Tracking the Status of Deformation of Kiri Dam through Statistical Analysis

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Abstract: Dams are important engineering structures meant for among others irrigation, hydro-electricity. Every engineering structure is however, susceptible to deformation over time and hence failure. The intention of this research is to establish whether there is any significant difference in the status of the dam for three epochs; 1982, 2003 and 2004. The observations for each monitoring point were taken at four months interval per year to produce three observations per year for each of the epoch under study. The monitoring points were established at chainage 500, chainage 1000 and chainage 1500 on the dam embankment with their most probable height values for the period under consideration. The observed parameters, the heights were rigorously adjusted using least squares parametric adjustment techniques to minimize the sum of the squares of errors. Analysis Of Variance (ANOVA) One-way test of hypothesis on the mean population was adopted. Various significant levels were used to test the hypothesis. The results and test of hypothesis showed that, except at chainage 500, null hypothesis was not rejected at the other chainages (1000, and 1500). It is therefore important to monitor chainage 500 regularly to checkmate precipitation of general dam movement and probable failure.

Keywords: Dam, deformation, engineering structure, failure, monitoring, Real Time Kinematic.

1 INTRODUCTION

A dam is a barrier built across a river in order to stop the water from flowing as in [1]. Dams are used to provide reservoir for irrigation, water supply system, hydro-electricity etc. thus contributing immensely to the national economy. Dams being large engineering structures are liable to deformation or movement occasioned either by pressures and stresses within the ground or structure itself, ground water pressure, surface displacement on the dam structure or the surrounding bedrock or chemical properties of the soil as in [2]. Any or a combination of these mentioned factors could initiate movement and hence failure of the dam. Since the consequences of Dam failure are always enormous, monitoring Dam movements has become an unavoidable option globally.

Kiri Dam is an earth Dam constructed since 1982 where there are both human and material existences at both upstream and downstream. Therefore the significance of elaborate investigation of the dam behavior to enhance the prediction of potential failure in order to provide timely mitigation is highly as important as its construction. Dam movement or deformation can be determined by monitoring, defined as an intermittent regular or irregular surveillance carried out to ascertain the extent of compliance with a predetermined standard or the degree of deviation from an expected norm as in [3]. It is an important component after construction as in [4]. Monitoring a dam involves various stages such as design of the monitoring plan, installation of monitoring devices, reading those devices at some pre-established frequencies, conversion of measurements to meaningful engineering quantities, interpretation of these quantities, comparison with models, dam inspection including timely warning information as in [5]. Monitoring can be done using conventional methods where field observations or measurements are taken manually applying Piezometers, Inclinometers, Total stress cells, Settlement devices, Triaxial deformation tubes, and other methods such as Geodetic monitoring, Photo imagery and data fusion, Laser scanning and referencing and so on. Global Positioning System (GPS) for example can be used to monitor Dam deformation near-real time as in [6]. Dam monitory can be undertaken Real time through GPS Real Time Kinematic (GPS RTK). Dam monitoring requires long-term measurements to determine small structural motions or displacements. The aim of this study is to establish statistically whether any deformation in respect of Kiri Dam is significant.

1.1Research Hypothesis

Dams are constructed with the intention to remains stable and serve its intended purpose over a reasonable period. Null hypothesis, the statistical tool used in this study is based on this concept. The null hypothesis is tested on the means using three populations, ANOVA One-way. The hypothesis is required to test whether or not there are significant differences between the means of three normally distributed populations.

This technique simultaneously makes use of the variability between and within each sample set. The null hypothesis is stated thus, there is no difference in the means of the normally distributed populations from where the various samples were chosen and it is expressed as Ho: μ1 = μ2 = μ3 =.....μ. In testing the hypothesis, HO is rejected if F > F1- α (K-1, N-K) and accepted if F < F1- α (K-1, N-K). The objective of the hypothesis is to test whether there is any significant difference in the behavior of the dam for three epochs; 1982, 2003 and 2004.

