UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BEng (HONS) CIVIL ENGINEERING

SEMESTER TWO EXAMINATION 2021/2022

GROUND AND WATER II

MODULE NO: CIE5005

Date: Tuesday 17th May 2022 **Time: 14:00 – 17:00**

INSTRUCTIONS TO CANDIDATES:

There are TWO Sections; A and B.

You will be supplied with TWO Answer Booklets by the Invigilator. Answer Section A in ONE Answer Booklet, and Section B in the other.

Section A: Q1 to Q4 (Answer THREE Questions from four).

Section B: Q5 to Q7 (Answer TWO Questions from three).

Formulae and Definitions are provided.

Lined Graph Paper and Supplementary Answer Sheets are available for your use.

Ensure that you write your Candidate Number or Desk Number on each Figure, Supplementary Sheet or Sheet of Graph Paper you use to answer the selected questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

SECTION A – ANSWER ANY THREE QUESTIONS (from Q1 to Q4)

Question 1:

Three pipes are connected in series to transmit the water between the two reservoirs (A and B) (**Figure Q1**). The diameters of the three pipes are 250mm, 150mm, and 350mm, respectively. The corresponding lengths of the pipes are 400m, 300m, and 350m. The discharge flowing in the pipes is 0.15m^3/s. The friction factor (f) of the three pipes is 0.024. Assume sharp-edged entrance from reservoir A into pipe 1 ($k = 0.5$), sudden contraction between pipe 1 and 2 ($k = 0.25$), sudden expansion between pipe 2 and 3 ($k = 0.1$), and exit into reservoir B ($k = 1$).

Determine the following:

(a) Total friction losses in the three pipes

(6 marks)

(b) Total minor losses in the pipeline

(8 marks)

(c) Difference between the water surfaces in the two reservoirs (H)

(6 marks)

Total 20 marks

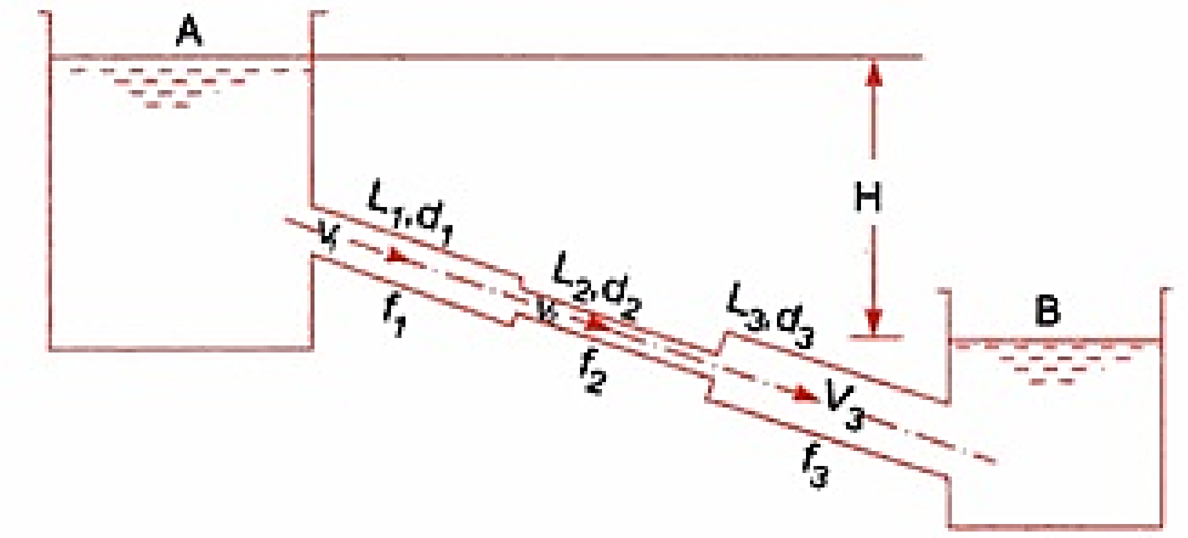

Figure Q1

Question 2:

Branching in pipes occur when water is brought by pipes to a junction when more than two pipes meet.

(a) Briefly discuss the principles need to be satisfied in order to find flows and pressure at the junction for such piping systems.

(**5 marks**)

(b) **Figure Q2** shows a typical three-reservoirs system. Determine the flow in pipe BJ & pipe CJ and the water elevation in tank C. Take fixed value for the friction factor, f = 0.025 for all pipes. Neglect the minor losses.

(**15 marks**)

Total 20 marks

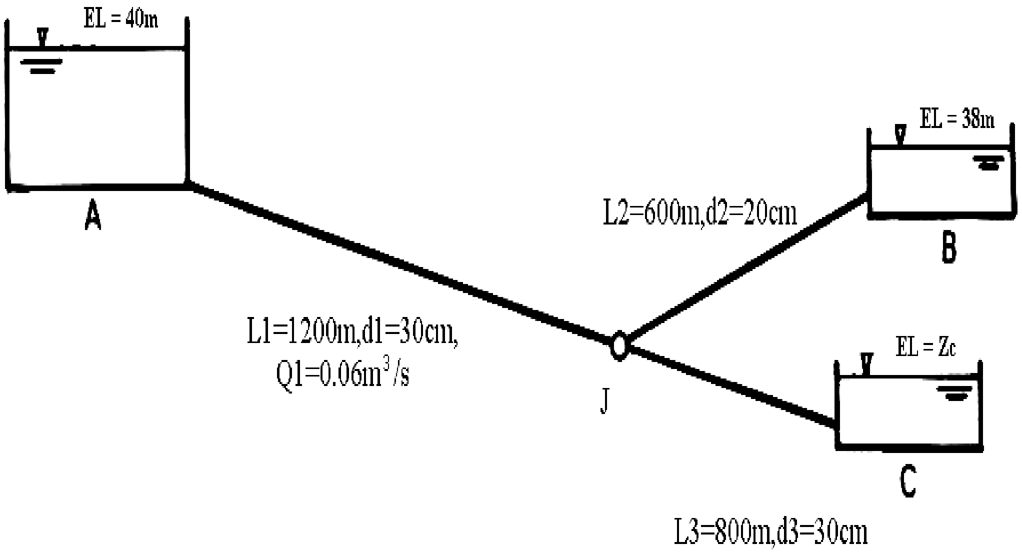

Figure Q2

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Question 3:

For the ring main pipe network shown in **Figure Q3** and data in **Table Q3.1**:

(a) Use Hardy Cross method, Darcy-Weisbach formula for pipe head loss and a fixed friction factor, *f* = **0.016** for all pipes, find the discharges in each pipes (**Make at least three iterations; use a table similar to Table Q3.2**).

(**15 marks**)

(b) Find the pressure head at point B; C, and D, if the pressure at A is **30 m** of water and A, B, C and D have the same elevation.

(**5 marks**)

Total 20 marks

Table Q3.1

Pipe	AB	BC	AC	CD	AD
Length (m)	1000	1000	1414	1000	1000
Diameter (mm)	150	200	200	300	200

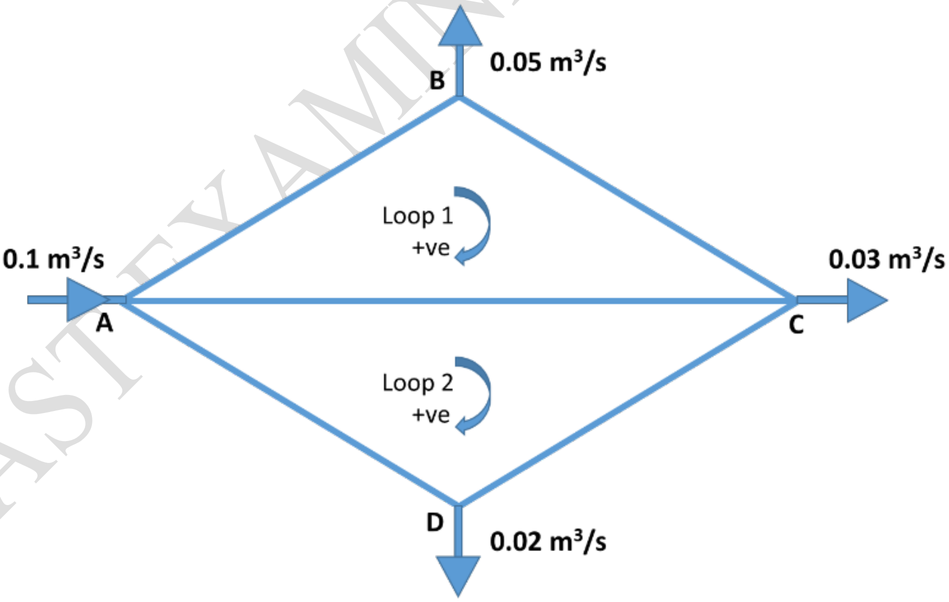

Figure Q3

Total 20 mark

Question 3 continues over the page….

