EWG "Dams and Earthquakes":

Behavior of the Dams Involved in April 2009 Seismic Sequence - Abruzzo (Italy)

Geol. Massimiliano Carcione
Eng. Matteo Sbarigia

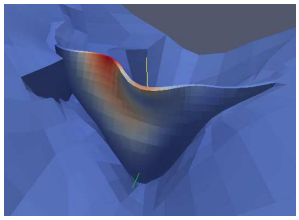
Rome February 6,7 2017

The Structure

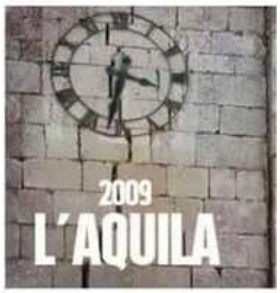
2009 Abruzzo Seismic Sequence

- **Seismological Items**
  (Geol. Massimiliano Carcione)

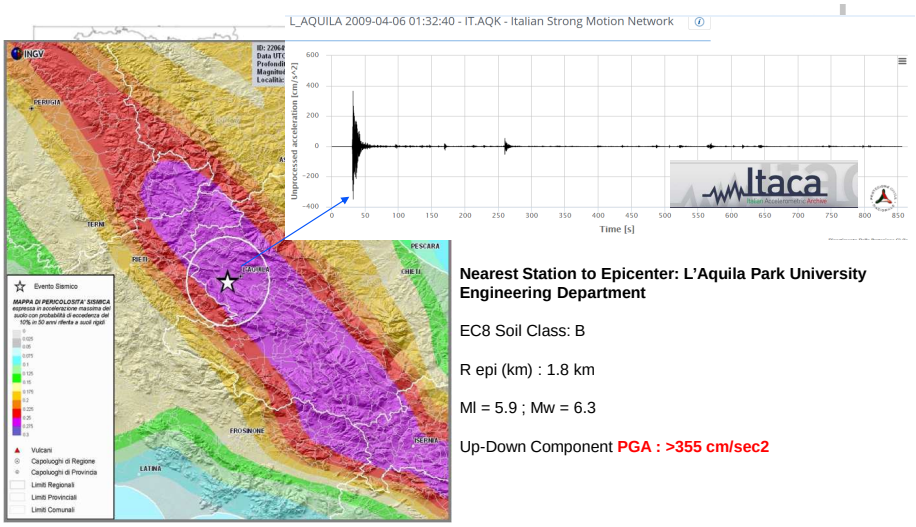
- **Effects on Enel Dams**
  (Eng. Matteo Sbarigia)



The Mainshock



• In 6th April 2009, L'Aquila clock stopped at 3:32 a.m.



• A strong Earthquake occurred in Abruzzo Region in an high hazard area
(Probabilistic seismic map for Italy – INGV 2004)

Nearest Station to Epicenter: L'Aquila Park University Engineering Department

EC8 Soil Class: B

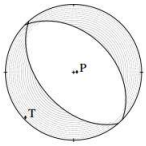
R epi (km) : 1.8 km

Ml = 5.9 ; Mw = 6.3

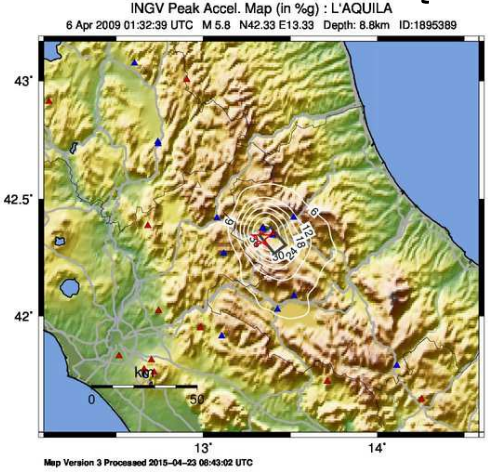
Up-Down Component **PGA : >355 cm/sec2**

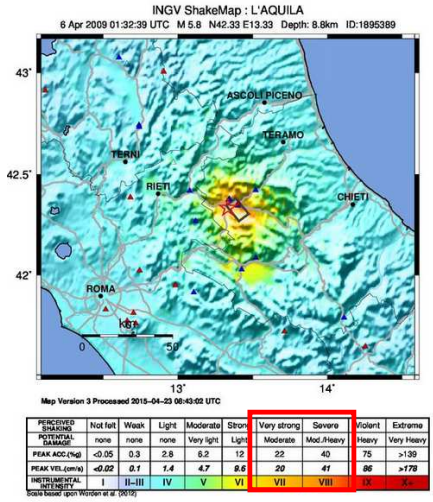
The Impact

Power Earthquake
Mw = 6.3



EQ Classification
- **Very Strong/Severe Earthquake**
- **Moderate/Heavy Potential Damage**
- **Focusing of Wave Energy in South-East Sector**





PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	<0.02	0.1	1.4	4.7	9.6	20	41	86	>178
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

The Effects

Extended damage

in the L'Aquila town and sourroundings on

Buildings

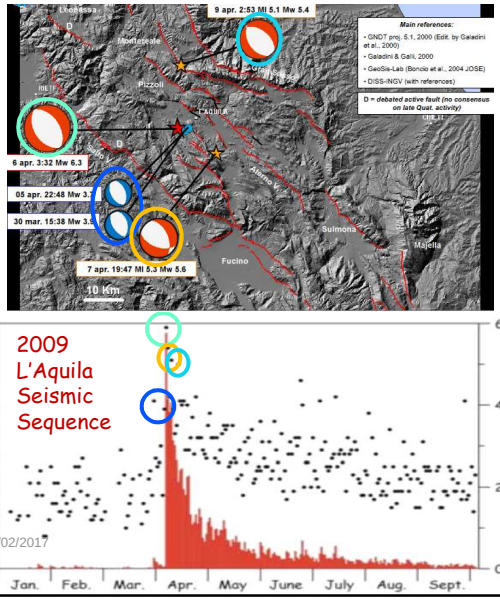
Infrastructures

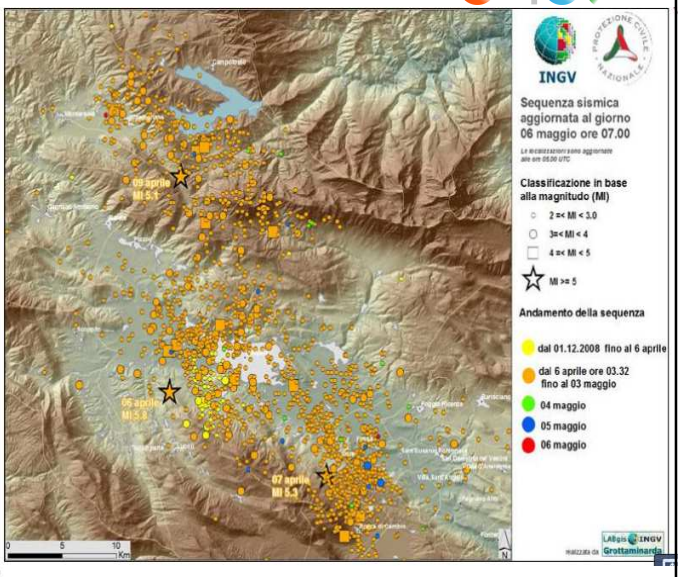
Induced Geotechnical Events

Heavy Final Balance

N° Death people:	**309**
N° Wounded people:	**>1600**
(€) Cost Damage:	**> 10 Mld €**

