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Earth Dam Design of the Mekin Hydropower Plant

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ABSTRACT

This work shows the results obtained from the design of the Earth Dam for the Mekin Hydropower project. This water retaining earth dam design includes the water retaining parts of the main dam and the auxiliary dam. To begin, the basic design data which includes the class of the water retaining structures, flood standard, characteristic water level and fetch length are determined. The work continues with the presentation of the exact location, and the different structures that constitute the earth dam. The dam slope and crest which make up the dam body are also presented followed by their sizing. In addition a study of the seepage-proofing soil and filling material of the dam body is done.

INTRODUCTION

The Mekin hydroelectric dam situated in the south region of Cameroon located after the confluence of the rivers Dja, lobo and Sabe, is constructed to produce 15MW. The main dam and auxiliary dam constitute a reservoir of approximately 11010km^2 with a volume of about $2 \times 10^8 m^3$.

The main dam and auxiliary dams are earth dams and their sizing, have presented a major challenge for African engineers and experts notably due to lack of documentation and sometimes experience. This work seeks to propose a simplified methodology based on international standards and a case study. It presents concrete results which are being implemented on the construction site of the dam. The earth dam is composed of principally the dam slope, dam crest and the dam body [1,6]. In this work, the basic design data necessary for the studies is presented. In this light, the class of water retaining structures, flood standard, characteristic water level, wind speed and fetch length are treated. The discussion of the dam body structures follows with the specification of its location, and arrangement of structures. In addition, the seepage-proofing soil and filling material of the dam body are treated in detail. Finally aspects of the dam body structure that include zoning of dam body, dam slope and dam crest elevation are discussed in detail.

Basic Design Data

Class of Water Retaining Structures [2,3,4]

(1) Main dam class 2
(2) Auxiliary dam class 2

Flood Standard and Characteristics Water Level [5,7]

Table 1-1: Characteristic water level of reservoir

Working condition	Flood standard (year)	Upstream water level (m)	Downstream water level (m)	
			Main dam	Aux. dam
Check flood level	2000	613.80	609.45	
Design flood level	100	613.45	608.20	No water
Normal high level	-	612.00	603.35	

Wind Speed and Fetch Length

(1) Average annual maximum wind speed 10.60m/s
(2) Fetch length 585.00m (main dam)
550.00m (aux.dam)

Arrangement of Structures

Main Dam

The main dam is connected to the approach road. The main dam is on the right side of the power station on the second order bottomland of Dja River. It is on the same axis of the power station, floor discharge sluicing gate, floating debris sluicing gate and overfall dam.

The total length of the main dam water retaining dam is 488.00m. See table 1-2 for parameters of control points.

Table 1-2: Parameters of main dam control points

Position	Stage No.	Coordinate	
		x	Y
Left side of main dam	Main Sta0+214.000	360439.8580	46882.1165
Right side of the main dam	Main Sta0+685.000	360840.5190	46634.5040

Auxiliary Dam

The water retaining dam of the auxiliary dam is at the mountain massif cove on the left bank of the Dja River. The dam axis has a 137.76 angle width the axis of the main dam toward the upstream.

The total length of the water retaining dam of the auxiliary dam is 295.00m. See table 1-3 for parameters of control points

Table 1-3: Parameters of auxiliary dam control points

Position	Stage No.	Coordinate	
		x	Y
Left side of aux. dam	Main Sta0+000.000	359877.8250	47411.1895
Right side of the aux. dam	Main Sta0+295.000	359959.3560	47127.6790

Dam Building Materials and Filling Requirements

Seepage-Proofing Soil

The seepage - proofing soil for the main and auxiliary dams is borrowed from the gravelly soil yard near Ekon Primary school on the right bank downstream of the dam site.

