

Supplementary Materials:

# Earth Dam Design for Drinking Water Management and Flood Control: A Case Study

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$$y_c = y_i \left( \frac{Z_c}{Z_i} \right)^{\frac{2}{M}} \quad (S1)$$

Hence:

$y_c$  = critical depth

$y_i$  = alternate depth

$Z_c$  = critical state section factor

$Z_i$  = alternate section factor

$$Z_c = \frac{Q}{\sqrt{g}} \quad (S2)$$

Hence:

$Z_c$  = critical state section factor.

$Q$  = critical discharge

$g$  = 9.81 [m/s<sup>2</sup>]

$$Z_i = A_i * \sqrt{D_i} \quad (S3)$$

Hence:

$Z_i$  = alternate section factor

$A_i$  = alternate water area

$D_i$  = alternate hydraulic depth

$$M = \frac{2 * \log \left( \frac{Z_1}{Z_2} \right)}{\log \left( \frac{y_1}{y_2} \right)} \quad (S4)$$

Hence:

$M$  = Hydraulic exponent for critical-flow computation

$Z_1$  = First value section factor

$Z_2$  = Second value section factor

$y_1$  = First value section depth

$y_2$  = Second value section depth

$$\left( \frac{K_1}{K_2} \right)^2 = \left( \frac{y_1}{y_2} \right)^N \quad (S5)$$

Hence:

$K_1$  = Difference in elevation

$K_2$  = Difference in elevation

$y_1$  = First value section depth

$y_2$  = Second value section depth

$N$  = Depth of depression in throat below crest

$$N = \frac{2 * \log \left( \frac{K_1}{K_2} \right)}{\log \left( \frac{y_1}{y_2} \right)} \quad (S6)$$

Hence:

$K_1$  = Alternate conveyance

$K_2$  = Alternate conveyance

$y_1$  = first value section depth

$y_2$  = Second value section depth

$N$  = Hydraulic exponent for uniform-flow computation

$$K_0 = \frac{Q}{\sqrt{S_0}} \quad (S7)$$

Hence:

$K_0$  = Conveyance

$Q$  = Discharge

$S_0$  = Slope of the water surface

$$K_i = \left(\frac{1}{n}\right) * A_i * R h_i^{\frac{2}{3}} \quad (S8)$$

Hence:

$K_i$  = Difference in elevation

$n$  = Coefficient of roughness

$A_i$  = Water area

$R$  = Hydraulic radius

$$\frac{dy}{dx} = \frac{S_0 - S_f}{\sqrt{1 - S_0^2} - \frac{Q^2 T}{g A^3}} = \frac{Num. \left(y + \frac{\Delta y}{2}\right)}{Den. \left(y + \frac{\Delta y}{2}\right)} = \frac{Num. \left(y_i + \frac{1}{2}\right)}{Den. \left(y_i + \frac{1}{2}\right)} \quad (S9)$$

Hence:

$S_0$  = Slope of the water surface

$S_f$  = Alternate of slope of water

$Q$  = Discharge

$T$  = Temperature of water

$g$  = Gravity acceleration

$A$  = Water area

$$\frac{\Delta y}{\Delta x} = \frac{Num. \left(y + \frac{\Delta y}{2}\right)}{Den. \left(y + \frac{\Delta y}{2}\right)}$$

$$\Delta x = \Delta y * \frac{Den. \left(y + \frac{\Delta y}{2}\right)}{Num. \left(y + \frac{\Delta y}{2}\right)}$$

$$d = \Delta h + hr + a \quad (S10)$$

Hence:

$d$  = Shelter above the static level of the reservoir.

$\Delta h$  = Wave drag lift (m)

$hr$  = Wave bearing height (m)

$a$  = 0.5 m (for all loose material dam categories)

$$\Delta h = 2 * 10^{-6} * \frac{DW^2}{gH} \cos(\alpha) \quad (S11)$$

Hence:

$\alpha$  = Angle between the axis normal to the axis of the dam and the wind direction.

