4.2 STRUCTURAL DESIGN

4.2.1 Design Principles

The forces acting on a cross section of pipeline arise from three main sources:

A) Weight of overlying fill, including any local surcharge.

B) Soil pressures transmitted to the pipe from surface loads, i.e. traffic and other transient loads.

C) Supporting reaction below the pipe.

The weight of water within the pipe is only significant for larger diameter pipes.

A: Weight of overlying fill

There are four main conditions in which pipes are installed:

a) "Narrow" trench.

b) "Wide" trench, or on the surface of ground over which an embankment is then built (positive projection condition).

c) Narrow trench over which an embankment is then built (negative projection condition).

d) Tunnel, heading or by jacking.

The load W_c imposed by the backfill on a pipe in a "narrow" trench can be found from Marston's formula from which the Tables have been compiled in Section 4.2.7.

These Tables are only applicable to rigid pipes laid in "Narrow" trench conditions.

B: Traffic and other transient loads

Measurements have shown that on large civil engineering works pipes may well be subjected to their highest loads during construction. Here, three categories of traffic loading are considered and rigid pipes should normally be designed to withstand the most onerous likely to occur.

If during construction it is clear that excessive site traffic loading will occur, the design should be checked accordingly or special crossing places must be designated.

a) **Main road loading** is intended to apply to all main traffic routes and to roads liable to be used for the temporary diversion of heavy traffic.

As a guide it may be assumed that such roads carry at least 200 commercial vehicles per day in each direction. HA and HB loading are assumed to use such roads (see BS 5400).

b) **Light road loading** applies to all other roads where heavy traffic is unlikely to pass.

c) **Field loading** applies to fields, gardens and lightly trafficked access tracks. This loading is also considered to be adequate to cater for occasional heaps or stacks of materials on the ground surface. Massive heaps or stacks likely to produce a more severe loading should be treated as a special design.

In assessing the loading category, regard should be paid to the possible future upgrading of a road. Pipes under verges should normally be treated as though under the road, with the possible exception of motorways and trunk roads and should take account of any planned road improvement. For non-public roads such as estate roads or roads within works, an assessment should be made of the heaviest vehicle likely to use the road, and one of the above three loading conditions selected as appropriate.

C: Supporting reaction below the pipe

British Standards for concrete pipes give maximum crushing loads for each diameter and strength class of pipe. Loads are applied in a 3 edged loading test described in BS 5911. The pipe must not collapse under the maximum load specified.

Proof test loads are also specified. Reinforced pipes must not crack by more than a specified amount under the proof load. The only proof load test for unreinforced pipes is the maximum load.

Pipes of a small diameter (up to DN 300) may fail as a beam. BS 5911 includes suitable values of bending moment resistance.

Pipe bedding

This term is used to describe the complete arc of material within the trench, or in the case of class "C" or class "D" beddings, a special preparation of the trench bottom.

Bedding factor

In the standard test on pipes the vertical loading and supporting reactions are line loads and any trench situation in the field is unlikely to produce such an onerous loading condition. The strength of the pipe determined in the crushing test can therefore be multiplied by a bedding factor which represents the amount by which the stresses in the pipe are reduced because of the spreading properties of the bedding for load and reaction.

The value of a bedding factor for a particular method of construction is not a precise figure but is affected by the quality of workmanship. The values given whilst being conservative assume a reasonable standard of workmanship and supervision. If the designer needs a somewhat higher bedding factor than stated a high standard of workmanship and supervision must be specified and guaranteed; alternatively a higher strength pipe may be considered. If this is an extra strength pipe adequate time must be allowed for the manufacturer to supply.

Factor of safety

To allow for unexpected site conditions or the vagaries of construction a minimum factor of safety of 1.25 should be allowed on the calculated loads.

4.2.2 Design Assumptions

Surface Conditions

The Tables in Section 4.2.7 are applicable only to a single pipeline laid in its own trench, and have been set out to give the loads on pipes under three surface conditions, Main Roads, Light Roads and Fields.

Backfill loads

The Tables are calculated using an equivalent soil density of 19.6 kN/m^3 (approximately 2 tonnes/m^3).

Traffic loads

The loads referred to in the design principles have values as follows:-

a) **Main roads**
Static wheel load of 86.5kN and an impact factor of 1.3, giving a Total Static wheel load of 112.5kN; contact pressure 1100kN/m^2.

b) **Light roads**
Static wheel load of 70kN and an impact factor of 1.5, giving a Total Static wheel load of 105kN; contact pressure 700 kN/m^2.

c) **Fields**
Static wheel load of 30kN and an impact factor of 2.0, giving a Total Static wheel load of 60 kN; contact pressure 400kN/m^2.

Superimposed loads

These are not included in the Tables. If however such loads are encountered and are of sufficient magnitude, an allowance should be made.

Water Loads

These are included in the Tables. If the pipe is laid below the ground water table, an allowance for this load is not needed. However, as these loads are small by comparison with other loads on the pipe, it has been considered appropriate to include them only for pipes of DN 600 and over.

Frictional factor Kμ

A value of 0.13 has been used for narrow trench conditions.

Minimum cover over pipe

a) It is advisable that pipes laid under roads should have cover over the pipe of not less than 1.2m. This cover should be maintained for main roads, light roads (which may on occasion carry main road traffic) and for pipes laid under grass verges adjacent to a road (Tables B3 and B4). Where pipes have to be laid with less than 1.2m cover special consideration is needed to reduce the risk of damage. Loads in columns headed 0.9 and 1.0 in Tables B3 and B4 should be used only as a guide.

b) For pipes laid in fields a minimum cover of 0.6m should be provided. At shallower depths there is a risk of damage from agricultural operations.

4.2.3 Design Method

The established method for calculation of loads on buried rigid pipes is summarised in BS EN 1295 National Annex A, the principles of which are explained below.

