Analysis of the Geodetic Monitoring Record of the Ladon Dam (Greece)

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GEODETIC MONITORING OF DAMS

- In the last 50 years there have been many cases of dam failure with high death toll even 200.000 dead and major destruction
- Geodetic Dam monitoring proved necessary to prevent or forecast such failures.
- Still very little is known about dam deformation
- Ladon dam is one of the very few dams for which a long geodetic monitoring record is available

Ladon Dam, Greece

type	: concrete gravity dam
crest length	: 101.5m
height	: 56m
use	: generation of electricity

Geodetic Monitoring System

• 6 monitoring stations on the crest of the dam and 2 control stations close to the abutments

• measurements of horizontal deflections and vertical displacements

•30 years of monitoring record (1968 - 2001)

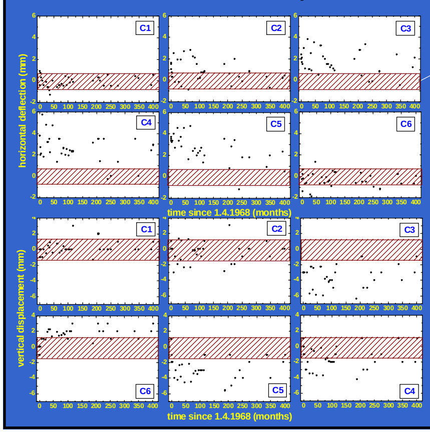
Horizontal deflections

Measurement of horizontal deflections of control stations along the dam crest from a a straight line using a high accuracy theodolite

Vertical displacements

Measurement of relative elevations of control stations are relative to a reference station at the abutments using high accuracy spirit leveling

Results from 30 years of monitoring



Uncertainty zone

ACCURACIES

horizontal deflections:
standard error: ± 0.7mm

vertical displacements:
standard error: ± 1.3mm

Results

- Small-amplitude (up to 7mm) displacements, but statistically significant
- Fluctuations in the sense of displacements

Questions

- Is there a pattern in the observed movements?
- Are displacements controlled by hydraulic load (reservoir level fluctuations)?
- This means, is there a **periodic signal** in our displacement data?
- Is the period in both displacements and reservoir level change equal, implying a causative relationship?

Data Analysis to answer these questions

Available Data

- Horizontal and vertical deflections of 6 control stations on the crest of the dam covering the time interval 1968 – 2001 (*not* equidistant)
- ambient temperature
- reservoir level fluctuations

We examined separately

the available data for control stations *C3* and *C4* in the *middle* of the crest of the dam for *2 time periods*: April 1968 – February 1978, April 1968 – October 2001

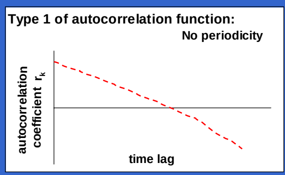
Techniques we used

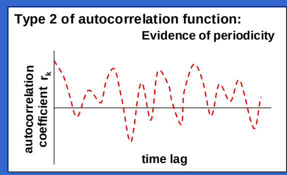
autocorrelation function
Lomb normalized periodogram

Autocorrelation function

(*in order to check the presence of periodicity in the values of the deflections and the reservoir level*)

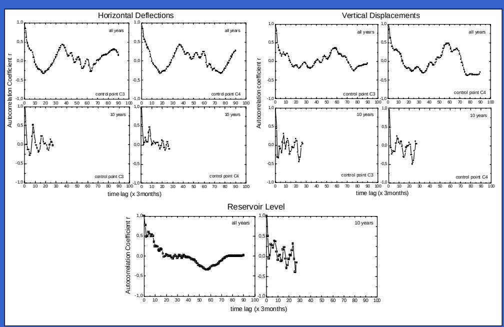
The autocorrelation function reveals how the correlation between any two values of the series changes as their separation changes.
In the case that there is a periodic signal in the data the autocorrelation function is a sinusoidal-type curve.





Data used:
Autocorrelation function requires *equidistant* data . Since we had no such data, predicted values calculated by a 3rd degree polynomial interpolation were used. This may of course introduce some bias.

Results of the autocorrelation analysis:



The sinusoidal-type of the autocorrelation function implies a *periodicity* in *all* data sets

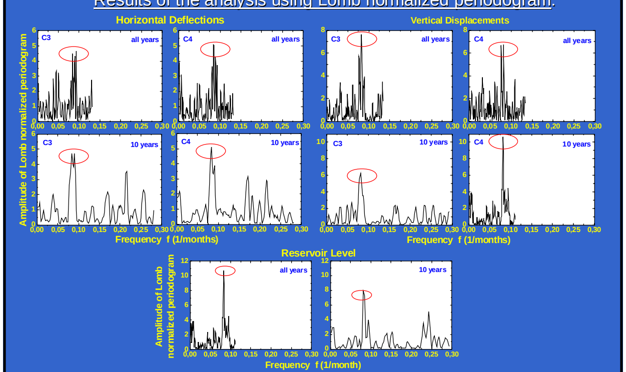
Since the autocorrelation revealed the existence of periodicity, we applied the

Lomb normalized periodogram technique in order to determine the possible dominant frequencies of the displacements of the dam and the fluctuations of the reservoir level

The method is somewhat equivalent to the Fourier Transforms. It is based on the minimalization of the sum of squares in least-squares fitting of sine waves to the data.

Data used:
raw data were used, for no equidistant observations are required. Thus uncertainties induced by interpolation were avoided.

Results of the analysis using Lomb normalized periodogram:



The deflections and the reservoir level have the *same* dominant period equal to *12 months*. This result was deduced for *all* 10 sets of raw data analyzed and for *both* time intervals examined (1968 – 1978 & 1968 – 2001)

Conclusion 1:

The amplitude of the displacements is small up to 7mm, though statistically significant at 2σ and even 3σ precision levels for most stations.

Displacements are maximum at control stations C3 and C4 at the middle of the dam, as is expected in any dam.

Conclusion 2:

The sinusoidal-type of the autocorrelation function in all 10 data sets of predicted values that were examined revealed that the displacements of the crest of the dam and the reservoir level are periodic.

Conclusion 3:

The analysis based on the Lomb normalized periodogram method indicated that both **horizontal deflections** and **vertical displacements** correspond to periodic functions with a period of 12 months, equal to that of the fluctuations of the reservoir level (20m).

This indicates a causative relationship between hydraulic load and dam deformation.

Conclusion 4:

The analysis indicated that almost 50 years after its construction, the Ladon Dam keeps its structural integrity; a result consistent with the absence of water leakage and other evidence of failure (cracks, etc.).

The Ladon Dam during the flooding period of February 2002.

Both spillways are simultaneously in use for the first time since the hydro plant became operational in 1955.