FIG Working Week 2012
Rome, 7 may 2012

Dam and reservoir engineering surveying

THE MONITORING OF GRAVITY DAMS: TWO TESTS IN SARDINIA, ITALY

Speaker:
Riccardo Monaci

Authors:
Riccardo Barzaghi
Livio Pinto
Riccardo Monaci

DIIAR – Politecnico di Milano, Italy

STRUCTURE OF THE WORK

- PART 1: Monitoring network of gravity dams
  - Measures of crest displacement in two existing dams
  - Modeling process of data series
- PART 2: Satellite technology
  - Experimetal GNSS network on Genna Is Abis Dam
  - Crest displacement: comparison between pendulums and GPS measures
  - Conclusions and future perspectives

Genna Is Abis Dam

TECHNICAL DATA

• Classification:	Solid gravity dam
• Height:	26 m
• Lenght:	1295 m
• Max basin capacity:	32 Mm^3
• Water use:	Drinking water supply, irrigation,flood lamination
• Management:	ENAS – ENte Acque Sardegna

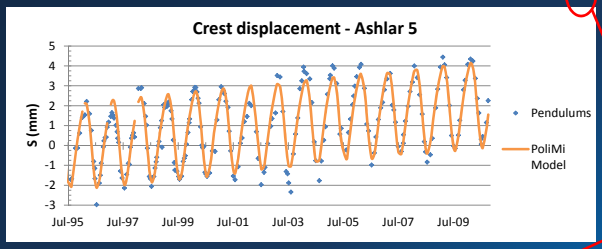
Cantoniera Dam

TECHNICAL DATA

• Classification:	Hollow buttress gravity dam
• Height:	100 m
• Lenght:	582 m
• Max basin capacity:	793 Mm^3
• Water use:	Drinking water supply, irrigation, hydroelectric energy
• Management:	ENAS – ENte Acque Sardegna

GENNA IS ABIS DAM – MODELING PROCESS

PoliMi Model → $S = a \cdot t + b + A \cos\frac{2\pi t}{T} + B \operatorname{sen}\frac{2\pi t}{T} + C \cos\frac{4\pi t}{T} + D \operatorname{sen}\frac{4\pi t}{T}$

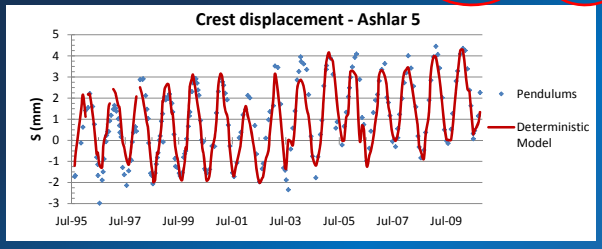


Statistics (mm)	
Standard deviation	0.53
Max residual	1.88
Min residual	-2.15

Time step (365 days)

Annual average of daily air temperature

Deterministic Model → $S = a \cdot T_{av\ year\ air} + b \cdot T_{av\ water} + c \cdot H + d \cdot H^2 + e$



Statistics (mm)	
Standard deviation	0.66
Max residual	1.92
Min residual	-1.82

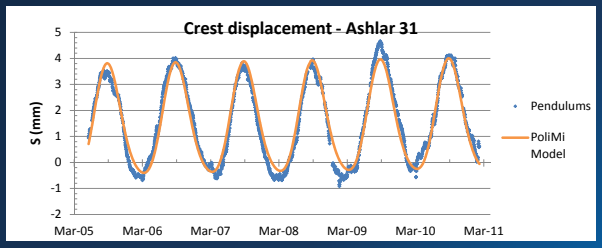
Water level

Annual moving average of water temperature

Positive values are crest displacement to downstream direction

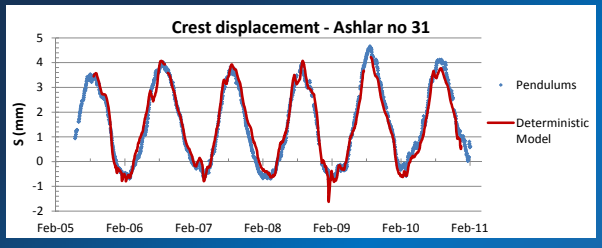
CANTONIERA DAM – MODELING PROCESS

PoliMi Model → $S = a \cdot t + b + A \cos\frac{2\pi t}{T} + B \operatorname{sen}\frac{2\pi t}{T} + C \cos\frac{2\pi t}{T} + D \operatorname{sen}\frac{2\pi t}{T}$