In general pipelines are laid in trenches and the pipes used are designed to carry the backfill, traffic loads and, when the diameter is 600mm or more, some part of the water load under working conditions.

In order to improve the load carrying capacity of the pipe it is laid on one of several classes of bedding (see Table B2). Each type of bedding is allocated a "bedding factor" (F_m) which may be regarded as a multiplier applied to the test load of the pipe.

The trench is excavated in the natural soil, the pipe is laid on the selected bedding and the trench backfilled. Load on the pipe due to the backfill develops as the fill material settles. The load on the pipe due to the backfill is therefore the weight of the backfill taken over the full trench width but reduced by the shear force from the trench walls acting upwards (see Fig.B1). The backfill load is calculated by using the Marston formula:

$$W_c = C_d \; w \; B_d^2$$

where:

W_c = Backfill load (KN/m)

C_d = Load coefficient, dependent on soil type and the ratio of cover depth to trench width

w = Soil density (kN/m^3)

B_d = Width of trench (m)

Provided that the trench width does not exceed the values given in the tables, the loads given are conservative and may be used with confidence.

The trench widths given will provide adequate working space around the pipe for laying and jointing and also sufficient room to place and consolidate the bedding specified.

As indicated, the friction acting against the backfill is provided by the trench walls and is roughly constant at a particular depth. If however the trench width is increased radically, B_d^2 in the Marston formula is also increased and a reappraisal of the load on the pipe must be considered.

Fig. B1

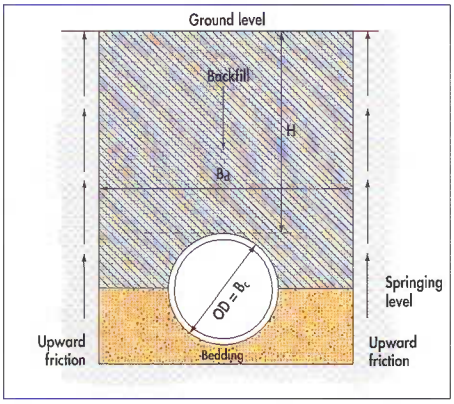
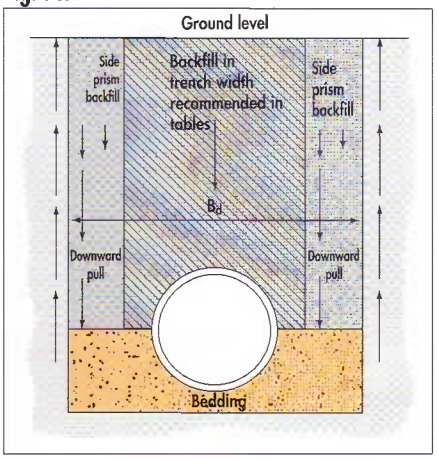


Fig. B2



For any depth there is a trench width where friction planes from the trench walls become remote from the pipe and no longer contribute to the reduction of the fill load. In fact the settlement of the side prisms of backfill tend to increase the load (see Fig.B2). This state is called the wide trench condition. It is a positive projection condition.

In preparing the tables, due consideration has been given as to whether at any trench width and depth, the narrow or wide trench condition and load is applicable, and the standard practice of using the lesser of these values has been adopted.

The tables give the total loads for pipes of all diameters specified in BS 5911: Part 100. This load includes loading from backfill and traffic for depths of cover over the top of the pipe as follows:

Main Roads and Light Roads - 1.2m to 8.0m
Fields - 0.6m to 8.0m

For DN 600 and above the water load shown is also included.

Table B1.
Crushing Test Loads: W_t

Crushing test loads kN/m			
Nominal size of pipe DN	Class L Maximum load	Class M Maximum load	Class H Maximum load
225	25	29	35
300	25	29	40
375	25	39	45
450	25	44	52
525	25	48	58
600	25	58	68
675	25	63	75
750	48	67	81
825	52	72	86
900	58	84	106
975	60	90	114
1050	64	95	120
1125	67	103	133
1200	72	109	138
1350	79	120	153
1500	87	130	165
1650	94	145	183
1800	103	155	193
1950	110	169	212
2100	120	183	230
2250	128	194	244
2400	135	207	263
2550	145	222	279
2700	155	233	294
2850	163	244	314
3000	169	259	326

4.2.4 Pipe Bedding

The load bearing capacity of an installed pipeline relates directly to the construction of the bedding which is intended to level out any irregularities in the formation, and provide uniform support around and along the length of the pipe barrel.

Pipe settlement will be kept to a minimum by the proper selection and compaction of the bedding material. The bedding should be compacted to a density not less than that of the natural soil in the sides and bottom of the trench. The bedding directly beneath or above the pipeline must not be over compacted otherwise line loading of the pipes will result.

On steep gradients, or where dewatering has taken place, it is important to restrict ground water movement within the completed trench. Selection of bedding or clay dams across the full width of the trench will assist in this.

Under no circumstances should blocks or bricks be placed beneath pipes. Any pegs used for setting out or levelling must be removed.

Bedding materials

Any stable soil will act adequately as a bedding material provided that it is placed and compacted around the pipeline. From a practical point of view granular material is compacted more readily and has become widely accepted.

The bedding material should be of similar particle size to that in the trench sides. Where the ground is clay or silt, bedding material must consist of all-in gravels to prevent the trench from becoming a drainage channel and carrying away fines from the trench walls and bedding and causing settlement of the pipes.

Granular bedding material

The ideal is crushed rock or gravel but similar locally available material having an angular or an irregular shape may be used. Rounded single sized material is not recommended as it may not provide a stable bed especially for heavy larger diameter pipes.

WRc Information and Guidance Note (IGN) 4-08-01

provides guidance on the particle size of material relating to pipe diameter.

Sands containing an excess of fine particles are more difficult to place and compact and will require a greater degree of supervision on site to achieve a stable embedment for the pipeline.

