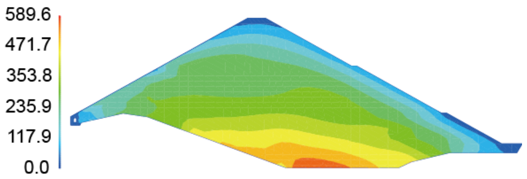
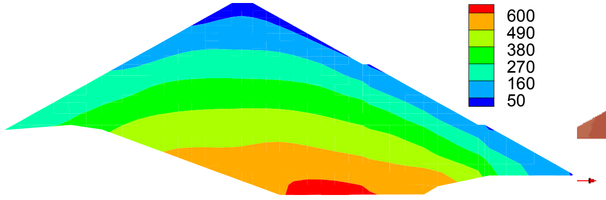
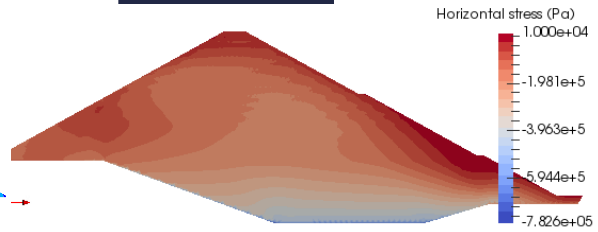


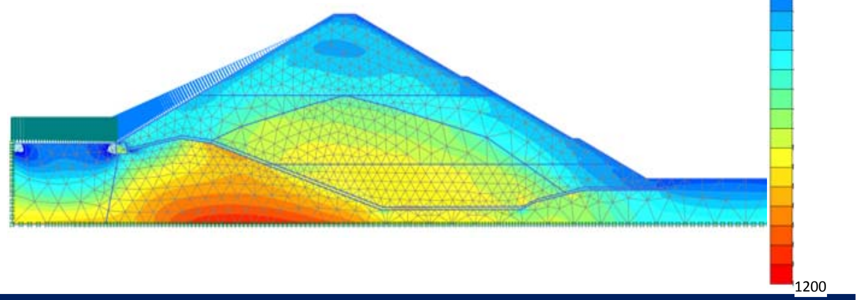
07Liu



10Mond



08Lu



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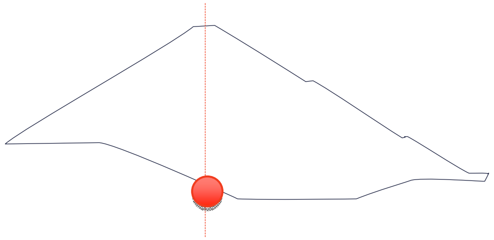
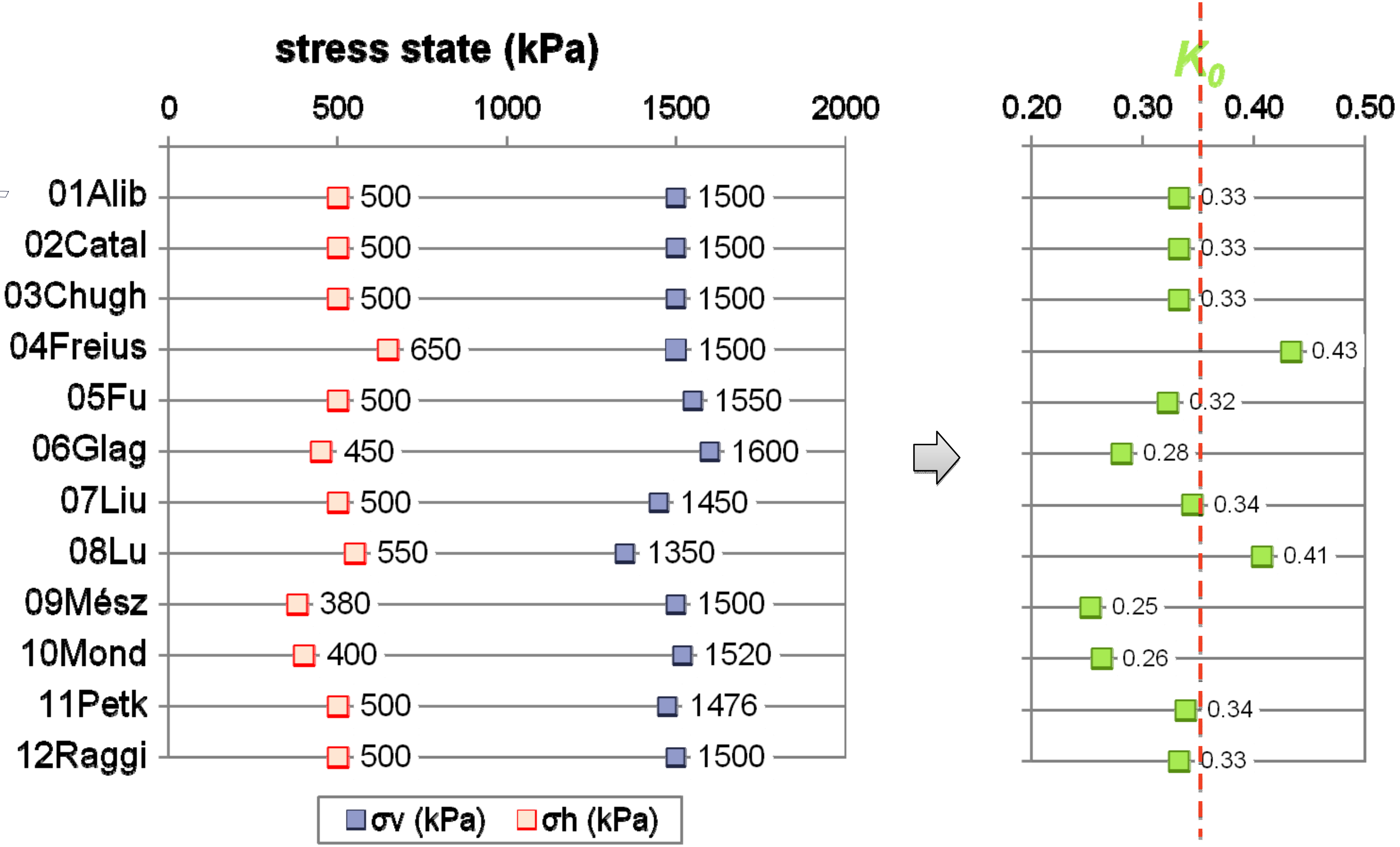
Part 1 _ STATIC CONDITIONS
Stress state





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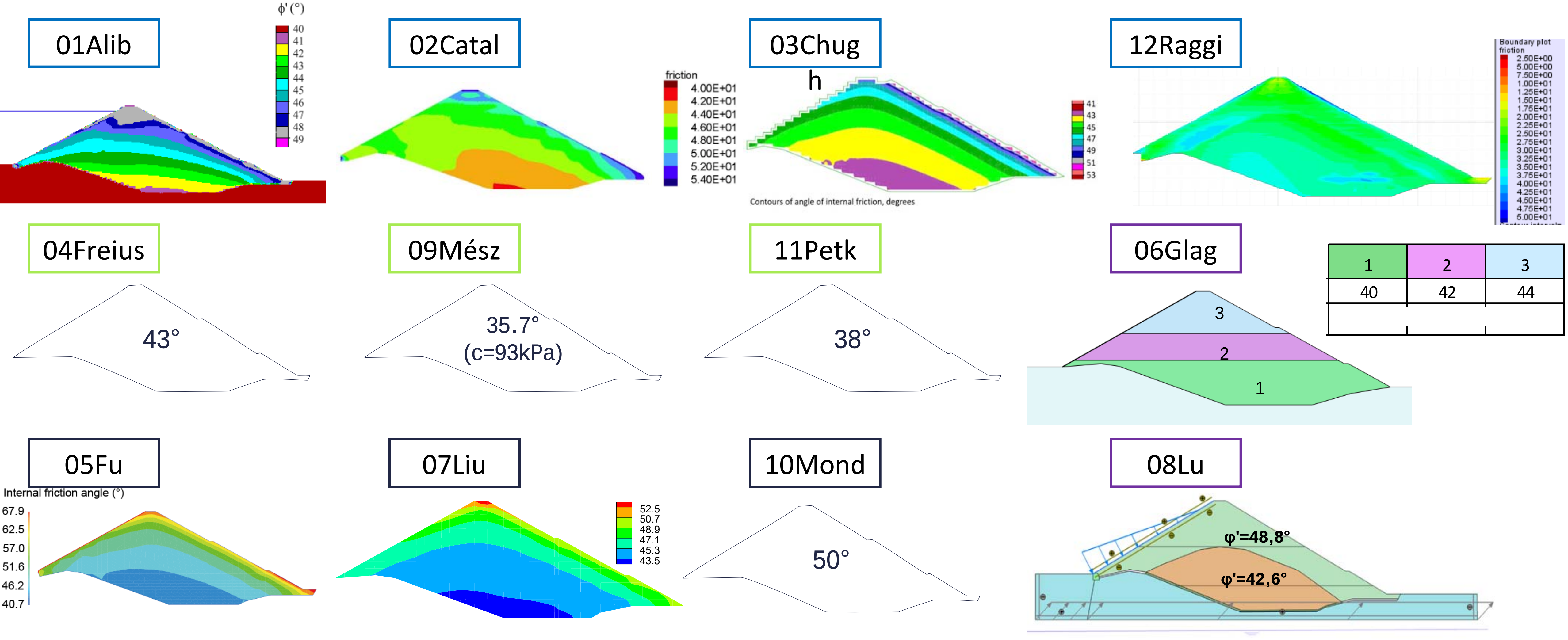
FLAC | SIGMA/W | PLAXIS | OWN FEM CODE

Part 1 _ STATIC CONDITIONS
Friction Angle (°)



1	2	3
40	42	44

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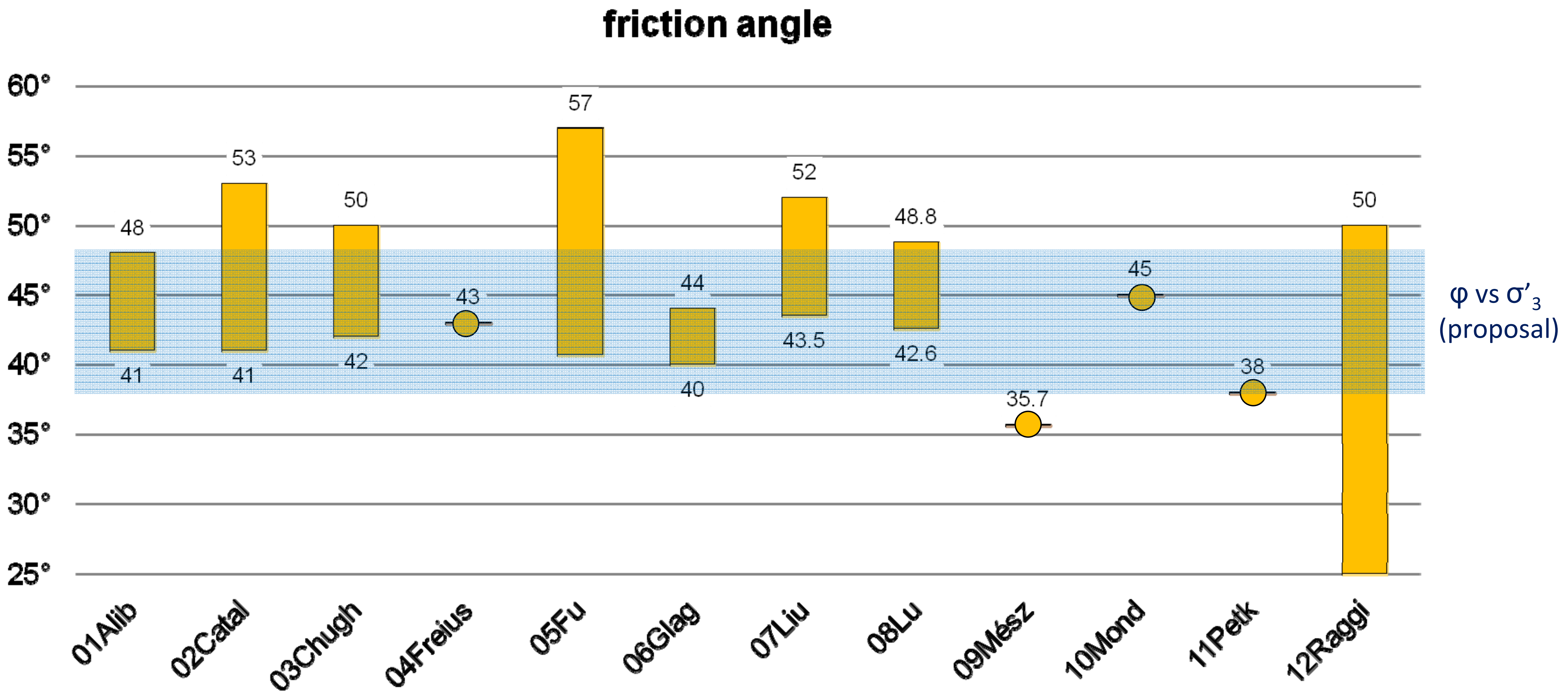
Part 1 _ STATIC CONDITIONS
Friction Angle (°)



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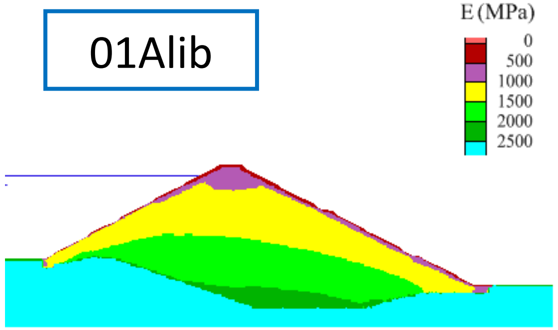
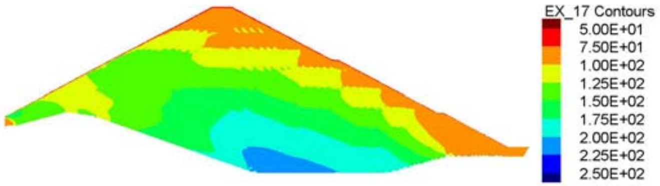
Part 1 _ STATIC CONDITIONS
Initial Young modulus (MPa)