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See Tables 1-4 and 1-5 for the particle diameter and quality index evaluation

Table 1-4: Particle diameter of soil unit: %

Dia. Mm	>20	20-10	10-5	5-2	2-1	1-0.5	0.5-0.25	0.25-0.075	0.075-0.005	<0.05
Particle content	2.00	9.00	23.80	10.90	2.90	2.00	3.80	7.20	33.00	5.40

Table 1-5: Evaluation of soil quality indices

Item	Technical index Seepage-proofing soil	Soil index of the borrow area Test index
Diameter over 5mm Particle content	<50%	34.80
Dia. Below 0.075mm Particle content	≥15%	38.40%
Max. particle diameter	<150mm Not exceeding 2/3 of rolling compacted layer thickness	Satisfied
Plasticity index	10~20	26.20 (a bit too large)
Permeability coefficient	After rolling compacted Less than 1×10^{-5} cm/s	Vertical:5.19×10^{-7} Horizontal:6.63×10^{-7}
Content of organic matter (in weight)	<2%	3.80%
Content of water soluble salt	<3%	0.20%
Natural water content	Optimum water content	25.1/21.4

According to indoor test of compacted soil, the design values of seepage-proofing soil body of the main and auxiliary dams are shown in table 1-6 [8, 10]

Table 1-6: Physico-mechanical indices of compacted soil

Statistical index	Max dry density	Optimum water content	Compressibility factor	Compressibility modulus	Cohesion	Int. friction angle	Permeability coefficient	
							vertical	horizontal
	P_{dmax}	W_{op}	a_v	E_s	C	φ	K_v	K_h
	g/cm³		MPa⁻¹	MPa	kPa	Degree	cm/s	
Average test value	1.83	19.20	0.08	19.46	57.00	32.60	5.19×10^{-7}	6.63×10^{-7}
Design value	1.80	19.00	0.08	19.45	25.00	25.00	6.00×10^{-7}	

Filling requirements for seepage-proofing soil:
Compactness: ≥ 98%
Water content: 17%- 24%

Filling material of dam body

The abandoned residues from the excavated main dam foundation, flood discharge sluicing gate, power station foundation pits and rain water channel are used as filling material for the main dam body. The abandoned residues from the excavated auxiliary dam foundation and link road between the main and the auxiliary dams are used as filling materials for the auxiliary dam body. If it is not sufficient, the rest is borrowed from the second order bottomland 100.00m downstream the main and auxiliary dams. The residues are mixed fillings for sand loam, silty sand, sand with gravel, medium coarse sand, gravel, chlorite schist.

See table 1-7 for composition of residues from each position and the physico-mechanical indices
See Table 1-8 for design values of soil material used for the main and auxiliary dams

Table 1-7 Composition of residues excavated from each position and the physico-mechanical indices

Usable soil layer	Permeability coefficient (cm/s)	Dry density (g/cm³)	Cohesion (kPa)	Internal friction angle (degree)	Compressive modulus (MPa)	Allowable hydraulic gradient	Type of destruction
Loam	5.80×10^{-3}	1.50	8.50	6.00	5.75	0.30	Flowing soil
Sandy loam	5.80×10^{-3}	1.45	8.50	7.00	11.35	-	Flowing soil
Gravelly loam	9.25×10^{-3}	1.55	13.00	13.00	9.67	0.30	Flowing soil
Medium coarse sand	4.65×10^{-2}	-	-	-	-	-	Piping
Sand-gravel	4.65×10^{-2}	-	-	-	-	0.10	Piping
Silty sand with gravel	4.65×10^{-2}	-	-	-	-	-	Piping
Gravel	1.75×10^{-2}	-	-	-	-	0.10	Piping

Table 1-8: Design indices of mixtures for dam body

Statistical	Max dry density	Compressive modulus	Cohesion	Internal friction angle	Permeability coefficient
	g/cm³	MPa	kPa	Degree	cm/s
Design value	>1.70	>15.00	0.00	>30.00	$>5.00\times10^{-3}$

