ISSN - 2277 - 2755

Journal of Agricultural Science and Environment

TOWARDS EFFECTIVE PLANNING, DESIGN AND MONITORING OF DAMS IN NIGERIA

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ABSTRACT

Besides serving as a center of tourist attraction, creating jobs for the unemployed, a rich source of fish and a fallback in times of drought, a dam also creates electricity from nothing other than the falling of water through its turbines. In Nigeria, like in many other parts of the world, dam projects are often seen as key to economic solution through hydroelectric power supply. The technology of dam construction in Nigeria is still experimental. There are so many unknown factors in dam design, construction and operation that may affect dam's safety and performance. Relying on field experience from various parts of Nigeria, this paper examines the essential details necessary for consideration in dam planning and design using the complete and accurate information on the important variables such as technical, environmental, socio-cultural, economic or cultural factors. The results of these examined factors indicated that most of dam projects in Nigeria are not properly planned. The basic planning flaws include hydrologic, environmental and social factors which are seen by dam builders as obstacles to be ignored, covered up or surrogated to engineering in the project planning. Incorrect calculation of flood flows has lead to dam failures and reservoir siltation has drastically reduced the lifespan of dams, making one to conclude that the entire concept of dam safety as a design criterion is a new one. It appears that Nigeria will have to live with these flaws and some of these cost for sometimes to come. There is, therefore, the need for us to reduce these through proper planning, design and monitoring of our dams. It is recommended that a comprehensive dam safety study of all old dams (i.e. ≥ 20 years) be carried out.

Key words: Agriculture, Dams, Failures, Irrigation, Spillway.

INTRODUCTION

A dam is a barrier that is built across a river in order to stop the water from flowing (Hornby, 2000). They are reservoirs or lakes primarily for storing water or to produce electricity. Dams therefore, are structures made up of various forms built across streams, springs or rivers. The hydraulic structures that are normally constructed across rivers, streams, or springs are weirs, barrages and dams. Dams can be earthfill, rockfill or concrete gravity structures in nature. They are generally classified as small or large dams depending on whether or not the height (H) of the crest level above the water-bed level is lower or greater than fifteen metres, that is for small dams, $H \leq 15$ m while for large dams $H > 15$ m.

Dams may be built for the supply of potable water to a community (e.g. Eleyele or Asejire in south west Nigeria) or for the generation of hydroelectric power (e.g., Kainji, Jebba and Shiroro in Niger State) or for irrigated agriculture (e.g., Bakolori in Sokoto State and Oyan in Ogun State). Other uses of dams include silt retention, fisheries, transportation, tourism and flood control. Any dam that combines several of the functions is called a multipurpose dam e.g. three Gorges dam on Yangtze River in China. On completion in 2009, this 182.88 m tall and 2.24 km long dam will be the largest in the World. The dam will be expected to protect China from annual floods and produce over one-tenth of Chinese electric power and supplement potable water supplies in Northern China (www.cruises.about.com, 2008). Examples of such multi purpose dams in Nigeria are Kainji, Shiroro, Kafin-Zaki, Dadinkowa, Kiri, Tiga, Zobe and Oyan.

Presently, Nigeria has over 300 dams (Ogheighe, 2002). In 1973, Nigeria was divided into 11 River Basin (RB) areas each under the Federal Ministry of Water Resources. The functions of these RBs include among others, the provision of potable water to many communities. Bakolori dam for example falls under the Sokoto-Rima Basin Development Authority in Northern Nigeria. The Tiga Dam, Challawa Gorge Dam and the Kafin Zaki Dam are located in the Hadejia – Jama' are River Basin in Northern -Nigeria (Figure 1a) while the Kainji, Jebba and Shiroro are found in the Niger Basin. Others that fall under Ogun-Osun River Basin in the South west (Figure 1b) include Asejire, Eleyele, Erinle, Oyan, Ikere-Gorge, Egbe, Ero, Erelu and Ejigbo. Success stories of dams in Nigeria include the generation of electricity mainly Kainji, Jebba and Shiroro. Kainji was designed to have a power generating capacity of 960 Mega watts. The dam generates electricity for all the large cities in Nigeria. It is 135 km long and about 30 km at its widest point and support a local fish industry (http/en.wikipedia.org, 2008). Another success story of dams in Nigeria is the increase in food production and hence poverty alleviation through irrigated agriculture and fisheries. The Bakolori dam has a design capacity to irrigate 35,000 ha of farmland, Kafin-zaki dam 125,000 challawa 40,000 and Tiga 20,000 ha. The planned irrigation area and operated irrigated area (ha) of 11 dams in Northern Nigeria is provided in Table 1.

Dams have equally done so much ecological and human damages in Nigeria in the last decade. Several lives have been lost, thousands of people displaced and several villages destroyed due to dam failures. The Federal Government is presently building the Gurrara dam at a cost of $0.4b to provide water to the capital city of Abuja through the laying of 70 km pipeline. Sooner than later, Nigerians will have to pay in full for the social, environmental and economic costs of this white elephant project.

METHODOLOGY

The methods of Dam planning and design employed in this paper, involves the review and updating of the existing procedures which are stated below viz:

(a) The physical planning of a dam which involves the following:-

- Obtaining the topographic maps of the area on a scale of 1 in 50,000, 1 in 100,000 and 1 in 200,000 for the purpose of identifying natural drainage channels (streams, springs and rivers).
- Conducting reconnaissance survey of the area for the purpose of identifying possible dam site locations
- Obtaining information on the climate of

the area with special reference to seasonal changes viz: dry and wet, monthly and annual rainfall records and the temperature of the environment (minimum and maximum). Such records may be for 20 to 50 years or more if available.

