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MATERIAL PROPERTIES AS A MEASURE OF THE AGING EFFECTS OF EMBANKMENT DAMS

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ABSTRACT: *Aging of embankment dams and their foundations is of concern to persons involved in their design, construction and operation. It is due to time-related changes in the structural properties of the materials of which the dam and its foundation are composed. Indirect evaluation of aging is by monitoring the effects and consequences of changes in structural properties and the actions causing them.This paper examined the geotechnical properties of ten (10) selected earth dams, from two States in the South-western Nigeria to consider aging effects on their materials properties. Soil samples were obtained from upstream and downstream sides of the dams from six locations at depth of 1.2 m. Geotechnical tests were carried out to determine Specific gravity, Soil classification, Maximum Dry Density (MDD) and Optimum Moisture Content (OMC), Liquid Limits (LL), Plastic Limit (PL), Plasticity Index (PI), and Coefficient of Permeability (CP). The results showed migration of fine grain (clay materials) from upstream to downstream side of the dam; which was an indication of fracturing within the embankments; thus, internal erosion is a possibility within the fractured zones. Prevention and mitigation of aging could be achieved through quality design, construction and operation. A well planned and performed monitoring program will help in early detection of aging scenarios; and provision of convenient access to all vital areas of the dam will enhance surveillance and regular maintenance*.

KEYWORDS: Aging scenarios, Structural properties, Indirect evaluation, Internal erosion, Regular maintenance

INTRODUCTION

Aging or deterioration of embankment dams and their foundations is of concern to persons involved in their design, construction and operation. These concerns extend throughout the entire life of the dam until safe abandonment or demolition. Design may mitigate effects of aging. Vigilance during construction may correct conditions contributing to aging. Monitoring during operation may identify aging processes which could impact on dam safety. The aging of dams, constructed of earth and rockfill material, as defined herein is due to time-related changes in the properties of the materials of which the structure and its foundation are composed.The International Commission on Large Dams (ICOLD), Committee on Dam Ageing, studied the various aging phenomena of concrete and embankment dams and appurtenant works (1986 – 1993) and prepared a report on their findings (ICOLD, 1994).

The report identified features of deteriorated structures, the processes of deterioration, good design practices, surveillance, detection and rehabilitation. Methods by which the deterioration may be controlled and perhaps prevented were also identified (USSD, 2010).

Aging scenarios

For an understanding of aging, it is necessary to establish the relationship between cause and effect leading to the degradation in structural properties of the dam or foundation. These processes are referred to as scenarios. The causes originate actions on the dam and/or foundation and may affect the material's structural properties. The consequences of deterioration may sometimes only be observed after some years of operation.

Table 1 lists the major aging scenarios for selected earth dams from the two states in the Southwestern Nigeria (Table 2).

Detection and measurement of aging

Detection and measurement are the basis for control of the aging scenarios. An up-to-date knowledge of the dam condition is required so that anomalous behavior is detected in sufficient time to allow appropriate intervention to correct the situation and avoid severe consequences. Direct evaluation of aging is possible by monitoring changes in structural properties. Indirect evaluation is by monitoring the effects and consequences of changes and the actions causing them. It is important to establish and maintain a strong data base to assess the impact of aging scenarios on dam safety. Jansen (2008) stated "Dam owners and engineers have access to a variety of advanced analytical tools for assessing the safety of a dam. When using these tools, it's important to remember that a mathematical tool is only as good as the data that supports it. Each dam site and its environment is unique, with different characteristics governing performance. This requires sensibly interpreting specific site conditions and their effect on dam safety."

Table 1: lists the major aging scenarios for earth dams

Foundation (soil or rock mass)	Dam body (embankment materials)	Other
-- Deformation -- Loss of strength -- Uplift pressure increase -- Internal erosion -- Foundation degradation	-- Deformation -- Loss of strength -- Pore pressure increase -- Internal erosion -- Embankment degradation -- Surface erosion	-- Seepage through concrete faced rockfill dams -- Permeability change -- Loss of bond between concrete structure and embankment -- Aging of geosynthetic Materials

MATERIALS AND METHODS

The selected dams are multipurpose: flood control, irrigation, community water supply, while the roadway serves as pedestrian or vehicular bridge across the river. The dams from Oyo state are being maintained by Oyo State Agricultural Development and Eradication Program (OYSADEP). The definite seasons in the regions (Oyo and Osun States) are wet and dry seasons. The wet season is between March and October, while dry season is between November and March, which is often accompanied by harmattan. Temperature is highest during February (32^{o}C) and lowest in July and August (27^{o}C). The rainfall is about 1200mm per annum. The regions lies in the area of ferruginous tropical soil derived mainly from basement complex and old sedimentary rock (Barbour).

