UNIVERSITY OF BOLTON

OFF CAMPUS DIVISION

WESTERN INTERNATIONAL COLLEGE FZE

BENG(HONS) CIVIL ENGINEERING

TRIMESTER TWO EXAMINATION 2021/2022

GROUND AND WATER STUDIES 2

MODULE NO: CIE5005

Date: Saturday 30th April 2022 **Time: 10:00am – 1:00pm**

INSTRUCTIONS TO CANDIDATES:

There are SIX questions on this paper.

Answer ANY FIVE questions.

Answer SECTION A and SECTION B on separate answer books.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

This examination paper carries a total of 100 marks.

Formula sheet/supplementary information is provided at the end of each section.

All working must be shown. A numerical solution to a question obtained by programming an electronic calculator will not be accepted.

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Module No. CIE5005

SECTION A- GROUND STUDIES

Q1

a) A flexible foundation is to be constructed on a layer of soil of finite vertical extent of 15m with a bulk unit weight of 21kN/m^3. The foundation is of length 5m and breadth 3m and it is to exert a uniform pressure of 200kN/m^2.

(i) Determine the immediate settlement under the centre and at the corner of the foundation if the elastic soil stiffness (E_u) is assumed to be 24MN/m^2 (Use **Figure Q1a- on Page 9)**

(8 marks)

(ii) Analyse the potential damage due to differential settlement for the above foundation.

(4 marks)

b) If the foundation is to be constructed over a layer of soil of infinite vertical extent with a bulk unit weight of 21kN/m^3 and it imposes a contact pressure of 200kN/m^2 on the surface of the foundation, determine the vertical stress at a depth of 15m beneath the centre of the foundation using **Figure Q1b- On Page 10.**

(4 marks)

c) Explain the following terms that may occur when carrying out a shear box test on sand. Ensure that you explain the anticipated density state of the soil as each term below is observed.

(i) ‘peak’ and ‘residual’ shear strength

(2 marks)

(ii) ‘dilation’ and ‘realignment’

(2 marks)

Total 20 marks

PLEASE TURN THE PAGE…..

Q2.

a) A series of consolidated undrained triaxial tests were conducted on a soil sample and the following results were obtained is given in **Table Q2 a**

Table Q2 a: Triaxial tests observation

Test No:	1	2	3
Cell Pressure (kN/m^2)	250	500	750
Deviator Stress at failure (kN/m^2)	152	300	455
Porewater Pressure at Failure (kN/m^2)	120	250	350

Using **Figure Q2a on Page 11** construct Mohr's stress circles and determine the effective stress parameters of the soil sample.

(7.5 marks)

b) Describe any two of the full range of shear strength testing methods available for different soil types both in the field and in the laboratory. Ensure that your discussions justify the use of specific test methods for specific soil types and also state the advantages and limitations of the methods selected.

(5 marks)

c) Determine the distribution of Effective stress, Pore Water Pressure and Total Stress at each soil strata using the **Figure Q2b on Page 12** and hence plot the diagram to illustrate the variation of total stress, pore water pressure and the effective stress with depth from ground surface to a depth of 12m below ground level. The water table is located at a depth of 4m below ground level within a 6m thick deposit of sandy gravel overlying 4m of clay.

(7.5 marks)

Total 20 marks

END OF SECTION A

PLEASE TURN THE PAGE SECTION B…

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SECTION B- HYDRAULICS

Q3.

a) A pipe joins two reservoirs whose head difference is 10m. The pipe is 200mm diameter, 1000m in length and has a friction factor λ value of 0.002 for a discharge of 36.4 l/s. The flow to the downstream reservoir is to be increased to 442l/s, by adding a second pipe of the same diameter that connects at some point along the old pipe and runs down to the lower reservoir. If the frictional head loss remains the same, how long should the new pipe be? Assume the friction factor same as the old pipe. Neglect all minor losses.

(12 marks)

b) A 300mm diameter main conveying water at a flowrate of 69 litres/sec falls 3.0m over a distance of 400m. If the pipeline has a roughness value k_s of 1.5mm and the pressure at the end is 3 bars, determine the pressure at the start in kN/m^2. **(Use the HRS Tables provided on Page 15 -19)**

(8 marks)

Total 20 marks

Q4.

a) The reservoir A at a treatment plant feeds two service reservoirs B and C as shown below in Figure Q4.

(i) Using the information given in Table **Q4.a**, make a sensible first estimate for the head at the pipe junction in system A. Briefly explain the reasons for your selections.

