World Bank / Lake Chad Basin Commission

APPRAISAL OF THE SAFETY OF THE TIGA AND CHALLAWA GORGE DAMS, NIGERIA

March 2002

Contents

1 INTRODUCTION

1.1 BACKGROUND

The two dams that are the subject of this report both supply dry season flows both to the Kano River Irrigation Project and for the supply of Kano City. Tiga dam, constructed on the Kano river, was commissioned in 1974 and Challawa Gorge dam, on the Challawa river, in 1992. These two rivers join just south of Kano City to form the Hadeija which in turn is the principal source of supply for both the wetlands and for the northern part of Lake Chad.

The river regulation effected by the operation of the two dams has resulted in a reduction of the flood peaks in the Hadeija which it is understood has had undesirable consequences on the environment and the social economy of the wetlands downstream. As part of a recent drive to address these problems, which are widespread in the Lake Chad Basin, the Lake Chad Basin Commission (LCBC) commissioned a project entitled "The Reversal of Land and Water Degradation Trends in the Lake Chad Basin" This project comprised, *inter alia* six pilot projects, one of which was devoted the problems of the Komadougou – Yobe basin wetlands, situated on the border of Niger and Nigeria.

During the environmental and social components of this pilot project the need to check the safet of the two dams was noted[1], and as a result the World Bank commissioned Mr L J S Attewill of Jacobs GIBB Ltd to prepare this appraisal of the safety of the Tige and the Challawa Gorge dams.

1.2 TERMS OF REFERENCE

The terms of reference for this appraisal and that of two dams in Nigeria are included as Annex A to this Report.

1.3 PREVIOUS STUDIES

Previous studies consulted for this appraisal are:

1.3.1 Tiga Dam Evaluation Report Volume I – Haskoning July 1978[2]

The objectives of this report, which was prepared shortly after the commissioning of Tiga dam, were:

- Collect all available design data and calculations to prepare a retrospective design report
- Carry out an evaluation of the design of the dam
- Collect all available construction records to prepare a construction report of the dam complete with as constructed drawings
- Prepare an Operation and Maintenance manual for the dam.

The results of the evaluation of the design and construction give considerable cause for concern: the main points are as follows:

- The design process was haphazard and incomplete
- The design of the outlets was ill conceived
- The foundation design and treatment was inadequate

- The embankment fill was compacted considerably dry of optimum and as a result fill density is low
- The wave protection was inadequate

1.3.2 Safety Evaluation of Existing Dams (SEED) examination of Tiga Dam – USBR 1987[3]

This evaluation was carried out after various signs of distress manifested themselves during the 1980's. The main conclusions of the safety evaluation were:

- there was no immediate danger of collapse at the time of the inspection when the reservoir level was at 523.7m, 3.6m below full storage level
- the dam should be classified as high hazard
- remedial works should be carried out on the embankment
- further studies were required to assess dam stability and spillway adequacy
- an emergency preparedness plan should be produced

1.3.3 Babtie Report on follow-up works

Many of the recommendations made by the USBR have been implemented, under the supervision of Babtie, who have submitted a report on the actions taken. This report was not available at the time of the visit but it is hoped that a copy will be made available shortly.

1.4 PROGRAMME OF WORK

Mr Attewill's itinerary for these appraisals was as follows:

Tuesday evening	5th March	Arrive Kano
Wednesday	6th March	Inspect both dams
Thursday morning	7th March	Discussions with Hadejia Jana'are River Basin Development Authority
Thursday evening		Returned to London via Amsterdam

1.5 ACKNOWLEDGMENTS

Mr Attewill wishes to acknowledge with thanks the contribution, assistance and support provided by the following:

<u>*LCBC staff*</u>
Mr Adamu – Executive Secretary
Mr Tochin – Administrative secretary
Dr Oguntola – Chief, Water Resources Unit

<u>*Hadejia Jama'are River basin Development Authority staff*</u>
Mr Alhaji Shehu Abdulkabir, Managing Director
Mr Yahaya Kazauro, Assistant General Manager, Operations & Maintenance
Mr Abdulsalam Ibrahim Yakasai, Engineer

2 DESCRIPTION OF THE DAMS

2.1 ACCESS

The Challawa Gorge dam is situated some 90km south west of the Kano city. The Tiga dam is situated 70km south of Kano city: the location of the two dams is shown in Figure 2.1. To access both dams it is necessary to cross their respective spillway discharge channels, which might be problematic in times of extreme flood.

