Influence of Engineering Properties of Soils on Failures and Distresses of Earth Dams in North-Eastern Nigeria

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Abstract **- The stability and water tightness of earth dams depend largely on the engineering properties of the construction materials. There are many cases of dam failures and distresses in north-eastern Nigeria that were not studied and documented. The objective of this study is to determine the influence of engineering properties of soils on failures and distresses of earth dams in the study area.**

A total of 22 randomly selected earth dams constructed with different soil materials in north-eastern Nigeria were studied. Data were obtained on failure modes using the Association of State Dam Safety Officials method. Soil samples collected were analysed for specific gravity (Gs), particle size distribution, Atterberg limits, compaction, California Bearing Ratio (CBR), permeability, triaxial compression and consolidation tests according to BS1377. The results were analysed using descriptive statistics.

Soil groups for constructing earth dams in the study area ranged from poorly graded sands to silty/clayey sands. Seventy-nine percent of the failed and distressed dams have embankment materials with Coefficient of uniformity of less than 5. Sixty-five percent of failed and distressed dams have Plasticity Index of 0-7. Eighty percent of functional dams have highly compacted soils with maximum dry density ranging from 1.84 to 2.01Mg/m^3. High permeability ranging from 0.018 to 0.110 m/day influenced 33% of dam failures. Consolidation tests showed a settlement of 1.18mm and 2.29mm for functional and failed dam respectively. The Gs (2.41-2.70), CBR values (11-46%), Cohesion (35-215kN/m^2) and angle of internal friction (3-18^o) influenced particular incidents without a trend.

Poor soil selection and application influenced the status of earth dams in north-eastern Nigeria. Soil testing, grouting, soil stabilisation, use of rock ripraps, impervious blankets and maintenance scheduling are suggested to minimise failures and ameliorate distresses.

Keywords: Earth dam, Soil properties, Distress, Failure, Compaction.

INTRODUCTION

Earth dams are constructed mainly from earth or soil. Earth dams for the storage of water for irrigation have been built since early times. They are of low heights, designed by empirical methods and their construction based on experience. However, developments in soil mechanics and new construction techniques have enabled engineers to build dams of very large heights and different configurations.

The two basic requirements to be satisfied by an earth dam are imperviousness and stability under all conditions of operations. Despite the advantages of materials and cost, earth dams are more susceptible to failures as compared to rigid gravity dams or any other type of dam.

Before the development of the discipline of soil mechanics, earth dams were being designed and constructed on the basis of experience, as no rational basis for their design was available. This probably led to the failure of various such earth embankments. However, in these days, these dams can be designed with a fair degree of theoretical accuracy, provided the properties of the soil placed in the dam are properly controlled. This condition makes the design and construction of such dams thoroughly interdependent. (Garg, 2008)

The recorded damages to earth dams ranges from complete catastrophic failure, resulting in large property damage and loss of life, to relatively minor deterioration or distressnes which may or may not necessitate remedial work. The worst type of failure occurs when the reservoir water suddenly breaks through the embankment and surges downstream in one devastating flood wave. Lesser damages or distresses may in the long run lead to complete failure if left unattended.

On a worldwide scale, it is clear that the objective of constructing stable dams is not always achieved. During the 1900–1965 periods, about 1% of the 9000 large dams in service throughout the world have failed, and another 2% have suffered serious accidents (Wrechein and Mambretti, 2009).

Knowledge of the principal lessons learned from failures and damages in the past is an essential part of the training of earth dam designer. (Pumia and Lal, 1992). On the basis of investigation reports on past failures by the same authors, it is possible to categorize the types of failures into three main broad classes namely; Hydraulic (40%), Seepage (30%) and Structural failures (30%). Structural failures of earth dams in Nigeria were explained in Umaru *et al.*, (2010).