(6 marks)

(ii) the Flow Balancing Method to approximately determine the flows entering the service reservoirs in Figure Q4. Use Table **Q4b** attached on Page 18

(8 marks)

Q4 continued over the Page

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Q4 continued

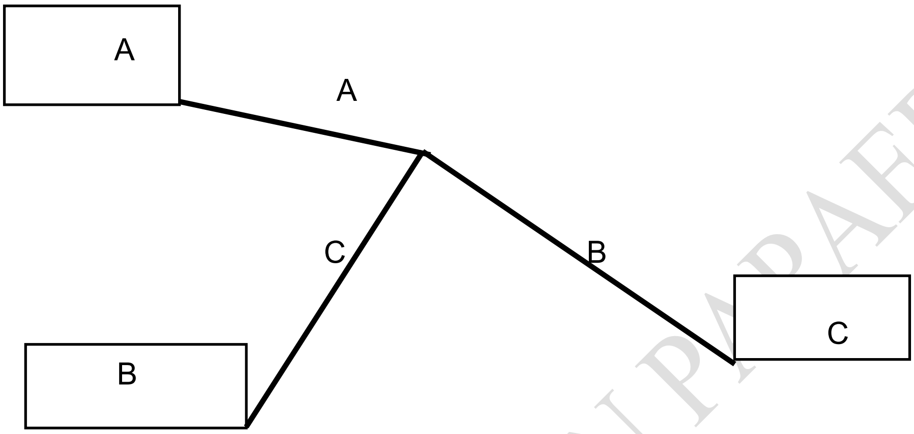

Figure Q4: System A

Table Q4a: Details of System A

Pipe	Length m	Diameter mm	Roughness mm	Reservoir	Water Level m (AOD)
A	720	300	1.5	A	300
B	560	200	1.5	B	285
C	650	200	1.5	C	280

b) Describe the basic rules applicable in the analysis of complex pipe network

(6 marks)

Total 20 marks

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Q5.

(a) A service reservoir is to be constructed to provide water supply for a town 1 km distant. A supply pipeline of 450mm is provided which connects the reservoir to the distribution system with a flowrate of 443 l/s. The pipe material is coated steel, which has a k_s value of 0.03 mm. The top water level in the reservoir is 400.0m AOD and the pipe level at the start of the distribution system is 360.7m AOD. Using Barr's equation, find the Darcy friction factor 'λ' and thus determine the pressure at the start of the distribution system. Assume the coefficient of dynamic viscosity 'μ' for water is 1.14×10^{-3} kg/ms

(14marks)

(b) Differentiate between Laminar and Turbulent flow velocity distribution. Use suitable equations and diagrams to support your findings.

(6 marks)
Total 20 marks

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Q6.

(a) A foul sewer system has to be designed for a town with an estimated population of 25000. State the general guidelines used for the design of this foul sewer system.

(6 marks)

(b) Details of an existing surface water sewer system are given below in **Table Q6a**. The pipes in the system have pipe roughness ks of 1.5mm and the time of entry for surface water is 5 minutes. Using the Rational method, complete **Table Q6b on Page 19.** provided, check whether the system is capable of withstanding a 1 in 10 years return period storm. **Use the Rainfall Table and HRS tables are provided under supplementary Information.**

Table Q6a. Drainage Design Data

1	**2**	**3**	**4**	**5**
Pipe Ref No	Pipe length (m)	Pipe gradient (1 in)	Imp. Area (ha)	Pipe dia. (mm)
1.00	150	62	0.15	225
1.01	170	105	0.12	300
2.00	220	182	0.13	225
2.01	160	71	0.11	300
1.02	180	53	0.20	300

(14 marks)

Total 20 marks

END OF QUESTIONS

PLEASE TURN THE PAGE FOR FORMULA SHEET SECTION A

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Formula Sheet for Section A

$$\sigma = \sigma' + u$$

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

$$\sigma_v = qI$$

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Supplementary Information Section A