2.2 TIGA DAM

2.2.1 History

The dam was based on a design of NEDECO but was constructed between 1970 and 1974 without professional engineering input. HJRBDA took over responsibility for operating and maintaining the dam in 1976 and as described in Section 1.3 above, commissioned a series of inspections, studies and remedial works

2.2.2 Characteristics

The Tiga dam is a zoned earthfill embankment whose main characteristics are as follows:

Embankment height river bed level	48m
Embankment length	6000m
Crest elevation	530.96masl
Upstream slope	1:3
Downstream slope	1:2.5
Crest width	7.6m
Outlets:	
- Main	3.65m diameter
- secondary	2no 0.9m diameter
Main spillway	
- 527.3m crest level	122m
- 527.6m crest level	527.6m
Emergency spillway	
- 525.1 m crest level	200m
- 526 m crest level	714m

2.2.3 Embankment design

The embankment profile is conventional with a wide central core of low permeability clayfill supported by shoulders of coarser material. Filter zones are provided to prevent migration of fine material from the core to the shoulders, and an internal drainage system to control the phreatic surface in the downstream shoulder. The embankment is founded on residual soil except at the core, where a narrow and in paces relatively deep trench was excavated down to the underlying bedrock.

Seepage through the foundation is limited by a grout curtain constructed from the bottom of the trench.

The embankment was originally provided with 14 standpipe piezometers which have since been augmented by a number of new piezometers.

2.2.4 Outlet works

The main outlet works comprises a 3.65m diameter steel pipes set in concrete in a trench excavated in rock at the close to the original river course. The inlet to the pipe is a submerged concrete structure containing a butterfly valve that can be used to dewater the pipe. A gallery situated on the left side of the pipe provides access to the inlet chamber. The pipe terminates at the outlet structure where the flow is discharged into the main canal. Flow is regulated by means of a 2.2m diameter Howell Bunger valve.

The two secondary inlets both comprise a 0.9m diameter steel pipe set into the base of the embankment. The inlet structure is submerged but there is no upstream flow control and no access. Flow is controlled at the downstream end of the pipe which discharges into the Kano river.

2.2.5 Spillway

The main spillway comprises an ogee-profile weir, 448m long and curved in plan, discharging into a channel excavated in rock. The level of the central 122m length of the weir is 30cm lower than the outer part. On either side of the weir there is a low embankment of total length 914m and whose crest level is ?? m below that of the Main dam, so that the dikes would act as supplementary spillways in times of extreme flood A 200m length of this dike immediately to the left of ths concrete spillway, was recently excavated to the level of the rock foundation.

2.3 CHALLAWA GORGE DAM

2.3.1 History

The project was initiated in 1975 by the Kano State Water and Resources and Engineering Agency (WRECA) which was responsible for both design and construction. HJRBDA, who took over responsibility in 1977, commissioned Haskoning to supervise the construction of the dam in 1980 which they did until their contract expired in 1983. Construction continued at a slow pace until 1989 when Julius Berger Nigeria PLC were appointed as the contractor and Water and Dam Services Company were appointed to supervise construction. The dam was completed in 1992.

2.3.2 Characteristics

The Challawa Gorge dam is a zoned earthfill embankment whose main characteristics are as follows:

Embankment height river bed level	42m
Embankment length	7804m
Crest elevation	527.45masl
Upstream slope	1:3
Downstream slope	1:2.5
Outlet	Twin 2.5m diameter

Main spillway: uncontrolled ogee

- crest level	523.76
- crest length527.6m crest level	600m

2.3.3 Embankment design

No information was available on the embankment design other than, like Tiga, it is of zoned earthfill construction. Relief wells were installed at 50m centres along the entire length of the downstream toe of the embankment.

2.3.4 Outlet works

The outlet works comprises twin 2.5m diameter (approx)steel outlet pipes passing from the inlet works at the upstream end to the outlet works at the embankment toe. The pipes are provided at the upstream end with a stoplog and a butterfly valve, which are both accessed via an intake tower and a footbridge to the dam crest. The two pipes terminate at the outlet structure where the flow is discharged into the river channel. Flow is regulated by means of a diameter Howell Bunger valve

2.3.5 Spillway

The spillway comprises a 600m long straight concrete ogee weir discharging into an excavated channel which converges to a width of several hundred meters. There is no emergency spillway

2.4 HYDROLOGY

2.4.1 Reservoir characteristics

The characteristics of the reservoirs are as follows:

	Tiga dam	Challawa Gorge dam
Full storage level (m)	527.3	537.45
Area at full storage level (km²)		100
Volume at full storage level (Mcm)	1968	904
Dead storage (Mcm)	123	26
Direct catchment area (km²)	6553	3857
Mean annual inflow (Mcm)	1300	-
Annual yield (Mcm)	-	470
Design flood (m^3/s)	3257 (10,000 year)	6500 (PMF)

2.4.2 Rainfall

Average annual rainfall in both catchments is approximately 1000mm, which falls in the period June – October.

