

BS 9295:2020+A1:2025



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Guide to the structural design of buried pipes

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Summary of pages

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Foreword

Publishing information

This British Standard is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 29 February 2020. It was prepared by Technical Committee B/505, *Wastewater engineering*. A list of organizations represented on this committee can be obtained on request to the committee manager.

Supersession

BS 9295:2020 superseded [BS 9295:2010](#), which has been withdrawn.

BS 9295:2020+A1:2025 supersedes BS 9295:2020, which is withdrawn.

Relationship with other publications

This British Standard is complementary to [BS EN 1295-1:2019](#) and [PD CEN/TR 1295-2:2005](#).

[BS EN 1295-1:2019](#) specifies general requirements for the structural design of buried pipes under various conditions of loading. Guidance is also given on the application of the nationally established methods of design declared by, and used in, CEN member countries at the time it was prepared. The established United Kingdom method is described as BS 9295.

[PD CEN/TR 1295-2:2005](#) summarizes the nationally established methods of design made available to CEN. The United Kingdom method is described in [A.9](#), which is consistent with [BS EN 1295-1:1997](#).

This British Standard gives further information to facilitate in full the structural design of buried pipes under various conditions of loading using the established United Kingdom method; it does not alter any of the provisions of [BS EN 1295-1:2019](#).

Information about this document

BS 9295:2020 was a full revision of the document, and introduced the following principal changes:

- incorporation of the content of National Annex A to BS EN 1295:1997; and
- inclusion of the Gumbel method for the design of buried pipes.

Text introduced or altered by Amendment No. 1 is indicated in the text by tags [A1](#) [A1](#). Minor editorial changes are not tagged.

Amendment No. 1 introduces changes to provide consistency of units between those commonly used and those necessary for direct numerical input to formulae. Where values are derived from graphs, this distinction of units is particularly important. For historic reasons, various figures and tables have contained source information in particular units. Different pipe standards also use different units for the same named variable.

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Where websites and webpages have been cited, they are provided for ease of reference and are correct at the time of publication. The location of a webpage or website, or its contents, cannot be guaranteed.

Use of this document

As a guide, this British Standard takes the form of guidance and advisory recommendations. It is not to be quoted as if it were a specification or a code of practice.

Presentational conventions

The guidance in this document is presented in roman (i.e. upright) type. Any recommendations are expressed in sentences in which the principal auxiliary verb is “should”.

Additional commentary, explanation and general informative material is presented in smaller italic type.

Where words have alternative spellings, the preferred spelling of the *Shorter Oxford English Dictionary* is used (e.g. “organization” rather than “organisation”).

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Introduction

This revision of BS 9295 has been prepared to maintain alignment with [BS EN 1295-1:2019](#), which now cites BS 9295 as the primary source of the methods accepted for the structural design of buried pipes in the UK. The opportunity has been taken to review various shortcomings in the earlier UK design methods, many of which have arisen due to changes in the nature of pipes over the period since those methods were originally published.

Changes from the methods previously published as [BS EN 1295-1:2019](#) and BS 9295 include the introduction of a new conceptual model for the design of buried flexible pipes focused on large-diameter structured-wall thermoplastics pipes, explicit consideration of the quality of workmanship envisaged during installation, non-circular shaped concrete pipes, and a wider range of bedding materials. Non-circular shaped pipes in materials other than concrete are not in common use in the UK so their design is not covered by this edition.

1 Scope

This British Standard gives the UK established method for the structural design of buried pipes under various conditions of loading. The procedures are explained, with tables listing the recommended design values for the appropriate variables in the design formulae, figures providing graphical information on vehicle surcharge loadings, and tables of rigid pipe bedding factors.

NOTE The scope of [BS EN 1295-1:2019](#) is restricted to the structural design of water supply pipelines, drains and sewers, and other water industry pipelines, whether operating at atmospheric, greater or lesser pressure.

Some aspects of longitudinal effects are discussed (see [Annex A](#)), but this topic is not fully covered.

The initial selection of options for the pipe material involves consideration of matters beyond structural design and is outside the scope of this standard.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes provisions, or limits the application, of this document¹⁾. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Standards publications

[BS EN 545](#), *Ductile iron pipes, fittings, accessories and their joints for water pipelines – Requirements and test methods*

[BS EN 598](#), *Ductile iron pipes, fittings, accessories and their joints for sewerage applications – Requirements and test methods*

[BS EN 622-4](#), *Fibreboards – Specifications – Part 4: Requirements for softboards*

[BS EN 1295-1:2019](#), *Structural design of buried pipelines under various conditions of loading – Part 1: General requirements*

[BS EN 1610:2015](#), *Construction and testing of drains and sewers*

[BS EN 1992-1-1:2004+A1:2014](#), *Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings*

[BS EN 13242:2002+A1:2007](#), *Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction*

¹⁾ Documents that are referred to solely in an informative manner are listed in the Bibliography.

Other publications

- [N1] YOUNG, O.C. and M.P. O'REILLY. *A guide to design loadings for buried rigid pipes*. Transport and Road Research Laboratory, Department of Transport. London: HMSO, 1983, Second Impression 1987.
- [N2] HIGHWAY AUTHORITIES AND UTILITIES COMMITTEE (HAUC). *New Roads and Street Works Act 1991. Specification for the reinstatement of openings in highways*. HAUC (UK), 2002.
- [N3] WASTE AND RESOURCES ACTION PROGRAMME (WRAP). *Quality Protocol: Aggregates from inert waste. End of waste criteria for the production of aggregates from inert waste*. Banbury: WRAP. 2013.

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in [BS EN 1295-1:2019](#) and the following apply.

3.1.1 buried pipe system

composite structure comprising the pipe, its joints and the surrounding soil embedment

3.1.2 pipe-soil system

conceptual two-dimensional structural unit comprising the buried pipe and an annulus of the surrounding soil, including pipe embedment and native ground, which interact to resist applied external and internal loads and/or imposed deformations

NOTE The size of soil annulus varies according to the relative stiffness of the pipe and the soil.

3.1.3 homogeneous

consisting of the same material with uniform density and mechanical characteristics throughout 

3.2 Symbols

For the purposes of this document, the following symbols apply.

NOTE The following table gives the units for the symbols, unless these are given as otherwise in the text.

Symbols	Description	Units ^{A1}
A	cross-sectional area  per unit length of the pipe wall 	 mm ² /mm 
B_c	outside diameter of pipe	m
B'_c	combined width of multiple pipes laid in parallel	m
B_d	effective width of trench	m
C_c	soil load coefficient in embankment conditions	—
C_d	soil load coefficient in narrow trench conditions	—
C_L	soil modulus adjustment factor (Leonhardt's coefficient)	—
C_w	water load coefficient	—
c_u	undrained compressive strength of cohesive soil	kPa
D	mean diameter of pipe (measured to neutral axis of wall)	m
D_f	strain factor	—
D_i	internal diameter of the pipe	m
D_L	deflection lag factor	—

Symbols	Description	Units ^{A)}
D_{Lsr}	deflection lag factor for semi-rigid pipes	—
D_R	reduction factor on long-term deflection due to internal pressure	—
E	flexural (Young's) modulus of elasticity of pipe material	$\langle A_1 \rangle$ MPa $\langle A_1 \rangle$
E_h	hoop tensile modulus of elasticity of pipe material	$\langle A_1 \rangle$ MPa $\langle A_1 \rangle$
E_p	modulus of elasticity of pipe material	MPa
E_p^*	plane strain modulus of pipe material	MPa
E_x	creep modulus of elasticity of pipe at time x	MPa
E'	overall modulus of soil reaction	MPa
E'_2	embedment soil (Spangler) modulus	MN/m ²
E'_3	native soil (Spangler) modulus	MN/m ²
F_b	buoyant force (destabilizing force)	kN/m
F_d	downward force (stabilizing force)	kN/m
F_m	bedding factor	—
F_s	factor of safety against buckling	—
F_{se}	factor of safety for rigid pipe material (external load design)	—
F_{si}	factor of safety for rigid pipe (internal pressure design)	—
f_{ctm}	factored tensile stress due to bending	MPa
$f_{ctm:fl}$	factored flexural tensile stress due to bending	MPa
GWL	level of groundwater	—
H	depth of cover to top of pipe	m
H_e	height of plane of equal settlement above top of pipe	m
HN	internal height	m
H_w	height of water table above invert of the pipe	m
I	second moment of area of the pipe wall per unit length	mm ⁴ /mm
I_σ	influence value for determination of soil stresses produced by surface loads	—
K	coefficient of lateral earth pressure	—
K_a	fully active value of K	—
K_o	at-rest value of K	—
k_{sc}	shallow cover reduction factor on soil modulus	—
K_x	deflection coefficient	—
M_H	bending moment $\langle A_1 \rangle$ at a given location on the pipe cross-section due to horizontal $\langle A_1 \rangle$ load $\langle A_1 \rangle$ text deleted $\langle A_1 \rangle$	$\langle A_1 \rangle$ kNm/m $\langle A_1 \rangle$
M_p	compacted density (modified Proctor density)	%
M_s	constrained soil modulus	MPa
M_{sb}	constrained soil modulus of the pipe zone embedment	MPa
M_{sn}	constrained modulus of native soil of the trench wall	MPa
M_{Ult}	total factored bending moment	kNm/m
M_v	bending moment $\langle A_1 \rangle$ at a given location on the pipe cross-section due to vertical $\langle A_1 \rangle$ load $\langle A_1 \rangle$ text deleted $\langle A_1 \rangle$	$\langle A_1 \rangle$ kNm/m $\langle A_1 \rangle$
$\langle A_1 \rangle M_{v,Wc}$	moment due to vertical soil pressure in narrow trench condition	kNm/m
$M_{v,Wc}$	moment due to vertical soil pressure in wide trench condition	kNm/m
$M_{v,CSU}$	moment due to vertical pressure from concentrated surcharge load	kNm/m

Symbols	Description	Units ^{A1}
$M_{h,Wc}$	moment due to horizontal soil pressure in narrow trench condition	kNm/m
$M_{h,W'c}$	moment due to horizontal soil pressure in wide trench condition	kNm/m
$M_{e,Ed}$	factored nett bending moment	kNm/m ^{A1}
m_{qh}	bending moment coefficient for egg-shaped pipe, horizontal	—
m_{qv}	bending moment coefficient for egg-shaped pipe, vertical	—
N	ring thrust in pipe wall	kN/m
N_{SPT}	penetration resistance in blows per 300 mm from a standard penetration test (SPT)	—
N_y	distortional component of ring thrust	kN/m
N_z	uniform component of ring thrust	kN/m
n	pipe-soil stiffness factor	—
n_w	number of waves around circumference of pipe	—
P	vertical pressure due to soil and surcharge	kN/m ²
P_{cr}	critical ^{A1} text deleted ^{A1} buckling pressure of flexible pipes	kN/m ²
^{A1} P_{cra}	short-term critical buckling pressure in air (without soil support)	kN/m ² ^{A1}
P_{crl}	long-term critical buckling pressure	kN/m ²
P_{crs}	short-term critical buckling pressure	kN/m ²
P_e	vertical soil pressure	kN/m ²
P_h	horizontal pressure due to soil load	kN/m ²
^{A1} $P_{h,w}$ ^{A1}	horizontal pressure at pipe springing level due to external water pressure	kN/m ²
^{A1} $P_{h,Wc}$	horizontal soil pressure in narrow trench condition	kN/m ²
$P_{h,W'c}$	horizontal soil pressure in wide trench condition	kN/m ² ^{A1}
P_i	internal water pressure	kN/m ²
P_{op}	working pressure	kN/m ²
P_r	radial pressure	kN/m ²
P_s	vehicle surcharge pressure	kN/m ²
^{A1} $P_{s(kPa)}$ ^{A1}	vehicle surcharge pressure expressed in kN/m ²	kN/m ²
P_u	short-term vacuum pressure	kN/m ²
P_{ult}	ultimate bursting pressure	kN/m ²
P_v	vertical pressure at mid-height of the pipe	kN/m ²
^{A1} Text deleted ^{A1}		
P_w	hydrostatic pressure due to groundwater at mid-height of the pipe	kN/m ²
P_{Wc}	vertical pressure due to soil load (narrow trench conditions)	kN/m ²
$P_{W'c}$	vertical pressure due to soil load (wide trench conditions)	kN/m ²
P_y	distortional pressure component	kN/m ²
P_z	uniform pressure component	kN/m ²
P'_h	horizontal pressure component of soil effective stress	kN/m ²
P'_v	vertical pressure ^{A1} component of soil ^{A1} effective stress	kN/m ²
P'_y	distortional pressure component of soil effective stress	kN/m ²
P'_z	uniform pressure component of soil effective stress	kN/m ²
p	projection ratio	—
q	out-of-roundness factor	—
Q_{vk}	characteristic value of vertical load (concentrated load)	—