Selected bedding and fill material

This should consist of uniform readily compatible material, free from tree roots, vegetable matter, building rubbish and frozen soil. When used as fill, the material should not contain large clay lumps or cobbles. When used as bedding, all clay lumps should be excluded.

"As dug" material may be used provided that it is readily compatible and provides stable embedment.

Classes of bedding and bedding factors

The strength of an installed pipeline depends on a combination of the strength of the pipe and the class of bedding.

The selection of the bedding class is influenced by many factors, which include the nature of the ground, the loads acting on the pipeline in the trench, availability of a particular strength class of pipe, and the local cost and availability of the bedding material.

Where imported granular material is expensive and where supervision of site work cannot be guaranteed, it is preferable to specify a lower class of bedding with a higher strength pipe, which is proved by works testing, rather than vice-versa.

Taking into account the cost of labour, it is generally more economical to lay the pipes on a bedding of non-cohesive materials, or alternatively scarify the trench bottom rather than hand trim the formation.

Normally loading calculations are made considering the pipeline in complete lengths, between manholes. The calculated strength class for a pipe to satisfy the most severe loading condition between each pair of manholes is then used throughout the length. However there are occasions when it may be necessary to use a higher bedding class for a short distance where locally the load is increased, for instance at a road crossing or in an embankment.

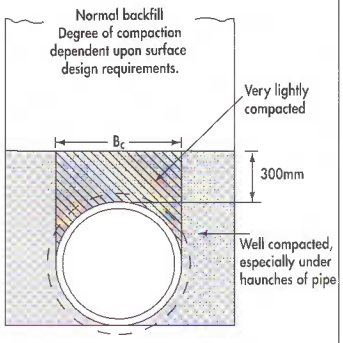
The normally accepted classes of pipe bedding are shown in Table B2 and in Fig. B3.

Table B2.
Types of Bedding

Bedding Class	Bedding factor	Description	Suitability
Class D	1.1	Hand trimmed flat bottom/ formation	Fine grained soils, relatively dry conditions
Class N	1.1	Flat bed of granular all-in or selected material	Rock, mixed soils
Class C	1.5	Shaped formation (or scarify)	Uniform soils relatively dry
Class F	1.5	Shaped bedding of granular material	General
Class B	1.9	180° non cohesive bedding material	General
Class S	2.2	Complete surround of non cohesive bedding material	General
Class A Plain	2.6	Plain concrete cradle	Seldom necessary. Higher strength pipe with granular bedding is more practicable and economic option.
Class A Reinforced	3.4	Reinforced concrete cradle	
Concrete Arches	Sometimes used where an existing pipeline is to be surcharged with additional fill or a road construction. Use the same bedding factor as Class A cradles but calculate loadings using the arch dimensions instead of the outside diameter of the pipe.		
Geotextiles Where appropriate, geotextiles may be used to contain bedding materials e.g. in running sand			

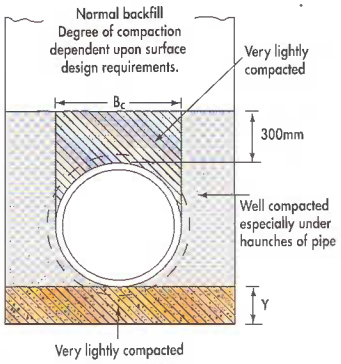
Fig. B3
Types of bedding

Class D
Hand trimmed flat bottom.
Bedding factor = 1.1



Suitable in fine grained soils and relatively dry conditions. Hand trim formation filling in any hollows. Form socket holes as appropriate with 50mm minimum clearance of sufficient length to permit jointing. Pipes are laid directly on the formation.

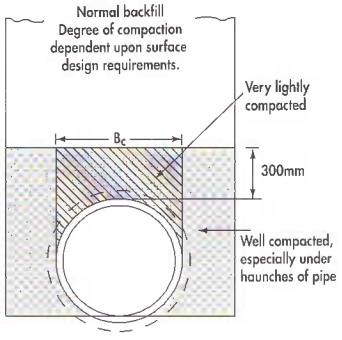
Class N
Flat granular layer.
Bedding factor = 1.1



Lay pipes on a flat layer of all-in or selected material (see Note 1).

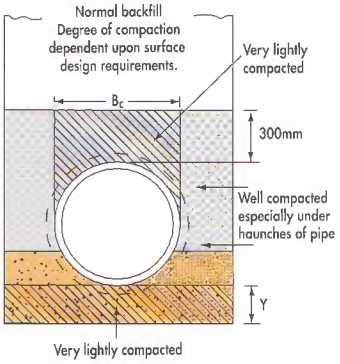
*Scarifying formation is generally adequate in practice.

Class C
Hand shaped bottom
Bedding factor = 1.5



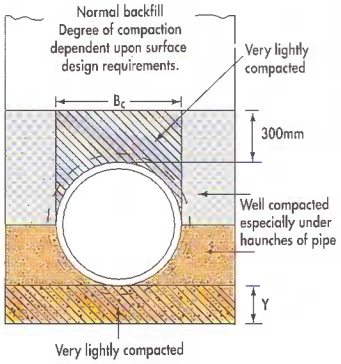
Suitable in uniform soils and relatively dry conditions. Bottom of the trench, or formation, profiled to fit the barrels over a width of not less than $^1/_2$ B_c with socket holes to give at least 50mm clearance under the sockets of sufficient length to permit jointing.*

Class F
Granular bedding
Bedding factor = 1.5



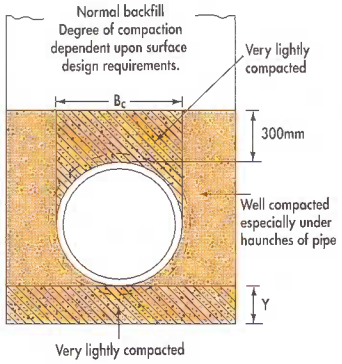
Lay pipes on a flat layer of granular bedding material on the formation, (see Note 1). Scoop out socket holes with 50mm minimum clearance; lay and joint pipes which will settle slightly in to the bedding. Sidefills, placed and well compacted in layers.