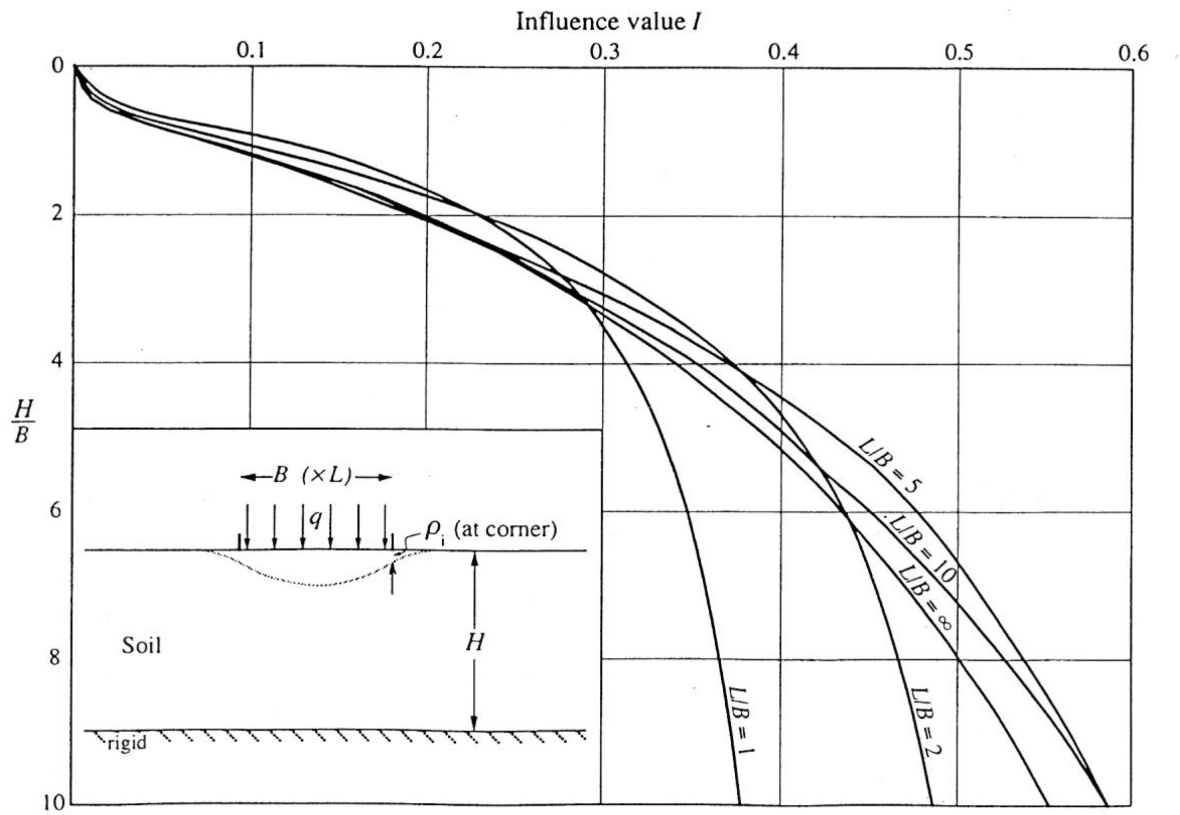

Figure Q1a. Influence values for immediate settlement

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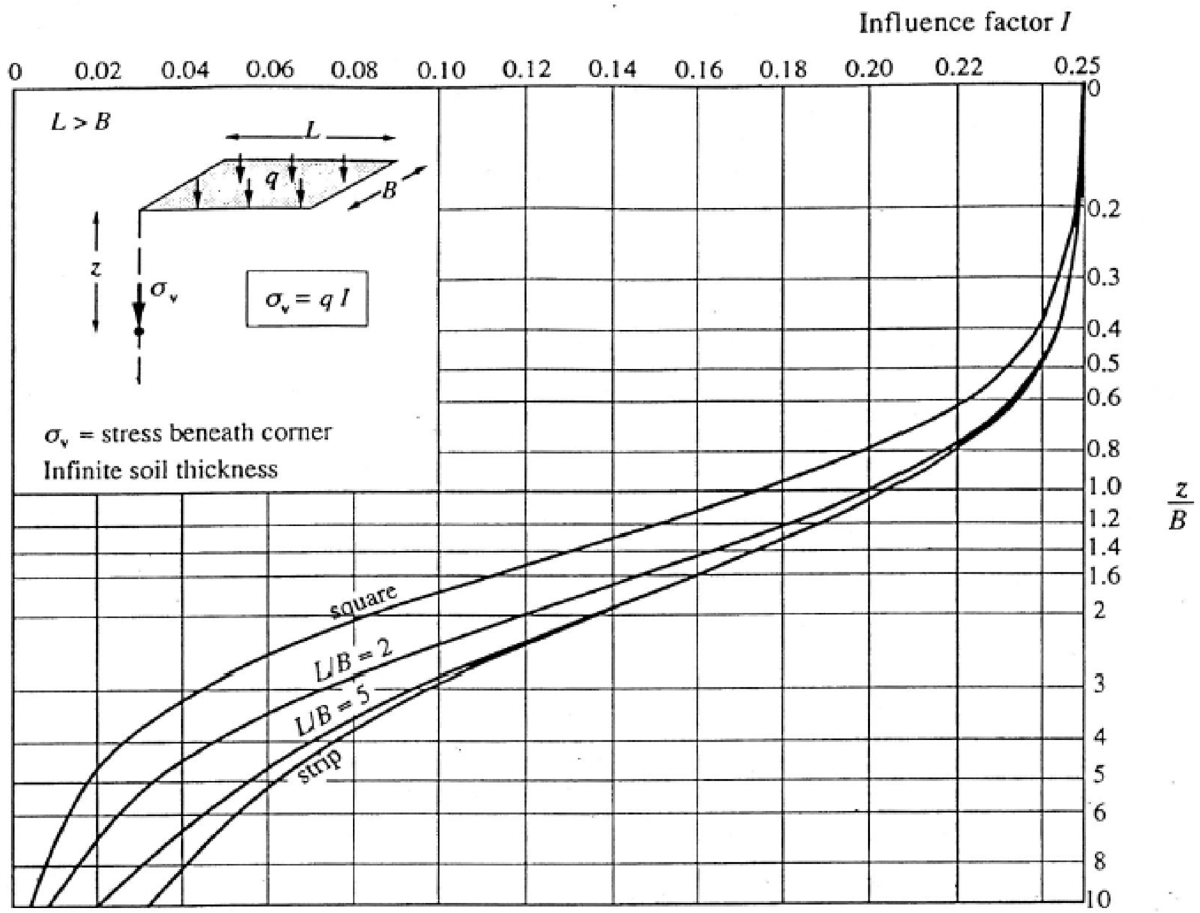