- Obtaining on the spot information and assessment of existing streams, springs, and rivers from the inhabitants of the dam site.
- Obtaining detailed geological information of the project area from reliable sources.
- Carrying out sub-soil investigation works down to reasonable depth in rocks of the proposed dam site(s).
- Thorough assessment and digestion of the detailed sub-soil investigation works report.
- Obtaining information on the occupation and culture of the community living in close proximity of the area proposed for the dam.
- Carrying out well detailed topographic survey of the area.

(b) Actual design of Dams.

The design of any dam, be it earthfill, rockfill or concrete gravity dam, must as of priority take the following factors into consideration:

Geology of the proposed dam site, catchment area of the proposed river to be dammed, flood discharge of the river, wave action on the dam site, evaporation effect on the dam reservoir, within the reservoir siltation and river bed loading as well as structural stability of structures that is proposed for the dam. This alone may involve the shear strength analysis and the slope slip circle analysis for upstream and downstream face of the dam most especially under various reservoir situations such as full reservoir capacity, sudden drawdown and dead storage. Correct interpretation of the analysis of the detailed sub-soil investigation report should include for both considerable distance up and downstream sides of the dam. Other factors include: seepage effect on the dam, availability of the construction materials for the dam, thorough analysis and digestion of reconnaissance survey report of the proposed dam site(s) and lastly the Environmental Impact Assessment Study (EIA) of the project.

Discussion of Dam Design Factors

Geological Information:

The safety of a dam depends above all on the characteristics of the geological foundations on which it is built. The hazards of dam failures are likely to increase if less suitable sites are exploited. The problem involved in building a dam on a geologically unfavorable site presents insuperable problems to even the best engineers. A deep knowledge of the geological formation of the proposed site is desirable to know the different rock types as well as relevant information on the minerals and predominant structural features in the rocks proposed for the dam foundation such as faults, joints, fractures, folds and cracks. The weight of the impounded reservoir will produce stream of water which if found on a weak foundation may undermine the dam and its appurtenant structures thereby resulting in failure. In addition, it is not just the properties of the dam site and the surrounding area that can cause problems but also the numerous ways in which these properties can be modified by the building of the dam and the reservoir. The geological information coupled with deep soil investigation down to the bedrock level will assist the dam engineer to put in place the necessary suitable foundation works for the proposed dam.

Catchment area

Estimation of the catchment area (from available and suitable topographic maps) of the stream and rivers to be dammed especially the upstream side of the proposed dam will permit the determination by the hydrologist of the likely floods to be generated and its extent, based on an acceptable contour level (Dogra, 1986). The yield of the river is also a function of the catchment area and the mean annual rainfall (Dogra, 1986).

Flood Discharge

Flood discharge estimation of the proposed stream or river, upstream of the dam site will assist the dam Engineer to propose adequate spillways. This will also prevent unnecessary overtopping of the dam, which may lead to failure. In estimating flood discharge, certain empirical formulae are used. Such empirical formulae are: Rye's equation, Fanning's formula, Bennie and Lap worth, Western State equation, Jarvis-Myers, Creager's formula, Fuller's equation, Modified Rational Method, McMaths equation and Pont Mousson. (Thomas, 1976). The estimated flood discharge is treated as theoretical flood discharge. Hence a safety factor ranging from 1.00 to 1.50 is adopted for the design flood discharge of the spill weir. In the determination of the spill weir size, a coefficient of discharge ranging from 1.8 to 2.0 is also adopted. Various empirical formulae on flood discharges is presented in Table 2. All these empirical flood discharge equations highlighted in this paper have their own merits and demerits. The dam engineer should also take cognizance of the site situation such as topography, vegetation and land use. Release of excess water in the reservoir should be controlled in order to avoid flood hazard to the people living downstream. This explains the importance of safety factor in dam design.

Wave effect

In an open environment, tornado may occur. If vast surface area of water is open to it, this may lead to upliftment of a mass volume of water. Wave action may arise under any windy storm. Dam engineers are therefore expected to take wave effect into consideration in dam planning and design more so, in the selection of dams final level of the crest. At any point in time, there should be no overtopping. It is generally considered that wave pattern will depend upon wind speed and duration as well as on the fetch and depth of reservoir and wave action on dam (Thomas, 1976). The basic equations for the selection of a dam's crest width, crest level and spill weir size are as shown in Table 3. The same table also shows the basic dimensions for cut-off wall in an earth dam.

Reservoir Siltation and Bed Loading

The lifespan of a reservoir depends on its sedimentation rate. This being reason why the actual benefits of past dam projects have fallen so short of expectations since the reservoirs have tended to silt up very much faster than anticipated due to failure to protect the dams catchment area from severe erosion problems especially in fragile terrains.

