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MAXIMIZING THE BENEFITS FROM WATER AND ENVIRONMENTAL SANITATION

Evaluation of the Challawa gorge dam spillway channel using a physical model

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The Challawa Gorge Dam is situated at Karaye, about 90km south east of Kano, Nigeria. The purpose for the dam include, irrigation, improvement of water supply to Kano city and other towns and settlements along the river system as well as fisheries and livestock development and recreation. Models of hydraulic structures have been found to be effective tools for optimizing the design of water conveyance facilities and water control works. This paper is a brief account of the model study of the Challawa Gorge Dam Spillway channel. A 1:50 model of the spillway and tailwater basin of the dam was built and tested under controllable conditions at the National Water Resources Institute, Kaduna. A point gauge equipped with a vernier was used to measure flow depths at three selected sections of the tailwater basin. The results of the test showed that the proposed tailwater basin is adequate.

Introduction

In September 1991, Julius Berger Nigeria Plc (JBN) asked the National Water Resources Institute, Kaduna, to submit a proposal for a model study on the Challawa Gorge dam Spillway Channel. A proposal was submitted and defended before JBN (Challawa) on 13th September, 1991. Around mid October, 1991 JBN gave the Institute the go-ahead to conduct a model study on the spillway tailwater channel. The NWRI constituted a team to undertake the study of which this author had the privilege of being assigned the role of the team leader (NWRI 1992).

The objective of the model study of the Challawa Gorge Dam Spillway Channel is an evaluation of the channel shape required for a smooth hydraulic flow in the tailwater basin. Site-specific conditions at the location of the spillway of the Challawa Gorge Dam are such that on the right side of the spillway the terrain is rocky and at a much higher elevation than on the left side of the 600 metres long spillway. It is evident that a straight tailwater channel basin will require considerable costs in excavation and compensation for buildings and farmland within close proximity of the right wing wall of the spillway. Gulliver and Wetzel (1984) expressed the view that, "A hydraulic model study can be performed to verify that the proposed design functions properly. The model may also be a tool to improve structure performance or to reduce anticipated construction costs".

Julius Berger Nigeria Plc provided the design flow conditions as well as relevant design drawings of the spillway structure and surrounding morphology (JBN & LAHMEYER INT. 1990). The model study team at the NWRI, Kaduna decided on a scale of 1:50 to model the horizontal and vertical dimensions of the spillway, stilling basin and tailwater basin. Using the same scale for the horizontal and vertical dimensions guarantees building an undistorted model of the prototype spillway which is 600m in length and 9.56m high. The spillway is designed as an uncontrolled overflow ogee crest spillway with a downstream stilling basin, a replica of the type III basin developed by the United States Bureau of Reclamation (USBR 1977).

Design of model

In a hydraulic model of this type with a free surface flow, inertia and gravity forces usually predominate. Thus model-prototype dynamic similitude is most closely approached by keeping the Froude number constant (Sharp 1981).

$$Fr=V/\{(gL) = \text{Inertia force/gravity force} \quad (1)$$

where Fr is Froude Number, V equals flow velocity, g equals acceleration of gravity and L equals a characteristic length dimension such as depth of flow.

The Froude number in the model must be equal to that of the prototype if dynamic similarity is to be achieved:

$$Fm = Fp$$

$$Vm/\{(gLm) = Vp/\{(gLp) \quad (2)$$

or

$$Vm/Vp = \{(Lm/Lp) \quad (3)$$

where m and p denote model and prototype respectively. The ratio Lm/Lp is the geometric scale, which in this model study was chosen to be 1:50. The velocity scale can be used to predict prototype velocities from measured model velocities because

$$Vp = Vm\ (Lp/Lm) \quad (4)$$

The discharge Q is proportional to the product of velocity and area so that

$V \; \Xi \; Q/L^2$

substituting in equation (3) gives

$$Qm/Qp = (Lm/Lp)^{5/2} \qquad (5)$$

This is the discharge scale to be employed to determine the discharge at which the model should be run to simulate a known prototype discharge. With the chosen 1:50 scale the corresponding dimensions of prototype and model are as follows:

ITEM	PROTOTYPE	MODEL
Length of Spillway	600m	12.00m.
Length of stilling basin	9.12m	0.18m
Height of baffle blocks	0.75m	0.015m
Height of end sill	0.65m	0.013m
Height of chute blocks	0.5m	0.010m
Velocity of approach upstream	1.58m/s	0.223m/s

The 10,000 year return period maximum peak discharge inflow of 6500m3 per sec. gives an outflow of 3860m3/sec. at the spillway. The corresponding outflow on the model spillway can be obtained using equation (5)

$Qm/3860 = (12/600)^{5/2} = (0.02)^{5/2} = 5.65685 * 10^{-5}$

$Qm = 3860 * 5.65685 * 10^{-5}$ m3/sec

$= 0.218$ m^3/sec or 218 1/sec

Va model = 0.223 m/sec

$hv = (Va)^2/2g = 0.223^2/(2*9.81) = 0.0025$

$Q = 2/3 * u * B \; 2g \; (H^{3/2} - h^{3/2})$

Assuming $u = 0.69$

Then $0.218 = 2/3 * 0.69 * 12 * 4.43 \; (H^{3/2} - 0.0025^{3/2})$

from which H = 0.049m

But H = h + hv

i.e 0.043 = h + 0.0025

h = 0.04m

Therefore the corresponding head of water on the crest of the model spillway to guarantee a flow of 218 1/sec is 0.04m or 4.0cm.

Construction and description of model

A 1:50 scale model of the spillway stilling basin and tailwater channel was built near the NWRI calibration tank. The tank served as a sump for the five submersible flight pumps that were used to circulate water through the model.

The construction of the model was by direct labour using mainly NWRI personnel and hired labour from outside the institute.

The slope of the tailwater embankment is 1:3 and water resistant plywood was used as the centre of embankment.

Templates were used to get the correct shape of the ogee spillway. Three coats of epoxy paint were applied on the ogee spillway to eliminate drag effects. Precut hard wood was used for the chute blocks and the baffle blocks in the stilling basin. The model consisted of the spillway, the stilling basin and the tailwater basin at the end of which is a 46cm by 50cm rectangular concrete channel to convey the outflow to a sump from which the water is recirculated over the model.

The model was tested by pumping water into a chamber 2m x 12m. The inlet pipe was a 300mm diameter steel pipe. Two lines of 57 holes 5cm diameter and at 18cm centre to centre were drilled on the 300mm diameter inlet pipe.

At the end of the inlet chamber are nine 1 metre wide sharp crested rectangular weirs over which water flows into another approach channel 0.7m by 12m before spilling over the spillway and then into the stilling basin and the tailwater basin.

Model test and observation

First major test and observation

Three different flows were passed over the 12m long spillway to see the behaviour of flow down the tailwater basin. The depth of flow within the tailwater basin at a number of points along profiles D, B and the control section were noted. Figure 1 shows the dimensions of profiles D, B and the control section which are at 20cm, 400cm and 600cm respectively from the stilling basin end sill. The result of the test is as shown in Table 1. Dye was poured along the length of the spillway to visualize the flow. A point gauge equipped with a vernier was used to measure flow depths within the tailwater basin. The water depths recorded in the tailwater basin are referenced to the concrete platform on top of which lies the floor protection. The observations made after the first main test of the model are as follows:

a) It was observed that the right bank caused a backwater effect that accounted for the high water levels noticed at points closer to the right embankment. For profiles D and B the depth of flow at the toe of the right bank was consistently higher when compared with water depths at the toe of the left embankment. However at the control section the reverse was the case. The reason for this being that at the control section, the flow from the right bank tends to move parallel to the direction dictated by the bank. The dye indicated that at the control the flow did not readily deviate to follow the curvature provided at the outlet. This results in the flow originating from the right bank pushing towards the left embankment making the water level to rise in addition to the rise in water level expected as a result of the constriction at the control section.

b) The flow originating from the left half of the spillway gets to the control section a little bit faster than the flow from the other half.