Filling requirements for dam body:
Relative density: ≥ 0.70

Dam Body Structure

Zoning of dam body

In the principle of the using local materials and balancing filling cutting, the zoning of various materials for the main and auxiliary dam bodies are listed in table 1-9

Table 1-9: Zoning of dam body (from up to down)

Item	Upstream revetment	cushion	Filtration layer	Seepage-proof body	Filtration layer	Dam	Downstream revetment	Downstream drainage body
Compo-sition	Grating gabion	aggregate	Sand gravel	Gravelly soil	Sand gravel	Residue mixture	Masonry frame sod	Dry masonry
thickness	0.30m	0.20m	0.30m		0.30		0.30m	

Dam Slope

In accordance with the characteristics of the type , height , structures class , dam body material and foundation of the main and the auxiliary dams and construction and application conditions , the same single slope is used for downstream of the main and the auxiliary dams. The slope ratio of the upstream dam face is 1:2.75 the slope ration of the downstream dam back is 1:2.00.

Dam Crest Elevation

The dam crest elevation is equal to the sum of static water level of reservoir and dam crest super elevation, and it is calculated with the following application conditions, the maximum value is taken [9,10]:

(1) Dam crest superelevation of design food level plus normal application condition
(2) Dam crest superelevation of normal storage level plus normal application condition
(3) Dam crest superelevation is calculated with this formula:

$$y = R + e + A \qquad (Eq\ 1)$$

Where: y- Dam crest superelevation, m

R- Altitude of maximum wave on the dam slope, m
e- Maximum height of water surface is wind, m
A- Safety height added

Design wave altitude:

$$R = K_p R_m \qquad (Eq\ 2)$$

Where: R_m – Average altitude of wave, m:

K_p – Ratio of wave altitude in different accumulative frequency to average wave altitude

According to engineering order, design wave altitude value is the altitude value $R_{1\%}$ whose cumulative frequency is 1%.

The upstream dam slope of the main dam and the auxiliary dam is 1:2.75, the side slope gradient is m=1.50-5.00, the average wave altitude is:

$$R_m = \frac{K_\Delta K_W}{\sqrt{1+m^2}}\sqrt{\hbar_m L_m} \qquad (Eq\ 3)$$

Where: m- Gradient factor for single slope

K_Δ Slope coarse frequency permeability coefficient, 0.80 is used;

K_W Experience coefficient:

$\hbar_m$ Wave element average wave height, m;

L_m Wave element, average wave length, m

Average wave height and average wave cycle are calculated with Putin Testing station formula:

$$\frac{g\hbar_m}{W^2} = 0.13th\left[0.7\left(\frac{g\hbar_m}{W^2}\right)^{0.7}\right]th\left\{\frac{0.0018\left(\frac{gD}{W^2}\right)^{0.45}}{0.13\left[0.7\left(\frac{g\hbar_m}{W^2}\right)^{0.7}\right]}\right\} \qquad (Eq\ 4)$$

$$T_m = 4.438\hbar_m^{0.5} \qquad (Eq\ 5)$$

$$L_m = \frac{gT_m^2}{2\pi}th\left(\frac{2\pi H}{L_m}\right) \qquad (Eq\ 6)$$

Where: T_m-average wave cycle, s;

W-calculated wind speed, m/s;

D-Fetch length, m;

H_m- average depth of waters, m;

g- Gravity acceleration, 9.81m/s;

H- Water depth in front of dam face, m.

The height of water surface in wind is calculated with the following formula:

$$e = \frac{KDW^2}{2gH_m}\cos\beta \qquad (Eq\ 7)$$

Where: e- water surface height in wind at the calculating point, m;

K- General friction coefficient, $K=3.60\times10^{-6}$;

β- Calculated included angle between wind direction and dam axis normal, degree.

Parapet walls are not provided on the crests of the main and the auxiliary dams. The calculated dam crest elevation is design elevation of the dam crest

See table 1-9 for calculated results of dam crest elevation.

