Geomatics techniques applied to auscultation of industrial structure: the case of oven 5 of SOCOCIM industries

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Abstract
To sustain technical ownership of its new industrial facilities and ensure the safety of people and equipment, SOCOCIM industries set up a monitoring system of new production units through auscultation service structures.
This is to achieve mathematically predict the dynamic behavior of three-dimensional solid with a rotary kiln with a length of 50 m and weighing on full capacity over 1000 tons. To thwart any occurrence of disorders associated with high mechanical activity of the soil, a specific arrangement of the foundation mass was conducted by use of stochastic calculations.

Keywords*: Surveying, Geodesy, parametric Compensation, Listening, Time Series, autoregression model.*

I. INTRODUCTION

The preparation of maintenance work in industrial plants now has use of study tools, modeling and simulation based on the exploitation of topographical measurements using specific mathematical models [1-2]. These analysis and simulation tools based on3D data are becoming more numerous and powerful [3-4-5].

Since 2008, the company SOCOCIM industries (West African Cement Company) has embarked on a modernization of its production units whose mistress idea is marked by a quest for quality and safety in compliance with environmental provisions force. The objective of this article is to study and translate the dynamic behavior of the massive production chain by use of stochasticcal culations by coupling time series analysis and parametric compensation.

II. LOCALISATION OF THE SITE

SOCOCIM industries (West African Cement Corporation) are located at the geographic coordinates 14.70° latitude and 17.25° west longitude.

Figure 1 : Localisation of SOCOCIM

III. METHODOLOGY AND MATERIALS

The methodology will be divided into two main parts:
i) Data acquisition
ii) Presentation and data processing.

a. Data acquisition

Prior to any collection of surveying data necessary to supply the bank chronic massive dynamic, is the creation of new topographical points of reference, serving as a support for future stations raise and auscultation.

III. 1. Implementation of the auscultation network

For not working directly on the work, a network of auscultation was implemented. The detection of absolute motions of the structure requires a linking of measuring points of the structure at sufficiently remote auscultation network area susceptible to the furnace operation related movements.

The establishment of new points of support is obtained by connecting existing system to the initial reference, which is the basis of previous work. This system is materialized on the ground by two terminals R2 and R3 of horizontal and vertical coordinates defined.

The three new items to reattach her: RFA1, RFA2, RFA3. The horizontal and vertical connecting of these points is made from the two reference terminalsR2 and R3, which unfortunately cannot be stationed because of intersight default between themselves first, then between them and the new terminals to be attached. The location of R2 and R3 terminals reveals other difficulties, mainly related to the narrow and congested places, which results in the field by the presence of obstacles still on the main lines of operation. The complete blockage of the GPS horizon by industrial buildings automatically excludes the possibility of application of the GPS method.

Given this situation, the best technical solution capable of giving good information remains the method of free station with forced centering on all affected **[6-7]**. The instrument used is the total station.

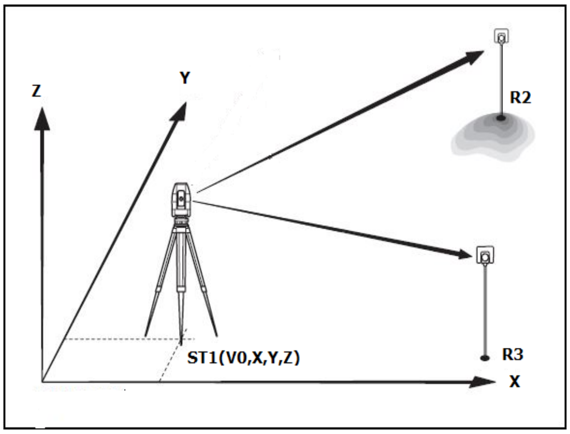

Figure 2: Free Station on ST1

We applied this method to create the ST1point from which we have reproduced a second intermediate station ST2, located on the loading ramp of coal, where a wide view of the scope allows for direct targeted on three new terminal link. The treatment of observations from field operations by total station TRIMBLEM 35 0 enabled the determination of new trigonometric points. Meanwhile, a direct digital leveling level SPRINTER 250 M was executed for control of the trigonometric method.

