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USING PIEZOMETER RECORDS TO EVALUATE THE STABILITY OF GORONYO AND TIGA DAMS IN NORTHERN NIGERIA.

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ABSTRACT

The stability of Goronyo dam on Rima river in Sokoto state and Tiga dam on Kano river in Kano state were evaluated by use of piezometer records from the dams that indicate porewater pressure changes from 1994 to 1997. Plots of these parameters against time (yearly) indicate abnormal increase in porewater pressures from values of 2748 to 2771 KPa and 4986 to 5139 KPa in some piezometers installed in Goronyo and Tiga dams, respectively. These increases in porewater pressures could be caused by core leakage and may lead to failure of the dams. It is recommended that the leaking spot of the dam core should be identified and remedied.

Key words: Piezometer records, dam stability, porewater pressure and dam instrumentation.

INTRODUCTION

A dam is a structure that is constructed across a river channel to retain or impound the water as a reservoir, and allow a certain quantity of the water to flow under, through or over the dam. According to Arthur (1961), dams may be classified on the basis of purpose and materials of construction. Dams are therefore referred to as water supply, irrigation, flood control, hydro-electric or multi-purpose. Dams are also referred to as concrete, earthfill or rockfill, depending on the major constituents of the dam structure. (Arthur, 1961). Concrete arch and concrete buttress are classified on the basis of the shape of the concrete structure. Earthfill and rockfill dams are also known as embankment dams, and when a dam comprises any two of concrete, earthfill or rockfill the term composite dam is used. A typical composite dam has a concrete river section to allow for overflow of water and construction of hydro-electric facilities and embankments at the wings. Availability of construction material and geology of the dam site usually determine the type of dam to be constructed at a given site.

Reservoirs constitute potential hazards to down-stream life and property. Dam failures can therefore result in unacceptable loss of life and property. According to Novak et al (1990), catastrophic failure of dams include: Malpasset in 1959 (France); Vajont in 1963 (Italy); and Macchu II in 1979 (India) that killed 421, 2000 and 2000 people respectively. Sherard (1963) estimated that 69% of causes of dam failures are due to geological factors such as defective foundation, earthquakes, bad construction materials, faulty design, poor construction and floods..

The stability of dam is its resistance to failure due to defects in the structure of the dam. These defects include cracking which may lead to internal erosion or core leakage, core/foundation settlement and internal deformation/movement in the dam. These defects are normally assessed by nature/quantity of seepage (discharge) measured by V- Notch weires, changes in porewater pressure measured by pezometers, maginitude of settlement measured by geodetic instruments and magnitude of deformation/movement measured by inclinometers. Most dam failures are inevitably preceded by a period of progressively increasing structural distress within the dam or its foundation. Dam instrumentation and monitoring programmes are intended to detect and where possible identify symptoms of distress at the earliest possible stage, thereby, providing an early warning of possible distress. The major parameters in monitoring dam behavior together with the instrumentation are presented in Table 1. The provision of monitoring instruments is an accepted practice for all dam of any magnitude (Novak et al, 1990: Thomas, 1976). In the context of new dams, instrumentation data is interpreted in a dual role to provide an indication of the validity of design assumptions and assessment of subsequent assumptions. The frequency of

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Table 1. Monitoring parameters and their relation to possible defects.
(From Novak et al, 1990)

Parameter	Instruments	Measurement	Example Defect	Dam Type
Seepage	Drains /underdrains to V-notch weirs (ideally several, isolating sections of dam / foundation)	Seepage flow quantity and nature of seepage water, e.g. clear or turbid	Could indicate initiation of cracking and / or internal erosion	E / C
Porewater pressure	Piezometers	Internal water pressure in earthfill	Leaking core, or incipient instability	E.
Uplift	Piezometers	Internal water pressure in concrete or rock foundation	Instability, sliding	C
Settlement	Precise survey (Surface)	Crest settlement	Tilting (C) or loss of freeboard (E) e.g. core subsidence, or foundation deformation	E/C
	Settlement gauges (internal)	Internal or relative settlement		
External deformation	Precise survey (surface)	Surface deflection	Local movement,	E/C
Internal deformation: (vertical / horizontal)	Inclinometers/ strain gauges or duct tubes	Internal or relative movement	Incipient instability	E
Stress/ pressure	Pressure cells	Total stress	Hydraulic fracture and internal erosion	C

"E = embankment dams, C = concrete dams.