D = Fetch (km)

W = Wind speed (m/s)

H = Depth (m)

Replacing:

$$\Delta h = 2 * 10^{-6} * \frac{1.6 * (13.59)^2}{9.81 * (20)} \cos (0)$$

$$\Delta h = 3 * 10^{-6} = 0$$

$$h_r = 2 * \frac{k_r}{m} h_{i\%}^3 \sqrt{\frac{\lambda}{h}} \quad (S12)$$

Hence:

$k_r$  = Roughness coefficient

$m$  = Upstream slope

$h_{3\%}$  = Wave height with 3% probability of occurrence

$\lambda$  = Wave length

$$k_r = 0.115 + 0.151 * \ln \frac{h}{D_e} \quad (S13)$$

Hence:

$k_r$  = Bearing coefficient

$h$  = Wave height above the upstream parameter

$D_e$  = Riprap diameter

$$k_r = 0.115 + 0.151 * \ln \frac{0.348}{0.14}$$

$$k_r = 0.25$$

$$D_e = 0.46 \frac{h}{m^{0.1}} \quad (S14)$$

Hence:

$D_e$  = Riprap diameter

$h$  = Wave height

$m$  = Upstream slope

$$D_e = 0.46 \frac{0.348}{(3.5)^{0.1}}$$

$$D_e = 0.14$$

$$h_{3\%} = k_{3\%} * h \quad (S15)$$

Hence:

$h_{3\%}$  = Wave height with 3% probability of occurrence

$k_{3\%}$  = Rolling coefficient with probability of 3% occurrence

$h$  = Wave height

$$h_{3\%} = 1.85 * 0.348$$

$$h_{3\%} = 1.85 \text{ m}$$

$$\lambda = \frac{9.78 * (\tau)^2}{2 * \pi} \quad (S16)$$

Hence:

$\lambda$  = Wavelength

$\tau$  = Wave period

$$\tau = 7.5 \frac{h^{3/5}}{W^{1/5}} \quad (S17)$$

Hence:

$\tau$  = wave period

$h$  = wave height

$W$  = wind speed

Replacing  $\tau$  in equation 17, we have:

$$\lambda = \frac{9.78 * (2.36)^2}{2 * \pi}$$

$$\lambda = 8.68 \text{ m}$$

From equation (13):

$$h_r = 2 * \frac{0.25}{3.5} 1.85^3 \sqrt{\frac{8.68}{0.348}}$$

$$h_r = 2 * \frac{0.25}{3.5} 1.85^3 \sqrt{\frac{8.68}{0.348}}$$

$$h_r = \mathbf{0.27 \text{ m}}$$

$$C_0 = m_0 C_1 C_2 C_3 C_4, \quad (\text{S18})$$

Donde:

$C_0$ : Discharge coefficient

$C_1$  = Affectation coefficient for loads other than project load.

$C_2$  = Coefficient of affectation due to the inclination of the wall.

$C_3$  = Affectation coefficient due to the effect of the sink downstream

$C_4$  = Affectation coefficient due to submersion.

The value of  $m_0$  was obtained through equation 22. Where  $Ho$  is the total or design hydraulic head, P is the height of the face, which is established from the height of the crest to the bottom of the channel, and the relationship  $\frac{P}{Ho}$  indicates the relative depth of arrival.

$$m_0 = \frac{0.385 + 3.9206 \left[ \frac{P}{Ho} \right]}{1 + 7.8192 \left[ \frac{P}{Ho} \right]}, \quad (\text{S19})$$

The coefficients of  $C_0$  were obtained through equations 23, 24, and 25. As it was not necessary to include a slope to the spillway, the value of C2 was 1.

$$C_1 = \frac{0.7917 + 0.7591 * \left[ \frac{Ho}{He} \right]}{1 + 0.5490 * \left[ \frac{Ho}{He} \right]}, \quad (\text{S20})$$

$$C_3 = 0.77 + 1.115 \left[ \frac{P}{Ho} \right] - 1.1997 \left[ \frac{P}{Ho} \right]^{1.5} + 0.306 \left[ \frac{P}{Ho} \right]^2, \quad (\text{S21})$$

$$C_4 = 0.0047 + 16.6579 \left[ \frac{hd}{Ho} \right] - 44.4645 \left[ \frac{hd}{Ho} \right]^{1.5} + 44.6722 \left[ \frac{hd}{Ho} \right]^2 - 15.8993 \left[ \frac{hd}{Ho} \right]^{2.5}, \quad (S22)$$

From equations 23-25. **He** is a variation of the hydraulic load due to the flow coefficient, originating in a relative floor position concerning the crest of the spillway. In contrast, the  $\frac{Ho}{He}$  ratio establishes the shape of the real sheet relative to that of the analysis. **hd** is the variation of the hydraulic load caused by the effects of drowning or submersion of the top.

