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3-D Spatial Analysis of Deformation at Ikpoba Dam From GPS Data

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Abstract

Earth dams are subject to external loading that induce deformation in the structure and its foundation. The self weight of the dam together with the reservoir water pressure induce stresses in the structure and with time creates horizontal and vertical displacement in the structure.

In this study, analysis of the measurement data obtained by differential GPS at the Ikpoba River Dam was carried out. The measurement system consisted of 19 control and reference stations. DGPS data were collected during two measurement campaigns carried out in 2008 and 2009 respectively using five dual frequency receivers. The computation and adjustment of each epoch measurement was carried out separately in the first instance. Thereafter simultaneous adjustment using the two measurement epoch data was carried out.Points displacements were then determined and 95% confidence ellipse used to carry out an analysis of the movement vector.

Analysis of the result indicated that nine of the points have moved in horizontal position while no horizontal movements have taken place in 10 locations. On the other hand, vertical shift has occurred in seven locations whereas no vertical movement has taken place in 13 locations both outside and along the Dam crest.

1.0 Introduction

Dams provide tremendous benefits including water supply for drinking, irrigation, domestic and industrial use, flood control and hydroelectric power.

However, dams also represent one of the greatest risks to public safety hence the integrity of a dam must be maintained to ensure its long term serviceability [1].

Earth fill dams are subject to external loads that induce deformation. The deformation starts occurring during the construction of the Dam. After construction, considerable movements of the crest and the body of the dam can develop during the first filling of the reservoir. During operation of the dam, the rate of deformation decreases with time. Intensity, rate and direction of movement in a specific point of the body of the dam or its crest may vary during the various phases of operation of the dam structure.

Thus, for a dam in operation, the magnitude of recorded damages may range from relatively minor deformation which may lead to remedial works, to complete catastrophe failure resulting in large property damages or loss of lives. Monitoring over the life of a dam structure using observation and instruments had come to be recognized as an expedient way to ensure the long term safety of the dam structure [2, 3].

On completion of the construction of dam structure it is advisable to establish monuments on the crest of the dam in order to measure the post construction settlement and the upstream and downstream movement of the crest [1]

For carrying out the necessary measurement, Global Navigation Satellite System (GNSS) offers great accuracy and less labour intensive than other techniques used in structural deformation monitoring [5, 6]. The method is suitable for detecting slowly occurring or "Silent" Earth quake [7] monitoring the displacement of engineering structures such as tall buildings [8, 9]. Monitoring Deformation in Dams [10, 11] and deflection in bridges [12, 13].

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1.0 General Description Of The Ikpoba Earthen Dam

The Ikpoba River Dam is located at the end of Okhoro road in Benin City, the capital of Edo State of Nigeria. The Dam water supply scheme was designed to supply 160,000,000 litres of water per day at optimum capacity. This accounts for 80% of the water requirement for Benin City, the capital of Edo State.

The Dam consists of a free over flow uncontrolled spillway flanked on both sides by earth embankment. The dam crest is at a height of 38m and that of the spillway is 35m.

The earthen embankment consist of compacted clayed – silty – sandy soils. The upstream slope to the crest and downstream slope up to elevation 35.3m are protected by rip-rap placed on sand and gravelly bed. The Dams embankment is of length 680m.

2.0 Field Data Collection

The data collection procedures required the use of Five Dual frequency GPS receivers with one receiver serving as control and the others as rovers to acquire data in differential mode. The reference and the control stations were occupied simultaneously with the Dual Frequency Leica 500 GPS receivers. A minimum of six satellites were tracked in each of the observing sessions which lasted for 1 hour in each station.

The GDOP values during observation session were less than 5 and minimum elevation angle of satellite was 15°. The data collection campaign took place in February 2008 and March 2009.

3.0 Data Processing And Adjustment Of Observation

The GPS data were processed using LEICA Office software. The Unknown ambiguity was fixed using Fast ambiguity resolution approach (FARA) statistics. The final base line solution were derived and coordinates of the control and rover positions computed together with the variance-covariance –matrices and the accuracy estimates for the two epoch.

4.0 Computation Of Deformation From A Deformation Model

In the course of adjustment of observation for deformation monitoring from epoch to epoch, there may be points whose position changes from epoch to epoch and those that remain stable for all observation epochs. To determine whether a point has moved or not, it is necessary to determine if difference in coordinates between epoch occur as a result of movement or due to error in observation results in one or both epochs.