Symbols	Description	Units ^{A)}
q_{vk}	characteristic value of vertical load (uniformly distributed load)	—
r_{i2}	internal radius at crown	m
r_m	mean pipe radius at springing level	m
r_{sd}	settlement deflection ratio	—
S_c	soil support combination factor	—
S_f	settlement of pipe invert	mm
S_g	settlement of the natural ground	mm
SLS	serviceability limit state	—
S_m	settlement of fill	mm
SN	ring stiffness class	—
S_x	ring creep stiffness (flexural) at time x	MPa
S_y	flexural ring stiffness of the pipe	MPa
S_z	compression stiffness of the pipe ring	MPa
t	pipe wall thickness	m
t_1	wall thickness at springings	m
t_2	wall thickness at the crown	m
t_3	wall thickness at the invert	m
ULS	ultimate limit state	—
U_s	uniform surcharge	kN/m ²
$W_{e,Ed}$	external load per unit length of pipe	kN/m
W_c	soil load per unit length of pipe in narrow trench conditions	kN/m
W'_c	soil load per unit length of pipe in embankment or wide trench conditions	kN/m
W_{csu}	concentrated surcharge load per unit length of pipe	kN/m
W_d	weight of dry soil above pipe	kN/m
W_e	total external load per unit length of pipe	kN/m
W_f	weight of saturated soil above pipe	kN/m
WN	internal width	m
W_p	proof load for rigid pipes	kN/m
W_{pipe}	pipe weight	kg/m
W_t	crushing strength of rigid pipes (maximum load for concrete pipes)	kN/m
W'_t	crushing strength of rigid pipes with internal pressure per unit length of pipe	kN/m
W_w	weight of liquid content of pipe	kN/m
x	elapsed or extrapolated time under load in creep test	H
Y	flexural stiffness ratio	—
Z	compression stiffness ratio	—
α	bedding angle	°
α_{EC1}	load classification factor from BS EN 1991-2	—
α_z	radial arching factor	—
γ	unit weight of soil	kN/m ³
γ_d	unit weight of dry soil	kN/m ³
γ_G	partial factor for permanent actions	—
$\gamma_{G,intw}$	partial factor for internal water weight	—

Symbols	Description	Units ^{A)}
γH	geostatic load value	—
γ_Q	partial factor for traffic/surcharge	—
γ_w	unit weight of water	kN/m ³
Δ	pipe diameter change	$\langle A_1 \rangle$ m $\langle A_1 \rangle$
$\langle A_1 \rangle \Delta/D$	ovalization (relative vertical diameter change)	— $\langle A_1 \rangle$
Δ_0/D	component of $\langle A_1 \rangle$ ovalization $\langle A_1 \rangle$ built in during $\langle A_1 \rangle$ pipe installation $\langle A_1 \rangle$	—
Δ_v	absolute vertical deflection	$\langle A_1 \rangle$ m $\langle A_1 \rangle$
δ	relative change of pipe diameter	— $\langle A_1 \rangle$ Text deleted $\langle A_1 \rangle$
δ_v	vertical ring deflection	— $\langle A_1 \rangle$ Text deleted $\langle A_1 \rangle$
δ_y	total out-of-round deflection of the pipe ring	— $\langle A_1 \rangle$ Text deleted $\langle A_1 \rangle$
δ_{y0}	initial out-of-round deflection during construction	— $\langle A_1 \rangle$ Text deleted $\langle A_1 \rangle$
δ_{y1}	out-of-round deflection due to external load	— $\langle A_1 \rangle$ Text deleted $\langle A_1 \rangle$
δ_{y2}	out-of-round deflection of pipe due to long-term consolidation settlement of embedment	— $\langle A_1 \rangle$ Text deleted $\langle A_1 \rangle$
δ_z	uniform component of ring deflection	— $\langle A_1 \rangle$ Text deleted $\langle A_1 \rangle$
ε_b	bending strain in pipe wall	$\langle A_1 \rangle$ — ^{B)} $\langle A_1 \rangle$
ε_c	combined strain in pipe wall	$\langle A_1 \rangle$ — ^{B)} $\langle A_1 \rangle$
$\varepsilon_{c,max}$	maximum compressive fibre strain	$\langle A_1 \rangle$ — ^{B)} $\langle A_1 \rangle$
$\varepsilon_{t,max}$	maximum tensile fibre strain	$\langle A_1 \rangle$ — ^{B)} $\langle A_1 \rangle$
ε_y	ring bending strain	$\langle A_1 \rangle$ — ^{B)} $\langle A_1 \rangle$
ε_z	ring compressive strain	$\langle A_1 \rangle$ — ^{B)} $\langle A_1 \rangle$
μ	coefficient of sliding friction within a mass of fill	—
μ'	coefficient of sliding friction of backfill against trench sides	—
ν	Poisson's ratio of pipe material	—
σ	stress in the pipe	MPa
σ_{bs}	bending stress in pipe wall	MPa
σ_c	design hoop stress (previously referred to as combined stress)	MPa
σ_z	mean ring compressive stress at any point in pipe wall	MPa

^{A)} Units except where defined differently in formulae.

^{B)} Throughout this document, values representing strain are deemed to be dimensionless decimal numbers. Care is needed in cases where product data use %. $\langle A_1 \rangle$

4 Concepts used in the structural design of buried pipes

4.1 The buried pipe system

The buried pipe system is a composite structure comprising the pipe, its jointing system and the surrounding soil embedment.

All pipes are longitudinal conveyors of fluids, and in the structural design of the buried pipe system it is generally necessary to take account of both the longitudinal and the cross-sectional response to both external and internal loads.

In determining the extent of influence of longitudinal effects on pipe design it is important to distinguish between flexibly jointed and continuously welded systems, and between gravity and pressure systems.

In both longitudinal and cross-sectional response, the soil embedment acts compositely with the pipe. The zone of structural influence of the soil surrounding the pipe depends on the relative properties of both pipe and soil and can extend beyond the trench fill and into the native ground.

4.2 Longitudinal and sectional behaviour

Most of the design formulae in this British Standard relate to the response of the buried pipe system in the plane of cross-section. However, the potential need to design for longitudinal stresses and strains should be taken into account, and include:

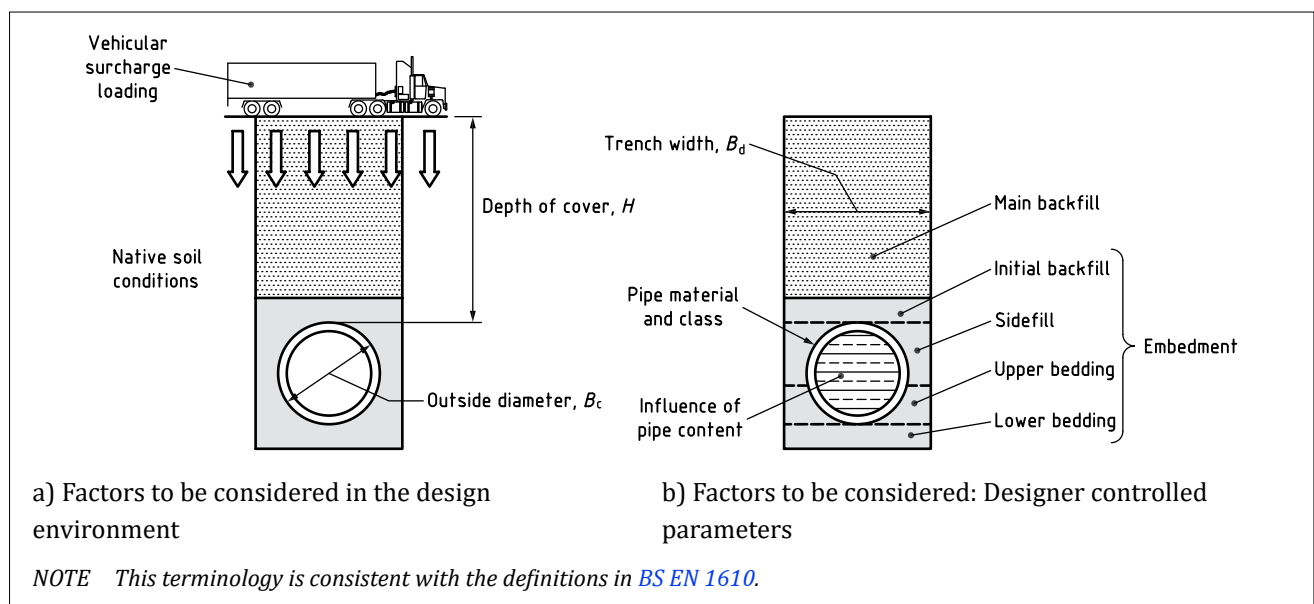
- a) longitudinal bending and/or joint rotations due to differential settlement or change of embedment (e.g. where the pipe enters other structures);
- b) for gravity pipes, settlement of the soil embedment which can be critical to control of line and level; and
- c) for pressure pipes, longitudinal pressurization stresses due, for example, to the Poisson effect and any changes of alignment which can be critical in the selection of joints, and of connections between pipes of different diameters or different materials.

4.3 Classification of buried pipes

Buried pipes are traditionally classified into one of three types: rigid, semi-rigid or flexible. This distinction relates to both the strain capacity of the pipe material and the stiffness of the pipe relative to that of the soil surround, especially in its cross-sectional response.

The purpose of the structural design of the cross-section of buried pipes is to ensure selection of optimum materials and embedments for the given installation, whilst meeting all the necessary design criteria to satisfy the limit states.

NOTE For design criteria see [Figure 1](#).

Figure 1 — Design criteria for pipes laid in open trench

Rigid pipe materials have low strain capacity and high relative stiffness and are designed on the basis of their inherent strength. Their deflection on loading is generally too small to derive significant structural support from the surrounding soil. Load is taken by the pipe and bending moments are developed in the pipe walls. Rigid pipes also attract an amplified backfill load upon burial and obtain a reaction from their bedding in response. The terms “soil load” and “backfill load” are used synonymously to describe the load imposed from the backfill after burial of the pipe.

Flexible pipe materials deflect towards an oval shape in response to loading and are able to develop significant lateral earth pressure from their surrounding embedment.

Semi-rigid pipe materials exhibit a range of behaviour between rigid and flexible.

Pipes of different materials are classified in the UK according to a strength or stiffness criterion to be proven by testing or otherwise established in design. Where the strength of pipes is established in a crushing test, they are classified as rigid. Typical classifications are given in Table 1.

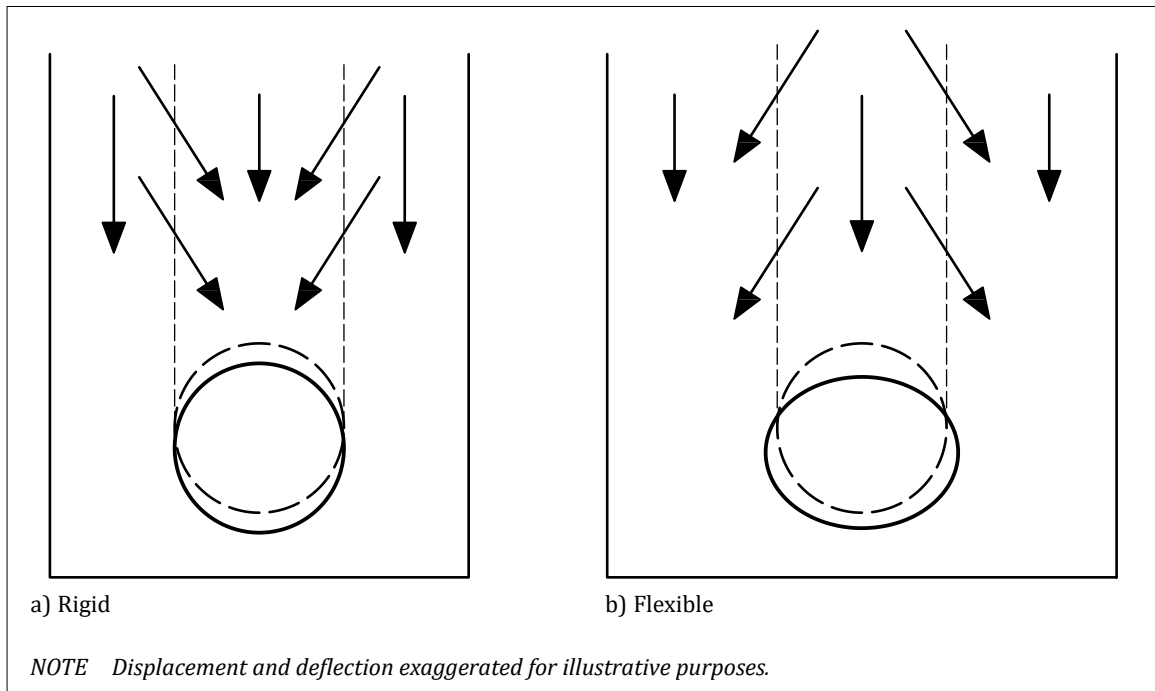
Table 1 — Pipe classification

Pipe material	Classification
Clay	Rigid
Concrete	Rigid
Reinforced concrete	Rigid
Ductile iron	Semi-rigid
Polymer concrete	Semi-rigid
Thick-walled steel	Semi-rigid
Steel-reinforced thermoplastics ^{A)}	Flexible
Thermoplastics	Flexible
Glass reinforced plastics ^{A)}	Flexible
Thin-walled steel	Flexible

^{A)} Classed as composite.

