FILL HEIGHTS OVER CONCRETE PIPES

P.I.P.E.S

CONCRETE PIPES STAY IN SHAPE

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INTRODUCTION

Concrete pipes are the most frequently used conduits for stormwater drains and outfall sewers. There are many sound reasons for this. One of the most important is the inherent strength of the pipe itself, which enables it to carry loads with little or no assistance from the surrounding soil.

As any buried conduit is part of a pipe-soil system, it is essential to understand how these two components interact, so that the pipes installed are structurally sound and economic for their particular application. The purpose of this article is to give a few basic guidelines about selecting the correct pipe strength for common applications of concrete pipe and provide references which explain how the strength under non-standard conditions or where a more rigorous analysis is justified, can be obtained.

BASIC THEORY

The theory for determining the loads on a buried rigid pipe was developed by Marsden and Spangler, and first published in 1913. This is expressed by a simple formula, which relates the factory test to the installed load and a bedding factor as follows:

$$W_T = W_E/B_F$$

Where : W_T is three-edge proof load ; W_E is total installed load; B_F is bedding factor;

The pipe strength is defined in terms of its D-load, which is the factory proof load expressed in kN/m of pipe length/m of pipe diameter. The proof load is a measure of the pipe's serviceability limit, which is normally taken to be a crack width greater than 0,25 mm over a length greater than 300 mm. In addition, a pipe must not collapse under an ultimate load that is 25 % higher than the proof load. The standard pipe classes given in SANS 676 and 677 for concrete pipes are 25D, 50D, 75D, and 100D. For special applications stronger pipes can be made.

INSTALLED LOADS

Installed loads consist of primary and secondary loads. Primary loads consist of the earth and traffic loads imposed on the pipe and internal pressures. Pipes are designed and tested to prove that they can carry these loads. Secondary loads result from soil movements, temperature effects and influence of structures. It is difficult to calculate these, hence they are accommodated at joints that provide flexibility and where necessary by using shorter pipes.

Earth loads are dependent upon the type of installation, backfill material, and height of fill. The standard installation conditions are a trench and an embankment. The trench installation occurs when the original and final ground levels correspond, and the pipes are placed in an excavation below this level. An embankment installation occurs when the final formation level is above the natural ground level and the pipes are laid at or below ground level and backfilled to the final formation level. Many pipes are laid in conditions where the loading is somewhere between that of a complete trench or a complete embankment, the lower and upper limits respectively of the loading conditions that occur. In practice, the complete trench installation is limited to a depth of about 8m, being ± the maximum that an excavator can dig, and the complete embankment or projection condition is seldom achieved at height to diameter ratios greater than 2,5, as the positive projection condition with a settlement times projection ratio ($r_{sd}p$) of 1,0 becomes the upper limit.

A useful concept to use in evaluating the loads on buried pipes is the geostatic load. This is the mass of soil prism directly on top of a pipe, excluding the effects of friction or cohesion. In a trench installation, the geostatic load is the product of the trench width, the fill height above the pipe, and the material density. In an embankment installation, the geostatic load is the product of the outside diameter of the pipe, the fill height above the pipe, and the material density.

When a pipe is installed in a trench, the frictional forces that develop between the column of fill above the pipe and the trench walls will act upwards and reduce the load on the pipe, which will always be less than the geostatic load. As the depth of trench increases, so do the frictional forces and when the ratio of fill height above the pipe to trench width reaches a value of ± 10, full arching action takes place and no matter how much deeper the trench, the load on top of the pipe will not increase.

When a pipe is installed in an embankment condition, the frictional forces between the column of earth above the pipe and the columns of earth adjacent to it will act downwards and increase the load on the pipe, which will always be greater than the geostatic load. Under an embankment, the loads on the pipe will keep on increasing as the fill height increases, but the relationship between fill height and load becomes linear for a given $r_{sd}p$ ratio.

These three installation conditions are illustrated below.