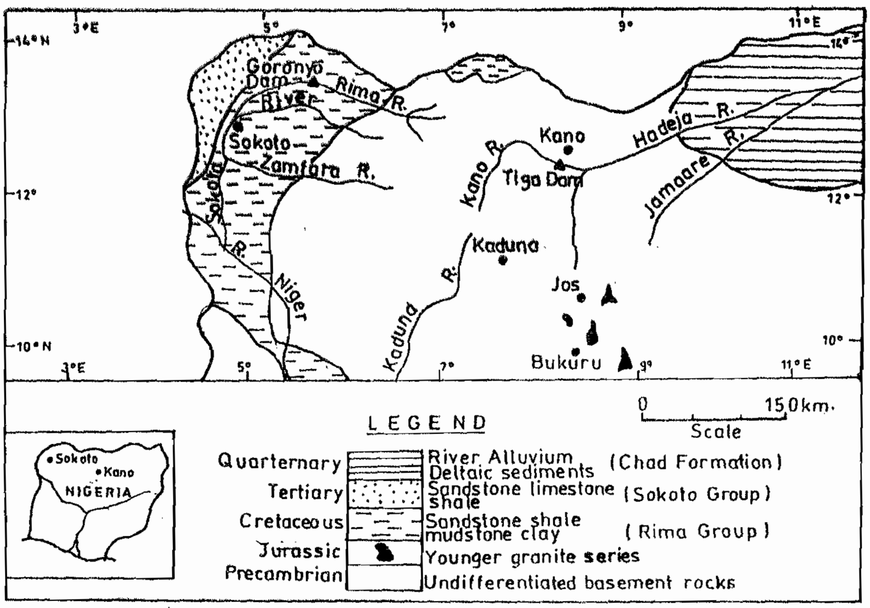

Figure 1 Geological map of Northern Nigeria with location of Goronyo and Tiga Dams.

monitoring depends upon the facilities available and conditions of the dam at that particular time. It may be daily, weekly or monthly as the case may be (Table 2).

In this paper, representative piezometer records that indicate porewater pressure variations from Goronyo and Tiga dams were used to evaluated the stability of the dams.

Dam and site description

The Goronyo dam is located on Latitude 13^0 30^1 N and Longitude 5^0 45^1E. It is an earthfull dam owned and operated by Sokoto-Rima River Basin Development Authority. It was constructed on Rima river between 1980 and 1984 for irrigation, water supply and flood control. The reservoir is situated near Katsina village about 25km east of Goronyo town and some 90 km northeast of Sokoto city in Sokoto State. The Tiga dam is located on Latitude 11^0 30^1N and longitude 8^0 20^1 E. It is also an earthfill dam owned and operated by Hadejia – Jamaare River Basin Development Authority. It was constructed on Kano river between 1970 and 1974 for irrigation and water supply. The reservoir is situated about 70km south of Kano

Table 2: Representative Monitoring Frequencies

Parameter	Frequency
Water level	daily
Seepage	daily
Porewa.er pressure	twice weekly (during construction), 1-3 Monthly (routine)
Settlement / deformation	daily (suspected serious slip), 1 – 2 monthly (routine).

Table 3: Technical Features of Goronyo and Tiga Dams

Paramber/location	Goronyo	Tiga
	Kano	
River	Rima	
Location /State	Sokoto	Kano
Type	Earthfill	Earthfill
Reservoir capacity (MCM)	974	1968
Height (M)	21	48
Crest length (M)	7210	6000
Crest width (M)	8.5	11.7
Catchment area (km^2)	21,445	6641
Purpose	1r, Ws Fc	Ir, Ws
Owner	SRRBDA	HJEBDA

LEGEND

MCM	=	Million cubic meter
Ir	=	Irrigation
Ws	=	Water Supply
Fc	=	Flood control
SRRBDA	=	Sokoto - Rima River Basin Development Authority
HJRBDA	=	Hadejia – Jamaire River Basin Development Authority

city. Figure 1 shows the location of the dams while Fig. 2 represents the dam cross sections. The characteristics of the dams are shown in Table 3.

The rainfall data of Table 4 effects the flows of Rima and Kano rivers where the dams were constructed and consequently the design/operation of the dams built on them.

The Goronyo dam is underlain by sandstones and mudstones of the Taloka Formation which belongs to the Rima Group of Iullemuden Basin (Kogbe, 1975; Oteze, 1975) (Table 5). The Tiga dam is silted in a Precambrian basement terrain. The major rock types include migmatites quartzites and gneisses.

Methodology

Records of Casagrande-type piezometers installed at Goronya and Tiga dams as P1, P2 .... P12 as indicators of porewater pressure values and time were obtained from Federal Ministry of water Resources, Abuja and Hadejia – Jamaare River Basin Development Authority, Kano. Fig 3 shows typical installations of the piezometers. Several of the instruments were installed in the dams but records of their performance were not properly documented. Only the few records that appear to be reasonable in terms of frequency and period of measurements were therefore selected to be used in the analysis. The analysis involves the plotting of piezometer records of Piezometer levels in metres and their corresponding porewater pressures valures in KPa versus time from January 1994 to December 1997 as illustrated in Figures 4 and 6 for Goronyo dam and Figures 5 and 7 for Tiga dam respectively. Lake levels of the dams at the same periods were also collected and plotted on graphs of piezometer levels versus time (Figures 4 and 6) to study the relationship between he two perameters.

