VOL. 5, NO. 11, NOVEMBER 2010 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences


www.arpnjournals.com

STRUCTURAL FAILURES OF EARTH DAMS IN NIGERIA: A CASE STUDY OF CHAM DAM IN GOMBE STATE

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ABSTRACT

The study investigates the reasons for failure of earth dams in Nigeria with emphasis on dams owned by the River Basin Development Authorities of the Federal Ministry of Agriculture and Water resources using Cham dam in Gombe State as case study. The general causes of earth dam failure were considered with emphasis on failures due to engineering factors. Cham dam failed in September 1998 after commissioning in December 1992 as a result of poor planning, inadequate study, inconsistent design, un-engineered construction and lack of dam safety monitoring team at site. Based on the findings, suggestions were given on how earth dam failures in Nigeria can be minimized in terms of adequate feasibility studies, good design, appropriate construction and an improved maintenance culture.

Keywords: earth dams, failures, seepage failure, hydraulic failure, structural failure, Nigeria.

1. INTRODUCTION

Water supports life. It remains one of the most valuable natural resources vital to the existence of any form of life. Qian, (2003) reported that all human's production activities could only be carried out with water. As important as water is ,it is a limited resource according to the same author; the total amount of all kinds of water is about 1.39 billion km^3 the world fresh water is only about 36 million km^3 representing less than 3% of worlds total water amount. The report from Wikipedia (2008) is even more alarming; 97% of world's total water is trapped in the oceans as salt water, 2.4% solidified in polar ice caps and glacier while about 0.6% is available as fresh water in lakes, rivers and ponds. The exploitation of water resources has increased tremendously in the last century all over the word; owing to the increase in human population and economic development making it imperative to use all available water resources.

In Nigeria, for instance, more than 50% of the geographical area lies in the Savannah and over time, this area has been vulnerable to the vagaries of periodic and severe droughts, affecting the survival of man and animals (Adeniji, 2003). Safe and economic design and construction of dams to store surplus river waters has thus assumed much greater urgency.

Dams are constructed to intercept run off and create a reservoir. The reservoir can be utilized to regulate runoff for use in any of the following two broad categories:

a) **Conservation:** This implies storage of surplus water at high flows for utilization at periods of deficient flows. This utilization could be for one or more of several purposes, for example, water supply, agriculture, hydro-power, navigation and even aesthetics.
b) **Flood control:** This entails regulation of floods by storing some of the flood flow and releasing it gradually later.

The function of a dam may have a bearing on its location and design. For example, a flood control reservoir may be subject to repeated rapid draw down while a conservation reservoir would seldom face such a situation. For earth dams, this would require different criteria for safety during sudden draw down (Oskoorouchi, 1988).

It is very difficult to say where and when the first man-made dam was built. Archeological evidences help in estimating that the very first man-made dam is at least 3000 to 5000 years old, whenever it was built that firs dam was almost certainly an irrigation dam. Its designer might have observed beavers at work or he might have thought it in some other way (Garg, 1984).

In Nigeria, most dams are constructed mainly by the Federal Ministry of Agriculture and Water Resources about 81% of which consisted of earth dams (Gundiri, 2004). Earth dams were made even popular since the creation of River Basin Development Authorities (R.B.D.A) under the Federal Ministry of water resources and Rural Development by Decree NO. 25 of 1976 (Toro, 1992).

Cham multipurpose dam was one of the dams constructed by the Upper Benue RBDA in Cham village, Gombe state. It is one of the small earth dams constructed by the Authority through direct labour at a cost of N8.9 million with a storage capacity of about 8 million cubic meters. The dam provided irrigation water for 500 ha of land, water supply to Cham village, flood protection for the village communities and properties downstream as well as providing a reliable source of water to a large number of herds around the area. The dam was commissioned in December 1992 and failed in September 1998. It is located between latitude 8°N and 12^0E of the Greenwich meridian.

Sherard *et al*, (1963) carried out an extensive survey on dam failures and he reported that failure in earth dams could be as a result of overtopping, embankment and foundation piping, differential settlement and cracks, embankment and foundation slides, slides during

construction, earthquake damage, reservoir wave action, damage due to borrowing animals, damage caused by water soluble material, flow slides due to spontaneous liquefaction, and damage due to surface drying.

In the early times Terzaghi in his experience in geotechnical engineering encountered many cases of failures - significantly due to lack of ability to predict and control ground water. Piping failures were abundant and also slope failures, bearing capacity failures and excessive settlements. (Burland, 2006)

Anonymous, (2003) pointed out that earth dam failures can be grouped into three general categories: overtopping failures, seepage failures, and structural failures. The three types of failure are often interrelated in a complex manner.