Figure Q1b. Giroud Curves for Influence Factors

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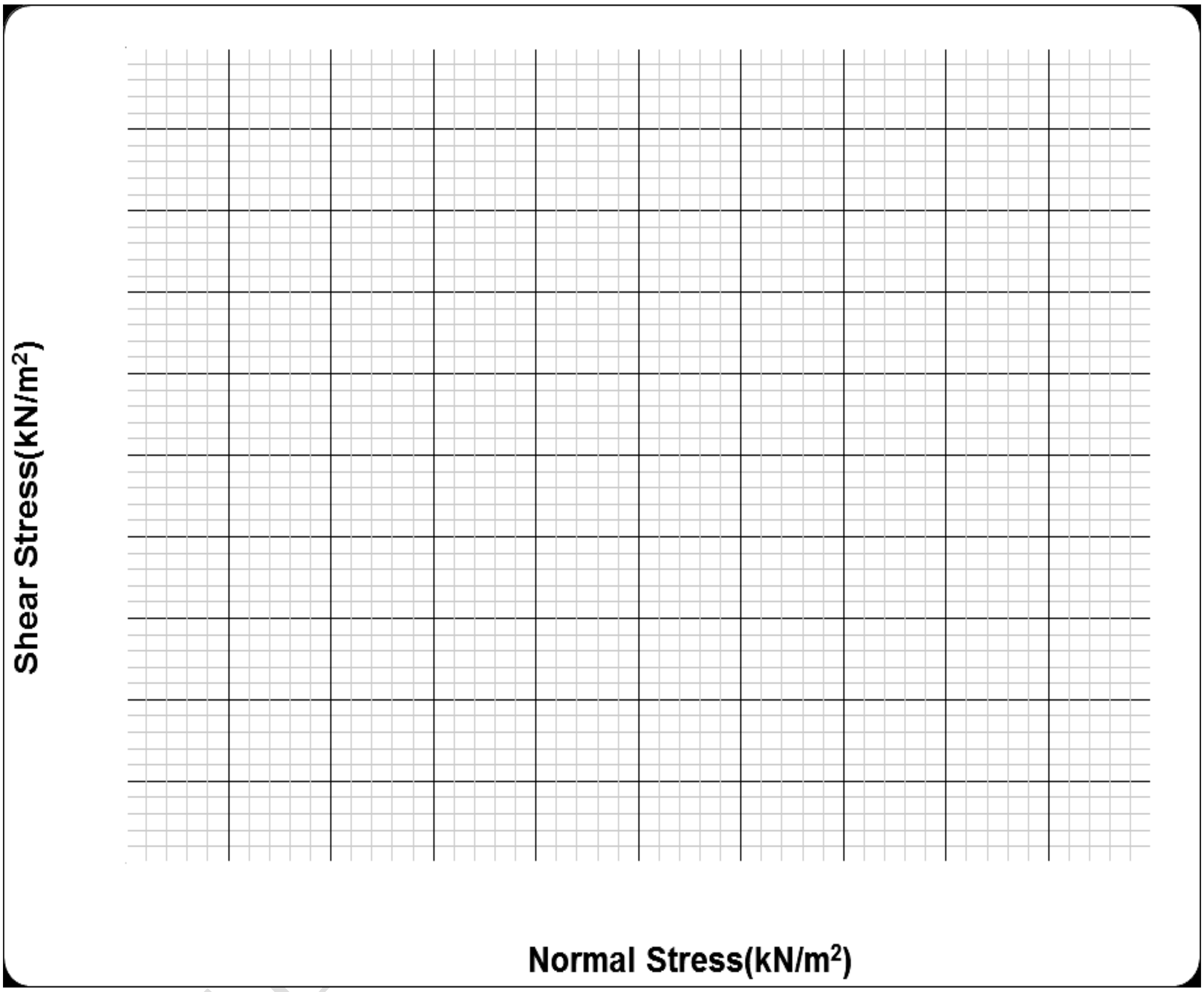

Figure Q2a.

