NATIONAL EXAMINATIONS

December 2012

04-BS-7 MECHANICS OF FLUIDS

Three (3) hours duration

Notes to Candidates

1. This is a **Closed Book** examination.

2. Exam consists of two Sections. **Section A is Calculative (9 questions)** and **Section B is Analytical (4 questions).**

3. **Do seven (7) questions from Section A (Calculative) and three (3) questions from Section B (Analytical).** Note that the Analytical Questions do not require detailed calculations but do require full explanations.

4. **Ten (10) questions constitute a complete paper.** (Total 50 marks).

5. **All questions are of equal value.** (Each 5 marks).

6. If doubt exists as to the interpretation of any question, the candidate is urged to submit, with the answer paper, a clear statement of any assumptions made.

7. Candidates may use one of the approved **Casio** or **Sharp** calculators.

8. **Reference data** for particular questions are given on pages 7 to 14. **All pages of questions attempted are to be returned with the Answer Booklet showing where readings were taken and which data was used. Candidates must write their names on these pages.**

9. **Constants** are given on page 15.

10. **Reference Equations** are given on pages 16 to 19.

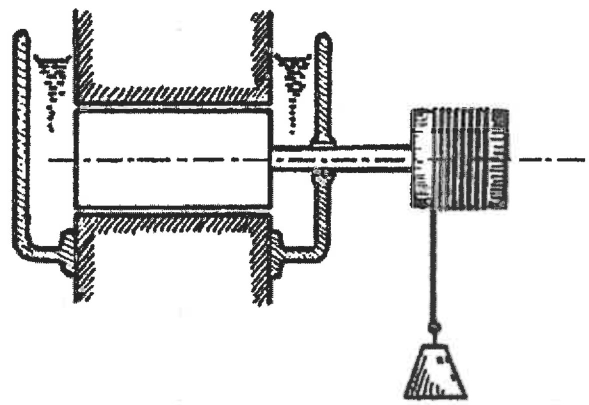
SECTION A CALCULATIVE QUESTIONS

<u>Do seven of nine questions</u>. Solutions to these questions must be set out logically with all intermediate answers and units given.

QUESTION 1

Refer to the Examination Paper Attachments Page 7 **Absolute Viscosity**

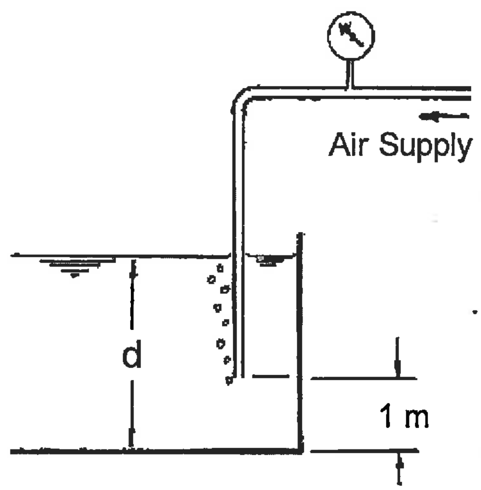
A speed limiting device is shown in the adjoining sketch. A drum 50 mm in diameter and 100 mm in length rotates within a bearing having a diameter 0.1 mm greater that that of the drum. The space between the drum and the bearing is flooded with SAE 30 Western oil at 30°C. Determine the maximum rate at which a 50 g weight will fall as its string unwinds from a separate drum of diameter 50 mm. Neglect end effects and friction in the seal. Refer to the attached chart for the viscosity of the oil.



(5 marks)

QUESTION 2

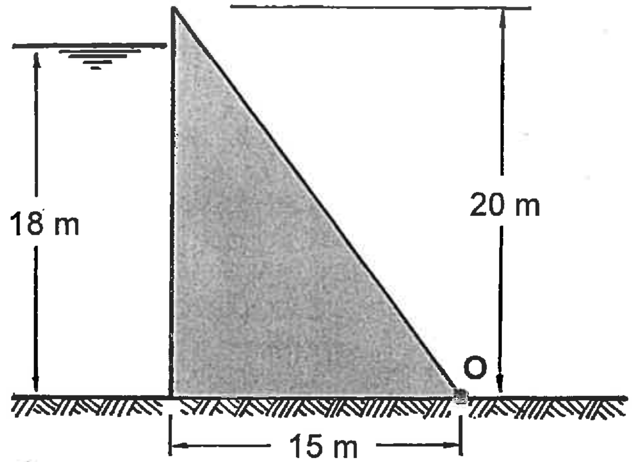
One means of determining the surface level of liquid in a tank is by discharging a small amount of air through a small tube, the end of which is submerged in the tank containing liquid of specific gravity 0.85, and reading the pressure on the gauge that is tapped into the tube. The level of the liquid surface in the tank can then be calculated. Write an equation to relate air pressure p to depth d in the tank. If the pressure on the gauge is 30 kPa, calculate the depth d of the liquid in the tank. Refer to the adjoining sketch for dimensions.



(5 marks)

QUESTION 3

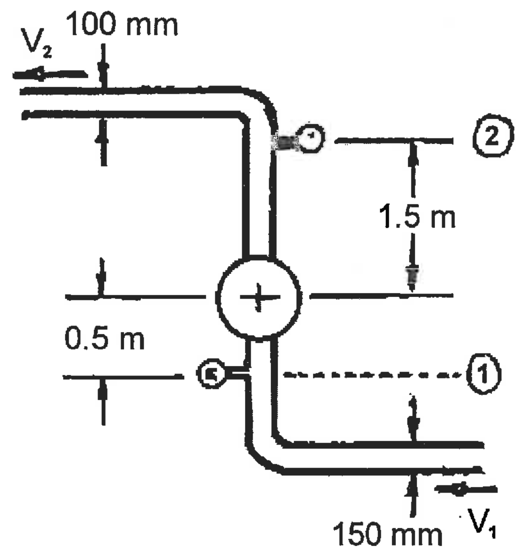
A gravity dam built of concrete has dimensions as shown in the adjoining sketch. It is filled with water to a depth of 18 m. To prevent cracking of the concrete or separation from the bedrock, the resultant force on the structure must pass through the middle third of the base so as to maintain compressive stress everywhere in the concrete and bedrock. By taking moments about the toe of the dam (Point O), determine the point (horizontal distance from Point O) through which the resultant force passes through the base and hence whether the dam is safe or not.