FLAC | SIGMA/W | PLAXIS | OWN FEM CODE

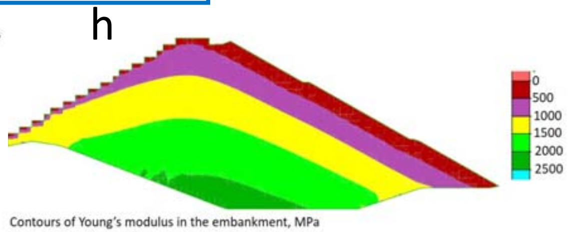
01Alib



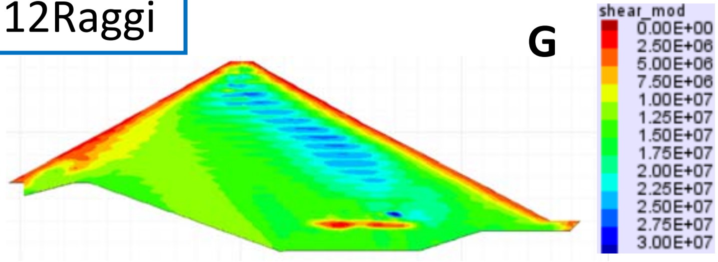
02Catal



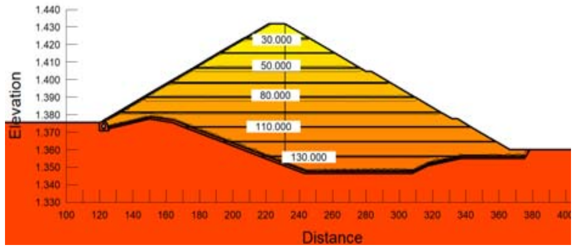
03Chug



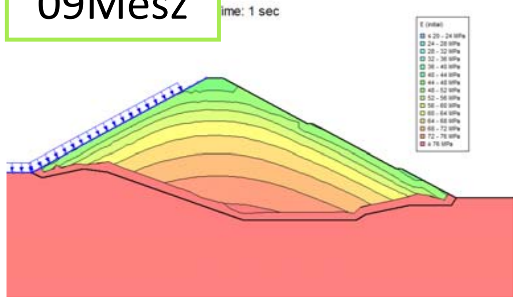
12Raggi



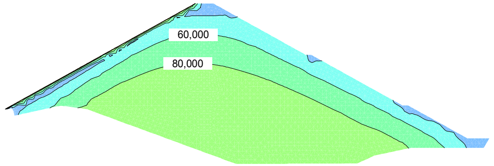
04Freius



09Mész

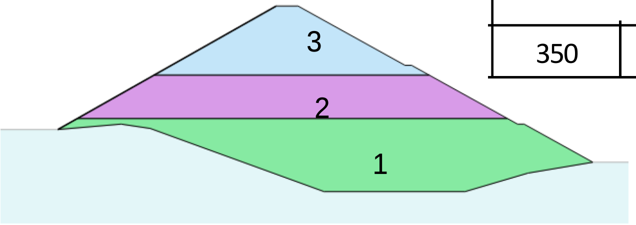


11Petk



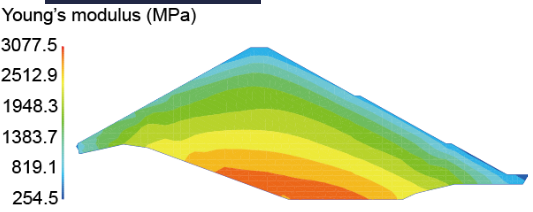
E ≤ 150,000.0 kPa

06Glag

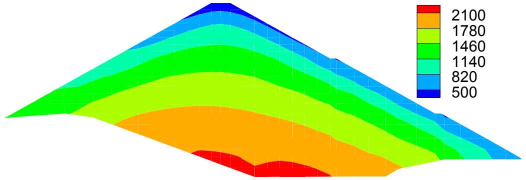


1	2	3
350	300	250

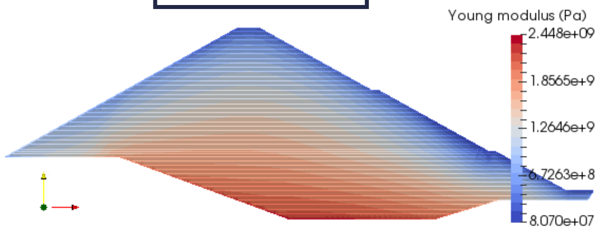
05Fu



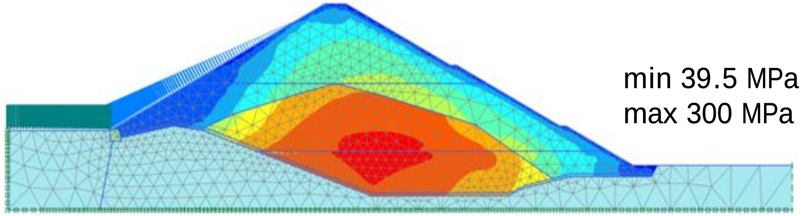
07Liu



10Mond



08Lu



min 39.5 MPa
max 300 MPa (?)

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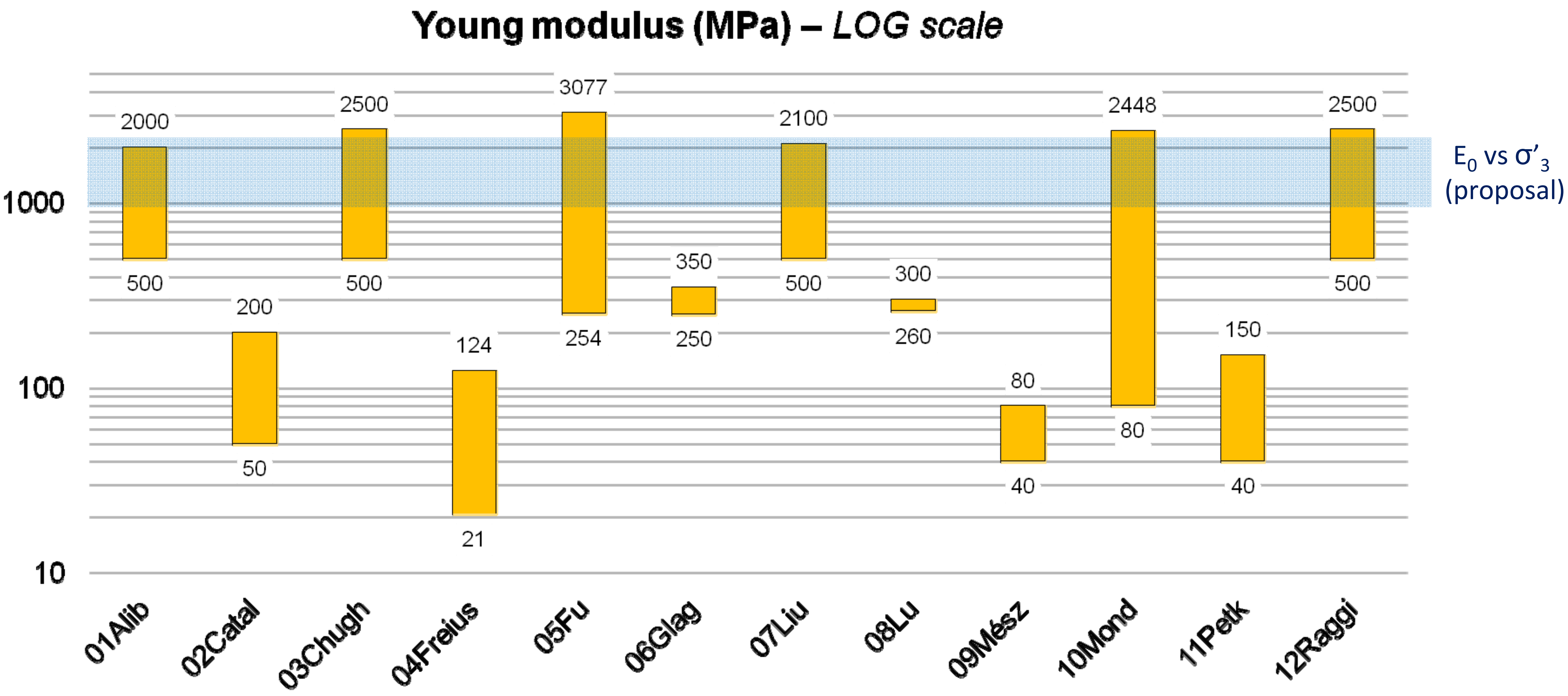
Part 1 _ STATIC CONDITIONS
Initial Young modulus (MPa)



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Part 2 _ Fundamental frequency

Natural frequency (eigenfrequency, *f*), is the frequency at which a system tends to oscillate in the absence of any driving or damping force.

The lower natural frequency contribute more to the total response of the system: comparing *f* with the external force frequency content can be an indicator for envisaging larger deformation/amplification phenomena.

Participants 01, 02, 03, 06, 07, 10, 12 provided evaluation of *f* by modeling the dam as undamped system (EQK-independent)

In general, *f* (**empty** reservoir) **<** *f* (**full** reservoir) --- the system responds more **rigidly**

Participants 04, 05, 08, 09, 11 provided an ex-post evaluation of *f* through crest/base ratio of signal recording spectra (EQK-dependent)

Different fundament frequency is observed for the two inputs.
This is due to dependence of stiffness and damping on the strain amplitude

Reservoir effect varies from case to case

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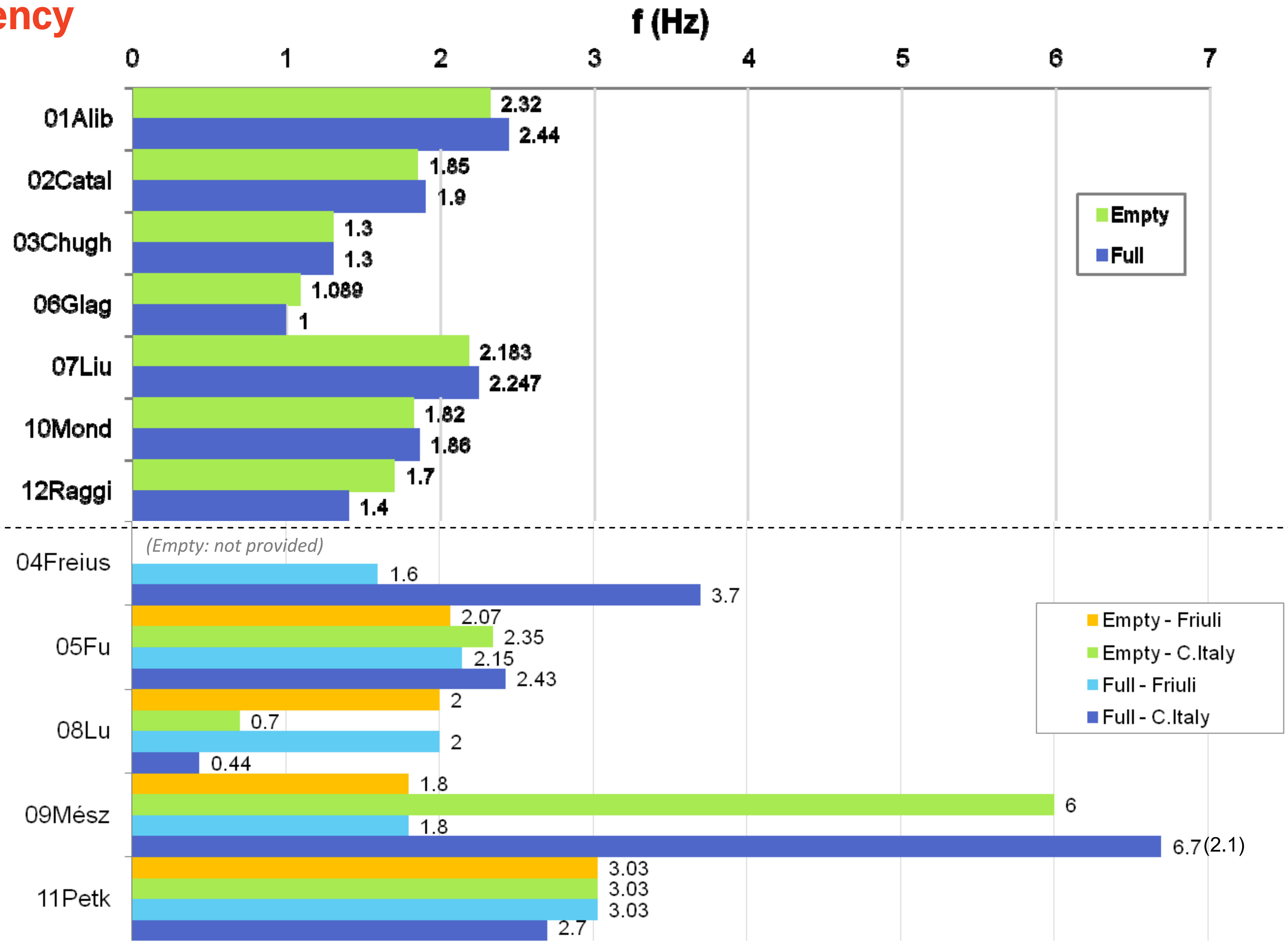
Part 2 _ Fundamental frequency

EQK-independent

EQK-dependent



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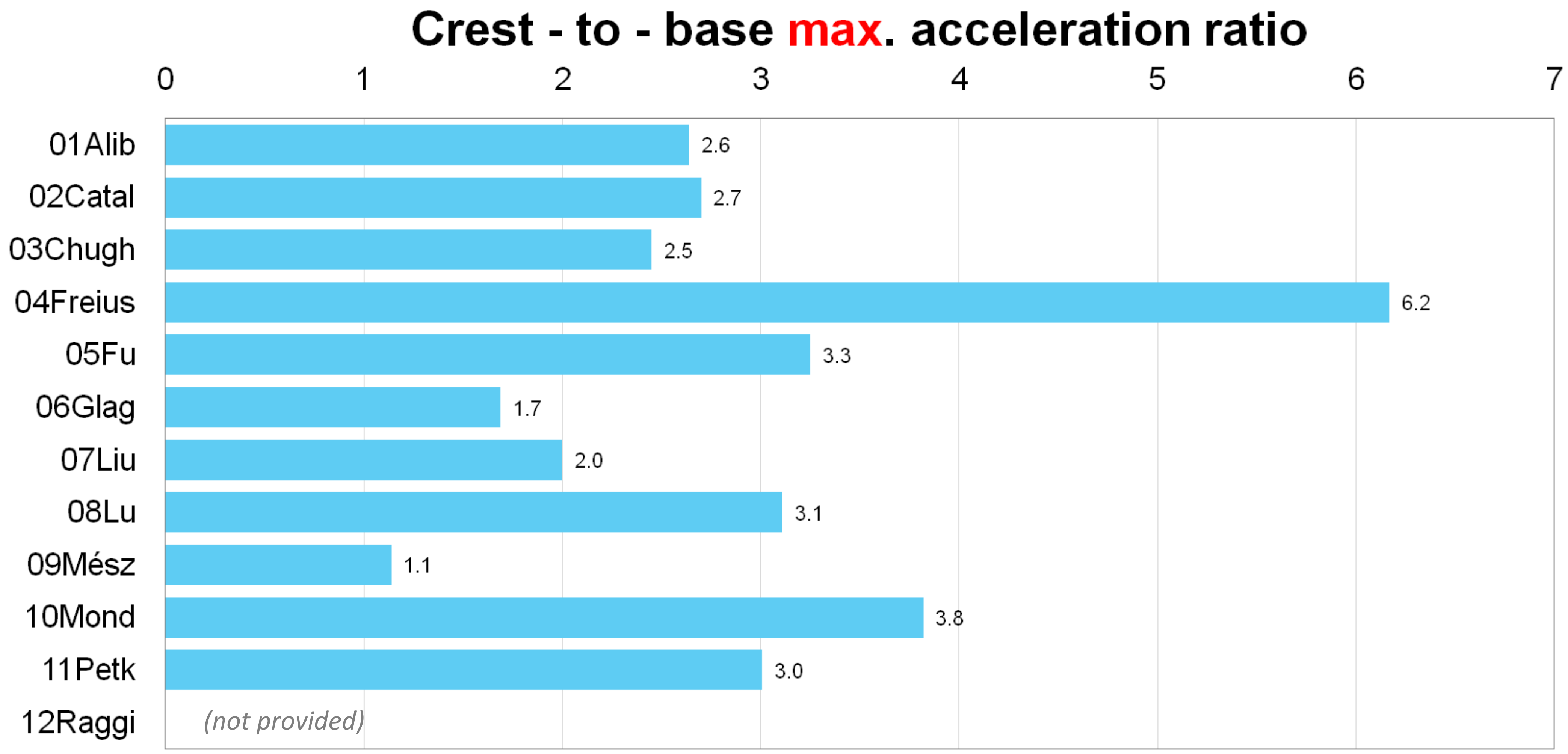
Part 2 _ Seismic Behaviour under 0.26g EQKs
Crest - to base max. acceleration ratio (H)