Statistics (mm)	
Standard deviation	0.37
Max residual	1.00
Min residual	-1.25

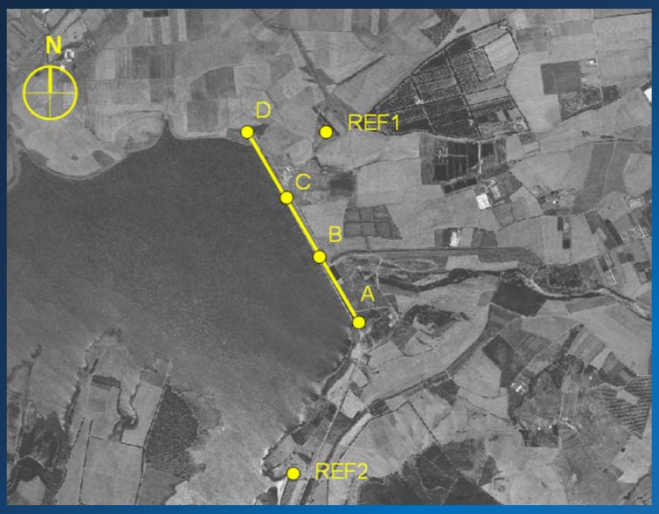
Deterministic Model → $S = a \cdot T_{av\ year\ air} + b \cdot T_{av\ water} + c \cdot H + d \cdot H^2 + e$



Statistics (mm)	
Standard deviation	0.30
Max residual	0.71
Min residual	-0.82

Positive values are crest displacement to upstream direction

GNSS network on Genna Is Abis



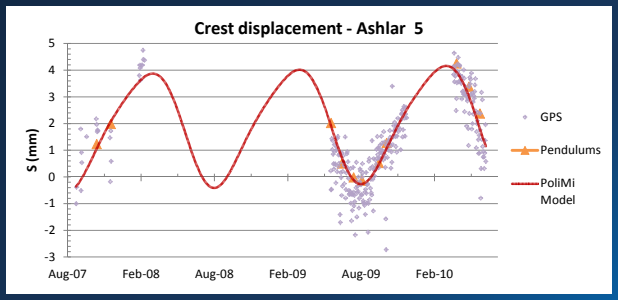
2 master stations

REF 1 REF 2

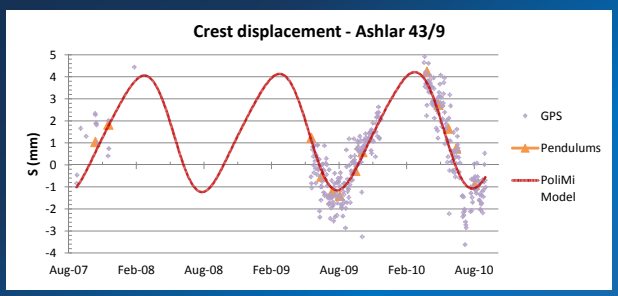
4 rover stations

A B C D

GNSS MEASURES AND POLIMI MODEL ADJUSTED ON PENDULUMS



Statistics (mm)	
Mean	**-0,19**
Std. deviation	**0,80**
Max residual	1,92
Min residual	-3,75



Statistics (mm)	
Mean	**-0,01**
Std. deviation	**0,87**
Max residual	2,48
Min residual	-3,65

Conclusions

Analysis of pendulum observations for Genna Is Abis and Cantoniera dams led to some important conclusions:

- Pendulums are suitable instruments to characterize and control dams, because of their high accuracy and reliability
- Applied models fit properly data series, revealing in due time possible existing critical deformations
- GPS follows crest displacement data series very well, proving satellite positioning suitable for detection of slow deformation in civil engineering structures

