Hydropower Plants: Generating and Pumping Units
Solved Problems: Series 1

1 ENERGY LOSS CALCULATION

Consider a piping system from a dam to a hydropower plant (see Figure 1) including fittings and valves. Answer to the questions, using the values provided in Figure 1 and the information from appendices A and B. The gravity acceleration and water kinematic viscosity are $g = 9.81$ ms^{-2} and $\nu_{water} = 10^{-6}\ \mathrm{m^2\ s^{-1}}$.

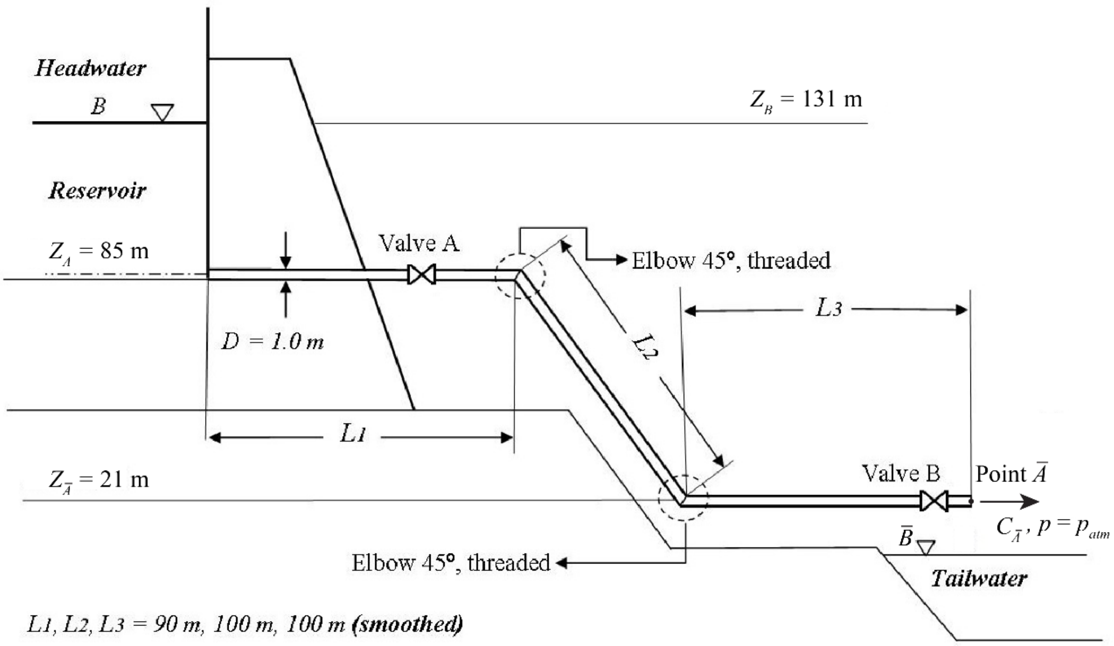

Figure 1: Dam piping system

1) Derive a relation between velocity $C_{\bar{A}}$ and head $Z_B - Z_{\bar{A}}$ based on energy balance, by i) neglecting and ii) considering energy losses $gH_{rB\div\bar{A}}$:
2) Calculate the velocity $C_{\bar{A}\_without\_Loss}$ at the point $\bar{A}$ and the discharge Q by assuming all the specific energy losses are negligible.
3) Calculate the Reynolds number neglecting the specific energy losses.
4) The actual discharge Q is 13.66 m^3 s^{-1}. Compute the singular and distributed specific energy losses, $gH_{rB\div\bar{A}\_\mathrm{singular}}$ and $gH_{rB\div\bar{A}\_distributed}$. Use *Figure A.1* to find the regular specific energy losses local coefficient λ. Consider the surface of the piping system as

perfectly smooth, and assume the valves *A* and *B* as gate valves, respectively fully open and ½ closed.

5) If the penstock diameter is increased to 1.2 m, compute the new regular and singular specific energy losses.
6) This time, compute the regular and singular specific energy losses if the penstock diameter is reduced to 0.8 m.