On the basis of investigation reports on most past failures by Punmia and Lal, (1992), they were able to categorize the types of failures into three main classes: (1) Hydraulic: 40% (2) Seepage: 30% (3) Structural failures: 30%

Investigations carried out by Arora, (2001) also showed that about 35% of failures of earth dams are due to hydraulic failures, about 30% are attributed to seepage failures and about 20% are as a result of structural failure. The remaining 7% of the failure are due to other miscellaneous causes such as accidents and natural disasters.

Failure of earth dams in Nigeria has resulted into considerable socio-economic and environmental losses and the objectives of this work are to find out the reasons that lead to these failures, find out in details what led to the failure of Cham dam and give suggestions on how to minimize earth dam failures in the country.

2. MATERIALS AND METHODS

Questionnaires were designed and distributed in the Department of Dams and Irrigation, Federal Ministry of Agriculture and Water Resources as well as the upper Benue RBDA Yola, the supervising body for Cham Dam. Hydro-meteorological data as well as information on topography and geology of the dam site was sourced from the upper Benue RBDA. Also, design drawings and reports from consultants were sourced from them. To get more information on the construction and maintenance of the dam, personal interviews were conducted with some officers and staff of the organization who were directly involved in the Cham Dam project.

In addition, details of its performance history was obtained by collecting and analyzing all available data on planning, design, construction and operational life of the dam. Visits were paid to the dam site and inspections were carried out on various parts of the dam body and appurtenant works. Photographs were also taken to highlight some features in order to aid interpretation.

3. RESULTS AND DISCUSSIONS

3.1 Observations

Only scanty information exists on the environmental setting of the study area, that is; geology, hydrology, drainage, topography and land use system. The dam is located within an area overlying the transition zone of *Jesse* and d*ukkul* formations of the Benue Basin deposited during the Cretaceous period. Interspaced within the area are outcrops of basaltic rocks similar to the basalts of the *Lunguda* upland. The overlying soils predominant at the project site are clay deposits of the *Dadiya* plains.

Hydrological data on the impounded river Cham in the form of river stage discharge records and catchment characteristics were not found in the UBRBDA library. However, a spillway with design inflow of $200m^3/s$ was found, but there was no design report showing details of how the determination of this inflow value was arrived at. Also, no topographic map of the catchment area of the river Cham was obtained in the UBRDA archives. Information gathered from some sources indicated that the topographic map covering the area was yet to be published.

Two design drawings, “UBRBDA-HQ 072/95” and “UBRBDA-HQ 081/96” were found in the records and they manifest marked differences between them. Comparisons between the two drawings show that the crest width was reduced from 10m to 8m; thus reducing the dam’s volumetric capacity. Also, there was a replacement of the “toe drain” in one design with a “toe weir” in the other one (Plate-1).

From drawings, it consisted of a zoned dam cross-section having a central impervious core and key trench of the same clay material. The core was bordered by a semi-pervious transition material which was in turn bordered by 'Rubble material' or mass boulders of rocks embedded in clayey soil. It was observed that the breached section of the dam does not seem to have the clearly delineated zones as described on the drawings (Plate-2).

The dam crest was designed to have compacted lateritic material overlying compacted gravel stones. The downstream and upstream faces of the dam were slopped at ratio 3:1 (3 horizontal and 1 vertical) and 2:1, respectively. The key trench was designed to be constructed to as much as 2.5m below original ground surface. Observation at the dam foundation around the breached section does not show any trench at sight. No need for key trench since foundation is rocky (Plate-3).

Plate-1. Position of toe weir at down stream covered by rubles.

Plate-2. A breached section through the dam shows a uniform material.

Plate-3. Dam foundation on rocky material not having a key trench.

Careful measurements also reveal a non-uniform crest level ranging from about 522.2 meters above sea level (MASL) to 524.78 MASL, instead of the uniform designed crest level of 523 MASL.

3.2 Survey report

Eye witness account of some resident farmers and verbal account of some members of staff of UBRDA who were involved in the project are the only reference materials on past dam incidents apart from the site inspections carried out. Some of these are:

a) Seepage at downstream dam toe, about 500m away from the right abutment and crest crack.
b) Land slide at the right abutment of the dam most likely induced by excess pore water pressure in confined soil, weak loose soil triggered by shock vibration, seepage or foundation movement (Plate-4).
c) Insufficient freeboard (near overtopping)
d) Incomplete construction of the spillway (Plate-5)
e) Incomplete construction of the dam crest leaving as it were, a very extensive depression at crest level.
f) Some farmers impounded water at the upstream side of the dam for use on their farms, only to release the water later with the incoming floods of 1998 thereby resulting in increased volume of water which eventually overtopped the dam.