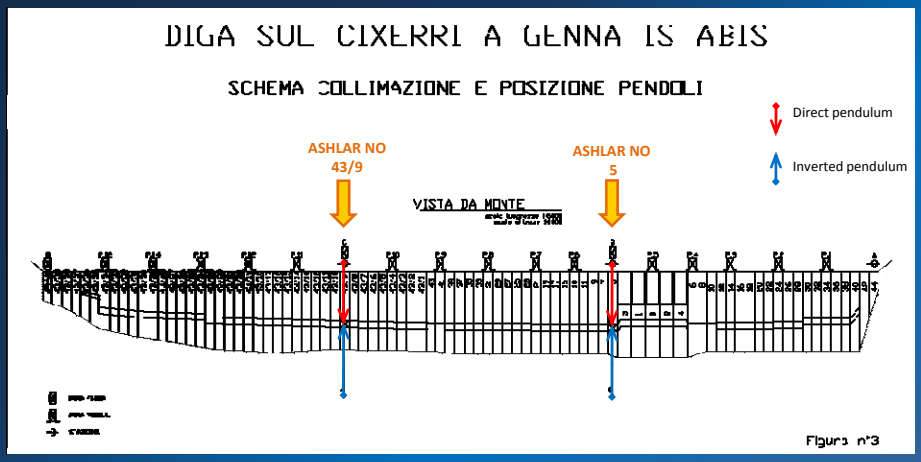
The GNSS technology can't replace traditional control instruments but can be used together with these other techniques to improve or design monitoring and alarm systems of large dams, raging required accuracy with reasonable economic efforts.

Thank you for your attention

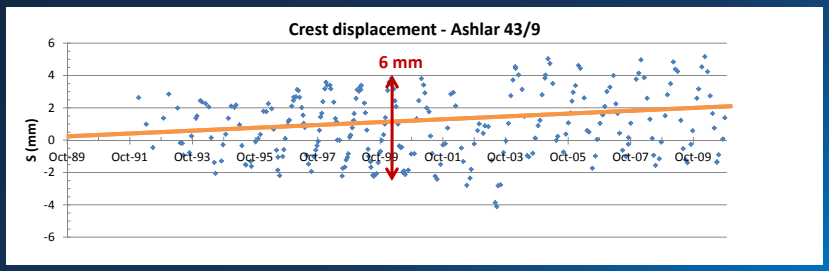
INSTALLED MONITORING INSTRUMENTS

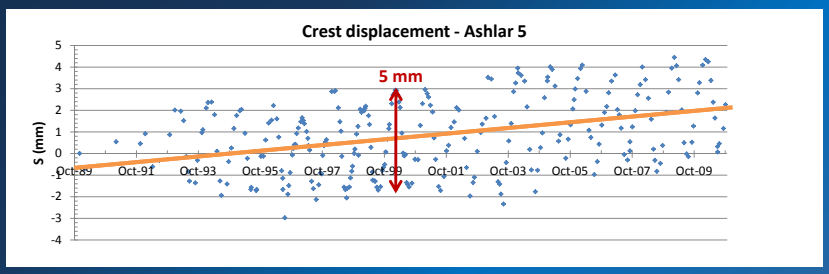
- 84 extensometers (accuracy: 0.002 mm)
- 77 extensometers (accuracy: 0.1 mm)
- Collimation system
- 2 pendulum chambers (ashlar no 5 and 43/9)

Each chamber contains two optical pendulums (a direct instrument and an inverted one) (accuracy: 0.02 mm)