Results

Tables 6 and 7 are pezometer records of piezometer level (m) lake leve' (m) and time (months/year), while Tables 8 and 9 represent the corresponding porewater pressures of the piezometer levels and time for Goronyo and Tiga dams, representively. The data of tables 6 and 7 were used in the preparation of Figures 4 and 5 while data of Tables 8 and 9 were used in the preparation of Figures 6 and 7.

Analysis of porewater pressure variations for Goronyo and Tiya dams in Figures 6 and 7

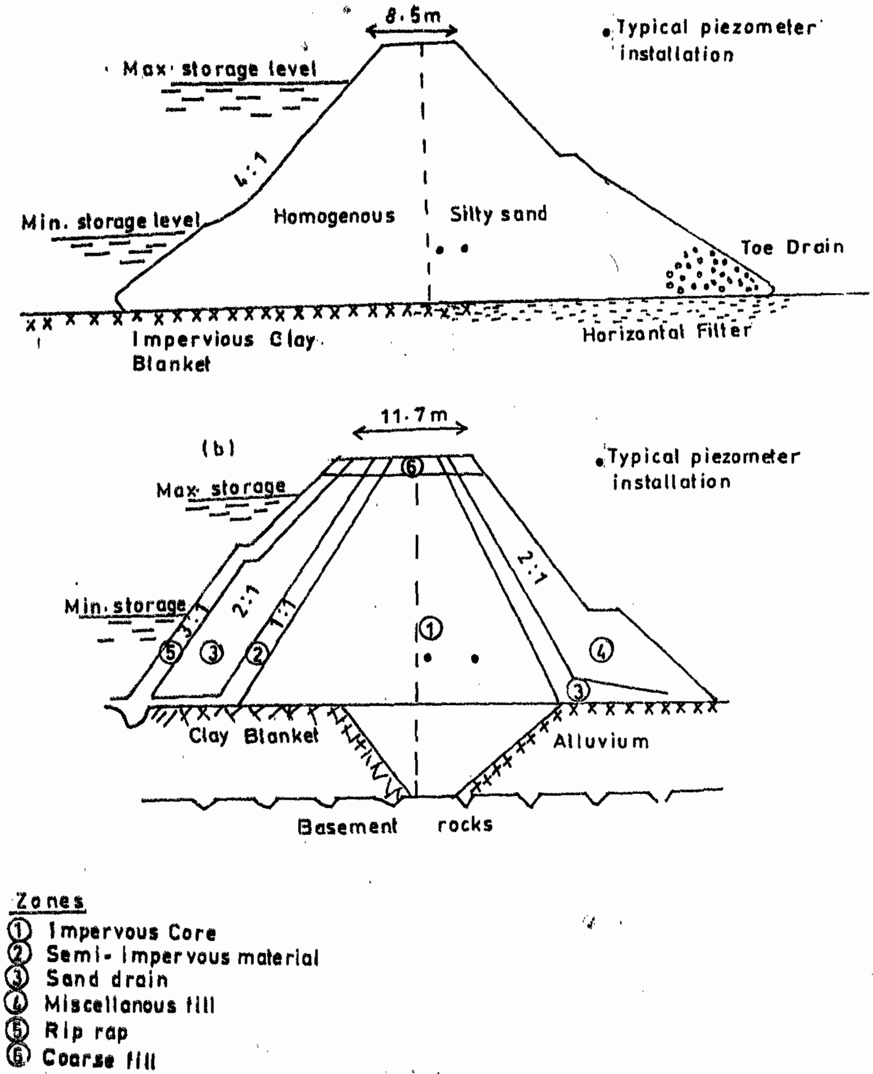

Fig. 2: Cross-sections of Goronyo and Tiga Dams
(a) Goronyo dam (b) Tiga dam

indicates abnormal increase of porewater pressures in pizometers P_7 and P_8 installed in Goronyo dam and piezometer P_3 installed in Tiga dam. The porewater pressure in P_7 and P_8 (for Goronyo dam) increased from normal values of 2748 to 2771KPa, while porewater pressure in P_3 (for Tiga dam) increased from normal values of 4986 to 513KPa .