When a pipe is installed in an open trench the ground is disturbed. The disturbed soil settles in the pipe trench, even after backfilling is complete. A rigid pipe is stiffer than the surrounding soil and, when consolidation of the backfill takes place in the pipe zone, the soil to the sides of the pipe tends to settle more than the soil over the pipe. By friction, load is transferred to the column of soil over the pipe so that the pipe attracts more load than the geostatic load alone. In response to this, a rigid pipe might settle marginally into its bedding. A flexible pipe is less stiff than the surrounding soil, so when buried, the column of soil over the flexible pipe settles more than the columns of soil to the sides. In other words, the flexible pipe deflects on loading and tends to shed load away from itself. [Figure 2](#) illustrates this aspect of rigid and flexible pipe behaviour.

Figure 2 — *Rigid and flexible pipe behaviour*



With time, the load distribution effects diminish as the soil surround settles back to a normally consolidated state. For the wide trench condition illustrated in [Figure 2](#), the most onerous backfill loading condition for a rigid pipe is shortly after installation, before the backfill consolidates. Conversely, the highest predicted backfill load for a flexible pipe is after all the beneficial shedding of load has taken place, so the load used is the geostatic value γH with no coefficients.

[Figure 3](#) shows a schematic diagram of the changes in the soil pressures following the burial of rigid and flexible pipes. For rigid pipes the evolution of soil pressures is shown for both wide and narrow trench conditions. In the narrow trench condition where part of the backfill load is transferred in the short term by friction to the trench walls (see [Clause 6](#)), the breakdown of such friction with time can lead to a long-term increase of vertical load and compensating horizontal load on the pipe.

4.4 Design models

In the traditional view of rigid and flexible pipe behaviour represented in [Figure 2](#), only vertical applied loads are shown. In practice, the buried pipe structure is subject to both vertical and horizontal applied loads in the plane of the cross-section. At the interface of the pipe with the soil both these components of load are modified by relative deformation, as illustrated in [Figure 3](#).

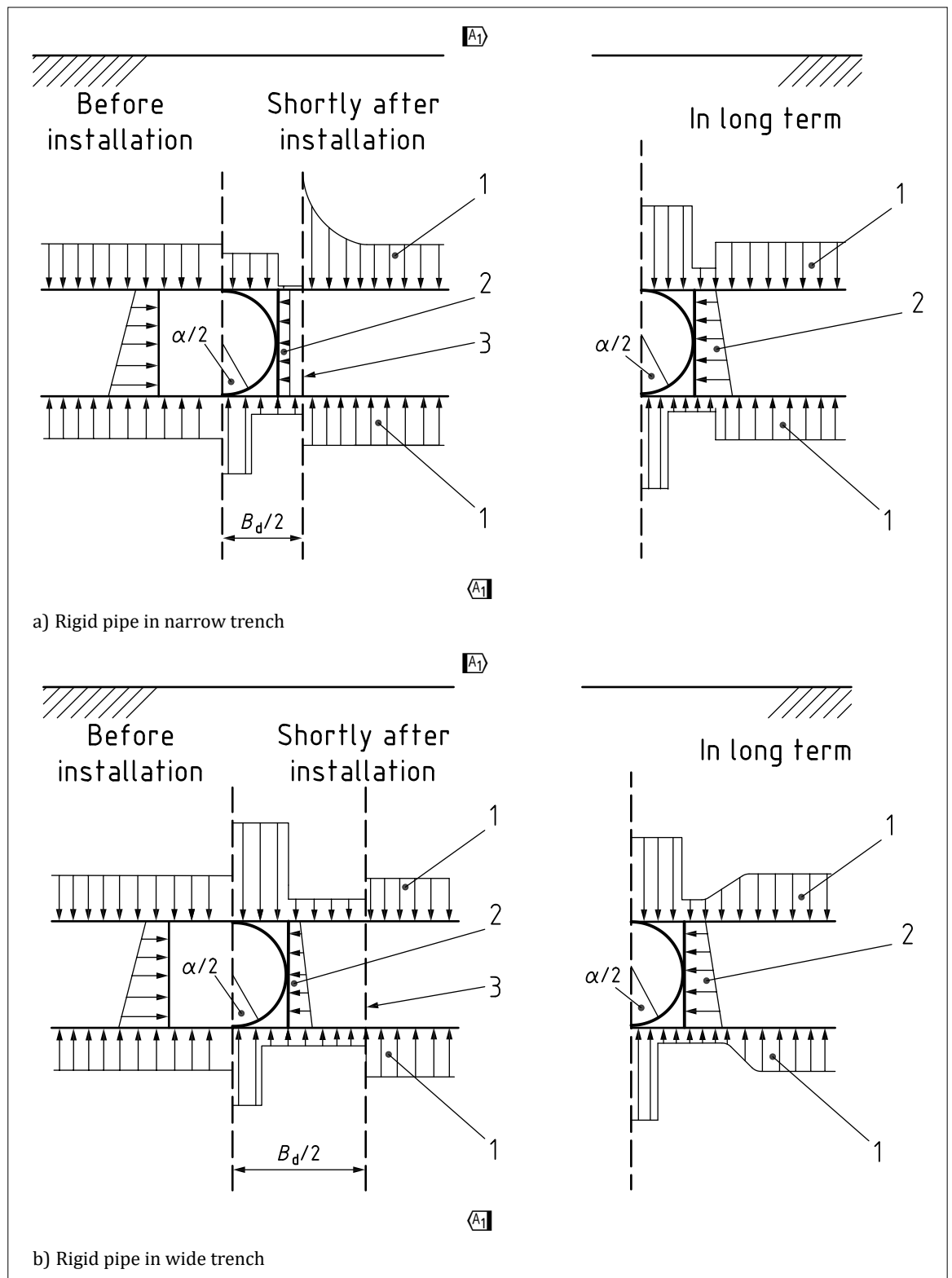
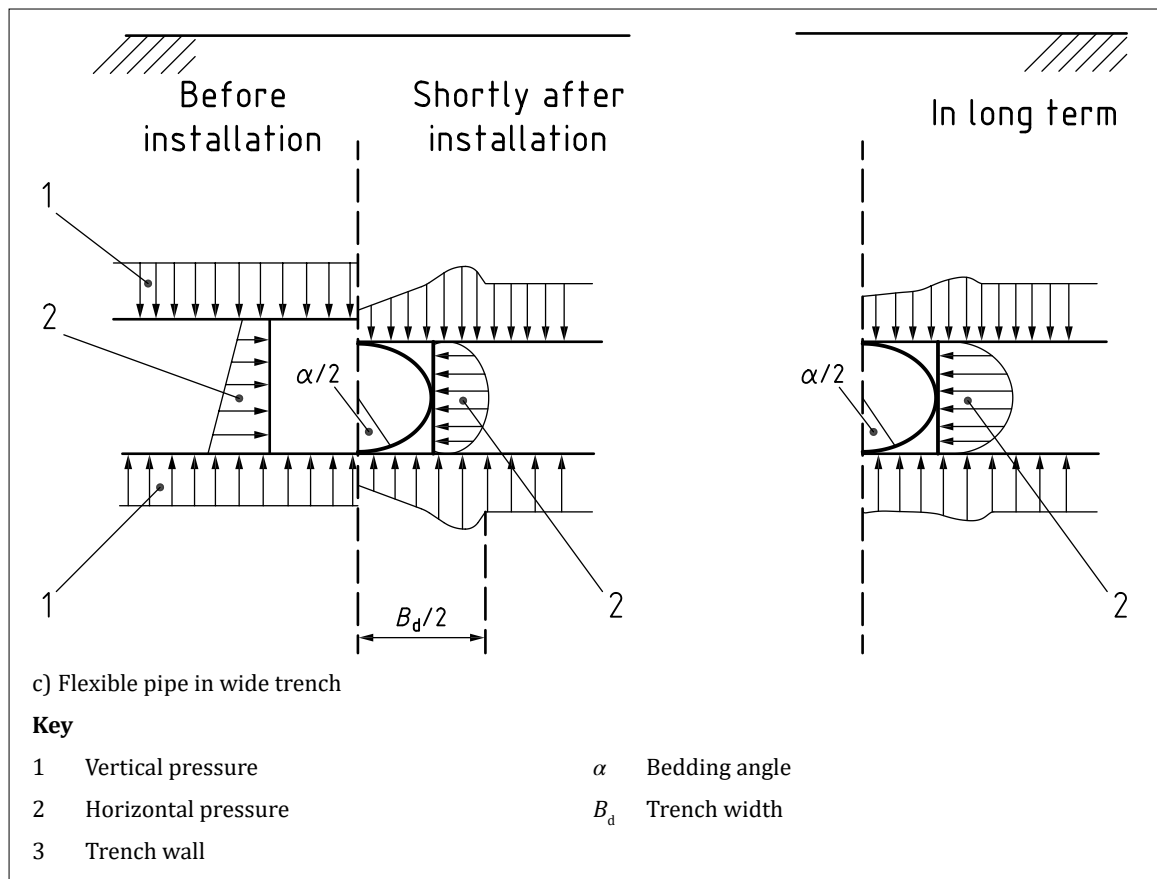
Figure 3 — Soil pressure changes immediately after pipe burial

Figure 3 — Soil pressure changes immediately after pipe burial (continued)

The traditional one-dimensional Marston-Spangler model of buried pipe loading originated with pioneering work at the Iowa Agricultural Engineering Station in the 1940s [1]. Marston examined the effect on vertical soil load reaching the crown of a buried rigid pipe of both the relative settlement of columns of soil either side of the pipe and friction on the walls of a vertically-sided trench. Noting that flexible corrugated metal pipes could support little vertical load on their own, Spangler developed a simple theoretical model in which the vertical load-carrying capacity of such pipes when buried is explained by passive lateral support from the soil surround in response to outward horizontal deflection of the pipe springings. Both models, however, neglect the horizontal component of applied load.

One consequence of neglecting the horizontal component of applied load in the traditional model is that the parameter used to characterize soil stiffness is not a fundamental engineering property of the soil and cannot be directly measured. The parameter concerned, the Spangler modulus, E' (also referred to as the modulus of soil reaction), is a semi-empirical parameter which is a function of the buried pipe system and the applied load distribution, and not the soil alone.

A second limitation of the traditional model is that it examines pipe response only in ring bending, which generates critical bending stresses in rigid pipes and deflection in flexible pipes. This, however, neglects stiffness and deformation of the pipe in a pure ring compression mode, which influences the response and critical design limit state of structured-wall flexible pipes in particular.

To overcome these limitations and to enable inclusion of structured-wall pipes, an additional design model (the Gumbel Method) is introduced in this document (see 7.3) with the following key features:

- replacement of Spangler modulus, E' , with a measurable constrained soil modulus, M_s , of the embedment, including both backfill and native soil; and
- adoption of a two-dimensional model of both loading, i.e. inclusion of the horizontal component of geostatic load, and response, i.e. in ring compression as well as ring bending, of the pipe-soil structure.

4.5 Short-term and long-term stiffness characteristics of polymeric pipe materials

4.5.1 Time-dependent material deformation expressed as apparent stiffness

All polymeric pipe materials, whether thermoplastics or thermosets, exhibit time-dependent creep deformation under load, or conversely relaxation of stresses with time where subject to fixed deformation. In the design of such pipes for limit states governed by stiffness, including deflection and buckling under net external pressure, it is conventional to express the effects of creep deformation or relaxation as an apparent time-dependent elastic modulus, E_x , of the material (also referred to as “creep modulus”) or apparent time-dependent ring stiffness, $S_x (= E_x I/D_3)$, of the pipe (also referred to as “ring creep stiffness”).

These time-dependent values are obtained by dividing the stress or load per unit length applied in a test by the strain or deflection respectively, measured at time x under load. For design load cases which endure beyond standard creep test durations of between 1 000 h and 10 000 h, the stiffness values are extrapolated to the relevant timeframe, up to the specified design life of the buried pipe.

The use of a stiffness parameter in this way to represent the effect of creep deformation under sustained load does not mean that the stiffness characteristics of polymeric pipe materials diminish with time. If a sample that has undergone previous creep deformation is unloaded and subjected to short-term testing, it generally exhibits the same stiffness as at the outset, or even marginally higher stiffness due to ageing effects.

4.5.2 Definitions of short-term stiffness

Conventionally, the value of elastic modulus or ring stiffness designated as “short-term” is that obtained from a standard ring stiffness test, of which the duration is different for thermoplastics and thermosetting pipes.