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Question 3 continued….

Table Q3.2

	Loop 1							**Loop 2**						
1st Trial	**Pipe**	**L (m)**	**D (mm)**	**K**	**Q (m^3/sec)**	**h_f (m)**	**h_f/Q**	**Pipe**	**L (m)**	**D (mm)**	**K**	**Q (m^3/sec)**	**h_f (m)**	**h_f/Q**
	AB	1000	150					**AC**	1414	200				
	BC	1000	200					**CD**	1000	200				
	CA	1414	200					**DA**	1000	300				
					Σ							**Σ**		
						ΔQ							**ΔQ**	
2nd Trial	**Pipe**	**L (m)**	**D (mm)**	**K**	**Q (m^3/sec)**	**h_f (m)**	**h_f/Q**	**Pipe**	**L (m)**	**D (mm)**	**K**	**Q (m^3/sec)**	**h_f (m)**	**h_f/Q**
	AB	1000	150					**AC**	1414	200				
	BC	1000	200					**CD**	1000	200				
	CA	1414	200					**DA**	1000	300				
					Σ							**Σ**		
						ΔQ							**ΔQ**	
3rd Trial	**Pipe**	**L (m)**	**D (mm)**	**K**	**Q (m^3/sec)**	**h_f (m)**	**h_f/Q**	**Pipe**	**L (m)**	**D (mm)**	**K**	**Q (m^3/sec)**	**h_f (m)**	**h_f/Q**
	AB	1000	150					**AC**	1414	200				
	BC	1000	200					**CD**	1000	200				
	CA	1414	200					**DA**	1000	300				
					Σ							**Σ**		
						ΔQ							**ΔQ**	

Candidate Number: ………………………………

Question 4:

a) Explain what you understand by time of entry, time of flow and time of concentration in storm sewer design. Why is the duration of the design storm in the Rational Method taken as the time of concentration? (**5 marks**)

b) A small separate storm sewer network has the characteristics presented in **Table Q4** and **Figure Q4**. Assume sewer gradient are fixed.

Table Q4

Sewer	Length (m)	Sewer Gradient (1:x)	Contributing Area (ha)
1.0	180	200	0.35
2.0	90	200	0.65
3.0	90	200	0.90
1.1	90	500	0.50

Design the network using the Rational Method for a **1-year** return period storm using a runoff coefficient of **0.85** and a time of entry **4 min**. Take pipe roughness, $\mathbf{k_s}$, as **1.5 mm**. Use the 'Ministry of Health' formulae to determine the design rainfall intensities. (**15 marks**)

Total 20 marks

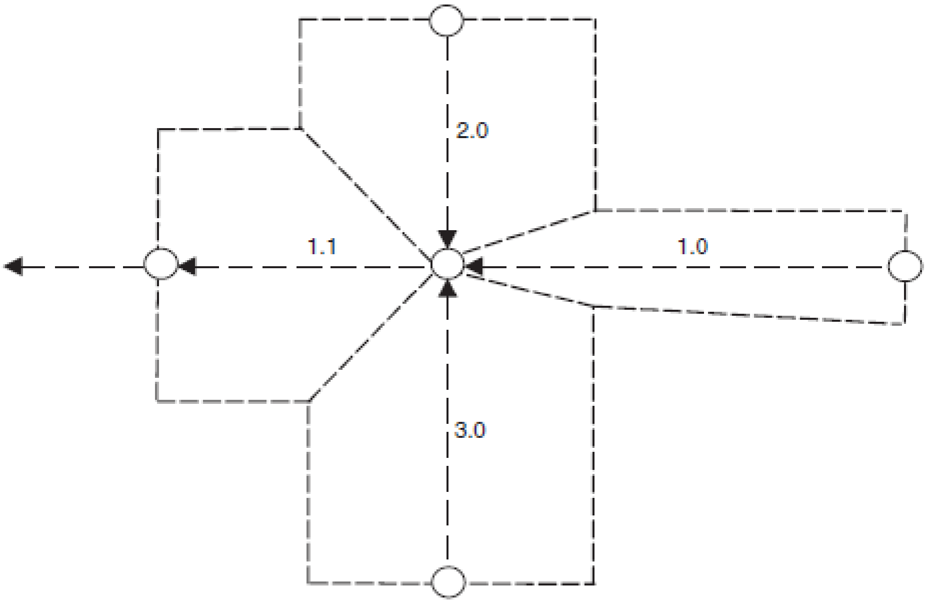

Figure Q4

END OF SECTION A

SECTION B – Answer ANY TWO questions (from Q5 to Q7)

5. a) A quick 'UU' triaxial compression test is to be carried out on a cylindrical clay sample. Show how Mohr's stress circles will be used to characterise the clay behaviour. Ensure that you label all axes and key points on the Mohr's stress circles you sketch. Also sketch the cylinder of clay showing the direction of all key stresses involved on key planes.

(**5 marks**)

b) A series of 'quick' unconsolidated undrained triaxial tests were conducted on a sample of clay with the results obtained being as follows:

Test Number	1	2	3
Cell Pressure (kN/m^2)	50	100	200
Vertical Stress at Failure (kN/m^2)	202	256	453

Using Figure Q5 (Page 8), or Graph Paper, and constructing Mohr's stress circles, determine the shear strength parameters of the soil sample. Use these values to describe the clay soil in geotechnical terms.

(**8 marks**)

c) State two shear strength testing methods available for clays in both the field and in the laboratory, briefly describing their limitations and advantages

(**4 marks**)

d) Explain what you would expect to occur when carrying out a shear box test on a very dense sand, using sketch diagrams, as appropriate, to explain why this behaviour is expected.

(**3 marks**)

Total 20 marks

Question 5 continues over the page….

Seat / Candidate Number : ……………………………………………………….