During any flood flow period, most natural channels (streams and rivers) have the flood water loaded with silts. As a result of the stagnant situation of the reservoir due to the blockage of the river flow by the dam, these silts become deposited, thereby leading to the inundation of the reservoir. Heavy sedimentation also means a corresponding loss of flood control capacity. A reservoir which is silting up cannot contain the volume of flood water it was designed to contain. In series of studies carried out on some of the major rivers in the northern part of Nigeria, Mrssrs Wakuti Consulting Engineers (1981) in a study conducted for Upper Benue River Basin Authority found out that the equivalent of 2000 to 3000 parts per million of flow in reservoir are transported as silts and that equivalent of 25% of the transported silts are deposited as bed load in the natural channels. Over a long period of time, if such a river is dammed, the reservoir is silted up thereby reducing the volume of the expected water storage. This is the current situation in some of our reservoirs. Oyan dam reservoir commissioned in 1984, and (using Wakuti's (1981) estimate of bed-load deposit to make rough calculations) should presently be having an approximate total siltation volume of 7.9 million cubic metres (7.9 x 10^6m^3) in 20 years. Egbe dam reservoir in Akoko division is located on Little Osse River with reservoir storage capacity of 23 x 106m 3. It was commissioned in 1989. The water supply scheme of the dam was designed to produce 60,000m^3/day. With a current population of the neighborhood community of about 554,360, the daily water demand should be in the region of 72,100m^3/day. Thus, in the last 15 years, siltation volume is likely to be in the region of 490,000m^3 (0.49 million m^3) or slightly higher than this figure. Asejire dam reservoir is located on Osun River. The dam was commissioned in 1972. For thirty four (34) years, the sediments deposited in this dam reservoir is probably of approximate volume of 6.542 x 10^6m^3. This estimate is based on a conservative current total daily water demand of Ibadan put at 454,281m^3, and serving a projected population figure of 1,682,521 at per capita consumption of 150 litres per day. A survey conducted by Badafash Nigeria Limited (BNL, 1998) on River Uke in Nasarawa township showed approximate volume of 14,000m^3 of sediments deposit in a storage capacity of 57,300m^3 and measured one kilometer upstream of a 3m high concrete weir (approximate 24.4% of reservoir volume). A direct visual observation showed that silts deposit was only one metre below the crest level of the weir.

Ambar River at a distance of 1.5km away from Lafia in Nasarawa State showed an estimated sediment volume deposited at about 91,130m^3 for a scheme commissioned in 1985. Site evidence showed that the pumps located by the side of the concrete weir pumped raw water that was mixed with coarse sand to the treatment works. This ugly situation has really affected the overall production capacity of the semi-packaged treatment works.

The already rehabilitated small Agodi dam reservoir behind Premier Hotel, in Ibadan showed approximate siltation volume of 29,700m^3 in the last 22 years. Currently the dam is serving Oyo State Ministry of Agriculture in the supply of fisheries as well as raw water to the University College Hospital.

The quantity of raw water supply to UCH is 3000m^3/day. A raw water pre-settling tank was constructed downstream of the dam prior to its being pumped to treatment works within the premises of UCH. The Department of Water Resources at the University of Agriculture, Abeokuta, Nigeria is currently monitoring some reservoirs in the South West to determine their current status.

Some existing reservoirs in the Northern area of Nigeria are shown in Table 1. The information provided here includes the capacity of the various reservoirs, number of years the dams have been in operation the planned irrigation works and the operated irrigation area in ha. Some of the reservoirs are to provide water for-irrigation, water supply, downstream release and reservoir loss. Cropping intensity during wet season is 100% while majority of them are 50% except for Chalawa, during the dry season. If Oyan dam, which is expected to supply water for irrigation on a landed area of 12,500 ha, is considered, average yield, based on all the year round farming, is 4.7 ton/ha x 12000 ha = 56400 tons. Allowing irrigation efficiency to be 60%, actual yield = 56400 x 0.6 = N33840 tons. Assuming farming operation is also conducted during the wet season, at the same efficiency, the actual yield = 33,840 tons. Total yield for all variety of crops = 67,680 tons. Assuming we consider crops to be rice only, at current market price of 384,000 per ton, the above production will result in #5,550m to #5,685m (US $37.9m) annually.

Evaporation Effect

A dam design engineer must allow for evaporation losses in storage reservoirs. For Oyan dam whose storage reservoir surface area is 40 km^2, the total monthly evaporation loss is approximately 6.44 x $10^6 m^3$. For an average maximum temperature of about 33 ^oC (or 19.4^{0}F) for Abeokuta township, the estimated monthly Potential Evaporation rate is 161mm (6.44ins). This is obtained by adopting Penman and Crowe's equations for determining monthly evaporation rate. For the Crowe's Equation: Potential Evaporation PE = fe. In Penman's Equation, e = 2.82 (T - 10) mm and f is a factor that varies from 0.6 to 0.8. (Wilson, 1975). However the Department of Geography, University of Ibadan in 1978 recommended monthly evaporation rate of 1254mm (5 ins) to the then Ogun State Water Corporation. Applying this figure, an annual evaporation loss of approximately 30.3 x $10^6 m^3$ will be obtained. No matter the size of the storage reservoir, evaporation loss must be allowed for in estimating overall storage capacity of the proposed dam reservoir.

Seepage Effect

No matter the type of construction materials used in building a dam, seepage is bound to occur. The seepage may be directly through the structures or below the foundations. In case of earth dams, the seepage is always generally through the embankment. When using homogeneous materials in the construction of an earth dam, **core** and cut-off sections are generally created and these sections are made up of impervious materials. For the purpose of design, seepage effect is generally assumed to be in the range of 5 to 10 % of the total water demand to be stored for irrigation and potable water supply. Materials best suited for embankment are generally displayed on engineering charts. Oyan dam reservoir (for example) has an annual seepage loss of approximate volume of 9.5 x $10^6 m^3$, where annual water storage of 158 x $10^6 m^3$ is required for both irrigation and water supply.