Discussion

Porewater pressure is the pressure of water that fills the pore space between the solid particles of a soil or rock. High porewater pressure in soils or rocks have the effect of reducing the contact forces between the solid particles of the soil or rock, according to effective stress principle (Franklin and

Table 4: Average Rainfall (mm) of Sokoto and Kano (1991 – 1995)

Monthly	Sokoto	Kano
January	0.0	0.0
February	0.0	0.0
March	2.6	0.57
April	5.3	29.4
May	63.2	45.5
June	63.6	102.6
July	171.9	161.3
August	133.1	181.6
September	145.6	178.5
October	4.4	24.9
November	0.0	0.35
December	0.0	0.0
Total	669.7	774.7

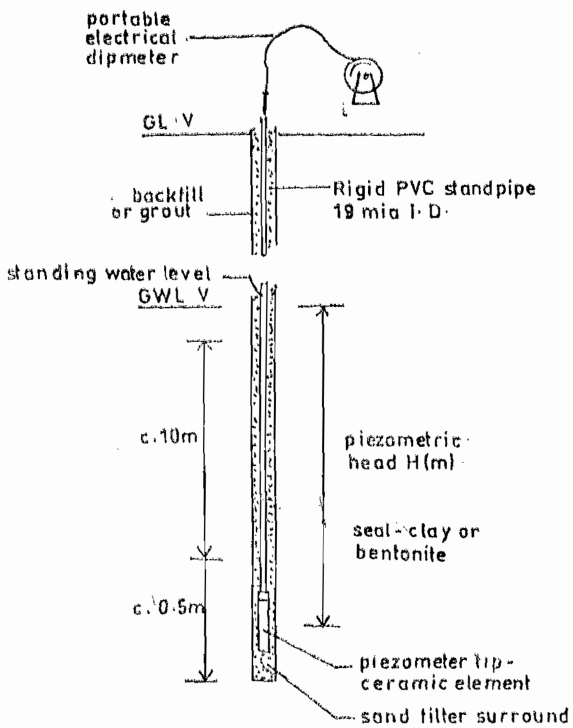

Figure 3. Casagrande type standpipe piezometer in borehole

Dusseault 1979; Graig, 1987). The equation below illustrates:

$$\sigma' = \sigma - U \qquad (1)$$

where σ' = Effective normal stress representing the stress transmitted through the soil skeleton only.

U = Porewater pressure as defined above

σ = Total normal stress on a plane within the soil or rock mass representing the force per unit area transmitted in a normal direction across the plane.

According to Armando (1987), porewater pressure may be expressed in "metres of water" or "Paschals" (m or Pa). High units of Paschals like kilopaschals (KPa) or megapaschaes (MPa) may also be used. Note that 1pa = IN/m^2 ($1KPa = 1KN/m^2$).

Porewater pressures expressed in meters of water (m) (piezometer levels) may then be

Table 5: Stratigraphic Sequence of Sokoto – Rima (Iullemedan) Basin

Age	Formation	Group	Thickness (m)	Lithology
Eocene/Pliocene	Gwandu		23	Mudstones, quartz sands
Paleocene	Gamba	Sokoto	20	Shale
	Kalambaina	Group	23	Shale / Limestone
	Dange		45	Shale / Limestone
Maastrichtia	Wurno		250	Sandstones, siltstone mudstones
	Dukamage	Rima	260	Shales, limestone
	Taloka	Group	1000	Sandstones / mudstones
Pre-Maastrichtia	Gundumi		25	Grits, Clays, sandstones
	Illo		50	Grits, clays sandstones
Precambrian	Basement			Gneisses, quartzites phyllites

Table 6: Piezometer / Lake Level Records From Goronyo Dam

Date	Lake Level (m)	Piezometer Levels											
		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}
26/12/94	285.70	276.27	279.00	282.30	278.00	282.50	278.29	278.38	278.97	278.00	275.40	276.80	281.25
11/5/95	284.11	280.14	278.79	282.34	279.00	281.97	279.00	282.00	278.00	277.00	275.88	276.40	280.70
28/5/95	283.35	279.86	278.95	281.86	278.73	282.00	278.73	277.91	279.00	262.09	276.36	277.55	280.00
11/7/95	284.44	280.98	279.13	282.42	281.58	282.00	281.58	280.20	277.77	282.44	278.00	277.81	280.78
26/9/96	287.03	281.22	279.06	282.96	281.90	282.06	281.70	280.70	277.34	281.35	279.16	280.80	279.34
14/11/97	286.22	280.94	280.18	282.29	281.28	28.28	281.28	280.34	218.13	281.37	279.09	277.91	281.00
12/4/97	284.34	279.93	278.82	282.35	281.59	281.97	279.59	282.95	278.95	278.09	276.81	277.46	280.90