(5 marks)

QUESTION 4

The diameters of the suction and discharge pipes of a pump are 150 mm and 100 mm, respectively. The discharge pressure is read by a gauge at a point 1.5 m above the center line of the pump, and the suction pressure is read by a gauge 0.5 m below the center line. The pressure gauge reads a pressure of 150 kPa and the suction gauge reads a vacuum of 30 kPa (negative gauge pressure) when gasoline having a specific gravity of 0.75 is pumped at the rate of 0.035 m^3/s. Calculate the electrical power required to pump the fluid if the pump efficiency is 75%.



(5 marks)

QUESTION 5

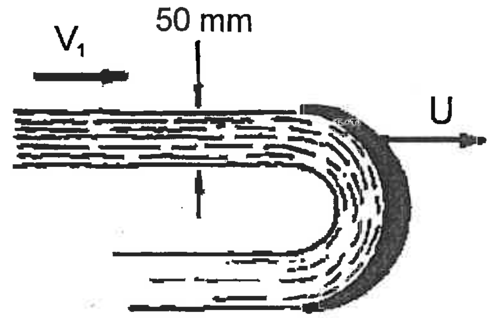
Refer to the Examination Paper Attachments Page 8 **Island Bend Dam**

If the dam is at its full supply level F.S.L. and <u>one</u> radial gate is fully opened by lifting it above the full supply level F.S.L., determine the discharge flow rate over the crest of the dam or spillway from that open gate. Take dimensions from the drawing. Assume that for this spillway (weir) the discharge coefficient C_d is 0.80. Note that the width of each gate is slightly greater than its height (not specifically stated on the drawing).

(5 marks)

QUESTION 6

A jet of water with a diameter of 50 mm and a velocity V_1 of 30 m/s strikes a curved plate and is turned completely through 180° without friction loss. The plate is driven by the jet and in the same direction as the jet.



V_1 = 30 m/s

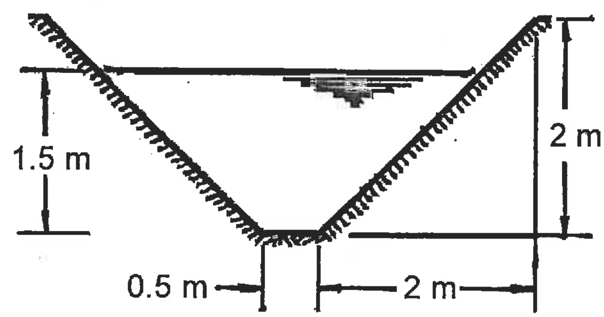
(a) Determine the plate speed U for maximum efficiency of energy transfer
(b) Calculate the force exerted on the plate.
(c) Calculate the power developed by the plate.
(d) Determine the efficiency of energy transfer.

(5 marks)

QUESTION 7

Refer to the Examination Paper Attachments Page 9 **Moody Diagram.**

Consider a concrete trapezoidal irrigation canal with cross section as shown that is 4.5 m wide by 2 m deep with 45° sides and 0.5 m wide bottom. Water is required to flow 1.5 m deep at a flow rate of 3 m^3/s. This canal is required to deliver water to a location 8 km from the source. Determine from general pipe flow relations the drop in elevation required to maintain the specified flow rate. Assume an appropriate roughness for the concrete.



(5 marks)

QUESTION 8

Refer to the Examination Paper Attachments Page 10 **Moody Diagram**, Page 11 **Tumut 2 Tunnels Data** and Page 12 **Tumut 2 Tunnels Layout.**

Tumut 2 Power Station has four Francis turbines. Water is supplied from the pondage via a pressure tunnel and is discharged through a tailrace tunnel to the Tumut River. From the data given on Page 11 determine the head loss in the pressure tunnel only, that is, between the pondage and the turbines. Assume that the concrete lining has an absolute roughness ε of 1 mm. The layout on page 12 is provided for orientation and does not require interpretation.

(5 marks)

QUESTION 9

Refer to the Examination Paper Attachments Page 13 **Drag Coefficients of Cyclists**.

The chart shows drag coefficients of cyclists in different configurations. Determine the maximum speed in km/hr that a regular cyclist should be able to maintain on a standard (no aerodynamic components) racing bicycle during a two hour cycling race. Neglect rolling resistance. Note that the drag force has to be calculated since that given in the table is only at a speed of 20 mph and will be different for the speed to be calculated.

Human generated power can be determined from the following equation which gives average power in kW over a given period of time where t is in minutes.

$$P = 0.373 - 0.097 \log_{10} t \qquad \text{for healthy young men}$$

(5 marks)

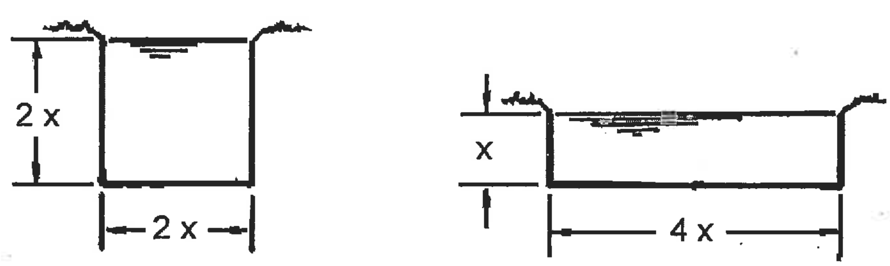
SECTION B ANALYTICAL QUESTIONS

***Do three of four questions.** These questions do not require detailed calculations but complete written explanations, with equations if appropriate, must be given to support the answers.*

QUESTION 10

Two open channels are shown in the sketches below. One is square in cross section and the other is rectangular being half the depth and twice the width as the first. Both are of similar concrete and carry water at the same volume flow rate. Determine which profile is better with regard to distance covered for the same drop in elevation (that is which requires the lesser slope). Justify the answer with appropriate equations.

(5 marks)



Square Channel

Rectangular Channel

QUESTION 11

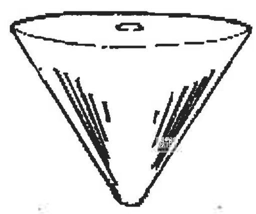
Sketch a typical hydraulic jump in a channel showing clearly the channel bottom and water surface. On this sketch draw in the hydraulic grade line (HGL) and energy grade line (EGL). Explain the phenomena occurring in the jump noting what parameters are changed within the jump. Describe a typical application of an hydraulic jump.