Calculations on COVADIS gave planimetric closing gaps of 3 mm on the ST4 checkpoint, while the maximum vertical closing gap is 1 mm. The results confirm those of direct leveling of the trigonometric method.

III.2. Mathematical tools

The error in an isolated observation is undetectable. It takes a large number of measures to exclude systematic errors and mistakes. To achieve a level of objective assessment of the dynamic behavior of the massive, monthly data collection campaign has been in place since 2009. To date, 252 topometric measurements (X, Y, Z) were collected from both sides of the three mass exactly at the same places, materialized by metal pins sealed firmly in the concrete. We propose to study these data by combining Fourier analysis to stochastic calculations of time series parametric compensation.

2.2.1. Harmonic analysis of time series

The astronomers were the first to use Fourier analysis of time series. They sought to detect seasonality hidden in their data. This approach has given birth to harmonic analysis.

In 1924, Whittaker and Robinson **[**6-7**]** have used this theory on the brightness of the star T-Ursa Major, observed 600 days, and showed that the gloss could be modeled using two harmonic functions, with periods 24 and 29 days.

$$F_i(t) = \sum_1^n (\rho_j \cos \omega_j\, t - \theta_j) + \varepsilon_t \qquad (1)$$

III.2.1. Autoregressive time series model

Two articles published in 1927 opened another route: Yule **[**9**]** and Slutsky **[**10**]** articles introduced in the literature autoregressive models, considering the shape of models:

$$F_t = \alpha F_{t-1} - \beta F_{t-2} \qquad (2)$$

Given two initial values, this suite has a seasonal behavior, based on α and β parameters. Yule noted that in fact the behavior depends on the complex roots of the equation:

$$z^2 - \alpha z - \beta = 0 \qquad (3)$$

and more particularly of their position relative to the unit disk. If the modulus is less than1, then there is a damped sinusoidal behavior. In fact, the general form of solutions will be:

$$F_i(t) = A\rho_i^t \cos(\omega t - \theta) \qquad (4)$$

III.2.2. Descriptive indices time series [11**]**

Central Tendency Index: Average

$$\bar{x} = \frac{1}{n}\sum_{t=1}^n x_t \qquad (5)$$

Dispersion index: empirical variance

$$\sigma(0) = \frac{1}{n}\sum_{t=1}^n (\bar{x} - x_t)^2 \qquad (6)$$

Dependency ratio: empirical auto covariance

$$\sigma(h) = \frac{1}{n-h}\sum_{t=1}^{n-h} (\bar{x} - x_t)\,(\bar{x} - x_{t+h}) \qquad (7)$$

Dependency ratio: empirical autocorrelation

$$\rho(h) = \frac{\sigma(h)}{\sigma(0)} \qquad (8)$$

Non parametric estimator: moving average

$$M_t = \frac{1}{2q+1}\sum_{i=-q}^q x_{t+i} \qquad (9)$$

III.3. Parametric compensation

The data is put as media comments and we will express them as functions of unknown parameters. Their chronological appearance leads us to consider periodic functional models as mathematical functions linking the best values observed time.

Functional models comments

$$F_i = A + B\sin(Ct_i + D) \qquad (10)$$

Matrix comments

$$A=\begin{bmatrix} \frac{\partial F_1}{\partial A} & \frac{\partial F_1}{\partial B} & \frac{\partial F_1}{\partial C} & \frac{\partial F_1}{\partial D} \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ \frac{\partial F_n}{\partial A} & \frac{\partial F_n}{\partial B} & \frac{\partial F_n}{\partial C} & \frac{\partial F_n}{\partial D} \end{bmatrix} \qquad (11)$$

Residue Matrix

$$v_1 = F_1 - Y_1^{obs}$$
$$v_2 = F_2 - Y_2^{obs}$$
$$\vdots$$
$$v_n = F_n - Y_n^{obs}$$

$$V = \begin{bmatrix} v_1 \\ \vdots \\ \vdots \\ \vdots \\ v_n \end{bmatrix} \qquad (12)$$

Unknown model parameters

$$X = \begin{bmatrix} A \\ B \\ C \\ D \end{bmatrix} \qquad (13)$$

Determinations of unknowns by parametric compensation and iterations.

