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FOURIER CORRELATION ANALYSIS OF DRĂGAN DAM 3D HORIZONTAL MOVEMENTS

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Abstract. Horizontal deformations monitoring of Drăgan dam is done by physically methods (i.e. inverse pendulum) and topographically methods (i.e. optoelectronic). The existence of different conclusions drawn from these deformations reveals the correlation importance of the two deformation systems. If there is a correlation then the deformations values differences will be provided by measuring errors; if the correlation is not present then the deformations values differences will be provided by coarse errors.
This paper is intended to compare the deformations for the 3D representation of deformations: 1D for the deformations along the upstream-downstream direction, 1D for the deformations along the left-right direction, 1D for the dam height. Fourier analysis [1-3, 6] is used to generate the correlations of deformations measured by the two different methods mentioned before for all studied dam plots at the same time – i.e. dam crust.
Keywords: deformation analysis, Fourier correlation, dam monitoring.

1. Introduction

Drăgan dam presents a double arch concrete structure featuring 120m height and 450m length at the crest. It has 33 vertical plots and generates a basin of about 120 million m^3 of water. Monitoring the deformations of large concrete dam is important to prevent fatal accidents of dam cracking. Dam crust deformations are measured physically with an inverse pendulum with a very good precision (10^{-2} mm) given by an optical coordioscope. The surveying method readings of dam crust deformations are done with an optoelectronic device called total surveying station. This method involves building a surveying network of reference points, from witch are measured sets of readings for the same deformations [4, 5, 7, 8].

For plots 7, 12, 19, 24 and 29 the time series provided from inverse pendulums consists in 2010 readings, from May 2000 until November 2005. This is the reason why the time series provided from the surveying targets (i.e. the control points) consists only of the deformations readings of control points placed nearest the measuring points of inverse pendulum.

This paper presents the time series correlations [1-3, 6] for five measuring points and their nearest control points, done only for plot 19, which is the middle vertical axis of the dam.

2. Method and samples

There are two ways to get the correlation information between two time series that have different numbers of readings, i.e. 2010 readings for the inverse pendulum and just 12 readings for the surveying method.

The first way is to select only the corresponding 12 dates, from the 2010 dates, that matches the dates for the surveying method. The second way is to interpolate the 12 dates from the surveying method and obtain 2010 readings dates that matches the inverse pendulum time series dates. In this paper we choose the first way which is to correlate these two different time series. As was mentioned before the correlation process involves two time series over 12 dates.

Furthermore, we consider horizontal deformations (X and Y) of plot 19 vertical axis. The vertical axis of plot 19 consist of five measuring/control points spatially distributed along the plot height (2D information). Time series of the vertical axis horizontal deformations gives the (2D+t) surfaces: first upstream-downstream deformations, denoted by HX, for the inverse pendulum readings and second upstream-downstream deformations, denoted by HXT, for the surveying readings.

In the same way were done the crustal (3D) dam correlations (3D = 1D the X + 1D the Y + 1D the height) that implies gathering the horizontal displacements time series for all five plots distributed along the vertical (height) of the dam (figure 1).

Correlation process may be a statistical one or a Fourier analysis one. The normalized Fourier correlation coefficient, $NFCC$, can be built from the Fourier analysis, described [1-3, 6] by

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

where $f(x), g(x)$ are two functions, x and k are two Fourier-conjugate variables (i.e. t as time and ν as frequency). From the authors experience the best way to correlate pure time series is the Fourier analysis method. When the information is time-spatially distributed the only way the correlation process can achieve consequent results is by Fourier correlation and not by statistical correlation – as the Pearson coefficient, R [2] – despite the symmetry of the two correlation coefficients.

