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1D AND 2D TIME SERIES FOURIER CORRELATIONS OF DRĂGAN DAM HORIZONTAL DISPLACEMENTS

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Abstract
Dam monitoring structural displacement is carried out through physical methods (inverted pendulum) and surveying methods (optoelectronic) [1-4]. The 1D and 2D time series Fourier analysis [5] is used to generate the correlations between the horizontal displacements 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.
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. 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. In this paper, we chose the second way.
There were selected two ways to interpolate the surveying time series: Gauss kernel smoothing and Fourier interpolation. 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.

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 m^3 of water. Monitoring the displacements of large concrete dams is important to prevent fatal accidents of dam cracking. The displacements 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 displacements are done with a total surveying station. This method involves building a local surveying network of control points, from which, sets of readings are measured for the same displacements [1-6] at the target points localized on the dam crust.

For plots (abutments) 7, 12, 19, 24 and 29, the time series provided from inverse pendulums consist in 1189 readings, from May 2005 until November 2008. The time series provided from the surveying epochs consist only in 8 readings of displacements 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 (abutment) 19, which is the middle vertical axis of the dam and performs the highest displacements.

2. Method and samples

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, from the 1189 readings with 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.

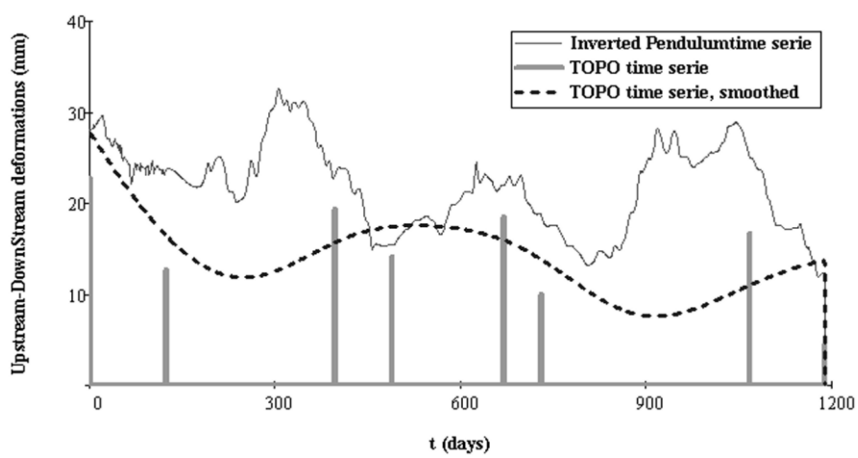


Figure 1. Time series of Drăgan dam displacements.

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).

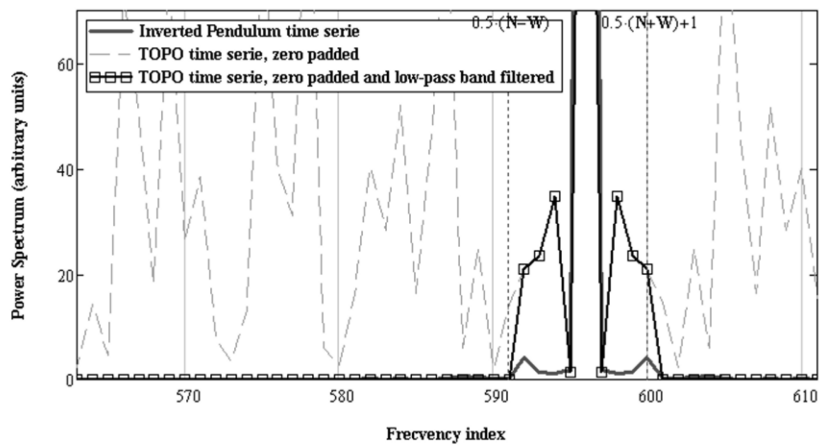


Figure 2. Power spectrum low-pass frequency filtering for Fourier interpolation.