**Table S1.** Data required for the normal depth.

Alternative	n	S0	K0	$A_i[m^2]$	$P_m[m]$
A	0.131	0.0006	51124.93	2301.46	198.87
				1617.21	113.03
B	0.100	0.0005	56004.56	1348.87	111.02
				1005.89	97.03
C	0.117	0.0003	72301.57	2626.55	174.36
				1777.70	131.69

$$Q_{design} = 1252.3 \frac{m^3}{s}$$

$$Y_1 = \text{Normal depth}$$

$$Y_2 = \text{NAMO}$$

$$S_0 = 0.0005$$

$$n_{sill} = 0.10005$$

$$\Delta y = 0.5 [m]$$

**Table S2.** Slopes for earthen dams [1].

Parameter	Calculation
Upstream slope	According to the table proposed by Nedrigi [1], for heights 15 and 50 m, a slope between 3 and 4 m is recommended.
Downstream slope	According to the table proposed by Nedrigi [1], for dam heights 15 and 50, a slope between 4 and 4.5 m is recommended.
Downstream berm	<p>Downstream depth = NAA – NSC</p> <p>Downstream depth = 20.91 – 20</p> <p>Downstream depth = 0.91</p> <p>The rockfill will have a height of 1m, at 21.5 m.a.s.l. and a width of 3m.</p> <p>NAA= Downstream level</p>

	NSC= bed level
Upstream berm	<p>Upstream berm level= NAMU – 2h  NAMU: Last maximum water level  Upstream berm level = 25-2(0.348) m.a.s.l.  Upstream berm level = 24.30 m.a.s.l.</p> <p>The protection width of the upstream slope has a thickness of 1m with a width of 3m.</p>
Riprap dimensions	$G_p = \frac{0.025 * \lambda^2 * \gamma_p}{\left(\frac{\gamma_p}{\gamma} - 1\right)^3 * \sqrt[3]{1 + m^3}}$ $D_e = \sqrt{\frac{G_p}{0.524\gamma_p}}$ $D_e = 0.46 * \frac{h}{m^{0.1}}$
Crown width	<p>According to the MOP of Spain [2]</p> $B = 3 + 1.5 \sqrt{H - 15}$ $B = 3 + 1.5 \sqrt{21 - 15}$ $B = 6.60 \text{ m}$
Geomembrane waterproofing	<p>To calculate the thickness you have to:</p> $t_g = 0.75 + \frac{H}{25}$ $t_g = 0.75 + \frac{21}{25}$ $t_g = 2 \text{ mm}$
Concrete facing thickness	<p>The following equation determines the concrete screen thickness in the upstream dam:</p> $t = 1 + (0.00735 * h)[ft]$ $t = 1 + (0.00735 * 68.9)[ft]$ $t = 0.46 \text{ m}$

1. Nedrigi, V.P. *Designer's Handbook. Hydraulic Structures [in Russian]*; Stroizdat: Moscow, 1983;
2. Ministerio de Obras Públicas de España *Instrucción Para Proyecto, Construcción y Explotación de Grandes Presas*; Madrid, España, 1967;



**Table S3.** Assessment of environmental impacts.

Activities	Environmental aspect	Impact	Identification of environmental impacts for this study																								Valuation		
			Severity (S)			Probability Occurrence (P)			Impact Relevance (T)	Extension (E)			Intensity (I)			Duration (Du)			Development (De)			Recovery (R)			Interaction (Ia)			Impact Magnitude (Mg)	Importance of the Impact (Imp)
			1	2	3	1	2	3		0	1	2	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2	Mg= E + I + Du + De + R + Ia	Imp = Mg x T
			positive	medium	negative	very unlikely	unlikely	certain	T=SxP	punctual	partiale	high	low	moderate	high	short term	medium term	permanent	long term	medium term	immediate	reversible	mitigable	irreversible	simple	cumulative	synergistic		
Land expropriation (dam context)	Gas emission	Air pollution		2				3	6		1			1		0			2		1			1			6	36	
	Noise generation.	Air pollution		2				3	6			2		1		1		1		0				1			6	36	
	Demolition of structures	Air and soil pollution		2				3	6			2		2		1		0			1						6	36	