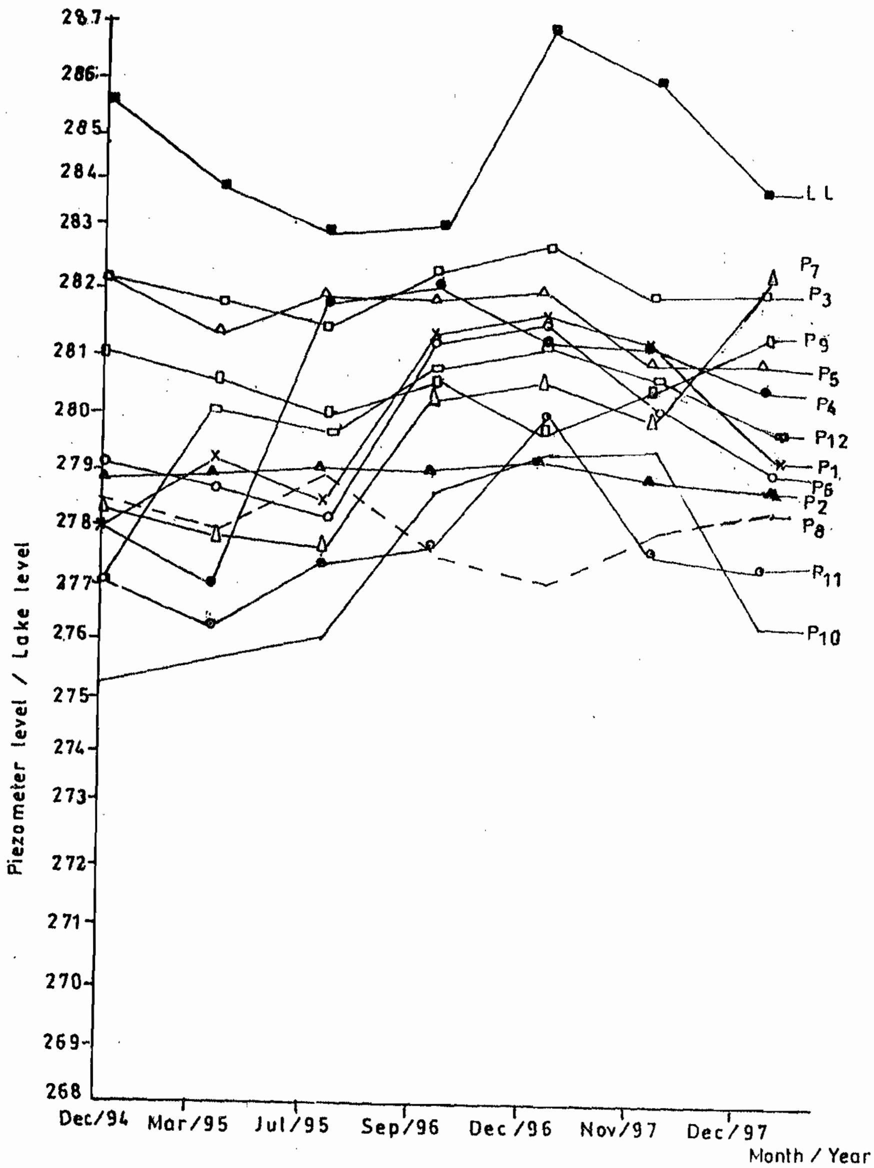

Figure 4: Plot of Piezometer Records (Piezometer Level) / Lake versus time for Goronyo Dam.

converted to Parchals (Pa) by multiplying the meters of water with the unit weight of water assumed to be 9.81 KN/m^3 in this study). Porewater pressure values of tables 8 and 9 were therefore derived from the piezometer levels of Tables 6 and 7 by application of the aforementioned conversion process.

The stability of embankment dams or soil mass generally depends on the shear strength of the compacted soil materials or soil mass which in turn is expressed as a function of effective normal stress thus:

$\tau = C' + \sigma' \tan \phi'$..............................(2)

where τ = Shear strength of soil mass (maximum resistance offered by soil mass at failure)

C' = Cohesion in terms of effective stress

ϕ' = Angle of internal friction in terms of effective stress

Increase in porewater pressure in embankment dams will therefore lead to reduction in effective stress/shear strength of the compacted soil material and may cause instability of the dam structure.