2.4.3 Floods

Tiga

Haskoning, in their 1979 report[2], estimated the peak flow and total flood volume of the 1 in 10,000 year flood event for a variety of flood durations. The 5 day flood was found to result in the largest flood rise, as follows:

Flood volume:	706Mcm
Peak inflow:	3257m^3/s
Peak outflow:	2043m^3/s
Peak reservoir level:	529.4m
Freeboard:	1.5m

From regional flood data[4] the peak flow estimated by Haskoning seems to be low by a factor of 2. In their 1987 report[3] the USBR recommended that the spillway should be designed to pass the Probable Maximum Flood (PMF) and that a new flood study should be carried out using the additional data collected the 1979 study. It is understood that this new study was carried out by Babtie, as a consequence of which a 200m length of the original emergency spillway was excavated, in 2000, to its rock foundations at 525.1masl. Subsequently in 2001, the wettest year in living memory in the area, the reservoir level rose to a peak level of 526.31m, its highest recorded level.

Challawa Gorge

The spillway at Challawa Gorge has apparently been designed to pass the PMF which was stated to be 6,500m^3/s by HJRBD. No information of the corresponding outflow or the peak reservoir level was available. During the inspection it was noted that the 2001 flood mark was some 200cm above the spillway level. This indicates that the peak outflow in 2001 was 115 m^3/s over the spillway plus the discharge through the outlet structure.

3 THE INSPECTION

3.1 TIGA DAM

3.1.1 Introduction

Due to lack of time, the inspection made by Mr Attewill cannot be considered a full and detailed inspection.

3.1.2 Upstream face

The upstream face of the dam is somewhat uneven as evidenced by an erratic shore line, as shown in the photograph: this observation tends to support poor construction control as suggested in the Haskoning report[2] although it could be a manifestation of post construction settlement due to poor compaction, which is also noted by Haskoning.

The upstream face is protected from wave attack by riprap which appeared, at the points where it was inspected, to have been dumped. As dumped riprap the average stone size is undoubtedly too small, as noted by the USBR team[3]. However the Haskoning report contains construction photographs in which the riprap was being placed by hand, a technique which in which smaller stones sizes can be tolerated. It is quite possible that the smaller stone specified for hand placing was retained even though the method pf placing was changed, presumably to speed progress. The consequence of inadequate stone size is of course higher maintenance costs. In addition there is a considerable amount of weed growth through the riprap layer which will further reduce its effectiveness in dissipating wave energy.

Upstream face of Tiga dam, looking west

3.1.3 Crest

The embankment crest, which is covered with a laterite road surface, is variable in width but otherwise appears to be sound. The was no sign of the longitudinal cracks noted by the USBR which have subsequently been repaired.

3.1.4 Downstream face

No evidence was noted of the underfilled profile resulting in local steepening reported by the USBR and which has since been remedied. The downstream face is covered with grass which can, if the grass cover is well established and dense, provide effective protection against surface erosion from rainfall.
In various places, however, large areas of grass had been burned which reduces the protection in the short term and which also revealed that the cover was not particularly dense.

3.1.5 Downstream drainage

The downstream drainage system has been rehabilitated since the USBR inspection and appeared to be in a reasonably good state of repair.

3.1.6 Outlet works

The absence of any lights precluded an inspection of anything but a short length of the downstream end of the access gallery. However the gallery walls felt dry and the tota;l seepage into the gallery and the inlet structure, which was conveyed in a floor drain, appeared to be low.

3.2 CHALLAWA GORGE DAM

3.2.1 Introduction

Due to lack of time, the inspection made by Mr Attewill cannot be considered a full and detailed inspection.

3.2.2 Upstream face

The upstream face of the dam is uniform and in good condition. The riprap protection was also in good condition with no bare patches or displacement evident.

3.2.3 Crest

The crest of the dam appeared uniform with no sign of any settlement or cracking

3.2.4 Downstream face

The downstream face presented a uniform appearance: the slope is protected from surface erosion by a layer of small rockfill.

3.2.5 Relief wells

A random check was made of one of the several hundred relief wells and it appeared to be clean and in good order. The total seepage through the left abutment of the dam and its foundations was estimated as 20-30l/s which is acceptable.

