BLACKMAX® POLYPROPYLENE PIPES AND FITTINGS

STRUCTURAL DESIGN

In engineering terminology, BlackMAX® pipes are considered to be flexible pipes. They are designed to deform or deflect diametrically within specified limits without structural damage after installation.

External soil and live loads on buried flexlble pipes will cause a small decrease in vertical diameter and simultaneously an increase in the horizontal diameter. The horizontal movement of the pipe walls into the soil material at the sides develops a passive resistance within the soil to support the external load. The soil type and density and height of water table (if present), all influence structural performance. The greater the effective soil modulus, the less the pipe will deflect and structural stability against buckling is also enhanced.

Information on an appropriate design procedure is given in Australian Standard AS/NZS 2566.1 "Buried flexible pipelines Part 1 - Structural design" and its Supplement. Alternatively, Iplex pipe design software, which is based on this standard is available from lplex Pipelines Australia.

BlackMAX® pipes have a relatively high pipe stiffness of not less than 8000 N/m.m, classified as SNS and are suitable for cover heights of 2 to 10 metres.

To properly assess the effect of site conditions on a proposed installation, specific information is needed for structural design. This includes:

- Pipe diameter
- Cover height
- Properties of native soil
- Width of embedment
- Properties of embedment material
- Height of water table
- Traffic loading
- Special requirements, such as concrete encasement or grouting

Professional advice should be obtained to determine the appropriate value of the effective soil deformation modulus for a particular installation. It will depend on the native soil type and condition, the pipe embedment material, its degree of compaction and its geometry (e.g. trench width/embedment width). Geotechnical surveys giving soil types and properties, including soil-bearing capacities, SPT (Standard Penetration Test) values at pipe depth and embedment compaction, will be relevant to the design.

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The following notation is used in this Section:

a = the radius of applied circle of loading (m)

b = embedment width each side of pipe at spring line (m)

B = trench width at pipe springline (m)

D = overall outside diameter of pipe (m)

E_e = embedment soil deformation modulus (MPa)

E_n = native soil deformation modulus (MPa)

E' = combined soil deformat1on modulus (MPa)

H = cover height (m)

h = bedding thickness (m)

k = overlay thickness (m)

p = presumptive (allowable) bearing pressure (kPa)

Δ = displacement or settlement (m)

ξ = leonhardt correction factor

GEOTECHNICAL INVESTIGATION

The conventional approach to a pipeline route investigation has been to assess the soil conditions at pipe depth by carrying out a drilling and soil sampling program along the alignment. While the intention in the past was often only to determine the presence of rock and to estimate trench stability for construction purposes, this investigation is now used for more detailed geotechnical reporting and includes additional information readily obtained from routine surveys. It includes design data such as the Standard Penetration Test (SPT) blow counts (at pipe depth), identification of native soil type and depth of water table. The designer will also require an assessment of the embedment material surrounding the pipe and the specified compaction procedure.

DERIVATION OF SOIL DEFORMATION MODULUS VALUES

The correct choice of soil moduli will have significant effects on design decisions. An approximate conversion of SPT blow counts to soil moduli is given in Table 2.0 of Australian Standard AS/NZS 2566.1. However many designers may have more confidence in basing their assessment on the widely available data on foundation design. Often this is contained in records obtained over many years and frequently gives correlations between SPT and allowable soil bearing pressures.

The soil deformation moduli stated in AS/NZS 2566.1 were originally derived from European design practice using soil bearing plate tests.

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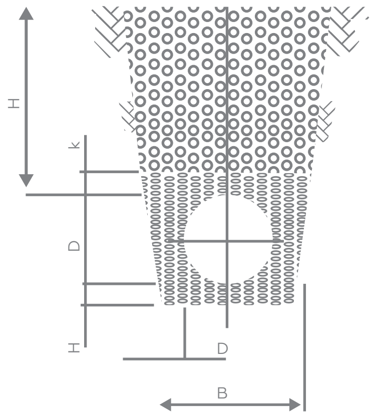
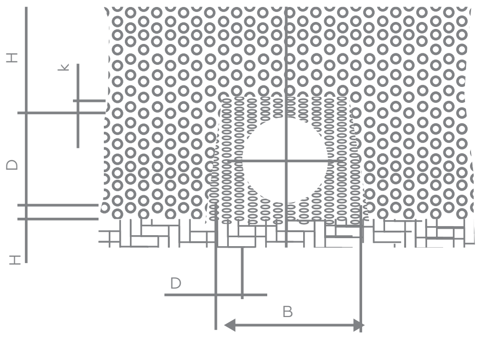
These moduli are generally about half the value of deformation moduli measured using standard laboratory tri-axial tests and should not be confused with these. Using allowable foundation bearing pressures, it is possible to derive the plate load or pipe design soil moduli from the Boussinesq's plate bearing theory for an elastic, homogeneous, isotropic solid. That is for a rigid plate and a soil Poisson's ratio of 0.5;

$$\Delta = \frac{1.18.p.a}{E_n}.10^{-3}$$

En - 0.03 xp Table 2.0 which is based on data published by Sowers[1] (1979), shows the result of applying this factor. Values of the soil deformation moduli are needed for both the native and embedment soils within a distance of 2.5 x the pipe diameter on each side of the pipe centre-line. The modulus for a given pipe embedment soil (E_e) can be estimated from Table 3.0.