PENDULUM DATA SERIES



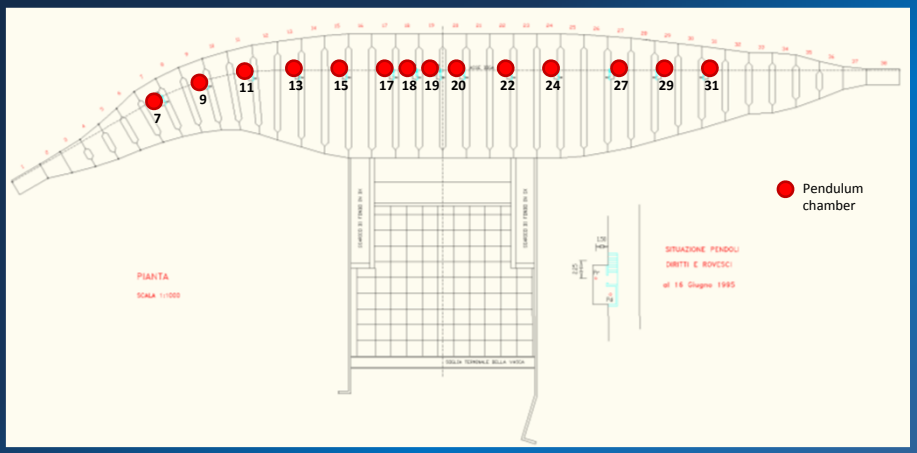


Positive values are crest displacement to downstream direction

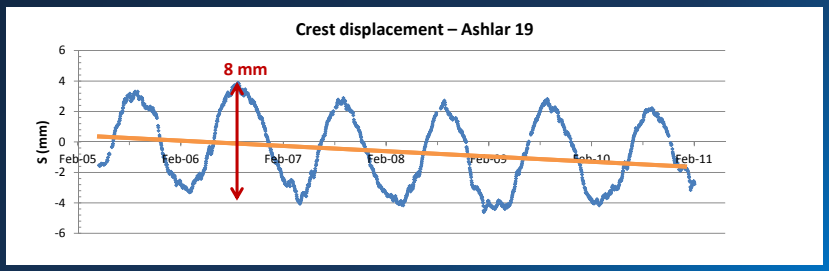
INSTALLED MONITORING INSTRUMENTS

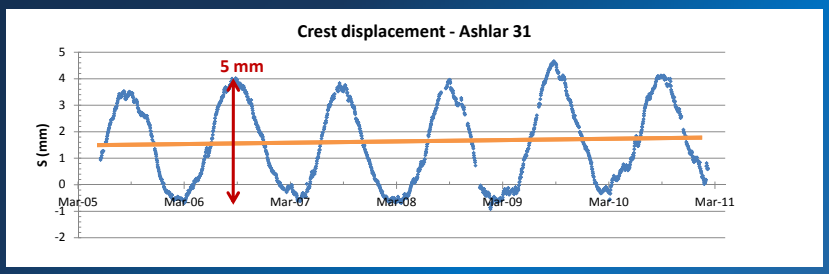
- 36 extensometers (rockmeters type)
- 54 conventional extensometers
- 122 mono-axial joint-meters
- 14 pendulum chambers

Each chamber contains two inverted pendulums and a direct instrument
(accuracy: 0.01 mm)



PENDULUM DATA SERIES





L'asse MV è perpendicolare allo sbarramento e coincide con la direzione monte – valle.
Gli spostamenti sono negativi se diretti verso valle

SELECTED MODELS

PoliMi

- Set only as a function of time
- No physical quantities
- Predictive

Period (365 days)

Time step

$$S = a \cdot t + b + A \cos\frac{2\pi t}{T} + B \sin\frac{2\pi t}{T} + C \cos\frac{4\pi t}{T} + D \sin\frac{4\pi t}{T}$$

Deterministic

- It depends only on measured physical quantities
- Based on cause - effect correlations

Annual average of daily air temperature

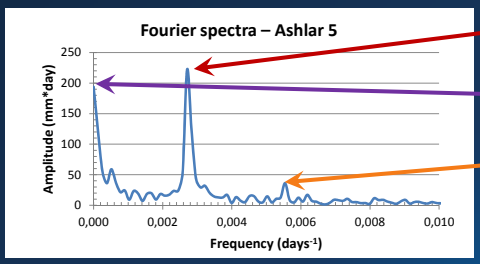
Water level

$$S = a \cdot T_{av\ year\ air} + b \cdot T_{av\ water} + c \cdot H + d \cdot H^2 + e$$

Two weeks moving average of water temperature

FAST FOURIER TRANSFORM (FFT)