(5 marks)

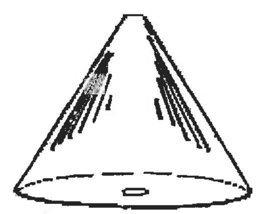
QUESTION 12

The sketch below shows two conical tanks A and B of the same geometry and dimensions but one is inverted. Both are filled with water and adequately vented at the top. Assuming each has a similar hole at the bottom to discharge this water, determine which will be emptied faster. Assume no change in the discharge coefficient due to the shape of the tank. Fully justify the answer with appropriate equations.

(5 marks)



Upright Tank **A**



Inverted Tank **B**

QUESTION 13

Refer to the Examination Paper Attachments Page 14 **Flow Coefficients for VDI Orifice Meter.**

Explain the following:

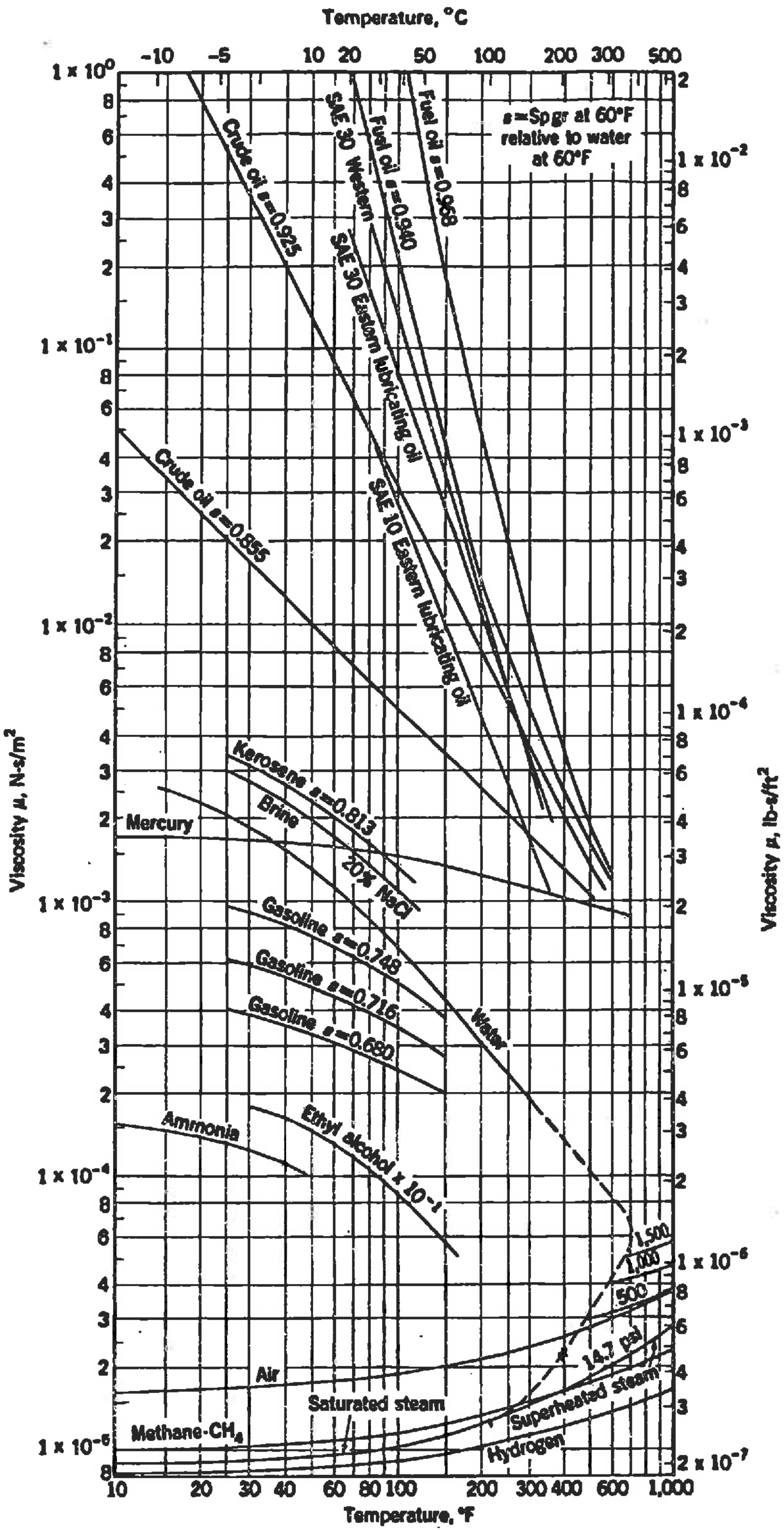
(a) Why the value of K increases with increasing Re at lower values of Reynolds Number.
(b) Why the value of K decreases with increasing Re at intermediate values of Reynolds Number
(c) Why the value of K is constant for increasing Re at high values of Reynolds Number.

To clarify the explanation sketch the flow pattern in the vicinity of the orifice showing streamlines for each of the three cases.

(5 marks)