TRENCH



EMBANKMENT

The information contained in this document should serve as a guide only and is subject to change without notice. For more information please contact Iplex Pipelines Australia Pty Ltd.

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TYPICAL ALLOWABLE FOUNDATION PRESSURES CONVERTED TO NATIVE SOIL MODULI

SELF DESCRIPTION	STANDARD PENETRATION RESISTANCE - BLOW COUNT OVER 300mm	ALLOWABLE FOUNDATION BEARING PRESSURES (KPa)	DERIVED SOIL DEFORMATION MODULI *En* (using Eqn 3.6) (MPa)
Loose sand, dry	5 - 10	70 - 140	2.1 -4.2
Firm sand, dry	11 - 20	150 - 300	4.5 - 9.0
Dense sand, dry	31 - 50	400 - 600	12 -18
Loose sand, inundated	5 - 10*	40 - 80	1.2-2.4
Firm sand, inundated	11 - 20*	80 - 170	2.4- 5.1
Dense sand, inundated	31 - 50*	240+	7
Soft clay	2 - 4	30-60	0.9 - 1.8
Firm clay	5 - 8	70 -120	2.1 - 3.6
Stiff clay	9 - 15	150 -200	4.5 -6.0
Hard clay	30+	400+	12+
Heavily fractured or partially weathered rock	50+	500 - 1200	15-36

**SPT before inundation*

EFFECTIVE SOIL MODULUS

Knowing the proportion of embedment and native soil in the side support zone, that is the trench width to pipe diameter (B/D) and the ratio of embedment modulus to native soil modulus (E_e/E_n), the Leonhardt factors given in Table 4.0 enable an overall effective soil modulus E^I to be determined using the equation:

$$E^I = \xi . E_e$$

Assuming a density of 20 kN/m^1 for the trench fill over the pipe, Table 5.0 will then give an estimate of the maximum safe cover heights.

Alternatively if the embedment widths comply with the following dimensions, pre-calculated safe minimum cover heights for a range of native and embedment soils are given in Table 6.0

DN (mm)	EMBEDMENT WIDTH
225	OD + 300mm
300	OD + 300mm
375	OD + 400mm
450	OD + 400mm
525	OD + 600mm
600	OD + 600mm

Note: Tables 3.5 and 3.6 have been compiled with reference to AS/NZS 2566.1 using the following assumptions:

1) Water table near surface
2) AUSTROADS HLP 400 traffic loading
3) Fill density of 20 kN/m^3

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EMBEDMENT SOIL MODULI

SELF DESCRIPTION	STANDARD DRY DENSITY RATION (%)	DENSITY INDEX (%)	DEFORMATION MODULI E_e (MPA)
Aggregate - single size	-	uncompacted 50 60 70	5 6 7 10
Aggregate - graded	-	uncompacted 50 60 70	3 5 7 10
Crushed rock	uncompacted 85 90 95	-	1 3 5 7
Sand and coarse grained soil with less than 12% fines	uncompacted 85 90 95	-	1 3 5 7
Coarse grained soil with more than 12% fines	85 90 95	-	1 3 5

** Note: These values are given in AS/NZS 2566.1 Buried flexible pipelines Part 1: Structural design Table 3.2.*

LEONHARDT CORRECTION FACTOR ξ

B/D	E_e/E_n						
	0.2	0.4	0.8	1	2	4	6
1.5	2.4	1.8	1.2	1.0	0.6	0.3	0.2
2.0	1.7	1.5	1.2	1.0	0.6	0.4	0.3
2.5	1.5	1.3	1.1	1.0	0.7	0.5	0.4
3.0	1.2	1.2	1.0	1.0	0.8	0.6	0.5
4.0	1.0	1.0	1.0	1.0	1.0	0.9	0.8
5.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

PERMISSIBLE COVER HEIGHT (METRES)

NOMINAL STIFFNESS	EFFECTIVE (COMBINED) SOIL MODULUS E^i (CALCULATED KNOWING E_n, E_e AND EMBEDMENT WIDTH B)							
	1.5 MPa	2.0 MPa	2.5 MPa	3.0 MPa	4.5 MPa	6.0 MPa	7.5 MPa	9.0 MPa
SN8	1.9	2.6	3.5	3.8	5.8	7.1	8.4	9.6
SN10	2.4	2.8	3.8	4.5	6.5	7.8	9.1	10.6

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For the locations given in the table below E' values equal to or greater than shown, BlackMAX® pipes will be adequate for AUSTROADS highway loadings. As cover heights increase to over 2.5 metres the effect of highway traffic loading on the buried culvert becomes negligible.