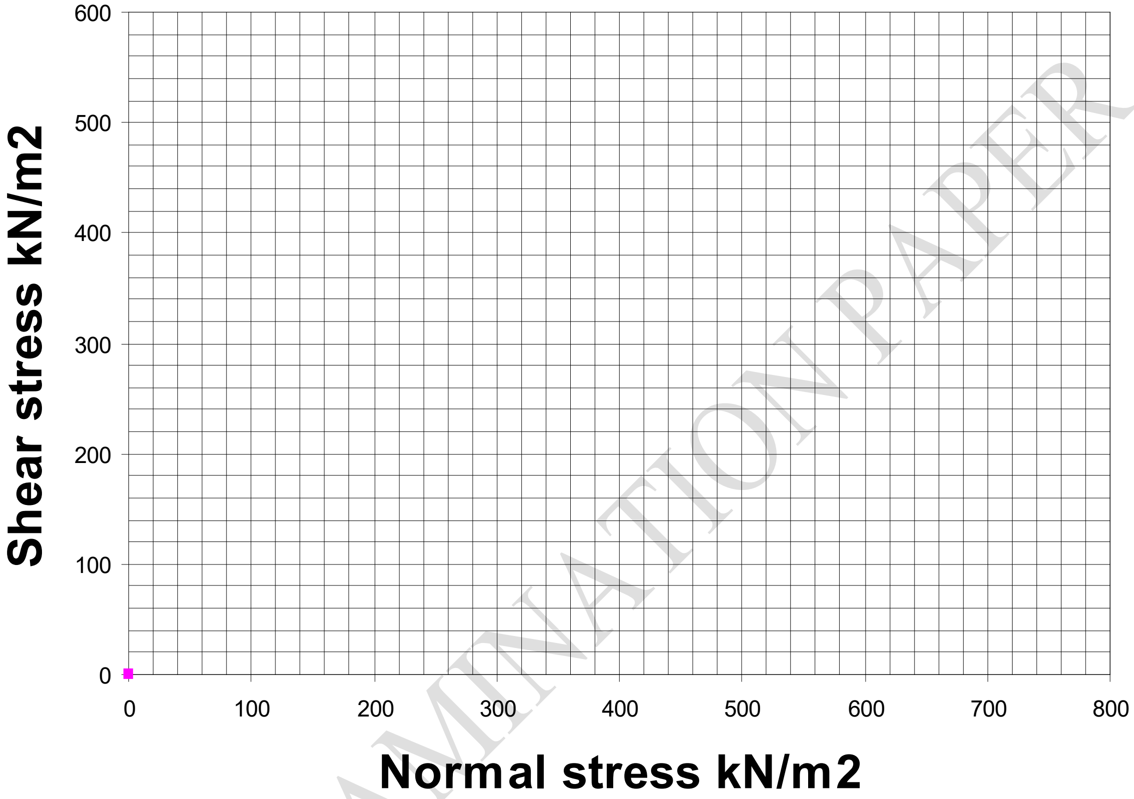

Figure Q5

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6. a) A flexible foundation of length 6m and breadth 4m is to exert a uniform pressure of 150kN/m^2 on the surface of an 8m layer of soil. Using Figure Q6a, determine the immediate settlement under the centre of the foundation if the elastic soil stiffness (E) is assumed to be 2.5MN/m^2.

(**6 marks**)

b) A flexible foundation of length 6m and breadth 4m is to exert a uniform pressure of 150kN/m^2 on the surface of a layer of soil of assumed infinite thickness. Using Figure Q6b, determine the total stress at a depth of 3m beneath a corner of the foundation.

(**5 marks**)

c) The following results were obtained from an oedometer test on a specimen of saturated clay:

Applied Stress (kN/m^2)	0	25	50	100	200	400	800
Void Ratio	0.968	0.933	0.894	0.863	0.816	0.767	0.721

i) Determine the value of m_v for an effective stress range from 40kN/m^2 to 190kN/m^2.

(**6 marks**)

ii) Calculate the consolidation settlement for a 5m thick layer of this clay, when the effective stress changes from 40kN/m^2 to 190kN/m^2.

(**3 marks**)

Total 20 marks

Question 6 continues over the page….

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Question 6 continued….

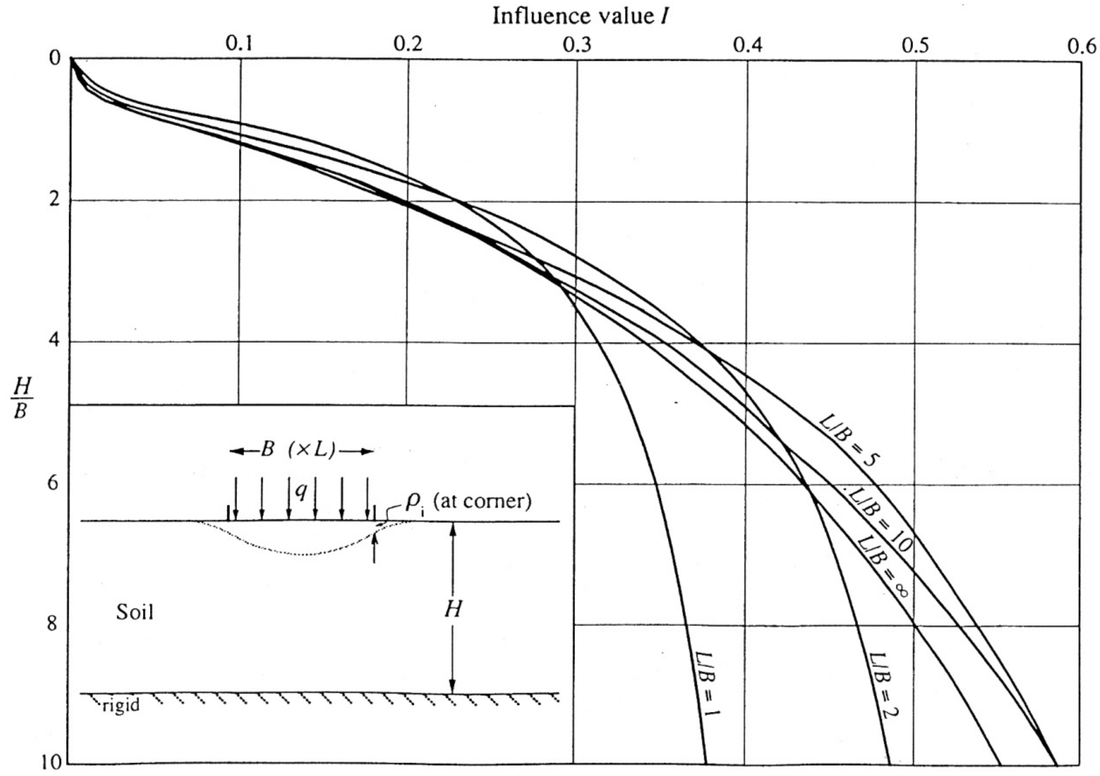

Figure Q6a

Question 6 continues over the page….

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Question 6 continued….