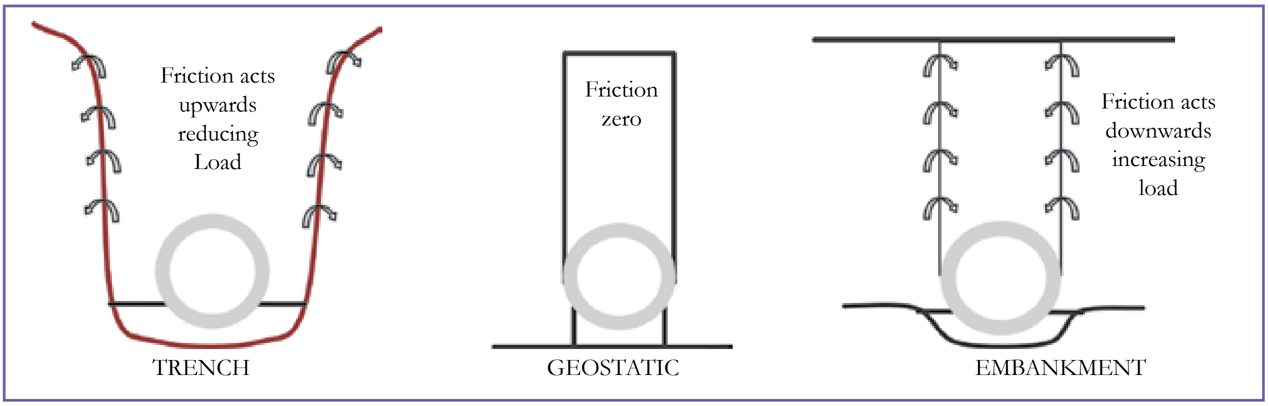

Figure 1 : Standard Installation Conditions

With a trench installation, the load from a clayey material will be greater than that from a sandy material because clay has a smaller internal angle of friction than sand and hence the load shedding onto the trench walls will be less. With an embankment installation, the loads from a sandy backfill material will be greater than those from a clayey material because the internal angle of friction is larger and, hence the load transfer onto the column of material directly above the pipe is greater. The fill height load tables given below have, therefore, been calculated for the worst case scenarios, namely a trench loading in a clayey material based on trench widths and an embankment loading under a sandy material based on outside pipe diameters. Earth loads are calculated from the formula:

$$W_E = C_E \gamma B^2$$

Where : W_E is earth load in kN/m ; C_E is earth load coefficient ; γ is density of fill material ; B is trench width (Bt) or pipe outside diameter (Bc) in m

The loads for complete arching to take place in a trench occur when $H/B_t \cong 10$ and can be calculated from the formulae below:

$$W_E = 2{,}63\gamma Bt^2 \text{ in sand}$$

$$W_E = 3{,}84\gamma Bt^2 \text{ in clay.}$$

Trench loads for a range of fill heights assuming a clayey material are given in Table 1. In this table and the others that follow hypothetical pipe dimensions have been used. For pipes with nominal diameters less than or equal to 1200mm, the external diameter is taken as 1.15 times and for the larger sizes as 1.2 times the nominal diameter.

Table 1: Trench loading on pipes in kN/m of pipe length SANS 1200DB widths for clay insitu $\gamma = 20$ kN/m^3

Pipe diameter mm	Pipe o/a dia. m	Trench width m	Height of backfill above top of pipe m															
			0.2	0.3	0.6	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0	10.0
225	0.259	0.859	3	5	9	15	21	26	30	34	37	40	44	48	50	52	53	54
300	0.345	0.945	4	5	10	17	23	29	34	39	42	46	51	56	59	61	63	64
375	0.431	1.031	4	6	11	18	26	32	38	43	48	52	59	64	68	71	73	75
450	0.518	1.118	4	6	13	20	28	36	42	48	54	58	66	72	77	81	84	87
525	0.604	1.204	5	7	14	22	31	39	47	53	59	64	74	81	87	92	96	99
600	0.690	1.290	5	8	15	23	33	42	51	58	65	71	81	90	97	102	107	111
675	0.776	1.376	5	8	16	25	36	46	55	63	70	77	89	99	107	114	119	124
750	0.863	1.663	7	10	19	31	44	57	69	80	90	99	115	129	141	152	161	168
825	0.949	1.749	7	10	20	32	47	61	73	85	95	105	123	139	152	164	174	182
900	1.035	1.835	7	11	21	34	50	64	77	90	101	112	131	148	163	176	187	196
1050	1.208	2.208	9	13	26	42	61	79	96	112	127	141	167	190	210	229	245	259
1200	1.380	2.380	9	14	28	45	66	86	104	122	138	154	183	209	233	254	273	290
1350	1.620	2.620	10	15	31	50	73	95	116	136	155	173	207	237	264	289	312	332
1500	1.800	2.800	11	17	33	53	78	102	125	147	167	187	224	258	288	316	342	365
1650	1.980	2.980	12	18	35	57	84	109	134	157	180	201	242	278	312	343	372	398
1800	2.160	3.360	13	20	39	65	95	125	153	180	206	231	279	323	363	401	436	468