The high porewater pressures observed in piezometers p_7 and p_9 of Goronyo dam as well as p_3 of Tiga dam are indications that the shear strength of the dams at those spots (p_7, p_9 and

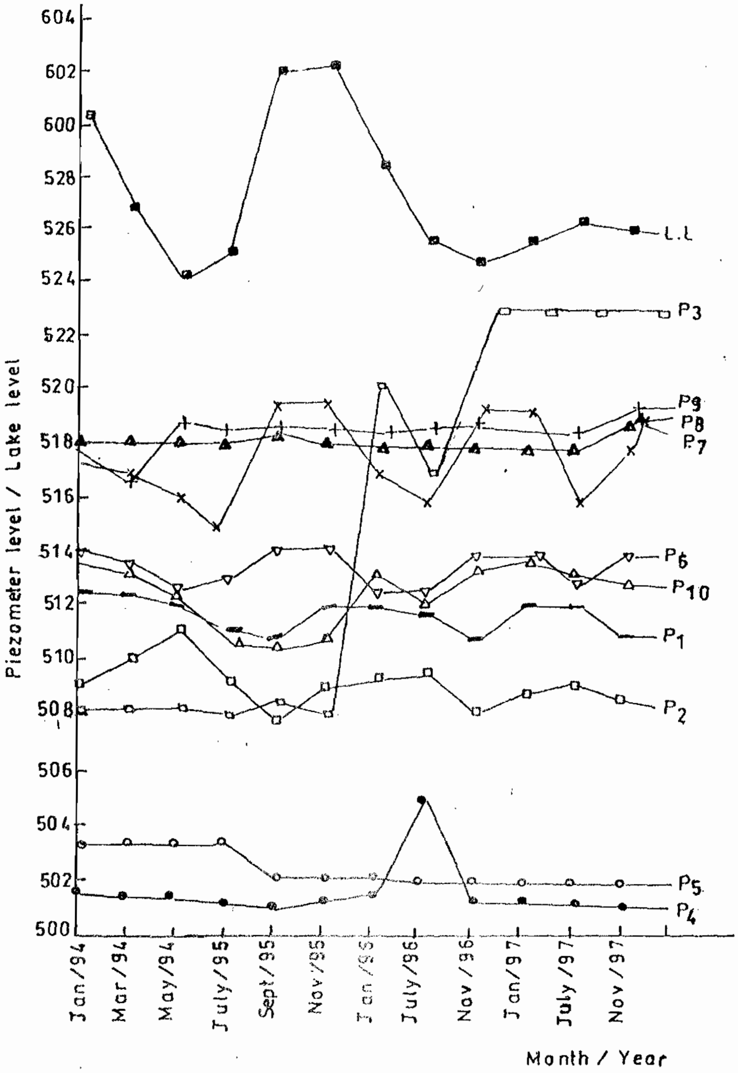

Figure 5: Plots of Piezometer Records (Piezometer Level) / Lake level Versus Time for Tiga Dam

Table 7 Piezometer/ Lake Level Records From Tiga Dam

Date	Lake levels	Piezometer levels									
		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
17/1/94	601.07	512.30	509.59	508.28	501.84	503.65	513.82	513.94	517.60	518.33	518.39
30/3/94	527.00	512.28	510.09	508.28	501.84	503.65	513.35	513.43	517.10	516.33	518.52
15/5/94	524.78	512.00	511.34	508.28	501.84	503.65	512.63	512.66	516.55	518.37	518.52
5/7/95	525.51	511.82	509.16	508.22	501.72	503.67	511.58	513.06	515.84	518.33	518.52
30/9/95	602.01	511.62	508.80	508.44	501.38	502.33	511.04	514.00	519.51	518.42	518.19
15/11/95	602.57	512.15	509.09	508.24	501.63	502.33	511.14	514.75	519.16	518.44	518.52
31/1/96	528.85	512.39	509.81	520.30	501.74	502.35	513.59	513.86	517.79	518.35	518. 27
5/7/96	525.91	511.94	509.43	515.39	505.45	502.35	512.04	513.18	516.10	518.35	518.52
7/11/96	525.10	511.71	508.81	523.86	501.67	502.38	513.47	514.46	518.94	518.36	518.10
2/1/97	525.91	512.16	509.22	523.86	501.67	502.36	514.03	514.15	518.36	518.36	518.00
30/7/97	527.76	512.10	509.59	523.86	501.76	502.36	512.39	513.50	516.89	518.36	518.10
3/11/97	526.94	511.84	509.19	523.87	501.71	50[illegible].33	[illegible]	514.25	518.71	[illegible]	518.47

TABLE 8: Corresponding Porewater Pressures Of Piezometer Levels From Goronyo Dam

Piezometer No. / Porewater Presure (KPa)