EXAMINATION PAPER ATTACHMENTS

QUESTION 1 ABSOLUTE VISCOSITY **NAME ....**

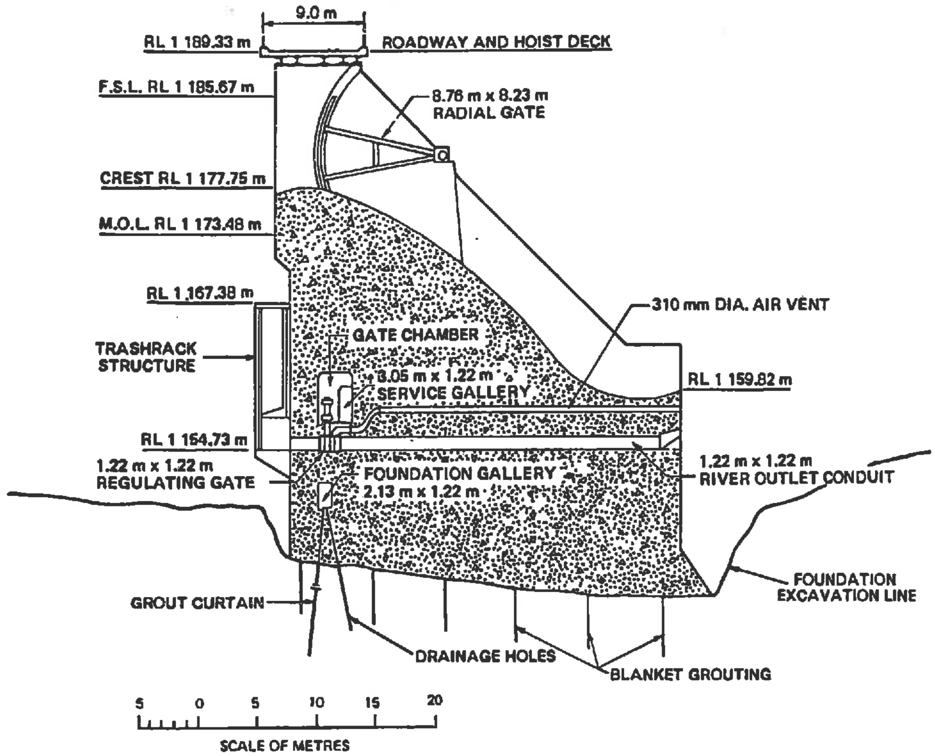


Absolute viscosity μ of fluids.