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Table 1-9: Calculated results of dam crest elevation unit:m

Position	Condition For Application	Water Level	Wind Speed	Fetch	R	E	A	Dam Crest Elevation
Main dam	Normal storage level	612.00	15.90		0.706	0.006	1.00	613.712
	Design flood level	613.45	15.90	585.00	0.682	0.005	1.00	615.137
	Check flood level	613.80	10.60		0.410	0.002	0.50	614.712
	Normal storage level	612.00	15.90		0.654	0.026	1.00	613.68
	Design flood level	613.45	15.90	550.00	0.716	0.010	1.00	615.176
	Check flood level	613.80	10.60		0.411	0.004	0.50	614.715

Through calculation:
The elevation of main dam crest is 615.137m; 615.20m is used for design;
The elevation of aux. dam crest is 615.176m; 615.20m is used for design.

Structure of Dam Crest

Width of Dam crest

In combination with the transportation and management requirements, and in consideration of traveling convenience for the villagers in forest areas on the banks of Dja River, there is no special requirement for the width of the dam crest. Therefore, the transportation inside the area are designed as one lane road, i.e the width of both the main and auxiliary dams is 4.00m, the power station, flood discharge sluicing gate, overfall dam, masonry gravity dam, main and auxiliary dams are all connected with 4.00m wide roads to main dam and the auxiliary dam.

Dam crest arrangement

Both the crests of the main and the auxiliary dams are of concrete pavement structure, concrete curbs are provided on the upstream and downstream sides. The dam crest tends towards the upstream in a gradient of 2.0%, drainage openings are reserved in 50.00m intervals in the upstream curbs, moreover, 1.20m railing is provided in the upstream of the dam crest.

Pavement structure: 0.20m concrete pavement, 0.20m broken stone road bed.

Seepage- Proofing Body

Earth seepage-proofing body zoned dam is used for both the main and auxiliary dams.

Gravelly soil borrowed from Ekok Primary school is used for the seepage- proofing body.

The slant wall seepage- proofing body is thickened gradually from up to down. The width of the top is 2.00m, the upstream slope is 1:2.75, the downstream slope ration is 1:2.00. When the maximum bearing water head of the main dam slant wall is 8.05m, the bottom thickness is 3.00m; when the maximum bearing water head of the auxiliary dam is slant wall is 5.30m, the bottom thickness is 2.40m. Both the slant wall thickness and bearing water head ration must meet the specification by not less than 1/5.
The elevation of the seepage- proofing body top is 614.80m. It is directly connected to the dam crest road surface.

Upstream of the seepage - proofing body is provided with 0.20m broken stone transition layer and 0.30m fine sand reverse filtration layer too.

Reverse Filtration

According to the table 1-4, the content of particles below 0.075mm in the seepage-proofing gravelly soil is 38.40%.
Requirements for filtering soil [10]:

$$D_{15} \leq 0.7mm + \frac{1}{25}(40 - A)(4d_{85} - 0.7mm) \qquad (Eq\ 8)$$

Where: A-Content of particles whose diameter is less than 0.075mm, %;

D_{15}– Weight of soil with reverse filtered particles smaller than this diameter covers 15% of the total soil weight, mm;

d_{85}–Weight of protected soil with articles less than this diameter covers 85% of the total weight of soil, mm.

Drainage requirements:

$$D_{15} \geq 5d_{15} \qquad (Eq\ 9)$$

Where: d_{15} weight of protected soil with particles less than this diameter covers 15% of the total weight of soil, mm.

According to table 1-4, A=38.40, d_{15}=0.0265mm, $d_{85} = 5.00mm$, diameter of fine sand particles in the reverse filtration layer in upstream and downstream of gravelly soil slant walls must meet the following requirement:

$$0.135\text{mm} \leq D_{15} \leq 1.90mm$$

Both upstream and downstream of the gravelly soil slant wall must be provided with 0.30m fine sand reverse filtration layer.