In the case of thermoplastics pipes, the duration of the standard ring stiffness test to [BS EN ISO 9969](#) is between 36 s and 90 s, dependent on diameter. In the case of thermosetting (GRP) pipes, the total duration of the standard ring stiffness test to [BS ISO 7685](#), including both ramp-up and hold steps, is 3 min. As appreciable creep deformation of thermoplastics occurs between 36 s or 90 s and 3 min under load, this means that the ring stiffness of a thermoplastics pipe of a declared SN (nominal ring stiffness) class is systematically lower on a like-for-like basis than that of a GRP pipe of the same SN class.

[A1] The standard definitions of SN are different for thermoplastics and GRP pipes. For thermoplastics, the number associated with ring stiffness class SN (as in SN 2, SN 4, etc.) represents the minimum value of ring stiffness expressed in kN/m² (kPa). For GRP, the number associated with nominal stiffness SN (as in SN 1 250, SN 2 500, etc.) represents the minimum value of ring stiffness expressed in N/m² (Pa). **[A1]**

4.5.3 Definitions of long-term stiffness, creep ratio and creep factor

Conventionally, the value of elastic modulus or ring stiffness designated as “long-term” is that obtained by extrapolation to a design life of 50 years from a standard ring creep test. Again, however, there are differences in the standard tests for thermoplastics and GRP pipes which require care in the derivation of comparable values of long-term stiffness for design.

In the case of thermoplastics, [BS EN ISO 9967](#) specifies a constant load ring test of 1 000 h duration, from which a “creep ratio” is derived as the ratio of deflection extrapolated to two years to the deflection measured after 6 min under load. Statistical tests are provided to determine the further duration of testing (up to maximum 10 000 h) required to extrapolate ring deflection to fifty years, to enable a fifty-year creep ratio to be determined where relevant for design. However, dividing the short-term ring stiffness determined in accordance with [BS EN ISO 9969](#) by the two-year or fifty-year creep ratio leads to overestimates of the apparent ring stiffness at two years and fifty years respectively, because it misses the, often substantial, creep deformation that takes place in a thermoplastics pipe between 36 s or 90 s and 6 min under load.

In the case of GRP, [BS EN ISO 7864](#) (test for ring creep stiffness under dry conditions) and [BS ISO 10468](#) (wet conditions) both determine a creep factor defined as the ratio of the deflection after 3 min under load to the deflection at time x , extrapolated from a test of standard 10 000 h duration. Unless otherwise specified, x is taken to be 50 years. It should be noted that:

- the creep factor defined for GRP and other thermosetting pipes is the inverse of the creep ratio defined for thermoplastics pipes; and
- unlike for thermoplastics, the long-term ring stiffness of GRP pipe can be validly obtained by multiplying the short-term ring stiffness determined in accordance with [BS ISO 7685](#) by the dry or wet creep factor, as applicable, because the 3-minute datum point used for the evaluation of creep factor matches the duration of the short-term test.

Finally, one reason for the conventional assumption of a fifty-year design life is that this is the furthest extrapolation that can reliably be made based on test data up to 10 000 h. Where the proven durability of the pipe material based on criteria other than stiffness justifies a design life longer than 50 years, the determination of long-term modulus or ring stiffness requires creep testing for an extended period. For example, to reliably predict creep stiffness at 100 years, at least 20 000 h of data are required.

4.5.4 Relevant timeframes for derivation of stiffness values used in design

In the design of buried flexible pipes, the value of creep stiffness applied in calculations (whether elastic modulus or ring stiffness) should always be matched to the timeframe of the load case under consideration.

The “short-term” modulus or ring stiffness of thermoplastics or GRP pipes declared by manufacturers based on the respective standard tests referred to in [4.5.2](#) and [4.5.3](#) can safely be used where the duration of load is less than the corresponding test duration of between 36 s and 3 min. These short-term values can thus generally be applied, for example, in computing response to internal surge pressures and wheel loads from moving traffic.

For other load cases commonly considered as short term, but which might in fact endure for several hours or days, for example, external groundwater pressure due to temporary saturation of trench backfill in storm conditions or vehicle surcharge from stationary traffic, the pipe stiffness applied should be appropriately downrated from the declared short-term value. In the absence of access to the pipe product test data from which the creep stiffness at the precisely relevant time point can be determined, the use of a declared two-year value is recommended as a conservative default for such cases.

For the computation of long-term pipe deflection (ovalization) due to earth and traffic loads, a two-year pipe ring stiffness can also be used safely. This is based on field tests amongst others by TEPPFA [2], as referred to in [PD CEN/TS 15223](#), which have shown that settlement of the embedment around a buried plastics pipe, due to the combined action of backfill load, repeated traffic surcharge and groundwater movements, typically stabilizes within a period of not more than two years. At that point the deformed shape of the pipe ring is effectively fixed, allowing the stresses associated with its deflection to relax out. While this applies in principle to all flexible pipes, not just the thermoplastics tested, in practice the difference between long-term deflection calculated based on a fifty-year rather than two-year ring stiffness is usually very small.

For all other long-term load cases and limit states, including the effects of a sustained groundwater table on pipe strains, and buckling response to combined soil and groundwater loads, the fifty-year elastic modulus or ring stiffness, appropriately determined from creep tests (see [4.5.3](#)), should generally be used.

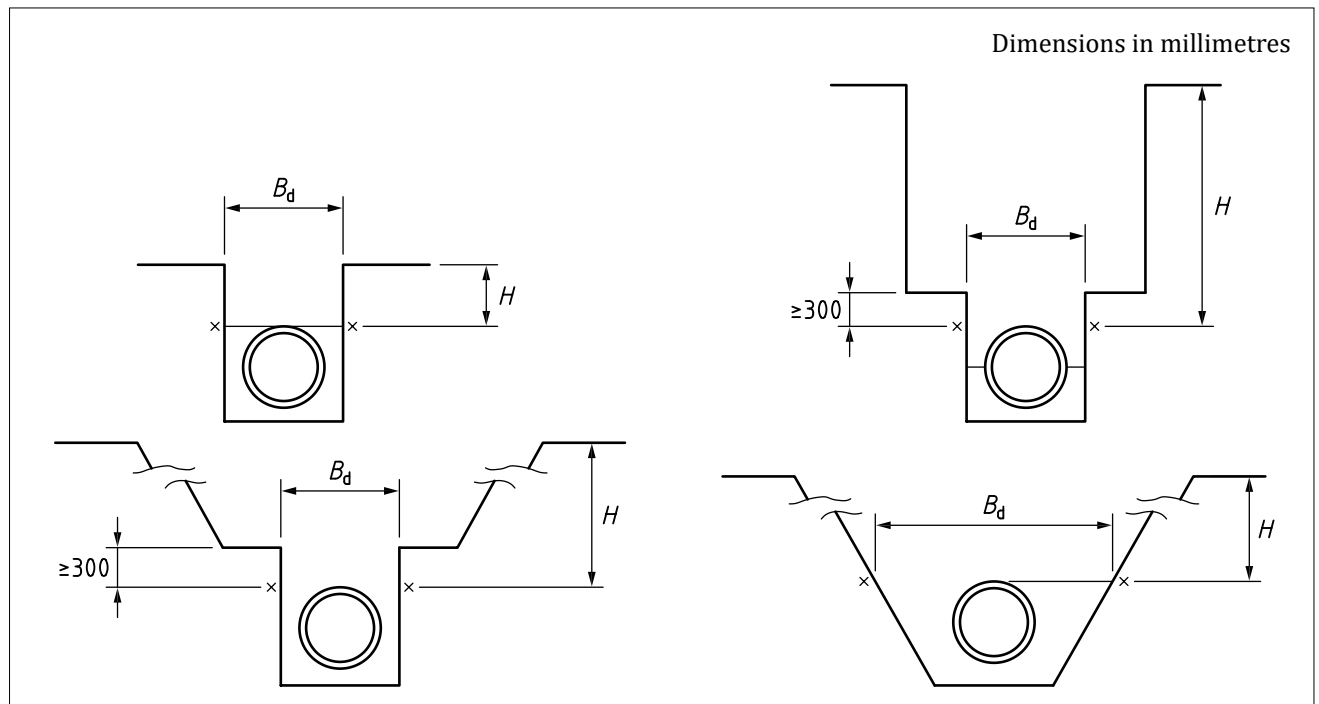
4.6 Classification of native/embedment soils and trench width

The zone of soil which has a structural influence on the buried pipe typically extends between one and two diameters from the pipe wall in all directions.

This zone invariably includes the trench base and, depending on trench width, both pipe embedment material and the native soil of the trench wall.

Trench shape and width are therefore key design parameters. Figure 4 defines the effective trench width, B_d , for different shapes of excavation.

Figure 4 — Effective trench width, B_d



The design of the trench cross-section, including specification of minimum trench width, should be such as to meet the requirements of BS EN 1610.

For rigid pipe design, trench width has an important influence on design loadings.

For flexible pipe design, the effective stiffness of the soil surround is expressed as a combination of the stiffnesses of embedment and native soil, respectively, as a function of trench width and pipe diameter.

The relevant classification and characteristics of both native and embedment soils are detailed in Clause 6, Clause 7 and Clause 8, as applicable.

4.7 Key parameters to be specified by the designer

The design specification should in all cases include as a minimum the following information and be communicated clearly to those constructing the works:

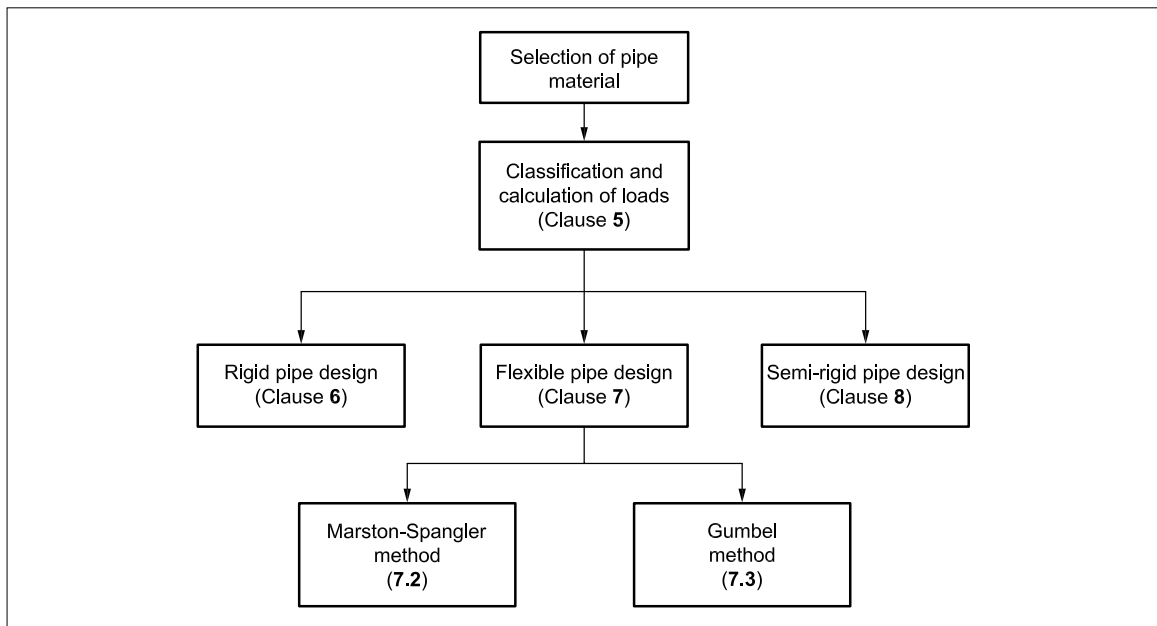
- specified minimum trench width;
- maximum trench width where this is a critical design parameter;
- pipe material class/specification;
- embedment details, including lower bedding, upper bedding and sidefill materials as defined by Figure 1, and levels of compaction required;
- assumed range of site conditions, including native soils and groundwater depth;
- measures to prevent flotation where applicable; and
- requirement for construction to be in accordance with BS EN 1610.

In addition, temporary works scenarios, including minimum cover and construction traffic loading, should be discussed with the installer if possible and incorporated in the design as appropriate. In all cases, the maximum construction traffic loading and associated depth of cover to the pipe assumed by the designer should form part of the construction specification.

4.8 Pipe and design method selection

Rigid, flexible or semi-rigid pipes can be inherently suited to certain applications, but pipe material selection is outside the scope of this British Standard. [Figure 5](#) sets out the clauses of this document that apply in each case.

Figure 5 — *Clauses applicable to the selection and design of pipe*



The choice between rigid pipe design, flexible pipe design or semi-rigid pipe design is determined by the anticipated pipe/soil behaviour (see [4.3](#)).

The choice between the two different flexible pipe design methods given in [7.2](#) and [7.3](#) in sizes below 900 mm is left to the designer, but for sizes above 900 mm and for structured-wall pipes generally, the Gumbel method (see [7.3](#)) is recommended.