Structural Stability

In homogeneous earth dams, the following structural stabilities are considered:

(1) Shear failure, (2) Slope Slip circle for the following conditions. (a) When upstream reservoir is about to be filled (b.) When reservoir is completely filled either to normal or flood water level and at (c.) Dead storage

For instance, if a cohesive soil whose bulk density is 19 kN/m^2, internal angle of friction is 20^0 and cohesive stress is 50 kN/m^2 (typical of most soils in Nigeria), is used as homogeneous materials in dams, the following parameters will obtain for a dam with overall height of 18m, upstream slope of 1:3, downstream face of 1:2.5, and maximum water level of 16m employing slope slip circle analysis. (Figures 3 and 4). This analysis will involve a safety factor of 2.42 (2.0) when dam's embankment is completed and reservoir is about to be filled. (a) When reservoir is completely full of water, safety factor is 3.89 (4.0) and (b) when the dam reservoir is at dead storage level, the safety factor is 2.89 (3.0)

Also for the same dam, when stability is considered against failure due to shear strength, the safety factor is 5.02.

Availability of Construction Materials

Dam can be earthfill, rockfill or concrete-gravity dam. Earthfill dam is an embankment dam constructed using compacted earth, which is either homogeneous or zoned, and containing more than 50% of earth. Rockfill dam is a dam that is made mostly of rock, either dumped in lifts or compacted in layers, as major structural element. Note, however, that impervious core must be provided, either at the upstream face or mid-section of the dam. In both earth and rockfill dams, anti-erosion work must be provided. Concrete gravity dam is a structure proportioned to its own weight and is capable of resisting the forces exerted upon it. If it is constructed on an adequate foundation, a solid concrete dam is a permanent structure which requires little maintenance. In the design of concrete gravity dam, the base width to its height is generally of the order: Base width $W > H/3$ Design consideration involves checking the concrete gravity dam for overturning and sliding (Thomas, 1976). Materials for construction must be thoroughly investigated. Soil probes are generally carried out at the up and downstream areas of the proposed dam site. Apart from material survey, topography also plays a major role in the determination of the type of construction material to be used in a dam. For instance, a dam to be constructed on a gorge will preferably be better constructed in concrete, more-so when there is marked presence of very hard rocks across the river channel of narrow width.

Environmental Impacts Assessment (EIA)

Below are some of the conditions to be borne in mind while embarking on EIA aspect of Dam planning and design for execution.

- Improvement of health conditions through the supply of potable water to the community.
- Improvement on the Living standards of the inhabitants of the project area.
- Boost to commerce and industry
- Improved yield on agricultural production due to all year round farming.
- Boost to tourism and recreation vide holiday resorts, hotels and motels (i.e enhance foreign exchange).
- Encouragement of women participation in agriculture on large scale (e.g., Lafia township experience where women are into rice farming).
- Reduction in rural – to – urban migration
- Creating job opportunities for the able bodied men and women, and lastly
- Flood control against downstream arable farmland of the dam.

Adverse Effects

Similarly, the expected adverse impacts of dam construction that must be taken into consideration during planning and design include viz:

Salination and Solidity of soils, excess siltation in the reservoir, increase in insect transmitted diseases such as malaria, yellow fever (hepatitis), and river blindness (onchocerciasis or bilharzias). Others are increase in water borne diseases such as diarrhea, cholera and dysentery, displacement of human settlements, and loss of wildlife and forest plants.

Mitigative Measures against adverse effects

A good planning and design of dam/ construction will take cognizance of the following mitigation measures against the adverse effects namely:

1. Salination and Sodicity: This can be abated by creating awareness through regular workshops and seminars for local farmers and constant advice on the type of fertilizers to be used, more-so for irrigated area.
2. Siltation of reservoir: this can be overcome by regular dredging either annually or biennially. Infact, provision should be made within the dam structure for self desilting to be operated manually or electrically.
3. Insect transmitted diseases: This can be prevented by the introduction of certain freshwater specie of fishes to the reservoir that will normally feed on the larva of the insects. Downstream water release will also aid in non-stagnliant nature of the water in the reservoir.
4. Water borne diseases: can be eradicated by organizing seminars, workshops and constant education of farmers. Wastes dumping into the reservoir should also be discouraged. If possible, resettlement of displaced indigenous people in the vicinity of the dam should be farther away from the reservoir.
5. Displacement of human settlements: Resettlement of the community affected should be given utmost priority and, compensation should also be paid to people affected.
6. Loss of wildlife and forest plants: This can be reduced by the re-introduction of wildlife and afforestation programs.

CONCLUSION

This study has revealed that Nigeria presently has 62 large and 100 small dams. 27 of the large dams are in the NW, 13 in the NE, 15 in NE/SE and 7 in SW/NE while 26 of the small ones are found in the N/W 12 in NE, 17 in NE/SE and 44 in SW/SE. (FMWR, 1995). Many of these water conservation systems have aged and most of them stand in severe need of maintenance and repair. Often, far greater returns have been obtained from preserving, maintaining and rehabilitating existing capital facilities than from investing the same resources in new facilities. Recent research conducted on the Eleyele dam/reservoir in Ibadan by the authors of this paper using remote sensing techniques showed that the reservoir is shrinking. This confirms the results obtained from earlier studies by FORMECU (1995) under the World Bank assisted Land Use and Vegetation Study. There is therefore urgent need for a visual dam inspection of all such existing facilities in Nigeria in order to determine their current status. This will lead to the restoration of these facilities to their rated capacities by dredging. In some cases, as a result of neglect, trees have grown on the embankments of these dams thereby creating avenues for seepage which may eventually lead to dam failure.