Dam failures may occur due to a variety of causes. The most common causes of dam failure are leakage and piping (35%), overtopping (25%), spillway erosion (14%), excessive deformation (11%), sliding (10%), gate failure (2%), faulty construction (2%), and earthquake instability (2%) (Lukman *et al*, 2011). The causes and effects of earth dam's failures in north eastern Nigeria were elaborated in Umaru *et al*.,(2014).

The causes of failure and damage of earth dams can be attributed to lack of adequate studies of the engineering properties of soils during design and construction of such dams. Failures and damages of dams in North Eastern Nigeria that were influenced by geology and hydrometreology factors were discussed in Umaru *et al.*, (2015).

A close look at the causes of most failures show that, the situation may be rescued partly by strict application of engineering properties (physical and hydraulic) of soils and hydrology in the design and construction of the dams. These properties were listed by Murthy (2008) as comprising of bulk density, porosity, permeability, submerged density, particle size distribution, friction, cohesion and water content among others.

Terzaghi was quoted by Arora, (2001) on the recommended side slopes and soil types for embankment dams. Signh, (2001) suggested the slopes and soils for small zoned earth dams on stable foundations. Agarwal, (2000) suggested general guidelines for embankment sections and suitability of soils for earth dams construction.

Brink *et al* (1982) suggested that the engineering properties of soils used for the construction of the zones of composite earth dams should include; grade of the soil, clay content, hydraulic conductivity, cohesion and angle of internal friction, liquid limit, plasticity index, optimum moisture content, linear shrinkage and dry density. Yohana *et a.,l* (2003) tested the engineering properties of anthills and found that the properties are similar to what Brink *et al* (1982) suggested. They recommended its use with mixtures of sand and gravel for the control of seepage in earth dams.

An attempt at approximate classification of core materials on the basis of resistance to concentrated leakage was proposed by Sherard (1953) as; Very Good, Good, Fair, Poor and Very poor Materials. Oskooruchi and Mehdibeigi, (1986) suggested that the selection of soil parameters for designing an earth and rockfill dam should be based on a range of activities from site visit to the selection of factor of safety.

This study attempts to investigate the influence of engineering properties of soils on failures and distresses of earth dams in North Eastern Nigeria.

METHODOLOGY

Nigeria, a West African Nation lies between Latitude 4º16'N and 13º52'N, and between Longitude 2º49'E and 14º37'E. North Eastern Nigeria (Fig. 1.) encompasses Borno, Yobe, Bauchi, Gombe, Adamawa and Taraba states. It is the home of a rapidly growing population of some 6.5 million Nigerians. Characterized by water scarcity, the climate of the region ranges from Sahel to Sudan Savannah (Adeniji, 2003). The choice for the study area is the availability of dams and their collapse and distressnes.