1.2 Study Area

The study area is located at latitude 09˚ 42′ and longitude 12˚ 01′ in Kiri, Adamawa state, Nigeria. It is bounded by Shelleng in the North, Borong in the South, Longuda district in the West and Dumne Yungur in the East (fig.1). The earth dam constructed across River Gongola has six concrete type spill way openings and is 1300m long, 20m above the river bed covering a catchment area of 56.2km2. It's designed flood for inflow is 4250m3/s and 4000m3/s for outflow while the flood water level is 171.5m.

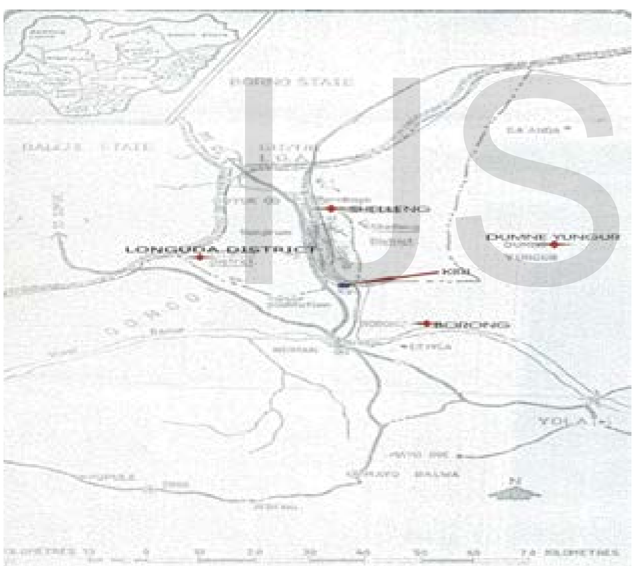

Fig.1, Map of Study Area

2 Material and Methods

The heights of the monitoring points obtained from Kiri dam site office were observed at an interval of four months per year using Kern GK1-1 level. Three monitoring points were chosen, at chainage 500, chainage 1000 and at chainage 1500 on the dam. Three epochs 1982, 2003 and 2004 were used for this study. The observed parameters were processed and twelve observation equations formed from the height differences between chainages. The twelve equations were solved and the Most Probable values (MPVs) of the heights obtained (Table 1) by rigorous least squares parametric techniques to minimize observational errors.

Table 1: Most Probable Values of heights of chainages

S/No	Chainage (m)	1982 (m)	2003 (m)	2004 (m)
1	500	174.352	174.313	174.304
2	600	174.353	174.308	174.299
3	700	174.358	174.303	174.288
4	800	174.369	174.292	174.286
5	900	174.367	174.328	174.260
6	1000	174.366	174.364	174.236
7	1100	174.438	174.359	174.284
8	1200	174.414	174.373	174.274
9	1300	174.360	174.358	174.289
10	1400	174.354	174.358	174.254
11	1500	174.291	174.315	174.204

The system of parametric normal equation is represented in matrix algebra by (1):

$$X = -[A^T PA]^{-1} A^T PL \qquad (1)$$

Where,
X = is the vector of the unknown least squares estimates or the MPVs of the heights,
A = design matrix,
P = Weight matrix,
L = Vector of observation or any known fixed quantity
Only the decimal parts of the repeated heights observation (Table 2) at each chainage as usual were used in the Preliminary computations for the ANOVA table (Table 3).