TO BE HANDED IN WITH THE ANSWER BOOK

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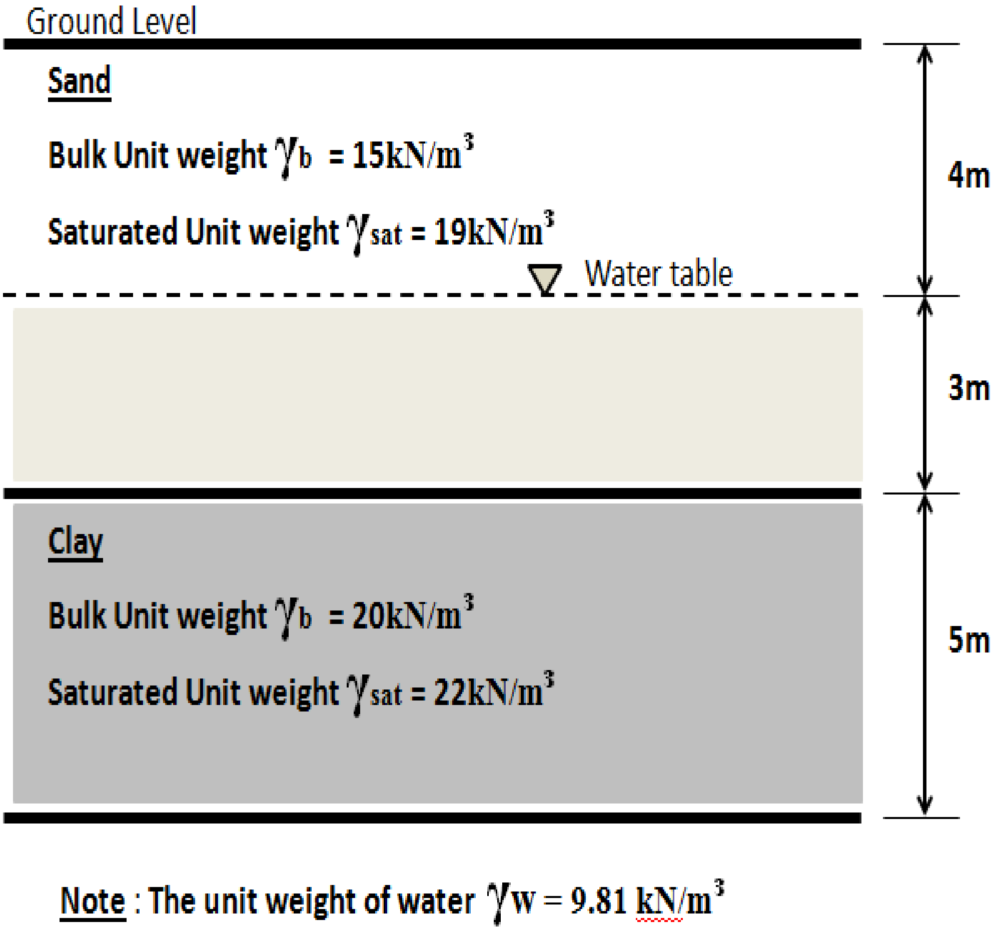

Figure Q2b.

END OF FORMULA SHEETS FOR SECTION A

PLEASE TURN THE PAGE FOR SECTION B FORMULA SHEET

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Formula sheet for Section B

$$z_1 + \frac{v_1^2}{2g} + \frac{P_1}{\rho g} = z_2 + \frac{v_2^2}{2g} + \frac{P_2}{\rho g} + h_f$$

$$Q = A\,v$$

$$h_f = \frac{\lambda\, L\, v^2}{2\, g\, d}$$

$$h_f = \frac{\lambda\, L\, Q^2}{12.1\, d^5}$$

$$h_f = S_o\, L$$

$$Re = \frac{v\, d}{\nu} = \frac{\rho\, v\, d}{\mu}$$

$$\nu = \frac{\mu}{\rho}$$

$$\frac{1}{\sqrt{\lambda}} = -2\log\left[\frac{k_s}{3.7d} + \frac{5.1286}{R_e^{0.89}}\right]$$

$$Q = 2.78\, A_p\, i$$

PLEASE TURN THE PAGE FOR SECTION B SUPPLEMENTARY INFORMATION

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Supplementary Information Section B

Rainfall Data

Rates of Rainfall in mm/h for a range of duration and return period for a specified location in the United Kingdom