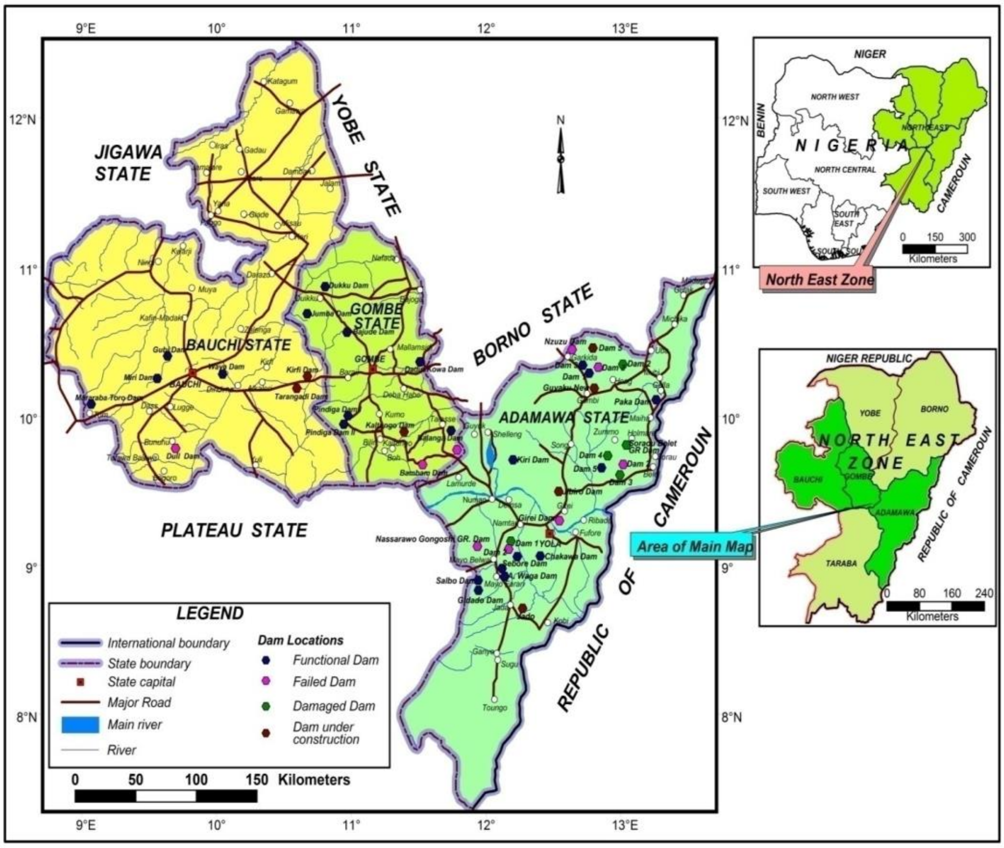

Fig 1. Map of Northeastern Nigeria showing dam locations and status

In this study, Adamawa, Gombe and Bauchi states were selected out of the six states that make up North Eastern Nigeria. The choice of the sampling is guided by the fact that there are very few dams in Borno and Yobe States and for logistic reasons.
The methodologies adopted for carrying out the study follows the Association of State Dam Safety Officials (ADSO) guideline, (2011) and the BS1377 (1990) as follows;

Field Work

The field work was carried out in form of visitations to selected dams in the study area for observations, measurements, photographs and picking of soil samples. The materials used were; measuring tape, Global Positioning System (GPS), camera, soil auger, hoe, shovel and scoop for removing and picking of soil samples and cement bags for carrying and transporting the samples to the laboratory. The 22 dams visited were randomly selected across the study area.

Laboratory Experiments

Soil samples were collected where appropriate, placed in cement bags and transported to the laboratory for the necessary tests. Soil tests were carried out in the soil mechanics laboratory of the Civil Engineering programme at the Abubakar Tafawa Balewa University of Technology (ATBU), Bauchi, Nigeria. Methods of test for soils for civil engineering purposes BS1377(1990) was adopted for the sampling, soil test and analysis.

Based on observation and inspection, soil samples were picked at the appropriate point (failure point, damaged point, stockpiled leftovers) and at different parts (embankment, core, shell, reservoir and spillway) of the dam for the tests and analysis. The different types of scientific and engineering tests that the samples were subjected to were; Specific gravity (Gs), Sieve analysis, Atterberg limits (PL, LL, PI), Compaction test (MDD & OMC), California Bearing Ratio (CBR), Permeability (K), Triaxial test (C and ϕ) and Consolidation test. The soil samples were picked from specific functional, distressed and failed dams across the study area.
All the data were analysed using Analysis of Variance (ANOVA) and descriptive statistics.