Apart from technical and environmental resources, dam planning requires an unusual extensive social and economic data. The planning process requires a high degree of knowledge of ecosystem dynamics and an ability to be able to make realistic predictions about their response to stresses of various kinds, and above all an understanding of the society and culture of the potentially affected people. Foreign experts who are responsible for planning of our dams in most cases are not engaged with problems from scratch but rely on their standardized blue prints. As a matter of fact dam construction in Nigeria should involve all stakeholders from the planning to implementation and monitoring. Since dam safety depends on continual vigilance which in turn-depends on regular and scrupulous monitoring. It is hereby suggested that the Federal Government should set up a dam safety inspection committee for regular inspection of dams, an exercise which may also involve some simple tests such as percolation test to detect seepages.

Table 1: Selected Dams in Northern Nigeria and their Characteristics

S/N	Dam Location	Reservoir capacity x 106m3	Active Storage x 106m3	Years of Operation	Water Demand & Loss x 106m3	Planned Irrigation Area (ha)	Operated Irrigation Area (ha.)
1	Tiga	1968	1845	16	927	22000	26000
2	Challawa	930	900	19	454	40000	12500
3	Watari	104.5	92.2	19	51	1700	1500
4	Karfin Zaki	2700	2500	16	1259	125000	50000
5	Bokolori	450	403	16	456	23000	23000
6	Goronyo	942	933	15	686	69000	17000
7	Zobe	177	170	17	180	8200	5000
8	Kontagora	340	195	20	225	11200	11200
9	Jakara	65.4	54.5	19	50	2000	2000
10	Tomas	60.3	56.6	19	50	1100	1800
11	Tangakawa	22	21	20	22	800	1200

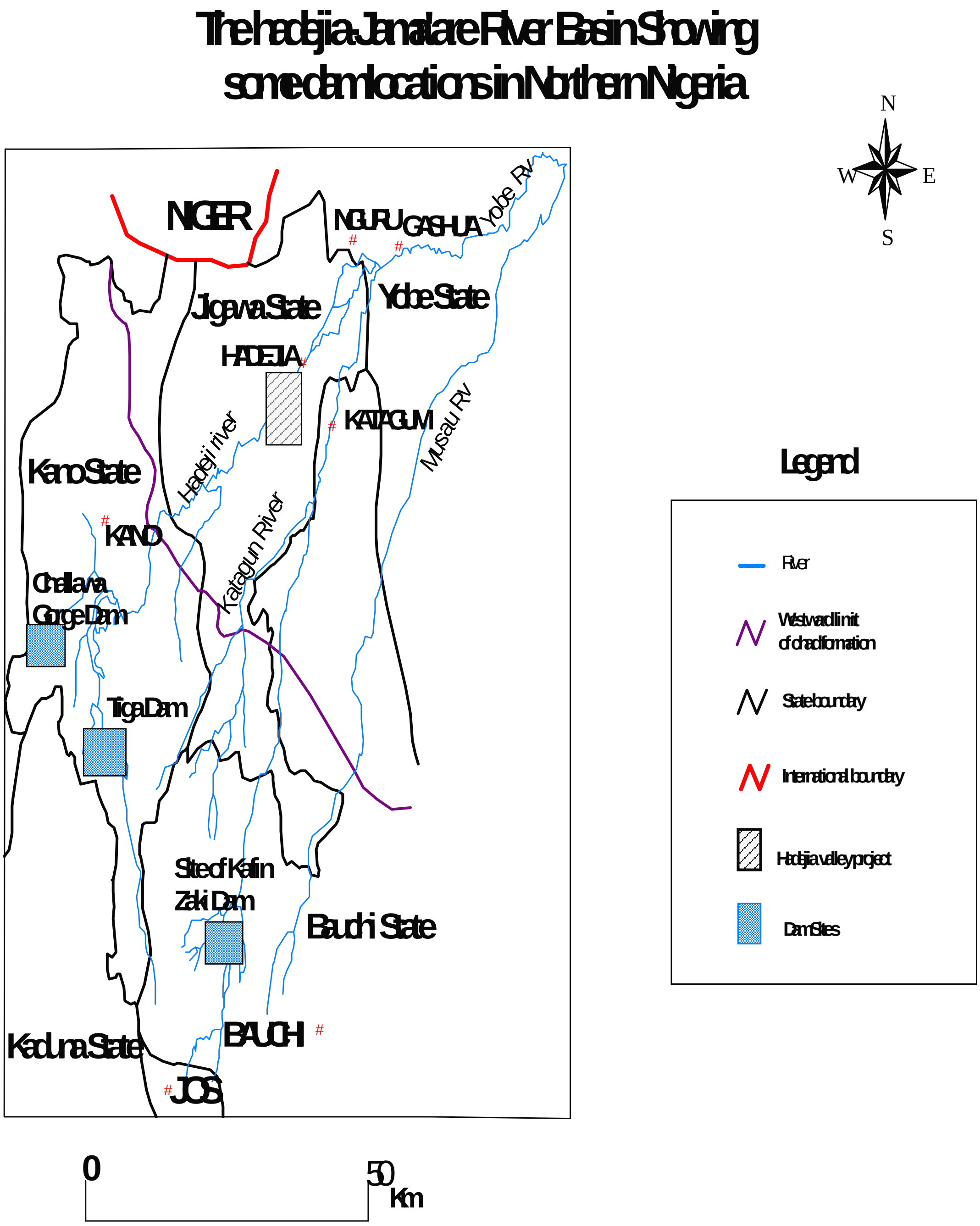


Figure 1a: Map of Hadejia-Jama'are River Basin showing some Dam locations in Northern Nigeria