Plate-4. Land slide (Slope failure) near the right abutment.

Plate-5. Uncompleted Spill-way.

Three basic dam failures have occurred at Cham dam as seen from the inspection carried out:

a) Hydraulic failure - Overtopping and near overtopping.
b) Seepage failure - Piping at downstream toe of the dam.
c) Structural failure - Cracking at various points on crest, settlement near the right abutment and complete breach of the embankment (Plate-6).

Plate-6. Complete failure of the dam.

The toe seepage occurred near the right abutment approximately at the location where the Cham river tributary crosses the dam axis. This is also the location where the present dam breach cut the dam at its lowest. It was observed that the irrigation release facility was too small to make any significant discharge to curtail the incoming floods of 1988. Even when the facility was set at maximum discharge, the flood was far greater than the discharge due to the facility. (Plate-7).

Plate-7. Exit of the Main Canal from the release facility.

The crest of the dam sagged from abutments to center after construction and with such a very small freeboard; any slight overtopping would lead to spill-over in the reservoir. Records have it that on 7th November 1992, the reservoir level was 520.85m and the lowest crest level was 522.14m of surface monument. Thus, the freeboard amounted only to 0.636m and water must have spilled over the crest at that point.

With frequent occurrence of low freeboard otherwise known as "near overtopping", the dam had been frequently endangered. The spillway was reported to have a capacity of 200m^3/s, while in another report it was to have a capacity of 75 m^3/s.

Comments by UBRBDA staff implied that the dam was not completed before it was hurriedly commissioned in December 1992 as the designed crest level was never achieved. Also, drawings prepared by the authority and its instrumentation consultant differed considerably in details, unlike what is expected of a typical cross section of the dam. For instance, the clay core of the dam was indicated as being vertical, flanked by semi pervious shells supposedly rock fill. In another instance, the core was shown to be a mixture of gravel and late rite resting on a gravely bedding.

CONCLUSIONS AND RECOMMENDATIONS

Earth dams in Nigeria fail as a result of human errors such as inadequate preliminary study on proposed construction site, discrepancies in the design, poor engineering applications during construction, absence of

qualified dam safety monitoring personnel on site and bad maintenance culture. The failure of Cham dam in particular can also be attributed to the hurried commissioning of the dam in 1992 without achieving the designed crest level among other reasons. The following recommendations are thus given with a view to reducing earth dam failures to the barest minimum in Nigeria:

a) Adequate study should be carried out on the project area to include, hydro-meteorology, geology and soil among others;
b) Design should be based on the results of the feasibility study carried out;
c) Projects should not be commissioned before they are fully completed;
d) Experts from all the relevant areas must be involved in the planning and development of the project;
e) Engineering procedure of project conception, implementation operation and maintenance should be strictly adhered to;
f) There should be a well designed and constructed spillway;
g) Construction should be strictly based on the design specifications and standards;
h) Side slopes in the upstream and downstream side of the dam should be about 3: 1 as this provides a very reliable stability;
i) Allowance of 60cm freeboard after settlement above maximum height of water if the length of the dam does not exceed 300m and if larger than this, more than 60cm;
j) The downstream slope should be protected against rainfall erosion by heavy gravel or rock riprap. Sod may also be provided to guard against erosion if the rainfall is sufficient to grow and maintain grasses;
k) If highly permeable material would be used at all in constructing the dam, it will be found least objectionable if applied at the outer parts of the dam to aid drainage as a fill. Particularly attention must be given to the use of impervious materials in the core;
l) There should be no danger of over-topping by water;
m) The seepage line should be well within the down stream face the dam. This is to prevent sloughing and possible failure;
n) Water passing through or under the dam should be unable to remove materials of the dam or the foundation;
o) There should be no opportunity for free flow of water from upstream to downstream face;
p) The foundation shear stress should be smaller than the shear strength to provide a suitable margin of safety;
q) Well equipped and adequate dam safety monitoring team should be on site all the time;
r) The operation and maintenance should be based on a standard manual;
s) Log books should be provided to enhance accurately in record taking as well as record keeping;
t) The site monitoring team should be well trained and they should be sent to refresher courses from time to time; and
u) All the instrumentation facilities should be well maintained to avoid malfunctioning.

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