Class B
180° Granular bedding
Bedding factor = 1.9



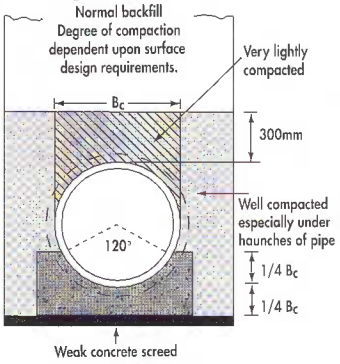
Lay pipes on a layer of granular bedding material on the formation (see Note 1).
Scoop out socket holes, lay and joint pipes, place and well compact layers of the same bedding material at each side of pipes, up to springing level, taking care not to displace them.

Class S
360° Granular bedding & surround
Bedding factor = 2.2



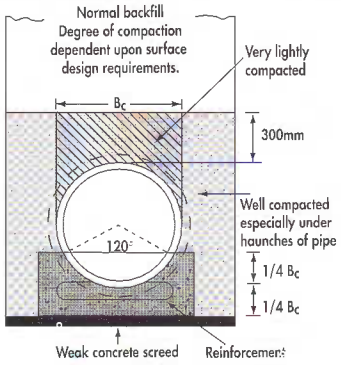
Lay, joint and bed pipes as for Class B then place and well compact layers of the same bedding material at each side, up to crown level, taking care not to displace the pipes. This is followed by 300mm of the same granular bedding material but lightly compacted directly over the pipe, after which ordinary backfilling is commenced.

Class A
Plain concrete cradle
Bedding factor = 2.6

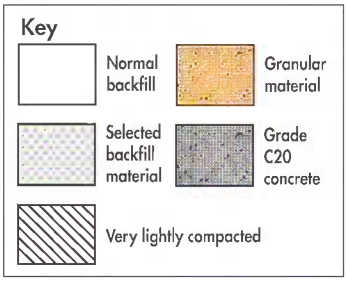


Class A concrete bedding, either plain or reinforced each with 120° cradle. Screed the formation,

Reinforced concrete cradle
Bedding factor = 3.4



place blocks on the screed to support pipes behind each socket. Lay pipes, using packers on blocks to achieve correct line and level. At pipe joints, form construction joints through concrete bed to ensure flexibility of pipeline. Minimum width of cradle $1\,^1/_4 B_c$ or B_c plus 200mm. Minimum thickness $^1/_4 B_c$. Pour concrete carefully from one side to prevent voids. Backfill when concrete has attained required strength.



NOTES:

1. Generally thickness of bedding (Y), minimum of 100mm under barrels and 50mm under sockets. In rock 200mm under barrels and 150mm under sockets. Minimal compaction directly beneath pipe.
2. Sidefills, whether of bedding material or of selected material, must be well compacted.
3. Backfill or bedding material to be highly compacted above sidefills to 300mm above the crown but lightly compacted directly over the pipe.
4. Normal backfill to be compacted as appropriate.
5. With reasonable workmanship and supervision these bedding factors are conservative.

4.2.5 Design Calculations

The calculated load "W_e", which is the total load a concrete pipe in a trench is required to sustain, is used in the design formula as follows:

$$W_t = \frac{W_e \times F_{se}}{F_m}$$

where W_t is the required BS test strength.
W_e is the load from Tables B3 or B4.
F_{se} is the factor of safety.
F_m is the bedding factor chosen.

Test strength of pipe (W_t)

The test strength of a concrete pipe may be referred to as W_p or W_t. Values are specified in BS 5911. (See Table B1).

For a reinforced concrete pipe W_p is the load which the pipe will sustain without developing a crack exceeding 0.25mm in width over a length of 300mm and W_t is the load which the pipe will sustain without collapse, irrespective of crack width.

However, to further simplify the procedure it is more straightforward to use in the calculation the maximum test load in every case and applying the factor of safety of 1.25 throughout.

4.2.6 Worked Examples

The symbols used in the examples are those referred to in Design Calculations (Section 4.2.4).

Example 1

What strength class is required of a 900mm concrete pipe to be laid under a main road with a cover over the top of the pipe 4.6m and on a 180° granular bed? (F_m = 1.9).

From Table B3 Main Roads.

Total load = 149kN/m
F_{se} = 1.25
F_m = 1.9

$$W_t = \frac{149 \times 1.25}{1.9} = 98.0 \text{ kN/m}$$

From Table B1.
900mm Class H Pipe - W_t = 106 kN/m
900mm Class M Pipe - W_t = 84 kN/m

Class H Pipe is required.

Note

Using Class S bedding W_t = 84.7kN/m and a Class M pipe could be used.

Example 2

The same pipe as in Example I passes under a light road with a depth cover of 7.4m. What class of bedding is required?

W_t = 106 kN/m (see Example 1)
From Table B4. Light Roads

$$W_e = 181 \text{ kN/m}$$

$$W_t = \frac{W_e \times 1.25}{F_m}$$

$$F_m = \frac{181 \times 1.25}{106} = 2.13$$

From Table B2. it will be seen that either Class A Plain bedding with F_m = 2.6, or Class S bedding with F_m = 2.2 may be used.

However it would be advisable (at this diameter) to compare the costs of the two beddings and the standard of workmanship before making a decision as to the bedding to be used.

Example 3

A 900mm pipeline consisting of Class M concrete pipes on a Class B bedding is to be laid across fields. What is the greatest depth of cover at which these pipes can be laid?.