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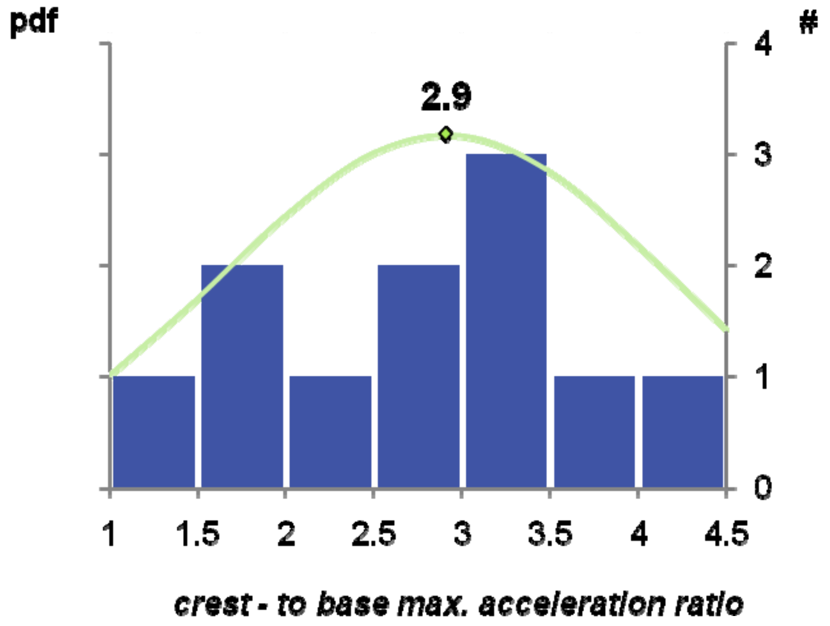
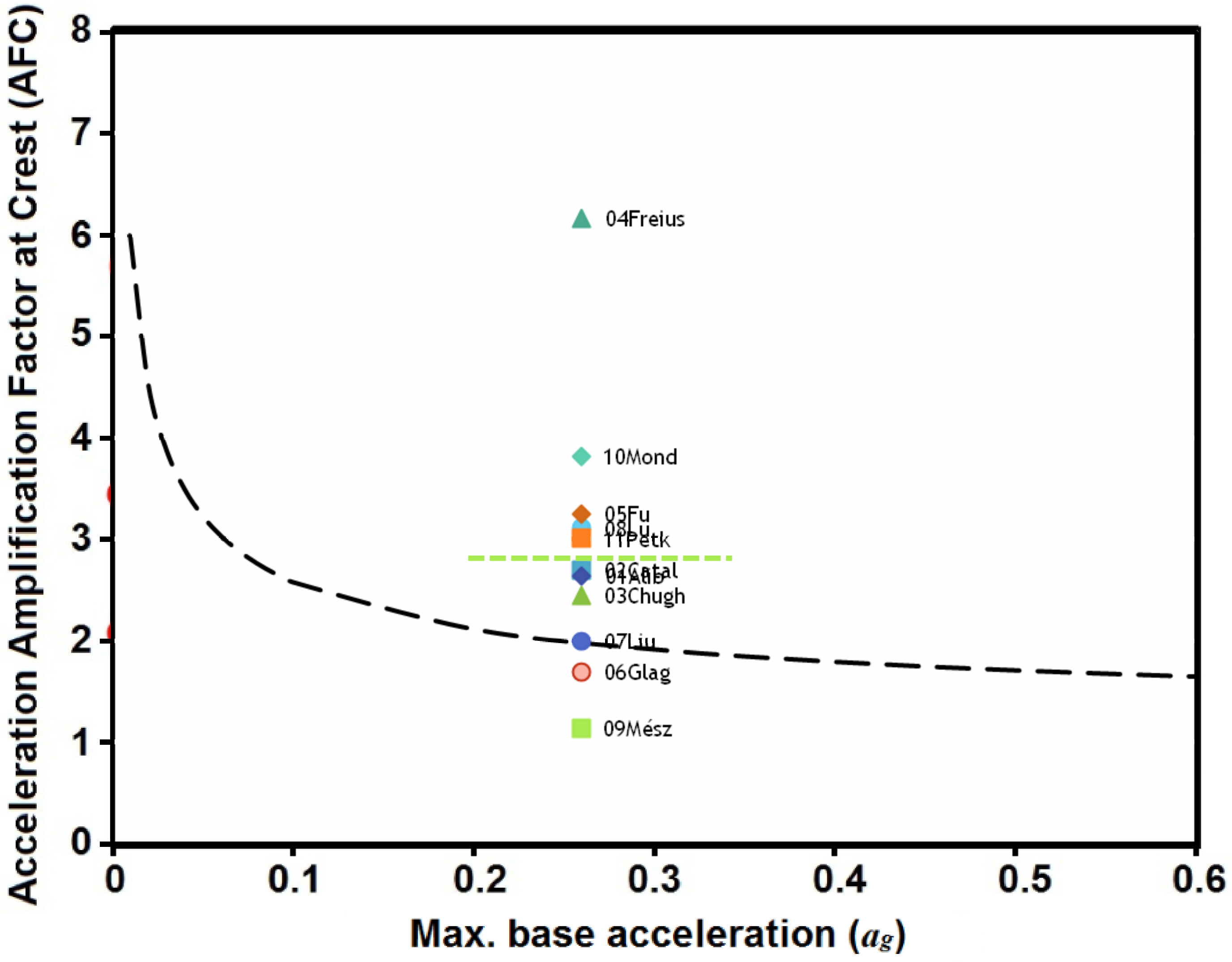
Part 2 _ Seismic Behaviour under 0.26g EQKs
Crest - to base max. acceleration ratio (H)
BENCHMARKING

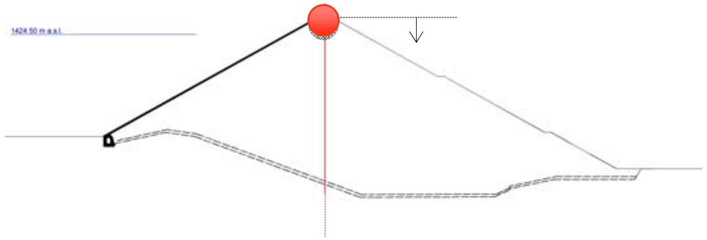
You et al. (2012)

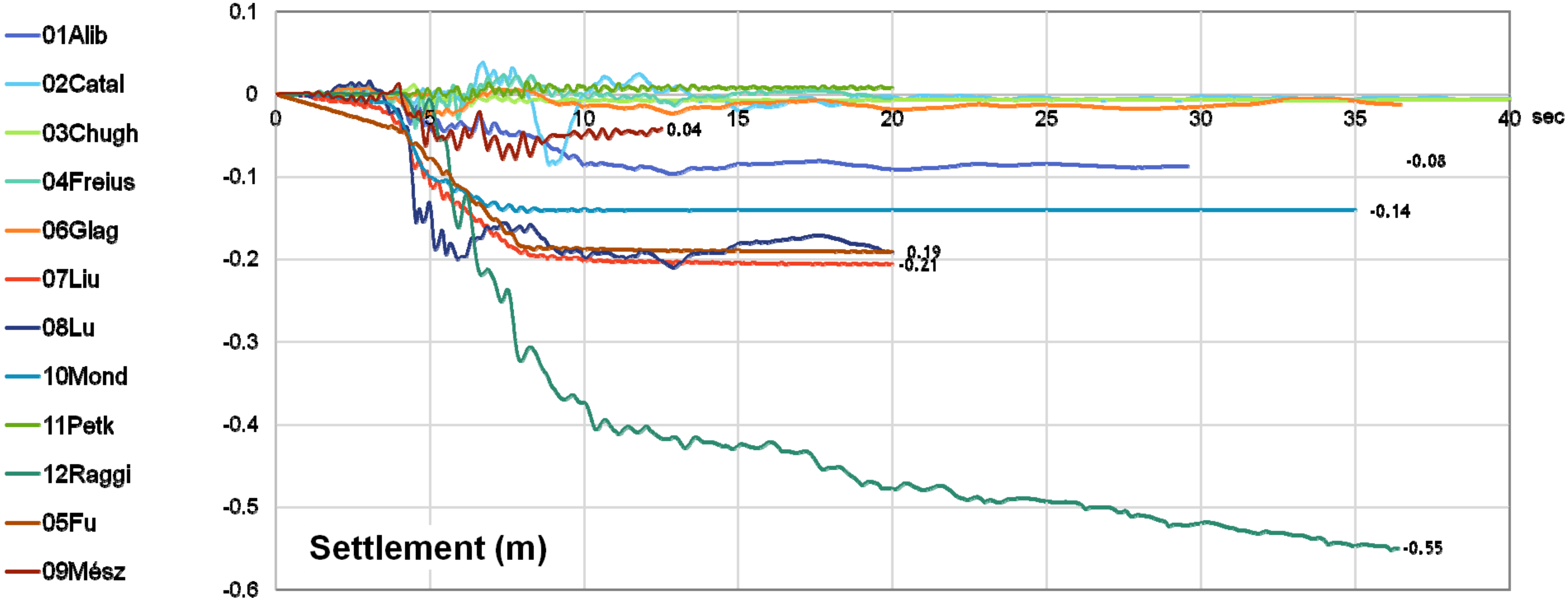




Yu L, X. Kong X, Xu B (2012). "Seismic Response Characteristics of Earth and Rockfill Dams". *Proceedings 15th World Conference on Earthquake Engineering*, 24- 28 September, Lisboa (Portugal).

Part 2 _ Seismic Behaviour under 0.26g EQKs
Time series
Crest settlements (m)





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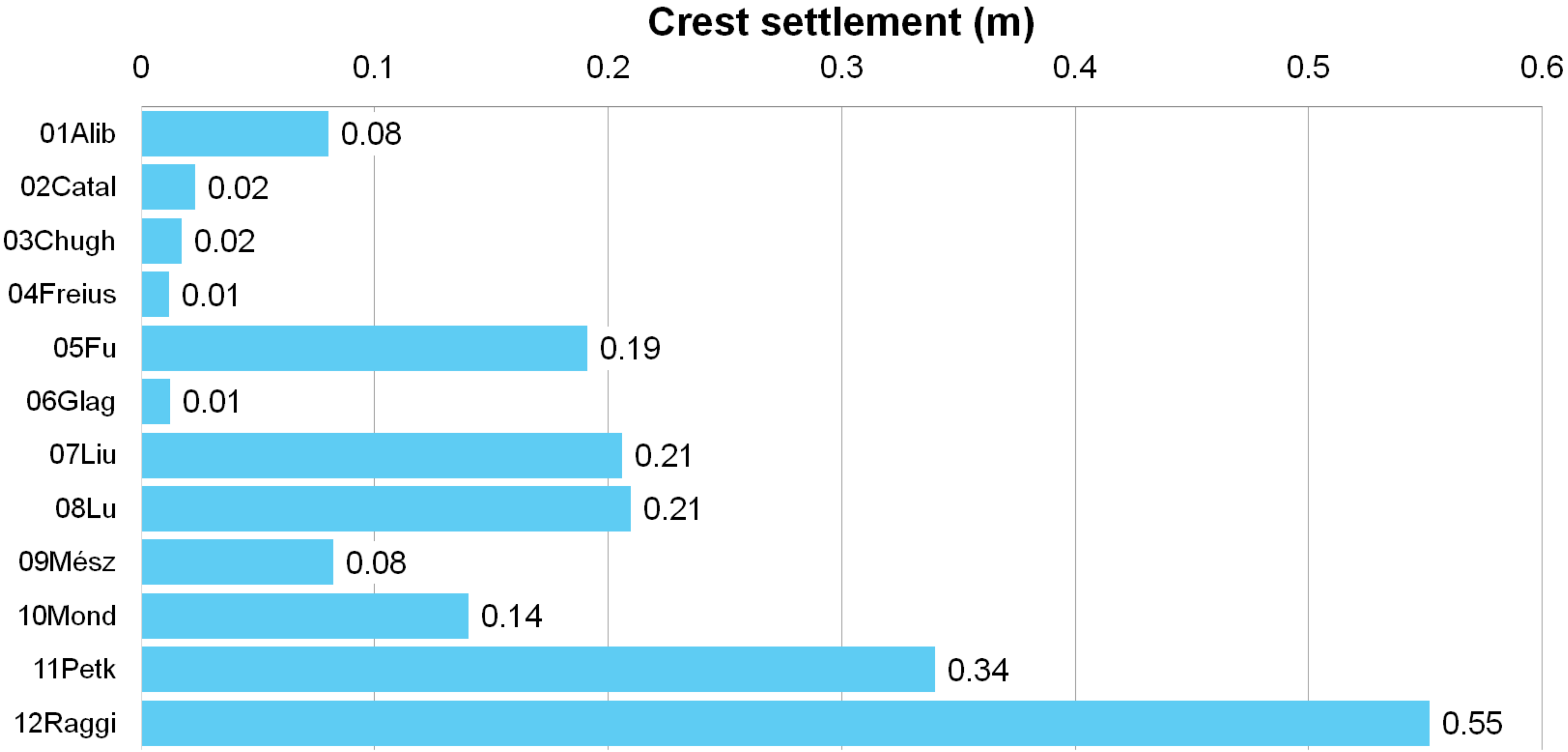
Part 2 _ Seismic Behaviour under 0.26g EQKs
Crest settlements (m)



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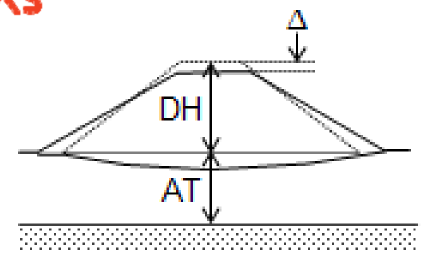
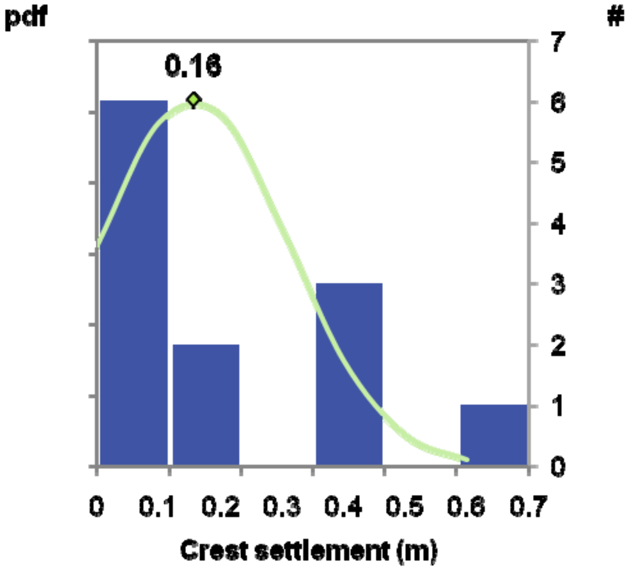
Part 2 _ Seismic Behaviour under 0.26g EQKs
Crest settlements (m)
BENCHMARKING