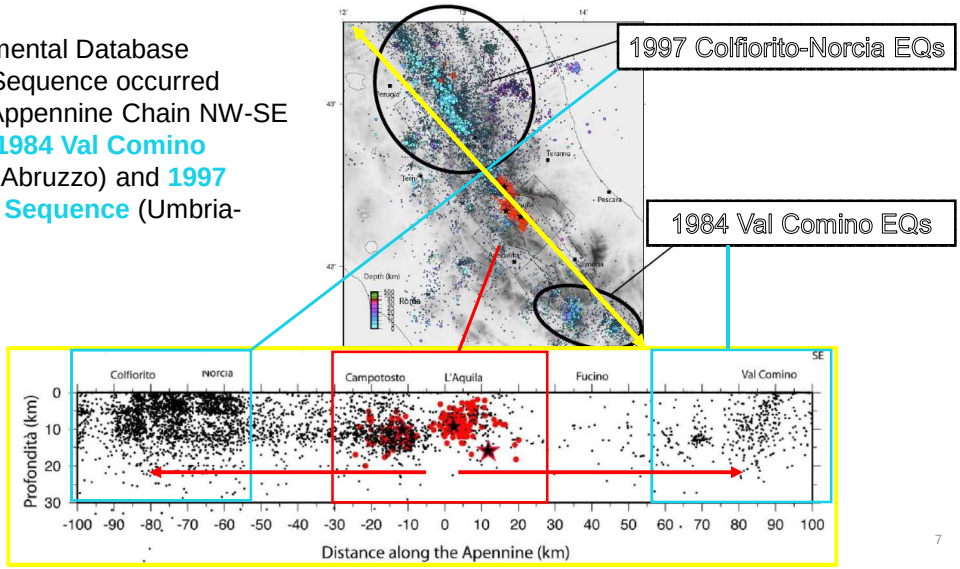
The Seismic Sequence



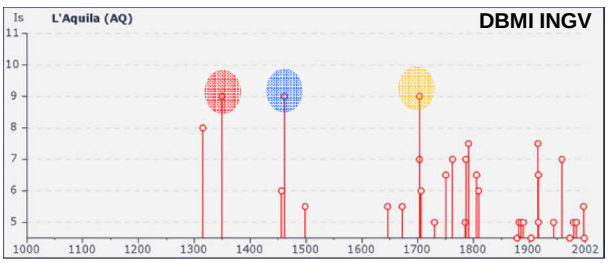


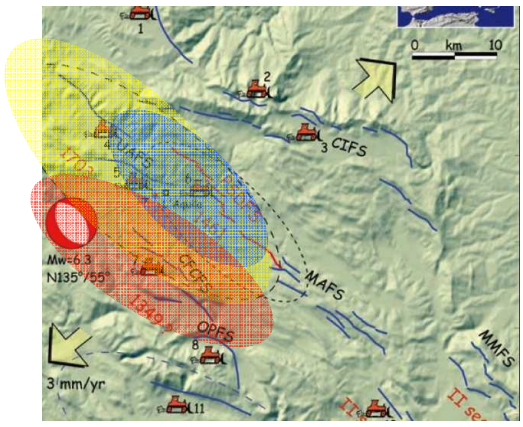
The Instrumental Seismicity

1980-2006 Instrumental Database L'Aquila Seismic Sequence occurred equidistant in an Appennine Chain NW-SE section between **1984 Val Comino Sequence** (Lazio-Abruzzo) and **1997 Colfiorito-Norcia Sequence** (Umbria-Marche)



The Historical Seismicity

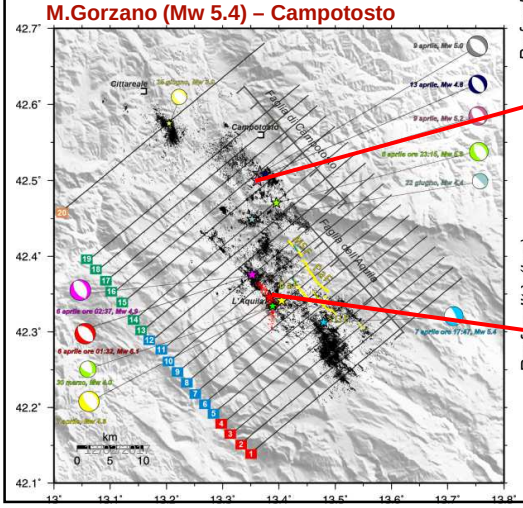


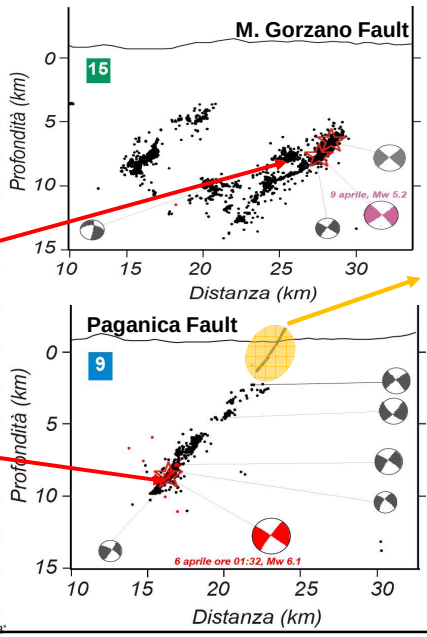


1451 & 2009 L'Aquila EQS are considered **Twin Events**
TR ~ 550 years

The Fault

Seismogenetic Fault Systems Activated:
Paganica (Mw =6.3) - L'Aquila
M.Gorzano (Mw 5.4) – Campotosto





Paganica fault system showed a max Surface Coeseismic Slip ~15cm

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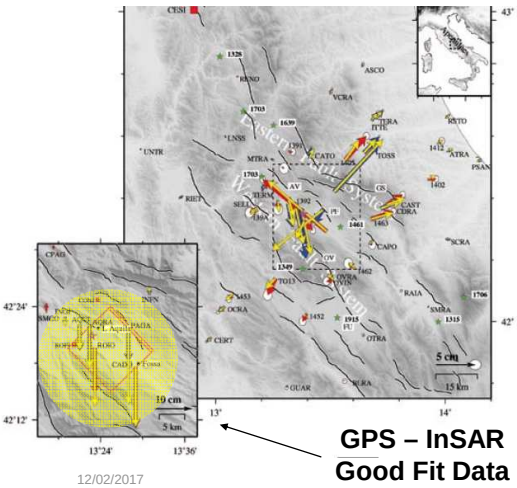
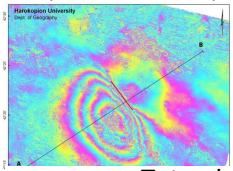
The Strain

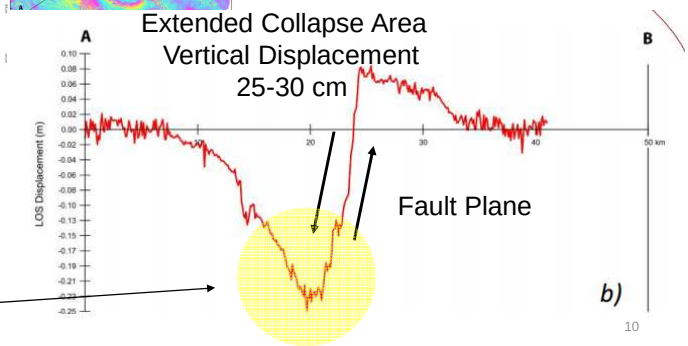
GPS Survey
(Cheloni et al. 2010)



GPS – InSAR Good Fit Data

Interferometric Syntetic Aperture Radar (InSAR Survey)
(Atzori et al. 2009)





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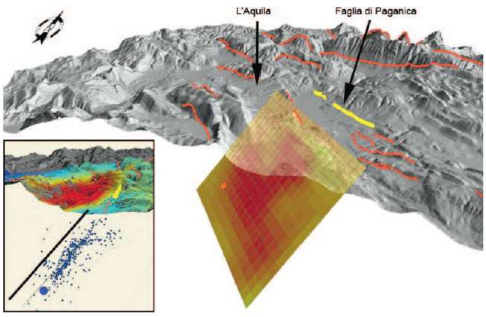
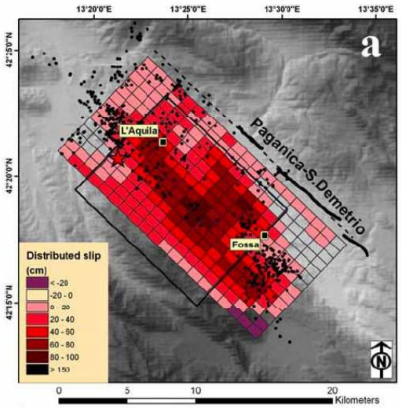
The Fault Slip Model



From Hypocenters and InSAR data a Fault Slip Model is defined:

47° SW dipping Normal Fault ~16 km long and ~12 km wide, with a maximum slip ~90 cm at ~ 9 km depth.