National Grid Reference 4833E 1633N

	RETURN PERIOD (YEARS)						
DURATION	1	2	5	10	20	50	100
2.0 MINS	85.6	93.4	120.5	138.3	158	187	213
2.5 MINS	76.5	87.5	113.4	130.4	149	177	202
3.0 MINS	66.3	82.3	107.2	123.4	141	168	192
3.5 MINS	62.8	77.8	101.7	117.3	135	161	184
4.0 MINS	59.6	73.8	96.8	111.8	128	154	176
4.1 MINS	59.1	73.1	95.9	110.8	127	152	174
4.2 MINS	58.5	72.3	95.0	109.8	126	151	173
4.3 MINS	57.9	71.6	94.1	108.8	125	150	172
4.4 MINS	57.4	71.0	93.2	107.9	124	149	170
4.5 MINS	56.9	70.3	92.4	106.9	123	148	169
4.6 MINS	56.3	69.6	91.6	106.0	122	146	168
4.7 MINS	55.8	69.0	90.8	105.1	121	145	166
4.8 MINS	55.3	68.3	90.0	104.2	120	144	165
4.9 MINS	54.8	67.7	89.2	103.4	119	143	164
5.0 MINS	54.3	67.1	88.5	102.5	118	142	163
5.1 MINS	53.9	66.5	87.7	101.7	117	141	162
5.2 MINS	53.4	65.9	87.0	100.9	116	140	160
5.3 MINS	53.0	65.4	86.3	100.1	115	139	159
5.4 MINS	52.5	64.8	85.6	99.3	115	138	158
5.5 MINS	52.1	64.3	84.9	98.5	114	137	157
5.6 MINS	51.7	63.7	84.2	97.8	113	136	156
5.7 MINS	51.2	63.2	83.5	97.0	112	135	155
5.8 MINS	50.8	62.7	82.9	96.3	111	134	154
5.9 MINS	50.4	62.2	82.3	95.6	110	133	153
6.0 MINS	50.0	61.7	81.6	94.9	110	132	152
6.2 MINS	49.3	60.7	80.4	93.5	108	130	150
6.4 MINS	48.5	59.8	79.2	92.2	107	129	148
6.6 MINS	47.8	58.9	78.1	90.9	105	127	146
6.8 MINS	47.1	58.0	77.0	89.6	104	125	144
7.0 MINS	46.4	57.2	75.9	88.4	102	124	143
7.2 MINS	45.8	56.4	74.9	87.3	101	122	141
7.4 MINS	45.2	55.6	73.9	86.1	100	121	139
7.6 MINS	44.5	54.8	72.9	85.0	99	119	138
7.8 MINS	44.0	54.1	71.9	84.0	97	118	136
8.0 MINS	43.4	53.4	71.0	82.9	96	117	135
8.2 MINS	42.8	52.7	70.1	81.9	95	115	133
8.4 MINS	42.3	52.0	69.3	81.0	94	114	132
8.6 MINS	41.8	51.4	68.4	80.0	93	113	131
8.8 MINS	41.2	50.7	67.6	79.1	92	112	129
9.0 MINS	40.8	50.1	66.8	78.2	91	110	128
9.2 MINS	40.3	49.5	66.0	77.3	90	109	127
9.4 MINS	39.9	49.0	65.3	76.4	89	108	125
9.6 MINS	39.4	48.4	64.6	75.6	88	107	124
9.8 MINS	39.0	47.9	63.8	74.8	87	106	123
10.0 MINS	38.6	47.4	63.1	74.0	86	105	121
10.5 MINS	37.6	46.1	61.5	72.1	84	102	118
11.0 MINS	36.7	44.9	59.9	70.2	82	100	116
11.5 MINS	35.8	43.8	58.4	68.5	80	97	113
12.0 MINS	35.0	42.8	57.0	66.9	78	95	111
12.5 MINS	34.2	41.8	55.7	65.4	76	93	108
13.0 MINS	33.4	40.8	54.4	64.0	75	91	106
13.5 MINS	32.7	39.9	53.3	62.6	73	89	104
14.0 MINS	32.0	39.1	52.1	61.3	72	87	102
14.5 MINS	31.4	38.3	51.0	60.0	70	86	100
15.0 MINS	30.8	37.5	50.0	58.8	69	84	98
16.0 MINS	29.6	36.1	48.1	56.6	66	81	94
17.0 MINS	28.6	34.8	46.3	54.6	64	78	91
18.0 MINS	27.6	33.5	44.7	52.7	62	76	88
19.0 MINS	26.7	32.4	43.2	51.0	60	73	85
20.0 MINS	25.9	31.4	41.8	49.3	58	71	83

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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