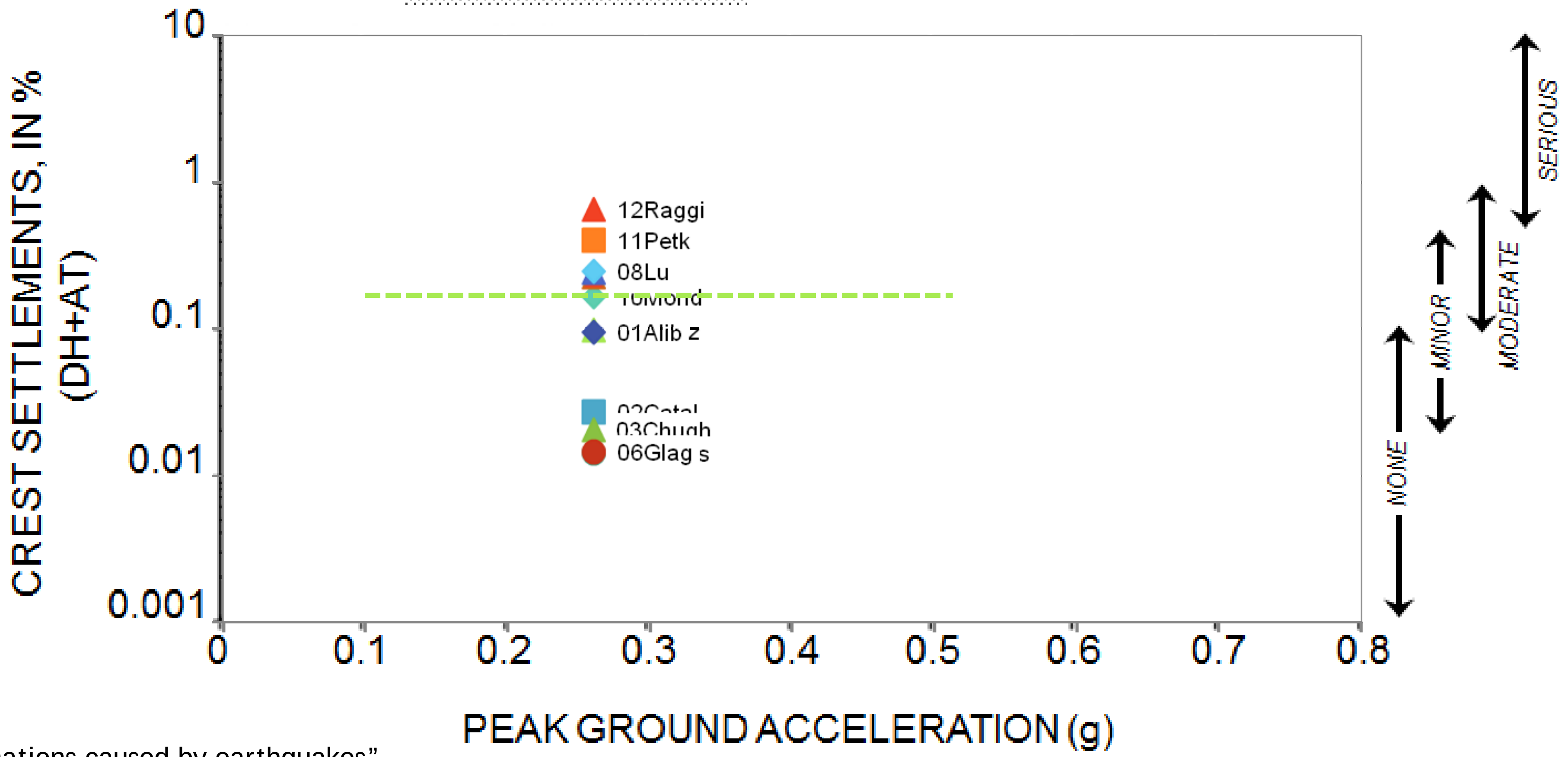
Swaisgood (2003)



$$\% \text{ STTLMT} = \frac{\Delta}{DH + AT} \times 100$$



Crest settlement / *H* = 0.17%
(*H* ≈ 84m)



Swaisgood JR (2003). "Embankment dam deformations caused by earthquakes". *Proceedings 7th Pacific Conference on Earthquake Engineering*, 13-15 February, Christchurch (New Zeland).

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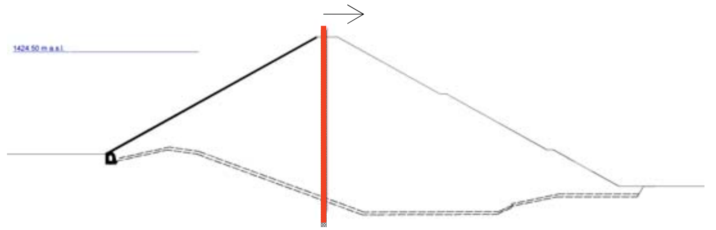
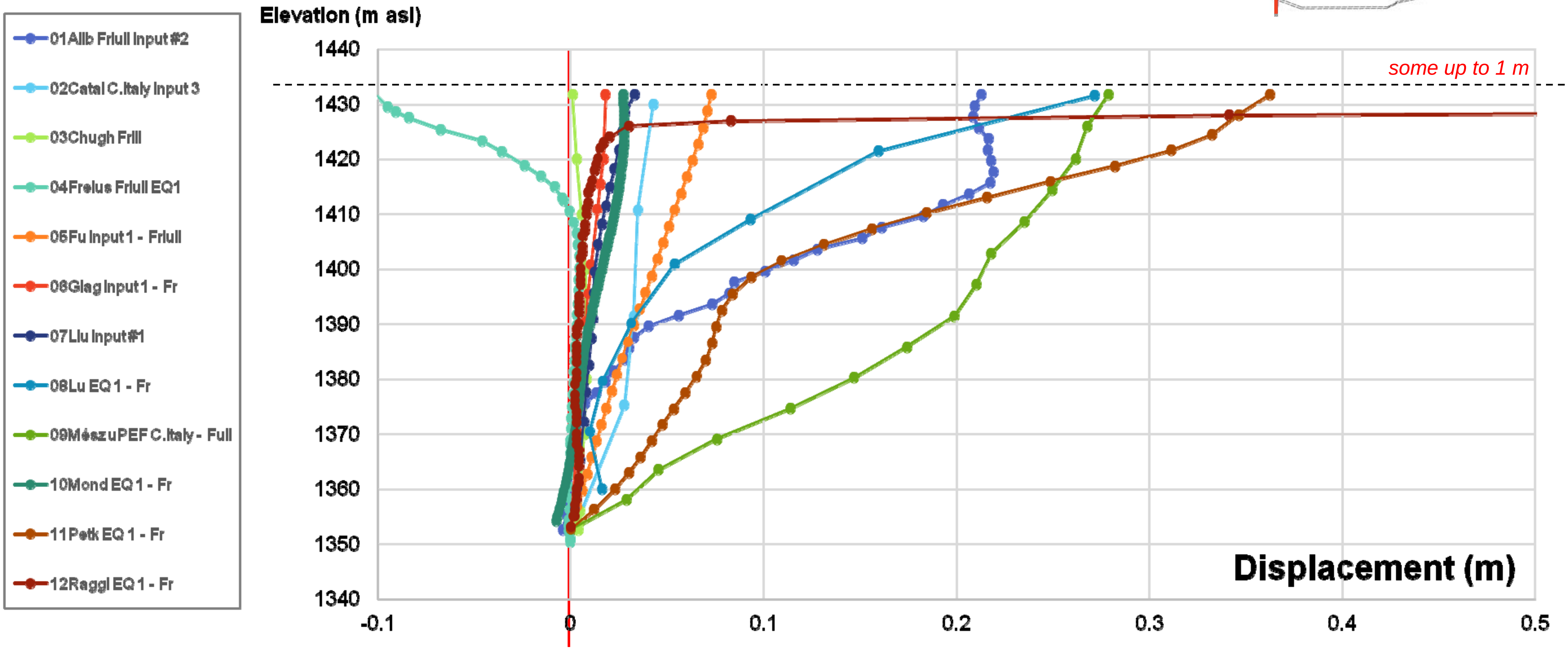
Department of Engineering, University of Perugia

Part 2 _ Post-seismic conditions
Horiz. Displacement of the central axis





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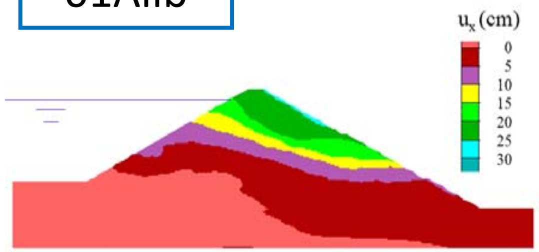
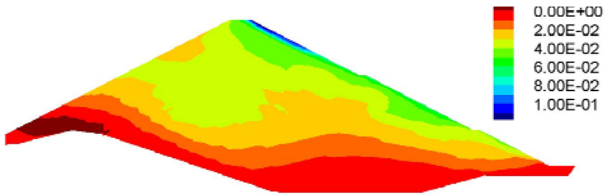
Part 2 _ Post-seismic conditions
Horizontal displacements (m)
Friuli EQK.

FLAC | SIGMA/W | PLAXIS | OWN FEM CODE

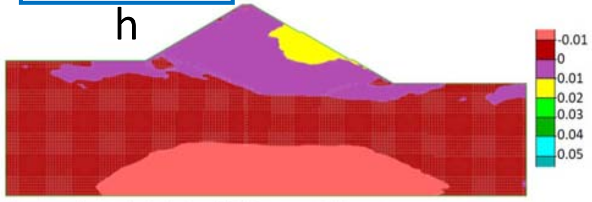
01Alib



02Catal

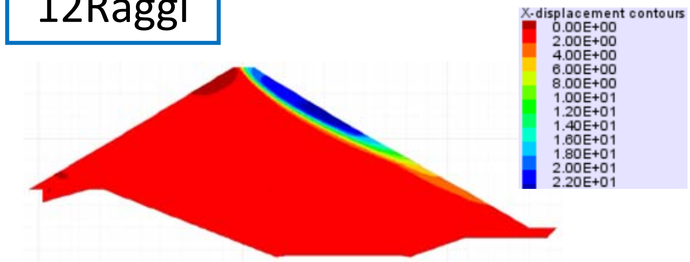


03Chug
h

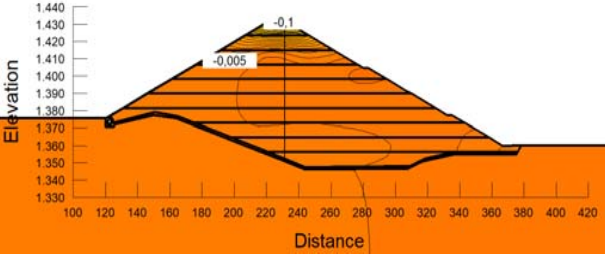


Contours of post-seismic horizontal displacements, Friuli event, m

12Raggi



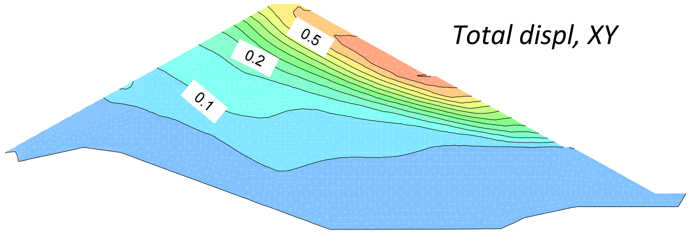
04Freius



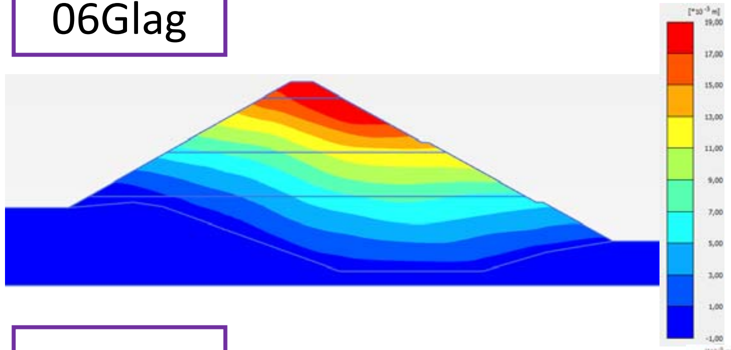
09Mész

(not provided)

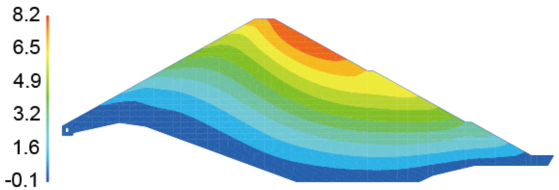
11Petk



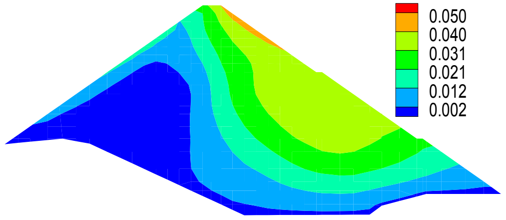
06Glag



05Fu

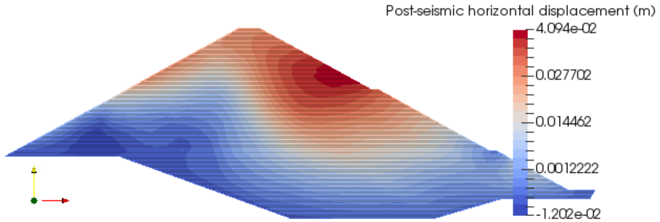


07Liu

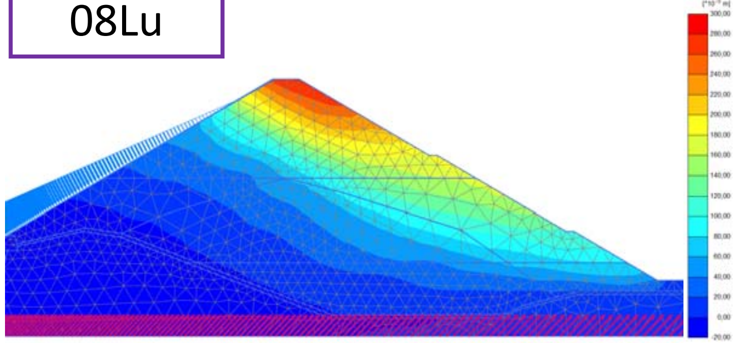


1# post-seismic horizontal displacement (Unit: m)

10Mond



08Lu



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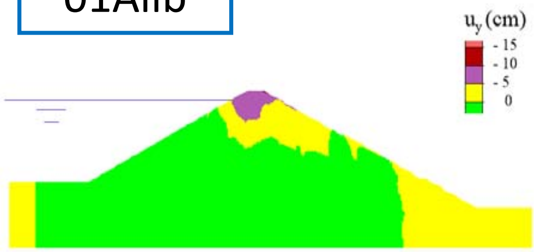
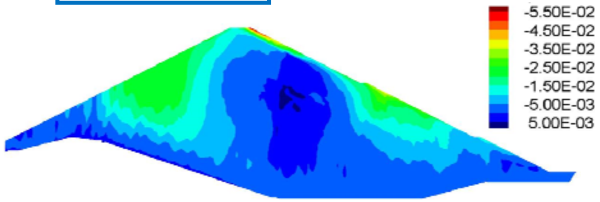
Part 2 _ Post-seismic conditions
Settlements (m)
Friuli EQK.