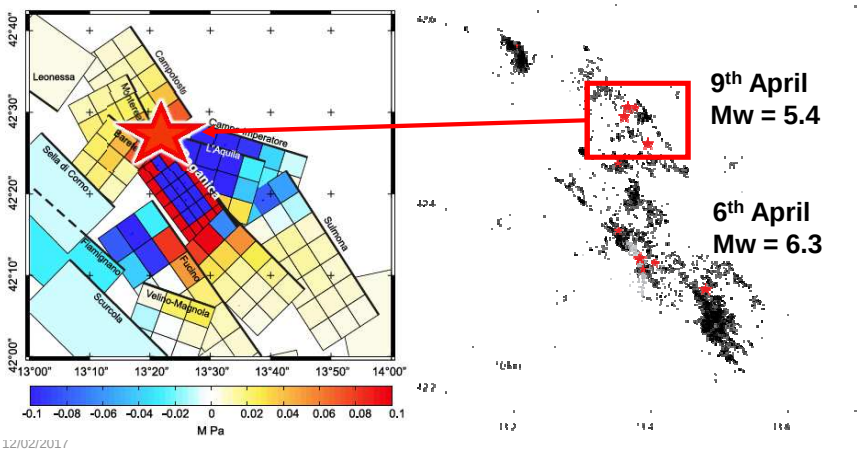
Surface Slip Model Projection



Slip model DinSAR data
Atzori et al., GRL 2009

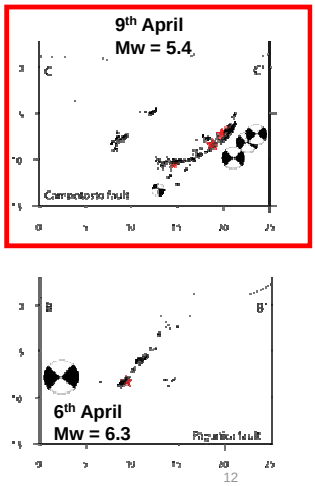
The Stress Change

Coulomb stress change on faults surroundings Paganica Fault due to the slip enstimeted from the InSAR Slip Model *(Walters et al. 2009)*



9th April Mw = 5.4

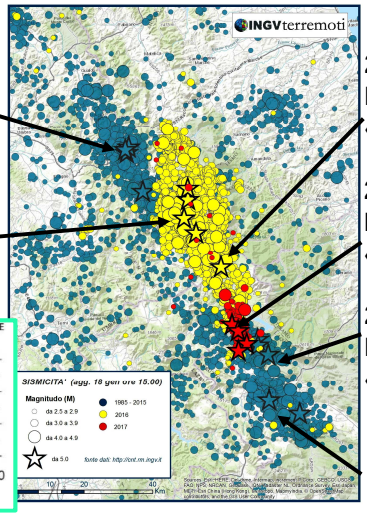
6th April Mw = 6.3



The Central Italy Seismic Evolution

1997 – 26th Sep
Mw = 6.0
«Colfiorito»

2016 - 30th Oct
Mw = 6.5
«Norcia»

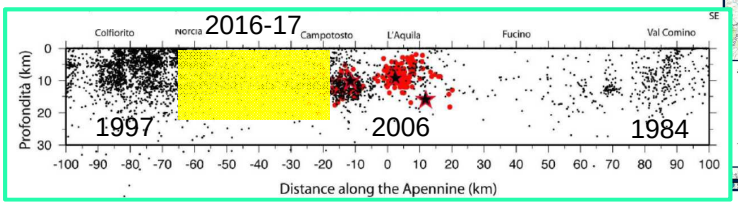


2016 - 24th Aug
Mw = 6.0
«Amatrice»

2017 - 18th Jan
Mw = 5.5
«Montereale»

2009 - 9th Apr
Mw = 5.4
«Campotosto»

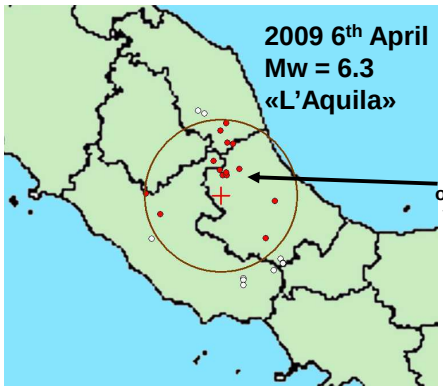
2009 - 6th Apr
Mw = 6.3
«L'Aquila»



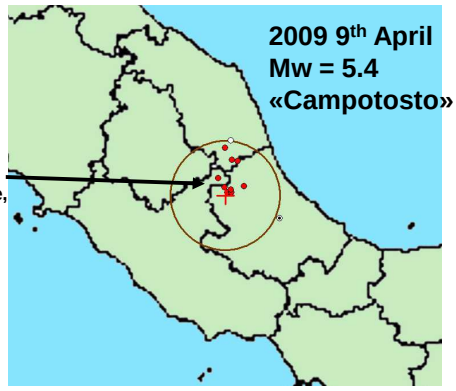
The Post-Seismic Dams Control

2009 L'Aquila Sequence involved many Enel Dams in Post-seismic Procedure Control

(Circ. Dams National Service, June 2002)



Neerest dams on Campotosto Lake, Vomano and Tronto River

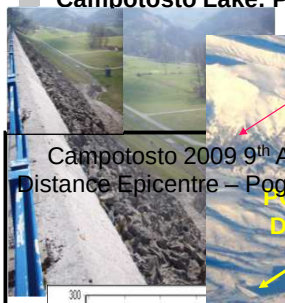


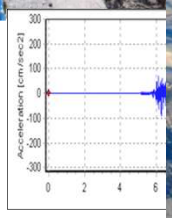
Seismic Epicentre
Dams inside the control zone → N° 14 ; R = 74 km
Dams near to the control zone for 20% radius increase → N° 11 ; R = 88,8 km

Seismic Epicentre
Dams inside the control zone → N° 9 ; R = 53 km
Dams near to the control zone for 20% radius increase → N° 2 ; R = 63,6 km

The Dams PGA

Campotosto Lake: Poggio Cancelli Dam





Accelerometer System installed at the dam bottom downstream side on 6th April 2009

Amatrice 2016, Aug 24 - Mw 6.0 (Ml = 6.0) : ***PGA HN*** 0.29 g D ~19 km

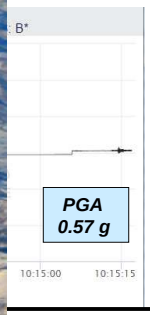
Norcia 2016, Oct 30 - Mw 6.5 (Ml = 6.1) : ***PGA HN*** 0.23 g D ~34 km