RESULTS AND DISCUSSION

California Bearing Ratio (CBR)

The CBR values of the materials of construction of the failed dams range from 11 to 46% (Table 1). The materials exhibit a wide range of behaviors under loading and range from very strong materials like well graded gravel to relatively weak materials like silts. The CBR values of materials of construction of the distressed dams were found to range from 14 to 28%. These materials can also exhibit a wide range of behavior under loading as will be characterized by a relatively strong material like clayed gravel to a relatively weak material like Silt. The CBR values of the materials of construction of the functional dams range from 14 to 36%. Again, these materials exhibit a range of behaviors under loading as shown by relatively strong materials like gravely clay to a weak material like silt. Although the minimum CBR for the failed dams is the lowest, the range is not significantly different from distressed and functional dam soils. This shows that the CBR values alone cannot predict failure, distressnes or functionality of earth dams in the study area, but have influenced particular failures when associated with other soil properties.

Table 1. Some Soil Properties and CBR Values

S/N	Name of Dam	Soil Sample location	Moisture Content (%)	Bulk Density Mg/m^3	Dry Density Mg/m^3	CBR (%)	Status
1.	Girei	SPLW	6.4	2.20	2.07	46	Failed
		EM					
		RSV	-	-	-	-	
2.	Guyaku GR Dam 2	RSV	-	-	-	-	Failed
		EM					
3.	Guyaku GR Dam 5	IN GULLY	-	-	-	-	Failed
		EM					
4.	Nzuzu Dam	SPLW	8.6	2.00	1.84	24	Failed
5.	NGGR Dam 1(Dalehi)	EM	14.8	1.94	1.69	20	Distressed
6.	NGGR Dam 2(Dalehi)	RSV	-	-	-	-	Failed
7.	Ali Walga Dam	EM	11.3	2.18	1.96	36	Functional
8.	SBGR Dam 3	RSV	-	-	-	-	Distressed
9.	SBGR Dam 4	EM	5.6	2.02	1.91	28	Distressed
		RSV	-	-	-	-	
10.	Dadinkowa Dam	EM	10.8	2.06	1.86	21	Functional
11.	Bambam Dam	EM	18.5	1.76	1.49	11	Failed
12.	Pindiga Dam I	EM/RSV	9.7	2.07	1.89	14	Functional
13.	Pindiga Dam II	EM/RSV	13.4	1.85	1.63	31	Functional
14.	Bojude	EM/RSV	8.9	1.87	1.72	24	Functional
15.	Jombo Dam Dukku	EM/RSV	15.5	1.70	1.47	25	Functional
16.	Dukku Dam(Kogin Dole)	EM	6.9	2.09	1.96	25	Functional
17.	Cham Dam	EM/RS	14.7	2.16	1.88	17	Failed
18.	Waya Dam	EM(SHELL)	10.8	2.07	1.87	15	Failed (rptdly)
		EM(CORE)	8.1	2.13	1.97	20	

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19.	Gubi Dam	EM(SHELL)	9.7	2.08	1.90	36	Functional
		EM(CORE)	12.1	2.15	1.92	34	
20.	Miri Dam	EM/RSV	11.8	2.15	1.92	14	Distressed
21.	Marraraba Ganye Toro Dam	EM/RSV	11.5	2.14	1.92	21	Functional
22.	Dull Dam	EM(Left)	15.9	2.00	1.73	19	Failed
		EM(Right)	10.8	2.23	2.01	23	

Soils were not sampled at some dams because of non cooperation of owners and logistic reasons
KEY; EM = Embankment, RSV = Reservoir, SPLW = Spillway

Coefficient of Permeability, K

In Table 2, the permeability of the materials of construction of the failed dams range from 1.21x10^{-8} to 1.21x10^{-6}m/s thus indicating a wide range of permeability phenomena from a practically impermeable material to a poor draining material. The permeability values for the distressed dams range from 1.76x10^{-8} to 5.65x10^{-8}m/s indicating that the materials are practically impermeable; and are thus excellent for use as construction materials for earth dams in this regard. The range of permeability values for the materials of construction of functional dams was found to be 8.76x10^{-8} to 1.82x10^{-7}m/s also signifying good materials that are impervious to some extent. About a third of the failed dams have their embankment soil materials with coefficient of permeability between 1.21x10^{-6} m/s to 2.10x10^{-7} m/s, suggesting the susceptibility of such dams to seepage failure. On a study of gully erosion in the north-eastern Nigeria, Obiefuna et al, (1999) obtained similar results.