FLAC | SIGMA/W | PLAXIS | OWN FEM CODE

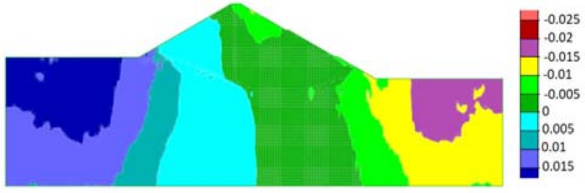
01Alib



02Catal

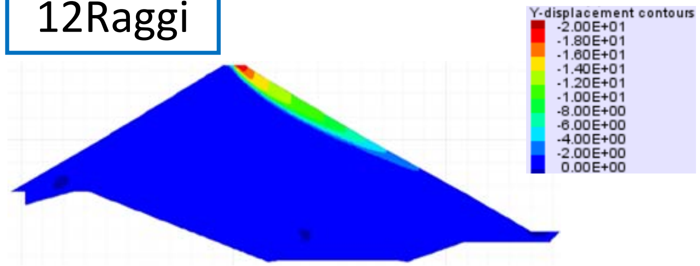


03Chug

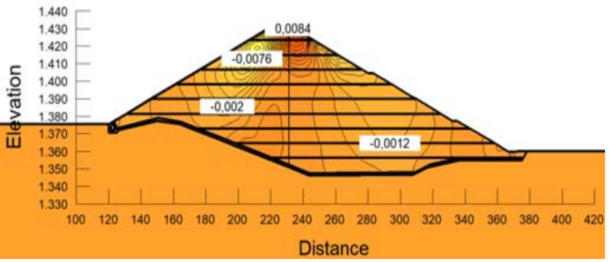


Contours of post-seismic vertical displacements, Friuli event, m

12Raggi



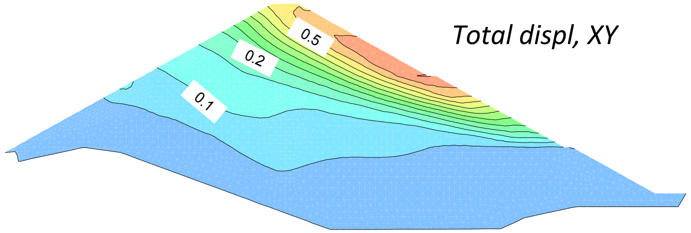
04Freius



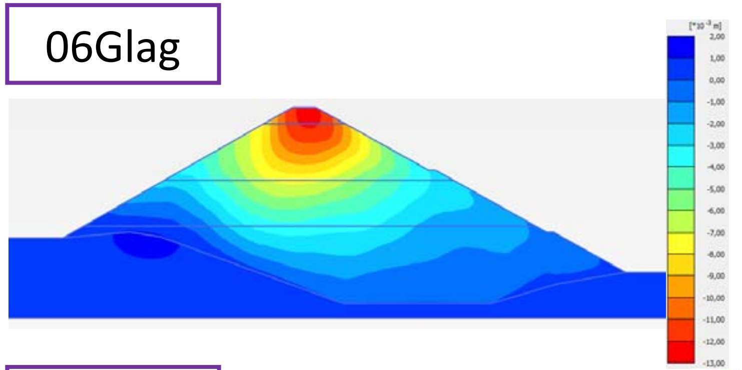
09Mész

(not provided)

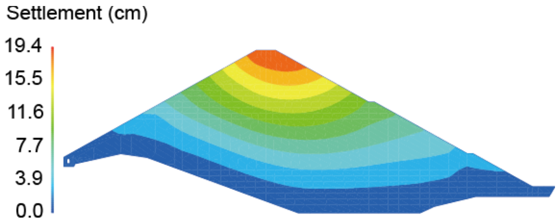
11Petk



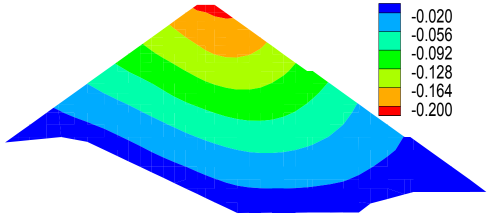
06Glag



05Fu

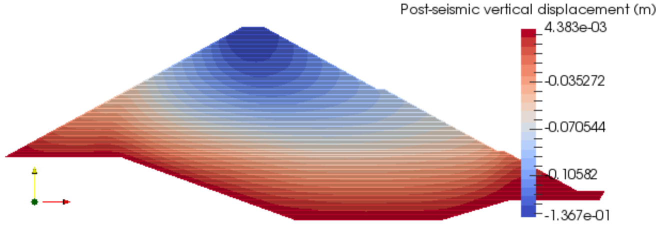


07Liu

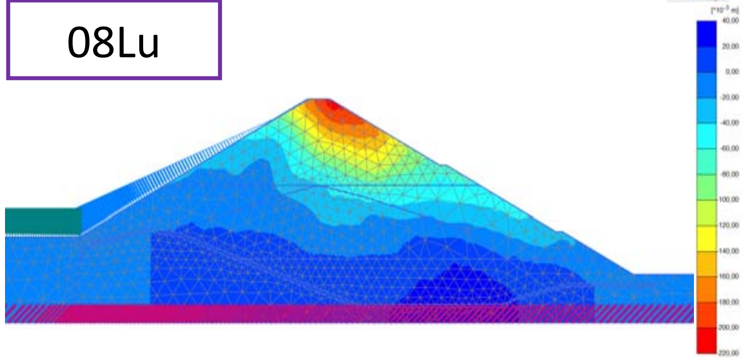


1# post-seismic vertical displacement (Unit: m)

10Mond



08Lu



ICOLD-BW 9th-11th September 2019 MILANO
Numerical analysis of dams

Alessia Vecchietti
Department of Engineering, University of Perugia

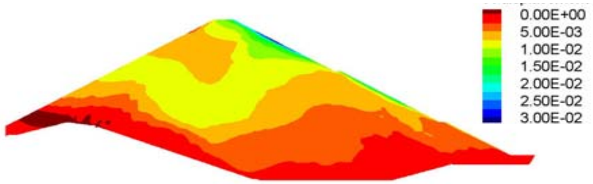
Part 2 _ Post-seismic conditions
Horizontal displacements (m)
C.Italy EQK.

FLAC | SIGMA/W | PLAXIS | OWN FEM CODE

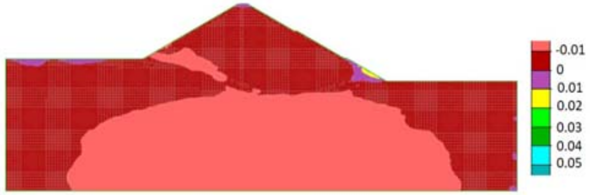
01Alib

(not provided)

02Catal

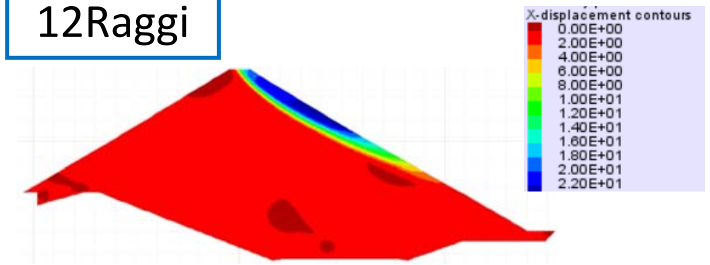


03Chug

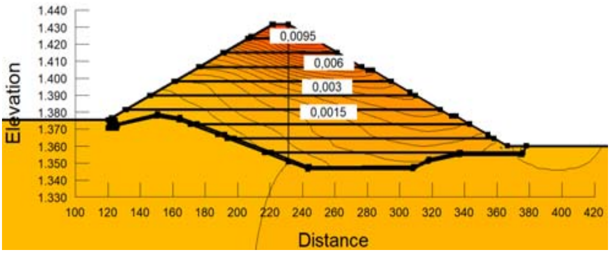


Contours of post-seismic horizontal displacements, Central-Italy event, m

12Raggi



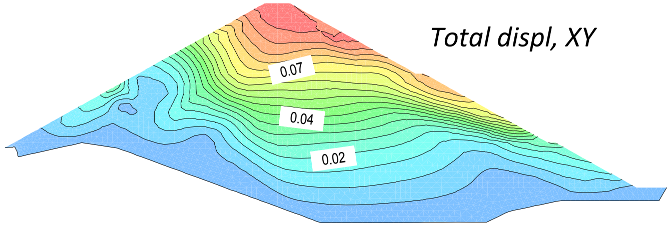
04Freius



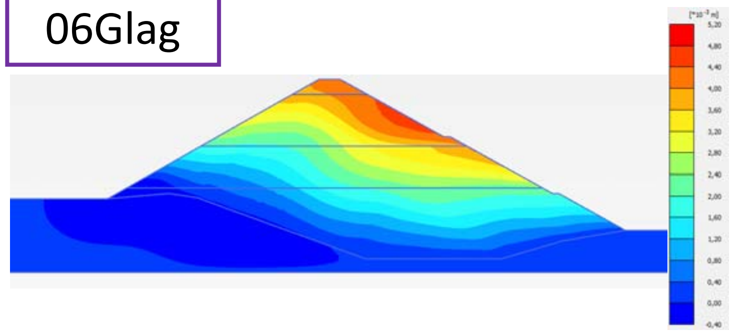
09Mész

(not provided)

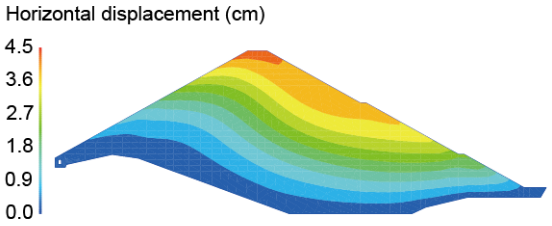
11Petk



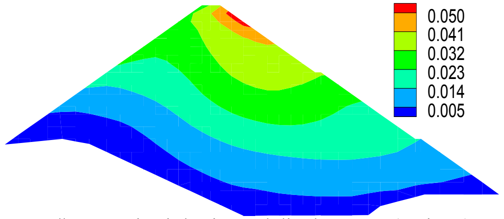
06Glag



05Fu

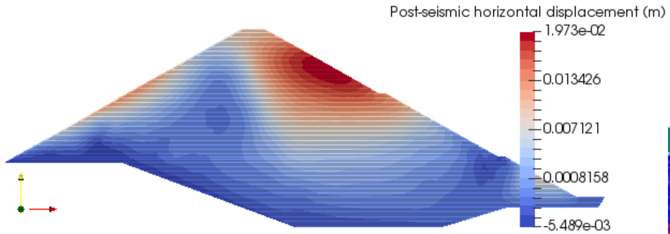


07Liu

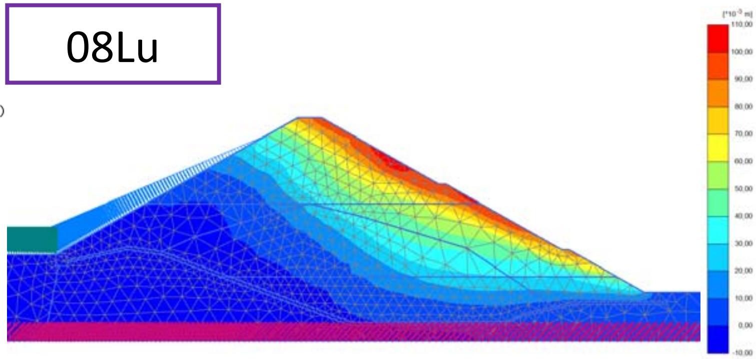


2# post-seismic horizontal displacement (Unit: m)

10Mond



08Lu



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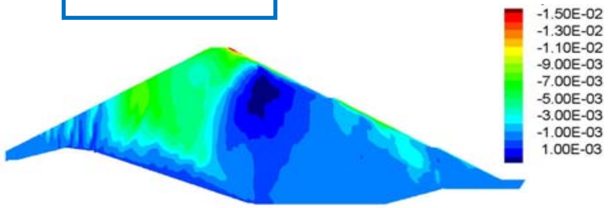
Part 2 _ Post-seismic conditions
Settlements (m)
C.Italy EQK.

FLAC | SIGMA/W | PLAXIS | OWN FEM CODE

01Alib

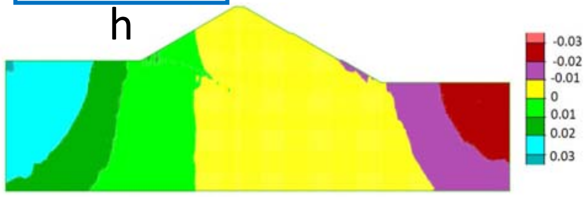
(not provided)

02Catal



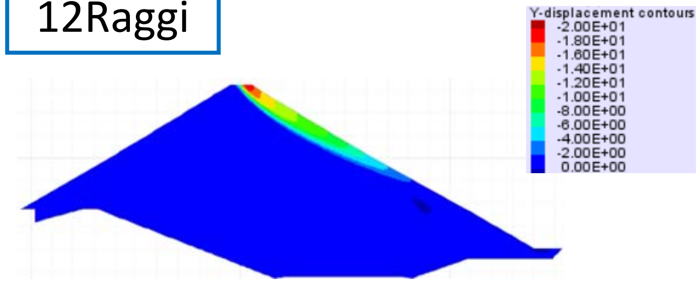
03Chug

h

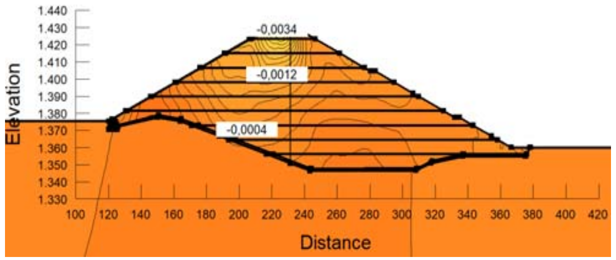


Contours of post-seismic vertical displacements, Central-Italy event, m

12Raggi



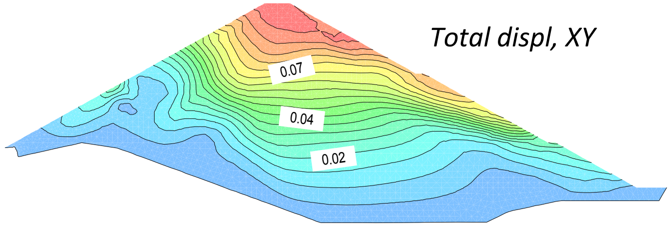
04Freius



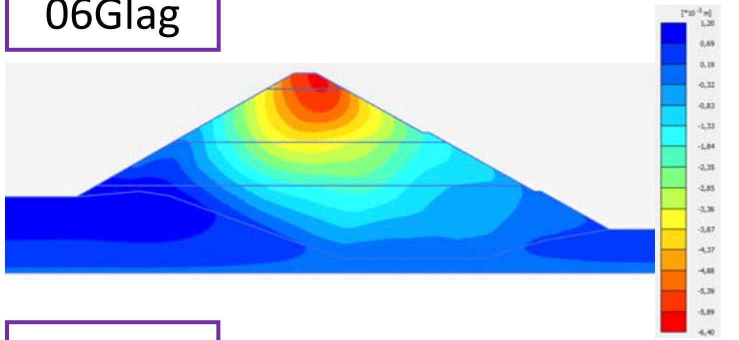
09Mész

(not provided)

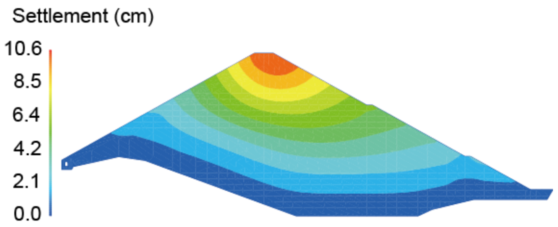
11Petk



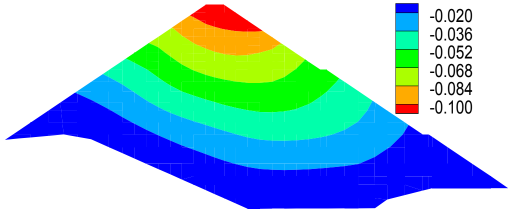
06Glag



05Fu

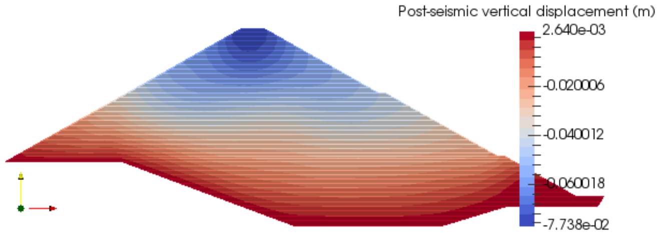


07Liu

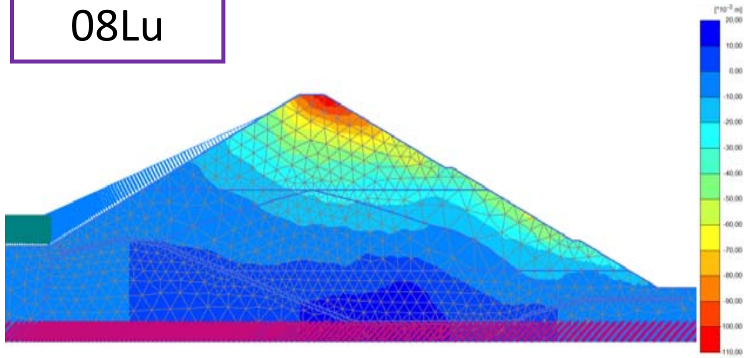


2# post-seismic vertical displacement (Unit: m)