Campotosto 2009 9th April: Ml=5.1 (Mw 5.4) HN

Distance Epicentre – Poggio Cancelli DAM: **7.94 km**

Monterale 2017 18th Jan: Ml=5.4 (Mw 5.5) HN

Distance Epicentre – Poggio Cancelli DAM: **5.44 km**



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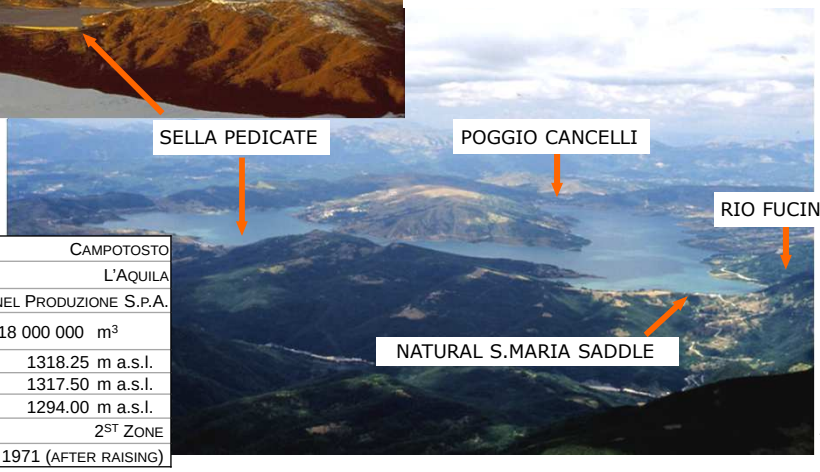
Campotosto Lake

2009 April 6th:

Impounding:122 000 000 m³

Water Level: 1309,50 m asl



Town	Campotosto
District	L'Aquila
Owner	Enel Produzione S.p.A.
Storage Capacity (Italian Law 584/94)	218 000 000 m³
Maximum Water Level	1318.25 m a.s.l.
Normal Water Level	1317.50 m a.s.l.
Minimum operating level	1294.00 m a.s.l.
Seismic Italian Classification (2009)	2ST Zone
Year of Completion	1971 (after raising)

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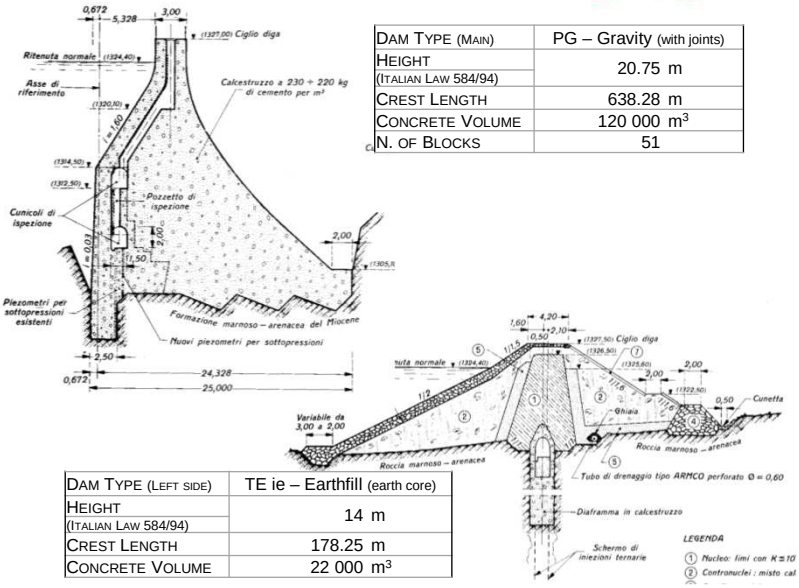
Sella Pedicate Dam

Characteristics



DAM TYPE (MAIN)	PG – Gravity (with joints)
HEIGHT (ITALIAN LAW 584/94)	20.75 m
CREST LENGTH	638.28 m
CONCRETE VOLUME	120 000 m³
N. OF BLOCKS	51

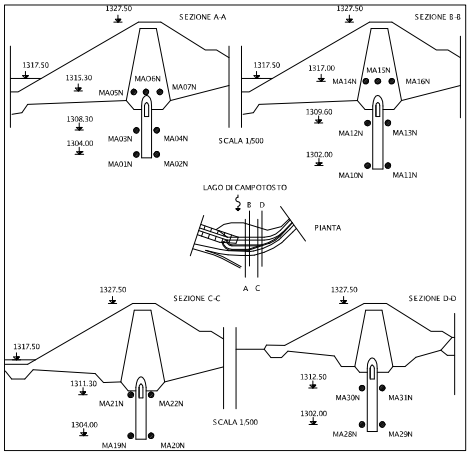
DAM TYPE (LEFT SIDE)	TE ie – Earthfill (earth core)
HEIGHT (ITALIAN LAW 584/94)	14 m
CREST LENGTH	178.25 m
CONCRETE VOLUME	22 000 m³

Sella Pedicate Dam

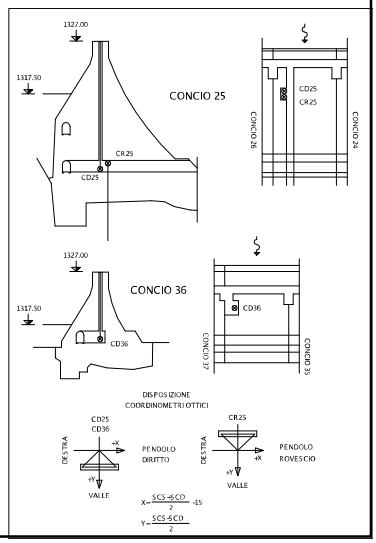
Monitoring system

Physical Quantity	Measure Points
Reservoir Level	1
Air Temperature	3
Water Temperature	4
Snow	1
Rain	1
Dam Leakeges	2
Downstream Seepages	12
Piezometric Line	42
Uplift	22
Concrete Temperature	9
Joints displacements	31
Fissures displacements	4
Dam Rotations	71
Levelling displacements	55
Planimetric displacements	6
Monitored points (total)	**264**

Pressure gauge (manometers)