$$\delta x_i = (AA^T)^{-1}A^T V \qquad (14)$$

$$X_{i+1} = X_i + \delta x_i$$

$$\delta x_k \approx 0$$
$$X_{k+1} \approx X_k$$

Standard deviation posteriori: it checks the consistency of the functional model with stochastic model measures.

$$\sigma_0 = \sqrt{\frac{V^T V}{n-4}} \qquad (15)$$

IV. Presentation of the results

IV.1. West frontage, landmark I

Table1: functional model coefficients

A	52.3504318
B	-1.19100695
C	-89.8833281
D	2011.41296

Table 2 : original series

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010	34	25	49	47	47	41
2011	53	62	56	51	55	47
2012	60	56	64	55	63	62
2013	64	61	57	54	52	
years	***jul***	***aug***	***sep***	***oct***	***nov***	***dec***
2010	42	35	46	56	55	50
2011	52	51	57	55	47	40
2012	58	56	61	61	62	66
2013						

Table 3: moving averages of order 12

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010						
2011	51	51	53	54	53	52
2012	55	56	56	57	57	59
2013						
years	***jul***	***aug***	***sep***	***oct***	***nov***	***dec***
2010	44	47	49	49	50	50
2011	53	53	53	53	54	55
2012	61	61	61	60	60	55
2013						

Table 4 : seasonal coefficients

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010						
2011	1.0357	1.2066	1.0464	0.9485	1.0355	0.9045
2012	1.0833	1.0055	1.1335	0.9688	1.0993	1.055
2013						
Average	**1.059**	**1.106**	**1.09**	**0.959**	**1.067**	**0.98**
Corrected average	**1.046**	**1.092**	**1.076**	**0.946**	**1.054**	**0.967**
years	***jul***	***aug***	***sep***	***oct***	***nov***	***dec***
2010	0.9446	0.7616	0.9293	1.13	1.1051	1.0139
2011	0.9869	0.963	1.0731	1.0362	0.8704	0.7334
2012	0.9569	0.9227	1.0038	1.0167	1.0373	1.2017
2013						
Average	**0.963**	**0.882**	**1.002**	**1.061**	**1.004**	**0.983**
Corrected average	**0.95**	**0.871**	**0.989**	**1.047**	**0.991**	**0.97**

Table 5: original series seasonally adjusted

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010	33	23	46	49	44	42
2011	50	57	52	54	52	49
2012	57	51	59	58	60	64
2013	61	56	53	57	49	
years	***jul***	***aug***	***sep***	***oct***	***nov***	***dec***
2010	44	41	46	53	55	52
2011	55	59	58	53	47	41
2012	61	64	62	58	63	68
2013						

Table 6: values calculated by the functional model

years	jan	feb	mar	apr	may	jun
2010	52	51	53	53	51	52
2011	53	53	51	53	53	51
2012	51	53	53	51	53	53
2013	53	51	53	53	51	
years	**jul**	**aug**	**sep**	**oct**	**nov**	**dec**
2010	53	52	52	54	52	51
2011	52	54	52	52	53	52
2012	51	52	54	52	51	53
2013						

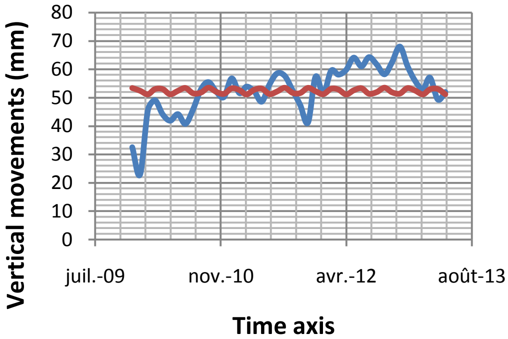

Figure 3: Graphs in mm of the functional model and the original data

IV.2. West frontage, landmark II

Table 7: functional model coefficients

A	75.20790436
B	-1.601899588
C	-96.61964359
D	2146.077768

Table 8 : original series

years	jan	feb	mar	apr	may	jun
2010	45	42	65	62	62	56
2011	73	84	77	72	76	68
2012	86	86	89	83	89	87
2013	91	85	83	82	81	

years	jul	aug	sep	oct	nov	dec
2010	56	51	65	77	77	73
2011	74	77	80	80	73	67
2012	88	85	87	89	92	97
2013						