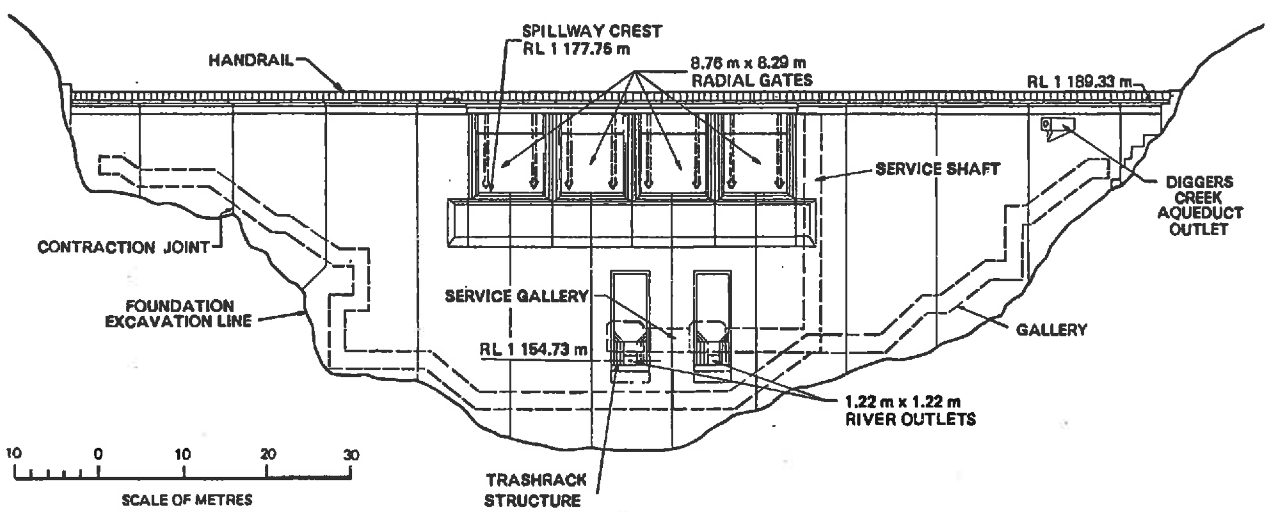
EXAMINATION PAPER ATTACHMENTS

QUESTION 5 ISLAND BEND DAM

Section through Island Bend Dam

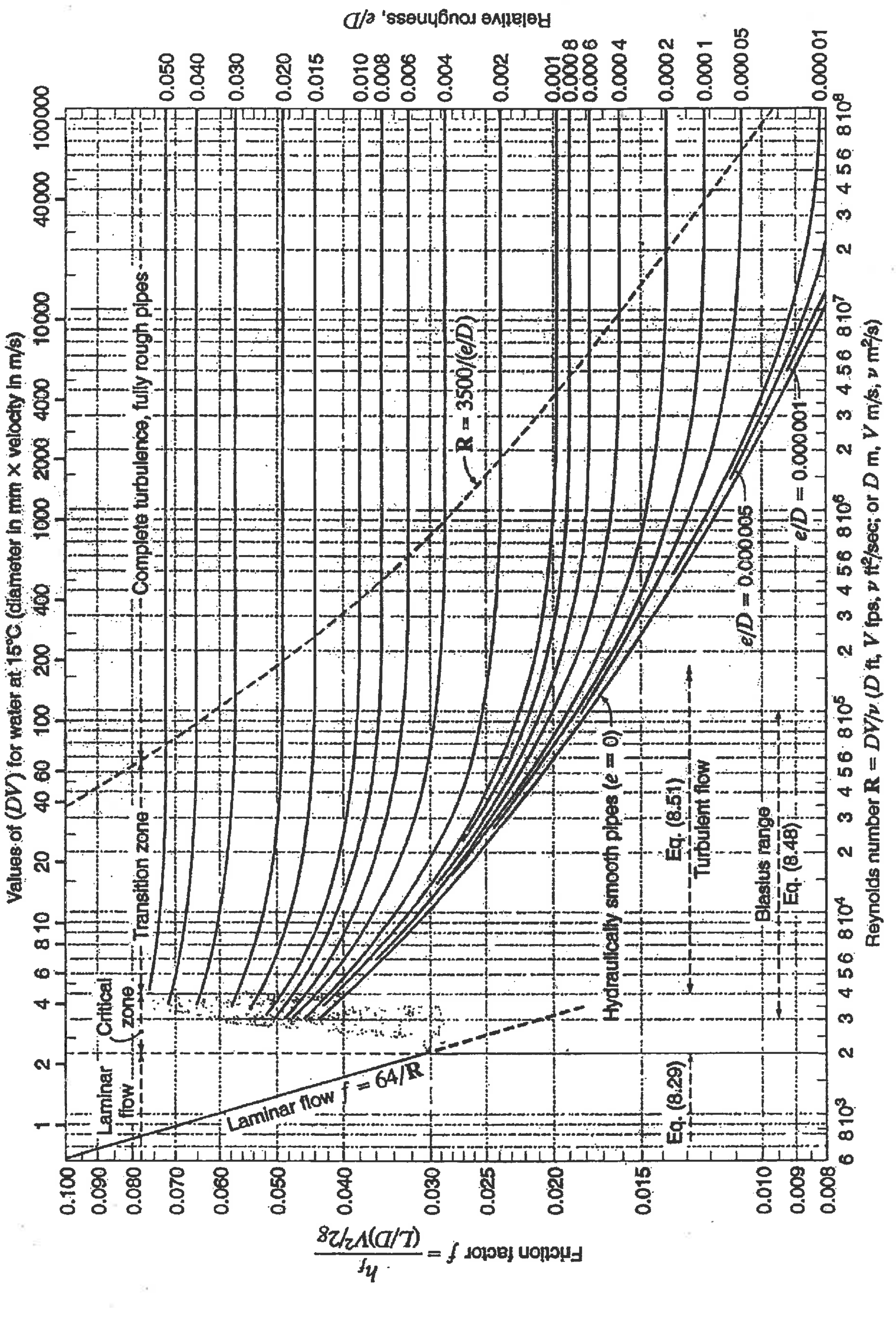


Upstream Elevation of Island Bend Dam



EXAMINATION PAPER ATTACHMENTS

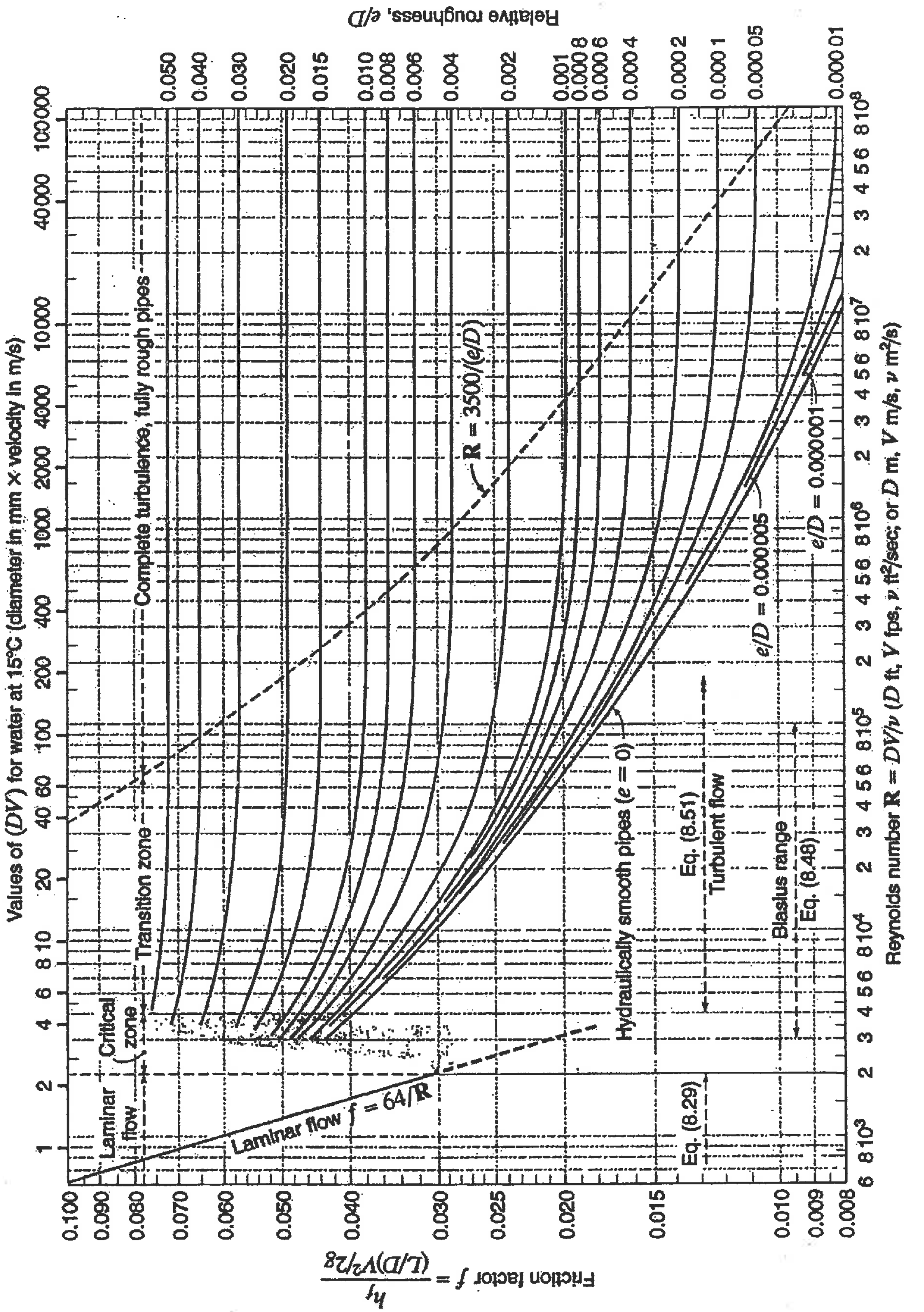
QUESTION 7 MOODY DIAGRAM NAME ....



Moody chart for pipe friction factor (Stanton diagram).

EXAMINATION PAPER ATTACHMENTS

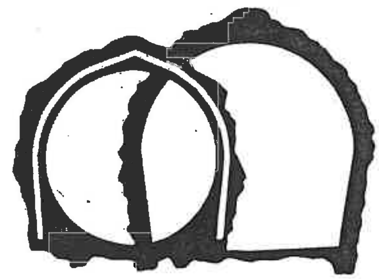
QUESTION 8 MOODY DIAGRAM **NAME** ....



Moody chart for pipe friction factor (Stanton diagram).

QUESTION 8 TUMUT 2 TUNNELS DATA

Tumut 2 Pressure and Tailwater Tunnels



TUMUT 1 TAILWATER TUNNEL

The Tumut 2 Pressure Tunnel delivers water from Tumut 2 Pondage to the Tumut 2 Pressure Shafts.

