Loughborough University

Water Power

23WSP035

Semester 1 In-Person Exam paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **2 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

Help during the exam

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

Answer **ALL FOUR** questions.

All questions carry equal marks.

Use a **SEPARATE** answer book for **EACH** question.

Use of a calculator is permitted - It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are not allowed).

A range of formulae and tables likely to be of benefit in the solution of these questions is provided at the rear of the paper.

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1. Water Resource

a) What is meant by the term "hydraulic head," and why is it important? What methods are typically used to measure hydraulic head? [7 marks]

b) Describe the three methods typically used to determine a river's flow rate. [12 marks]

c) A river catchment with an area of 367 km^2 receives a measured total annual rainfall of 1248.3 mm. Calculate the average flow rate. Why might the measured value be different? [6 marks]

2. Civil Engineering

a) A client has asked you to report on a proposed hydropower site and give an initial recommendation for the type of scheme to install. The site is in a mountainous and sparsely populated area with consistently high rainfall and a large catchment, and comprises a steep-sided valley which is both wide and deep. There is a large and fast-flowing river in the bottom. A geotechnical survey of the area shows that the local rock is a highly permeable limestone covered in places with an impermeable clay. On some parts of the valley walls there is evidence of soil creep and minor land slippage. What type of scheme might you suggest? Explain your reasoning. [11 marks]

b) Many run-of-river schemes make use of an open channel with additional features such as a silt basin and one or more spillways. What are silt basins and spillways, and why would they be included? Why might a scheme use a channel rather than connecting the penstock directly to the intake? Give two reasons and explain your answer. [8 marks]

c) Give three sources of head loss in a typical hydroelectric scheme, and explain why they lead to a reduction in hydraulic head. [6 marks]

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3. Water Turbines

a) A small natural reservoir has an annual average incoming flow rate of 2 m^3/s from its catchment area and is located at the top of a 300 m drop. Calculate the available water power and explain why a Pelton type turbine would be an appropriate choice to exploit the resource. [5 marks]

b) The Pelton wheel will be coupled to an electrical generator with a design speed of 400 rpm. Calculate the diameter of the Pelton wheel needed to maximise efficiency for the given resource (you can assume the required bucket speed is half the water jet velocity and **do not** need to prove it here). [6 marks]

c) If the penstock has a diameter of 0.7 m and a pipe friction coefficient of 0.025, calculate the head loss due to friction. How much does this alter the optimum Pelton wheel diameter? [10 marks]

d) If the reservoir were not large enough to fully smooth out the catchment flow, describe the challenge in capturing the variable power available. How could you modify the scheme design to allow for this? [4 marks]

4. Marine Power

a) What is meant by the term “capture width ratio”? Give examples of device types which have a high capture width ratio and a lower capture width ratio. [3 marks]

b) Waves present a very significant untapped renewable energy resource, particularly in the UK. Explain why commercial exploitation and large-scale generation of energy using wave power is challenging. [7 marks]

c) Explain why the amount of energy in waves is higher in deeper water than it is in shallow water, assuming identical weather conditions. [2 marks]

d) An estuary on the right-hand side of a channel between two land masses has an average depth of 27 m and a length of 180 km. Explain why the tidal range in this location is likely to be significantly higher than due to lunar/solar gravitational effects alone. [13 marks]

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Formulae you might find helpful:

Kinetic Energy: $KE = \frac{1}{2}mv^2$

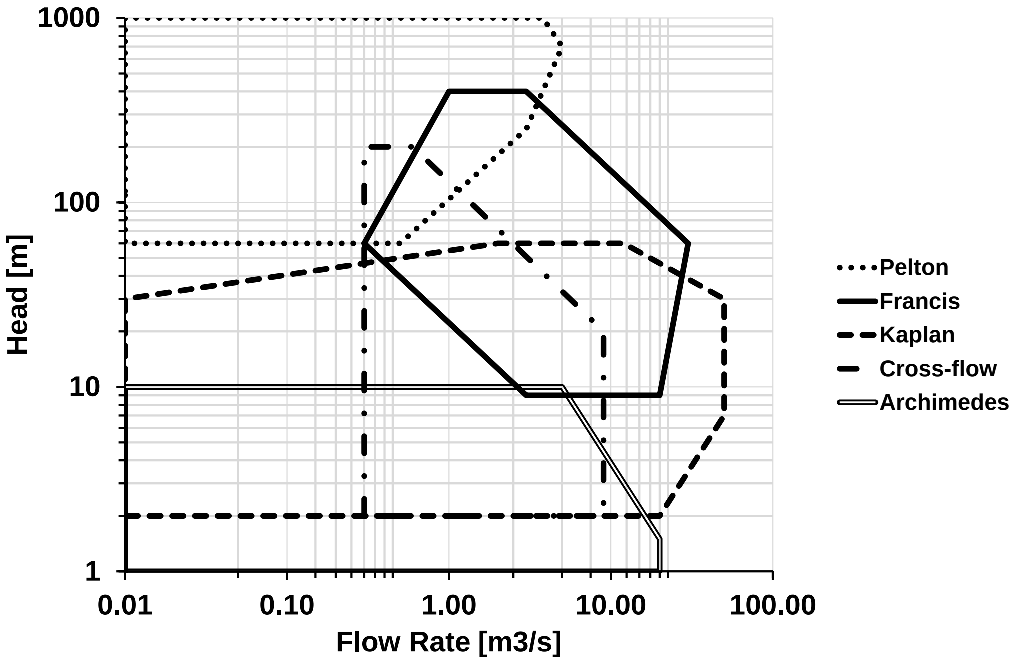
Gravitational Potential Energy: $PE = mgh$

Angular velocity [rad/s]: $\omega = \frac{v}{r}, \left(1\,rpm = {}^{2\pi}/_{60}\ rad/s\right)$

Torque from momentum change: $\tau = 2\rho rQ(v - u)$

Flow rate through a closed system: $Q = Av$

Turbine selection guide:



Power output of a hydropower scheme: $P = \eta\rho gQH$

Penstock pipe friction head loss: $h_f = \lambda \frac{Lv^2}{2gD}$

where: L = pipe length in metres, D = pipe diameter, λ = pipe friction coefficient

Turbulence head loss: $h_t = \frac{Kv^2}{2g}$ *where: K = turbulence constant*

Turbine specific speed: $N_s = n\sqrt{\frac{P}{H^{5/2}}}$ *where: P is in* ***kW****, n is in rpm and H is in m*

General wave velocity: $v = \frac{\lambda}{T}$

Shallow water wave velocity: $v = \sqrt{gD}$