Table 2: Embankment loading on pipes in kN/m of pipe length-full projection

$r_{sd}p$ = 1.0 or sand insitu γ = 20kN/m^3

Pipe diameter mm	Pipe o/a dia. m	Height of backfill above top of pipe m															
		0.2	0.3	0.6	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0	10.0
225	0.259	0	2	5	9	13	17	22	26	31	35	44	52	61	70	79	87
300	0.345	2	2	6	12	17	23	29	35	41	47	58	70	82	93	105	117
375	0.431	2	3	7	14	22	29	36	44	51	58	73	87	102	117	131	146
450	0.518	2	3	8	15	26	35	44	52	61	70	87	105	122	140	157	175
525	0.604	3	4	9	17	30	41	51	61	71	82	102	122	143	163	184	204
600	0.690	3	5	10	18	32	47	58	70	82	93	117	140	163	187	210	233
675	0.776	3	5	11	20	35	52	66	79	92	105	131	157	184	210	236	262
750	0.863	4	6	12	22	37	56	73	87	102	117	146	175	204	233	262	292
825	0.949	4	6	13	23	39	59	80	96	112	128	160	192	224	257	289	321
900	1.035	4	7	14	25	42	61	85	105	122	140	175	210	245	280	315	350
1050	1.208	5	8	16	28	46	68	92	121	143	163	204	245	286	327	367	408
1200	1.380	6	9	18	32	51	74	100	129	163	187	233	280	327	373	420	466
1350	1.620	7	10	21	37	58	83	111	142	177	216	274	329	383	438	493	548
1500	1.800	7	11	23	40	64	90	119	151	187	228	304	365	426	487	548	608
1650	1.980	8	12	25	44	69	97	127	161	199	240	335	402	468	535	602	669
1800	2.160	9	13	27	47	74	104	136	171	210	252	348	438	511	584	657	730

The load for a positive projection, for all practical purposes, will be maximum at a $r_{sd}p$ ratio of 1,0 and can be calculated from the formulae below:

$$W_E = 1{,}69\gamma B_C H \text{ in sand}$$

$$W_E = 1{,}54\gamma B_C H \text{ in clay.}$$

Embankment loads for a range of fill heights are given in Table 2.

Traffic loads are dependent upon the wheel loads, spacing and contact areas, and the distribution of these through the fill. The standard traffic loads applicable to national highways are given in TMH7: Code of Practice for the Design of Highway Bridges and Culverts in South Africa, which also describes the way in which these loads should be applied to a buried pipe or culvert.

The tabulation of traffic loads given below is based on the NB36 equivalent vehicle point load distributed through the fill at 45°, as described in TMH7. At the lower fill heights there may be other TMH7 loads that are more severe than the NB36 point

Table 3: Loading on pipes in kN/m of pipe length from the NB36 equivalent point load.

Pipe diameter mm	Pipe o/a dia. m	Height of backfill above top of pipe m																NB36 Equivalent point load kN
		0.2	0.3	0.6	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0	10.0	
225	0.259	78	51	21	10	5	3	2	1	1	1	1	0	0	0	0	0	114
300	0.345	92	62	26	12	7	4	3	2	1	1	1	1	0	0	0	0	114
375	0.431	103	71	31	15	8	5	3	2	2	1	1	1	0	0	0	0	115
450	0.518	112	78	35	17	10	6	4	3	2	2	1	1	1	0	0	0	116
525	0.604	119	85	39	19	11	7	5	3	2	2	1	1	1	1	0	0	117
600	0.690	125	90	43	22	12	8	5	4	3	2	1	1	1	1	0	0	118
675	0.776	123	95	46	24	14	9	6	4	3	2	2	1	1	1	1	0	120
750	0.863	121	99	49	25	15	9	6	5	4	3	2	1	1	1	1	0	121
825	0.949	119	100	52	27	17	10	7	5	4	3	2	1	1	1	1	1	123
900	1.035	118	99	55	29	18	11	8	6	4	3	2	2	1	1	1	1	125
1050	1.208	115	97	60	33	21	13	9	7	5	4	3	2	1	1	1	1	129
1200	1.380	113	96	64	36	24	15	10	8	6	5	3	2	2	1	1	1	133
1350	1.620	109	94	67	40	28	18	12	9	7	5	4	3	2	2	1	1	138
1500	1.800	108	94	67	43	31	20	14	10	8	6	4	3	2	2	1	1	144
1650	1.980	107	94	68	46	34	22	15	11	9	7	5	3	3	2	2	1	149
1800	2.160	107	94	69	49	37	24	17	13	10	8	5	4	3	2	2	1	156

