CORRELATIONS OF DRĂGAN DAM HORIZONTAL DEFORMATIONS 1D AND 2D INTERPOLATED TIME SERIES

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***Abstract**: Usually dam monitoring structural deformation is carried out through physical methods (inverted pendulum) and surveying methods (optoelectronic). The 1D and 2D time series Fourier analysis is used to generate the correlations between the horizontal deformations measured by these two different methods. In this paper the 2005-2008 time series have 1189 points from inverted pendulum and only 8 points from surveying measuring epochs. In order to generate accurate results, a Fourier interpolation and a Gaussian kernel smoothing of the surveying time series data are done. A comparison between 2000-2005 and 2005-2008 time series correlation results for plot (abutment) 19 of the Drăgan Dam, from Cluj County, Romania is also provided.*

***Keywords:** deformation analysis, Fourier correlation, interpolation, dam monitoring.*

1. Introduction

Drăgan dam presents a double arch concrete structure featuring 120 m height and 450 m length at the crest, with 33 vertical plots and generates a basin of about 120 million m3 of water. Monitoring the deformations of large concrete dams is important to prevent fatal accidents of dam cracking. The deformations of the dam crust are measured physically with an inverted pendulum with a very good precision (10-2 mm) given by an optical coordiscope. The surveying (topographical) method readings of dam crust deformations are done with a surveying total station. The last method involves building a local surveying network of control points, from which, sets of readings are measured for the same deformations (Alba, 2006; Behr, 1998) at the target points localized on the dam crust.

For plots 7, 12, 19, 24 and 29, the time series provided by the inverse pendulums consist in 1189 readings, from May 2005 until November 2008. The time series provided by the surveying epochs consist in only 8 readings of deformations at the target points placed near the measuring points of the inverted pendulums.

This paper presents the time series Fourier correlations for five target points and their nearest measuring points, done only for plot 19, which is the middle vertical axis of the dam.

2. Theory

There are two ways to get the correlation information between two time series that have different numbers of readings. The first way is to select only the corresponding 8 readings out of the 1189 readings provided by the inverted pendulum, which match the surveying method dates (figure 1). The second way is to interpolate the 8 readings from the surveying method and to obtain N=1189 readings time series, which match the inverse pendulum time series (figure 2, 3). In this paper, we chose the second way.

There were selected two ways to interpolate the surveying time series (figure 4): Gauss kernel smoothing and Fourier interpolation (*W* is the low-pass frequency filter window).

The horizontal deformations within the inverse pendulum time series (1D+t) are denoted by x (figure 1, the thin line) and the surveying time series are denoted by xT (figure 1, the thick line). The x direction represents the upstream-downstream direction and the y direction represents the left-right side direction, both referenced in a local coordinate system. Furthermore, we consider only the horizontal deformations (x and y) in five target points of the vertical axis belonging to plot 19.

The vertical axis of plot 19 consists in five measuring/target points (figure 4a, 5a) spatially distributed along the plot height – i.e. one vertical bolded line from figure 4a, 5a. The (2D+t) time series of the horizontal deformations which were correlated are: Hx and HxT , the upstream-downstream from the inverse pendulum readings and from the surveying readings (figure 4a); consequently, Hy and HyT , the left-right side from the inverse pendulum readings and from the surveying readings (figure 4b).

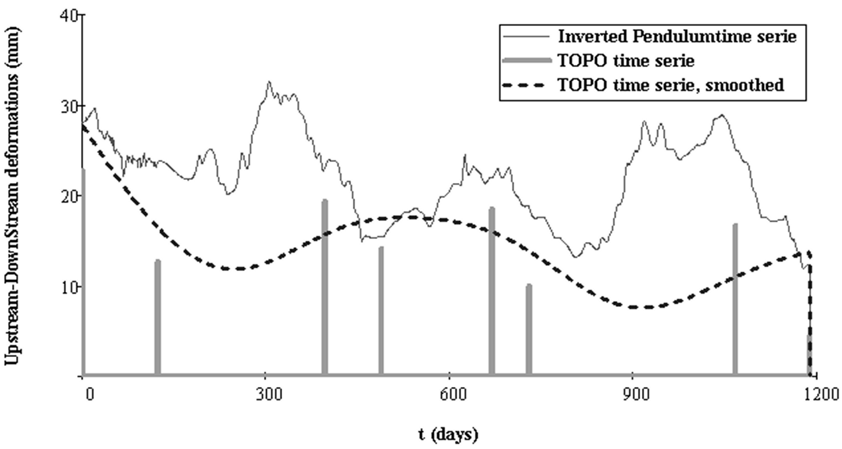


Fig. 1. Time series of Drăgan dam deformations.