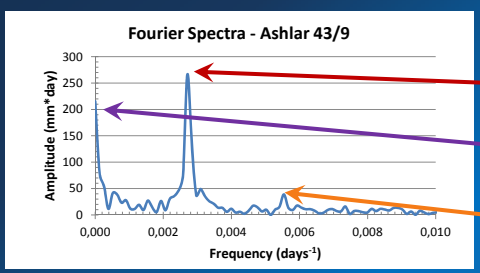
PoliMi Model – Genna Is Abis Dam



F = 0,00271 days^{-1} → T = 369 days
Linear trend

F = 0 → T = ∞
Linear trend

F = 0,00554 days^{-1} → T = 180 days
Linear trend

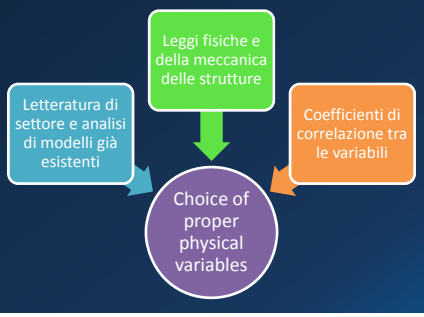


F = 0,00271 days^{-1} → T = 369 days
Linear trend

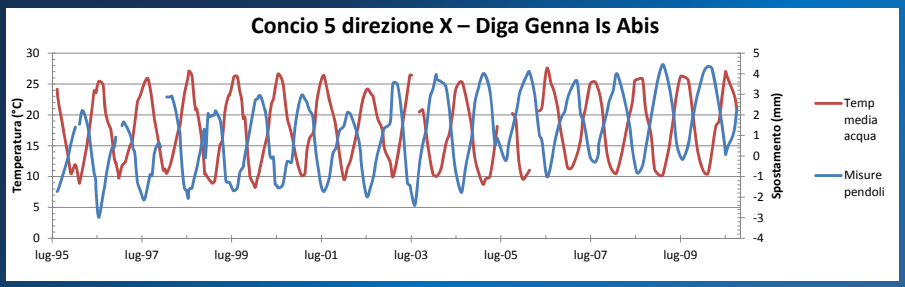
F = 0 → T = ∞
Linear trend

F = 0,00554 days^{-1} → T = 180 days
Linear trend

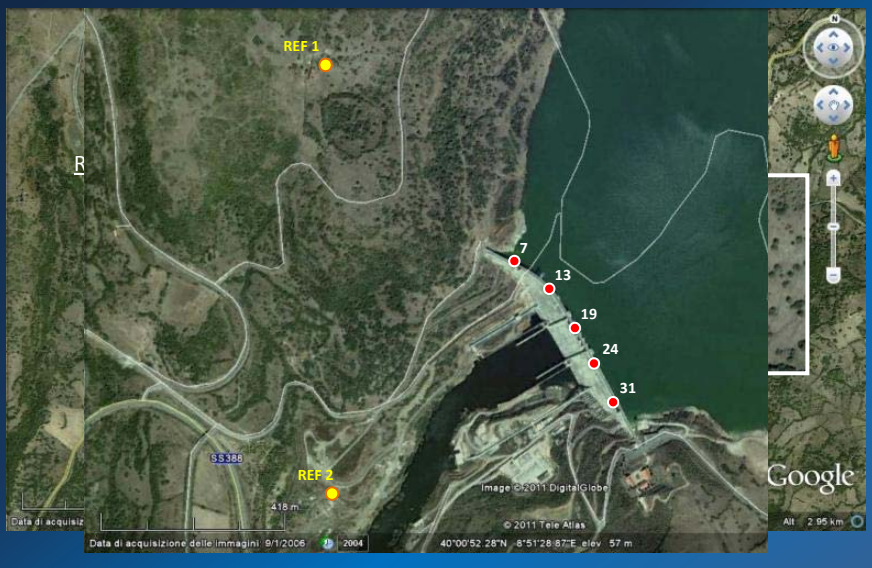
Come scegliere le grandezze fisiche da inserire nel modello?