Table 2: List of selected Earth Dams from Oyo and Osun States in Southwestern Nigeria

		Year of Completion	Reservoir Capacity cumes
S/N	Embankment Dam location		
1.	Irawo dam, Atisbo LGA, Oyo State	1999	300,000
2.	Oje-owode Saki-East LGA, Oyo state	1995	290,000
3.	Igbeti dam, Olorunsogo LGA, Oyo State	2001	518,000
4.	Ikoyi-ile dam, Oriire LGA, Oyo State	1964	108,000
5.	Eleyele dam ,Ibadan, Oyo State	1939	1,550,000
6.	Pade dam, Akinyele LGA, Oyo State	2000	174,000
7.	Awba dam, UI, Ibadan, Oyo State	1972	230,000
8.	New Erinle (Ede) dam, Ede North LGA, Osun State	1988	94,000,000
9	Erinle dam (old), osun State	1954	5,300,000
10.	Eko-ende dam, Ifelodun LGA, Osun State	1979	910,000

For the geotechnical investigation, disturbed soil samples were obtained from both upstream and downstream sides of the dam embankment at three different points located at a depth of 1.2 m - 1.4 m. The tests carried out according to B.S 1377: Part 2 of 1990 included, sieve analysis for soil classifications, compaction test for maximum dry density (MDD) and optimum moisture content (OMC), Atterberg limits to measure liquid limits (LL), plastic limit (PL) and the plasticity index (PI) Permeability test was also carried out to ascertain the coefficient of permeability (k) of the soil samples.

THE RESULTS OF LABORATORY ANALYSES OF SOIL SAMPLES

The summary of results of laboratory tests was presented in Tables 3-7, while Figures 1-6 showed the effects of aging scenarios. Comprehensive discussions on the results from the geotechnical tests were presented below:

Tables 3-7: Engineering and geotechnical properties of soil samples collected from upstream and downstream slopes.

Specific Gravity

The specific gravity values of the samples were indication of light particle density. This may lead to floatation of particles and there is tendency for soil particles migration (Table 3).

Table 3: Geotechnical Analyses Of Embankment Dams In Southwestern, Nigeria Cont'd

		UPSTREAM Values	DOWNSTREAM Values
S/N	Embankment Dam location	SPECIFIC GRAVITY	
1.	Irawo dam, Atisbo LGA, Oyo State	2.72	3.37
2.	Oje-owode Saki-East LGA, Oyo state	2.50	2.55
3.	Igbeti dam, Olorunsogo LGA, Oyo State	2.79	2.47
4.	Ikoyi-ile dam, Oriire LGA, Oyo State	2.44	2.38
5.	Eleyele dam ,Ibadan, Oyo State	2.05	2.12
6.	Pade dam, Akinyele LGA, Oyo State	-	-
7.	Awba dam, UI, Ibadan, Oyo State	1.25	1.26
8.	New Erinle (Ede) dam, Ede North LGA, Osun State	2.72	2.58
9	Erinle dam (old), osun State	2.41	2.46
10.	Eko-ende dam, Ifelodun LGA, Osun State	2.47	2.44

Grain Size Analysis

According to the unified classification, the results obtained from grain size distribution curves of the materials showed the samples were coarse-grained low clay (CL) group, which is an evidence of erosion of fine particles from the original material (Table 4).

Atterberg limits

Soil materials were generally, of low plasticity at the upstream and medium plasticity at the downstream. The Atterberg limit values depicted a kind of washing of fine particles from upstream and deposit at the downstream. These observations correlated with the unified classification of the grain sizes distribution (Table 5).

Compaction Test: Moisture – Density Relation

The maximum dry densities obtained are within the limiting values. The optimum water content values obtained at upstream are averagely, lower than values at the downstream . This inferred the level of the looseness of the soils at the upstream of embankment, and deposit of fine materials at the downstream side of the dam (Table 6).

Table 4: Geotechnical Analyses Of Embankment Dams In Southwestern, Nigeria Cont'd

		UPSTREAM Values	DOWNSTREAM Values
S/N	Embankment Dam location	Particle Size Analysis (%)	
1.	Irawo dam, Atisbo LGA, Oyo State	0.23	0.68
2.	Oje-owode Saki-East LGA, Oyo state	1.96	2.47
3.	Igbeti dam, Olorunsogo LGA, Oyo State	21.21	23.71
4.	Ikoyi-ile dam, Oriire LGA, Oyo State	9.65	11.80
5.	Eleyele dam ,Ibadan, Oyo State	4.68	2.43
6.	Pade dam, Akinyele LGA, Oyo State	58.8	37.8
7.	Awba dam, UI, Ibadan, Oyo State	30.30	30.0
8.	New Erinle (Ede) dam, Ede North LGA, Osun State	0.13	1.35
9	Erinle dam (old), osun State	10.61	11.43
10.	Eko-ende dam, Ifelodun LGA, Osun State	1.88	1.73

Table 5: Geotechnical Analyses Of Embankment Dams In Southwestern, Nigeria Cont'd