2 GENERAL HYDRAULIC POWER PLANT

2.1 Basic calculation for a hydraulic power plant

In Figure 2, the sketch of a hydraulic power plant located in Brazil is shown. The elevations of the headwater and tailwater reservoirs are $Z_B = 304$ m and $Z_{\overline{B}} = 252$ m, respectively. The rated discharge is Q = 539 m^3 s^{-1} and the global efficiency η is 0.91. If necessary, use the following values of gravity acceleration and water density:

g = 9.81 m s^{-2}, ρ = 1'000 kg m^{-3}

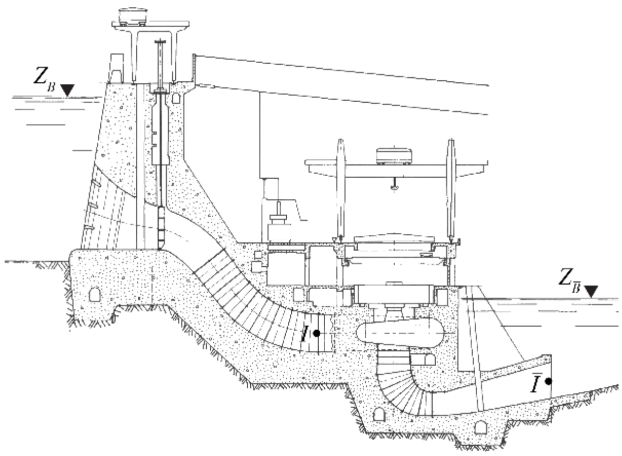

Figure 2 Sketch of the hydraulic power plant and the detail of the turbine

7) Express the potential specific energy of the installation by Z_B, $Z_{\overline{B}}$, and g.
8) Taking into account the specific energy losses $gH_{rB \div I}$ between *B* and *I*, and $gH_{r\overline{I} \div \overline{B}}$, between $\overline{I}$ and $\overline{B}$ ($gH_r > 0$), express the available specific energy *E* by g, Z_B, $Z_{\overline{B}}$, $gH_{rB \div I}$ and $gH_{r\overline{I} \div \overline{B}}$.
9) Calculate the water velocity in the penstock. Use the value of the penstock diameter $D_{penstock}$ = 7 m.
10) Calculate the Reynolds number in the penstock using the kinetic viscosity ν = 10^{-6} m^2 s^{-1}.

2.2 Practical study for the specific energy loss

Here, the specific energy loss calculation is applied to the practical case for the hydraulic power station detailed in *Section 2.1.*

11) Knowing that the regular specific energy loss in a penstock can be expressed as:

$$gH_{r1\div 2} = K_r \frac{C^2}{2} = \lambda \frac{L_{1\div 2}}{D}\frac{C^2}{2} \tag{1}$$

Express the distributed specific energy loss gH_r as a function of the local coefficient of the distributed specific losses λ, the length of the penstock $L_{penstock}$, the diameter of the penstock $D_{penstock}$ and the discharge Q.

Then, reflect on the importance of the penstock diameter and explain why it is a key parameter to reduce the specific energy loss under a constant discharge.

12) The local coefficient of the distributed specific energy losses λ is dependent on the Reynolds number Re and can be calculated by the Churchill formula as follows:

$$\lambda = 8\left[\left(\frac{8}{\mathrm{Re}}\right)^{12} + \frac{1}{(A+B)^{\frac{3}{2}}}\right]^{\frac{1}{12}}$$

$$\text{with } A = \left[2.457 \cdot \ln \frac{1}{\left(\frac{7}{\mathrm{Re}}\right)^{0.9} + 0.27\frac{k_s}{D_{penstock}}}\right]^{16} \text{ and } B = \left(\frac{37530}{\mathrm{Re}}\right)^{16} \tag{2}$$

Where k_s is the equivalent sand roughness, whose value which depends on the penstock material. For instance, $k_s = 10^{-6}$ for stainless steel and $k_s = 3 \times 10^{-3}$ for rough concrete.

Calculate the local coefficient values λ_{steel} and $\lambda_{concrete}$ when using i) stainless steel and ii) rough concrete as the penstock material. Then, calculate the distributed specific energy loss in the penstock for both cases. Use the penstock length $L_{penstock} = 100$ m.

13) Assuming that the total specific energy losses of the singular specific energy losses (intake, elbow, etc…) and the specific energy losses $gH_{r\bar{I}\div\bar{B}}$ are equivalent to 1% of the gross head, calculate the available specific energy E for both cases.

14) For both cases, calculate the available power P and compare the difference between both cases.

15) In this power plant, the grid frequency is $f_{grid} = 60$ Hz and the number of poles is $z_p = 88$. Deduce the angular rotational frequency of the runner ω.