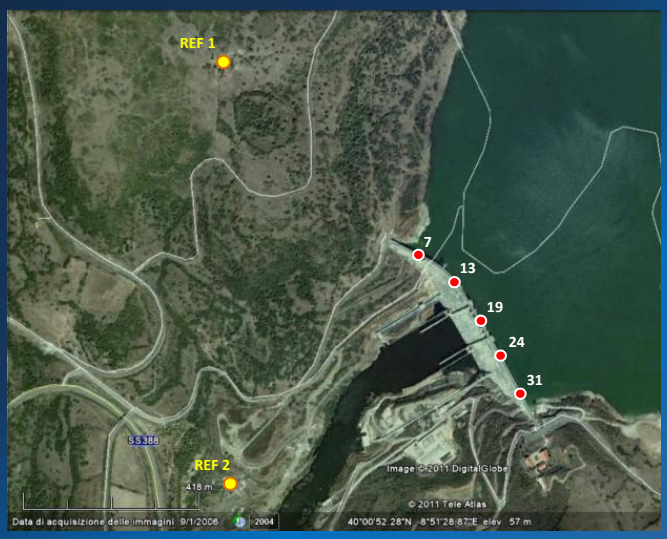
	Concio 5 X	Concio 43/9 X
Temperatura aria	-0,642	-0,738
ΔT aria-acqua	0,215	0,146
Temperatura media acqua	-0,824	-0,881
Quota invaso	0,325	0,299



Project of GNSS network on Cantoniera Dam



Project of GNSS network on Cantoniera Dam

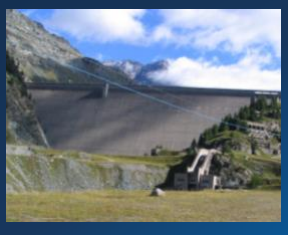


Classification of dams

Concrete gravity dam

Hollow buttress gravity dam

Arch dam



Quaira Dam (BZ)

Malga Bissina Dam (TN)

Cancano Dam (SO)

Il GNSS nel controllo delle strutture

GNSS =Global Navigation Satellite System

VANTAGGI

- Rilevamento in continuo
- Dati in formato digitale
- Assenza di operatori sul posto
- Trasmissione dati in remoto
- Costo contenuto

SVANTAGGI

- Precisione conseguibile (millimetrica)
- Visibilità dei satelliti
- Rumore ambientale

Nonostante la precisione millimetrica è possibile sfruttare la tecnologia GNSS per il monitoraggio delle grandi dighe ?

La modellazione

È una procedura che cerca di ricostruire l'andamento di una determinata serie storica di misure mediante l'impiego di una equazione matematica.

MODELLI UTILIZZATI

PRESENTI IN LETTERATURA

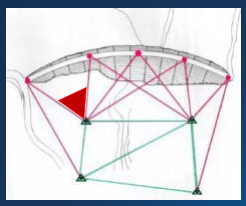
- ~~Carosio – Dupraz~~
- **De Sortis – Paoliani**

SINTETIZZATI EX – NOVO

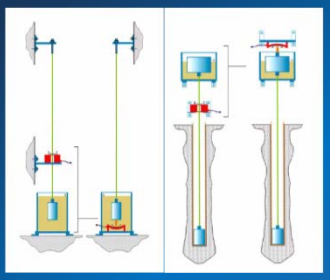
- **Modelli "predittivi"**
- **Modelli "fisicamente basati"**

Monitoring instruments

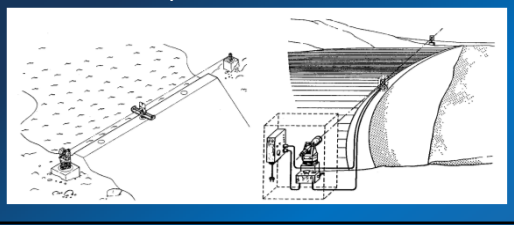
• Stazione totale



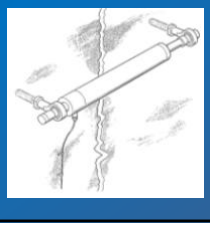
• Pendulums



• Collimation systems



• Extensometers



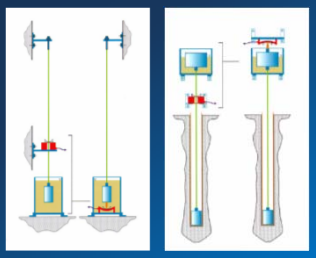
STRUMENTI TOPOGRAFICI CLASSICI

• Stazioni totali

• Collimatori

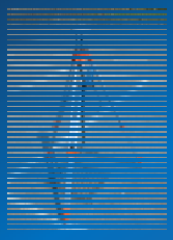
•Estensimetri

•Pendoli



STRUMENTI TOPOGRAFICI MODERNI

• Apparati GNSS



ANALISI DELLE SERIE STORICHE