Drainage of Dam Body

Dry masonry slope face drainage is adopted for both the upstream and downstream of the main and auxiliary dams.

Based on the dam seepage calculation, the dam slope escapement points at downstream of the main and the auxiliary dams are low, the drainage body is 1.00m higher than the dam flood ground, so it is built with rock blocks, the average thickness is 0.45m, and 2.00m wide banket is provided for the drainage body foot.

Slope Protection

Rock blocks are used to protect the upstream slopes of the main and auxiliary dams while wood frame sod is used to protect the downstream slopes.

Upstream slope protection [10]

The rock mass and thickness for slope protection is calculated with the following formulas:

$$D = 0.85D_{50} = 1.018K_t \frac{\rho_w \sqrt{m^2+1}}{\rho_k - \rho P_w\ m(m+2)} h_p \qquad (Eq\ 10)$$

$$Q = 0.85Q_{50} = 0.525\rho_k D^3 \qquad (Eq\ 11)$$

$$When\ L_m/h_p \leq 15, t = \frac{1.67}{K_t} D \qquad (Eq\ 12)$$

$$When\ L_m/h_p > 15, t = \frac{1.82}{K_t} D \qquad (Eq\ 13)$$

Where: D – conversed ball diameter of rock block, m;

Q– mass of rock block, t;

D_{50}–average diameter of rock block, m;

Q_{50}–average mass of rock block, t;

t– thickness of slope protection, m;

K_t–coefficient varying with the slope ratio;

P_k–density of rock block, t/m^3;

P_w– density of water, t/m^3;

h_p– wave height whose accumulative frequency is 5%

Refer to table 1-10 for parameter calculation results upstream slope protection thickness.

Table 1-10: Calculation results of slope protection thickness

Position	Type of slope protection	Design wave height (m)	Thickness of slope protection (m)	Mass of rock block (kg)	Design thickness (m)
Main dam	Dry masonry	0.360 (5%)	0.11	0.70	0.30
Auxiliary dam	Dry masonry	0.340 (5%)	0.10	0.55	0.30

Through calculation, both the particle diameter and thickness of the upstream slope protection of the main and auxiliary dams are small, so the thickness of 0.30m is used for design according to the structure.

The slope protection is made from the dam foot to the dam crest. Dry masonry substrate is provided at the dam foot, the dam crest is connected to the curbs.

Downstream slope protection

The downstream wood frame sod slope protection is made from the dam crest to the slope face drainage body. The frame size is 3.00m$\times 3.00m$, the wood height is 0.30m, the thickness is 0.02m, the earth in the frame by 0.30m, sodding is done in the frame.

CONCLUSION

The objective of this work was to design the main dam and auxiliary dam of the Mekin hydro electric plant.

The simplified methodology used in the design of the Mekin Earth dam was based on international standards. Concrete results were obtained which are being implemented on the construction site of the dam.

Detailed studies of the basic design data and the arrangement of structures enabled us determining the dam building materials to be used and filling requirements for the seepage proofing soil and the dam body structure.

Through evaluation and calculations, it was concluded that the main dam is a gravelly soil sand- gravel dam. The dam crest elevation is 615.20m, the dam crest width is 4.00m, the maximum dam height is 9.45m, the slope ration of the upstream dam face is 1:2.75, and the slope ratio of the downstream back is 1:2.00. The type of auxiliary dam is completely the same as that of the main dam. Gravelly soil sand-gravel dam is used, the dam crest elevation is 615.20m., the dam crest width is 4.00m, the maximum dam height is 6.70m, the slope ratio of the upstream dam face is 1:2.75, the slope of the downstream back is 1:2.00. And for each dam, grating gabions are used on the upstream of the dam body for slope protection and wood frame sod is used on the downstream for slope protection. Dry masonry is used at the dam foot for drainage on the slope. Cutoff trench is provided in the dam foundation for seepage proofing, gravel earth is backfilled deep into the base rock.

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