Date	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}
26/12/94	2710.21	2736.99	2769.36	2729.18	2771.33	2730.02	2730.90	2736.70	2727.18	2701.67	2715.41	92759.06
11/5/95	2748.17	2734.93	2769.78	2736.99	2766.13	2736.99	2766.42	2727.18	2725.22	2706.38	2711.48	2753.67
28/5/95	2745.43	2736.50	2765.05	2734.34	2766.42	2734.34	2726.30	2736.99	2724.24	2711.48	2722.77	2746.80
11/7/95	2756.41	2738.27	2770.54	2762.30	2766.42	2762.30	2748.76	2724.92	2770.24	2727.18	2725.32	2764.26
26/9/96	2758.77	2835.68	2775.84	2765.44	2767.01	2763.48	2753.67	2720.71	2760.14	2738.56	2754.65	2740.33
14/11/97	2756.02	2748.57	2769.26	2759.36	2759.36	2759.36	2750.14	2728.45	2760.24	2737.87	2726.30	2756.61
12/4/97	2746.11	2735.22	2769.85	2762.40	2766.13	2742.78	2775.74	2736.50	2767.30	2715.51	2721.88	2755.63

Table 9 Corresponding Porewater Pressures Of Piezometer Levels From Tige Dam

Piezometer No./Porewater Pressures (KPa)

Date	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}
17/1/94	5025.66	4999.08	4986.23	4923.05	4940.81	5040.57	5041.75	5077.66	5084.82	5085.41
30/3/94	5025.47	5003.98	4986.23	4923.05	4940.81	5035.96	5036.75	5072.75	5065.20	5086.68
15/5/94	5022.72	5016.25	4986.23	4923.05	4940.81	5028.90	5029.20	5067.36	5085.21	5086.68
5/7/95	5020.95	4994.86	4985.64	4921.87	4941.00	5018.60	5033.12	5060.39	5084.82	5086.68
30/9/95	5018.99	4991.33	4987.80	4918.13	4927.86	5013.30	5042.34	5096.39	5085.70	5083.44
15/11/95	5024.19	4994.17	4985.83	4920.99	4927.86	5014.29	5049.70	5092.96	5085.90	5086.68
31/1/96	5026.55	5001.24	5104.14	4922.07	4928.05	5038.32	5040.97	5079.52	5085.01	5084.23
5/7/96	5022.13	4997.51	5055.98	4948.65	4928.05	5023.11	5034.30	5062.94	5085.01	5086.68
7/11/96	5019.88	4991.43	5139.07	4921.38	4928.34	5037.14	5046.85	5090.80	5085.11	5082.52
2/1/97	5024.29	4995.45	5139.07	4921.38	4928.15	5042.63	5043.81	5085.11	5085.11	5081.58
30/7/97	5023.70	4999.08	5139.07	4922.27	4928.15	5026.55	5032.44	5070.69	5085.11	5082.52
3/11/97	5021.15	4995.15	5139.16	4921.28	4927.86	5029.20	5044.79	5088.55	5091.31	5086.19

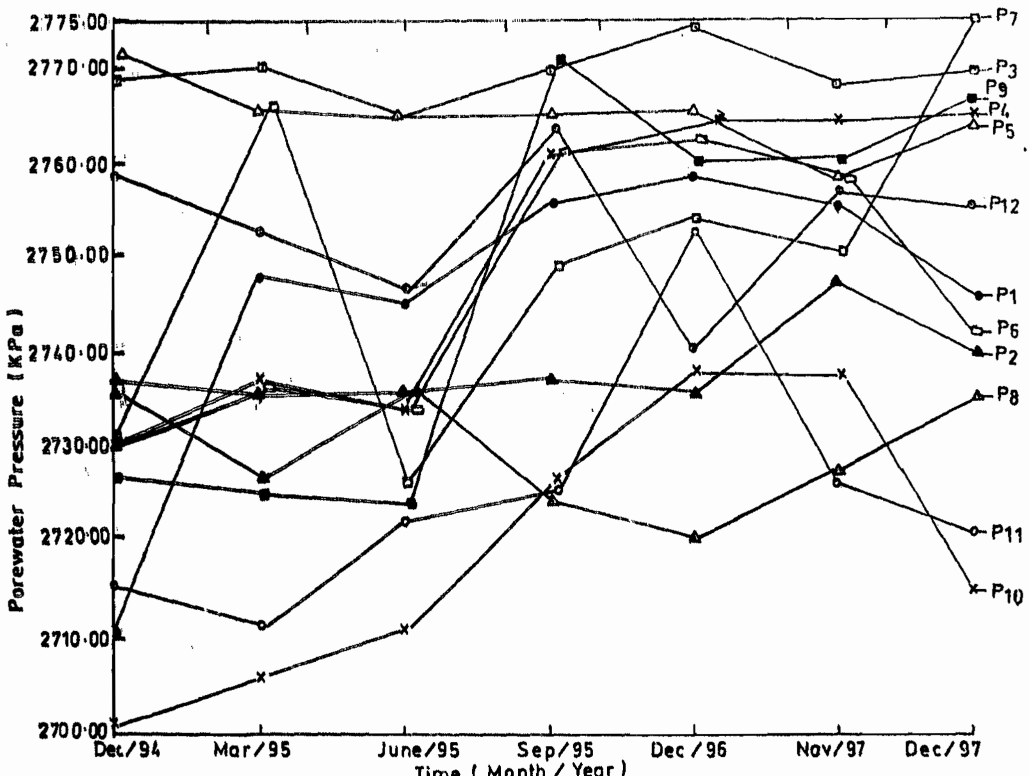

Figure 6 Plot of Porewater Pressure values (Derived from Piezometer levels) Versus Time for Goronyo Dam.