10Mond



08Lu



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FLAC | SIGMA/W | PLAXIS | OWN FEM CODE

Part 2 _ Post-seismic conditions
Post-seismic displacements: a summary

(from contour plots)	Post-seismic horizontal displacements	Post-seismic settlements	Maximum strains
01Alib	31 cm	13.5 cm	1%
02Catal	3 cm in general, up to 10 cm localized on top d/s slope	2 cm in general, up to 5.5 cm localized on top d/s slope	up to 0.45% localized on the d/s slope
03Chugh	+/- 2 cm		0.05% (locally 0.15%)
04Freius	<10 cm	< 1 cm	0.43%
05Fu	8 cm	19 cm	0.04%
06Glag	2 cm	1.2 cm	-
07Liu	50 cm	20 cm	0.40%
08Lu	37 cm	21 cm	1.30%
09Mész	up to 1 m in h-direction		-
10Mond	3 cm	14 cm	0.30%
11Petk	36 cm	34 cm	1.3% (in the facing)
12Raggi	40 cm *(except local failure)*		1e3 (@ FAILURE SURFACE)

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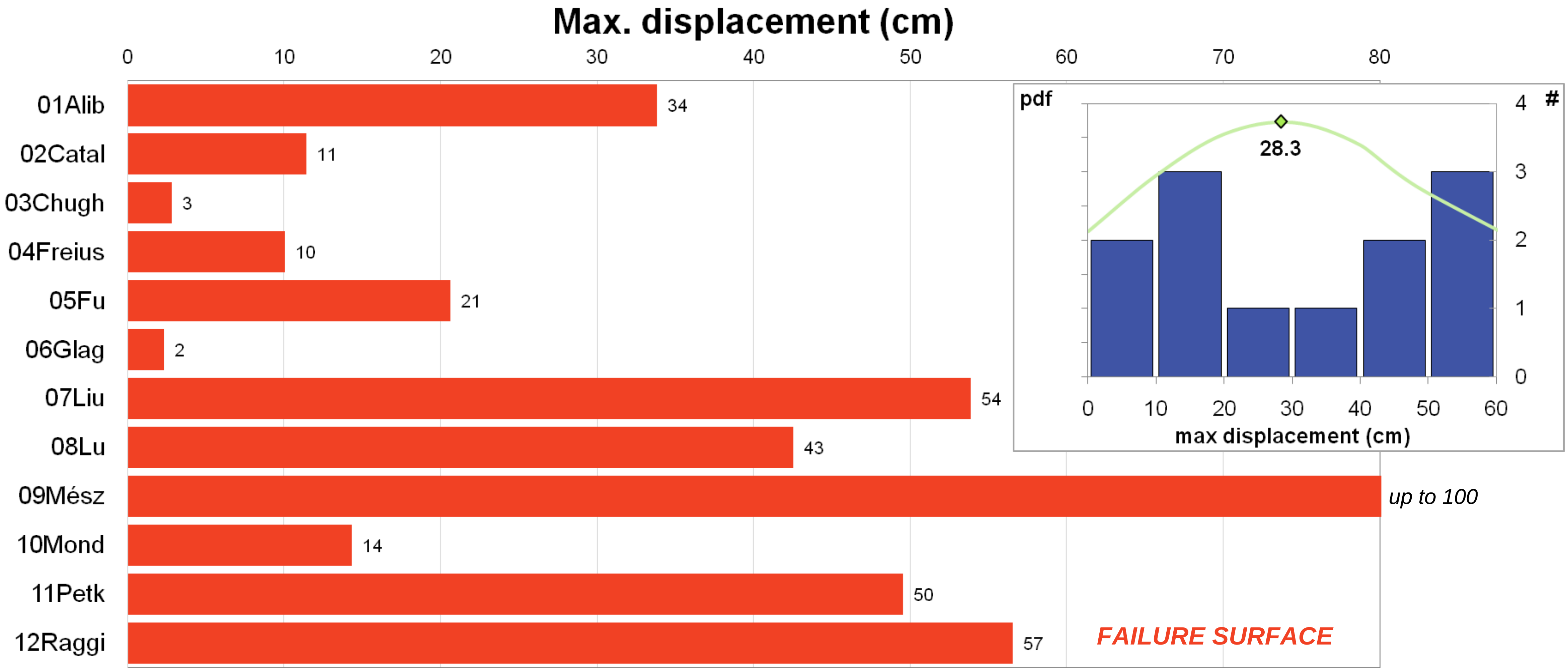
Part 2 _ Post-seismic conditions
Post-seismic displacements: a summary



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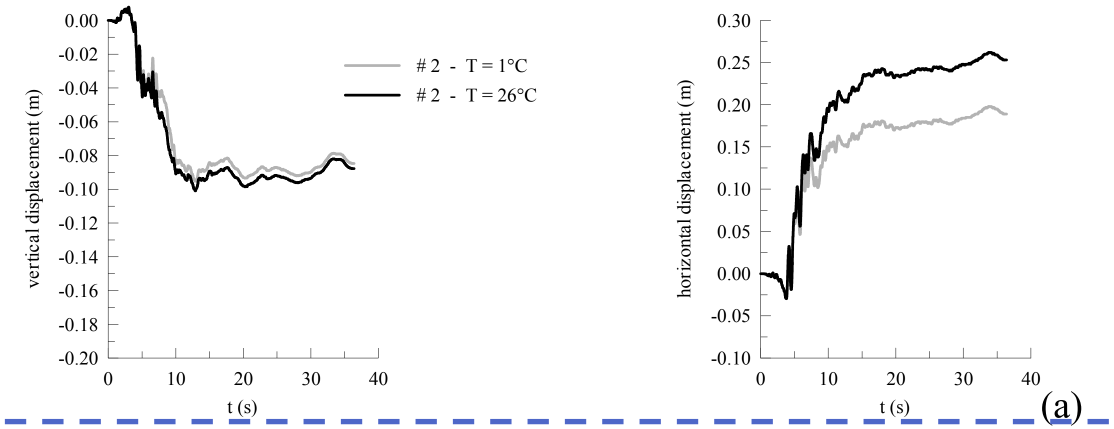
Part 3 (Optional) _ Bituminous facing analyses

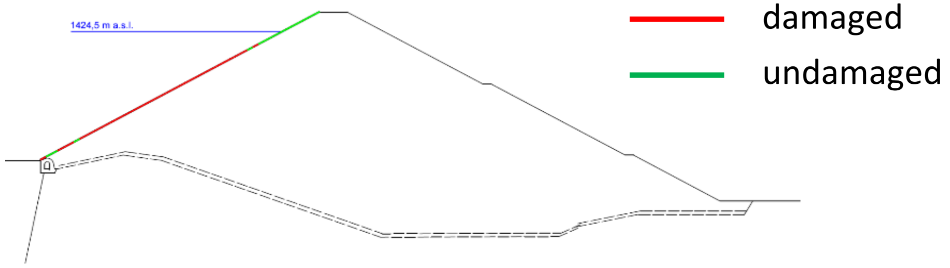
01Alib

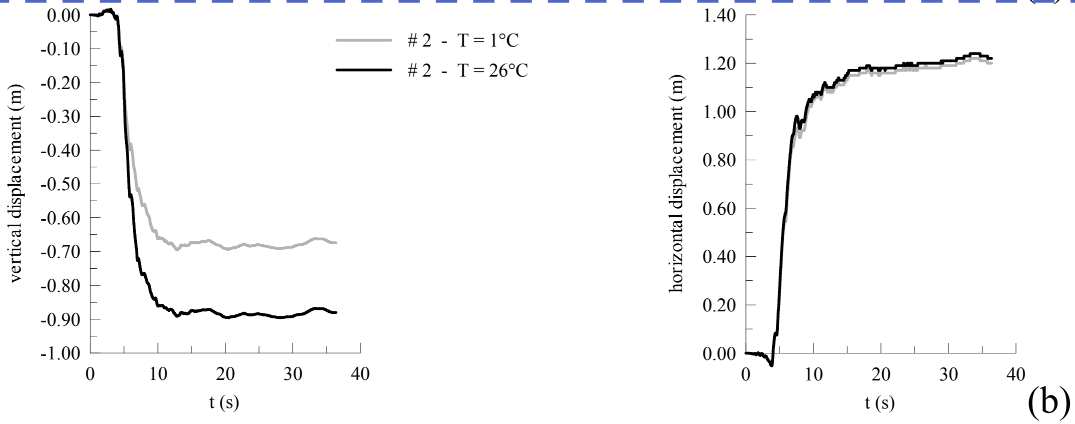
Analyses considered *T*=1°C and *T*=26°C and Friuli 1976 HNE (most severe EQK)
A stiffer facing contributes in reducing the final horizontal displacement.

Permanent displacements seem acceptable in both cases



Analyses for CLS input motion (0.454g)





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Part 3 (Optional) _ Bituminous facing analyses

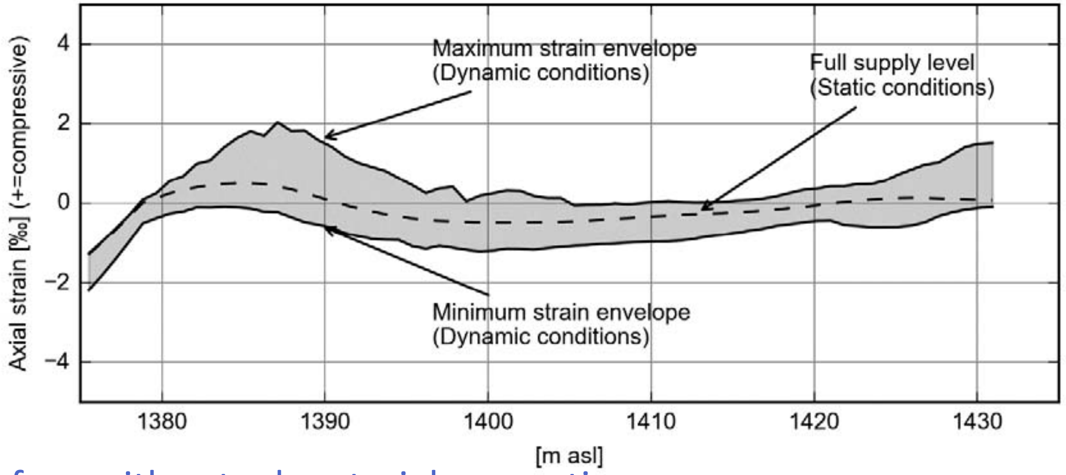
02Catal

Conservative analysis (glued membrane not resisting to bending moments) and analysis with actual properties (E = 14 GPa, interface with a friction angle of 32°).

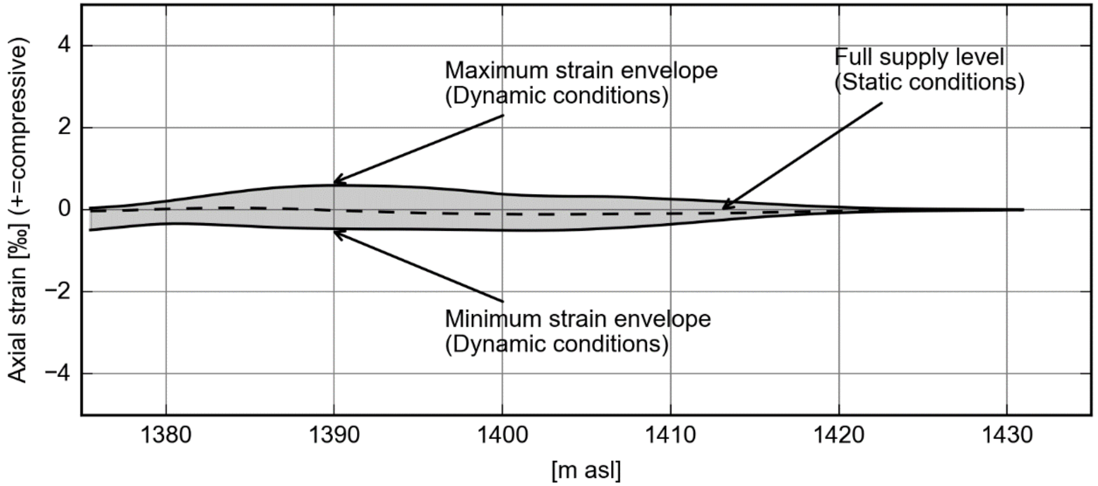
Assessment conducted checking asphalt face tensile capacity vs. strain rate and temperature according to Ishii & Kamijo (1988) "Design for asphaltic concrete facing of Sabigawa upper dam"

The safety of the asphalt facing can be guaranteed.

asphalt glued to the dam (conservative):



asphalt face with actual material properties:



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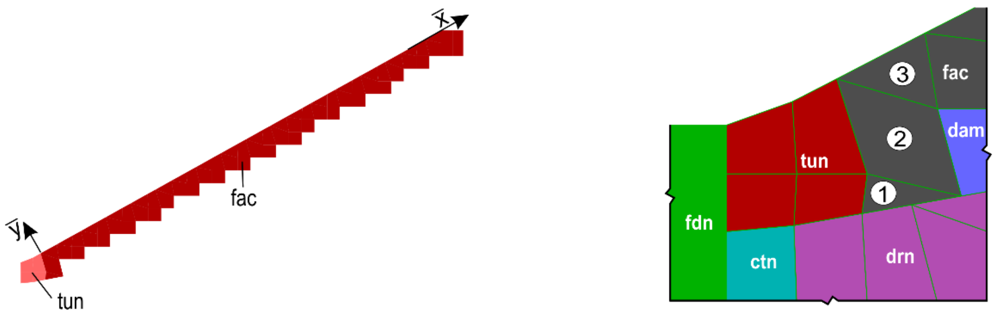
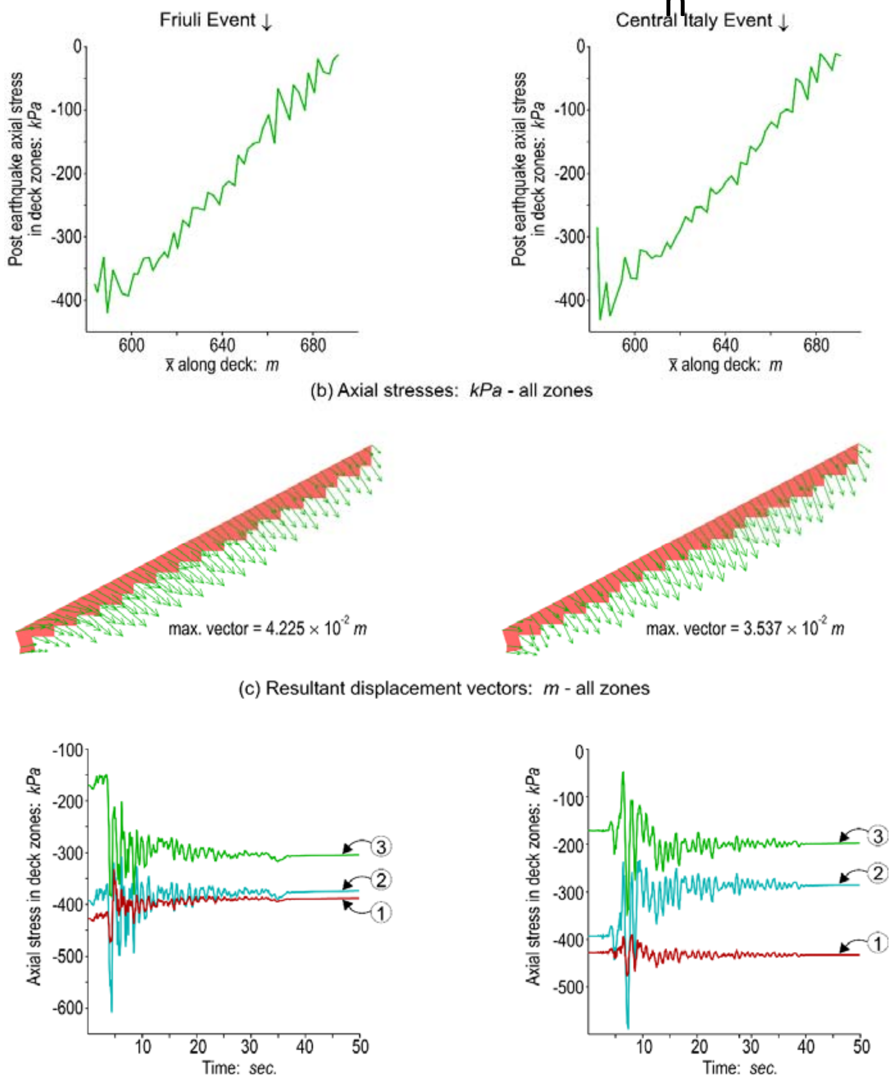
Part 3 (Optional) _ Bituminous facing analyses