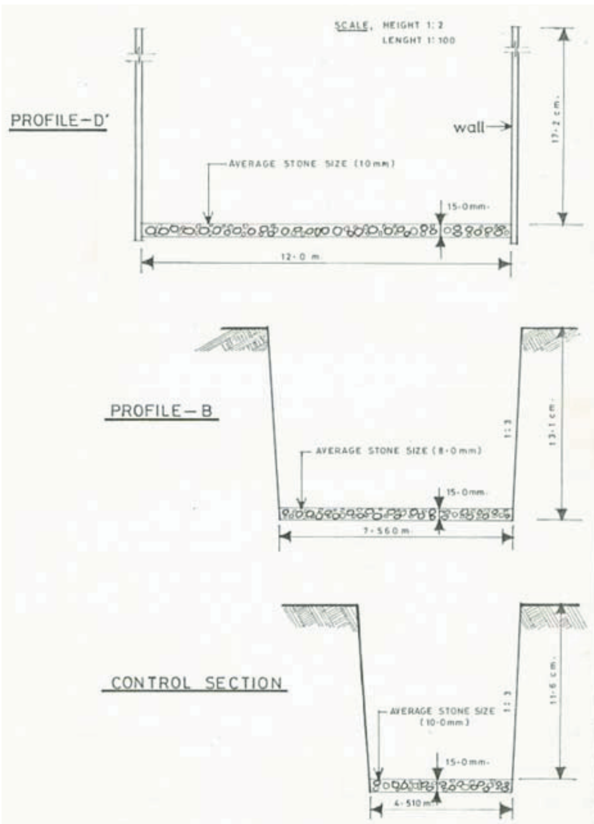

Figure 1. Tailwater channel cross sections

c) The hydraulic jump was submerged in the right side of the spillway within a length of about 4 metres from the right bank. The jump is unrestricted for the remaining length of the spillway.

d) The tendency for toe erosion was observed along isolated portions along the heavy protection immediately adjacent to the stilling basin end sill. The reason for this phenomenon is that the floor protection is not compacted and the falling jet on the floor easily detaches the protection. Compaction is not feasible as the bed protection is only 15mm thick and furthermore placed on a concrete floor. A concrete floor is required to guarantee the floor level at all test flows and to rule out significant losses of water so that when a given quantity of flow passes over the spillway the same flow can be observed as it passes through the tailwater basin and the constricted area.

The other area where erosion was observed was at the control section in the area around the toe of the right embankment. It was noticed that there was some turbulence around the rectangular piers supporting the sharp crested rectangular weirs. It was noticed that there was some turbulence around the rectangular piers supporting the sharp crested rectangular weirs.

Final test and observations

Before conducting the final tests on the model, some of the problems noticed while conducting the test reported in 2.1 were corrected. The following are the remedial actions taken before the final major test.

i.) In order to slow down the flow adjacent to the left bank so that all flows originating over the full length of the spillway get to the control section at about the same time, a triangular sill was installed along a portion of the control section. The sill which is rectangular in plan has a triangular side elevation, tapering from a height of 5cm at the toe of the left embankment to zero height at a distance 208.5cm from the toe of the left embankment.

ii) To minimize the turbulence noticed around the rectangular piers supporting the plate weirs, the rectangular piers were reshaped to triangular piers.