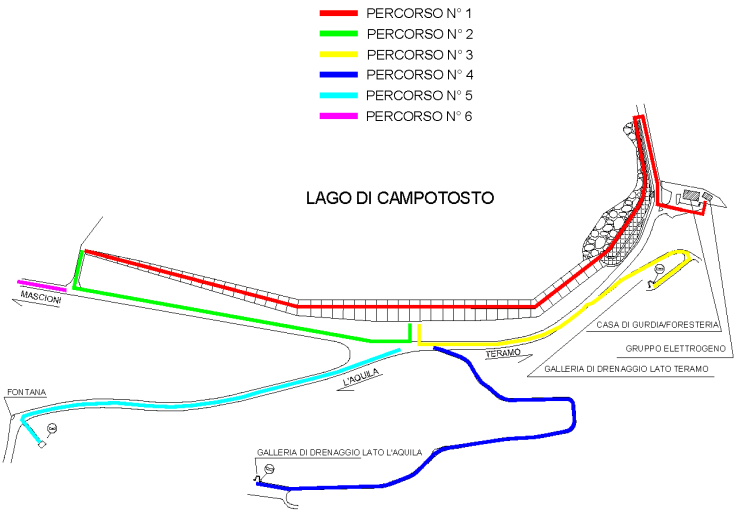
Pendulums



Sella Pedicate Dam

Effects

Inspection evidences



Oil coming out from pendulum tank

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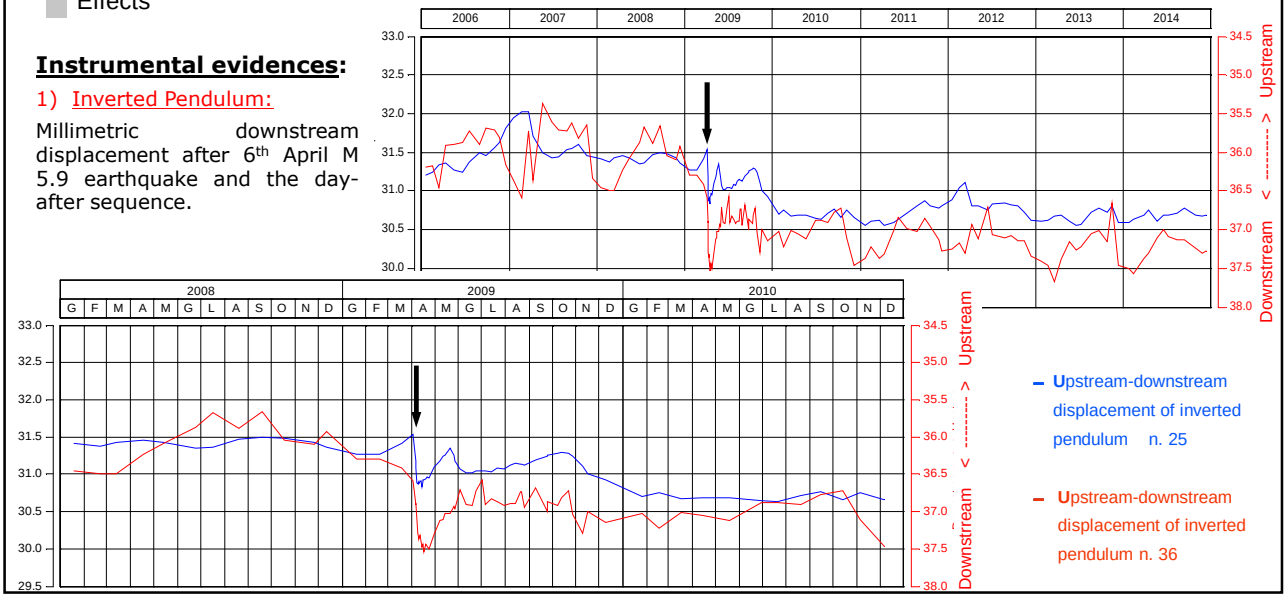
Sella Pedicate Dam

Effects

Instrumental evidences:

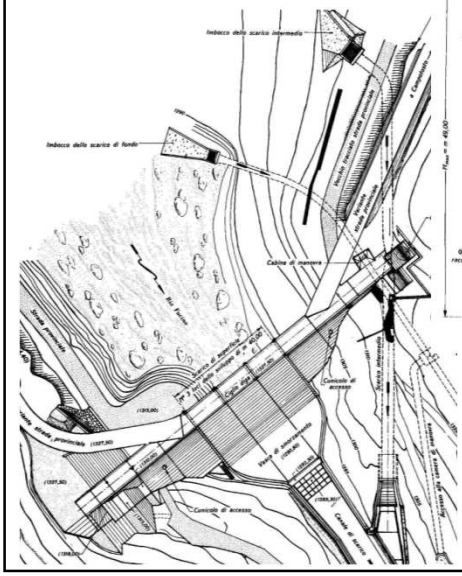
1) Inverted Pendulum:

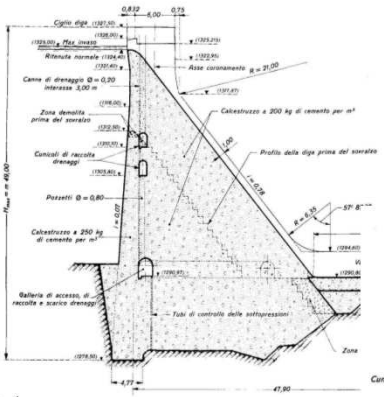
Millimetric downstream displacement after 6th April M 5.9 earthquake and the day-after sequence.



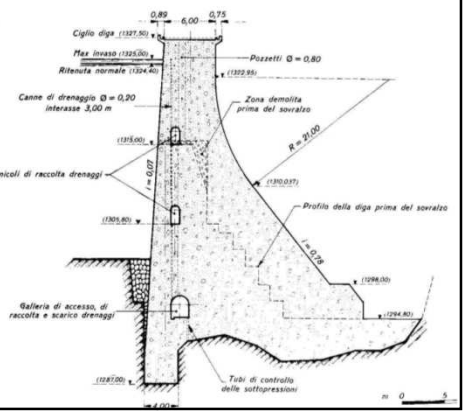
Rio Fucino Dam

Characteristics





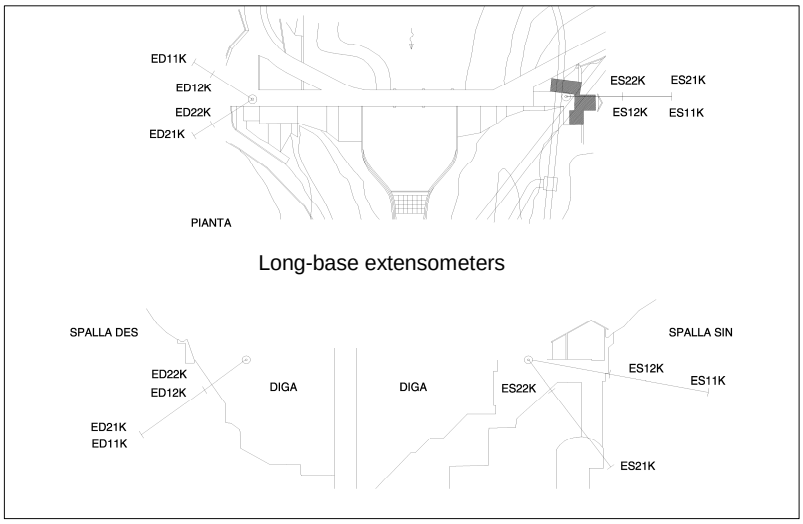
DAM TYPE (MAIN)	PG – Gravity (with joints)
HEIGHT (ITALIAN LAW 584/94)	36.70 m
CREST LENGTH	144 m
CONCRETE VOLUME	77 200 m^3
N. OF BLOCKS	12



Rio Fucino Dam

Monitoring system

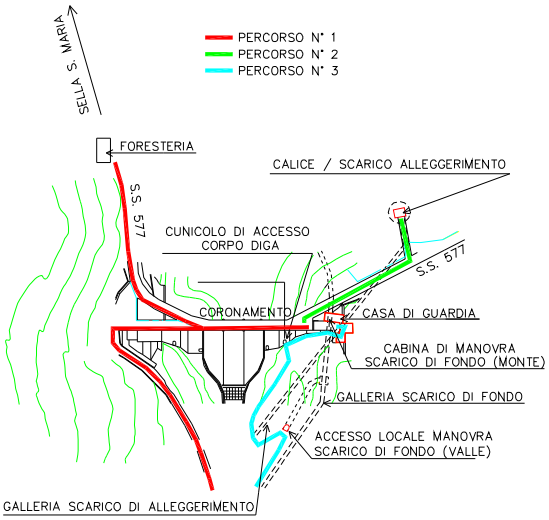
Physical Quantity	Measure Points
Reservoir Level	1
Air Temperature	2
Water Temperature	4
Snow	1
Rain	1
Dam Leakeges	1
Piezometric Line	14
Concrete Temperature	10
Joints displacements	19
Abutments deformation	8
Dam Rotations	49
Levelling displacements	18
Planimetric displacements	12
Monitored points (total)	**140**

