Economic Penstock Diameter (Steel Cost against Head Loss)

Penstock diameter minimising the annual cost of steel plus energy lost to friction, with the shell thickness from hoop stress and the velocity and head loss.

Method: Economic diameter by annual cost minimisation

Input parameters

Unit system: SI

Parameter	Value	Unit
Design flow	21,600	m³/h
Penstock length	800.00	m
Gross head	150.00	m
Pressure rise allowance (water hammer)	1.3000	
Allowable steel stress × joint efficiency	120.00	MPa
Corrosion allowance and minimum extra	2.0000	mm
Installed steel cost	3.0000	
Annual capital charge rate	10.000	%
Value of energy (per kWh)	0.060000	
Equivalent full-flow hours per year	5,000.0	
Darcy friction factor	0.013000	
Plant efficiency	88.000	%

Calculated results

Parameter	Value	Unit
Economic diameter	1,719.7	mm
Shell thickness at the bottom	15.702	mm
Velocity	2.5833	m/s
Friction loss as share of head	1.3718	%
Minimum annual cost (currency)	122,053	

Notes for this case

• Annual cost = a·c_s·(steel mass) + (lost power)·t_y·p_e, steel mass from hoop thickness t = p_dD/(2σ_a) + c_a (pressure part averaged over the length, rising linearly with depth), lost power ρgQh_fη/1000 kW. The golden-section search finds the minimum. Costs are per kg of steel and per kWh in any one currency; the optimum is flat, so round up to a standard size and check water hammer and buckling.

Formula and method

$$C_a(D) = a\,c_s\rho_s\pi D\bar{t}\,L + \rho g Q h_f(D)\eta\, t_y p_e, \quad t = \frac{p_d D}{2\sigma_a} + c_a, \quad h_f = f\frac{L}{D}\frac{v^2}{2g}$$

Variables

Q	Design flow	m³/s
L	Penstock length	m
H	Gross head	m
k_s	Pressure rise allowance (water hammer)	-
σ_a	Allowable steel stress × joint efficiency	Pa

c_a	Corrosion allowance and minimum extra	m
c_s	Installed steel cost	-
a	Annual capital charge rate	-
p_e	Value of energy (per kWh)	-
t_y	Equivalent full-flow hours per year	-
f	Darcy friction factor	-
η	Plant efficiency	-
D_{opt}	Economic diameter	m
t	Shell thickness at the bottom	m
v	Velocity	m/s
h_f/H	Friction loss as share of head	-
C_a	Minimum annual cost (currency)	-

Method and standards

Economic diameter.

Assumptions and limits

- Constant friction factor; steel cost proportional to mass; one diameter along the length.

References

Economic diameter by annual cost minimisation

Report details

Report reference	FCC-MFRA-YPYZ (the same inputs always give the same reference)
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Release checks	3 reference cases of this calculator, computed independently, are checked on every release

Results are for engineering estimation. Verify critical designs against the referenced standards and your own data.

This calculator online

https://calc.firecad.com/boilers-power-plant/hydro-power/penstock-economic-diameter

Open this case on calc.firecad.com →

Reopens the calculator with the inputs of this report.