5 Classification and calculation of loads

5.1 Introduction

The external loads on buried pipes fall into three principal categories:

- a) earth loads (geostatic);
- b) groundwater loads (hydrostatic); and
- c) surcharge (live) loads, which are further sub-categorized as follows:
 - 1) vehicular loads on pipes under roads;
 - 2) agricultural vehicle loads on pipes under fields;
 - 3) construction vehicle loads on pipes on active construction sites; and
 - 4) rail traffic loads on pipes under railways.

The calculation of external geostatic and hydrostatic loads, as well as internal loads due to both dead weight of pipe contents and their pressurization, can be found in the applicable clause for the pipe type designation (see [Figure 5](#)).

5.2 Vehicle surcharge loads

Vehicle loading covers road traffic, field traffic and rail traffic loading. In previous editions of BS 9295 describing the structural design of buried pipes, there was a category for “light road” loading. Vehicle load classification has changed, and any public road is now assumed to be accessible to heavy lorries, with some designated exceptions where weight limits for old bridge structures apply. This edition excludes the “light road” loading category from the main guidance on structural design.

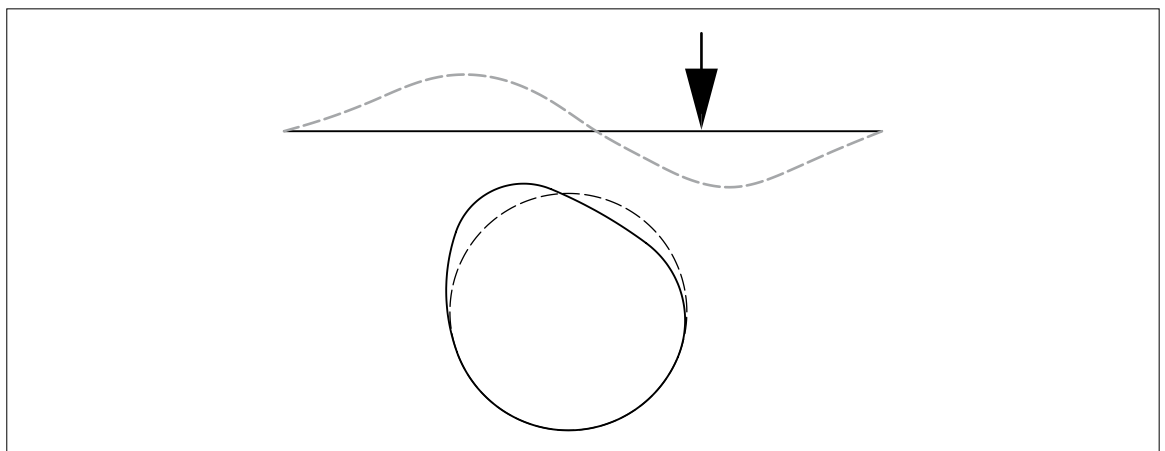
Graphs of surcharge pressure due to road vehicles, other vehicles and railways are given in 5.3, 5.4 and 5.5.

The maximum loading on a pipe depends upon its depth and diameter.

In some circumstances (e.g. shallow-buried, large-diameter, flexible pipes) horizontal loads arising from cornering, braking or eccentric loads (see Figure 6) should also be accounted for. Such loading can lead to asymmetrical deformation modes resisted primarily by the three-dimensional stiffness of the pipe and shear strength of the ground above the pipe, rather than by horizontal stiffness of the soil at pipe springings level. Shallow-buried flexible pipes subject to surcharge from construction vehicles prior to laying of a road pavement are particularly vulnerable to large asymmetrical deformations associated with shear failure in the relatively unconfined soil surrounding shoulders and crown.

NOTE Analysis of asymmetrical deformations of shallow-buried flexible pipes due to horizontal and/or eccentric vertical surcharge loads is outside the scope of this standard. Guidance on minimum depths of soil cover to reduce the risk that such loading could be more critical for design than vehicle loads applied symmetrically over the pipe crown is given in 5.4, 7.3.1 and A.11.4.

Figure 6 — Illustration of eccentric surcharge load on pipe



5.3 Road and field surcharge loads

The main road vehicle loadings described in this subclause correspond to the worst case of either Load Model 1 (General Verification) or Load Model 2 as specified in BS EN 1991-2:2003. Field loading is as specified in the TRRL guide [N1]. As an alternative to these sources, Newmark’s integration of Boussinesq’s formula may be used to give the resultant load at pipe crown at a certain depth from the wheel loading. Figure 7 and Figure 8 indicate how traffic load decreases with depth of cover, whereas backfill load increases.

Figure 7 — Loading configurations

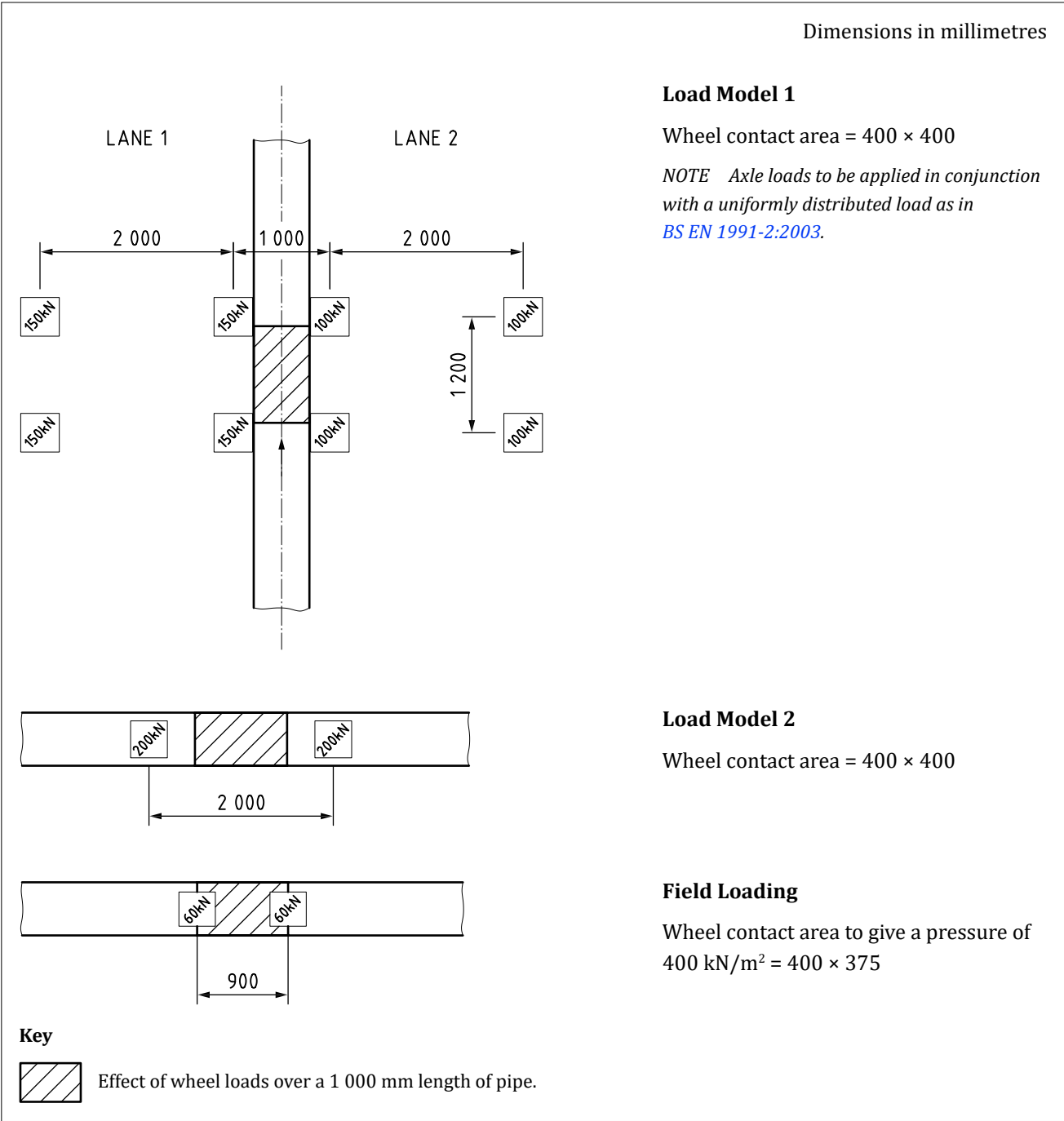
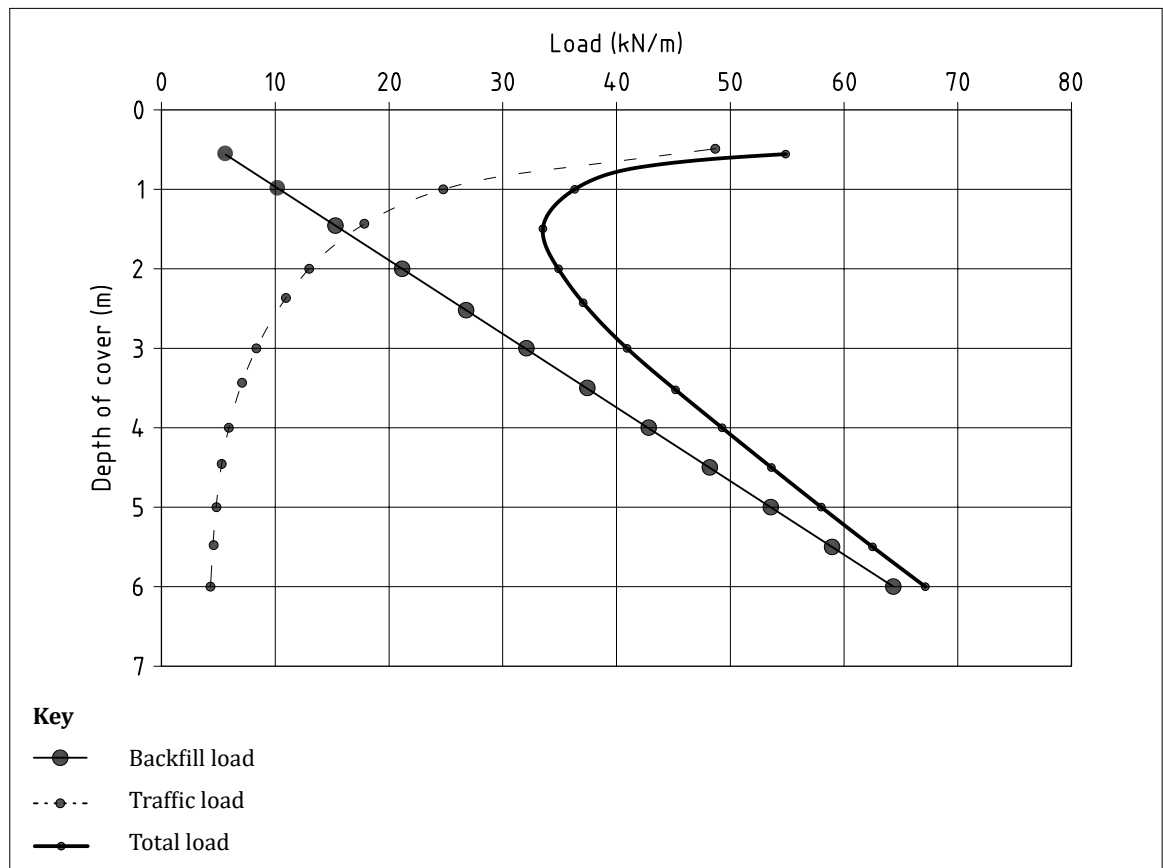


Figure 8 — Example of calculated backfill, road traffic surcharge and combined loadings expressed as a line load on a rigid DN300 pipe



The values of vehicle surcharge loads tabulated in Table 2 have been determined as the higher of the pressures calculated from Load Model 1 and Load Model 2 of BS EN 1991-2:2003 (see A.25). Attenuation of wheel loads with depth is in accordance with the dispersion angles given in BS EN 1991-2:2003.

The same data are presented in graphical form in Figure 9.