W_t = 84kN/m
F_m = 1.9

$$\text{Total load to be carried} = \frac{84 \times 1.9}{1.25} = 128.0 \text{kN/m}$$

From Table B5. Fields.
Total load at 4.2m = 126 kN/m.
Total load at 4.4m = 130 kN/m.

Maximum cover under these conditions is 4.3m (approx.)

4.2.7 Load Tables

Table B3

Total Design Loads - Main Roads."H" = 0.9 metres to 8.0 metres

Nominal Dia. in mm	Outside Dia. in mm	Recommended Trench Width	Water Load included in kN/m	Total design load "W_e" in kiloNewtons per metre of pipe for cover depths "H" in metres																																					Nominal Dia. in mm
				0.9	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0	5.2	5.4	5.6	5.8	6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.8	8.0	
225	280	0.7	-	31.9	31.4	28.5	28.3	27.7	27.9	28.5	28.6	29.9	30.7	31.4	32.0	32.2	32.4	32.6	32.9	33.2	33.2	33.3	33.5	33.7	33.9	34.1	34.2	34.3	34.5	34.7	34.9	35	35	35.1	35.1	35.2	35.2	35.3	35.3	35.4	225
300	380	0.75	-	43.4	38.9	37.8	38.3	37.8	37.9	38.0	38.1	38.2	38.3	38.5	38.7	38.9	39.0	39.2	39.5	39.8	40.1	40.4	40.6	40.8	41.1	41.3	41.5	41.7	41.9	42.1	42.3	42.4	42.5	42.7	42.8	42.9	43.0	43.2	43.2	43.3	300
375	500	1.05	-	55.7	53.9	50.1	49.1	48.1	49.4	50.5	51.6	52.6	54.3	56.1	57.8	58.8	59.9	60.9	61.9	62.9	63.7	64.5	65.4	66.3	67.3	67.9	68.7	69.4	70.2	70.9	71.5	72.2	72.8	73.5	74.0	74.6	75.1	75.7	76.3	76.9	375
450	580	1.15	-	64.3	62.8	55.7	58.4	57.3	58.0	59.3	60.7	62.1	63.2	64.2	65.4	66.1	66.8	67.8	68.8	69.7	70.8	71.9	73.0	74.0	74.8	75.7	76.7	77.5	78.4	79.2	80.0	80.9	81.7	82.5	83.2	83.9	84.4	85.0	85.6	86.2	450
525	670	1.20	-	73.2	71.6	66.7	65.7	66.2	66.8	67.6	68.4	69.0	70.0	71.0	72.0	72.8	73.7	74.7	75.8	76.9	78.0	79.1	80.3	81.4	82.5	83.7	84.5	85.3	86.2	87.3	88.4	89.4	90.4	91.3	92.3	93.0	93.7	94.5	95.2	95.8	525
600	790	1.35	2.1	86.5	82.4	79.2	78.9	79.1	79.6	80.4	81.4	82.4	83.5	84.7	86.1	87.0	88.0	89.4	90.9	92.3	93.7	95.1	96.6	98.1	99.5	101	102	104	105	107	108	109	110	111	112	113	114	115	116	118	600
675	880	1.45	2.6	95.8	93.2	87.3	86.7	87.0	87.3	88.1	88.9	89.5	90.8	92.1	93.4	94.4	95.4	97.0	98.6	100	102	103	105	107	108	110	111	113	114	116	117	119	120	121	122	124	125	126	128	129	675
750	950	1.50	3.3	104	100	94.5	93.4	93.6	94.0	94.7	95.5	96.2	97.6	99.0	100	102	103	104	106	108	109	111	113	115	117	119	120	122	123	125	126	128	129	131	132	134	135	137	139	140	750
825	1040	1.60	3.9	113	109	103	102	101	101	102	103	104	105	107	108	109	110	112	114	116	118	119	121	123	125	127	129	131	133	135	136	138	140	142	143	145	147	148	150	151	825
900	1120	1.90	4.7	122	118	111	110	111	112	115	118	121	124	126	128	130	132	135	137	140	143	146	149	152	155	157	160	163	166	169	171	174	177	179	182	184	186	189	192	193	900
975	1200	2.00	5.5	131	127	119	117	117	119	123	126	125	131	133	136	138	140	143	146	148	151	155	158	161	164	167	170	173	175	178	181	184	187	190	192	195	198	201	204	207	975
1050	1300	2.05	6.4	141	135	128	125	127	128	130	132	136	139	141	144	146	148	151	154	157	160	164	167	170	173	176	179	183	186	189	192	195	198	201	204	207	209	212	215	218	1050
1125	1370	2.20	7.3	147	143	136	132	133	134	138	143	147	150	152	155	158	160	164	167	171	175	178	182	185	189	193	196	200	204	207	211	214	218	221	225	228	231	234	238	241	1125
1200	1490	2.30	8.3	158	153	147	142	143	145	148	152	155	158	160	163	166	169	172	176	179	183	187	191	195	199	203	207	211	215	218	221	225	229	233	237	240	244	247	250	253	1200
1350	1650	2.45	10.6	175	169	163	160	160	161	163	166	170	173	176	179	182	185	188	192	196	200	205	209	213	218	222	226	230	234	239	243	247	251	255	259	263	267	271	274	278	1350
1500	1830	2.60	13.0	192	187	180	177	177	178	181	184	187	190	193	196	198	201	205	209	214	218	223	228	232	237	241	246	251	255	260	264	269	273	278	282	287	291	296	300	305	1500
1650	2010	2.80	15.7	209	204	199	194	193	195	199	203	207	210	214	217	220	223	228	233	238	243	248	253	258	264	269	274	280	285	290	296	301	306	311	317	321	326	331	336	342	1650
1800	2240	2.95	18.7	234	228	222	218	217	218	220	223	225	228	232	235	238	241	246	251	257	262	268	273	279	284	290	296	301	307	313	319	324	330	335	341	346	352	357	362	368	1800
1950	2400	3.10	22.5	261	251	239	233	232	233	236	239	244	247	250	253	256	259	264	269	275	281	287	293	299	305	311	317	323	330	336	342	348	354	360	366	372	378	384	390	396	1950
2100	2560	3.25	25.5	278	267	255	249	247	249	252	254	257	260	263	267	270	273	278	284	289	295	302	308	315	321	328	334	340	346	353	359	366	372	379	385	392	398	404	410	416	2100
2250	2730	3.40	29.4	298	287	275	289	267	267	270	272	275	278	280	283	287	291	297	302	308	315	321	328	335	242	349	356	362	369	376	382	389	396	403	410	417	423	430	437	444	2250
2400	2890	3.55	33.3	317	304	292	286	284	284	287	289	292	295	298	301	305	309	315	321	327	334	341	348	355	362	370	377	384	391	399	406	414	421	428	435	443	450	457	464	471	2400
2550	3050	3.70	37.3	335	323	311	304	301	301	303	306	309	312	315	311	323	328	334	340	346	354	361	369	377	384	392	399	407	414	422	431	439	447	454	461	469	477	485	493	501	2550
2700	3210	3.85	42.2	357	342	329	323	320	320	323	326	329	331	334	336	341	345	352	358	365	373	381	388	396	405	413	421	429	437	446	454	462	471	480	488	496	504	512	520	528	2700
2850	3370	4.00	47.1	379	362	345	341	337	337	340	343	345	348	351	354	359	364	371	378	384	393	401	409	417	426	434	443	452	461	470	478	486	495	504	514	523	532	540	549	558	2850
3000	3540	4.15	52.0	396	381	367	361	358	359	361	363	364	367	370	374	378	382	390	398	405	414	422	431	439	448	457	466	475	484	494	503	512	521	531	540	549	559	568	577	586	3000