8
continued

Gradient	Pipe diameters in mm: 50	75	80	100	125	150	175	200	225	250	275	300
0.00075	0.108	0.145	0.152	0.178	0.208	0.236	0.262	0.286	0.310	0.333	0.354	0.375
1/ 1333	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	0.112	0.150	0.157	0.184	0.215	0.244	0.270	0.296	0.320	0.344	0.366	0.388
1/ 1250	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	0.115	0.155	0.162	0.190	0.222	0.251	0.279	0.305	0.330	0.354	0.378	0.400
1/ 1176	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	0.119	0.159	0.167	0.195	0.228	0.259	0.287	0.314	0.340	0.365	0.389	0.412
1/ 1111	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	0.122	0.164	0.172	0.201	0.235	0.266	0.295	0.323	0.350	0.375	0.400	0.423
1/ 1053	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	0.125	0.168	0.176	0.206	0.241	0.273	0.303	0.332	0.359	0.385	0.410	0.434
1/ 1000	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	0.132	0.177	0.185	0.217	0.253	0.286	0.318	0.348	0.377	0.404	0.430	0.456
1/ 909	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	0.138	0.185	0.194	0.226	0.264	0.299	0.332	0.364	0.394	0.422	0.450	0.476
1/ 833	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	0.144	0.193	0.202	0.236	0.275	0.312	0.346	0.379	0.410	0.440	0.468	0.496
1/ 769	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	0.149	0.200	0.209	0.245	0.286	0.324	0.360	0.393	0.426	0.457	0.486	0.515
1/ 714	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	0.155	0.207	0.217	0.254	0.296	0.335	0.372	0.407	0.441	0.473	0.504	0.533
1/ 667	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	0.160	0.214	0.224	0.262	0.306	0.347	0.385	0.421	0.455	0.488	0.520	0.551
1/ 625	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	0.165	0.221	0.231	0.271	0.316	0.357	0.397	0.434	0.470	0.504	0.536	0.568
1/ 588	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	0.170	0.228	0.238	0.279	0.325	0.368	0.408	0.447	0.483	0.518	0.552	0.585
1/ 556	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	0.175	0.234	0.245	0.286	0.334	0.378	0.420	0.459	0.497	0.533	0.567	0.601
1/ 526	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	0.180	0.240	0.251	0.294	0.343	0.388	0.431	0.471	0.510	0.547	0.582	0.617
1/ 500	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	0.189	0.252	0.264	0.308	0.360	0.407	0.452	0.495	0.535	0.574	0.611	0.647
1/ 455	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	0.197	0.264	0.276	0.322	0.376	0.426	0.473	0.517	0.559	0.599	0.638	0.676
1/ 417	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	0.205	0.275	0.287	0.336	0.392	0.443	0.492	0.538	0.582	0.624	0.665	0.704
1/ 385	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	0.213	0.285	0.298	0.349	0.407	0.460	0.511	0.559	0.604	0.648	0.690	0.731
1/ 357	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	0.221	0.295	0.309	0.361	0.421	0.477	0.529	0.578	0.626	0.671	0.715	0.757
1/ 333	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	0.229	0.305	0.319	0.373	0.435	0.493	0.546	0.598	0.646	0.693	0.738	0.782
1/ 313	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	0.236	0.315	0.329	0.385	0.449	0.508	0.563	0.616	0.666	0.715	0.761	0.806
1/ 294	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	0.243	0.324	0.339	0.396	0.462	0.523	0.580	0.634	0.686	0.736	0.783	0.829
1/ 278	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	0.250	0.333	0.349	0.407	0.475	0.537	0.596	0.652	0.705	0.756	0.805	0.852
1/ 263	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