Table 2 — Surcharge pressures (kN/m^2), $\overline{A_1} P_{s(\text{kPa})} \overline{A_1}$, as a function of depth to cover to crown, H

H (m)	Main roads	Fields and gardens	H (m)	Main roads	Fields and gardens	H (m)	Main roads	Fields and gardens
0.5	–	85	1.7	45	16	3.8	22	3.8
0.6	144	70	1.8	43	15	4	21	3.4
0.7	120	58	1.9	41	13	4.5	19	2.7
0.8	101	49	2	39	12	5	17	2.2
0.9	86	42	2.2	35	10	5.5	16	1.9
1	74	36	2.4	33	9	6	15	1.6
1.1	67	32	2.6	31	7.7	6.5	14	1.3
1.2	62	28	2.8	29	6.7	7	13	1.2
1.3	58	25	3	27	5.9	8	12	0.9
1.4	54	22	3.2	26	5.2	9	11	0.7
1.5	51	20	3.4	24	4.7	10	10	0.6
1.6	48	18	3.6	23	4.2	–	–	–

The tabulated surcharge pressures can be determined approximately using the following:

$$\text{Roads: } \overline{A_1} P_{s(\text{kPa})} \overline{A_1} = 76.46 H^{-0.923} \quad (1)$$

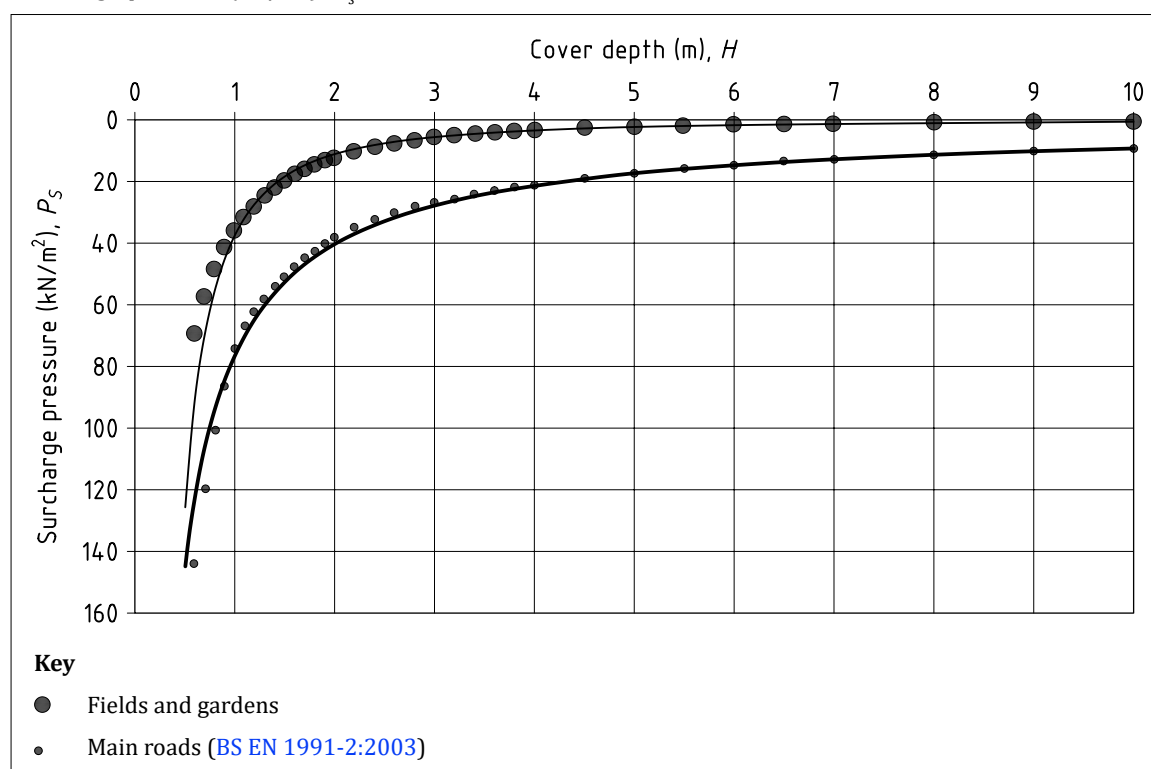
$$\text{Fields: } \overline{A_1} P_{s(\text{kPa})} \overline{A_1} = 37.44 H^{-1.75} \quad (2)$$

$\overline{A_1}$ where:

$P_{s(\text{kPa})}$ is the numerical value of the surcharge pressure P_s expressed in kilopascals (kPa, i.e. kN/m²); and

H is the cover depth expressed in metres (m). $\overline{A_1}$

Figure 9 — Surcharge pressure (kN/m²), P_s , due to vehicle wheels



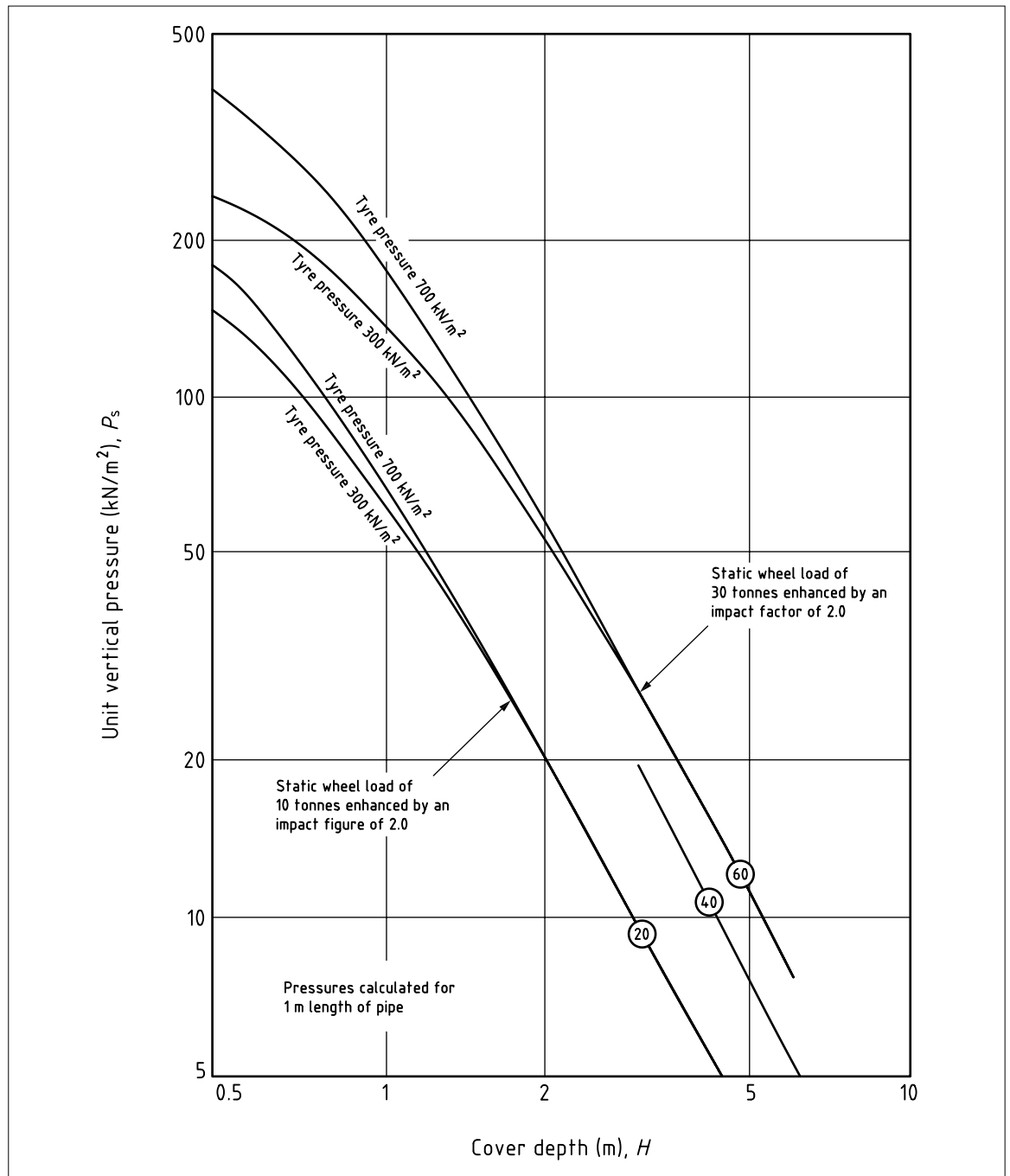
5.4 Surcharge pressure due to construction vehicles

As a guide, Figure 10 presents design surcharge loads due to construction traffic, derived from the TRRL guide [N1], which take account of both wheel loads and tyre pressure of heavy construction plant in use at that time. Construction plant can be particularly damaging to newly constructed pipes, due to a combination of reduced cover to the pipes (lower than the designed final installation) and often poor soil conditions leading to rutting. This puts the construction vehicle wheels much closer to the pipe crown than is usually accounted for in design. These scenarios can be accounted for in the following ways:

- specific construction vehicle design, taking account of the heaviest construction load and the reduced cover; and
- engineer-designated plant crossing points, which either have appropriate levels of cover or are specially engineered to mitigate the loads, e.g. bridging slabs, concrete surrounds, road plates.

These surcharge pressures might not be applicable to other items of construction plant, in which case the TRRL Guide [N1] should be consulted.

The minimum recommended depth of unpaved soil cover over flexible pipes subject to construction vehicle surcharge is the greater of 0.9 m or half the outside diameter of the pipe.

Figure 10 — Surcharge pressure, P_s , due to construction vehicles

5.5 Railway loadings

The main line rail vehicle loading described in this subclause corresponds to [BS EN 1991-2:2003](#), Load Model 71 (load classification factor, $\alpha_{EC1} = 1.0$), shown in [Figure 11a](#)) and is identical to [BS EN 1991-2:2003](#) and its UK National Annex RU load configuration.

NOTE The α factor is used for load classification of railway traffic loading on bridges and structures beneath the track. The selection of the α factor value is a national choice to be decided by the authority responsible for the infrastructure below the track.

The light rail vehicle loading described in this subclause corresponds to (the now withdrawn) [BS 5400-2 RL](#) (Rail London) load configuration shown in [Figure 11b](#)). There is no corresponding Eurocode “light rail load” model in [BS EN 1991-2:2003](#), but a future edition could include this.

An example of combined earth and surcharge pressures, P_s , on a pipe is presented in graphical form in [Figure 8](#). It specifically relates to a road traffic surcharge scenario, but more generally describes the relationship between earth and surcharge loading regardless of the type of traffic.

The dispersal of pressure with depth for the two railway loading models is shown in [Figure 12](#) and [Figure 13](#) for a single-track railway and a pipe crossing it at right angles. The multiplication factor to be used when the crossing is under more than one railway track is shown in [Figure 14](#).