Table 2: Repeated observations at each chainage

S/N	1982	2003	2004	Chainage
1	174.353	174.313	174.304	500
2	174.344	174.299	174.296	500
3	174.345	174.306	174.286	500
4	174.366	174.364	174.234	1000
5	174.365	174.296	174.307	1000
6	174.367	174.219	174.297	1000
7	174.291	174.315	174.204	1500
8	174.288	174.278	174.296	1500
9	174.290	174.263	174.284	1500

Table 3: Preliminary computation for ANOVA Table

S/N		1982	2003	2004	Result	Chainage
1		0.353	0.313	0.304		500
2		0.344	0.299	0.296		500
3		0.345	0.306	0.286	N = 9	500
4	Total, T_i	1.042	0.918	0.886	T = 2.846	
5	Mean	0.347	0.306	0.295	$\bar{x}$ = 0.316	
6	T^2_i/n_i	0.362	0.281	0.262	T^2/N = 0.8999684444	
7		0.366	0.364	0.234		1000
8		0.365	0.296	0.307		1000
9		0.367	0.219	0.297	N = 9	1000
10	Total, T_i	1.098	0.879	0.838	T = 2.815	
11	Mean	0.366	0.293	0.279	$\bar{x}$ = 0.313	
12	T^2_i/n_i	0.402	0.258	0.234	T^2/N = 0.881	
13		0.291	0.315	0.204		1500
14		0.288	0.278	0.296	N = 9	1500
15		0.290	0.263	0.284	T = 2.509	1500
16	Total, Ti	0.869	0.856	0.784	$\bar{x}$ = 0.316	
17	Mean	0.290	0.285	0.261	T^2/N = 0.6994534444	
18	T_i^2/n_i	0.252	0.244	0.205		

The statistical parameters (Table 4) were computed using the following (2) – (7) [7]:

$$BSS = \left[\sum_{i=0}^{K}\left(\frac{T_i^2}{n_i}\right) - \frac{T^2}{N}\right] \quad (2)$$

$$WSS = TSS - BSS \quad (3)$$

$$TSS = \sum_{i=1}^{K}\sum_{j=1}^{n_i} x_{ij}^2 - \frac{T^2}{N} \quad (4)$$

$$S_1^2 = \frac{BSS}{K-1} \quad (5)$$

$$S_2^2 = \frac{WSS}{N-K} \quad (6)$$

$$F = \frac{S_1^2}{S_2^2} \quad (7)$$

Where,

BSS = Between Sum of Squares

WSS = Within Sum of Squares

TSS = Total Sum of Squares

$$T = \sum T_1 + \sum T_2 + \sum T_3 + \sum T_n$$

T1, T2, T3,…….Tn = Sum of repeated observations in set 1, 2, 3…n

ni = Number of observations in a set, i = 1, 2, 3…n

N = ∑ni

x = Observations

S_1^2, S_2^2 = Variances of two independent samples

K = Total Number of sets

V1 = degree of freedom 1 (δf1) = K – 1

V2 = degree of freedom 2 (δf2) = N – K

Using (2) – (7):

At chainage 500,

BSS = 4.526222222E-03

WSS = 3.093333333E-04

TSS = 4.835555556E-03

S12 = 2.263111111E-03

S22 = 5.155555556E-05

F = 43.89655172

At chainage 1000,

BSS = 0.01302688889

TSS = 0.026687555556

WSS = 0.01366066667

S12 = 6.513444444E-03

S22 = 2.276777778E-03

F = 2.860816944

At chainage 1500,

BSS = 1.397555556E-03

TSS = 7.837555556E-03

WSS = 6.44E-03

S12 = 6.987777778E-04

S22 = 1.073333333E-03

F = 0.6510351967

Table 4: Computed statistical parameters for each chainage

S/N	Source	Sum of squares	δf	Mean square	F - Ratio	Chainage
1	Between	4.526222222E-03	$V_1 = 2$	2.263111111E-03	43.896551	500
2	Within	3.093333333E-04	$V_2 = 6$	5.155555556E-05		500
3	Total	4.835555556E-03	8			500
4	Between	0.01302688889	$V_1 = 2$	6.513444444E-03	2.8608169	1000
5	Within	0.01366066667	$V_2 = 6$	2.276777778E-03		1000
6	Total	0.026687555556	8			1000
7	Between	1.397555556E-03	$V_1 = 2$	6.987777778E-04	0.65103520	1500
8	Within	6.44E-03	$V_2 = 6$	1.073333333E-03		1500
9	Total	7.837555556E-03	8			1500

The computed statistics, F were compared with the nominal statistics (Table 5) to decide whether or not to accept or reject the Null hypothesis.