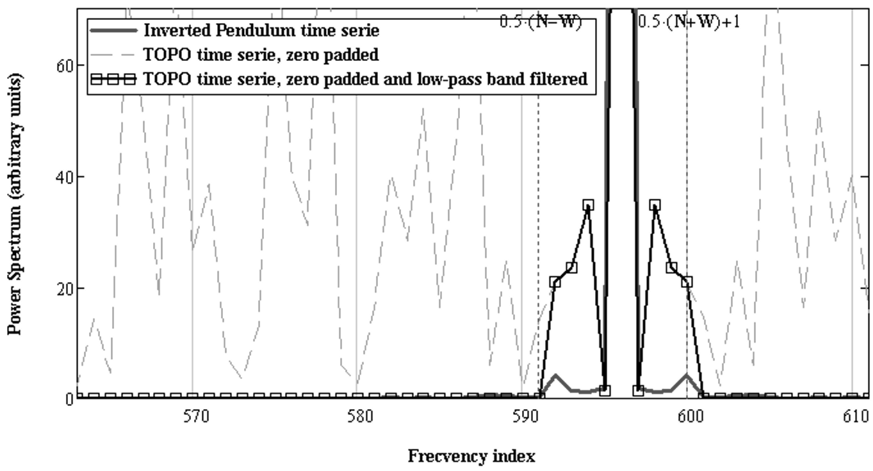


Fig. 2. Power spectrum low-pass frequencies filtering for Fourier interpolation.

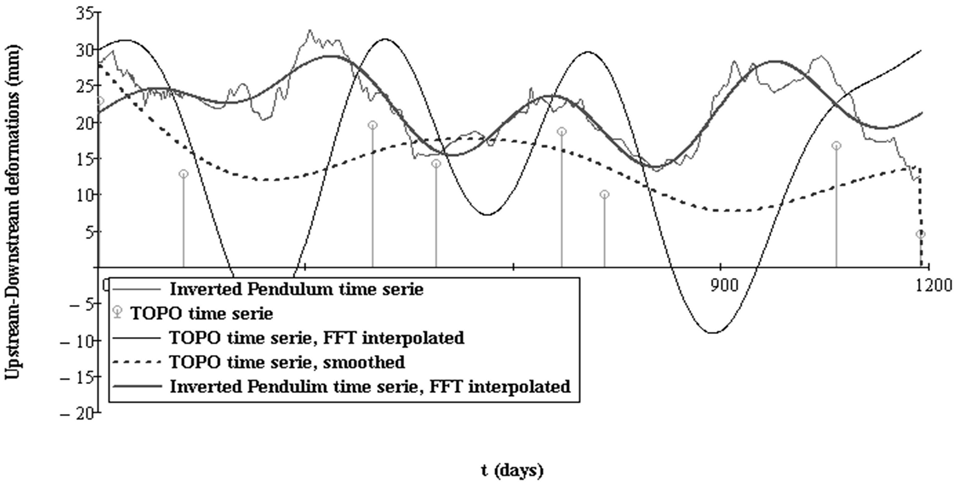
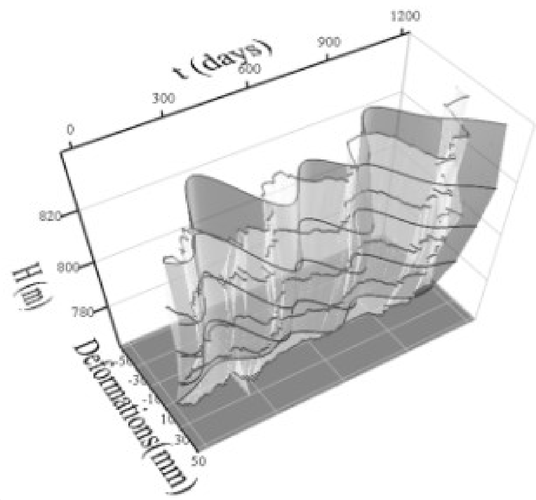
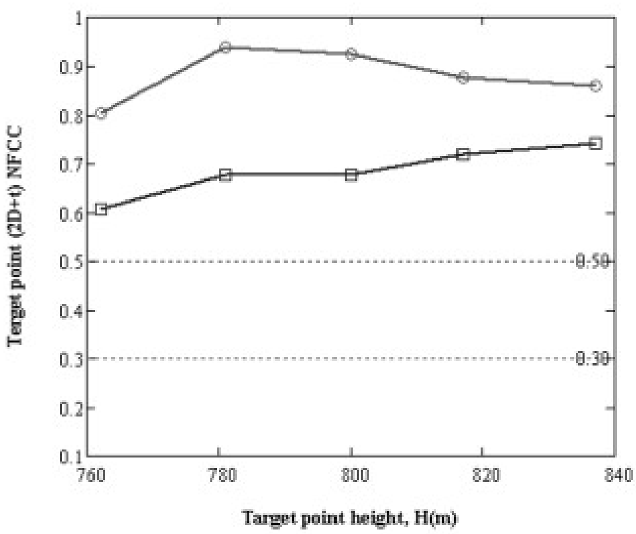