Table 2. Some Soil Properties and Permeability Values

S/N	Name of Dam	Soil Sample Location	Moisture Content (%)	Bulk Density ρ(Mg/m^3)	Dry Density, ρ_d (Mg/m^3)	Void Ratio	Permeability, K (m/s)	Status
1.	Girei	SPLW	8.0	2.17	2.01	0.294	1.21x10^{-6}	Failed
		EM	18.5	1.88	1.59	0.535	2.33x10^{-8}	
		RSV	1.31	1.97	1.95	0.323	2.73x10^{-6}	
2.	Guyaku GR Dam 2	RSV						Failed
		EM	6.8	2.09	1.96	0.342	4.9x10^{-8}	
3.	Guyaku GR Dam 5	IN GULLY						Failed
		EM						
4.	Nzuzu Dam	SPLW	13.7	2.00	2.29	0.135	2.79x10^{-8}	Failed
5.	NGGR Dam 1(Dalehi)	EM	7.6	2.16	2.01	0.199	5.65x10^{-8}	Distressed
6.	NGGR Dam 2(Dalehi)	RSV	15.4	1.83	1.59	0.635	9.33x^{-8}	Failed
7.	Ali Walga Dam	EM						Functional
8.	SBGR Dam 3	RSV	11.8	2.03	1.82	0.357	2.31x10^{-8}	Distressed
9.	SBGR Dam 4	EM	10.8	1.80	1.63	0.552	1.76x10^{-8}	Distressed
		RSV	11.5	2.17	1.95	0.349	1.79x10^{-8}	
10.	Dadinkowa Dam	EM	21.5	2.03	1.67	0.551	8.78x10^{-8}	Functional
11.	Bambam Dam	EM/RSV	12.5	1.99	1.77	0.429	2.61x10^{-8}	Failed
12.	Pindiga Dam I	EM/RSV	15.7	2.03	1.76	0.460	7.71x10^{-8}	Functional
13.	Pindiga Dam II	EM/RSV	20.1	2.63	1.67	0.614	2.02x10^{-8}	Functional
14.	Bojude	EM/RSV	15.6	2.03	1.76	0.534	2.46x10^{-8}	Functional
15.	Jombo Dam Dukku	EM/RSV	6.6	2.08	1.95	0.282	4.43x10^{-8}	Functional
16.	Dukku Dam(Kogin Dole)	EM	11.1	2.13	1.92	0.354	1.82x10^{-7}	Functional
17.	Cham Dam	EM/RSV	1.76	1.98	1.95	0.364	3.42x10^{-8}	Failed
18.	Waya Dam	EM(SHELL)	14.5	2.04	1.77	0.478	4.29x10^{-6}	Failed (rptdly)
		EM(CORE)	13.9	2.01	1.77	0.469	2.01x10^{-7}	
19.	Gubi Dam	EM(SHELL)	14.5	2.05	1.79	0.469	3.00x10^{-8}	Functional
		EM(CORE)	7.8	2.03	1.88	0.399	1.23x10^{-8}	
20.	Miri Dam	EM/RSV	5.36	2.10	1.99	0.322	3.91x10^{-8}	Distressed
21.	Marraraba Ganye Toro Dam	EM/RSV	9.3	2.03	1.86	0.452	1.64X10^{-8}	Functional
22.	Dull Dam	EM(Left)	8.84	2.11	1.94	0.289	1.4x10^{-8}	Failed
		EM(Right)	11.48	2.10	1.88	0.400	1.21x10^{-8}	

KEY; EM = Embankment RSV = Reservoir SPLW = Spillway

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Shear Strength

The range of values for Cohesion C and Angle of Internal friction ϕ for the dams in the study area are as shown in Table 3.