Note 1. Pipes at shallower depths will need special consideration.

Table B4

Total Design Loads - Light Roads. "H" = 0.9 metres to 8.0 metres

Nominal Dia. in mm	Outside Dia. in mm	Recommended Trench Width	Water Load included in kN/m	Total design load "W_e" in kiloNewtons per metre of pipe for cover depths "H" in metres																													Nominal Dia. in mm
				0.9	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0	5.2	5.4	5.6	5.8	6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.8	8.0	
225	280	0.7	-	27.1	25.0	23.1	22.0	21.8	21.9	22.5	23.3	24.2	25.3	26.2	27.2	27.6	28.0	28.4	28.9	29.3	29.7	30.1	30.4	31.0	3.1	31.4	31.7	32.0	32.3	32.6	32.8	33.1	32.2	33.4	33.5	33.5	33.6	33.7	33.8	33.9	225
300	380	0.75	-	36.9	34.3	31.5	30.0	29.4	26.8	29.9	30.1	30.5	31.0	31.6	32.2	32.6	33.0	3.5	34.1	34.7	35.2	35.7	36.3	36.8	37.3	37.8	38.1	38.4	38.7	39.0	39.3	39.6	39.9	40.2	40.4	40.7	41.0	1.2	41.4	41.6	300
375	500	1.05	-	47.3	44.1	40.6	38.6	38.3	38.7	39.7	41.2	42.7	44.8	46.9	48.9	50.5	52.1	53.5	54.8	56.1	57.4	58.6	59.9	61.1	62.2	63.4	64.3	65.3	66.3	67.2	68.0	68.8	69.6	70.4	71.1	71.8	75.2	73.3	74.0	74.5	375
450	580	1.15	-	56.4	51.0	47.6	45.2	44.8	45.5	46.6	48.4	50.3	52.0	53.6	55.2	56.4	57.5	59.0	60.5	62.0	63.5	64.9	66.4	67.7	68.9	70.3	71.5	72.7	73.8	74.7	75.9	77.0	77.9	78.8	79.6	80.4	81.3	82.1	82.9	837	450
525	670	1.20	-	61.9	58.3	54.5	52.0	51.5	52.2	53.5	54.4	55.5	57.4	58.8	60.3	61.6	62.9	64.5	6.2	68.0	69.6	71.3	72.9	74.3	75.8	77.3	78.7	80.0	81.4	82.6	83.8	84.9	86.0	87.1	88.3	89.2	90.2	91.1	92.0	92.9	525
600	790	1.35	2.1	72.9	68.2	63.8	62.3	62.3	62.9	63.7	64.7	66.3	68.7	70.4	72.2	72.9	75.4	77.6	79.6	81.7	83.7	85.6	87.7	89.6	91.6	93.7	95.4	97.2	100	101	102	104	105	106	108	109	110	111	112	114	600
675	880	1.45	2.6	80.4	75.5	70.1	68.7	68.2	68.4	69.1	70.1	71.4	73.6	75.8	78.1	79.8	81.5	83.8	86.4	88.4	90.7	93.1	95.3	97.4	99.4	102	103	105	107	109	111	113	114	116	117	119	120	122	123	125	675
750	950	1.50	3.3	87.5	81.0	75.7	73.6	72.8	73.5	74.6	75.8	77.0	79.0	81.4	83.8	85.6	87.5	90.0	92.6	95.0	97.4	99.9	102	105	107	110	112	114	116	118	119	121	123	125	127	129	130	132	134	136	750
825	1040	1.60	3.9	94.7	94.1	83.4	80.4	78.9	78.8	79.4	80.9	82.7	84.8	87.3	89.7	91.7	93.7	96.4	99.2	102	104	107	110	112	115	117	120	122	125	127	129	131	133	135	135	139	141	143	145	147	825
900	1120	1.90	4.7	101	95.1	88.1	84.8	85.3	87.4	91.3	95.2	99.1	102	105	109	112	114	118	122	125	129	133	136	140	143	147	150	154	157	160	163	166	169	173	176	178	181	183	186	188	900
975	1200	2.00	5.5	109	106	94.5	90.8	91.2	93.1	96.1	100	104	108	112	115	118	121	124	128	132	136	140	144	148	152	156	159	163	166	169	173	176	179	182	185	188	192	195	198	201	975
1050	1300	2.05	6.4	116	110	101	97.1	97.1	98.9	102	106	110	114	118	121	124	127	131	135	140	144	148	153	156	160	164	168	172	176	179	183	186	189	193	196	199	203	206	209	212	1050
1125	1370	2.20	7.3	122	115	107	103	103	104	109	114	119	124	128	132	135	139	143	148	153	157	161	167	171	175	180	184	188	193	197	201	205	209	213	217	220	224	227	230	233	1125
1200	1490	2.30	8.3	130	123	115	110	110	112	117	122	126	130	134	138	142	145	150	155	160	165	170	175	180	184	189	194	198	203	207	211	215	219	224	228	232	235	239	243	246	1200
1350	1650	2.45	10.6	143	135	127	122	122	124	128	132	137	141	146	151	155	159	164	169	175	180	185	191	196	201	207	212	216	221	226	231	236	240	245	249	254	258	262	266	270	1350
1500	1830	2.60	13.0	156	149	140	133	133	136	140	145	150	155	159	164	168	172	178	184	190	196	202	208	213	219	225	230	235	241	246	251	257	262	267	272	277	282	287	292	297	1500
1650	2010	2.80	15.7	169	162	152	147	146	149	154	160	165	171	176	181	186	191	198	204	211	218	224	231	237	244	250	257	263	270	275	281	287	293	299	305	310	316	321	327	332	1650
1800	2240	2.95	18.7	185	177	167	161	161	164	169	173	178	184	190	196	201	206	213	220	227	234	242	249	255	262	269	276	283	290	296	303	309	316	322	328	334	340	346	352	359	1800
1950	2400	3.10	22.5	198	190	181	174	172	175	180	186	192	198	205	211	216	221	228	236	243	251	259	267	274	281	288	295	303	310	317	325	332	339	346	352	359	366	373	380	387	1950
2100	2560	3.25	25.5	209	201	191	185	184	186	191	197	202	209	215	222	227	232	240	248	246	264	272	279	287	295	303	311	319	327	334	342	349	356	363	371	378	385	391	398	404	2100
2250	2730	3.40	29.4	224	216	205	199	198	199	205	211	216	223	230	236	242	248	256	264	273	281	290	298	307	315	324	331	339	347	355	363	372	379	386	394	402	409	418	427	435	2250
2400	2890	3.55	33.3	236	228	217	212	211	213	219	223	229	236	243	250	256	263	272	281	289	298	308	317	326	334	342	352	360	367	377	386	394	402	411	419	427	434	442	450	458	2400
2550	3050	3.70	37.3	249	239	231	226	225	225	232	237	243	250	257	265	272	279	288	297	306	315	325	334	344	354	363	372	381	390	399	409	418	426	435	443	452	461	470	479	488	2550
2700	3210	3.85	42.2	263	255	245	238	237	238	245	250	256	264	272	280	287	294	304	314	324	333	343	353	363	373	382	392	402	412	422	432	441	451	461	470	479	487	496	505	514	2700
2850	3370	4.00	47.1	277	270	259	252	250	251	258	265	271	279	287	295	303	310	320	331	341	351	361	372	382	394	403	414	425	435	445	454	464	474	485	495	505	514	524	534	544	2850
3000	3540	4.15	52.0	292	284	274	267	266	267	273	279	285	293	302	311	319	327	337	348	359	370	380	391	402	413	424	434	445	456	467	478	488	499	509	520	530	540	550	560	570	3000