Fig. 3. Horizontal deformation time series interpolations.

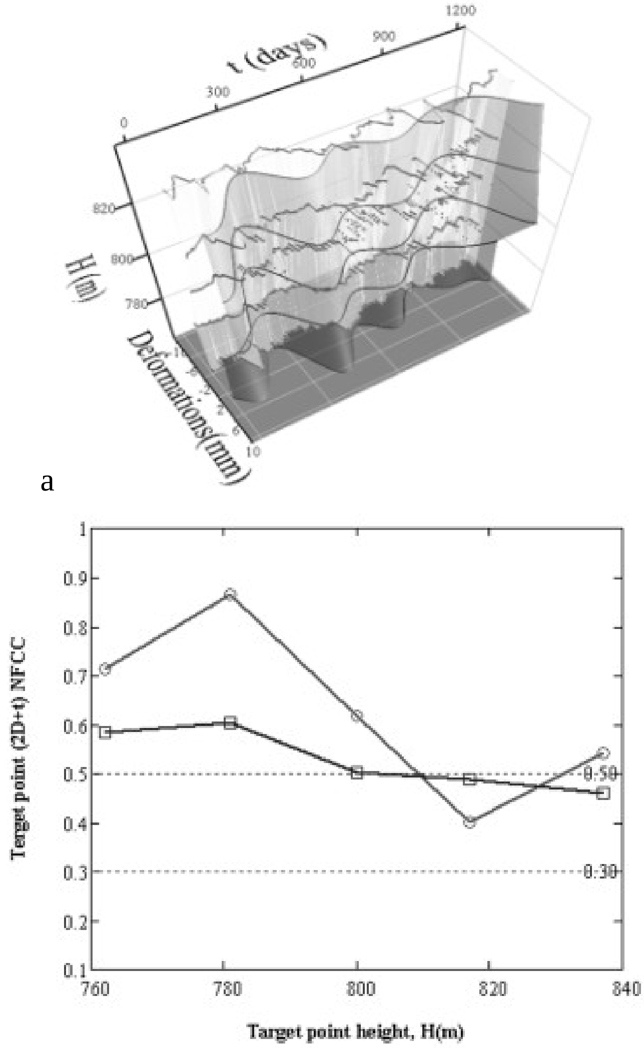


a



b

Fig. 4. Plot 19 vertical axis upstream-downstream deformations: a - (2D+t) time series; b – (1D+t) Fourier correlations for the five target points.



a

b

Fig. 5. Plot 19 vertical axis left-right side deformations: a - (2D+t) time series; b – (1D+t) Fourier correlations for the five target points.

The correlation process may be a statistical analysis or a Fourier spectral one. The normalized Fourier correlation coefficient, $NFCC$ can be built from the Fourier analysis, described (Grierson, 2006) by

$$NFCC(f(t),g(t)) = \max_t \left[\frac{\left[\left| f(t)\otimes g(t) \right|^2 \right]}{\max_t \left[\left| f(t)\otimes f(t) \right| \right]^{0.5} \cdot \max_t \left[\left| g(t)\otimes g(t) \right| \right]^{0.5}} \right] \quad (1)$$

$$= \max_t \left[\frac{\mathcal{F}^{-1}\left[\overline{F(-\nu)} \cdot G(\nu) \right](t)}{\max_t \left[\mathcal{F}^{-1}\left[\left| F(\nu) \right|^2 \right](t) \right]^{0.5} \cdot \max_t \left[\mathcal{F}^{-1}\left[\left| G(\nu) \right|^2 \right](t) \right]^{0.5}} \right]$$

where $f(t), g(t)$ are two functions, $F(\nu)$ $G(\nu)$ are their Fourier transforms, t is the time, ν is the frequency, F^{-1} is the inverse Fourier transform. When the information is time-spatially distributed (2D+t), the only way the correlation process can achieve consequent results is by Fourier correlation (Pytharouli et al., 2004; Pytharouli & Stiros, 2005) and not by statistical correlation.