03Chugh

For both seismic events, max. axial stresses occur in the deck occur in the zones adjacent to the drainage tunnel:



(a) Deck zones: all zones (left), select zones (right)



(b) Axial stresses: *kPa* - all zones

(c) Resultant displacement vectors: *m* - all zones

(d) Axial stress histories: *kPa* - select zones

- the **axial stresses in the deck are compressive and their magnitudes are less than the strength**
- the deck zones attached to the tunnel **do not experience axial tension** during the seismic loadings

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Part 3 (Optional) _ Bituminous facing analyses

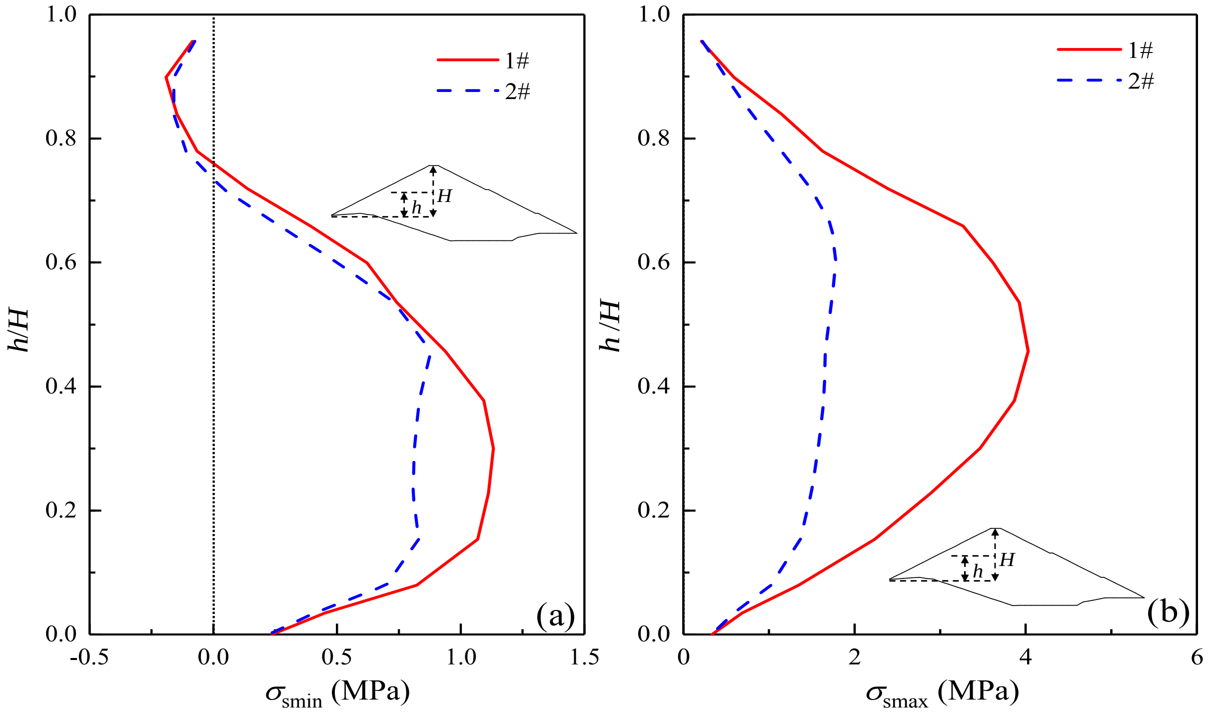
07Liu

Interface model from Liu et al 2019
Computation of min (tensile) and max (compressive) slope-direction stresses

•Min. stress occurred from 0.73 to 1.0 *H* (0.19 MPa for 1# and 0.16 MPa for 2#) < tensile strength (0.95 MPa)

•**Max. stress occurred at 0.46*H*** (4.03 MPa) for 1# and 0.60*H* (1.78 MPa) for 2# **> compressive strength** (1.49MPa)

Protective measures should be applied in compressive stress zone to improve the aseismic capability of the slab



Minimum and maximum slope-direction stress of face slab

Part 3 (Optional) _ Bituminous facing analyses

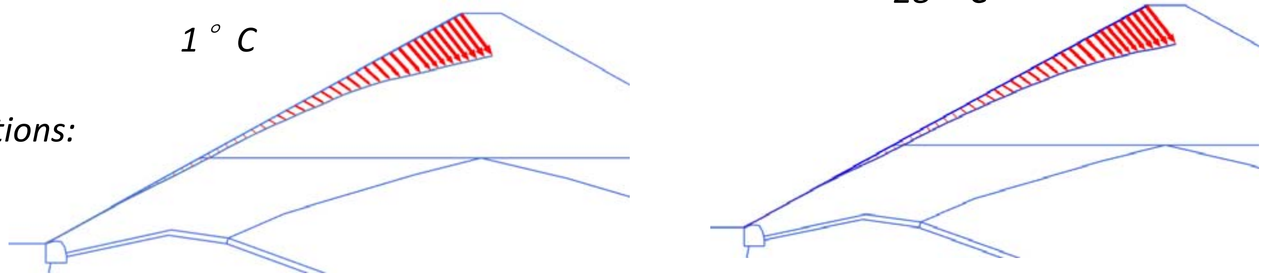
08Lu

Maximum allowed bending moment is calculated
5/6*EI suggested by Plaxis

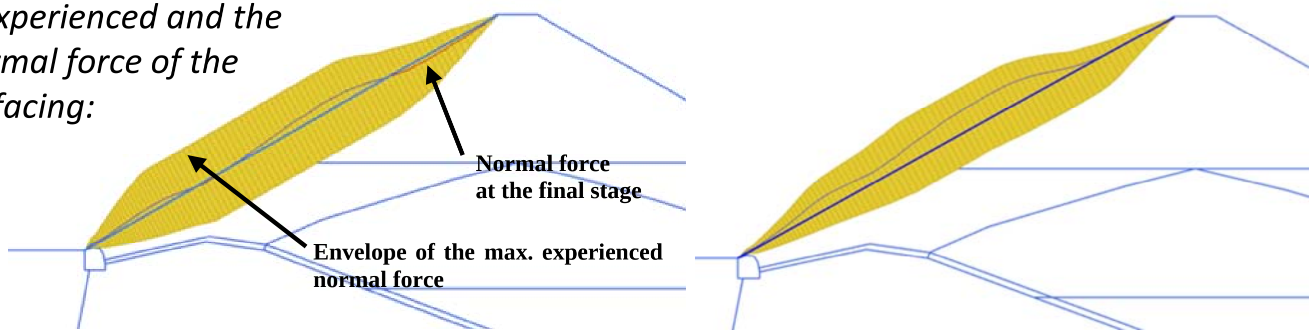
Deformations:

1 ° C

28 ° C



Maximum experienced and the last step normal force of the bituminous facing:



- at 1°C, both the tensile and compressive stress > 950 kPa over 1/2 of facing length
- at 28°C, tensile stress > capacity for 1/3 of facing length; compressive stress < capacity

Crack occurrence questionable
28°C more favourable than 1°C

Alessia Vecchietti
Department of Engineering, University of Perugia

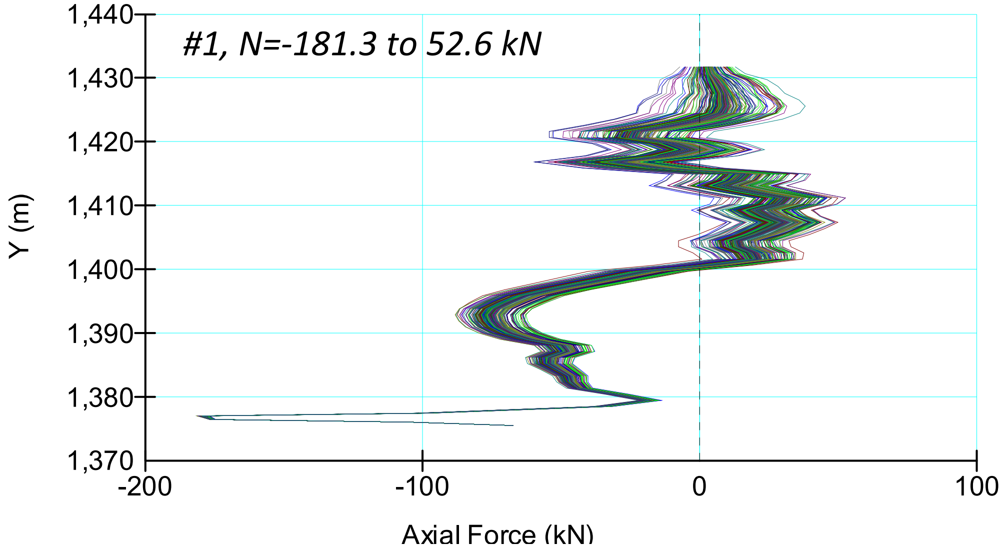
Part 3 (Optional) _ Bituminous facing analyses

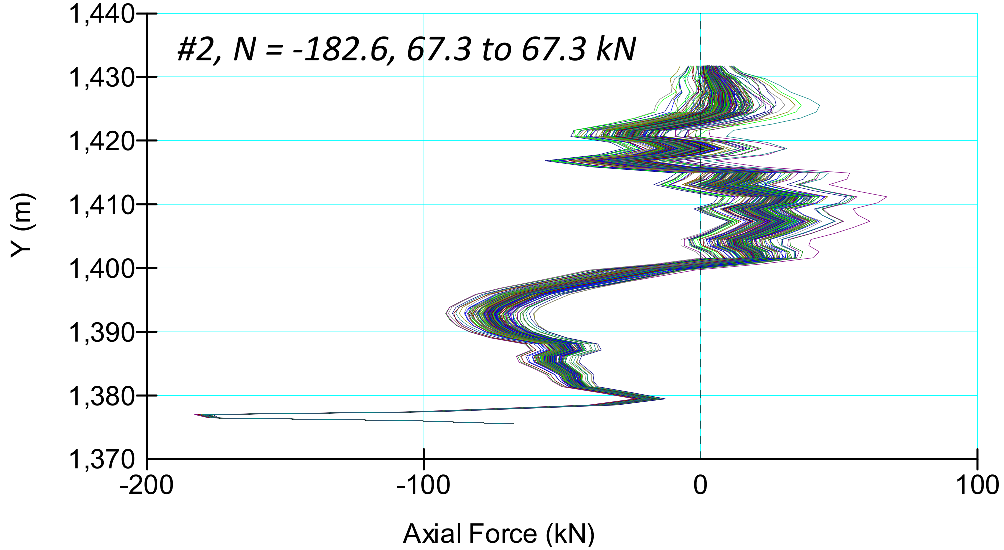
11Petk

Calculation of axial forces during the seismic excitation (equivalent linear analysis)

Maximal tension force of 181.3 kN (182.6 kN) and compression force of 52.6 kN (67.3 kN)
 < specific strength (fc=1.46 GPa and ft=0.95 GPa)

Axial forces in the asphaltic facing:





No case of disruption of the water impermeability of the watertight element

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Department of Engineering, University of Perugia

ICOLD-BW 2019
9th-11th September
MILANO

Numerical analysis of dams

CIGB ICOLD

10th September 2019

Theme B:
Seismic analyses of Menta Embankment dam

Remarks

Manuela Cecconi
Department of Engineering, University of Perugia

Dipartimento di Ingegneria
Department of Engineering

Remarks

The analyses performed have demonstrated the ability of numerical investigations to predict the behavior of Menta dam upon static and seismic conditions.

Good agreement in stress predictions (stress profiles in static conditions) at the end of construction and impoundment was achieved through different numerical methods, codes and constitutive models.

In seismic conditions, no general trend is observed for first natural frequency and its dependence on the empty/full reservoir.

Except for one proposed solution, independently of the numerical methods the crest-to base acceleration ratio for Menta dam and for the considered seismic inputs is about 2.9.

Geotechnical properties have been inferred from:
Experimental lab. available data (from the proposal): 10/12
Data derived from previous studies: 2/12
Literature recommendations and Software Manuals: 3/12
Experience gained from previous investigated case studies and engineering practice (3/12)

…and/or their combination

Manuela Cecconi
Department of Engineering, University of Perugia

The observed general trend upon seismic conditions, shared among all Participants

- horizontal displacements varying in the range 2- 60 cm
- vertical settlements varying in the range 2 – 20 cm, except for one proposed solution
- except from one case, no failure mechanisms have been detected.

Apparently, it seems that the obtained results are not strongly affected by the complexity of constitutive soil models and numerical solutions.

The basic dam behaviour trends and mechanisms are fairly captured by different numerical models.

Some Authors believe that vertical shaking component plays a primary role in the overall dam behaviour. Only two Contributors have considered only horizontal shaking.

Hydro-dynamic pressures have been generally neglected. It is believed that this results in a more conservative evaluation.

Bituminous facing (optional).
6 Contributors have assessed the seismic behavior of the bituminous facing in terms of stress, strain and expected performance.
Temperature effects have been taken into account.
The obtained results are not entirely consistent. In some cases, damage occurrence has been detected.
This point needs more focus.