Table 9: moving averages of order 12

years	jan	feb	mar	apr	may	jun
2010						
2011	71	73	75	76	76	75
2012	81	82	83	84	85	87
2013						
years	**jul**	**aug**	**sep**	**oct**	**nov**	**dec**
2010	62	65	68	68	69	70
2011	76	77	77	78	79	80
2012	88	88	88	88	87	81
2013						

Table 10 : seasonal coefficients

years	jan	feb	mar	apr	may	jun
2010						
2011	1.0341	1.1556	1.0282	0.9469	1.0036	0.9071
2012	1.0557	1.0449	1.0713	0.9908	1.0509	1.0053
2013						
Average	**1.045**	**1.1**	**1.05**	**0.969**	**1.027**	**0.956**
Corrected average	**1.033**	**1.088**	**1.038**	**0.958**	**1.016**	**0.945**
years	**jul**	**aug**	**sep**	**oct**	**nov**	**dec**
2010	0.9049	0.7937	0.9624	1.1304	1.1122	1.048
2011	0.9742	1.001	1.0348	1.0287	0.9232	0.8383
2012	0.9956	0.9625	0.9878	1.0167	1.0528	1.2044
2013						
Average	**0.958**	**0.919**	**0.995**	**1.059**	**1.029**	**1.03**
Corrected average	**0.947**	**0.909**	**0.984**	**1.047**	**1.018**	**1.019**

Table 11: original series seasonally adjusted

years	jan	feb	mar	apr	may	jun
2010	44	39	62	64	62	59
2011	71	77	74	75	75	72
2012	83	79	86	87	88	92
2013	88	78	80	86	80	
years	**jul**	**aug**	**sep**	**oct**	**nov**	**dec**
2010	59	57	66	74	76	72
2011	78	85	81	76	72	66
2012	93	94	88	85	90	95
2013						

Table 12: values calculated by the functional model

years	jan	feb	mar	apr	may	jun
2010	77	74	75	77	74	76
2011	74	76	75	74	77	74
2012	77	74	75	76	74	76
2013	74	77	75	74	77	

years	*jul*	*aug*	*sep*	*oct*	*nov*	*dec*
2010	76	74	77	74	75	77
2011	75	76	74	76	75	74
2012	75	74	77	74	76	76
2013						

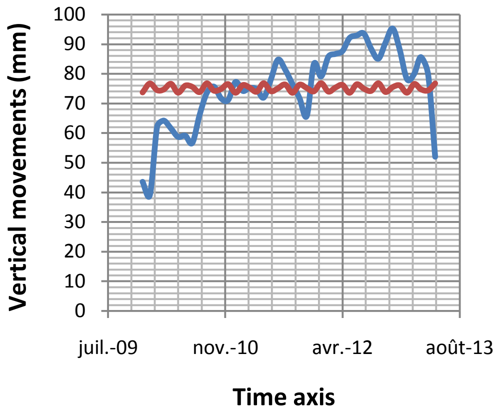

Figure 4: Graphs in mm of the functional model and the original data

IV.3. West frontage, landmark III

Tableau 13 : functional model coefficients

A	83.3547104
B	1.22508893
C	67.1008807
D	180.662735

Table 14 : original series

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010	70	56	77	73	75	68
2011	79	89	84	80	83	77
2012	89	89	92	88	96	90
2013	103	98	98	96	94	
years	*jul*	*aug*	*sep*	*oct*	*nov*	*dec*
2010	67	62	72	81	80	78
2011	81	77	82	83	77	70
2012	91	94	95	96	96	105
2013						

Table 15: moving averages of order 12

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010						
2011	78	79	80	81	81	80
2012	85	86	87	88	89	92
2013						
years	*jul*	*aug*	*sep*	*oct*	*nov*	*dec*
2010	72	74	76	76	77	77
2011	81	82	82	82	83	84
2012	94	95	96	96	96	95
2013						