The statistical significance of the correlation coefficient values is: 0.10 – 0.29 for weak; 0.30 – 0.49 for average, 0.50 – 1.00 for strong (figure 4b, 5b, 6).

3. Results and Discussions

The (1D+t) case of Fourier correlations was done in two ways: first, between the x, y and Fourier interpolated xT, yT time series, $FixT$, $FiyT$ - with boxed line in figure 4b, 5b; second, between the x, y and Gauss kernel smoothed xT, yT time series, $GKixT$, $GKiyT$ - with circled line in figure 4b, 5b.

The (2D+t) case of Fourier correlations was also done between the Hx and $FiHxT$, $GKiHxT$ and Hy and $FiHyT$, $GKiHyT$ (i.e. vertical axis of plot 19 - figure 6).

Both ways of the (1D+t) case Fourier correlations have $NFCC$ values that qualify them as: highly correlated for upstream-downstream direction (figure 4b) and average to strongly correlated for left-right side direction (figure 5b).

The results of Fourier correlation for (2D+t) case time series denote that the horizontal deformations measured by the inverse pendulum and by the surveying method are strongly correlated_for (Hx vs. $FiHxT$, $GKiHxT$) and just average to strongly correlated for (Hy vs. $FiHyT$, $GKiHyT$) (figure 6).

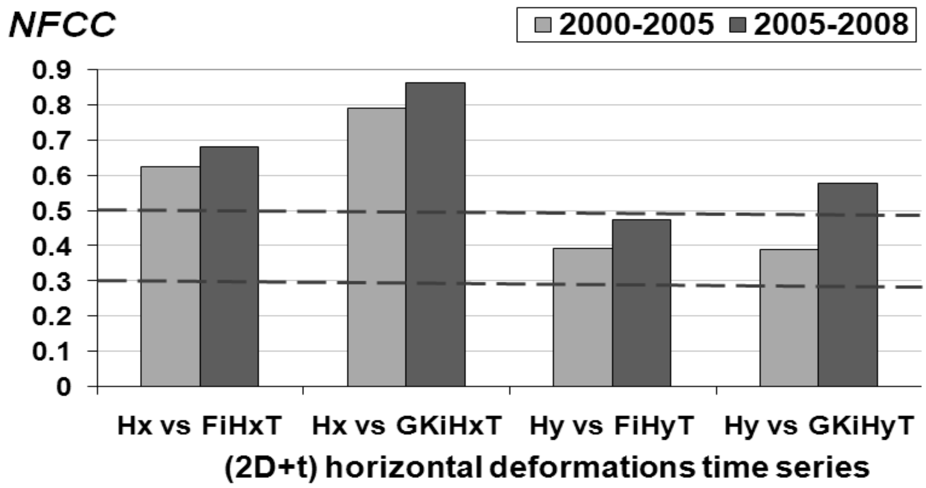


Fig. 6. (2D+t) Fourier correlation results for plot 19 – comparison between 2000-2005 and 2005-2008 regarding the horizontal deformation time series.

4. Conclusions

Fourier correlation analysis of the structural dam horizontal deformations measured by physical method and by surveying method is presented. As correlation inputs were used: the (1D+t) deformations time series at target points and the (2D+t) deformations time series of the entire vertical axis of the dam median plot. Despite that the (1D+t) correlation results show an overall (2000-2005, 2005-2008) strong correlation, the (2D+t) correlation results show average to strong correlation of the horizontal deformations (figure 6). This means that the (2D+t) Fourier correlation analysis is more suitable to diagnose the dam’s long term behaviour.

From figure 3, one can note that the surveying time series have lost some important dam deformation extreme values presented in inverted pendulum time series. Thus, in order to achieve a better structural dam crust diagnose, the authorized monitoring institutions should double the number of the surveying epochs.

Figure 6 emphasizes the difference between the Fourier correlation results calculated for the two mentioned time intervals. Better correlations are obtained for the period 2005-2008 in comparison with the period 2000-2005, because of the improved measuring technology.

Future research can involve (3D+t) analysis of all the dam’s plots in order to provide a more accurate dam status diagnosis.

5. References

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