Thus error analysis have to be carried out to determine whether significant movements of the monitoring points have occurred between the monitoring campaign or not. Analytical modeling may be used to analyze spatial (horizontal and vertical) displacements of the monitoring points. Point displacements Δ_J are calculated by differencing the adjusted coordinates of this point *J* for the most recent survey campaign (*k+1*), from the coordinates obtained at reference time (*k*) by using equation. [4, 6].

$$\Delta_J = \begin{bmatrix} X_J^{(K+1)} - X_J^{(K)} \\ Y_J^{(K+1)} - Y_J^{(K)} \\ Z_J^{(K+1)} - Z_J^{(K)} \end{bmatrix} = \begin{bmatrix} \Delta X_J \\ \Delta Y_J \\ \Delta Z_J \end{bmatrix}, \qquad (1)$$

where: $X_J^{K+1}, Y_J^{K+1}, Z_J^{K+1}$ - the adjusted coordinates at time t_{k+1}; X_J^K, Y_J^K, Z_J^K - the adjusted coordinates at time t_k; K=1,2,…,m (m – number of epochs of observations); *J*=1,2,…,n (n – number of monitoring points.

Each movement vector has magnitude and direction expressed as point displacement coordinate differences. These vectors describe the displacement field over a given time interval. Displacements that exceed the amount of movement expected under normal operating conditions will indicate possible abnormal behavior. Comparison of the magnitude of the calculated displacement and its associated survey accuracy indicates whether the reported movement is more likely to be due to survey error and this can be determined as follows [14].

$$\left| D_J \right| < (E_J) \qquad (2)$$

Where D_J - the magnitude of the displacement for point *J*, which can be calculated as following : [1, 15].

$$\left| D_J \right| = \sqrt{(X_J^{k+1} - X_J^k)^2 + (Y_J^{k+1} - Y_J^k)^2 + (Z_J^{k+1} - Z_J^k)^2} \qquad (3)$$

$$\left| D_J \right| = \sqrt{(\Delta X_J)^2 + (\Delta Y_J)^2 + (\Delta Z_J)^2} \qquad (4)$$

But E_J - the maximum dimension of combined 95% confidence ellipse for point *J*, is calculated as follows[1] :

$$E_J = 1.96\sqrt{(m_{\Delta_J}^{K+1})^2 + (m_{\Delta_J}^{K})^2} \quad (5)$$

Where $m_{\Delta_J}^{K+1}$ is the standard error in position for the most recent survey; $m_{\Delta_J}^{K}$ is the standard error in position for the (initial) or reference survey.
Thus if $|D_J| < E_J$ – the point has not moved; while, if $|D_J| > E_J$ – the point has moved.
The resulting coordinates of monitoring points must be converted into meaningful engineering values by using the suggested analysis method. In this study, Point displacements in horizontal and vertical components were calculated individually by differencing the adjusted coordinates between two epochs of observations (Table 1). The comparison of the magnitude of the calculated displacement and their associated surveying accuracy was carried out for both epoch. The results are presented in Table 2.
Table 1 gives the magnitude of the calculated coordinate differences and the associated displacement in 3D for 2008 and 2009 measurement results. The magnitude of movement between the epoch and the maximum dimension of the combine95% angular ellipse E were computed for all the points in the network and are presented in the Table 2.

Table1-horizontal and vertical displacement of Ikpoba Dam

AUGUST, 2007 Ikpoba Dam Deformation					FEBRUARY, 2008 Ikpoba Dam Deformation					
STATION	EASTING(m)	NORTHING(m)	ELEVATION	DISTANCE(m)	STATION	EASTING(m)	NORTHING(m)	ELEVATION	DISTANCE(m	DISPLACEMENT(m)
DEFM 1SI	623128.44	6308274.47	70.1783		DEFM 1SI	623128.4451	6308274.47	70.1777		
DEFM 2SI	623221.2516	6308251.23	61.9667	96.030	DEFM 2SI	623221.2515	6308251.23	61.9667	96.024	0.005
DEFM 3SI	623906.0451	6308150.29	59.9948		DEFM 3SI	623906.0252	6308150.27	59.9738		
DEFM 4SI	623920.0521	6308154.84	59.4035	14.740	DEFM 4SI	623920.2678	6308154.74	59.3213	14.941	-0.202
DEFM 5SI	623989.773	6308172.11	60.047		DEFM 5SI	623989.7549	6308172.1	60.0346		
DEFM 6SI	623312.5994	6308260.12	59.3978	682.868	DEFM 6SI	623312.5931	6308260.12	59.3946	682.858	0.011
DEFM 7SI	623263.8808	6308273.84	64.0012		DEFM 7SI	623263.877	6308273.81	63.9708		
DEFM 8SI	624021.2574	6308182.37	62.7709	762.881	DEFM 8SI	624021.2494	6308182.35	62.7525	762.875	0.006
DEFM 9SI	623962.5038	6308189.51	59.1518		DEFM 9SI	623962.494	6308189.5	59.1375		
DEFM10SI	623325.2375	6308271.41	59.7463	642.508	DEFM10SI	623325.2365	6308271.42	59.7486	642.501	0.007
DEFM 11SI	623267.3582	6308281.74	64.1902		DEFM 11SI	623267.3506	6308281.72	64.1663		
BMB 1	623942.992	6308185.89	58.1805	682.426	BMB 1	623942.9894	6308185.86	58.1457	682.432	-0.007
RF 1	623328.6813	6308259.12	58.3442		RF 1	623328.6762	6308259.09	58.3189		
RF 2	623401.9359	6308249.78	57.7295	73.850	RF 2	623401.9337	6308249.77	57.7259	73.850	0.000
RF 4	623597.3922	6308226.6	57.8185		RF 4	623597.4097	6308226.59	57.8034		
RF 7	623626.4967	6308220.1	57.8527	29.821	RF 7	623626.4943	6308220.09	57.8414	29.802	0.019
RF 8	623701.5221	6308214	57.6189		RF 8	623701.5181	6308214.11	57.7324		
RF 9	623799.385	6308202.53	57.7544	98.533	RF 9	623799.3769	6308202.47	57.6973	98.548	-0.016
RF 10	623897.1886	6308190.96	57.7931		RF 10	623897.2059	6308190.89	57.729		
DEFM 1SI	623128.44	6308274.47	70.1783	773.371	DEFM 1SI	623128.4451	6308274.47	70.1777	773.391	-0.020