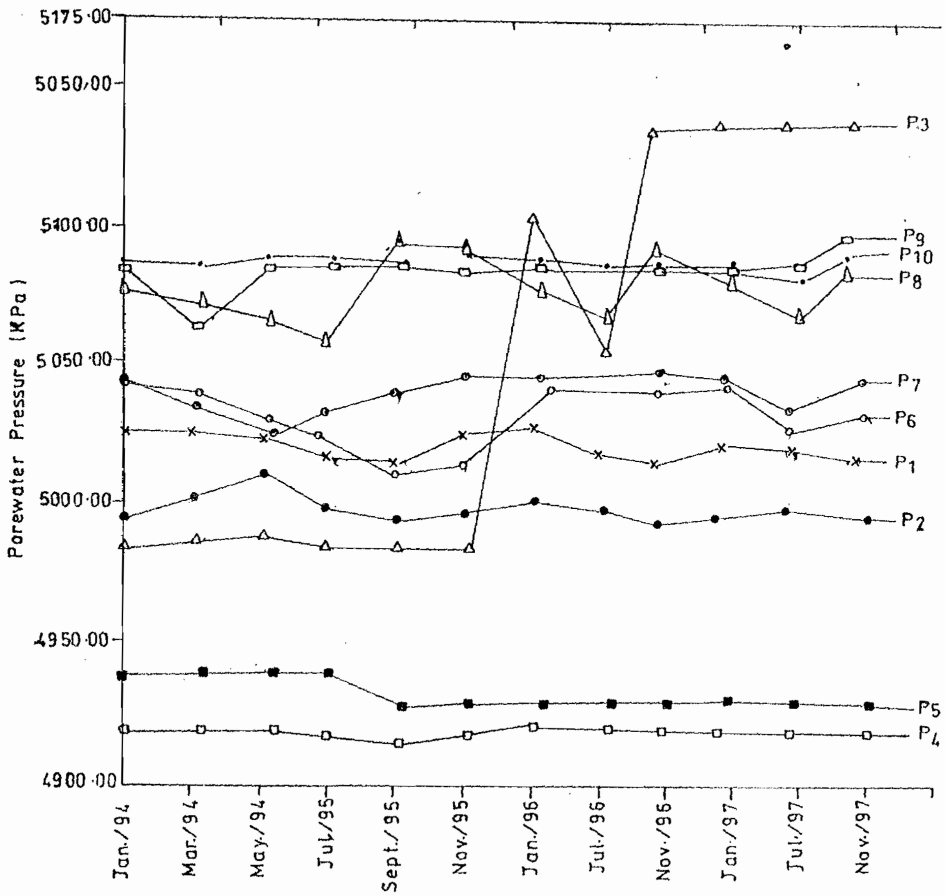

Figure 7 Plot of Porewater Pressure Values (Derived from Piezometer levels) Versus Time for Tiga Dam.

p_3) have been reduced. The stability of the dams are therefore threatened due probably to core leakage (Table 1) and detailed investigations should be instituted to determine the exact cause of the core leakage/increase in porewater pressure and the relevant remedial action. Figures 4 and 5 also indicate that changes in the lake levels of the dams have no influence on the piezometer levels and therefore on the porewater pressure. The lake levels of the dam depend generally on the climate of the area (rainfall), the discharge of the rivers where the dams were constructed and the rate of abstraction of water from the reservoirs while the pizometer level (porewater pressure) depend on the subsurface conditions at the dam site including geology, dam foundation and embankment materials.

CONCLUSION AND RECONMMENDATION.

Collection and analysis of piezometer / lake level records from Goronyo and Tiga dams in Northern Nigeria have shown that:

1. Abnormal high porewateer pressure changes were observed in piezometers p_7 and p_9 as well as p_3 installed in Goronyo and Tiga dams, respectively. These spots should have correspondingly low effective strans/low sheer shear strength and therefore incipient instability. The instability may be caused by core leakage.
2. The lake levels have no influence on the porewater pressure values of the dams as recorded in the piezometers.

In order to increase the stability of the dams and prevent their possible failures, due to porewater pressure problems, it is recommended that:

1. The spots with and causes of abnormally high porewater pressure changes should be identified and relevant remedial action taken.
2. Similar studies should be undertaken in other large dams in Nigeria to assess their stability.

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