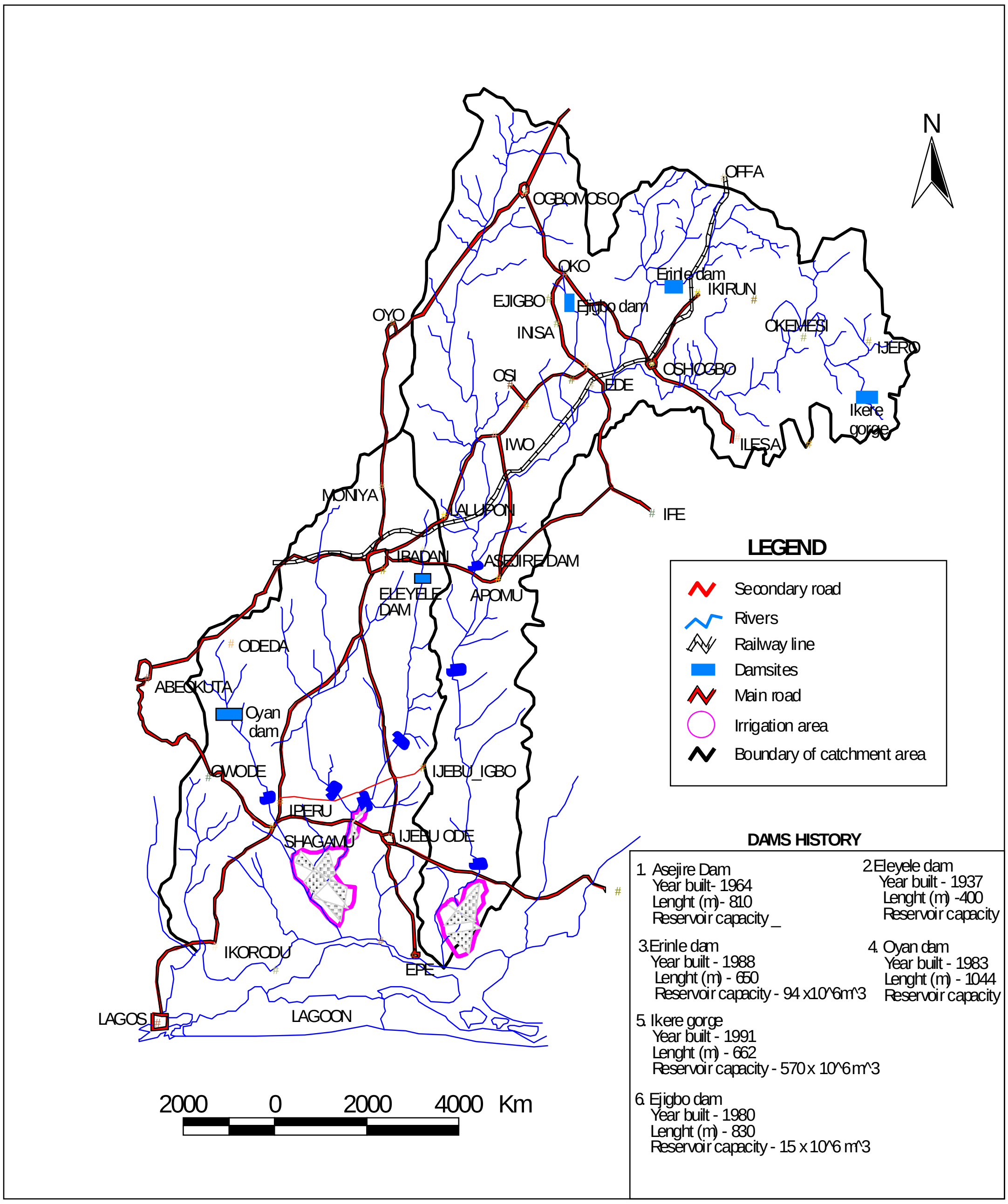


Figure 1b: Ogun–Osun River showing some dam locations in the South-Western parts of Nigeria

Table 2: Various empirical formulae used in Estimating Flood Discharges

S/N	Basic Flood Equations	
1	Ryve's Equation	Q=9.1 x A 2/3
2	Fanning's Formulae	Q=2.6 x A5/6
3	Binnie & Lapworth	Q=11.4 x A2/3
4	Western State Eqtn.	Q=16 x A 0.62
5	Jarvis – Myers	Q=36 x A0.5
6	Creager's formula	Q=26 x 0.391Ab
7	Fuller's formula	Q=av 2 x A 0.8 Q=Qav(1+0.8log T) Q=max = Q (1+1.5A-0.3)
8	Modified Rational Method	Q=0.278 x C x Cs x I x A I = 8175 / (T + 33) mm/hr or I= 10.000 / (T + 36)
9	Mc Maths Eqtn.	Q=2 x C x 1 x A 4/5 x S1/5
10	Pont Mousson	Q= 0.031 x C x 1 x A
	Q= discharge in litres per sec C= flow index varies form 0.2 to 0.25 I=Rainfall in mm/year *A*= catchment *area in km2*	

Source: Thomas (1976). The engineering of large dams

Remarks

A= Catchment area in km^2.

Q= Theoretical flood

Discharge in m^3/sec

T= Rainfall intensity in mm/hr for a return period of 25 years.

C= run-off coefficient, varies from 0.4 to 0.90.

$$Cs = \frac{2 \times tc}{(2tc + td)}$$

tc = to + td = concentration time

t_o = time for run-off to flow towards drain (5-10 mins.)

Td = L /V

L = length of drain

V = assumed velocity of flow in drain varies from o.6 to 2.4m/sec.

S = Natural slope of catchment area.

C = 300 – 500.