Table 2- Horizontal and Vertical Component OF Movements.

Point	For horizontal components					For vertical component		
	ΔX_J **mm**	ΔY_J **mm**	$\sqrt{\Delta X_J^2 + \Delta Y_J^2}$ **mm**	$E_J^{horiz.} = 1.96\sqrt{m_{\Delta X_J^2} + m_{\Delta Y_J^2}}$ **mm**	**Movement or not**	ΔZ_J **mm**	$E_J^{ver.} = 1.96\sqrt{m_{\Delta Z_J^2}}$ **mm**	**Movement or not**
DEFM 1SI	5.10	-1.10	5.22	4.82	Yes	0.60	8.68	No
DEFM 2SI	-0.10	0.10	0.14	10.95	No	0.00	8.19	No
DEFM 3SI	-19.90	-19.30	27.72	54.83	No	21.00	53.20	No
DEFM 4SI	215.70	-102.40	238.77	55.71	Yes	82.20	54.09	Yes
DEFM 5SI	-18.10	-10.90	21.13	60.16	No	12.40	58.58	No
DEFM 6SI	-6.30	-2.70	6.85	16.08	Yes	3.20	13.03	No
DEFM 7SI	-3.80	-29.80	30.04	13.31	Yes	30.40	10.18	Yes
DEFM 8SI	-8.00	-18.20	19.88	62.19	No	18.40	60.62	Yes
DEFM 9SI	-9.80	-14.30	17.34	58.23	No	14.30	56.64	Yes
DEFM10SI	-1.00	1.60	1.89	16.81	No	-2.30	13.82	No
DEFM 11SI	-7.60	-23.10	24.32	13.54	Yes	23.90	10.40	Yes
BMB 1	-2.60	-34.40	34.50	56.96	No	34.80	55.36	No
RF 1	-5.10	-26.00	26.50	17.02	Yes	25.30	14.05	Yes
RF 2	-2.20	-5.00	5.46	21.47	No	3.60	18.87	No
RF 4	17.50	-10.10	20.21	34.00	No	15.10	32.00	No
RF 7	-2.40	-12.50	12.73	35.93	No	11.30	33.99	No
RF 8	-4.00	113.00	113.07	40.86	Yes	-113.50	39.04	No
RF 9	-8.10	-56.60	57.18	47.36	No	57.10	45.65	No
RF 10	17.30	-64.50	66.78	53.90	Yes	64.10	52.27	Yes
DEFM 1SI	5.10	-1.10	5.22	4.82	Yes	0.60	8.68	No

5.0 Analysis Of Results

Table 1 gives the coordinates and displacement of the monitoring control and reference points in the network. From the table, maximum displacement of 202mm occurred between DEFM 3 and DEFM 4 and minimum displacement of 7mm occurred between the baseline DEFM II and BMB1. Analysis of both horizontal and vertical movements in Table 2 revealed that for the period of observation between 2008 and 2009, 9 points were observed to have moved in the horizontal component whereas 10 monitoring points can be said to be stable. Maximum movement of 238.8mm occurred in DEFM 4SI whereas minimum movement of 1.9mm occurred in the DEFM 10SI. In the vertical direction, 7 points were observed to have moved whereas no movement occurred in horizontal direction. A 12 points maximum vertical movement occurred on DEFM 4SI with a value of 82mm whereas minimum vertical movement of 14mm occurred at the point DEFM 9SI

7.0 Conclusion

Based on the presented analysis, the value of movement of 238.8mm horizontal and 82mm vertical in DEFM 4S1appears high and the points should be excluded from the list of stable control for future deformation monitoring.
Further observation need to be carried out to see the behavior of this and other points where movement appears to be abnormal and before final conclusion can be drawn about the behavior of the structure as a rigid body.

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