Figure 11 — Loading configurations for LM 71 and RL railway loading models

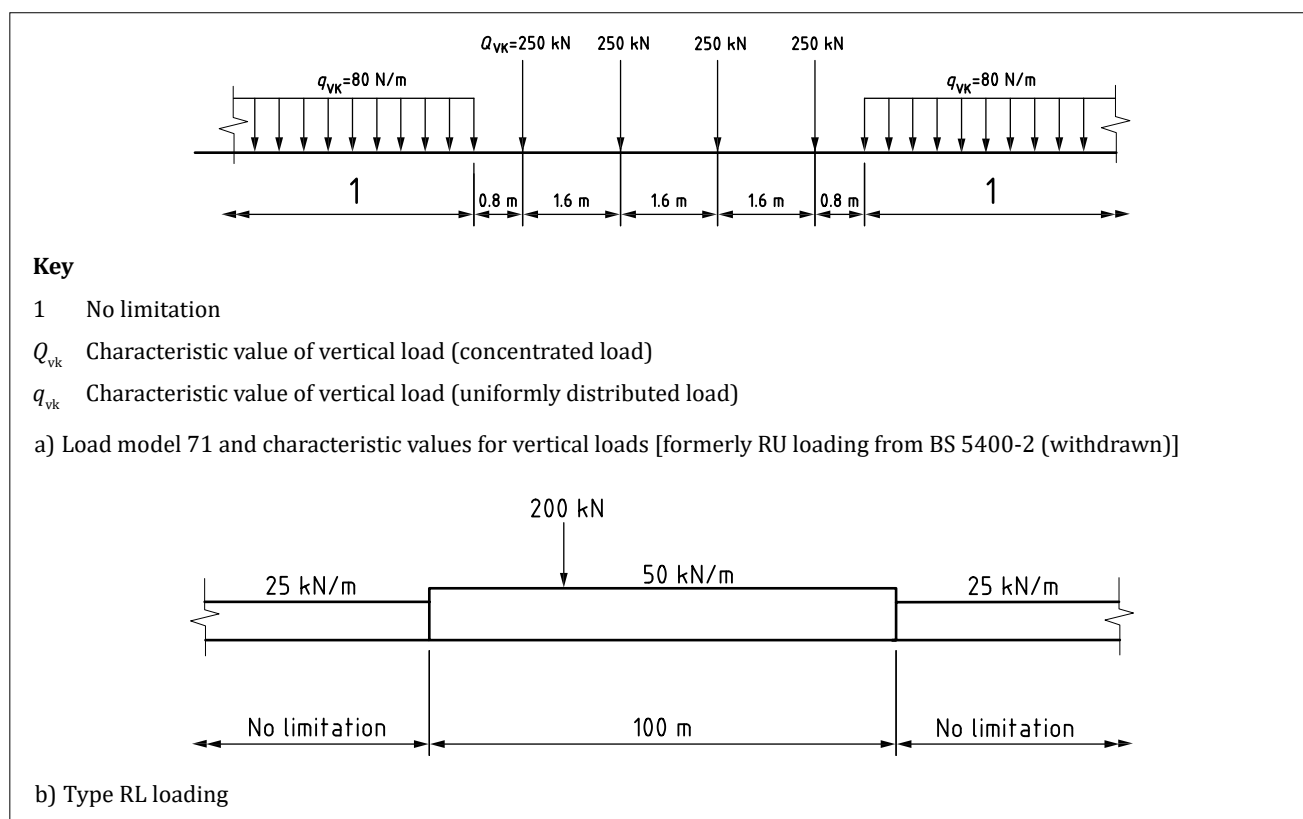
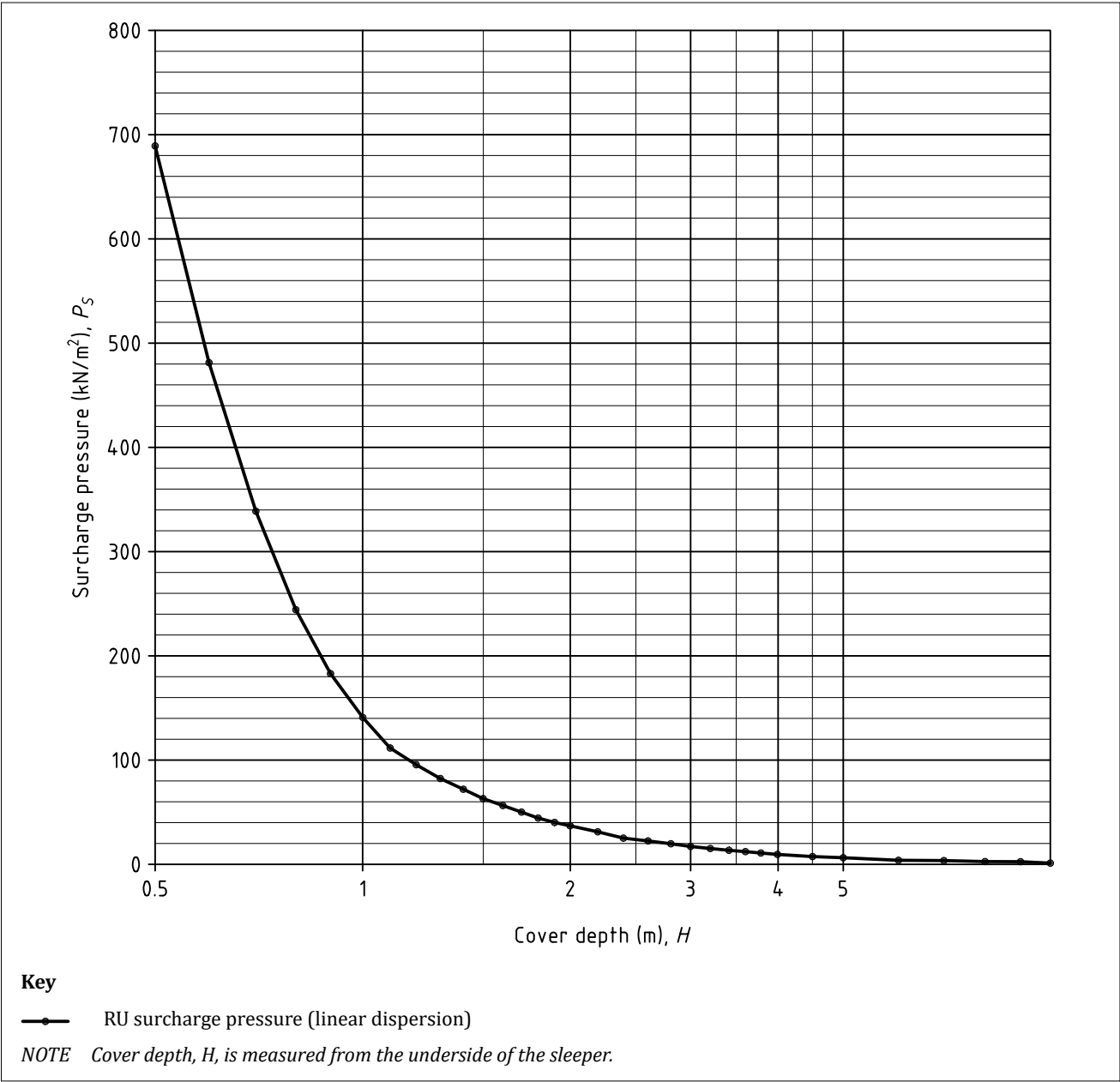
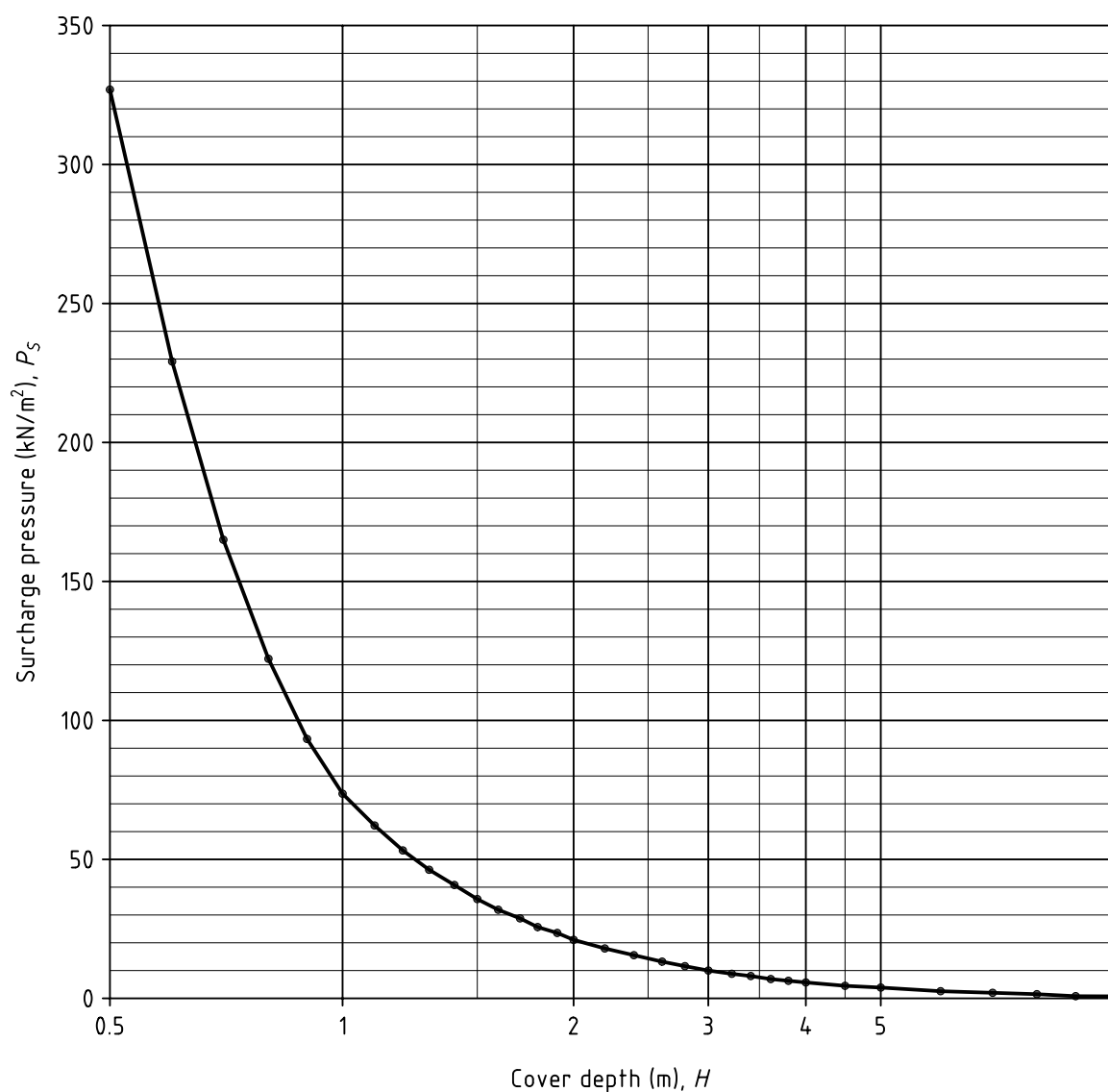


Figure 12 — BS EN 1991-2:2003, load model 71 ($\alpha = 1.0$) (RU to BS 5400-2²⁾) surcharge pressure at depth



²⁾ Withdrawn.

Figure 13 — Rail London (RL to BS 5400-2³⁾) surcharge pressures at depth**Key**

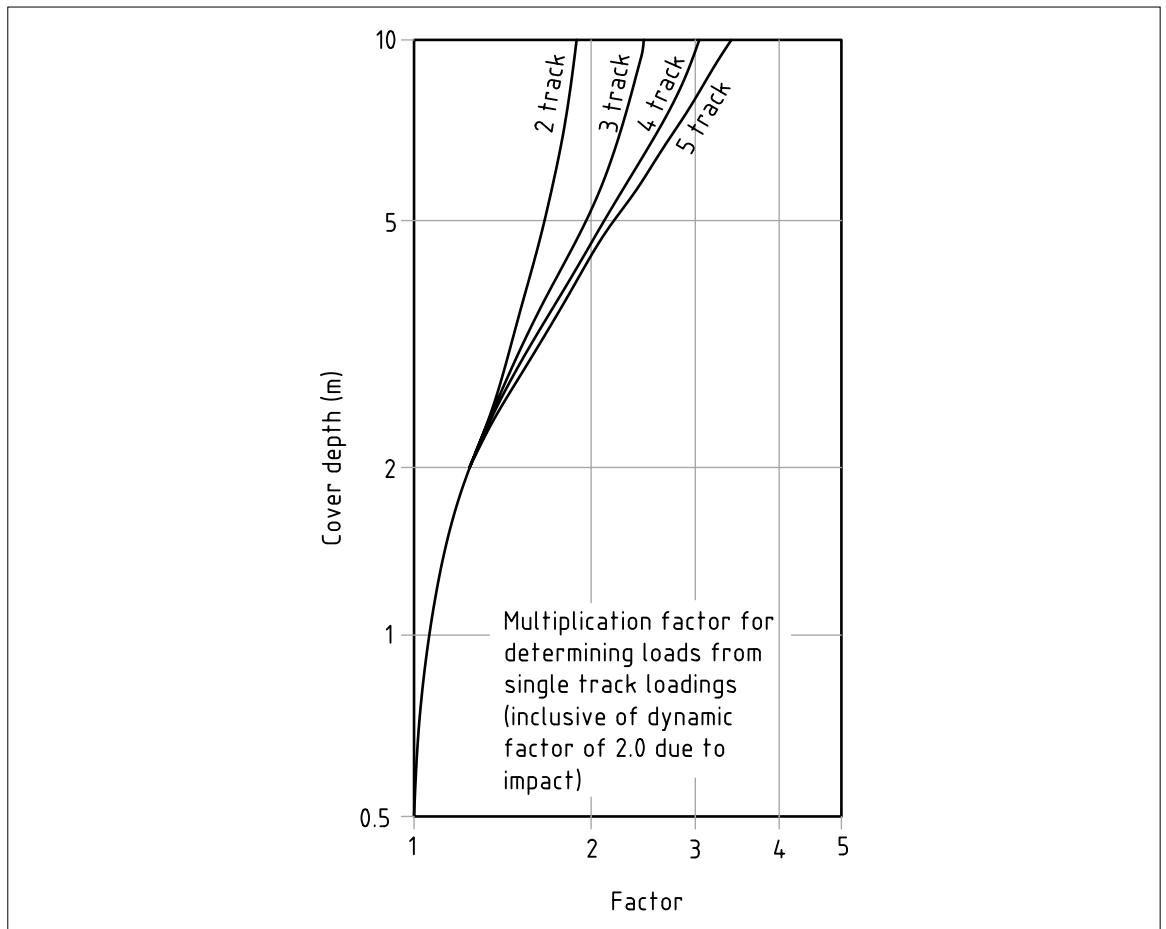
—●— RU surcharge pressure (linear dispersion)

NOTE 1 Pressures are calculated for 1 000 mm length of pipe. Discontinuities are due to changes in position of the 1 000 mm length of pipe in relation to the track. Cover depth, H , is measured from the underside of the sleeper.

NOTE 2 Inclusive of dynamic factor (due to impact) of 2.0 for RU and 1.2 for RL.

NOTE 3 For diameters greater than 600 mm, an appropriate alpha factor is selected from [BS EN 1991-2:2003](#).