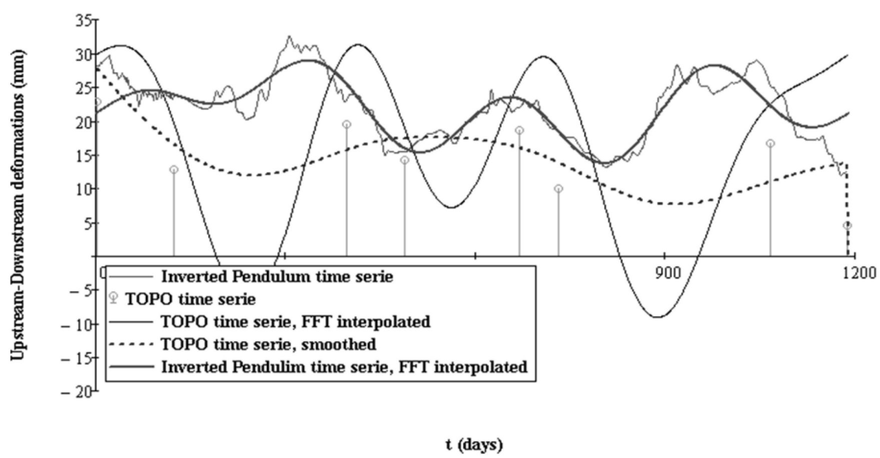


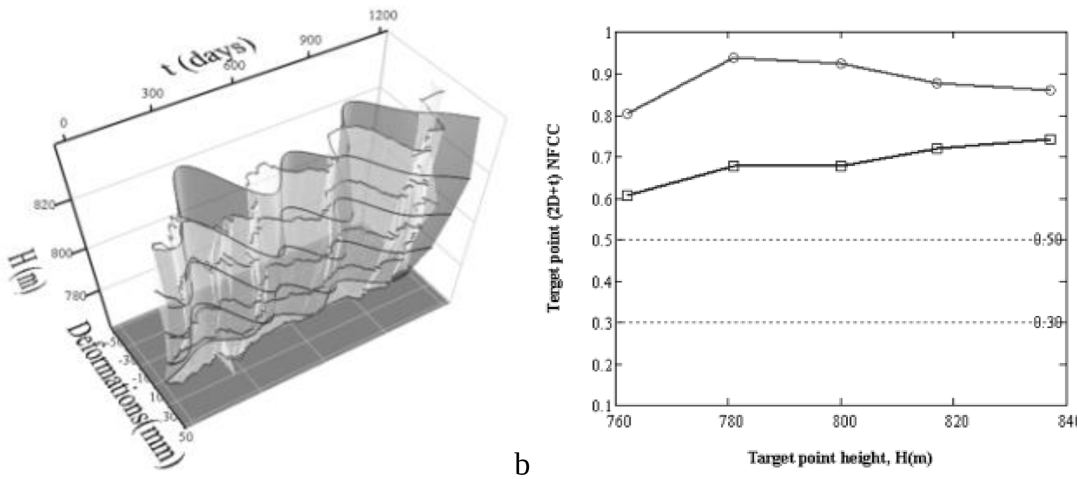
Figure 3. Horizontal displacements time series interpolations.

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

The vertical axis of plot 19 consists of 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 horizontal displacements correlated are: upstream-downstream denoted by Hx , for the inverse pendulum readings and upstream-downstream displacements, denoted by HxT , for the surveying readings (figure 4a), and consequently, Hy and HyT, the left-right side from the inverse pendulum readings and from the surveying readings (figure 5a). The correlation process may be a statistical or a Fourier spectral analysis one. The normalized Fourier correlation coefficient, $NFCC$, can be built from the Fourier analysis, described [7] by