Table 3. Triaxial Compression Test Results (Quick Undrained)

S/N	Name of Dam	Soil Sample location	Cohession, C (kN/m^2)	Angle of Imternal Friction, ϕ (°)	Status
1.	Girei	SPLW			Failed
		EM	74	5	
		RSV			
2.	Guyaku GR Dam 2	RSV			Failed
		EM	215	3	
3.	Guyaku GR Dam 5	IN GULLY			Failed
		EM	60	20	
4.	Nzuzu Dam	SPLW	40	13	Failed
5.	NGGR Dam 1(Dalehi)	EM	70	5	Distressed
6.	NGGR Dam 2(Dalehi)	RSV			Failed
7.	Ali Walga Dam	EM			Functional
8.	SBGR Dam 3	RSV			Distressed
9.	SBGR Dam 4	EM			Distressed
		RSV			
10.	Dadinkowa Dam	EM	40	50	Functional
11.	Bambam Dam	EM/RSV	100	5	Failed
12.	Pindiga Dam I	EM/RSV	85	13	Functional
13.	Pindiga Dam II	EM/RSV	100	8	Functional
14.	Bojude	EM/RSV	62	7	Functional
15.	Jumbo Dam Dukku	EM/RSV			Functional
16.	Dukku Dam(Kogin Dole)	EM	70	14	Functional
17.	Cham Dam	EM/RS	95	23	Failed
18.	Waya Dam	EM(SHELL)	35	18	Failed (rptdly)
		EM(CORE)	123	10	
19.	Gubi Dam	EM(SHELL)	61	18	Functional
		EM(CORE)	40	24	
20.	Miri Dam	EM/RSV	60	17	Distressed
21.	Marraraba Ganye Toro Dam	EM/RSV	45	10	Functional
22.	Dull Dam	EM(Left)	70	20	Failed
		EM(Rigth)	100	13	

Key; Em = Embankment, Rsv = Reservoir, Splw = Spillway

The soil materials for the failed dams have C and ϕ values in the range of 35 to 215 kN/m^2 and 3 to 18° respectively, showing an excellent soil as far as the shear strength properties are concerned. The ranges of C and ϕ for the distressed dams was found to be 60 – 70 kN/m^2 and 5 – 17° respectively, this indicate a good shear strength property for embankment in dam construction. The functional dams have their range of C and ϕ as 40 – 100 kN/m^2 and 8 – 50° respectively. This also indicates a material with good shearing strength characteristics. Ironically, the shear strength of the failed dams seems to be better than the distressed and functional dams. Thus, shear strength parameters alone may not be a good indication for failure, distress or functionality of dams in the study area.

Atterberg Limits and Plasticity Index (PI)

In Table 4 the PI values for failed dams were found to vary from 0 to 20 indicating a range of behavior for the construction materials from non-plastic to highly plastic. The range of PI values for distressed dams was 0 to 11, showing a range of behaviors for the embankment materials from non-plastic to soils of medium plasticity. PI values for the functional dams were found to be similar to the failed dams (0 - 21) indicating non-plastic to highly plastic materials. Sixty five percent of failed and distressed dams have their Plasticity indexes between 0 and 7 meaning failures and distresses affect embankments whose soil materials are of low plasticity.

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Table 4. Atterberg Limits (Cone Test)