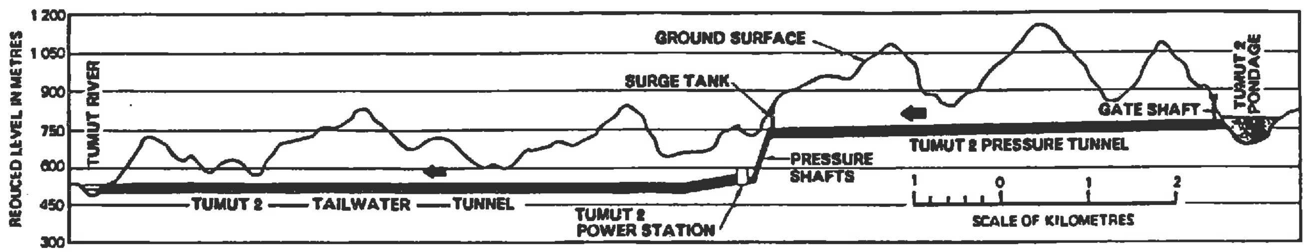
Capacity:	125 m³/s	**Volume of Excavation:**	206 400 m³
Length:	4 760 m (4.8 km)	**Volume of Concrete:**	29 800 m³
Section:		**Geology:**	Granitic gneiss and granite with dolerite and porphyry
Lined:	Circular, 6.40 m diameter		
Percentage Lined:	100%	**Construction Period:**	November 1958 to September 1961

The Tumut 2 Tailwater Tunnel returns water from Tumut 2 Power Station to the Tumut River downstream.

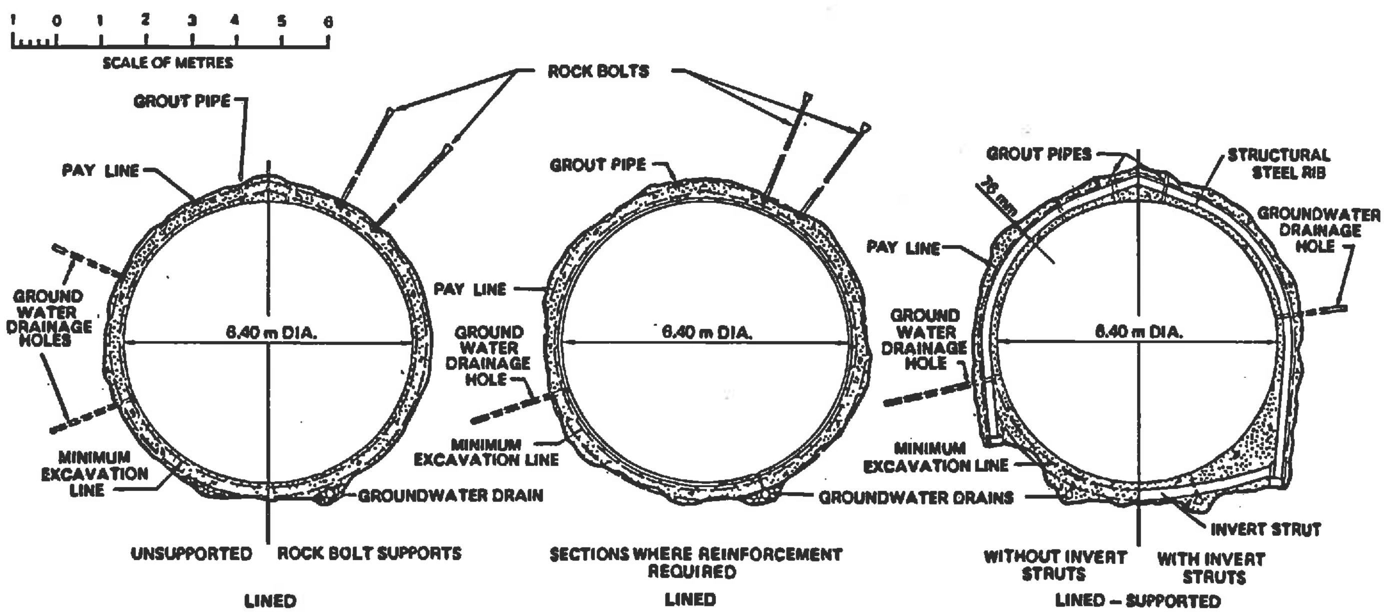
Capacity:	125 m³/s	**Geology:**	Granite with granitic gneiss and porphyry and basic dikes, then gneissic granite with quartzite slate and siltstone at outlet end
Length:	6 460 m (6.5 km)		
Section:			
Lined:	Circular, 6.40 m diameter	**Other Features:**	Tailwater surge tank (The first 335 m at surge tank end has a diameter of 9.14 m)
Percentage Lined:	100%		
Volume of Excavation:	267 600 m³	**Construction Period:**	June 1958 to September 1961
Volume of Concrete:	61 200 m³		

QUESTION 8 TUMUT 2 TUNNELS LAYOUT

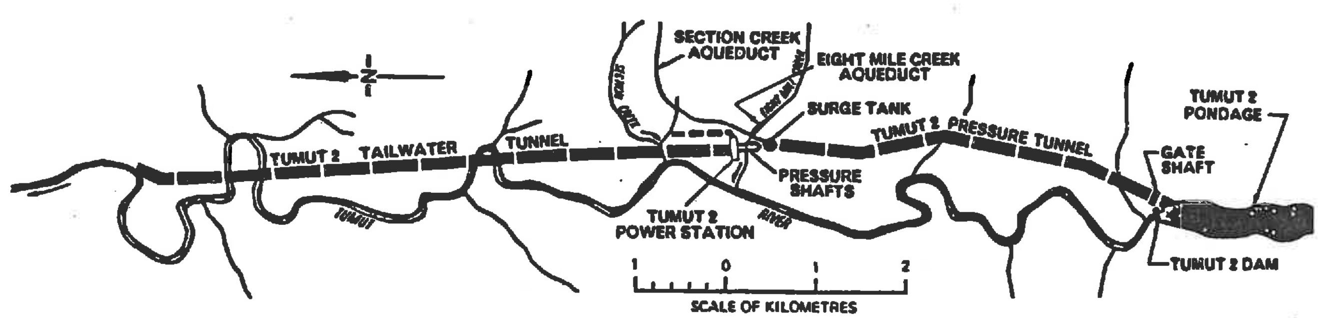
Profile of Tumut 2 Pressure and Tailwater Tunnels



Tunnel Cross-Sections



Plan of Tumut 2 Pressure and Tailwater Tunnels



EXAMINATION PAPER ATTACHMENTS

QUESTION 9 DRAG COEFFICIENTS FOR CYCLISTS

Applications to Ground Vehicles

TABLE 6.1 Aerodynamic and rolling resistance data for several bicycle-rider configurations travelling at a speed of 20 miles/hour (8.9 m/s)