Camp construction	Deforestation	Soil contamination	3	3	9	2	2	1	0	0	1	6	54
	Loss of vegetation cover	Soil contamination	2	2	4	2	2	1	1	1		7	28
	Air quality	Increase in CO2 emissions	2	2	4	1	0	1	1	2	2	7	28
	Presence of particulate matter	Fine particles that can affect project workers	3	3	9	2	1	1	2	2	1	9	81
	Wastewater discharge	Change in BOD and COD concentration in the Vinces Riverbed	2	3	6	1	1	1	2	1	1	7	42



Filled with enhancement material	Increased pressure on slopes	Slope stability	1	2	2	1	2	2	1	1	1	8	16
	Generation of lubricant waste	Control and transport of this waste	2	2	4	0	1	1	1	1	1	5	20
	Deforestation	Loss of species habitat	2	3	6	2	2	2	2	2	0	10	60
	Pollutant discharge	Action of heavy metals, solvents and pesticides	1	2	2	1	1	1	1	1	1	6	12
Camp waste management, workshops,	Generation of lubricant waste	Fauna/flora alteration	3	2	6	1	1	1				3	18

		Concrete waste generation	Lack of control in transportation to specialized collection points	2	2	4	0	1	1				2	8
		Solid waste generation		2	2	4	1	1	1				3	12
Construction of the hydraulic structure		Concrete waste generation	Lack of control in transportation to specialized collection points	2	3	6	0	1	1				2	12
		Solid waste generation		2	3	6	1	1	1				3	18
		Recycling of metallic materials.		2	2	4	1	0	0				1	4
Filling phase	Vegetation rehabilitation in the plain.	Reforestation	Increases soil productivity	1	3	3	1	2	2	0	0	0	5	15
	Soil quality improvement			1	3	3	1	2	2	0	0	0	5	15



**Table S4.** Prevention/mitigation measures.

<b>Environmental impact</b>	<b>Prevention/mitigation measures</b>
Water contamination by the discharge of pollutants.	<ul style="list-style-type: none"><li>• Maintenance processes that include using different machinery must be carried out in facilities with grease traps and grit traps.</li><li>• Adapt a particular site to store materials away from the body of water.</li></ul>
Increase in noise levels and atmospheric emissions.	<ul style="list-style-type: none"><li>• Program work cycles of two hours of continuous noise with two hours of rest.</li><li>• Implement silencers in the vehicles that operate in the project.</li><li>• Establish a single schedule for loading and unloading materials.</li></ul>
Waste generation	<ul style="list-style-type: none"><li>• The removed material must be stored so that it loses moisture to facilitate its disposal in places authorized by the corresponding entity.</li></ul>
Alteration of vegetation cover	<ul style="list-style-type: none"><li>• Rehabilitate disturbed soils to guarantee the fertility of areas where landscaping is proposed.</li><li>• Correct stability of slopes in the geotechnical design.</li></ul>
Soil contamination	<ul style="list-style-type: none"><li>• Avoid spillage of oil or other substances used in the construction process.</li><li>• Make the concrete mixtures on a platform to avoid soil contamination.</li></ul>
Natural water current alteration.	<ul style="list-style-type: none"><li>• Slope stabilization, replanting and keeping the site free of debris.</li><li>• Request the permit to occupy the channel.</li><li>• Generate the most negligible impact on the hydraulic system and follow the guidelines of the occupation permit for the channel obtained.</li></ul>
Generation of vegetable waste	<ul style="list-style-type: none"><li>• Remove the vegetable waste so that it is not contaminated with other materials to reuse it in the final landscaping of the work.</li></ul>
Generation of particulate matter	<ul style="list-style-type: none"><li>• The work front must be closed with mesh.</li><li>• Construction materials must be covered for protection against air and water.</li><li>• Use of personal protective equipment.</li></ul>