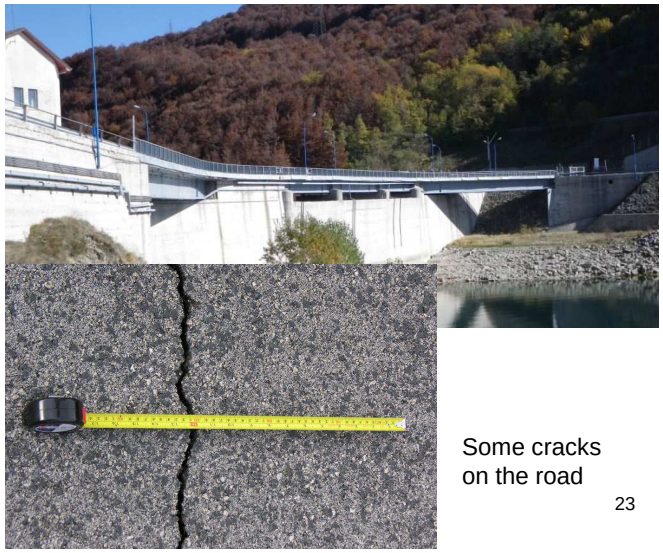


Rio Fucino Dam

Effects

Inspection evidences





Some cracks on the road

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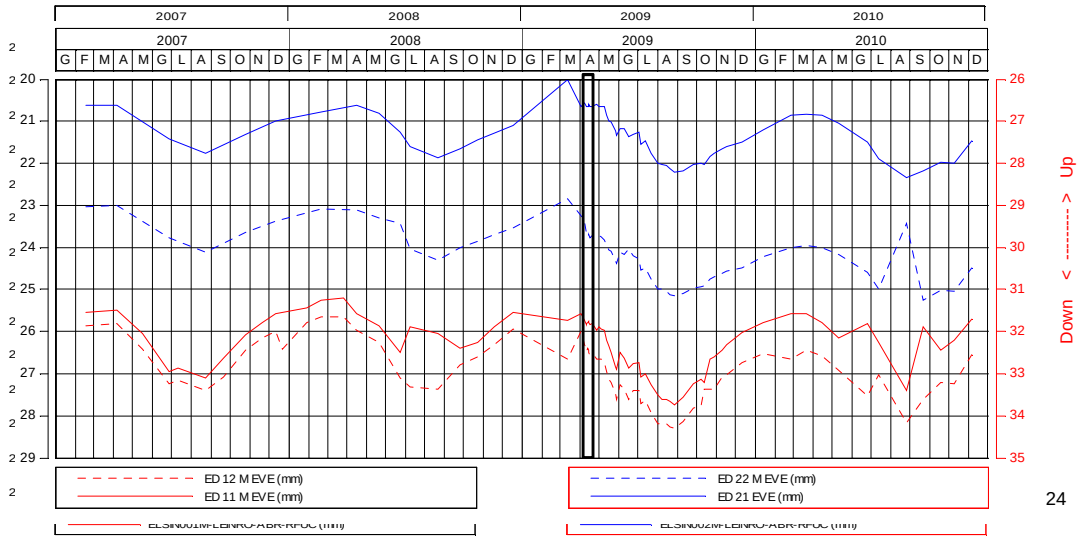
Rio Fucino Dam

Effects

No instrumental evidences



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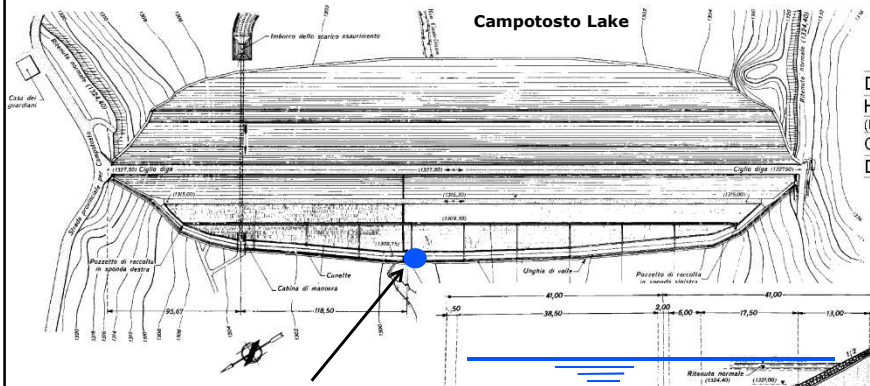
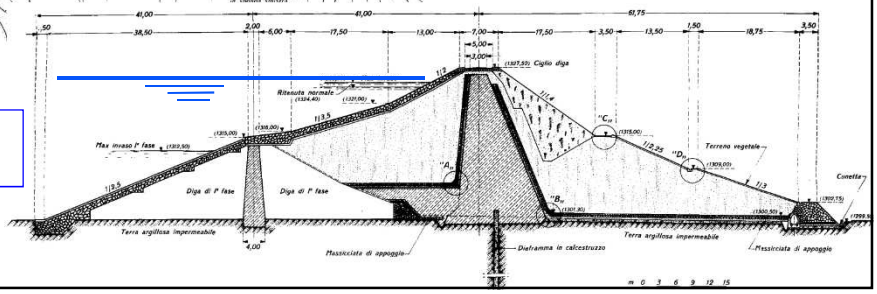
Poggio Cancelli Dam

Characteristics



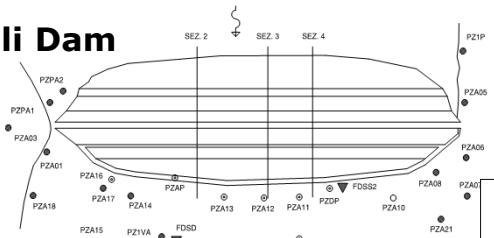
DAM TYPE (LEFT SIDE)	TE ie – Earthfill (earth core)
HEIGHT (ITALIAN LAW 584/94)	27.30 m
CREST LENGTH	500 m
DAM VOLUME	720 000 m³



Accelerometer System installed at the dam bottom downstream side on 8th April2009

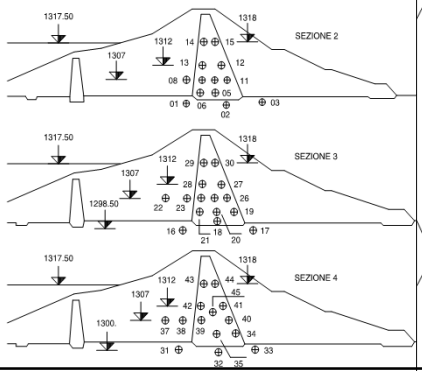
Poggio Cancelli Dam

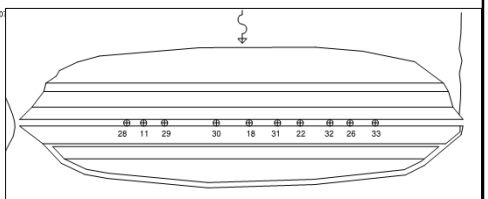
Monitoring system



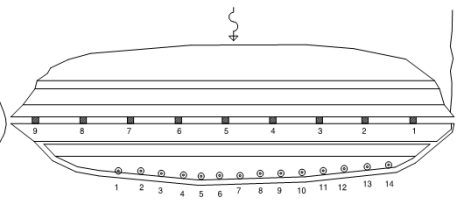
Piezometers

Physical Quantity	Measure Points
Reservoir Level	1
Air Temperature	2
Water Temperature	4
Snow	1
Rain	1
Dam Seepages	4
Abutments Seepages	2
Downstream Seepages	9
Piezometric Line	73
Levelling displacements	23
Assestimetric displacements	10
Planimetric displacements	18
Monitored points (total)	**148**