Table 16 : seasonal coefficients

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010						
2011	1.0153	1.1332	1.0427	0.9881	1.0286	0.9634
2012	1.0471	1.0349	1.0528	0.9948	1.0731	0.9824
2013						
Average	**1.031**	**1.084**	**1.048**	**0.991**	**1.051**	**0.973**
Corrected average	**1.027**	**1.08**	**1.044**	**0.987**	**1.047**	**0.969**
years	*jul*	*aug*	*sep*	*oct*	*nov*	*dec*
2010	0.937	0.8435	0.9456	1.0614	1.0447	1.0095
2011	1.0024	0.9439	1.0024	1.0103	0.9234	0.8341
2012	0.9665	0.9911	0.9944	1.0016	0.9968	1.1014
2013						
Average	**0.969**	**0.926**	**0.981**	**1.024**	**0.988**	**0.982**
Corrected average	**0.965**	**0.922**	**0.977**	**1.02**	**0.984**	**0.978**

Table 17: original series seasonally adjusted

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010	68	52	74	74	71	70
2011	77	82	80	81	79	79
2012	87	82	88	89	92	93
2013	100	91	94	97	90	
years	*jul*	*aug*	*sep*	*oct*	*nov*	*dec*
2010	70	67	73	79	81	79
2011	84	83	84	81	78	72
2012	94	102	97	94	98	107
2013						

Table 18: values calculated by the functional model

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010	84	82	84	84	82	83
2011	85	83	82	85	83	82
2012	84	84	82	84	84	82
2013	83	85	83	83	85	
years	*jul*	*aug*	*sep*	*oct*	*nov*	*dec*
2010	84	82	83	85	83	83
2011	84	84	82	84	84	82
2012	83	84	82	83	85	83
2013						

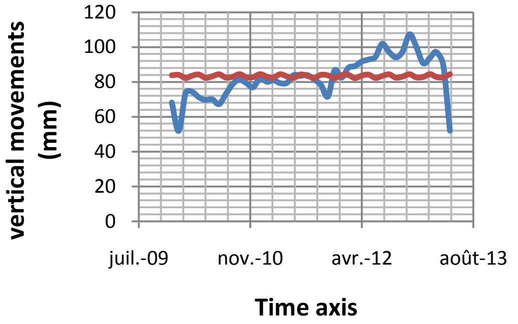

Figure 5 : Graphs in mm of the functional model and the original data

IV.4. East frontage, landmark I

Table 19 : original series

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010	30	28	48	45	44	41
2011	51	58	53	48	52	40
2012	51	47	53	50	58	60
2013	55	56	42	42	47	
years	*jul*	*aug*	*sep*	*oct*	*nov*	*dec*
2010	41	36	47	65	52	49
2011	45	42	46	52	47	42
2012	39	57	51	55	53	53
2013						

Table 20: moving averages of order 12

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010						
2011	49	49	50	50	49	48
2012	49	50	50	51	51	51
2013						
years	*jul*	*aug*	*sep*	*oct*	*nov*	*dec*
2010	44	46	48	48	49	49
2011	48	48	48	47	48	49
2012	52	53	52	52	51	47
2013						

Table 21: seasonal coefficients

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010						
2011	1.032	1.182	1.074	0.956	1.065	0.832
2012	1.049	0.948	1.055	0.981	1.137	1.165
2013						
Average	**1.041**	**1.066**	**1.065**	**0.969**	**1.101**	**0.999**
Corrected average	**1.026**	**1.05**	**1.049**	**0.955**	**1.085**	**0.985**

years	*jul*	*aug*	*sep*	*oct*	*nov*	*dec*
2010	0.9164	0.7768	0.9722	1.3434	1.0621	0.9968
2011	0.933	0.8757	0.9669	1.0992	0.9776	0.8626
2012	0.7434	1.0786	0.9721	1.0656	1.0314	1.1295
2013						
Average	**0.864**	**0.91**	**0.97**	**1.169**	**1.024**	**0.996**
Corrected average	**0.852**	**0.897**	**0.956**	**1.153**	**1.009**	**0.982**

Table 22: original series seasonally adjusted

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010	29	26	45	47	41	42
2011	49	55	51	50	48	41
2012	50	45	51	52	53	61
2013	54	53	40	44	43	
years	*jul*	*aug*	*sep*	*oct*	*nov*	*dec*
2010	48	40	49	56	52	49
2011	53	47	48	45	47	43
2012	46	64	53	48	53	54
2013						