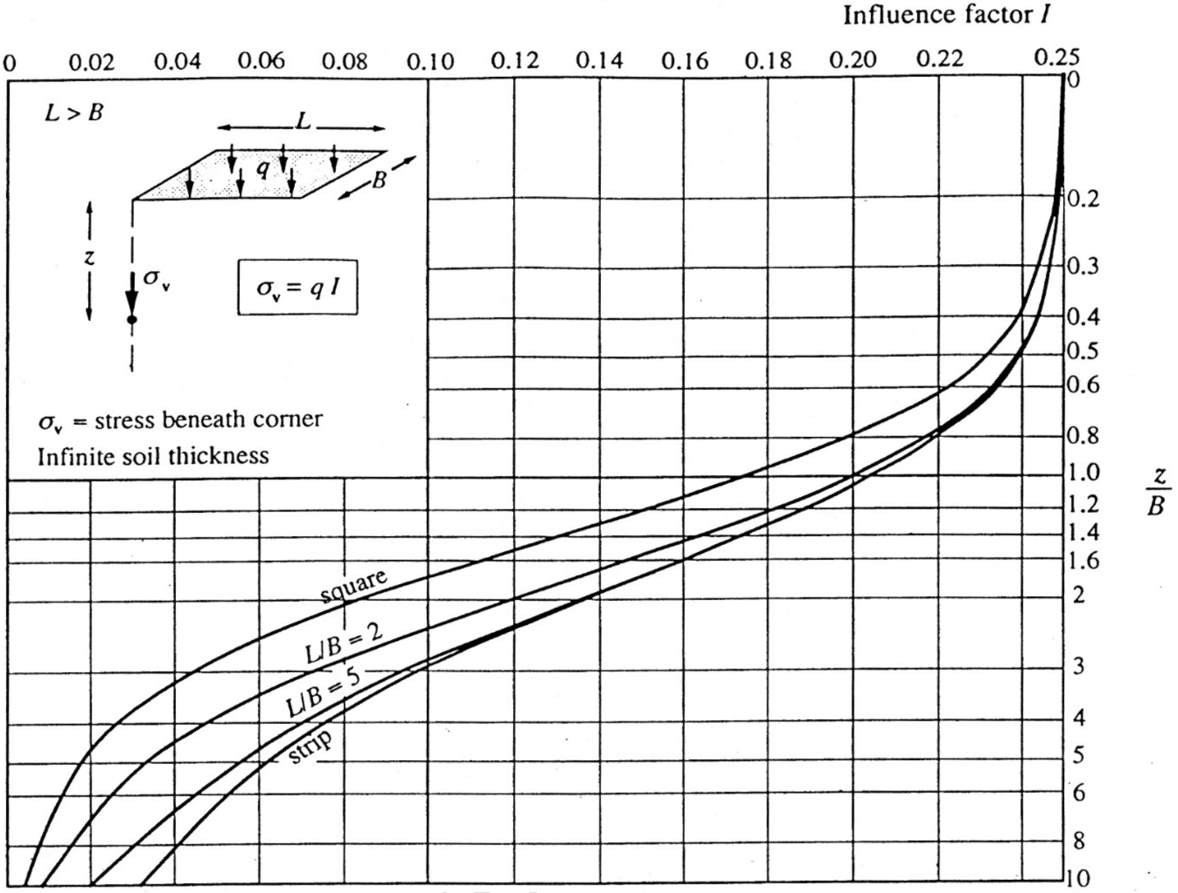

Fig Q6b

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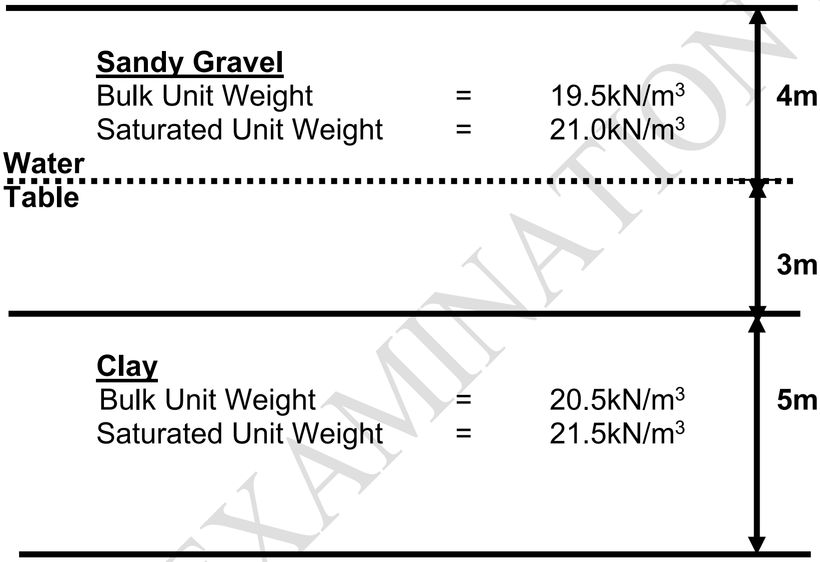
7. a) Describe how an “excess pore water pressure” is generated in a soil situated beneath a proposed wide embankment. Explain the type of soil that would need to be present for an excess pore water pressure to be generated, and then describe in geotechnical detail the process of consolidation that occurs.

(**5 marks**)

b) Using Figure Q7 determine the total stress, pore water pressure and effective stress at each strata change and at the location of the water table and hence plot a graph to illustrate their variation with depth from ground surface to a depth of 10m below ground level. The water table is located at a depth of 3m below ground level within a 5m thick deposit of sandy gravel overlying 5m of clay.

(**15 marks**)

Total 20 marks



NOTE: Assume that Unit Weight of Water = 10kN/m^3

Figure Q7

END OF QUESTIONS

Formulae sheets over the page….

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Geotechnical Formulae

$$\rho_i = \frac{qB}{E_u} . I$$

$$\Delta e = \frac{\Delta H}{H} . (1 + e_o)$$

$$m_v = \frac{\Delta e}{\Delta \sigma} . \frac{(1)}{(1 + e_o)}$$

$$\sigma_v' = \sigma_v - u$$

$$\Delta H = m_v \Delta \sigma_v' H$$

$$\sigma_v = q I$$

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Principles of Flow in Pipes

Reynold Number: $R_e = \frac{\rho V D}{\mu} = \frac{VD}{v}$

Darcy-Weisbach: $h_f = \frac{fL}{D}\frac{V^2}{2g} = \left(\frac{8fl}{\pi^2 g D^5}\right) Q^2$

Hazen-Williams: $h_f = \frac{10.7\,L}{C_{HW}^{1.852}\,D^{4.87}}\,Q^{1.852} = \left(\frac{10.7\,L}{C_{HW}^{1.852}\,D^{4.87}}\right)Q^{1.852}$

Modified Darcy-Weisbach : $H_f = \left(\frac{fL}{D} + \sum K\right)\frac{V^2}{2g} = \left(\frac{8fl}{\pi^2 g D^5} + \frac{8\sum K}{\pi^2 g D^4}\right) Q^2$

Hagen-Poiseuille: $h_f = \frac{32\mu L V}{\rho g D^2}$

Colebrook-White: $\frac{1}{\sqrt{f}} = -2.0\,log\left(\frac{k}{3.7D} + \frac{2.51}{Re\sqrt{f}}\right)$

Swamme-Jain: $\frac{1}{\sqrt{f}} = -2\,log\left(\frac{k}{3.7D} + \frac{5.74}{Re^{0.9}}\right)$

Barr: $\frac{1}{\sqrt{f}} = -2\,log\left(\frac{k}{3.7D} + \frac{5.1286}{Re^{0.89}}\right)$

Combination of the Colebrook-White and the Darcy-Weisbach equations:

$$Q = -2A\sqrt{2gD\frac{h_f}{L}}\,log\left(\frac{k}{3.7D} + \frac{2.51\nu}{D\sqrt{2gD\frac{h_f}{L}}}\right)$$

Local Head Loss: $h_l = K\frac{V^2}{2g}$

Borda-Caront head losses equation for sudden expansions: $\frac{(V_1 - V_2)^2}{2g}$

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Hardy-Cross Head-Balance Correction: $\Delta Q = -\frac{\sum H_{l_{0,i}}}{2\sum \frac{H_{l_{0,i}}}{Q_{0,i}}}$

Cornish Quantity-Balance (Nodal) Correction: $\boldsymbol{\Delta Z} = \frac{2\left[\sum \boldsymbol{Q}_{0,i} - \boldsymbol{F}\right]}{\sum \frac{\boldsymbol{Q}_{0,i}}{\boldsymbol{H}_{l_{0,i}}}}$

Design of Foul Sewer System

Dry Weather Flow (DWF): DWF = PG + I + E

Manning's formula for velocity: $V = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$

Recommended values of sewer wall roughness:

Type of conduit	White-Colebrook (mm)	Manning ($m^{1/3}/s$)
Street sewers, storm water culverts, properly constructed	1.5	0.013
Old sewers and concrete culverts		0.017
main sewers	1.0	0.0125
pumping lines	0.4	0.011

Design of Storm Sewer System

Time of Concentration: $t_c = t_e + t_f$

Rational Formula (Lloyd-Davies, 1946): $Q_p = 2.78CiA$

Ministry of Health Formulae (1930) for Rainfall Intensity:

$$i = \frac{750}{D + 10} \quad \textit{For storms beteen 5 and 20 min duraton}$$

$$i = \frac{1000}{D + 20} \quad \textit{For storms beteen 20 and 120 min duraton}$$

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Bilham's Formula (1938) for Rainfall Intensity:

$$i = \frac{60}{D} * \left[(T * D * 2.022x10^2)^{0.2817} - 2.54\right]$$

The Modified Rational Formula: $Q_p = 3.61 C_v i A$

Pumps:

Manometric head/discharge relationship: $Hp = AQ^2 + BQ + C$

For n identical pumps in series: $H_{np} = nH_p = n[AQ^2 + BQ + C]$, with $Q_{np} = Q$

For n identical pumps in parallel: $H_{np} = H_p = A\left(\frac{Q_{np}}{n}\right)^2 + B\left(\frac{Q_{np}}{n}\right) + C$, with $Q_{np} = nQ$

For variable speed pumps: $\frac{Q}{Q_1} = \frac{N}{N_1}$ and $\frac{H_p}{H_{p1}} = \left(\frac{N}{N_1}\right)^2$