S/N	Dam	Soil Sample location	Liquid Limit, LL (%)	Plastic Limit,PL (%)	Plasticity Index,PI	Status
1.	Girei	SPLW	13	-	-	Failed
		EM	19	-	-	
		RSV	18	-	-	
2.	Guyaku GR Dam 2	RSV	-	-	-	Failed
		EM	22	15	7	
3.	Guyaku GR Dam 5	IN GULLY	25	23	2	Failed
		EM	30	23	7	
4.	Nzuzu Dam	SPLW	24	18	6	Failed
5.	NGGR Dam 1(Dalehi)	EM	24	14	10	Distressed
6.	NGGR Dam 2(Dalehi)	RSV	16	-	0	Failed
7.	Ali Walga Dam	EM	19	-	0	Functional
8.	SBGR Dam 3	RSV	30	19	11	Distressed
9.	SBGR Dam 4	EM	26	-	0	Distressed
		RSV	9	-	0	
10.	Dadinkowa Dam	EM	27	16	11	Functional
11.	Bambam Dam	EM	47	27	20	Failed
12.	Pindiga Dam I	EM/RSV	46	25	21	Functional
13.	Pindiga Dam II	EM/RSV	24	21	3	Functional
14.	Bojude	EM/RSV	25	15	10	Functional
15.	Jombo Dam Dukku	EM/RSV	27	18	9	Functional
16.	Dukku Dam(Kogin Dole)	EM	15	-	0	Functional
17.	Cham Dam	EM/RSV	43	23	20	Failed
18.	Waya Dam	EM(SHELL)	24	17	7	Failed (rptdly)
		EM(CORE)	21	-	-	
19.	Gubi Dam	EM(SHELL)	23	-	0	Functional
		EM(CORE)	18	-	0	
20.	Miri Dam	EM/RSV	22	15	7	Distressed
21.	Marraraba Ganye Toro Dam	EM/RSV	23	17	6	Functional
22.	Dull Dam	EM(Left)	27	19	8	Failed
		EM(Right)	29	19	10	

KEY; EM = Embankment, RSV = Reservoir, SPLW = Spillway

Compaction; Optimum Moisture Content (OMC) and Maximum Dry Density (MDD)

In Table 5, the range of values for the OMC (%) and MDD (Mg/m^3) of the failed dams were 7.6 - 13.2 and 1.64 - 1.84. These values show a wide range of behavior for the soil under compaction from coarse-grained non cohesive to fine-grained cohesive material. The values of OMC and MDD for the distressed dams range from 8.7 to 10.7 and 1.75 to 2.01 respectively. This depicts materials from coarse-grained non-cohesive to fine-grained cohesive soils. The OMC and MDD of the functional dams were also found to follow a similar trend with values ranging from 6.5 – 11.7 and 1.65 - 2.00 respectively signifying embankment materials from coarse-grained non-cohesive soil to fine-grained cohesive material. There is an obvious overlap in the values of MDD and OMC from the results of the standard proctor compaction tests for all the dams in the study area. Most functional dams (80%) have MDD of 1.84 Mg/m^3 and above. This shows that the denser the embankment soil materials the more the stability.

Table 5. Compaction Test Results

S/N	Name of Dam	Soil Sample location	Optimum Moisture Content,OMC (%)	Maximum Dry Density, MDD (Mg/m^3)	Status
1.	Girei	SPLW			Failed
		EM	10.5	1.80	
		RSV	-	-	
2.	Guyaku GR Dam 2	RSV	-	-	Failed
		EM	10.4	1.82	
3.	Guyaku GR Dam 5	IN GULLY	-	-	Failed
		EM	11.2	1.80	
4.	Nzuzu Dam	SPLW	7.6	1.84	Failed
5.	NGGR Dam 1(Dalehi)	EM	10.7	1.75	Distressed
6.	NGGR Dam 2(Dalehi)	RSV	-	-	Failed
7.	Ali Walga Dam	EM	6.5	2.00	Functional
8.	SBGR Dam 3	RSV	-	-	Distressed
9.	SBGR Dam 4	EM	8.7	2.01	Distressed
		RSV	-	-	