Appendix A

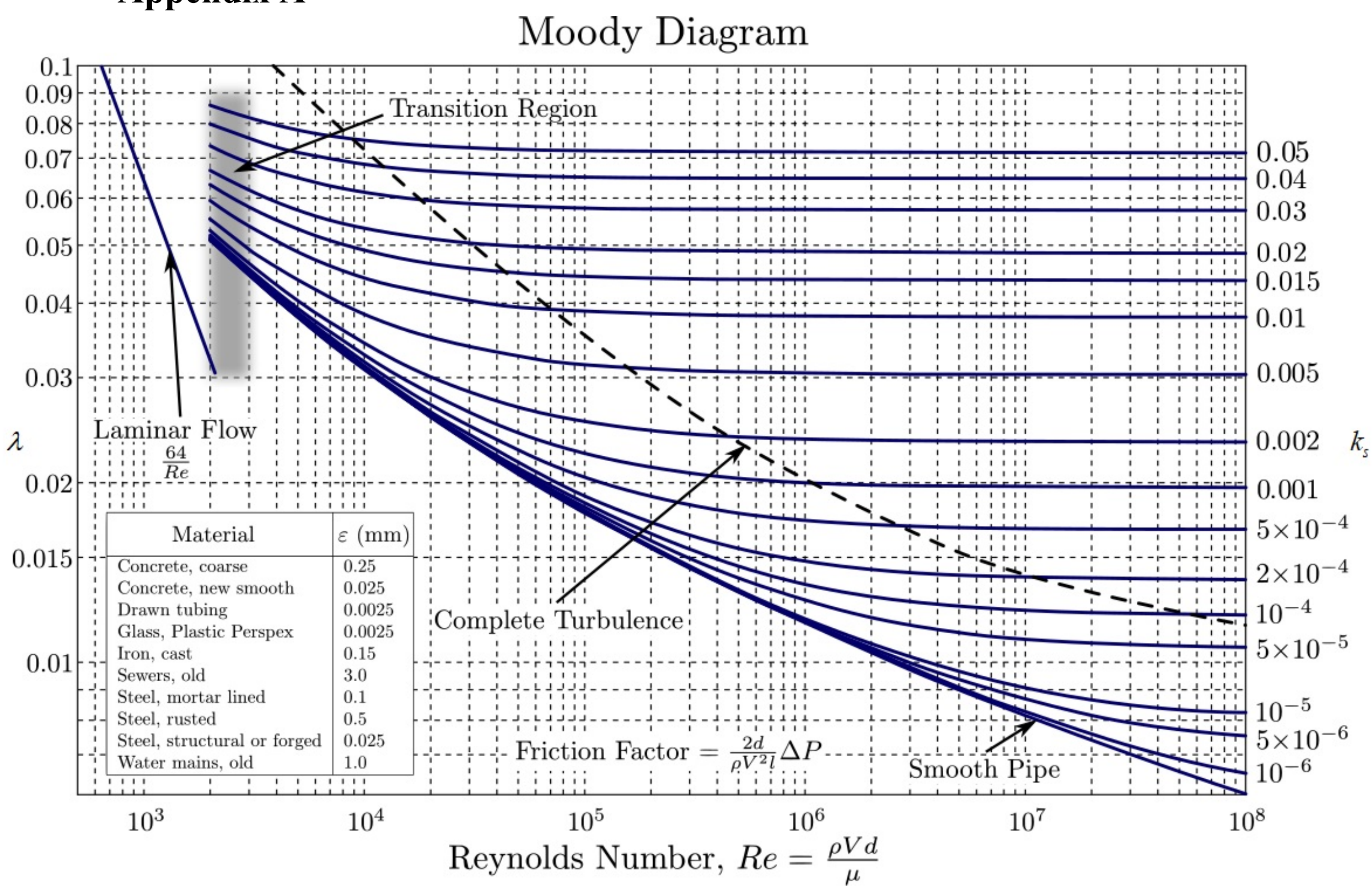

Figure A.1: Distributed specific energy losses local coefficient for pipe flow

Appendix B

Table B.1: Specific energy loss coefficients of bends, elbows, fittings, etc.

Fitting	*k* [-]
Sharp intake connection	0.5
Globe valve, fully open	10.0
Angle valve, fully open	2.0
Gate valve, fully open	0.15
Gate valve, 1/2 closed	2.10
Swing check valve, flow	2.0
Elbow 90° – flanged	0.3
Elbow 90° – threaded	1.50
Long radius 90°, flanged	0.20
Long radius 90°, threaded	0.70
Elbow 45°, threaded	0.40