Table 5: General Statistical parameters

Degree of freedom	1 - α	$F_{1-\alpha}$
$V_1 = 2$	.0005	.0005
$V_2 = 6$	.001	.001
	.005	.005
	.01	.01
	.025	.025
	.05	.052
	.10	.107
	.25	.302
	.50	.780
	.75	1.76
	.90	3.46
	.95	5.14
	.975	7.26
	.99	10.9
	.995	14.5
	.999	27.0
	.9995	34.8

Source: [8]

ANOVA One-way test of hypothesis on the mean was adopted using different significant levels to test the hypothesis.
From Tables 4 and 5:

Chainage 500;
At $\alpha = 0.05$, $F1 - \alpha\ (V1 , V2) = F.95\ (2,6) = 5.14$
At $\alpha = 0.01$, $F1 - \alpha\ (V1 , V2) = 10.9$
At $\alpha = 0.10$, $F1 - \alpha\ (V1 , V2) = 3.46$
At $\alpha = 0.0005$, $F1 - \alpha\ (V1 , V2) = 34.8$

Chainage 1000;
At $\alpha = 0.05$, $F1 - \alpha\ (V1 , V2) = F.95\ (2,6) = 5.14$

At α = 0.01, F1 – α (V1 , V2) = 10.9
At α = 0.10, F1 – α (V1 , V2) = 3.46
At α = 0.25, F1 – α (V1 , V2) = 1.76
At α = 0.0005, F1 – α (V1 , V2) = 0.00050

Chainage 1500;
At α = 0.05, F1 – α (V1 , V2) = F.95 (2,6) = 5.14
At α = 0.01, F1 – α (V1 , V2) = 10.9
At α = 0.10, F1 – α (V1 , V2) = 3.46
At α = 0.5, F1 – α (V1 , V2) = 0.780
At α = 0.25, F1 – α (V1 , V2) = 1.76
At α = 0.0005, F1 – α (V1 , V2) = 0.00050

3 RESULTS AND DISCUSSIONS

The results of the ANOVA test on the mean population in reveal that at chainage 500, the null hypothesis failed and thus rejected at all the tested significance levels 0.05, 0.01, 0.10 and 0.0005 implying that the deformation is significant. At chainage 1000, the null hypothesis test was accepted at significant levels 0.05, 0.01 and 0.10 but failed and rejected at significant levels 0.25 and 0.0005 considered statistically as very high significant levels. At chainage 1500, the null hypothesis test was accepted at significant levels 0.05, 0.01 and 0.10 but failed and thus rejected at significant levels 0.5, 0.25 and 0.0005.

From the results of the test of Null hypothesis, it is statistically indicative that chainage 500 needs some attention. This is needed because a problem in a location in a large engineering structure if not checked and corrected could spread quickly and creates general failure. In chainage 1000 and chainage 1500, the null hypothesis is generally accepted as the significant levels at which the test failed are too highly significant to warrant any worries.

4 CONCLUSIONS

At chainages 1000 and 1500 and at 0.05 significant level, Null hypothesis was not rejected and it is thus concluded that there is no significant deformation of the dam at these points but at chainage 500, Null hypothesis was rejected even at highly significant levels. It is therefore concluded that there is significant deformation of the dam at this chainage.

The general implication of this research is that, there are actual deformation at each of the monitoring point as indicated by failure of the null hypothesis though noticeable only at too highly significant levels at chainages 1000 and 1500. The null hypothesis was rejected at all the possible and testable statistical levels at chainage 500. Though only chainage 500 showed significant deformation at the tested significant levels, at the long run if not checked and timely proactive measures taken, this could precipitate general movement of the dam and hence general failure.

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