Principles of Flow in Open Channels

Saint-Venant equations for open channel flow:

$$\frac{\partial y}{\partial t} + D\frac{\partial V}{\partial x} + V\frac{\partial y}{\partial x} = 0; \frac{1}{g}\frac{\partial V}{\partial t} + \frac{V}{g}\frac{\partial V}{\partial x} + \frac{\partial y}{\partial x} = S_0 - S_f$$

Alternate Depth Relations for rectangular channels:

$$(y_2 - y_1) = \frac{q^2}{2g}\left(\frac{1}{y_1^2} - \frac{1}{y_2^2}\right) = \frac{y_c^3}{2}\left(\frac{1}{y_1^2} - \frac{1}{y_2^2}\right); (Y_2 + Y_1) = 2Y_1^2 Y_2^2; \text{ where } Y = \frac{y}{y_c}$$

Sequent (Conjugate) Depth Relations for a Hydraulic Jump in a horizontal rectangular channels:

$$Y_1 Y_2 (Y_1 + Y_2) = 2; Y = \frac{y}{y_c}; \left(\frac{y_1}{y_2}\right) = \frac{\sqrt{1+8Fr_2^2} - 1}{2}; \left(\frac{y_2}{y_1}\right) = \frac{\sqrt{1+8Fr_1^2} - 1}{2}; Fr = \frac{V}{\sqrt{gy}}$$

Energy Head loss at the Hydraulic Jump $= E_1 - E_2 = \frac{(y_2 - y_1)^3}{4y_1 y_2}$

The power dissipated by the hydraulic jump $P = \rho g Q(E_1 - E_2) = \frac{\rho g Q (y_2 - y_1)^3}{4y_1 y_2}$

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Steady Uniform flow Equations: Chezy $\boldsymbol{V = C\sqrt{RS_0}}$; Manning: $\boldsymbol{V = \frac{1}{n} R^{2/3} S_0^{1/2}}$

Equivalent (Composite) Manning Roughness Coefficient:

Lotter: $n_e = \frac{PR^{\frac{5}{3}}}{\sum_{i=1}^{N} \frac{P_i R_i^{\frac{5}{3}}}{n_i}}$ Horton-Einstein: $\boldsymbol{n_e = \left(\frac{\sum_{i=1}^{N} P_i n_i^{\frac{3}{2}}}{P}\right)^{\frac{2}{3}}}$ Pavlovskij $\boldsymbol{n_e = \left(\frac{\sum_{i=1}^{N} P_i n_i^2}{P}\right)^{\frac{1}{2}}}$

Compound Channel Sections:

$Q = (\sum_{i=1}^{N} K_i) S_0^{\frac{1}{2}}$; where $K_i = \frac{A_i R_i^{\frac{2}{3}}}{n_i}$

$\alpha = \frac{\sum_{i=1}^{N} V_i^3 A_i}{V^3 A} = \frac{\left(\sum_{i=1}^{N} A_i\right)^2}{\left(\sum_{i=1}^{N} K_i\right)^3} \sum_{i=1}^{N} \frac{K_i^3}{A_i^2}$ $\beta = \frac{\sum_{i=1}^{N} A_i V_i^2}{V^2 A} = \frac{\sum_{i=1}^{N} A_i}{\left(\sum_{i=1}^{N} K_i\right)^2} \sum_{i=1}^{N} \frac{K_i^2}{A_i}$;

Surface Profile Equation for steady gradually varied flow in prismatic channels:

$$\frac{dy}{dx} = \frac{S_0 - S_f}{1 - \frac{\alpha T Q^2}{g A^3}} = \frac{S_0 - S_f}{1 - Fr^2}$$

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HRS Tables

ks = 1·500mm
i = 0·00015 to 0·004

ie hydraulic gradient =
1 in 6667 to 1 in 250

Water (or sewage) at 15° C
full bore conditions.

velocities in m/s
discharges in l/s

Gradient	Pipe diameters in mm:											
	50	75	80	100	125	150	175	200	225	250	275	300
0.00075 1/ 1333	0.108	0.145	0.152	0.178	0.208	0.236	0.262	0.286	0.310	0.333	0.354	0.375
	0.212	0.641	0.764	1.397	2.550	4.163	6.295	8.999	12.327	16.329	21.051	26.539
0.00080 1/ 1250	0.112	0.150	0.157	0.184	0.215	0.244	0.270	0.296	0.320	0.344	0.366	0.388
	0.219	0.663	0.790	1.444	2.636	4.303	6.505	9.299	12.739	16.873	21.752	27.422
0.00085 1/ 1176	0.115	0.155	0.162	0.190	0.222	0.251	0.279	0.305	0.330	0.354	0.378	0.400
	0.226	0.684	0.815	1.490	2.719	4.438	6.710	9.591	13.137	17.401	22.432	28.278
0.00090 1/ 1111	0.119	0.159	0.167	0.195	0.228	0.259	0.287	0.314	0.340	0.365	0.389	0.412
	0.233	0.704	0.839	1.534	2.800	4.570	6.908	9.874	13.524	17.913	23.092	29.109
0.00095 1/ 1053	0.122	0.164	0.172	0.201	0.235	0.266	0.295	0.323	0.350	0.375	0.400	0.423
	0.240	0.724	0.863	1.578	2.879	4.698	7.101	10.149	13.901	18.412	23.734	29.918
0.00100 1/ 1000	0.125	0.168	0.176	0.206	0.241	0.273	0.303	0.332	0.359	0.385	0.410	0.434
	0.246	0.744	0.886	1.620	2.955	4.822	7.289	10.417	14.268	18.897	24.359	30.705
0.00110 1/ 909	0.132	0.177	0.185	0.217	0.253	0.286	0.318	0.348	0.377	0.404	0.430	0.456
	0.259	0.781	0.930	1.701	3.102	5.062	7.651	10.934	14.975	19.833	25.564	32.223
0.00120 1/ 833	0.138	0.185	0.194	0.226	0.264	0.299	0.332	0.364	0.394	0.422	0.450	0.476
	0.271	0.817	0.973	1.778	3.243	5.292	7.997	11.428	15.651	20.727	26.715	33.674
0.00130 1/ 769	0.144	0.193	0.202	0.236	0.275	0.312	0.346	0.379	0.410	0.440	0.468	0.496
	0.282	0.851	1.014	1.853	3.379	5.512	8.329	11.902	16.299	21.584	27.820	35.065
0.00140 1/ 714	0.149	0.200	0.209	0.245	0.286	0.324	0.360	0.393	0.426	0.457	0.486	0.515
	0.293	0.884	1.053	1.924	3.509	5.723	8.648	12.358	16.923	22.410	28.883	36.404
0.00150 1/ 667	0.155	0.207	0.217	0.254	0.296	0.335	0.372	0.407	0.441	0.473	0.504	0.533
	0.304	0.916	1.091	1.993	3.634	5.928	8.957	12.798	17.525	23.206	29.908	37.696
0.00160 1/ 625	0.160	0.214	0.224	0.262	0.306	0.347	0.385	0.421	0.455	0.488	0.520	0.551
	0.314	0.947	1.127	2.060	3.755	6.125	9.255	13.223	18.107	23.976	30.900	38.946
0.00170 1/ 588	0.165	0.221	0.231	0.271	0.316	0.357	0.397	0.434	0.470	0.504	0.536	0.568
	0.324	0.977	1.163	2.125	3.873	6.317	9.544	13.636	18.671	24.723	31.862	40.157
0.00180 1/ 556	0.170	0.228	0.238	0.279	0.325	0.368	0.408	0.447	0.483	0.518	0.552	0.585
	0.334	1.006	1.198	2.187	3.987	6.503	9.824	14.036	19.219	25.447	32.795	41.333
0.00190 1/ 526	0.175	0.234	0.245	0.286	0.334	0.378	0.420	0.459	0.497	0.533	0.567	0.601
	0.343	1.034	1.231	2.249	4.099	6.684	10.097	14.426	19.752	26.152	33.703	42.476
0.00200 1/ 500	0.180	0.240	0.251	0.294	0.343	0.388	0.431	0.471	0.510	0.547	0.582	0.617
	0.353	1.061	1.264	2.308	4.207	6.860	10.363	14.805	20.271	26.839	34.588	43.590
0.00220 1/ 455	0.189	0.252	0.264	0.308	0.360	0.407	0.452	0.495	0.535	0.574	0.611	0.647
	0.370	1.114	1.327	2.423	4.415	7.200	10.876	15.537	21.271	28.163	36.293	45.738
0.00240 1/ 417	0.197	0.264	0.276	0.322	0.376	0.426	0.473	0.517	0.559	0.599	0.638	0.676
	0.387	1.165	1.387	2.533	4.615	7.524	11.365	16.235	22.227	29.428	37.922	47.790
0.00260 1/ 385	0.205	0.275	0.287	0.336	0.392	0.443	0.492	0.538	0.582	0.624	0.665	0.704
	0.403	1.213	1.445	2.638	4.806	7.836	11.835	16.906	23.144	30.641	39.484	49.758
0.00280 1/ 357	0.213	0.285	0.298	0.349	0.407	0.460	0.511	0.559	0.604	0.648	0.690	0.731
	0.419	1.260	1.500	2.739	4.990	8.135	12.287	17.551	24.026	31.808	40.988	51.652
0.00300 1/ 333	0.221	0.295	0.309	0.361	0.421	0.477	0.529	0.578	0.626	0.671	0.715	0.757
	0.434	1.305	1.554	2.837	5.168	8.424	12.723	18.173	24.877	32.935	42.438	53.479
0.00320 1/ 313	0.229	0.305	0.319	0.373	0.435	0.493	0.546	0.598	0.646	0.693	0.738	0.782
	0.449	1.349	1.606	2.931	5.339	8.704	13.145	18.775	25.701	34.024	43.841	55.246
0.00340 1/ 294	0.236	0.315	0.329	0.385	0.449	0.508	0.563	0.616	0.666	0.715	0.761	0.806
	0.463	1.391	1.656	3.023	5.506	8.975	13.554	19.358	26.499	35.080	45.201	56.959
0.00360 1/ 278	0.243	0.324	0.339	0.396	0.462	0.523	0.580	0.634	0.686	0.736	0.783	0.829
	0.477	1.432	1.705	3.112	5.668	9.238	13.951	19.925	27.274	36.105	46.522	58.623
0.00380 1/ 263	0.250	0.333	0.349	0.407	0.475	0.537	0.596	0.652	0.705	0.756	0.805	0.852
	0.490	1.472	1.753	3.198	5.825	9.494	14.337	20.476	28.028	37.102	47.806	60.240
	Coefficient for part-full pipes:											
	14	20	20	25	35	40	45	50	60	70	70	80