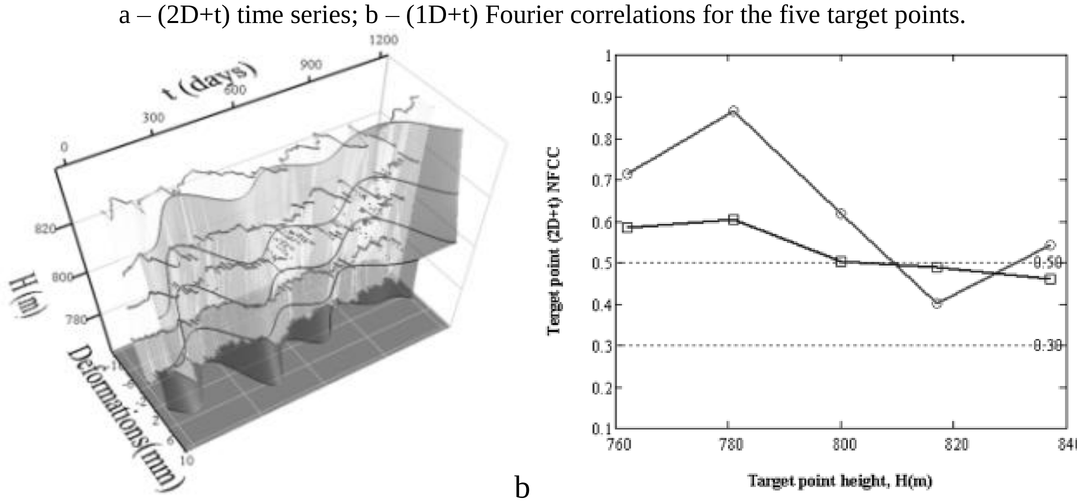
$$NFCC(f(t),g(t)) = \max_x \left[\frac{\mathcal{F}^{-1}\left[\overline{F(-\nu)}\cdot G(\nu)\right](t)}{\max_x \left[\mathcal{F}^{-1}\left[|F(\nu)|^2\right](t)\right]^{0.5} \cdot \max_x \left[\mathcal{F}^{-1}\left[|G(\nu)|^2\right](t)\right]^{0.5}} \right] \qquad (1)$$

where $f(x), g(x)$ are two functions, $F(k), G(k)$ are their Fourier transforms, t is time, ν is frequency, $\mathcal{F}^{-1}$ 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



a b

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



a b

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

Fourier correlation (Pytharouli, S, 2004; Pytharouliand & Stiros, 2005) and not by statistical correlation – as the Pearson coefficient – despite the symmetry of the two definitions of the correlation coefficients.

Statistical significance of the correlation coefficient values are: 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 were 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.

Also the (2D+t) case of Fourier correlations were 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 strong correlated for upstream-downstream direction (figure 4b) and average to strong correlated for left side-right side direction (figure 5b).

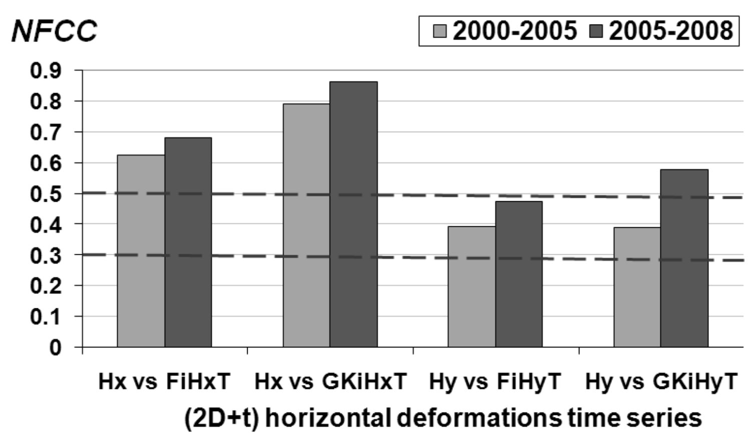


Figure 6. (2D+t) Fourier correlations results for plot 19 – comparison between 2000-2005 and 2005-2008 horizontal displacements time series.

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

Conclusions

Fourier correlation analysis of the structural dam horizontal displacements measured by physical method and by surveying method is presented. As correlation inputs were used: the (1D+t) time series of the displacements at target points and the (2D+t) time series of the displacements of entire vertical axis of the median plot of the dam. 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 displacements. 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 displacements peaks presented in inverted pendulum time series. Thus, in order to achieve a better structural dam crust diagnose, the law enforced monitoring institutions have to double the number of the surveying epochs.

Figure 6 emphasize the difference between the Fourier correlations results calculated for the two time intervals, with better correlations for 2005-2008 than 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's status diagnosis.

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