Note 1. Pipes at shallower depths will need special consideration.

Table B5
Total Design Loads - Fields, etc.. "H" = 0.6 metres to 8.0 metres

Nominal Dia. in mm	Outside Dia. in mm	Recommended Trench Width	Water Load included in kN/m	Total design load "W_e" in kiloNewtons per metre of pipe for cover depths "H" in metres																																	Nominal Dia. in mm
				0.6	0.9	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0	5.2	5.4	5.6	5.8	6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.8	8.0	
225	280	0.7	-	23.5	21.0	20.0	18.2	18.0	18.1	19.0	20.2	21.4	22.8	24.0	25.0	26.0	26.5	27.0	27.5	28.0	28.5	28.9	29.4	29.9	30.3	30.7	31.0	31.3	31.6	31.9	32.1	32.5	32.8	32.9	33.1	33.2	33.4	33.5	33.6	33.7	33.9	225
300	380	0.75	-	31.2	25.7	24.7	23.9	24.0	24.7	25.8	26.5	27.3	28.0	29.0	29.7	30.5	31.0	31.7	32.3	33.0	33.7	34.3	34.8	35.5	36.0	36.5	37.0	37.5	37.9	38.3	38.5	38.8	39.2	39.5	39.8	40.1	40.4	40.6	40.9	41.2	41.4	300
375	500	1.05	-	39.1	33.0	32.0	31.0	31.2	32.1	33.7	35.8	37.7	39.6	42.0	44.4	46.9	48.6	50.3	51.8	53.3	54.9	56.2	57.6	58.8	60.0	61.2	62.5	63.6	64.6	65.7	66.6	67.5	68.4	69.1	69.9	70.4	71.4	72.2	72.8	73.4	74.0	375
450	580	1.15	-	46.1	37.7	36.9	36.4	36.8	37.7	39.3	41.6	43.5	45.4	37.2	49.1	51.0	52.9	54.8	56.6	58.5	60.5	61.9	63.7	65.2	66.6	68.0	69.4	70.6	71.8	73.0	78.2	75.1	76.3	77.3	78.2	79.1	80.0	80.7	81.5	82.3	83.1	450
525	670	1.20	-	52.2	42.7	41.9	41.4	42.2	43.2	45.4	47.6	49.6	51.3	53.3	55.3	57.4	58.9	60.5	62.4	64.3	66.2	67.9	69.7	71.5	73.1	74.6	76.3	77.7	79.0	80.5	81.8.	83.1	84.3	85.4	86.5	87.7	88.7	89.6	90.6	91.6	92.6	525
600	790	1.35	2.1	61.7	50.7	49.5	48.9	50.5	53.0	54.8	57.4	59.3	61.4	63.7	66.2	69.0	70.9	75.0	77.4	79.6	81.8	86.2	83.9	86.2	88.3	90.3	92.5	94.3	96.0	97.9	99.6	101	103	104	106	107	108	109	111	112	113	600
675	880	1.45	2.6	68.0	56.1	53.9	53.5	54.9	56.9	59.3	61.7	64.0	66.4	69.1	61.6	74.0	76.5	78.5	81.0	83.6	86.2	88.7	91.1	93.6	95.8	98.1	100	102	104	106	108	110	112	113	115	116	118	120	121	123	124	675
750	950	1.50	3.3	73.1	60.9	58.8	57.8	59.3	61.3	63.7	65.7	68.7	71.	174.0	76.9	79.8	82.4	85.0	87.6	90.2	92.7	95.1	97.8	101	103	106	108	110	113	115	117	118	120	122	124	126	128	130	132	134	136	750
825	1040	1.60	3.9	78.2	66.2	64.7	62.8	64.2	66.2	68.4	70.6	73.6	76.1	79.4	82.4	85.4	87.8	90.1	93.2	96.2	99.2	102	105	108	111	113	116	119	121	124	126	128	130	132	134	136	138	140	142	144	146	825
900	1120	1.90	4.7	83.8	71.1	68.7	67.3	68.2	71.1	76.2	82.4	87.8	91.7	96.1	100	104	107	10	114	118	123	126	130	134	138	142	146	149	152	156	159	162	165	168	172	175	177	180	182	185	187	900
975	1200	2.00	5.5	89.1	76.1	71.1	72.1	73.1	76.5	81.0	87.3	92.7	96.9	101	105	110	113	118	121	125	129	134	138	142	146	150	154	158	161	164	168	171	175	178	181	184	188	191	194	197	200	975