Configuration			D_f Drag Force		Rolling Resistance		Drag Coefficient	Frontal Area A	
			lbf	N	lbf	N	$C_D = \frac{D_f}{\frac{1}{2}\rho U_\infty^2 A}$	ft²	m²
European Upright Commuter	*40-lb bike, 160-lb rider, tires: 27 in. dia., 40 psi*		6.14	27.3	1.20	5.34	1.1	5.5	0.51
Touring (Arms Straight)	*25-lb bike, 160-lb rider, tires: 27 in. dia., 90 psi*		4.40	19.6	0.83	3.69	1.0	4.3	0.40
Racing (Fully Crouched)	*20-lb bike, 160-lb rider, tires: 27 in. dia., 105 psi*		3.48	15.5	0.54	2.4	0.88	3.9	0.36
Aerodynamic Components (Fully Crouched)	*20-lb bike, 160-lb rider, tires: 27 in. dia., 105 psi*		3.27	14.5	0.54	2.4	0.83	3.9	0.36
Partial fairing (Zzipper, Crouched)	*21-lb bike, 160-lb rider, tires: 27 in. dia., 105 psi*		2.97	13.2	0.54	2.4	0.70	4.1	0.38
Recumbent (Easy Racer)	*27-lb bike, 160-lb rider, tires: 20 in. front, 27 in. rear, 90 psi*		2.97	13.2	0.94	4.2	0.77	3.8	0.35
Drafting (Closely Following Another Bicycle)	*20-lb bike, 160-lb rider, tires: 27 in. dia., 105 psi*		1.94	8.63	0.54	2.4	0.50	3.9	0.36
Blue Bell (Two Wheels, One Rider)	*40-lb bike, 160-lb rider, tires: 20 in. front, 27 in. rear, 105 psi*		0.61	2.7	0.8	4	0.12	5.0	0.46
Vector Single (Three Wheels)	*68-lb bike, 160-lb rider, tires: 24 in. front, 27 in. rear*		0.51	2.3	1.02	4.54	0.11	4.56	0.424

EXAMINATION PAPER ATTACHMENTS

QUESTION 13 FLOW COEFFICIENTS FOR VDI ORIFICE METER

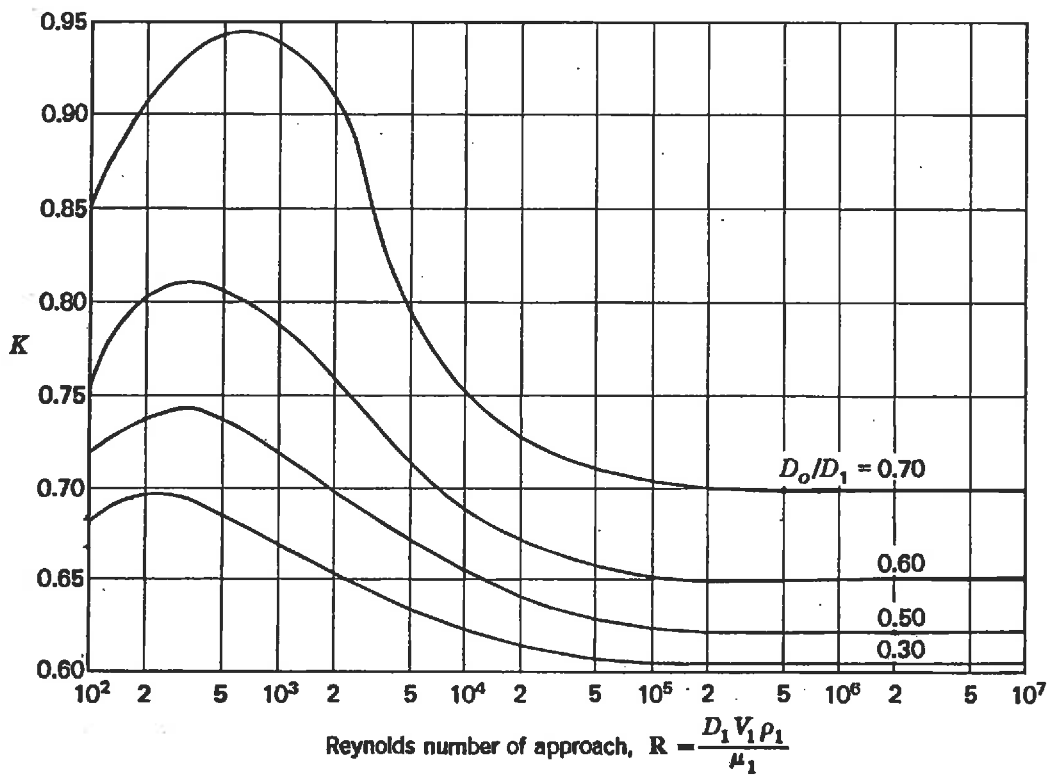


Figure 12.23 **VDI orifice meter and flow coefficients for flange taps.** (*Adapted from NACA Tech. Mem.* 952.)

04-BS-7 MECHANICS OF FLUIDS

GENERAL REFERENCE INFORMATION

CONSTANTS

In engineering calculations a high degree of accuracy is seldom attained due to the neglect of minor influences or the inaccuracy of available data.. For consistency in calculations however the following reasonably accurate constants should be used:

Atmospheric Pressure p_o = 100 kPa
Gravitational Acceleration g = 9.81 m/s^2
Specific Gravity of Water = 1.00
Specific Gravity of Glycerine = 1.26
Specific Gravity of Mercury = 13.56
Specific Gravity of Benzene = 0.90
Specific Gravity of Carbon Tetrachloride = 1.59
Density of Water ρ = 1000 kg/m^3
Density of Sea Water ρ = 1025 kg/m^3
Density of Concrete ρ = 2400 kg/m^3
Density of Air ρ = 1.19 kg/m^3 (at 20°C), ρ = 1.21 kg/m^3 (at 15°C)
Absolute Viscosity of Water μ = 1.0 x 10^{-3} Ns/m^2
Absolute Viscosity of Air μ = 1.8 x 10^{-5} Ns/m^2
Surface Tension of Water σ = 0.0728 N/m (at 20°C)
Specific Heat of Water c_p = 4.19 kJ/kg°C
Specific Heat of Air c_p = 1005 J/kg°C
Specific Heat of Air c_p = 718 J/kg°C
Gas Constant for Air R = 287 J/kg°K
Gas Constant for Helium R = 2077 J/kg°K
Gas Constant for Hydrogen R = 4120 J/kg°K