3.2.6 Outlet works

The intake tower appeared to be in excellent condition with no sign of any seepage from the reservoir. The condition of the hydromechanical equipment appeared to be good although a proper inspection could not be made because the lights were not working.

3.2.7 Spillway

The spillway appeared to be in excellent condition. There is moderate to severe erosion of the ford, where the discharge channel crosses the old road, several hundred metres downstream of the embankment which does not pose a problem at present but which should be kept under observation in the future.

4 THREATS TO THE INTEGRITY OF THE DAMS

4.1 TIGA DAM

4.1.1 Slope stability

The safety factors calculated by Haskoning were unacceptably low:

Upstream slope, rapid drawdown:	F = 1 – 1.2
Downstream slope, steady seepage, static conditions:	F = 1.17

The USBR report recommended that a programme of investigation should be carried out to recover undisturbed samples of fill material for laboratory testing so that the stability can be re-appraised. They also recommended that a seismic hazard assessment should be carried out to determine appropriate design seismic accelerations. It is understood that this work has been carried out by Babtie and this will be reviewed when a copy of their report is made available.

4.1.2 Internal erosion

Provided the filter material was correctly specified the dam should be protected against internal erosion. A much bigger threat is posed by the possibility of piping both through the cut-off trench and piping associated with the secondary draw off conduits.

<u>Piping through cut –off trench</u>
The material placed in the cut off trench, where the possibility of arching action might severely reduce vertical stresses in the fill, is vulnerable to piping. This was the mode of failure of the Teton dam in the United States which had a very similar cut-off. There is also a reference in the USBR report to the possibility of the fill material being dispersive: if this has not already been investigated it should be as dispersive soils are much more prone to piping than non dispersive soils.

<u>Piping associated with secondary draw-offs</u>
The two secondary outlets comprise 24 inch (0.6m) diameter steel pipes in which the flow is controlled only by a valve at the downstream end. The entire length of the pipe is thus under full reservoir pressure and if (when) a leak develops in the pipe, water will escape from the pipe at high pressure into the surrounding fill material. It is likely that this fill will then be eroded by the high pressure water jet and piping failure of the embankment may ensue. There is of course no means of access to repair leaks that may develop and the only recourse is to block the submerged inlet using divers to place either a stop log or sand bags.

4.1.3 External erosion

As has been noted the stone size of the riprap is inadequate to protect the wave erosion. The replacement of the riprap layer, especially at the higher levels, would be very desirable but is probably unrealistic in the short term. It is particularly necessary therefore that the riprap is subject to annual inspections and remedial works where necessary to repair any damage.

Similarly it is important to promote a better cover of grass on the downstream face. Surface erosion from rainfall in a single season will not threaten the integrity of the dam but if it is not remedied the cumulative effect can be very serious. The achievement of good grass cover will therefore reduce the amount of maintenance that would otherwise be necessary.

4.1.4 Floods

The revised flood study recommended by the USBR was carried out by Babtie with the result that a 200m section of the dike forming the emergency spillway was excavated. The Babtie report on the revised flood study will be reviewed when it becomes available to check that the current spillway can pass the PMF.

4.2 CHALLAWA GORGE DAM

4.2.1 Slope stability

No information is available on the calculated factor of safety of Challawa Gorge. The design calculations should be examined to determine the critical safety factors. If, on the basis of supported or of reasonable shear strength parameters, the safety factors appear adequate, then no further action is required. If these calculations are not available or if the factors of safety are considered to be marginal, then new investigations and stability analyses should be carried out.

4.2.2 Internal erosion

A properly designed relatively new dam such as Challawa Gorge dam should not be at risk from piping failure. The original design report should be reviewed to ensure that there is no risk of piping at Challawa Gorge.

4.2.3 External erosion

The riprap appears to be adequate to protect the slope from wave attack, although this should be verified by a detailed review of the actual stone size and the design wave height.

4.2.4 Floods

The spillway at Challawa Gorge dam has been designed to pass the PMF and therefore there risk of overtopping by a flood has already been minimised.

5 EMERGENCY PLANNING

5.1 RESPONSIBILITY

It is understood that Nigerian Law holds the dam owner responsible for the safety of his dam. In the case of Tiga and Challawa Gorge the dams are owned by the Hadejia Jana'are River Basin Development Authority who are also responsible for the operation and maintenance of the dams.

5.2 SURVEILLANCE

Although there is no formal safety plan at either Tiga and Challawa Gorge, regular readings are made and records kept as follows:

- Reservoir level: daily
- Releases: daily
- Seepages: monthly
- Piezometers and well water levels: monthly.