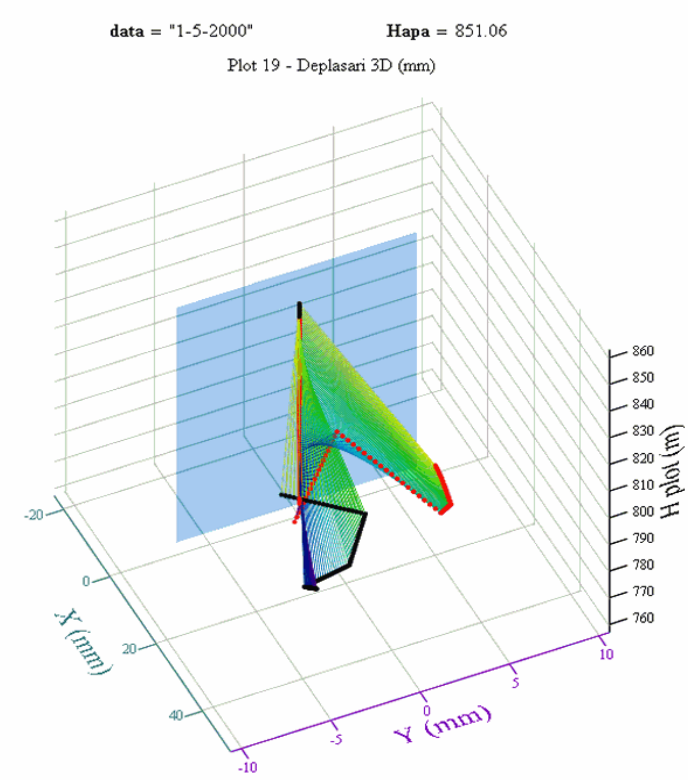

Figure 1 3D vertical plane plotting of plot 19 vertical axis. HX, HY, respectively (HX, HY, H)- continous line and HXT, HYT, respectively (HXT, HYT, H)- doted line, for may-2000. The blue surface represents the water elevation (level, height) in the dam at every time (moment in time).

3. Results and Discussions

Table 3 shows the comparison between the correlation results from both ways: the Fourier correlation and the L_p norm (p=2.5) of the (3D) correlation sets for the each of five plots.

The (3D) Fourier correlations were done in two ways. In the first way were done the pure (3D) Fourier correlations of the every plot for all 12 dates. In the second way the Lp norm of (3D) correlations results were calculated providing the Lp score ($p = 2.5$) over all 12 dates. The normalized Fourier correlation coefficient, $NFCC$, and the Lp score denotes strong correlations between all 3D distributed horizontal deformations measured by inverse pendulum (HX, HY, H time series) and by surveying method (HXT, HYT, H time series).

Table 1. Numerical results and the conclusions from Fourier 3D (1D+1D+1D) correlations between inverse pendulum displacements, (HX, HY, H), and topographical displacements, (HXT, HYT, H), for Drăgan Dam plots.

NFCC (3D)													Correlation type (3D+t)			*p = 2,5*	
Luna	mai 2000	noi 2000	mai 2001	noi 2001	mai 2002	noi 2002	mai 2003	noi 2003	mai 2004	noi 2004	mai 2005	noi 2005	*weak*	*average*	*strong*	*Lp(CnF)*	
Plot 7	0,650	0,422	0,398	0,504	0,272	0,315	0,356	0,218	0,458	0,214	0,352	0,374	3	8	1	0,405	*Average correlation*
Plot 12	0,118	0,293	0,212	0,523	0,406	0,205	0,309	0,255	0,237	0,107	0,385	0,172	7	4	0	0,305	*Average correlation*
Plot 19	0,299	0,642	0,358	0,339	0,585	0,480	0,365	0,425	0,725	0,414	0,485	0,499	0	9	2	0,492	*Average correlation*
Plot 24	0,376	0,088	0,167	0,232	0,562	0,181	0,081	0,034	0,085	0,042	0,098	0,457	3	3	0	0,286	*Weak correlation*
Plot 29	0,330	0,144	0,150	0,098	0,235	0,135	0,203	0,336	0,187	0,132	0,252	0,494	8	3	0	0,263	*Weak correlation*
													5	7	0	*0.350*	*Average correlation*
Mean Values	0,355	0,318	0,257	0,339	0,412	0,263	0,263	0,254	0,338	0,182	0,314	0,399	*0.307*	...	7/5 = 1,4	⇒	⇓ *Average correlation*

4. Conclusions

Fourier space-time (2D + t) planar displacements correlations of the vertical axes of dam plots given by inverse pendulum and topographic measurements are average to strong correlated. In terms of comparison, the (1D + t) correlations are strong, and the (2D + t) correlations are only average-strong. This is because when building a series of values of planar deformations (HX, HY, respectively HXT, HYT) for vertical axes of the plot of the 1D (X, Y, respectively XT, YT) are involved "imperfect correlation" of them - but just strong correlation. Therefore it is desirable that inverse pendulum and the topographic measurements to be performed with high accuracy and to pursue the elimination of systematic errors.

The comparison results of the Fourier correlation between the 3D distributed horizontal movements time series of dam plots (HX, HY, H) and (HXT, HYT, H), reveal an average correlation type (table 1). This leads to the conclusion that it is necessary to increase the spatial resolution of target points on the vertical axis of the dam plots for higher statistical significance of the correlation.

From the quantitative and qualitative point of view previous correlations results (3D+t) for the period 2000-2005 between physical measurements and a topographic measurements the correlation type is average for the whole dam Drăgan. This type of correlation enables the achievement of forecasts movements from the inverse pendulum measurements for topographic measurements and times needed for making them so as not to lose characteristic variations, and especially those non-characteristic movements of the dam – i.e. dam monitoring [4, 5, 7, 8].

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