ks = 1·500mm   i < 0·004

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8 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	0.256	0.342	0.358	0.418	0.487	0.551	0.612	0.669	0.723	0.776	0.826	0.875
1/ 250	0.503	1.511	1.799	3.282	5.978	9.743	14.713	21.013	28.762	38.074	49.057	61.816
0.00420	0.263	0.351	0.367	0.428	0.499	0.565	0.627	0.686	0.741	0.795	0.846	0.896
1/ 238	0.516	1.549	1.844	3.365	6.127	9.986	15.080	21.536	29.478	39.021	50.277	63.353
0.00440	0.269	0.359	0.376	0.439	0.511	0.579	0.642	0.702	0.759	0.814	0.867	0.917
1/ 227	0.528	1.586	1.888	3.445	6.273	10.224	15.438	22.047	30.177	39.946	51.468	64.854
0.00460	0.275	0.367	0.384	0.449	0.523	0.592	0.656	0.718	0.776	0.832	0.886	0.938
1/ 217	0.540	1.622	1.931	3.523	6.416	10.456	15.788	22.547	30.860	40.850	52.633	66.320
0.00480	0.281	0.375	0.393	0.458	0.534	0.605	0.671	0.733	0.793	0.850	0.905	0.959
1/ 208	0.552	1.658	1.973	3.600	6.555	10.683	16.130	23.035	31.529	41.735	53.773	67.756
0.00500	0.287	0.383	0.401	0.468	0.545	0.617	0.685	0.748	0.809	0.868	0.924	0.978
1/ 200	0.564	1.692	2.014	3.675	6.692	10.905	16.466	23.514	32.184	42.602	54.889	69.162
0.00550	0.301	0.402	0.421	0.491	0.572	0.648	0.718	0.785	0.849	0.911	0.970	1.026
1/ 182	0.592	1.776	2.114	3.857	7.022	11.443	17.276	24.671	33.766	44.695	57.585	72.558
0.00600	0.315	0.420	0.440	0.513	0.598	0.677	0.750	0.820	0.887	0.951	1.013	1.072
1/ 167	0.618	1.856	2.209	4.030	7.337	11.956	18.051	25.776	35.278	46.695	60.161	75.802
0.00650	0.328	0.438	0.458	0.534	0.623	0.704	0.781	0.854	0.924	0.990	1.054	1.116
1/ 154	0.644	1.933	2.301	4.197	7.640	12.448	18.794	26.836	36.728	48.614	62.632	78.915
0.00700	0.341	0.454	0.475	0.555	0.646	0.731	0.811	0.887	0.959	1.028	1.095	1.159
1/ 143	0.669	2.007	2.389	4.357	7.931	12.922	19.508	27.856	38.123	50.460	65.009	81.910
0.00750	0.353	0.470	0.492	0.574	0.669	0.757	0.840	0.918	0.993	1.064	1.133	1.200
1/ 133	0.693	2.078	2.474	4.511	8.212	13.379	20.198	28.840	39.470	52.241	67.303	84.799
0.00800	0.365	0.486	0.508	0.593	0.691	0.782	0.867	0.948	1.025	1.099	1.170	1.239
1/ 125	0.716	2.147	2.556	4.661	8.484	13.822	20.865	29.792	40.772	53.964	69.522	87.594
0.00850	0.376	0.501	0.524	0.612	0.713	0.806	0.894	0.978	1.057	1.133	1.207	1.278
1/ 118	0.738	2.214	2.635	4.806	8.747	14.250	21.512	30.715	42.034	55.634	71.673	90.303
0.00900	0.387	0.516	0.540	0.630	0.734	0.830	0.920	1.006	1.088	1.166	1.242	1.315
1/ 111	0.760	2.279	2.712	4.946	9.002	14.666	22.139	31.611	43.259	57.255	73.761	92.933
0.00950	0.398	0.530	0.555	0.647	0.754	0.853	0.946	1.034	1.118	1.199	1.276	1.351
1/ 105	0.781	2.342	2.788	5.083	9.251	15.071	22.750	32.482	44.451	58.832	75.792	95.491
0.01000	0.408	0.544	0.569	0.664	0.774	0.875	0.971	1.061	1.147	1.230	1.309	1.386
1/ 100	0.802	2.404	2.861	5.216	9.493	15.465	23.345	33.331	45.612	60.368	77.770	97.983
0.01100	0.429	0.571	0.597	0.697	0.812	0.918	1.018	1.113	1.203	1.290	1.374	1.454
1/ 91	0.841	2.522	3.002	5.473	9.960	16.225	24.491	34.967	47.850	63.329	81.583	102.786
0.01200	0.448	0.597	0.624	0.728	0.848	0.959	1.064	1.163	1.257	1.348	1.435	1.519
1/ 83	0.879	2.636	3.137	5.718	10.406	16.951	25.586	36.530	49.988	66.158	85.226	107.375
0.01300	0.466	0.621	0.650	0.758	0.883	0.999	1.107	1.210	1.309	1.403	1.494	1.581
1/ 77	0.916	2.744	3.266	5.954	10.834	17.648	26.637	38.029	52.039	68.871	88.721	111.776
0.01400	0.484	0.645	0.674	0.787	0.916	1.037	1.149	1.256	1.358	1.456	1.550	1.641
1/ 71	0.951	2.849	3.390	6.180	11.246	18.318	27.648	39.472	54.012	71.482	92.083	116.012
0.01500	0.501	0.668	0.698	0.815	0.949	1.073	1.190	1.301	1.406	1.508	1.605	1.699
1/ 67	0.984	2.950	3.510	6.399	11.643	18.964	28.623	40.864	55.916	74.001	95.328	120.099
0.01600	0.518	0.690	0.721	0.842	0.980	1.109	1.229	1.344	1.453	1.557	1.658	1.755
1/ 62	1.017	3.047	3.626	6.610	12.027	19.590	29.567	42.210	57.758	76.437	98.466	124.051
0.01700	0.534	0.711	0.744	0.868	1.010	1.143	1.267	1.385	1.498	1.605	1.709	1.809
1/ 59	1.049	3.142	3.739	6.815	12.400	20.196	30.481	43.515	59.543	78.799	101.507	127.882
0.01800	0.550	0.732	0.766	0.893	1.040	1.176	1.304	1.425	1.541	1.652	1.759	1.862
1/ 56	1.079	3.234	3.848	7.014	12.761	20.784	31.369	44.782	61.276	81.092	104.460	131.602
0.01900	0.565	0.752	0.787	0.918	1.069	1.209	1.340	1.465	1.584	1.697	1.807	1.913
1/ 53	1.109	3.323	3.954	7.208	13.113	21.357	32.232	46.014	62.961	83.322	107.332	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

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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…

Table Q4b. Flow balancing Method

	1st estimate H_j = ………………….m					2nd estimate H_j = ………………………..		
Pipe	**h_f across Pipe (m)**	**S_O (1 in)**	**Q (litre/s)**	**Q (m^3/s)**	**Q/hf**	**hf across Pipe (m)**	**S_O (1 in)**	**Q (litre/s)**
A								
B								
C								
Error in Q = Δ Q =						**Error in Q = Δ Q =**		
$\Delta H = \dfrac{2\,\Delta Q}{\sum Q/h_f}$								

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Table Q6b. Drainage Design

Pipe length ref No	Pipe length (m)	Pipe gradient (1 in)	Vel (m/s)	Time of flow (min)	Time of Conc. (min)	Rate of rainfall i (mm/hr)	Imp. Area (ha)	Cumulative Imp. Area A_P (ha)	Flow Q (l/s)	Pipe dia. (mm)
1.00	150	62					0.15			225
1.01	170	105					0.12			300
2.00	220	182					0.13			225
2.01	160	71					0.11			300
1.02	180	53					0.20			300

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