Note

5 years return, 1= 6175/(T + 29)
10 years return 1= 7500/(T + 29)
15 years return 1= 6710/(T + 30)
20 years return 1= 7940/(T + 36)

Crest Width

Japanese Code (1957): $W = 3.6 \times H^{1/3} - 3$

USDI Bureau of Reclamation: $W = \frac{H + 50.02}{16.4}$

Cut – off trench size

Dept = H/4

Base width = H/3

Side slope 1:1 or 1:11/5

Embankment Slope

Upstream face 1:2 – 1:4

Downstream face 1:2 - 1:3

Wave Action

wave height **$Hw = 0.34F^{1/2} + 0.76 – 0.26^{1/4}$**

where F = fetch of lake (farthest tip of man-made lake to upstream face of dam)

V =1.5 +2Hw (Galliard's Equation)

And V = Wave propagation velocity in metres/sec.

$$\text{Freeboard} = 0.75Hw + \frac{V^2}{2g}$$

and g = acceleration due to gravity assumed to be $10m/sec^2$.

Cohesive force $CoFr = \frac{C \times R \times \theta \times \pi}{180}$

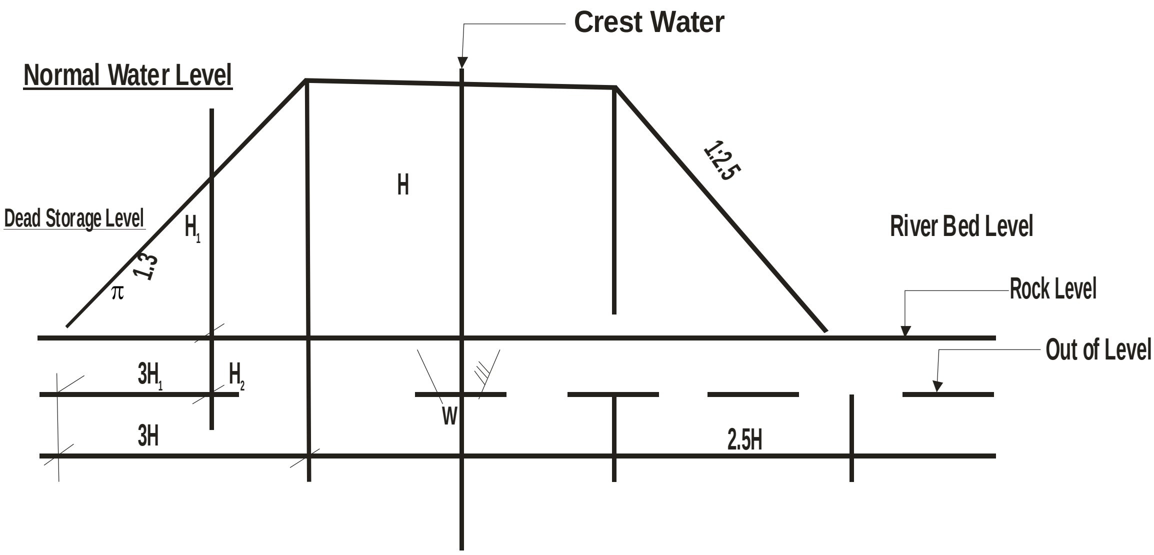
Weight of slice $W = 0.5\,(H_1 + H_2)\Upsilon_e$

Normal force $= W \cos\alpha$

Tangential force $= W \sin\alpha$

Total normal force $= CoFr + \Sigma W\cos\alpha \tan\theta$

Safety factot SF $= \frac{CoFr + \Sigma W\cos\alpha \tan\theta}{\Sigma W \sin\alpha}$



Average share force $S = H1 - H_2^2 * \tan^2(45 - \theta/2)$

Figure 2: Dam Section Analysis (slope analysis)

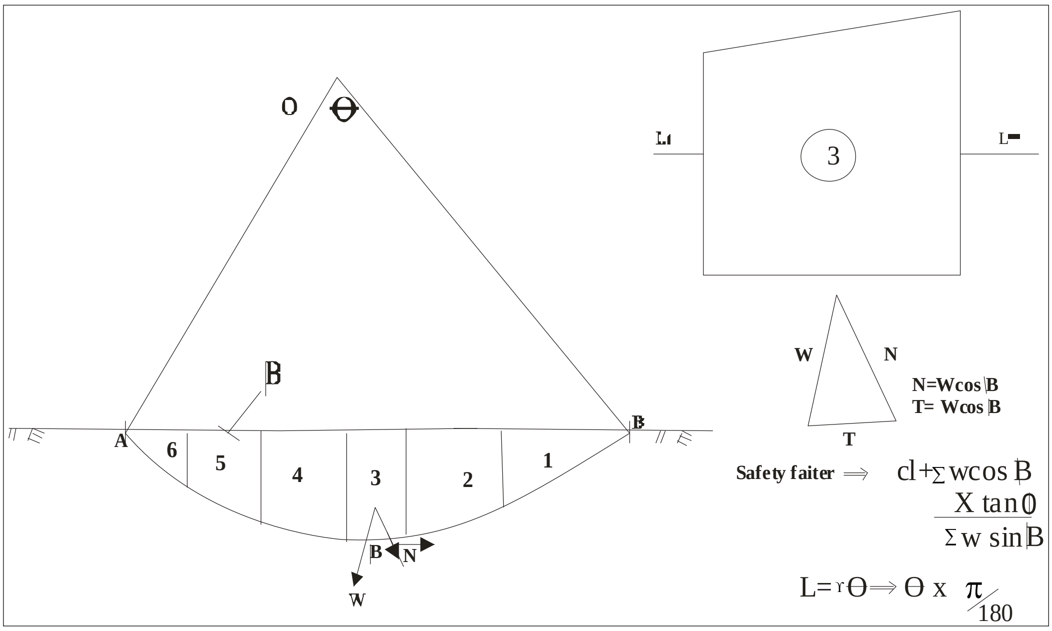


Figure 3: Cohesive soil with friction

Normal water depth: H_1 (m)