PLEASE TURN THE PAGE….

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continued

ks = 1·500mm
i = 0·004 to 0·1
ie hydraulic gradient =
1 in 250 to 1 in 10

Water (or sewage) at 15° C
full bore conditions.

velocities in m/s
discharges in l/s

Gradient	Pipe diameters in mm:											
	50	75	80	100	125	150	175	200	225	250	275	300
0.00400 1/ 250	0.256 0.503	0.342 1.511	0.358 1.799	0.418 3.282	0.487 5.978	0.551 9.743	0.612 14.713	0.669 21.013	0.723 28.762	0.776 38.074	0.826 49.057	0.875 61.816
0.00420 1/ 238	0.263 0.516	0.351 1.549	0.367 1.844	0.428 3.365	0.499 6.127	0.565 9.986	0.627 15.080	0.686 21.536	0.741 29.478	0.795 39.021	0.846 50.277	0.896 63.353
0.00440 1/ 227	0.269 0.528	0.359 1.586	0.376 1.888	0.439 3.445	0.511 6.273	0.579 10.224	0.642 15.438	0.702 22.047	0.759 30.177	0.814 39.946	0.867 51.468	0.917 64.854
0.00460 1/ 217	0.275 0.540	0.367 1.622	0.384 1.931	0.449 3.523	0.523 6.416	0.592 10.456	0.656 15.788	0.718 22.547	0.776 30.860	0.832 40.850	0.886 52.633	0.938 66.320
0.00480 1/ 208	0.281 0.552	0.375 1.658	0.393 1.973	0.458 3.600	0.534 6.555	0.605 10.683	0.671 16.130	0.733 23.035	0.793 31.529	0.850 41.735	0.905 53.773	0.959 67.756
0.00500 1/ 200	0.287 0.564	0.383 1.692	0.401 2.014	0.468 3.675	0.545 6.692	0.617 10.905	0.685 16.466	0.748 23.514	0.809 32.184	0.868 42.602	0.924 54.889	0.978 69.162
0.00550 1/ 182	0.301 0.592	0.402 1.776	0.421 2.114	0.491 3.857	0.572 7.022	0.648 11.443	0.718 17.276	0.785 24.671	0.849 33.766	0.911 44.695	0.970 57.585	1.026 72.558
0.00600 1/ 167	0.315 0.618	0.420 1.856	0.440 2.209	0.513 4.030	0.598 7.337	0.677 11.956	0.750 18.051	0.820 25.776	0.887 35.278	0.951 46.695	1.013 60.161	1.072 75.802
0.00650 1/ 154	0.328 0.644	0.438 1.933	0.458 2.301	0.534 4.197	0.623 7.640	0.704 12.448	0.781 18.794	0.854 26.836	0.924 36.728	0.990 48.614	1.054 62.632	1.116 78.915
0.00700 1/ 143	0.341 0.669	0.454 2.007	0.475 2.389	0.555 4.357	0.646 7.931	0.731 12.922	0.811 19.508	0.887 27.856	0.959 38.123	1.028 50.460	1.095 65.009	1.159 81.910
0.00750 1/ 133	0.353 0.693	0.470 2.078	0.492 2.474	0.574 4.511	0.669 8.212	0.757 13.379	0.840 20.198	0.918 28.840	0.993 39.470	1.064 52.241	1.133 67.303	1.200 84.799
0.00800 1/ 125	0.365 0.716	0.486 2.147	0.508 2.556	0.593 4.661	0.691 8.484	0.782 13.822	0.867 20.865	0.948 29.792	1.025 40.772	1.099 53.964	1.170 69.522	1.239 87.594
0.00850 1/ 118	0.376 0.738	0.501 2.214	0.524 2.635	0.612 4.806	0.713 8.747	0.806 14.250	0.894 21.512	0.978 30.715	1.057 42.034	1.133 55.634	1.207 71.673	1.278 90.303
0.00900 1/ 111	0.387 0.760	0.516 2.279	0.540 2.712	0.630 4.946	0.734 9.002	0.830 14.666	0.920 22.139	1.006 31.611	1.088 43.259	1.166 57.255	1.242 73.761	1.315 92.933
0.00950 1/ 105	0.398 0.781	0.530 2.342	0.555 2.788	0.647 5.083	0.754 9.251	0.853 15.071	0.946 22.750	1.034 32.482	1.118 44.451	1.199 58.832	1.276 75.792	1.351 95.491
0.01000 1/ 100	0.408 0.802	0.544 2.404	0.569 2.861	0.664 5.216	0.774 9.493	0.875 15.465	0.971 23.345	1.061 33.331	1.147 45.612	1.230 60.368	1.309 77.770	1.386 97.983
0.01100 1/ 91	0.429 0.841	0.571 2.522	0.597 3.002	0.697 5.473	0.812 9.960	0.918 16.225	1.018 24.491	1.113 34.967	1.203 47.850	1.290 63.329	1.374 81.583	1.454 102.786
0.01200 1/ 83	0.448 0.879	0.597 2.636	0.624 3.137	0.728 5.718	0.848 10.406	0.959 16.951	1.064 25.586	1.163 36.530	1.257 49.988	1.348 66.158	1.435 85.226	1.519 107.375
0.01300 1/ 77	0.466 0.916	0.621 2.744	0.650 3.266	0.758 5.954	0.883 10.834	0.999 17.648	1.107 26.637	1.210 38.029	1.309 52.039	1.403 68.871	1.494 88.721	1.581 111.776
0.01400 1/ 71	0.484 0.951	0.645 2.849	0.674 3.390	0.787 6.180	0.916 11.246	1.037 18.318	1.149 27.648	1.256 39.472	1.358 54.012	1.456 71.482	1.550 92.083	1.641 116.012
0.01500 1/ 67	0.501 0.984	0.668 2.950	0.698 3.510	0.815 6.399	0.949 11.643	1.073 18.964	1.190 28.623	1.301 40.864	1.406 55.916	1.508 74.001	1.605 95.328	1.699 120.099
0.01600 1/ 62	0.518 1.017	0.690 3.047	0.721 3.626	0.842 6.610	0.980 12.027	1.109 19.590	1.229 29.567	1.344 42.210	1.453 57.758	1.557 76.437	1.658 98.466	1.755 124.051
0.01700 1/ 59	0.534 1.049	0.711 3.142	0.744 3.739	0.868 6.815	1.010 12.400	1.143 20.196	1.267 30.481	1.385 43.515	1.498 59.543	1.605 78.799	1.709 101.507	1.809 127.882
0.01800 1/ 56	0.550 1.079	0.732 3.234	0.766 3.848	0.893 7.014	1.040 12.761	1.176 20.784	1.304 31.369	1.425 44.782	1.541 61.276	1.652 81.092	1.759 104.460	1.862 131.602
0.01900 1/ 53	0.565 1.109	0.752 3.323	0.787 3.954	0.918 7.208	1.069 13.113	1.209 21.357	1.340 32.232	1.465 46.014	1.584 62.961	1.697 83.322	1.807 107.332	1.913 135.220
	Coefficient for part-full pipes:											
	18	25	30	35	45	50	60	70	80	90	100	110