Assestimeters

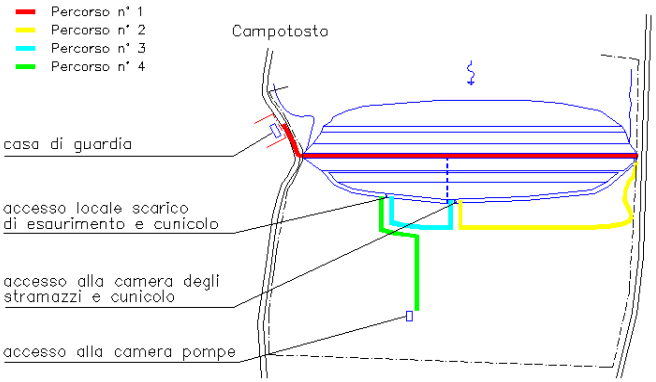


Levelling

Poggio Cancelli Dam

Effects

Inspection evidences



Slight widening of the historical crack into the bottom culvert

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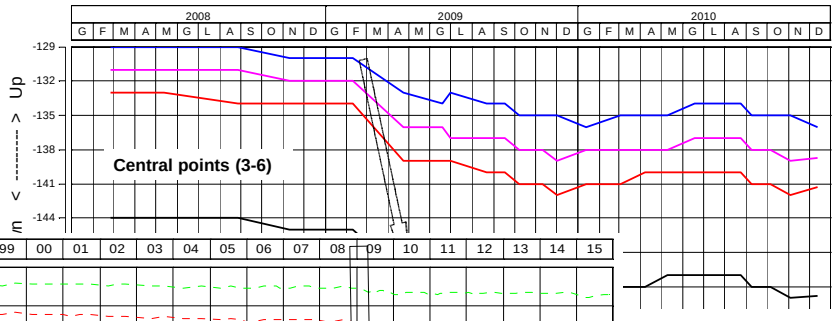
Poggio Cancelli Dam

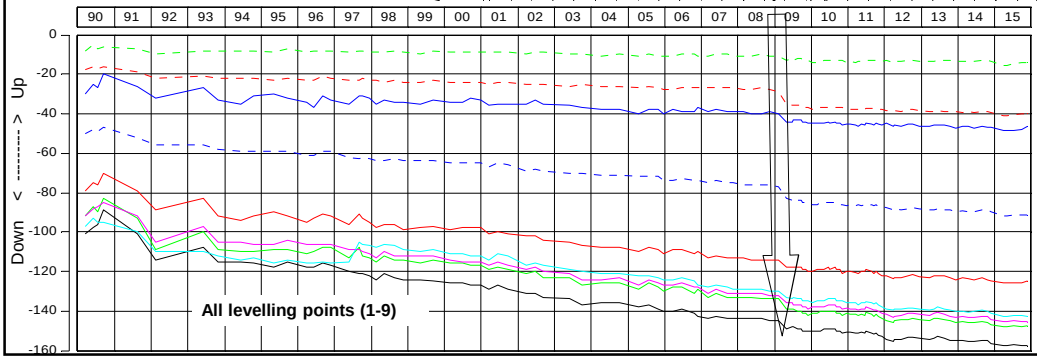
Effects

Instrumental evidences:

Levelling on the crest:

Millimetric lowering of the crest points after the 2009 April sequence. The central part about 3-4 mm





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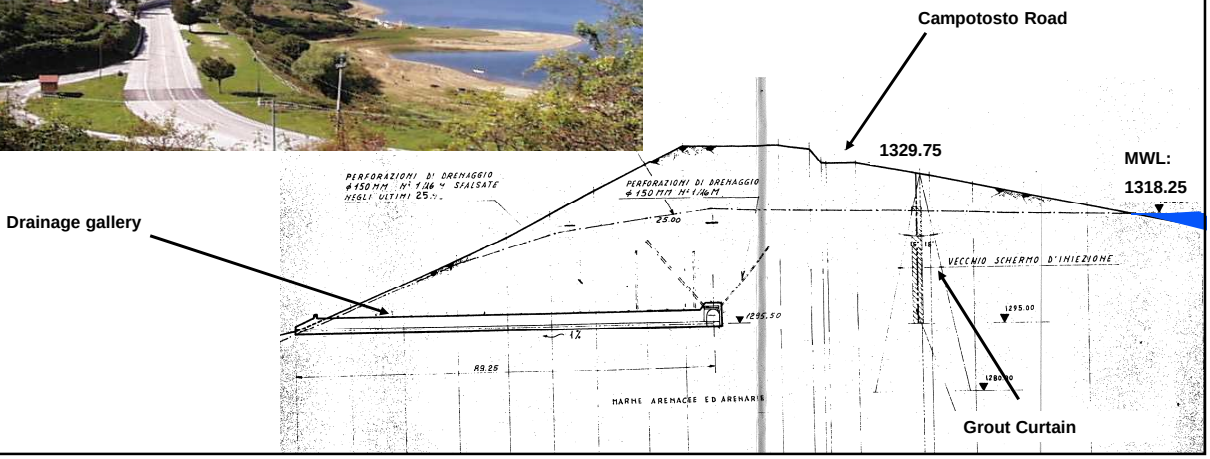
Santa Maria Natural Saddle

Characteristics

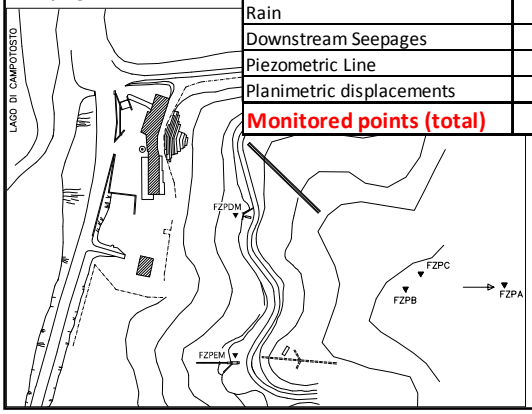


Santa Maria Natural Saddle

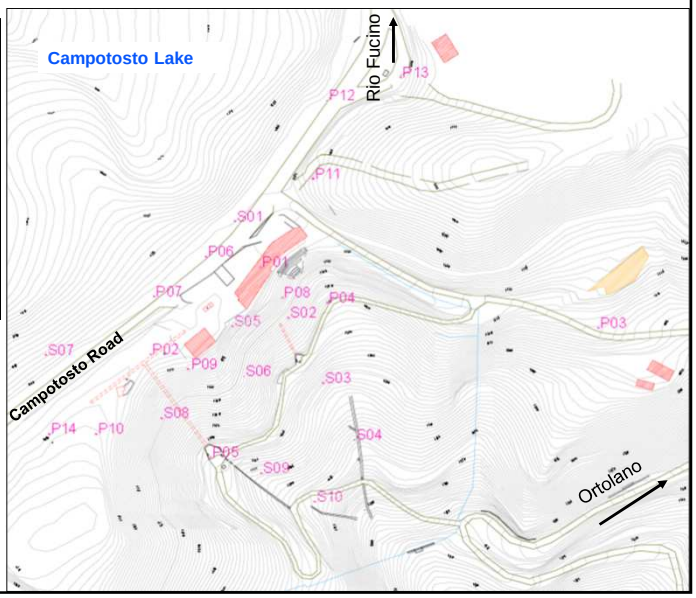
Monitoring system

Physical Quantity	Measure Points
Reservoir Level	1
Air Temperature	2
Water Temperature	2
Snow	1
Rain	2
Downstream Seepages	7
Piezometric Line	23
Planimetric displacements	4
Monitored points (total)	**42**