MINIMUM COVER HEIGHTS (FROM AS/NZS 2566 PART 1)

LOCATION		MINIMUM HEIGHT OF COVER H (m)*	Minimum value of E', (MPa)
Not subject to vehicular loading		0.30	Not applicable
Subject to vehicular loading	- not in roadways	0.45	2.0
	- in sealed roadways	0.60	2.0
	-in unsealed roadways	0.75	1.5
Pipes in embankment conditions or subject to construction equipment loading		0.75	2.0

**Subject to variation by the regulatory authority.*

Note: *The tables above for BlackMAX® (SN8) pipes with pipe design parameters as follows:*

- Vertical deflections ≤ 5%
- Buckling factor of safety of 2.5
- Assuming highway loading

WORKED EXAMPLE

Problem:

A DN600 BlackMAX® drainage pipeline is proposed for an installation under a major highway. The pipes will be laid in a trench with a standard width of 1200 mm and a cover height of up to 6 metres. The native soil material at pipe depth is a stiff clay and the pipes will be embedded in a 10mm aggregate compacted to a density index of 70%.

Determine whether BlackMAX® is suitable?

Solution:

Referring to Table 2.0 as a guide for selection of soil deformation moduli it would be reasonable to use E_n = 4.5 MPa. For the embedment material refer to Table 30. For gravels/aggregates compacted to 70% DI, the modulus E_e would be 10.0 MPa.

Therefore:

E_e / E_n = 10.0/4.5 = 2.22 and,

B/D_e = 1200/600 = 2.0

From Table 4.0, The Leonhardt's Correction Factor = 0.58

Using Equation 7.0, The Effective modulus, $E' = \xi \times E_e$

E' = 0.58 x 10

E' =5.8 MPa

From Table 5.0, by interpolation for E' of 5.8 MPa, the permissible cover height for BlackMAX® pipes= 6.9 metres and therefore these pipes are suitable.

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EFFECT OF CONSTRUCTION LOADS ON BURIED BLACKMAX® (PP) PIPES

The recommended minimum (final) cover heights for buried flexible pipelines in different installation conditions are tabulated in Table 4.1 of Australian Standard AS/NZS 2566.2 and are empirically derived from accepted installation practice. They are similar to those used for rigid pipes.

However some authorities have requested information on the performance of flexible pipes under construction loads where the cover heights may be considerably lower. A theoretical evaluation is possible using the design procedure for flexible pipes given in AS/NZS 2566.1 Clause 4.7 “Superimposed Live Loads” provided that these covers may be less than the prescribed design minimum. That is at covers less than 400mm where loads are due to compaction equipment, it is reasonable to assume there will be some load dispersion but that this will reduce progressively in a linear fashion to nil as covers reduce from 400mm to zero.

Minimum (construction) cover heights have been calculated using this approach. Assumptions have been made with regard to the native soil modulus, with a value of 3 MPa being considered appropriate. This corresponds to a firm clay with a presumptive foundation bearing pressure of about 100KPa or SPT blow count of 6+ per 300mm. A firm inundated sand would have a similar modulus. The embedment modulus has been taken to be 7MPa from Table 3.2 of AS/NZS 2566.1 as this is typical of good quality embedment material. The calculated minimum (and maximum) covers for the range of compaction equipment in Table 3.7 are shown in Table 3.8.

On site, the effect of compaction equipment on flexible pipes can be checked by monitoring changes in ring deflection. Details of allowable deflections are given in clause 5.7 of AS/NZS 2566.2. Although higher ring deflections will not damage polypropylene pipes, excessive initial ring deflections, e.g more than 4%, should be avoided as the magnitude of the deflection after installation is often used as the prime indicator of whether the specified side support compaction has been achieved. Compaction of the side support zone before allowing the compaction equipment to operate on the overlay above the pipe will assist in this respect. Where the allowable limit has been exceeded the pipeline installation may be rejected. In these circumstances it may be acceptable to recover and re-use the same pipes with increased side support compaction.

COMPACTION EQUIPMENT

TYPE	VIBRATORY RAMMER	VIBRATORY TRENCH ROLLER (2t)	EXCAVATOR COMPACTION WHEEL	VIBRATORY ROLLER
Model	BS62Y	-	-	CAT CS653
Number of axles	1	2	1	1
Axle spacings	N/A	970mm	N/A	N/A
Bearing length ‘a’	330mm	200mm	200mm	200mm
Bearing length ‘b’	330mm	865mm	580mm	2200mm
Wheel load ‘P’	33KN	72KN	155KN	218KN

SUMMARY OF COVER HEIGHT CALCULATIONS FOR B/D $\geq$ 1.66*

PIPE DIMENSIONS	MINIMUM COVERS USING COMPACTION EQUIPMENT IN TABLE 3.7				ALLOWABLE MAXIMUM COVERS FOR SOIL PLUS CONSTRUCTION LOADS
	VIBRATORY RAMMER	VIBRATORY TRENCH ROLLER (2t)	EXCAVATOR COMPACTION WHEEL	VIBRATORY ROLLER	
SN8	230mm	220mm	670mm	470mm	6000mmm

**B = trench width at spring line, D = external pipe diameter*