load. As many pipelines are laid in open veld and through residential areas, these loading conditions and the corresponding construction standards are not always applicable. Hence, the impact of traffic loading if it does occur could be more severe and it should be distributed at 30°. However, under these circumstances a lower live load value could be used.

BEDDING FACTORS

The bedding to a pipe consists of the cradle underneath which supports it and transfers the load to the founding material, and the blanket on top, which cushions it from the main fill and helps to distribute the loads. These elements ensure that the loads and reactions on the installed pipe are distributed around the circumference of the pipe thus enabling it to carry more load than in the factory three-edge bearing test where the loads and reactions are concentrated.

Table 4: Standard bedding classes and factors

CLASS	TRENCH	EMBANKMENT	BEDDING ANGLE
A	2.6	3.8	120°
B	2.0	2.35	180°
C	1.5	2.0	90°
D	1.1	N/A	0°

The amount by which the bedding enhances the load-carrying capacity of a pipe is called the bedding factor. For trench installations, this factor is based on vertical reaction only. For embankment installations, the factors are slightly higher as lateral reactions are also taken into account. As the width of support under the pipe increases, so does the value of the bedding factor. The material used in the bedding cradle can be either a flexible granular material, in which case the bedding reaction will be parabolic, or a rigid material, such as concrete or soilcrete, in which case the reaction will be uniform and the bedding factor higher. Bedding details and the corresponding factors given in SANS 10102 are given in Table 4.

It is important to note that although the concrete Class A bedding gives a higher bedding factor than the granular one, it is generally not recommended because it can cause point loads and high stress concentrations on the pipe if it deforms, even slightly. Should there be concerns about the stability of the bedding material, a soilcrete rather than a concrete bedding cradle should be used.

During the design stage it is preferable to use a low class bedding in combination with a high class pipe, as it is much easier to upgrade the bedding on site than to re-order pipes should the installed loads be greater than those anticipated at design stage.

STRENGTH REQUIREMENTS

By using the earth and live loads, and the bedding factors from Table 4 in the simple formula previously given under the heading "Basic Theory", the required pipe strengths (factory test loads) can be determined for most site conditions. Should the fill heights exceed those covered by the tables, then the loads determined by the formulae for the limiting cases should be applied. These loads may well be in excess of what the standard pipe and bedding class combinations can carry, in which case one of the more specialised installation techniques, such as jacking through a constructed fill or induced trenching should be used. For this type of installation, specialist advice should be sought.

When pipes are installed under an embankment the loads on them will be dependant on two dimensional variables, namely pipe overall diameter and fill height. However, when pipes are installed in a trench, the loads will be dependent on three dimensional variables, namely pipe overall diameter, trench width, and fill height, with no fixed ratio between the former two dimensions. Hence, a simple table can be constructed for the pipe bedding class combinations to take a range of fill heights under embankment conditions, but a series of tables would be required to do the same for trench conditions.

FILL HEIGHT TABLES

As the loads on a pipe installed in a trench are dependent upon the trench width and those on a pipe installed under an embankment on the outside diameter of the pipe, it is convenient to express the loads in the former case in terms of the trench width for each pipe diameter and, in the latter case, in terms of the pipe overall diameter.

Tables 5 and 6 give the pipe strength requirements in terms of D-Loads when pipes are to be used in a trench, using the trench widths stated in SANS 1200DB, or embankment installation, plus the NB36 loading with the pipes placed on a class C bedding. These tables will meet the requirements for most site conditions encountered, as the values used are based on the most severe combination of variables.