10.	Dadinkowa Dam	EM	11.2	1.84	Functional
11.	Bambam Dam	EM	12.2	1.56	Failed
12.	Pindiga Dam I	EM/RSV	8.4	1.87	Functional
13.	Pindiga Dam II	EM/RSV	11.7	1.65	Functional
14.	Bojude	EM/RSV	9.7	1.84	Functional
15.	Jombo Dam Dukku	EM/RSV	10.8	1.70	Functional
16.	Dukku Dam(Kogin Dole)	EM	7.2	1.91	Functional
17.	Cham Dam	EM/RSV	13.2	1.64	Failed
18.	Waya Dam	EM(SHELL)	10.8	1.96	Failed (rptdly)
		EM(CORE)	10.2	1.83	
19.	Gubi Dam	EM(SHELL)	6.7	1.89	Functional
		EM(CORE)	10.2	2.00	
20.	Miri Dam	EM/RSV	9.4	1.88	Distressed
21.	Marraraba Ganye Toro Dam	EM/RSV	9.5	1.94	Functional
22.	Dull Dam	EM(Left)	8.8	1.84	Failed
		EM(Right)	8.9	1.95	

KEY; EM = Embankment, RSV = Reservoir, SPLW = Spillway

Soil Texture (Sieve Analysis)

The classes of soil found in the construction materials of the failed dams include poorly graded sand (SP), well graded sand (SW), uniformly graded sands of low plasticity (SP-SC) and non-plastic well graded silty sands of low plasticity (SW-SM). This shows a wide range of soil materials that can exhibit a wide range of behavior when used as construction materials for earth dams. The distressed dams were found to have been constructed with poorly graded sands (SP), well graded sands (SW) and well graded silty sands of low plasticity (SW-SM). This also shows that the distressed dam's construction materials vary widely from poorly graded sands to well graded silty sands of low plasticity. The soil materials for the functional dams include poorly graded sands (SP), well graded sands (SW) and uniformly graded silty sands of low plasticity (SP-SM). Embankment soil materials with Coefficient of uniformity of less than 5 accounted for about 79% of the failures and distresses. This implies that there is lack of finer particles in the soil that can help in cementation.

CONSOLIDATION SETTLEMENT

The average settlement of failed dam soil materials was found to be 2.29 mm while that of a functional dam was found to be 1.18 mm, meaning that more settlement was recorded for the failed dam than functional dam. Hence, the weaker the soil the greater the chances of failure. This also agrees with Adejumo *et al*. (2012) on their work on major weak soils.

In summary a wide range of soil groups were used for construction of earth dams in north-eastern Nigeria. This ranged from poorly graded sands to Silty/Clayey sands. The soils are good enough to be used as construction materials for earth dams. Dams whose embankment soil materials have Specific gravity (Gs) of 2.63 and below exhibited greater (92%) failures and distresses than those with higher Gs. This means that the cleaner the soil grains the less will be the cementing effects between them. Embankment soil materials with Coefficient of uniformity of less than 5 accounted for about 79% of the failures and distresses. This means that, uniform graded soil lack the finer particles and intermediate particles that help in binding the soil together. Sixty five percent of failed and distressed dams have their Plasticity index (PI) values between 0 and 7 meaning failures were recorded in embankments with low plasticity. Most functional dams (80%) have high MDD of 1.84 mg/m^3 and above. This shows that the denser the embankment soil material the more stable will be the embankment. Good percentage of the failed dams (33%) have their embankment soil materials with coefficient of permeability between 1.21x10^{-6} m/s to 2.10x10^{-7} m/s, suggesting the susceptibility of such dams to seepage failure.

The Properties of soil can influence failure, distressnes or functionality of earth dams in conjunction with other engineering factors (feasibility studies, design and construction), geological factors and hydrometreological conditions.(Umaru, 2014, Umaru et al. 2014; 2015)

The soil tests results were analyzed with respect to failure, distressnes and functionality using ANOVA. The result shows that there are no significant differences in the soil properties with respect to status of the dams in the study area. In categorical terms, soil properties alone cannot determine failure, distressnes or functionality of earth dams in the study area, because geology as well as hydrometreology also has effects on the status of the dams as suggested by Umaru, (2014) and Umaru et al. (2014; 2015)

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