Seepages



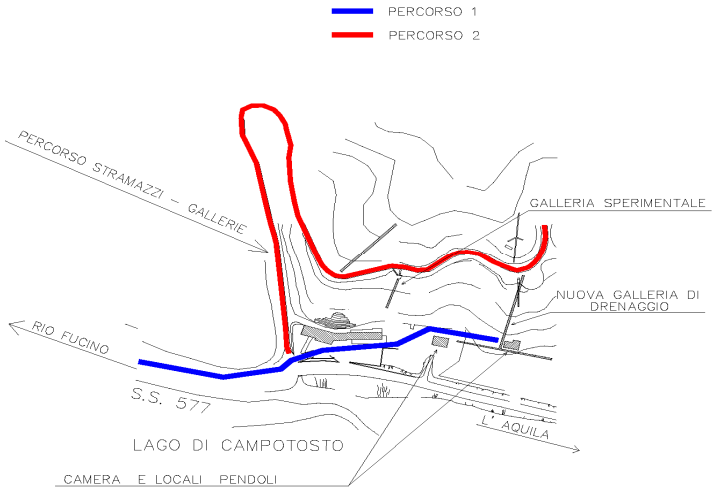
Piezometers



Santa Maria Natural Saddle

Effects

No inspection evidences



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Santa Maria Natural Saddle

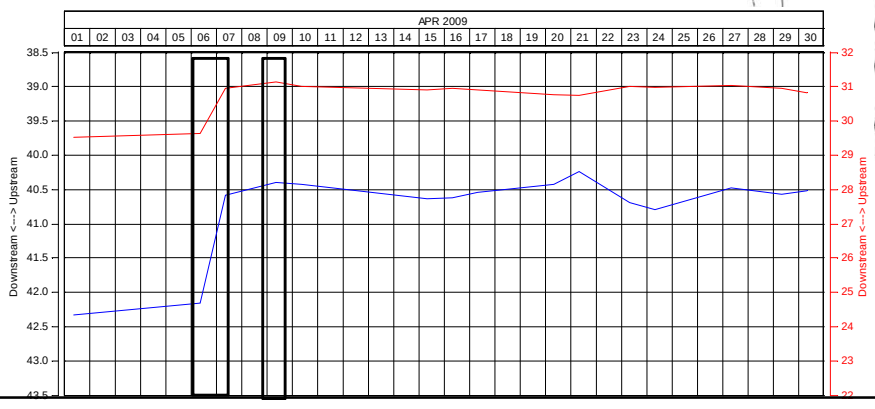
Effects

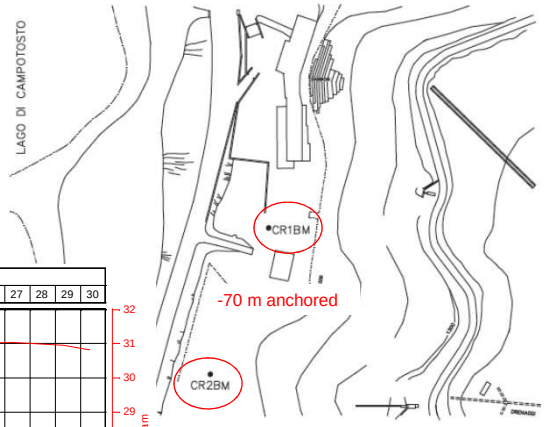
<u>Instrumental evidences</u>:

1) <u>Inverted pendulums:</u>

Millimetric upstream displacement after 6/7th April earthquake sequence (1-2 mm).

No displacement after 9th 5.1ML earthquake





– Upstream-downstream displacement of inverted pendulum n. 1

– Upstream-downstream displacement of inverted pendulum n. 2

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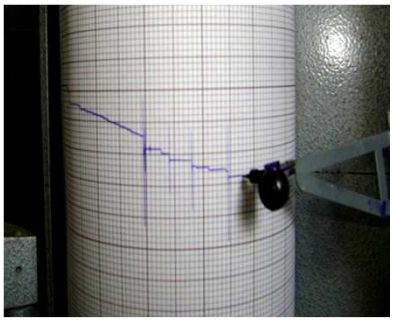
Santa Maria Natural Saddle

Effects

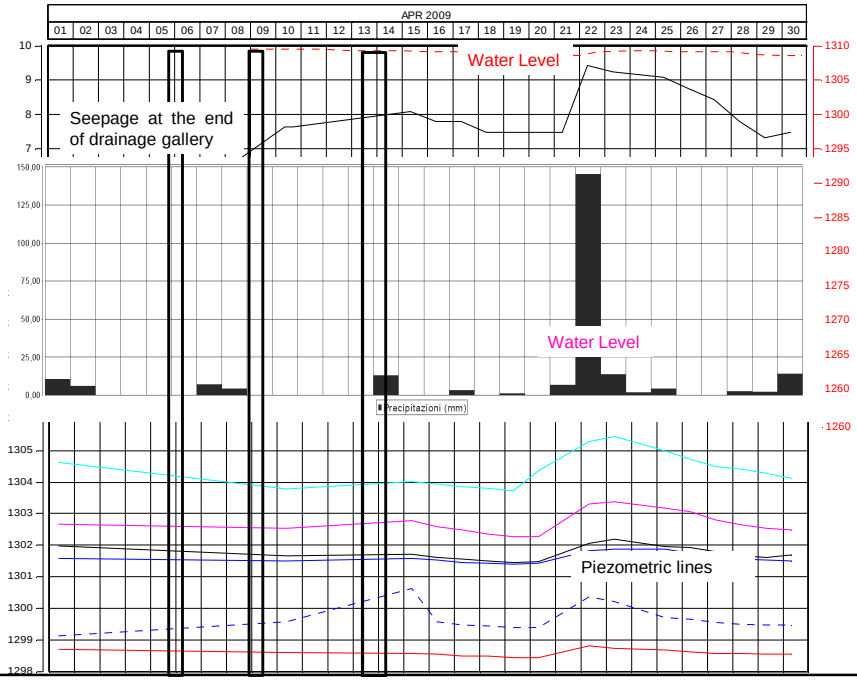
Instrumental evidences:

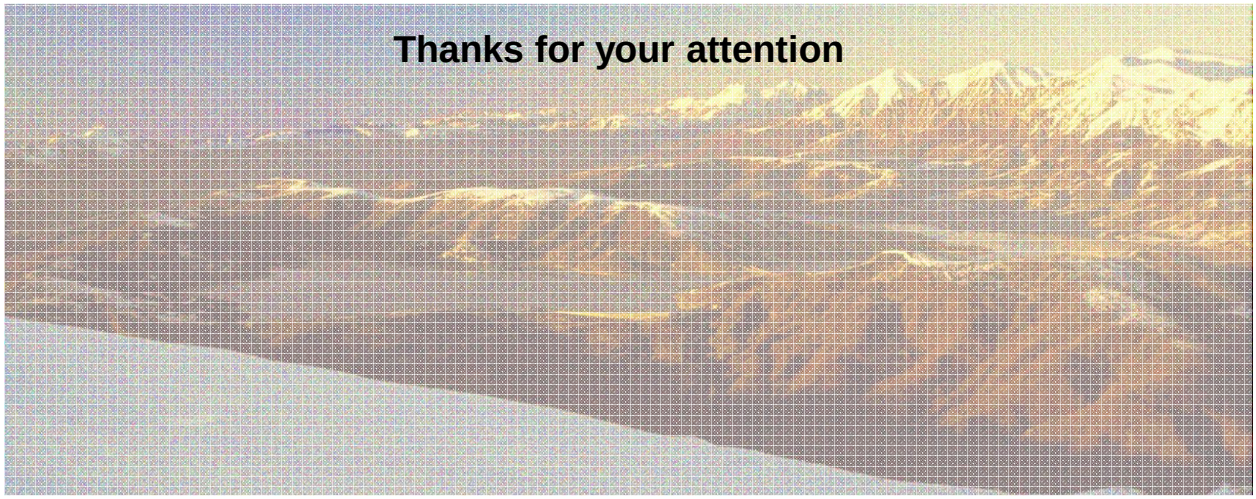
2) Piezometers and Seepages:

Apparently increasing in value, but due to very heavy rainfall on 22th April



Seepages automatic gauge
(" improper " accelerometer)





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