Table 22: original series seasonally adjusted

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010	48	46	49	49	46	48
2011	50	47	46	49	48	46
2012	48	49	46	47	50	47
2013	46	49	49	46	48	
years	*jul*	*aug*	*sep*	*oct*	*nov*	*dec*
2010	49	46	47	50	47	47
2011	49	48	46	48	49	46
2012	46	50	47	46	49	48
2013						

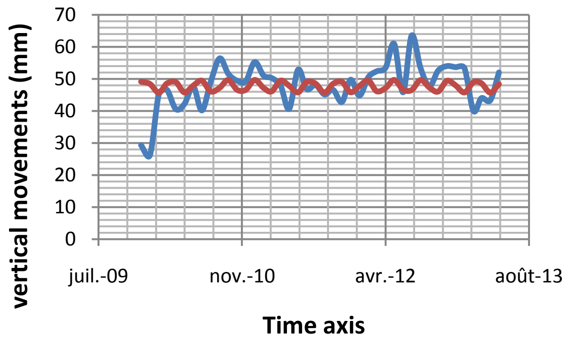

Figure 6: Graphs in mm of the functional model and the original data

IV.5. East frontage, landmark II

Table 23: functional model coefficients

A	69.5871416
B	2.33716736
C	-90.4136278
D	2012.19355

Table 24 : original series

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010	38	41	62	58	59	56
2011	71	81	73	68	71	65
2012	73	74	80	75	84	86
2013	81	81	69	68	73	
years	*jul*	*au g*	*sep*	*oct*	*nov*	*dec*
2010	56	53	66	85	73	72
2011	63	67	68	79	70	69
2012	63	84	80	83	79	80
2013						

Table 25: moving averages of order 12

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010						
2011	69	70	71	72	71	71
2012	73	75	76	77	77	78
2013						
years	*jul*	*aug*	*sep*	*oct*	*nov*	*dec*
2010	61	64	66	67	68	68
2011	71	71	71	71	72	73
2012	79	79	79	78	78	71
2013						

Table 26 : seasonal coefficients

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010						
2011	1.036	1.161	1.028	0.944	1.002	0.921
2012	0.997	0.989	1.055	0.975	1.092	1.106
2013						
Average	**1.017**	**1.075**	**1.042**	**0.96**	**1.047**	**1.014**
Corrected average	**1.004**	**1.061**	**1.028**	**0.947**	**1.033**	**1**
years	*jul*	*aug*	*sep*	*oct*	*nov*	*dec*
2010	0.930	0.820	0.993	1.261	1.074	1.045
2011	0.891	0.945	0.960	1.113	0.970	0.941
2012	0.801	1.060	1.014	1.065	1.015	1.121
2013						
Average	**0.875**	**0.942**	**0.99**	**1.147**	**1.02**	**1.036**
Corrected average	**0.863**	**0.929**	**0.976**	**1.131**	**1.006**	**1.022**

Table 27: original series seasonally adjusted

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010	38	39	60	61	57	56
2011	71	76	71	72	69	65
2012	73	70	78	79	81	86
2013	81	76	67	72	71	
years	*jul*	*aug*	*sep*	*oct*	*nov*	*dec*
2010	65	56	68	75	73	70
2011	73	72	70	70	70	68
2012	73	90	82	73	79	78
2013						

Tableau 28: values calculated by the functional model

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010	70	71	67	72	68	69
2011	67	71	70	68	72	68
2012	71	67	72	69	69	72
2013	70	70	68	72	68	
years	*jul*	*aug*	*sep*	*oct*	*nov*	*dec*
2010	71	67	71	69	69	72
2011	70	71	68	72	68	69
2012	67	71	70	68	72	68
2013						

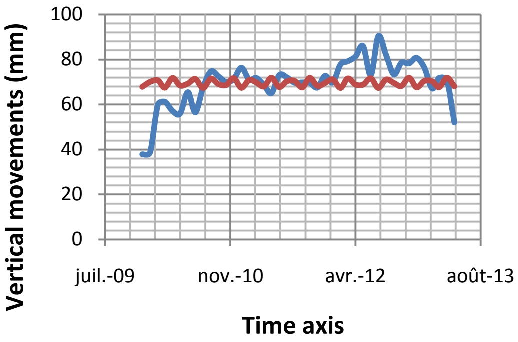

Figure 7: Graphs in mm of the functional model and the original data

IV.6. East frontage, landmark III

Table 29: functional model coefficients

A	85.9775766
B	-2.10982092
C	-89.8141707
D	2010.18797

Table 30 : original series

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010	65	59	79	75	76	73
2011	85	93	87	84	84	80
2012	87	88	97	92	101	103
2013	102	104	89	91	96	
years	*jul*	*aug*	*sep*	*oct*	*nov*	*dec*
2010	73	66	77	94	84	82
2011	82	84	80	91	84	86
2012	77	97	94	99	99	101
2013						