NOMENCLATURE FOR REFERENCE EQUATIONS (SI UNITS)

a	Width	m
A	Flow area, Surface area	m^2
CV	Calorific value	J/kg
c_p	Specific heat at constant pressure	J/kg°C
b	Width	m
D	Diameter	m
E	Energy	J
F	Force	N
g	Gravitational acceleration	m/s^2
h	System head	m
h_L	Head loss	m
H	Pump or turbine head	m
I	Moment of inertia	m^4
k	Ratio of specific heats	
k	Loss coefficient	
K	Constant	
L	Length	m
m	Mass	kg
M	Mass flow rate	kg/s
N	Rotational speed	rev/s
p	Pressure	Pa (N/m^2)
P	Power	W (J/s)
q	Specific heat	J/kg
Q	Flow rate	m^3/s
r	Radius	m
R	Specific gas constant	J/kg K
T	Temperature	K
U	Blade velocity	m/s
v	Specific volume	m^3/kg
V	Velocity	m/s
V	Volume	m^3
w	Specific work	J/kg
W	Work	J
y	Depth	m
z	Elevation	m
η	Efficiency	
μ	Dynamic viscosity	Ns/m^2
ν	Kinematic viscosity	m^2/s
ρ	Density	kg/m^3
σ	Surface tension	N/m
τ	Thrust	N
τ	Shear stress	N/m^2

REFERENCE EQUATIONS

Equation of State

$$p\,v = R\,T$$
$$p = \rho\,RT$$

Universal Gas Law

$$p\,v^n = \text{constant}$$

Compressibility

$$\beta = -\Delta / V\,\Delta p$$

Viscous Force and Viscosity

$$F = \mu\,A\,du / dy$$
$$\mu = \tau\,du / dy$$
$$\nu = \mu / \rho$$

Capillary Rise and Internal Pressure due to Surface Tension

$$h = (\sigma \cos\theta / \rho\,g) \times (\text{perimeter} / \text{area})$$
$$p = 2\,\sigma / r$$

Pressure at a Point

$$p = \rho\,g\,h$$

Forces on Plane Areas and Centre of Pressure

$$F = \rho\,g\,y_c\,A$$
$$y_p = y_c + I_c / y_c\,A$$

Moments of Inertia

Rectangle: $I_c = b\,h^3 / 12$
Triangle: $I_c = b\,h^3 / 36$
Circle: $I_c = \pi\,D^4 / 64$

Volumes of Solids

Sphere: $V = \pi D^3 / 6$
Cone: $V = \pi D^2 h / 12$
Spherical Segment: $V = (3 a^2 + 3 b^2 + 4 h^2) \pi h / 2 g$

Continuity Equation

$$\rho_1 V_1 A_1 = \rho_2 V_2 A_2 = M$$

General Energy Equation

$$p_1 / \rho_1 g + z_1 + V_1^2 / 2 g + q_{in} / g + w_{in} / g$$
$$= p_2 / \rho_2 g + z_2 + V_2^2 / 2 g + h_L + q_{out} / g + w_{out} / g$$

Bernoulli Equation

$$p_1 / \rho g + z_1 + V_1^2 / 2 g = p_2 / \rho g + z_2 + V_2^2 / 2 g$$

Momentum Equation

Conduit: $F_R = p_1 A - p_2 A - M (V_2 - V_1)$
Free Jet: $F_R = - \rho Q (V_2 - V_1)$

Flow Measurement

Venturi Tube: $Q = [C A_2 / \{1 - (D_2 / D_1)^4\}^{1/2}][2 g \Delta h]^{1/2}$
Flow Nozzle: $Q = K A_2 [2 g \Delta h]^{1/2}$
Orifice Meter: $Q = K A_o [2 g \Delta h]^{1/2}$

Flow over Weirs

Rectangular Weir: $Q = C_d (2 / 3) [2 g]^{1/2} L H^{3/2}$

Power

Turbomachine: $P = \rho g Q H$
Free Jet: $P = ½ \rho Q V^2$
Moving Blades: $P = M \Delta V U$

Aircraft Propulsion

$$F_{thrust} = M (V_{jet} - V_{aircraft})$$
$$P_{thrust} = M (V_{jet} - V_{aircraft}) V_{aircraft}$$
$$E_{jet} = ½ (V_{jet}^2 - V_{aircraft}^2)$$
$$P_{jet} = ½ M (V_{jet}^2 - V_{aircraft}^2)$$

$$E_{fuel} = CV_{fuel}$$
$$P_{fuel} = M_{fuel}\, CV_{fuel}$$
$$\eta_{thermal} = P_{jet} / P_{fuel}$$
$$\eta_{propulsion} = P_{thrust} / P_{jet} = 2\, V_{aircraft} / (V_{jet} + V_{aircraft})$$
$$\eta_{overall} = \eta_{thermal} \times \eta_{propulsion}$$

Wind Power

$$P_{total} = \tfrac{1}{2}\, \rho\, A_T\, V_1^3$$
$$P_{max} = 8/27\, \rho\, A_T\, V_1^3$$
$$H_{max} = P_{max} / P_{total} = 16/27$$

Reynolds Number

$$Re = d\, V\, \rho / \mu$$

Flow in Pipes

$$h_L = f\, (L / D)\, (V^2 / 2\, g)$$
$$D_e = 4\,(\text{flow area}) / (\text{wetted perimeter})$$
$$D = D_e \quad \text{for non-circular pipes}$$
$$L = L_{total} + L_e \quad \text{for non-linear pipes}$$
$$(L / D) = 35\, k \quad \text{for } Re \sim 10^4$$

Drag on Immersed Bodies

Friction Drag: $F_f = C_f\, \tfrac{1}{2}\, \rho\, V^2\, B\, L$ $(B = \pi\, D)$
Pressure Drag: $F_p = C_p\, \tfrac{1}{2}\, \rho\, V^2\, A$
Total Drag: $F_D = C_D\, \tfrac{1}{2}\, \rho\, V^2\, A$

Aircraft Wing: $F_L = C_L\, \tfrac{1}{2}\, \rho\, V^2\, A_{wing}$
Aircraft Wing: $F_D = C_D\, \tfrac{1}{2}\, \rho\, V^2\, A_{wing}$

Karmen Vortex Frequency

$$f \approx 0.20\, (V / D)\, (1 - 20 / Re)$$