ks = 1·500mm   i < 0·1

PLEASE TURN THE PAGE….

ks = 1·500mm
i = 0·004 to 0·1
ie hydraulic gradient =
1 in 250 to 1 in 10

Water (or sewage) at 15° C
full bore conditions.
velocities in m/s
discharges in l/s

8
continued

Gradient	Pipe diameters in mm : 50	75	80	100	125	150	175	200	225	250	275	300
0.02000 1/ 50	0.580 1.138	0.772 3.410	0.807 4.058	0.942 7.396	1.096 13.456	1.240 21.914	1.375 33.073	1.503 47.214	1.625 64.603	1.742 85.494	1.854 110.130	1.963 138.743
0.02200 1/ 45	0.608 1.195	0.810 3.578	0.847 4.257	0.988 7.759	1.150 14.116	1.301 22.989	1.442 34.695	1.577 49.528	1.704 67.768	1.827 89.682	1.945 115.523	2.059 145.536
0.02400 1/ 42	0.636 1.248	0.846 3.738	0.885 4.448	1.032 8.106	1.202 14.747	1.359 24.016	1.507 36.244	1.647 51.738	1.780 70.792	1.908 93.682	2.032 120.675	2.151 152.026
0.02600 1/ 38	0.662 1.300	0.881 3.892	0.921 4.631	1.075 8.439	1.251 15.352	1.415 25.001	1.569 37.730	1.714 53.859	1.853 73.693	1.987 97.520	2.115 125.618	2.239 158.251
0.02800 1/ 36	0.687 1.349	0.914 4.040	0.956 4.807	1.115 8.760	1.298 15.934	1.468 25.949	1.628 39.159	1.779 55.899	1.924 76.483	2.062 101.212	2.195 130.373	2.324 164.241
0.03000 1/ 33	0.711 1.397	0.947 4.182	0.990 4.977	1.155 9.069	1.344 16.496	1.520 26.863	1.685 40.539	1.842 57.868	1.991 79.176	2.134 104.775	2.272 134.961	2.405 170.021
0.03200 1/ 31	0.735 1.443	0.978 4.320	1.023 5.141	1.193 9.368	1.389 17.040	1.570 27.748	1.741 41.873	1.903 59.772	2.057 81.781	2.205 108.221	2.347 139.399	2.484 175.611
0.03400 1/ 29	0.758 1.488	1.008 4.454	1.054 5.300	1.230 9.657	1.431 17.566	1.619 28.605	1.795 43.166	1.961 61.617	2.120 84.305	2.273 111.561	2.419 143.701	2.561 181.029
0.03600 1/ 28	0.780 1.531	1.038 4.584	1.085 5.455	1.265 9.939	1.473 18.078	1.666 29.437	1.847 44.422	2.018 63.409	2.182 86.756	2.339 114.804	2.490 147.877	2.635 186.289
0.03800 1/ 26	0.801 1.574	1.066 4.710	1.115 5.605	1.300 10.212	1.514 18.575	1.712 30.247	1.898 45.643	2.074 65.152	2.242 89.140	2.403 117.958	2.558 151.939	2.708 191.406
0.04000 1/ 25	0.822 1.615	1.094 4.833	1.144 5.751	1.334 10.479	1.553 19.059	1.756 31.035	1.947 46.832	2.128 66.849	2.300 91.462	2.466 121.030	2.625 155.895	2.778 196.389
0.04200 1/ 24	0.843 1.655	1.121 4.953	1.173 5.894	1.367 10.739	1.592 19.532	1.800 31.805	1.995 47.993	2.181 68.505	2.357 93.726	2.527 124.026	2.690 159.754	2.847 201.250
0.04400 1/ 23	0.863 1.694	1.148 5.071	1.200 6.033	1.400 10.993	1.629 19.993	1.842 32.555	2.042 49.125	2.232 70.121	2.413 95.938	2.586 126.951	2.753 163.522	2.914 205.996
0.04600 1/ 22	0.882 1.733	1.174 5.185	1.227 6.170	1.431 11.241	1.666 20.444	1.884 33.290	2.088 50.233	2.282 71.701	2.467 98.099	2.644 129.811	2.815 167.205	2.980 210.635
0.04800 1/ 21	0.901 1.770	1.199 5.297	1.254 6.303	1.462 11.484	1.702 20.886	1.924 34.008	2.133 51.316	2.332 73.247	2.520 100.214	2.701 132.610	2.876 170.809	3.044 215.174
0.05000 1/ 20	0.920 1.807	1.224 5.407	1.280 6.434	1.492 11.721	1.737 21.318	1.964 34.711	2.178 52.377	2.380 74.762	2.573 102.286	2.757 135.350	2.935 174.339	3.107 219.620
0.05500 1/ 18	0.965 1.896	1.284 5.672	1.343 6.749	1.566 12.296	1.822 22.362	2.060 36.411	2.284 54.941	2.496 78.420	2.698 107.290	2.892 141.971	3.079 182.866	3.259 230.361
0.06000 1/ 17	1.009 1.980	1.341 5.926	1.403 7.050	1.635 12.845	1.904 23.360	2.152 38.034	2.386 57.390	2.607 81.916	2.819 112.071	3.021 148.297	3.216 191.013	3.404 240.623
0.06500 1/ 15	1.050 2.062	1.396 6.169	1.460 7.340	1.702 13.371	1.981 24.316	2.240 39.592	2.484 59.740	2.714 85.268	2.934 116.657	3.145 154.365	3.347 198.827	3.543 250.466
0.07000 1/ 14	1.090 2.140	1.449 6.402	1.516 7.618	1.767 13.877	2.057 25.237	2.325 41.090	2.578 62.000	2.817 88.494	3.045 121.070	3.264 160.203	3.474 206.346	3.677 259.937
0.07500 1/ 13	1.128 2.216	1.500 6.628	1.569 7.886	1.829 14.366	2.129 26.126	2.407 42.536	2.668 64.182	2.916 91.607	3.152 125.328	3.378 165.836	3.596 213.601	3.807 269.075
0.08000 1/ 13	1.166 2.289	1.550 6.846	1.621 8.146	1.889 14.839	2.199 26.985	2.486 43.935	2.756 66.291	3.012 94.617	3.256 129.446	3.489 171.285	3.714 220.618	3.932 277.914
0.08500 1/ 12	1.202 2.359	1.598 7.058	1.671 8.397	1.948 15.297	2.267 27.818	2.563 45.290	2.841 68.336	3.105 97.535	3.356 133.437	3.597 176.565	3.829 227.419	4.053 286.480
0.09000 1/ 11	1.237 2.428	1.644 7.263	1.719 8.642	2.004 15.742	2.333 28.626	2.637 46.606	2.924 70.321	3.195 100.368	3.453 137.313	3.701 181.693	3.940 234.023	4.171 294.798
0.09500 1/ 11	1.271 2.495	1.689 7.463	1.767 8.879	2.059 16.175	2.397 29.413	2.710 47.887	3.004 72.252	3.283 103.124	3.548 141.082	3.803 186.680	4.048 240.446	4.285 302.888
0.10000 1/ 10	1.304 2.560	1.733 7.658	1.813 9.111	2.113 16.596	2.459 30.179	2.780 49.133	3.082 74.133	3.368 105.808	3.641 144.754	3.902 191.537	4.154 246.701	4.396 310.768
	Coefficient for part-full pipes : 20	35	35	45	50	70	80	90	100	110	120	130

ks = 1·500mm i < 0·1

PLEASE TURN THE PAGE….