Table 5: Required D-load pipes for Bf = 1.5 and combined
NB 36 & trench loading for clay insitu $\gamma = 20 kN/m^3$

Pipe diameter mm	Pipe o/a dia. m	Trench width m	Height of Backfill above top of pipe m															
			0.2	0.3	0.6	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0	10.0
225	0.259	0.859	250	175	100	75	100	100	100	125	125	125	150	150	150	175	175	175
300	0.345	0.945	225	150	100	75	75	75	100	100	100	125	125	125	150	150	150	150
375	0.431	1.031	200	150	100	75	75	75	75	100	100	100	125	125	125	150	150	150
450	0.518	1.118	175	150	75	75	75	75	75	100	100	100	100	125	125	125	150	150
525	0.604	1.204	175	125	75	75	75	75	75	75	100	100	100	125	125	125	125	150
600	0.690	1.290	150	125	75	50	75	75	75	75	100	100	100	125	125	125	125	125
675	0.776	1.376	150	125	75	50	50	75	75	75	75	100	100	100	125	125	125	125
750	0.863	1.663	125	100	75	50	75	75	75	75	100	100	125	125	150	150	150	150
825	0.949	1.749	125	100	75	50	75	75	75	75	100	100	125	125	125	150	150	150
900	1.035	1.835	100	100	75	50	75	75	75	75	100	100	100	125	125	150	150	150
1050	1.208	2.208	100	75	75	50	75	75	75	100	100	100	125	125	150	150	175	175
1200	1.380	2.380	75	75	75	50	50	75	75	75	100	100	125	125	150	150	175	175
1350	1.620	2.620	75	75	50	50	50	75	75	75	100	100	125	125	150	150	175	175
1500	1.800	2.800	75	50	50	50	50	75	75	75	100	100	125	125	150	150	175	175
1650	1.980	2.980	50	50	50	50	50	75	75	75	100	100	100	125	150	150	175	175
1800	2.160	3.360	50	50	50	50	50	75	75	75	100	100	125	125	150	150	175	175

Table 6: Required D-load pipes for Bf = 2.0 and combined NB36 & embankment loading for sand insitu $\gamma = 20kN/m^3$

Pipe diameter mm	Pipe o/a dia. m	Height of backfill above top of pipe m															
		0.2	0.3	0.6	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0	10.0
225	0.259	175	125	75	50	50	50	75	75	75	100	100	125	150	175	200	200
300	0.345	175	125	75	50	50	50	75	75	75	100	100	125	150	175	200	200
375	0.431	150	100	75	50	50	50	75	75	75	100	100	125	150	175	200	200
450	0.518	150	100	50	50	50	50	75	75	75	100	100	125	150	175	200	200
525	0.604	125	100	50	50	50	50	75	75	75	100	100	125	150	175	200	200
600	0.690	125	100	50	50	50	50	75	75	75	100	100	125	150	175	200	200
675	0.776	100	75	50	50	50	50	75	75	75	100	100	125	150	175	200	200
750	0.863	100	75	50	50	50	50	75	75	75	100	100	125	150	175	200	200
825	0.949	75	75	50	50	50	50	75	75	75	100	100	125	150	175	200	200
900	1.035	75	75	50	50	50	50	75	75	75	100	100	125	150	175	200	200
1050	1.208	75	75	50	50	50	50	50	75	75	100	100	125	150	175	200	200
1200	1.380	50	50	50	50	50	50	50	75	75	100	100	125	150	175	200	200
1350	1.620	50	50	50	50	50	50	50	75	75	100	125	125	150	175	200	225
1500	1.800	50	50	50	50	50	50	50	75	75	100	125	125	150	175	200	225
1650	1.980	50	50	50	50	50	50	50	75	75	75	125	125	150	175	200	225
1800	2.160	50	50	50	50	50	50	50	75	75	75	100	125	150	175	200	225

REFERENCES

The information given above is adequate to select the pipe and bedding class combination for most concrete pipe installations. However, should a more detailed analysis be required where the actual material properties, installation conditions, and live load details are known, the designer should use the procedures given in SANS 10102 Parts I and II: Code of Practice for the Selection of Pipes for Buried Pipelines. Useful reference publications are:

Committee of State Road Authorities. **TMH7: Code of Practice for the Design of Highway Bridges and Culverts in South Africa.** Department of Transport: Republic of South Africa, 1987

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