The dams are also inspected periodically by experienced senior staff of the HJRBDA.

5.3 POPULATION AT RISK

5.3.1 Tiga dam

Tiga dam is situated immediately upstream of a relatively densely populated irrigation area: further downstream several substantial villages and towns – for instance are situated in the potential flood plain. It is estimated that the population at risk is tens of thousands.

5.3.2 Challawa Gorge dam

The area downstream of the dam as far as the confluence with the Kano river is relatively sparsely populated: downstream of the confluence the population at risk is the same as for Tiga dam.

5.4 WARNING SYSTEM

There is no formal warning system at either Tiga or Challawa Gorge dams.

5.5 EMERGENCY PREPAREDNESS

5.5.1 Routine maintenance

Routine maintenance is of a high standard, given the budgetary constraints. It is important that the lights in the outlet works are repaired in both dams, as routine inspections are far less revealing by torchlight and in an emergency the lack of lights would be a hazard.

It is not known how often the upstream control equipment – the butterfly valves and stop log gates at Challawa Gorge - are exercised: if they are not opened or closed for operational reasons, they should be operated once a year to ensure that all components work.

5.5.2 Plant

Earthmoving plant – excavators, trucks and compactors – should be kept available in the vicinity of each dam for use in case of emergency repairs are required. It is understood that such plant is available close to Tiga dam. The situation at Challawa Gorge is not known.

5.5.3 Emergency Action Plan

It is understood that at neither dam does an Emergency Action Plan exist.

6 CONCLUSIONS & RECOMMENDATIONS

6.1 THREATS FACING THE DAM S

6.1.1 Tiga dam

The main threats facing the integrity of Tiga dam, in decreasing order of probability:

1. internal erosion due to arching of fill material over cut off trench
2. internal erosion caused by a fracture of one of the two secondary outlet pipes
3. slope failure under seismic load

Further study would be required to assess the probability of failure from each of these threats, but the combined probability must be considered as being high.

6.1.2 Challawa Gorge dam

By contrast the probability of the failure of Challawa Gorge dam to the main threats of external erosion, internal erosion and instability must be several orders of magnitude lower than at Tiga.

6.2 RECOMMENDATIONS: DAM SAFETY

6.2.1 Tiga dam

It is necessary to review the Babtie report in the light of the USBR recommendations to determine the nature, extent and priority of actions required to improve the safety of Tiga dam. The threats to the integrity of Tiga dam summarised in section 6.1.1 above are all due to inadequate design and structural solutions to mitigate the risks would be extremely expensive. It is therefore necessary to rely on non-structural solutions, as detailed in section 6.3 below. Consideration should also be given to reducing the full storage level by additional excavations of the emergency spillway on the left bank.

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6.2.2 Challawa Gorge dam

The original design of the Challawa Gorge dam should be reviewed to ensure that it meets modern standards. If design parameters are not available it is recommended that a programme of sampling and testing should be undertaken to provide any deficiencies in data.

6.3 RECOMMENDATIONS: SAFETY PLAN

6.3.1 Monitoring

The performance of the dams are already being monitored but the extent of the monitoring at Tiga should be improved. Increased seepage is the best indicator of impending piping failure, so it is recommended that the seepage measurement and monitoring system should be improved, extended and automated. An accurate level survey should be carried out along the dam crest and downstream shoulder at least once a year at the end of the dry season

Essential records that should be kept are:
- Daily readings of reservoir
- Weekly readings of seepage flows
- Monthly readings of piezometers and wells
- Annual level survey of the dam crest

Most importantly, vulnerable areas: the downstream toe, especially in the vicinity of the outlets, should be inspected weekly throughout the year by the maintenance staff and twice yearly by qualified dam engineers.

An annual report should be compiled describing the performance of each dam should be prepared. These reports should detail instrument readings and their analysis

6.3.2 Early warning

It is recommended that an early warning system be installed at Tiga dam. The warning would comprise sirens in communities immediately downstream and radio or telephone links to the civil authorities elsewhere in the area of inundation. This area should be determined from a dam break analysis if this has not already been carried out. The HJRBDA should cooperate to the fullest extent with the civil authorities in the preparation of an action plan.

References

[1] Lake Chad Basin GEF Project: "Integrated Environmental and Social Assessment" - January 2002

[2] Haskoning: "Tiga Dam Evaluation Report", July 1978

[3] USBR: "SEED examination of Tiga dam", 1987

[4] Farquharson et al: "Caracteristiques statistiques de la crue regional en Afrique de l'Ouest" Hydrologie continentale, vol 8 no.1 1, 1993