		UPSTREAM Values			DOWNSTREAM Values		
S/N	Embankment Dam location	Atterberg Limits (%)					
		LL	PL	PI	LL	PL	PI
1.	Irawo dam, Atisbo LGA, Oyo State	47.1	17.7	29.4	24.8	17.3	7.5
2.	Oje-owode Saki-East LGA, Oyo state	25.3	12.3	13.0	25.0	17.7	7.3
3.	Igbeti dam, Olorunsogo LGA, Oyo State	40.7	17.0	23.7	55.3	22.2	33.1
4.	Ikoyi-ile dam, Oriire LGA, Oyo State	28.7	21.0	7.7	23.8	16.5	7.3
5.	Eleyele dam ,Ibadan, Oyo State	38.4	23.2	14.4	40.0	21.9	17.1
6.	Pade dam, Akinyele LGA, Oyo State	60.0	24.0	36.0	68.0	33.0	35.0
7.	Awba dam, UI, Ibadan, Oyo State	36.2	29.6	6.5	48.8	23.2	25.6
8.	New Erinle (Ede) dam, Ede North LGA, Osun State	23.7	17.4	6.3	23.3	15.0	8.3
9	Erinle dam (old), osun State	30.7	18.5	12.2	27.9	18.8	9.1
10.	Eko-ende dam, Ifelodun LGA, Osun State	30.6	20.0	10.6	28.3	19.2	9.1

Table 6: Geotechnical Analyses Of Embankment Dams In Southwestern, Nigeria Cont'd

		UPSTREAM Values		DOWNSTREAM Values	
S/N	Embankment Dam location	Compaction Tests			
		MDD	OMC	MDD	OMC
1.	Irawo dam, Atisbo LGA, Oyo State	1.79	8.92	1.77	11.80
2.	Oje-owode Saki-East LGA, Oyo state	1.78	12.40	1.80	10.30
3.	Igbeti dam, Olorunsogo LGA, Oyo State	2.03	10.33	1.85	15.33
4.	Ikoyi-ile dam, Oriire LGA, Oyo State	1.94	8.80	1.85	9.94
5.	Eleyele dam ,Ibadan, Oyo State	1.83	11.20	1.82	12.60
6.	Pade dam, Akinyele LGA, Oyo State	0.30	17.00	0.26	14.20
7.	Awba dam, UI, Ibadan, Oyo State	1.59	16.41	1.56	15.40
8.	New Erinle (Ede) dam, Ede North LGA, Osun State	1.92	11.08	1.88	9.00
9	Erinle dam (old), osun State	2.02	10.20	2.06	9.70
10.	Eko-ende dam, Ifelodun LGA, Osun State	1.99	12.76	2.04	7.34

Table 7: Geotechnical Analyses Of Embankment Dams In Southwestern, Nigeria Cont'd

		UPSTREAM Values	DOWNSTREAM Values
S/N	Embankment Dam location	Permeability(cm/s)	
1.	Irawo dam, Atisbo LGA, Oyo State	2.35x10-6	2.78x10-6
2.	Oje-owode Saki-East LGA, Oyo state	4.82x10-5	5.32x10-5
3.	Igbeti dam, Olorunsogo LGA, Oyo State	8.18x10-4	1.35x10-4
4.	Ikoyi-ile dam, Oriire LGA, Oyo State	8.88x10-7	6.43x10-7
5.	Eleyele dam ,Ibadan, Oyo State	6.93x10-5	6.95x10-5
6.	Pade dam, Akinyele LGA, Oyo State	2.17x10-6	2.50x10-6
7.	Awba dam, UI, Ibadan, Oyo State	2.03x10-7	1.78x10-7
8.	New Erinle (Ede) dam, Ede North LGA, Osun State	7.27x10-7	4.29x10-7
9	Erinle dam (old), osun State	5.41x10-7	6.14x10-7
10.	Eko-ende dam, Ifelodun LGA, Osun State	5.87x10-7	5.71x10-7

Figures 1-6 showed deteriorations of some sections of the selected dams:

Figure 1: Downstream side of the spillway with fractured floor

Figure 2: Seepage water flowing out at downstream toe

Figure 3: The Crest of the dam covered with vegetation

Figure 4: Disjointed concrete slabs at upstream face

Figure 5: Dislocated stone riprap with tree vegetation at upstream side

Figure 6: Disjointed stone riprap at upstream side

CONCLUSIONS AND RECOMMENDATIONS

The results from this report were of the opinion that the selected earth dams were generally loosed and permeable, due to aging effects on the material properties. Also, pictures from the visual observations (Figures 1-6) showed deteriorations of some sections of the dams, and hence, possibility of erosion of fine particles from the upstream to downstream of the dam embankment; which is a major factor in aging scenarios. The following recommendations were suggested:

1. Direct evaluation of aging by monitoring changes in structural properties.
2. Indirect evaluation by monitoring the effects and consequences of changes and the actions causing them.
3. Establish and maintain a strong data base to assess the impact of aging scenarios on dam safety.
4. Investigations involving geophysical methods such as electromagnetic, vertical electrical sounding and lateral profiling methods should be applied to detect the fractured zones.
5. The following methods such as foundation grouting, installation of upstream blanket or installation of relief wells should be used to control the quantity of internal erosion.
6. Good drainage facilities such as Sand Filter and Toe Gravel Drains, Relief wells should be provided at the dam toe of embankment.

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