Cut-Off Trench depth: H_2 (H/4) (m)

Internal friction angle of soil: Ø

Cohesive stress of soil: C KN/m^2

Basic Equations

Average shear force $S = \frac{\gamma \times)H_1^2 - H_2^2) \times Tan^2 (45-Ø/2)}{2}$

By Considering a metre strip of dam's length

Average unit shear stress $S_a = {}^{S}/_{3H1 \times 1}$

Maximum unit shear stress $= 1.4 X \times S_a$

But actual Shear strength at normal water level is given by S. S_{max}, where

S. $S_{max} = C + \gamma H_1 \tan Ø$

For earth dam not to fail due to shear force effect on it, the safety factor is given by

S F (Shear) = ${}^{S.Smax}/_{1.4Sa}$

$$SF = \frac{(C + \gamma H_1 \tan Ø)3H_1}{S}$$

Design Data Input for Slope Slip Circle Analysis

1. Break slope bounded by circle into series of slices of equal width

Height of slice	-	H1 (m)
Height of slice	-	H_2 (m)
Width of slice	-	W (m)
Unit weight of soil	-	γ_c
Inclined angle	-	α^o
Angle subtended at center	-	$Ø^o$
Radius of Circle	-	R
Cohesive stress of soil	-	C
Unit weight of water	-	γ_w
Unit weight of submerged soil		$\gamma_s = \gamma_c - \gamma_w$
Unit weight of partially submerged soil		$\gamma_a = 0.5(\gamma_c + \gamma_s$

Table 4: Dam's stability about to be filled on completion

Slice No.	Heights of Slice h (m)	Width of Slice b (m)	Inclined Angle of Normal force ao	Weight of Slice W (Ybh) (kN)	Normal force WCosao	Tangential force Wsinao	Average Height of Slice (m)
1	0 – 4.5	3	42	128.25	95.31	85.82	2.25
2	4.5 – 5.5	3	45	285.00	201.53	201.53	5.00
3	5.5 – 7.5	3	45	370.50	261.98	261.98	6.50
4	7.5 – 9.0	3	32	470.25	389.79	241.19	8.25
5	9.0 – 9.5	3	28	527.25	465.53	247.53	2.25
6	9.5 – 10.5	3	30	570.00	493.63	285.00	10.00
7	10..5– 11.0	3	30	612.75	530.66	306.38	10.75
8	11 – 11	3	30	627.00	543.00	313.50	11.00
9	11 –11	3	20	627.00	589.19	214.45	11.00
10	11 –11	3	17	627.00	599.60	183.32	11.00
11	11 – 10.5	3	9	612.75	605.21	95.86	10.75
12	10.5 – 10	3	8	584.25	578.56	81.31	10.25
13	10 – 9.0	3	7	541.50	537.46	65.99	9.5
14	9.0 – 8.0	3	2	484.50	484.20	16.91	8.5
15	8.0 – 7.0	3	2	427.50	426.91	22.37	7.5
16	7.0 – 5.5	3	-2	356.25	356.03	-12.43	6.25
17	5.5- -4.0	3	-6	270.75	269.27	-28.30	4.75
18	4.0 – 2.5	3	-12	185.25	181.20	-38.52	3.25
19	2.5 – 0	3	-20	95.00	89.27	-32.49	1.25
	Total				**7707.35**	**2519.39**	

REMARKS

Total Resisting force	=	6098.68 kN
Total Sliding force	=	2519.39 kN
Safety Factor	=	2.42

Table 5: Conditions of Dam's Reservoir when completely filled up and at dead storage

S/n	Dam's reservoir completely filled up			Dam's reservoir at dead storage		
1.	60.76	45.15	40.65	94.50	70.23	63.23
2.	135	95.46	95.46	210.00	148.49	148.49
3.	175	124.10	124.10	273.00	193.04	193.04
4.	222.75	188.90	118.04	346.50	293.85	183.62
5.	249.75	220.52	117.25	388.50	343.03	182.39
6.	270.00	233.83	135.00	420.00	363.73	210.00
7.	290.25	257.21	148.50	462.00	400.10	231.00
8.	297.00	257.21	148.50	462.00	400.10	231.00
9.	297.00	279.09	101.58	462.00	434.14	158.01
10.	297.00	284.02	86.83	462.00	441.81	135.08
11.	290.25	286.68	45.41	451.50	445.94	70.63
12.	276.75	274.06	38.52	430.50	426.31	59.91
13.	256.50	254.59	31.26	399.00	396.03	48.63
14.	229.50	229.36	8.01	357.00	356.78	12.46
15.	202.50	202.22	10.60	315.00	314.57	16.49
16.	168.75	168.65	-5.89	262.50	262.34	-9.16
17.	128.25	127.55	-13.41	199.50	198.41	-20.85
18.	87.75	85.83	-18.24	136.50	133.52	-28.38
19.	45.00	42.29	-15.39	70.00	65.78	-23.94
Total		**3650.85**	**1193.39**		**5679.10**	**1856.39**

REMARKS

Dam's reservoir completely filled up

Total Resisting force = 4622.24 kN

Sliding = 1193.39 kN

Safety Factor = 3.87

Dam's reservoir at dead storage

Total Resisting force = 5360.46 kN

Sliding force = 1856.39 kN

Safety Factor = 2.89

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(Manuscript received: 23rd April, 2008; accepted: 27th October, 2009).