Manuela Cecconi
Department of Engineering, University of Perugia

ICOLD-BW 2019
9th-11th September
MILANO

Numerical analysis of dams

CIGB ICOLD

10th September 2019

Theme B:
Seismic analyses of Menta Embankment dam

Closure

Giacomo Russo
Department of Earth Science, Environment and Resources, University of Napoli Federico II
(formerly Department of Civil and Mechanical Engineering, University of Cassino and Southern Lazio)

DiSTAR Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse

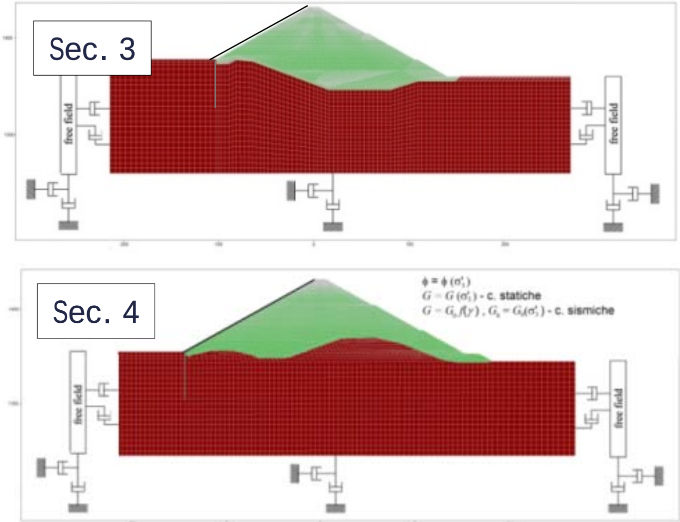
DICeM

Theme B Formulators: G. Russo, A. Vecchietti, M. Cecconi, V. Pane, S. De Marco, A. Fiorino

Comparison with previous analyses

A. Vecchietti (2019) - Geotechnical behavior of a Bituminous Faced Rockfill Dam in static and seismic conditions – PhD Thesis

Non-linear time-history FDM analyses



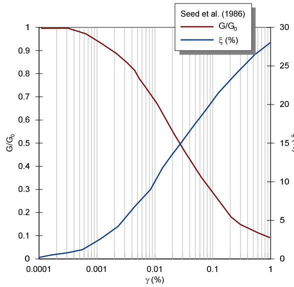
Rockfill constitutive model:

$\varphi = \varphi\,(\sigma'_3)$

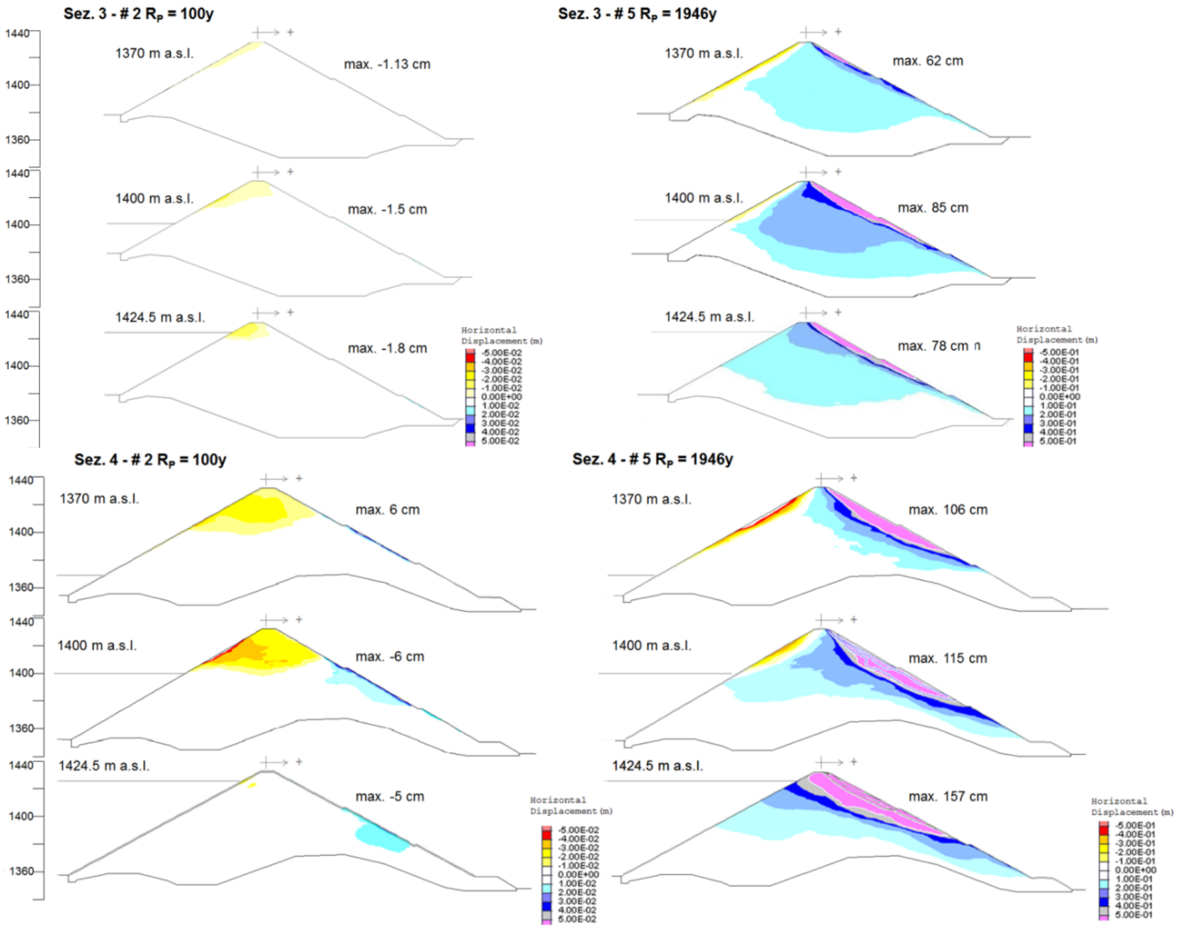
$G = G\,(\sigma'_3)$ (static analyses)

$G/G_0 = f\,(\gamma)$ (dynamic analyses)

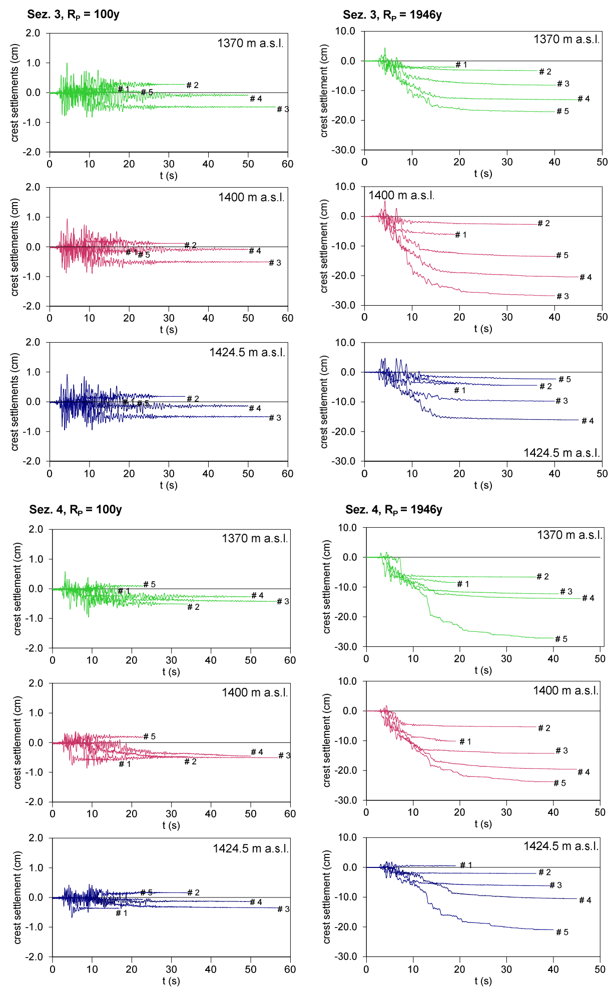
hysteretic damping shear stiffness and damping depend on shear strain level



Residual horizontal displacements (*e.g., #2 R_P =100y and #5 R_P = 1946y*)



Crest settlements:



Giacomo Russo
Department of Earth Science, Environment and Resources, University of Napoli Federico II

Comparison with previous analyses

A. Vecchietti (2019) - Geotechnical behavior of a Bituminous Faced Rockfill Dam in static and seismic conditions – PhD Thesis

According to requirements of Italian Rules, analyses for R_P = 100y (a_g = 0.13g) and R_p = 1946y (a_g = 0.454g) were performed

- for frequent, **moderately intense seismic events** the dam exhibits a substantial **elastic behaviour**, with limited residual displacements and settlement, corresponding to **negligible/small damaging level**

- for rare, **strong seismic event** the dam experiences **large displacements** (up to 90 cm), which reach larger values on limited, shallow portions of downstream slope uppermost berm. Embankment behaviour can be subjected to **moderate to severe damages, even if overall failure mechanisms are prevented**

- crest settlements are **not expected to cause dam overtopping** in full reservoir conditions

- **damages** to the impervious facing are likely to occur; assessment of bituminous facing damage scenarios conducted by means of seepage and stability analyses indicated that **hydraulic safety is ensured**

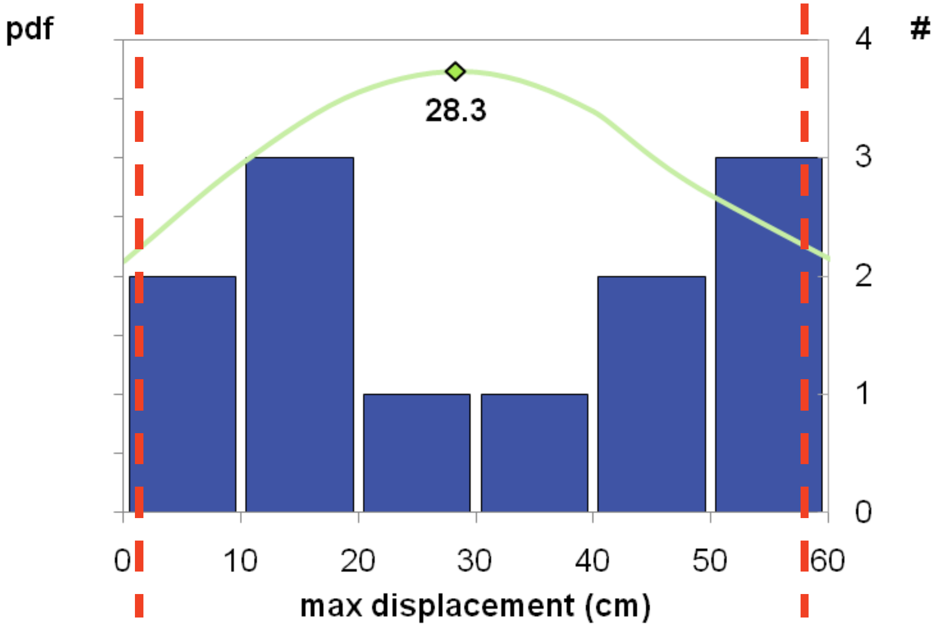
Giacomo Russo
Department of Earth Science, Environment and Resources, University of Napoli Federico II

Comparison with previous analyses

A. Vecchietti (2019) - Geotechnical behavior of a Bituminous Faced Rockfill Dam in static and seismic conditions – PhD Thesis

Maximum displacements

ag = 0.13g	BENCHMARK 0.26g	ag = 0.454g
< 2 cm	2 to 60 cm average: ~28 cm	generally < 60 cm (max 90 cm) τ_{max} exceeded on thin portions along the downstream slope



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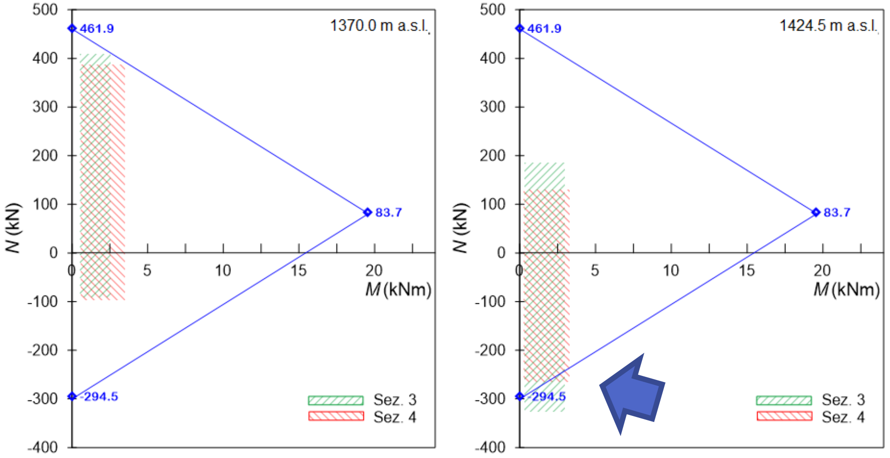
Comparison with previous analyses

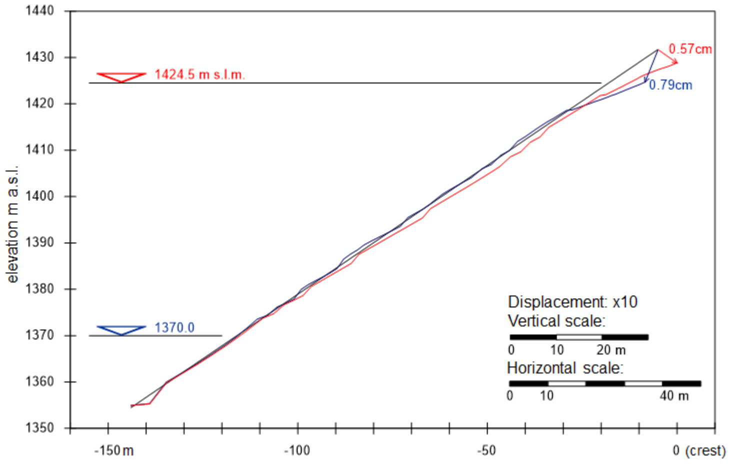
A. Vecchietti (2019) - Geotechnical behavior of a Bituminous Faced Rockfill Dam in static and seismic conditions – PhD Thesis

Bituminous facing

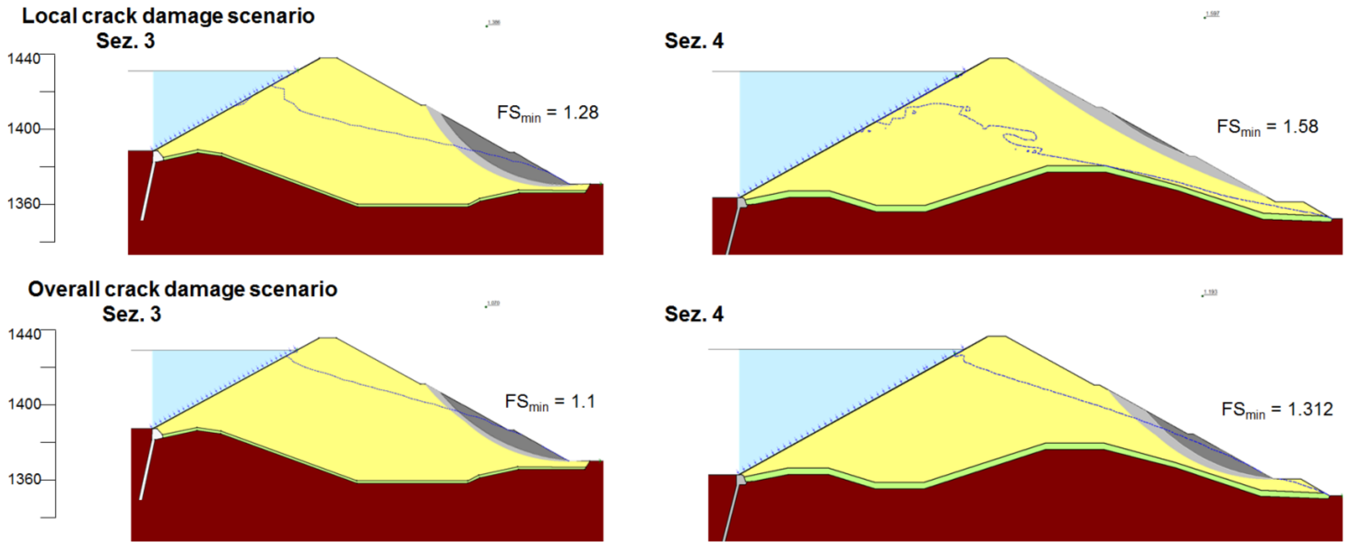
Max. internal forces (N-M)



Deformed shape:



Seepage and stability analyses with damaged facing:



- local crack: an area located at about 2/3 of the embankment high is pervious and lets the water flowing into to embankment;
- overall crack: the bituminous facing loses its integrity and its hydraulic conductivity increases from 1×10^{-12} m/s up to 1×10^{-6} m/s.

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Comparison with previous analyses

Società Risorse Idriche Calabresi

University of Perugia
Department of Engineering

University of Cassino and Southern Lazio
Dept. of Civil and Mechanical Engineering

University of Napoli Federico II
Dept. of Earth Science, Environment and Resources

Sergio De Marco

Andrea Fiorino

Manuela Cecconi

Alessia Vecchietti

Vincenzo Pane

Giacomo Russo

Thank you very much to everybody!