Table 30: moving averages of order 12

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010						
2011	82	83	84	85	85	85
2012	89	90	91	92	93	94
2013						
years	*jul*	*aug*	*sep*	*oct*	*nov*	*dec*
2010	76	78	80	81	81	82
2011	85	85	86	86	87	89
2012	95	96	97	96	96	89

2013						

Table 31: seasonal coefficients

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010						
2011	1.024	1.116	1.031	0.983	0.992	0.943
2012	0.981	0.980	1.071	1	1.090	1.096
2013						
Average	**1.003**	**1.049**	**1.052**	**0.992**	**1.042**	**1.02**
Corrected average	**0.995**	**1.04**	**1.043**	**0.984**	**1.033**	**1.012**
years	*jul*	*aug*	*sep*	*oct*	*nov*	*dec*
2010	0.966	0.85	0.958	1.163	1.031	1.008
2011	0.963	0.983	0.933	1.057	0.961	0.968
2012	0.809	1.005	0.973	1.030	1.027	1.139
2013						
Average	**0.913**	**0.946**	**0.955**	**1.084**	**1.007**	**1.039**
Corrected average	**0.905**	**0.939**	**0.947**	**1.075**	**0.998**	**1.03**

Table 32: original series seasonally adjusted

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010	65	57	75	76	74	72
2011	85	89	83	85	81	79
2012	87	85	93	94	98	102
2013	103	100	85	93	93	
years	*jul*	*aug*	*sep*	*oct*	*nov*	*dec*
2010	81	71	81	87	84	80
2011	91	89	84	85	84	83
2012	85	103	99	92	99	98
2013						

Table 33: Values calculated by the functional model

years	*jan*	*feb*	*mar*	*apr*	*may*	*jun*
2010	84	85	88	85	84	88
2011	88	86	84	87	88	84
2012	84	86	88	85	85	88
2013	88	85	84	88	87	
years	*jul*	*aug*	*sep*	*oct*	*nov*	*dec*
2010	87	84	86	88	85	85
2011	85	88	85	84	88	87
2012	86	84	87	88	84	85
2013						

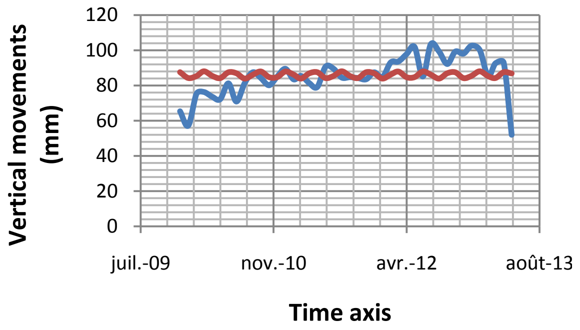

Figure 8: Graphs in mm of the functional model and the original data

Tableau 34: Standard deviation compared to the original data and the original data corrected

	Posteriori standard deviation compared to the original data (mm) σ	**Posteriori standard deviation compared to the original data seasonally adjusted (mm) σ**
West frontage, landmark I	10	11
West frontage, landmark II	14	16
West frontage, landmark III	12	15
East frontage, landmark I	8	9
East frontage landmark II	12	13
East frontage, landmark III	11	14

V. Conclusion

The results obtained in this work have shown the appropriateness of using the technique of compensation to predict the vertical movements of a great work of art. This approach is particularly interesting for the civil engineering segment where accuracy may be tolerable at levels of 5 cm. The results obtained by the functional model are indeed very similar to those from the stochastic model. We have also demonstrated the lack of seasonality in the observed data series. The parameters of functional model that we have determined are sufficiently robust to civil engineering; their predictability line hardly exceeds14 mm. We can say that we have established a method of control and monitoring of movements of large civil engineering works with an ability to anticipate the occurrence of future events.

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