With the amendments in place, three different flows were passed over the model and measurements taken in a similar manner as recorded for the first major test. The results are as presented in Table 2. Two different dye colours - blue and yellow were used for the flow visualization. The dyes were poured along the entire length of the spillway, one colour for the left half and the other colour for the right half of the spillway. The following observations were made from the tests.

a) There was a slowing down of the flow on the left embankment. The flow originating from the left side of the spillway and the right side arrives at about the same time at the control section.

b) Much of the outflow at the control section still occurred in sections nearer the left embankment than the right embankment. The flow still did not readily follow the curvature provided at the end of the right bank.

c) The erosion of the floor protection within close proximity of the stilling basin on the left portion of the spillway was still noticed. Also floor protection within close proximity of the toe of the right embankment along the control section got removed and transported downstream.

d) There was no overtopping of the embankment on either side during all flows up to the maximum flow of 218 1/sec.

Conclusion

The main conclusions that can be drawn from the model study are as follows:

a) The observed depths of flow in the model are within the range expected from the prototype. However the protection against overtopping can be improved.

b) The displacement of the floor protection in portions adjacent to the end sill of the stilling basin is not likely to occur on the prototype. This is because the protection on the prototypes tailwater basin will be placed on properly compacted laterite and the depth of protection is good enough to permit proper compaction to take place. Since there will be a reasonable degree of interlocking between the stones, it is unlikely that the stones can easily be detached.

c) The tailwater basin as proposed is adequate to handle the peak outflow of 3860 m^3/sec from the spillway if there is an occurrence of the 10,000 year return period flood of 6500 m^3/sec flowing into the Challawa Gorge Dam.

Finally water resources projects are time consuming and costly undertakings. The stability, suitability and performance of such projects cannot be left to chance. The decision to proceed with the model study on Challawa Gorge Dam Spillway Channel was based upon potential performance improvement, risk reduction and scaling down construction costs. Post-construction, trial and error solutions of hydraulic problems in the prototype can be very expensive, and may be unsuccessful. The unusual shape of the Challawa Ceorge Dam Spillway channel required a physical model to have an idea how the real prototype would perform.

A 1:50 model of the dam's spillway, stilling basin and tailwater channel was built and tested under controllable operating conditions at the NWRI and the results were satisfactory.

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Table 1. Test measurements on model with no sill at control section

FLOW IN PROTOTYPE m3/s.	FLOW IN MODEL m3/s	HEAD , h ON WEIR Cm.	FLOW DEPTHS AT PROFILE D Mm.				FLOW DEPTHS AT PROFILE B Mm.			FLOW DEPTHS AT CONTROL SECTION. Mm.		
			R	R1	R2	L	R	M	L	R	M	L
2121	0.120	3.8	73.5	70	68.2	36.1	77.6	61.4	65.2	35	52.1	60.2
2828	0.160	4.6	89.4	83	74.5	59.5	96.4	79.9	83.8	49.7	74.6	85.9
3692	0.209	5.5	98.1	94.4	90.0	64.6	104.5	88.4	86.9	73.7	94.0	108.2

Table 2. Test measurements on model with sill on a portion of control section

Flow in Prototype M3/s	FLOW IN MODEL m3/s	HEAD, h ON WEIR Cm.	FLOW DEPTHS AT PROFILE D Mm.					FLOW DEPTHS AT PROFILE B Mm.			FLOW DEPTHS AT CONTROL SECTION Mm.		
			R	R1	R2	R3	L	R	M	L	R	M	L
1600	0.105	3.15	63.0	55.9	55.6	30.9	33.5	74.3	54.0	56.6	30.0	33.2	69.5
2917	0.165	4.70	89.0	81.6	72.7	45.3	50.0	100.0	76.7	78.5	35.0	68.1	85.3
3860	0.218	5.66	96.8	89.4	83.0	63.2	67.8	109.0	96.0	94.7	84.0	101.0	108.0

Notes on Tables 1 and 2.

R1 = R + 100cm.
R2 = R + 200cm
R3 = R + 600cm (For table 2 only)

R - The toe of right embankment R1 = R + 100cm
L - The toe of the left embankment E2 = R + 200cm
M - Midway between toes of the right and left embankment
Control section is at 6m from stilling basin end sill
R3 = R + 600cm (For Table 2 only).