1050	1300	2.05	6.4	94.4	81.3	78.9	77.2	78.5	81.4	85.9	92.2	98.1	102	107	12	116	119	123	127	132	137	141	146	150	154	158	162	167	171	176	179	182	185	188	192	195	198	202	205	209	213	1050
1125	1370	2.20	7.3	99.2	36.0	83.9	81.2	83.2	86.3	90.6	97.1	104	109	116	122	126	130	133	139	144	149	154	159	164	169	173	178	182	187	191	195	199	203	208	212	216	219	223	226	230	234	1125
1200	1490	2.30	8.3	102	91.9	89.2	87.9	89.0	92.2	97.1	104	110	116	122	127	132	136	140	145	150	156	161	167	172	177	182	187	192	196	201	205	209	213	218	222	227	231	235	238	242	246	1200
1350	1650	2.45	10.6	115	99.1	98.1	97.6	99.1	103	107	115	120	127	132	138	144	150	155	160	166	171	176	182	188	193	199	204	209	214	219	24	229	234	239	243	248	252	257	261	266	271	1350
1500	1830	2.60	13.0	125	112	109	108	110	113	18	126	131	138	144	152	156	161	167	173	179	185	191	198	204	210	216	222	228	233	239	244	249	255	260	265	270	275	280	5	290	295	1500
1650	2010	2.80	15.7	134	121	118	118	120	125	129	137	44	152	159	167	174	180	187	193	199	206	213	221	227	234	241	247	254	260	267	273	279	285	291	297	30	3309	314	320	326	332	1650
1800	2240	2.95	18.7	145	133	130	130	132	136	143	152	161	165	172	180	187	194	201	207	214	222	229	237	244	251	259	266	273	280	287	294	300	307	314	320	326	332	338	345	351	357	1800
1950	2400	3.10	22.5	156	144	142	141	142	146	152	161	170	179	186	193	201	207	213	221	229	237	246	254	262	270	278	285	293	300	307	315	323	330	337	344	350	357	364	371	378	385	1950
2100	2560	3.25	25.5	167	153	152	150	152	156	163	172	180	187	196	204	212	218	225	233	241	249	258	266	275	283	291	299	307	315	324	331	339	346	354	361	367	376	383	389	396	403	2100
2250	2730	3.40	29.4	178	164	162	162	164	167	175	183	192	200	208	217	226	232	240	247	256	265	274	284	293	302	311	320	328	36	344	352	361	369	377	384	382	400	407	415	422	430	2250
2400	2890	3.55	33.3	188	175	173	172	175	180	186	195	203	212	222	231	240	246	253	262	272	281	291	301	311	320	330	38	347	356	365	374	383	391	400	408	417	425	432	440	447	454	2400
2550	3050	3.70	37.3	199	185	183	183	185	191	198	207	216	225	235	244	253	260	268	278	288	298	308	318	329	338	348	358	368	377	386	396	405	415	424	433	441	450	459	468	476	485	2550
2700	3210	3.85	42.2	209	196	194	194	198	202	209	20	230	238	249	259	268	276	285	294	304	315	326	336	347	358	368	378	388	398	408	418	428	438	447	457	467	476	485	494	503	512	2700
2850	3370	4.00	47.1	219	208	206	206	210	214	222	231	242	251	268	273	282	290	298	310	321	332	344	355	366	377	387	398	409	420	431	441	451	461	471	482	492	502	511	521	531	542	2850
3000	3540	4.15	52.0	229	219	216	216	220	227	235	245	255	265	277	287	297	306	314	326	337	349	361	373	384	396	407	419	430	41	452	463	474	485	496	507	518	528	537	547	557	568	3000