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continued

ks = 1·500mm
i = 0·004 to 0·1
ie hydraulic gradient =
1 in 250 to 1 in 10

Water (or sewage) at 15° C
full bore conditions.
velocities in m/s
discharges in m³/s

Gradient	Pipe diameters in mm: 350	375	400	450	500	525	600	675	700	750	800	825
0.00400 1/ 250	0.967 0.093	1.012 0.112	1.055 0.133	1.139 0.181	1.219 0.239	1.257 0.272	1.370 0.387	1.477 0.528	1.511 0.582	1.579 0.698	1.645 0.827	1.678 0.897
0.00420 1/ 238	0.991 0.095	1.037 0.115	1.081 0.136	1.167 0.186	1.249 0.245	1.289 0.279	1.404 0.397	1.513 0.542	1.549 0.596	1.618 0.715	1.686 0.848	1.719 0.919
0.00440 1/ 227	1.015 0.098	1.061 0.117	1.107 0.139	1.194 0.190	1.278 0.251	1.319 0.286	1.437 0.406	1.549 0.554	1.586 0.610	1.657 0.732	1.726 0.868	1.760 0.941
0.00460 1/ 217	1.038 0.100	1.085 0.120	1.132 0.142	1.221 0.194	1.307 0.257	1.349 0.292	1.469 0.415	1.584 0.567	1.621 0.624	1.694 0.748	1.765 0.887	1.800 0.962
0.00480 1/ 208	1.060 0.102	1.109 0.122	1.156 0.145	1.248 0.198	1.335 0.262	1.378 0.298	1.501 0.424	1.618 0.579	1.656 0.637	1.731 0.765	1.803 0.906	1.838 0.983
0.00500 1/ 200	1.082 0.104	1.132 0.125	1.180 0.148	1.274 0.203	1.363 0.268	1.407 0.304	1.532 0.433	1.652 0.591	1.691 0.651	1.766 0.780	1.840 0.925	1.876 1.003
0.00550 1/ 182	1.135 0.109	1.187 0.131	1.238 0.156	1.336 0.212	1.430 0.281	1.476 0.319	1.607 0.454	1.733 0.620	1.773 0.682	1.853 0.819	1.930 0.970	1.968 1.052
0.00600 1/ 167	1.186 0.114	1.240 0.137	1.293 0.163	1.396 0.222	1.494 0.293	1.541 0.334	1.679 0.475	1.810 0.648	1.852 0.713	1.936 0.855	2.016 1.014	2.056 1.099
0.00650 1/ 154	1.235 0.119	1.291 0.143	1.346 0.169	1.453 0.231	1.555 0.305	1.605 0.347	1.748 0.494	1.884 0.674	1.928 0.742	2.015 0.890	2.099 1.055	2.140 1.144
0.00700 1/ 143	1.281 0.123	1.340 0.148	1.398 0.176	1.508 0.240	1.614 0.317	1.665 0.361	1.814 0.513	1.956 0.700	2.001 0.770	2.091 0.924	2.178 1.095	2.221 1.187
0.00750 1/ 133	1.327 0.128	1.387 0.153	1.447 0.182	1.561 0.248	1.671 0.328	1.724 0.373	1.878 0.531	2.024 0.724	2.072 0.797	2.165 0.956	2.255 1.134	2.299 1.229
0.00800 1/ 125	1.370 0.132	1.433 0.158	1.494 0.188	1.613 0.256	1.726 0.339	1.781 0.385	1.940 0.548	2.091 0.748	2.140 0.824	2.236 0.988	2.329 1.171	2.375 1.270
0.00850 1/ 118	1.413 0.136	1.477 0.163	1.541 0.194	1.662 0.264	1.779 0.349	1.836 0.397	2.000 0.565	2.156 0.771	2.206 0.849	2.305 1.018	2.401 1.207	2.448 1.309
0.00900 1/ 111	1.454 0.140	1.520 0.168	1.585 0.199	1.711 0.272	1.831 0.359	1.889 0.409	2.058 0.582	2.218 0.794	2.270 0.874	2.372 1.048	2.471 1.242	2.520 1.347
0.00950 1/ 105	1.494 0.144	1.562 0.173	1.629 0.205	1.758 0.280	1.881 0.369	1.941 0.420	2.114 0.598	2.279 0.816	2.333 0.898	2.437 1.077	2.539 1.276	2.589 1.384
0.01000 1/ 100	1.533 0.147	1.603 0.177	1.672 0.210	1.804 0.287	1.930 0.379	1.992 0.431	2.169 0.613	2.339 0.837	2.393 0.921	2.501 1.105	2.605 1.309	2.656 1.420
0.01100 1/ 91	1.608 0.155	1.682 0.186	1.753 0.220	1.892 0.301	2.025 0.398	2.089 0.452	2.276 0.643	2.453 0.878	2.510 0.966	2.623 1.159	2.732 1.373	2.786 1.489
0.01200 1/ 83	1.680 0.162	1.757 0.194	1.832 0.230	1.976 0.314	2.115 0.415	2.182 0.472	2.377 0.672	2.562 0.917	2.622 1.009	2.740 1.210	2.854 1.435	2.910 1.556
0.01300 1/ 77	1.748 0.168	1.829 0.202	1.907 0.240	2.057 0.327	2.202 0.432	2.272 0.492	2.474 0.700	2.667 0.954	2.730 1.050	2.852 1.260	2.971 1.493	3.029 1.619
0.01400 1/ 71	1.815 0.175	1.898 0.210	1.979 0.249	2.135 0.340	2.285 0.449	2.358 0.510	2.568 0.726	2.768 0.991	2.833 1.090	2.960 1.308	3.083 1.550	3.144 1.681
0.01500 1/ 67	1.879 0.181	1.965 0.217	2.049 0.257	2.210 0.352	2.365 0.464	2.441 0.528	2.658 0.752	2.866 1.025	2.933 1.129	3.064 1.354	3.192 1.604	3.254 1.740
0.01600 1/ 62	1.940 0.187	2.029 0.224	2.116 0.266	2.283 0.363	2.443 0.480	2.521 0.546	2.746 0.776	2.960 1.059	3.029 1.166	3.165 1.398	3.297 1.657	3.361 1.797
0.01700 1/ 59	2.000 0.192	2.092 0.231	2.181 0.274	2.354 0.374	2.519 0.495	2.599 0.563	2.830 0.800	3.051 1.092	3.122 1.202	3.262 1.441	3.398 1.708	3.465 1.852
0.01800 1/ 56	2.059 0.198	2.153 0.238	2.245 0.282	2.422 0.385	2.592 0.509	2.674 0.579	2.913 0.824	3.140 1.123	3.213 1.237	3.357 1.483	3.497 1.758	3.566 1.906
0.01900 1/ 53	2.115 0.203	2.212 0.244	2.306 0.290	2.488 0.396	2.663 0.523	2.748 0.595	2.993 0.846	3.226 1.154	3.301 1.270	3.449 1.524	3.593 1.806	3.664 1.958
Coefficient for part-full pipes:	120	130	140	150	200	200	200	250	250	250	300	300

ks = 1·500mm   i < 0·1

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