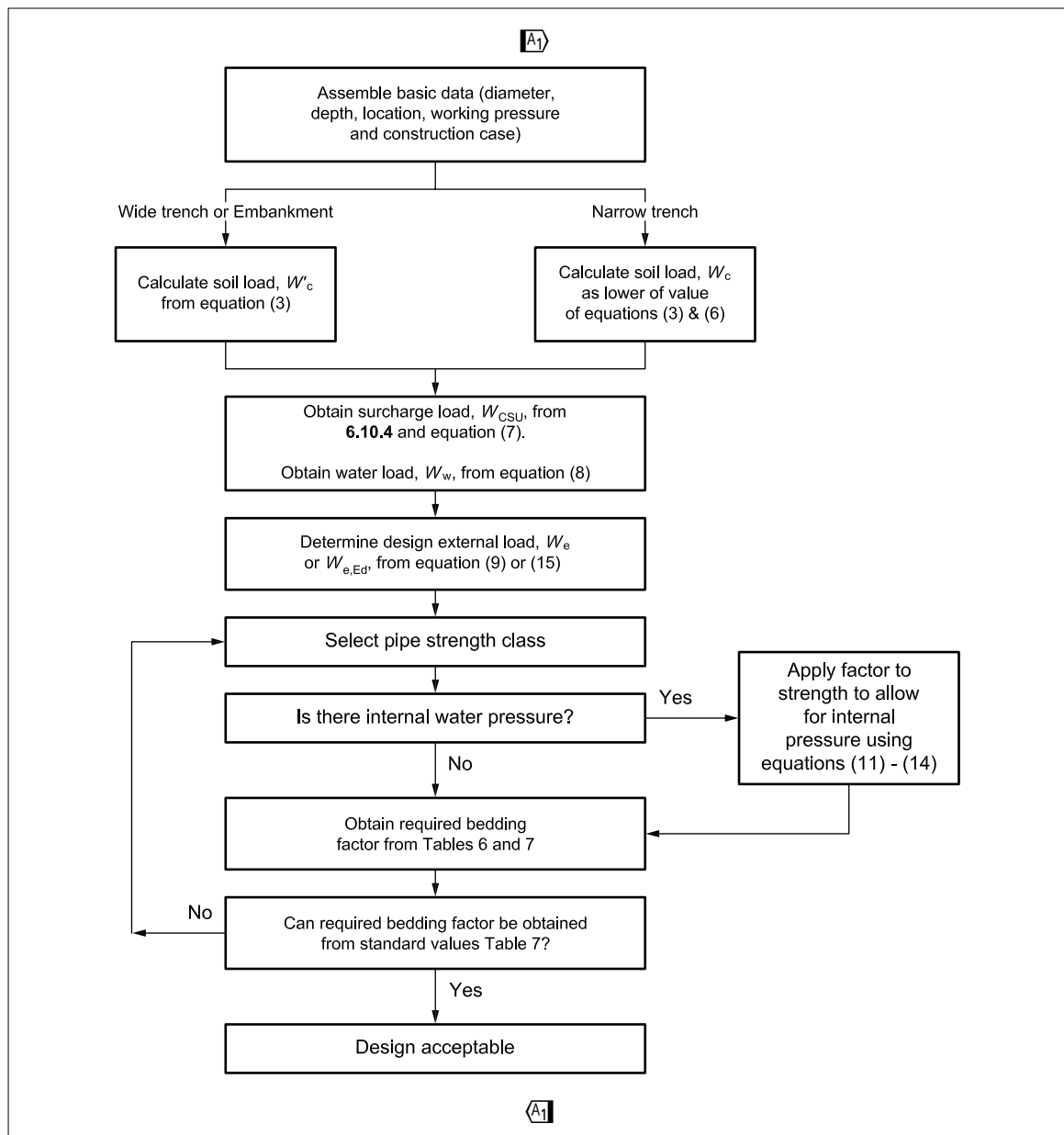
³⁾ Withdrawn.

Figure 14 — Factor for calculating multi-track railway loadings

6 Rigid pipe design

COMMENTARY ON CLAUSE 6

This clause gives the design formulae, identified by equation numbers which are referred to in the flowchart in [Figure 15](#), which sets out the design procedure for rigid pipes. [A1](#) Some worked examples of rigid pipe design are given in [B.1](#). [A1](#)

Figure 15 — Flowchart for pipe design with rigid pipes

6.1 General

Rigid pipes rely on their embedment to distribute the loads imposed by backfill and traffic to reduce the circumferential bending moments in the pipe walls. Their response to vertical loading applied at the crown is to settle marginally into their supporting material until sufficient support reaction, with an associated bedding angle, α (see [Figure 3](#)), is achieved. The larger the bedding angle, the lower the circumferential bending moment induced in the pipe wall.

The basic governing formula for the design of buried rigid pipe is:

$$\text{vertical load capacity} = \text{crushing strength} \times \text{bedding factor}$$

where the bedding factor takes account of bedding angle and soil load distribution generally (see [6.7](#)).

6.2 Wide and narrow trenches

There are two installation conditions: pipes installed in wide trenches or embankments and pipes installed in narrow trenches. For all pipe installations the loads arising from both conditions should be calculated for the selected maximum trench width and the lower of the two loads, W_c or W'_c , used in the design specifying the installation condition. In the absence of specific information, it is safe to assume the trench is wide. Figure 16 illustrates the effect of trench width on the relative size of these two loads.

A separate calculation of vertical backfill load on the pipe is generally conducted for each condition and the results compared. Depending on the assumed trench geometry, either calculated load might prove to be larger.

Figure 16 — Effect of trench width, B_d , on calculated vertical backfill load on pipe

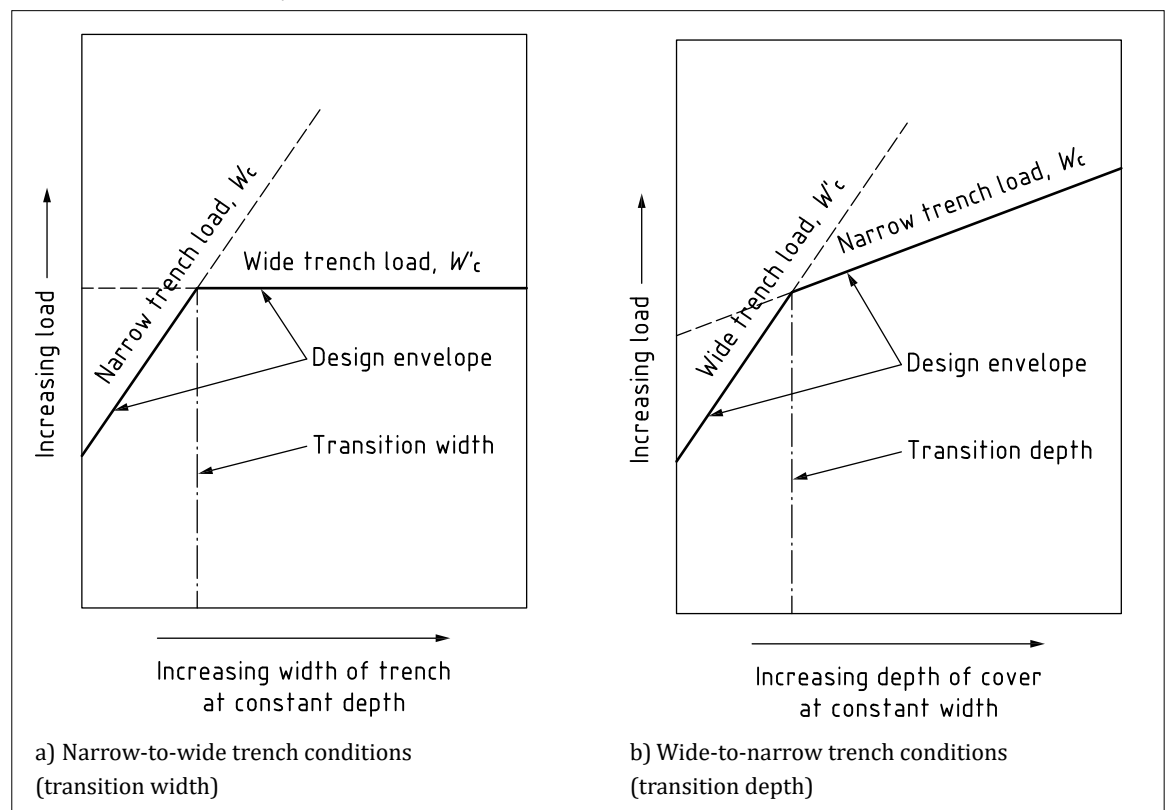


Figure 16 also illustrates what is known as the “transition width” and the “transition depth”. For a narrow trench at a particular depth the load, W'_c , increases as the trench width increases, up to a maximum value given by the wide trench formula.

When the loads calculated by the two methods are equal, the “transition width” is reached. Although the load calculated by the narrow trench formula increases beyond that width, the pipe will not in reality experience a load greater than the wide trench load.

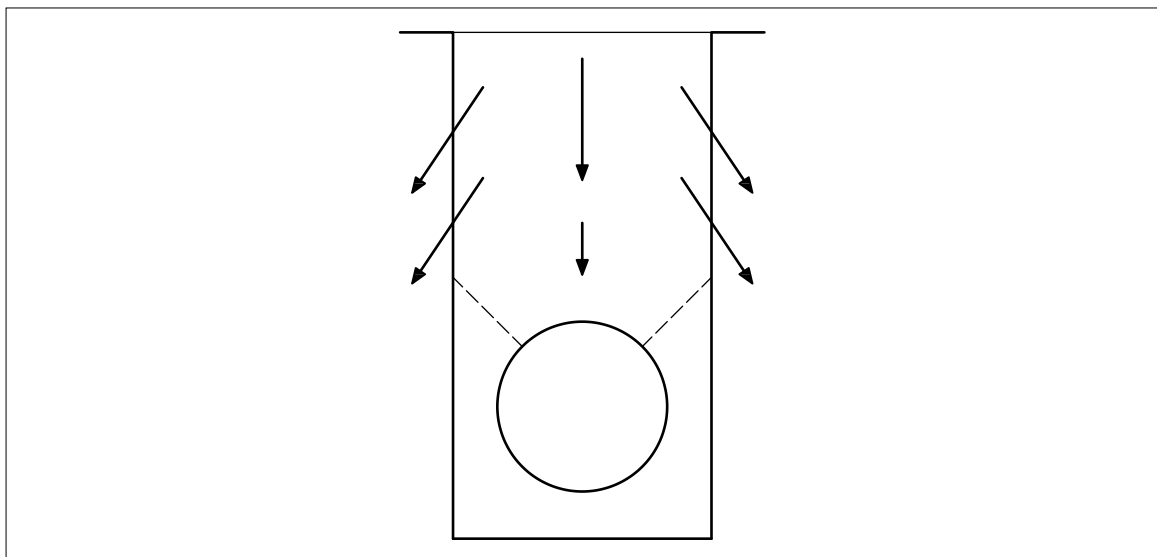
Similarly, in a trench of a particular width but varying depth, it is possible for wide trench conditions to apply in the shallower sections of the trench and for narrow trench conditions to apply in the deeper sections. The depth at which the loads calculated by both formulae are equal is known as the “transition depth”. At depths beyond the transition depth, the narrow load applies.

For the wide-to-narrow trench condition [see [Figure 16b](#)]] the soil load coefficient, C_d , is used and takes account of what is known as the “silo effect” (see [Figure 17](#)). This is the phenomenon, first observed in grain silos during the 19th century, whereby settlement of backfill transfers load by friction to the walls of a vertically-sided trench. If the trench is sufficiently narrow, this can substantially reduce the vertical load on a rigid pipe compared with that arising in wide trench conditions, at least in the short term [see [Figure 3b](#)]].

The theory from which values of C_d are derived assumes that 100% of the friction-reduced backfill load is supported by the pipe: as the trench width increases, the total of this backfill load increases. However, in practice a proportion is supported by the columns of sidefill adjacent to the pipe. This has the effect that the narrow trench formula, which predicts relatively low design loads on the pipe if the trench walls are sufficiently close, becomes over-conservative as trench width increases. For this reason, it is conventional to adopt the lower of the calculated narrow and wide trench loads for design (see [Figure 16](#)).

If, however, the walls of the trench are not close enough to have a beneficial effect, then the pipe is designed as if in a wide trench. Designers should be mindful of how an installation is likely to be carried out on site and whether this can ensure construction of a trench whose width does not exceed the maximum specified at any point, so that the whole trench depth is available to relieve load.

Figure 17 — The silo effect



6.3 Complete and incomplete projection

Within the wide trench design, the concept of complete and incomplete projection is addressed. These refer to a line known as the “plane of equal settlement” and to whether this line falls above ground level (complete projection: see [Figure 18](#)) or below (incomplete projection: see [Figure 19](#)). The plane of equal settlement refers to the point at which the settlements of soil to the sides of the pipe and over the pipe are equal.

Loads should be calculated using both complete and incomplete projection formulae [[equations \(4\) and \(5\) in 6.10.2](#)] and the lesser of the two calculated loads used for design.

NOTE Generally this calculation shows that the incomplete projection case is the more common situation, except for pipes installed at a shallow depth of cover.

Figure 18 — Complete projection

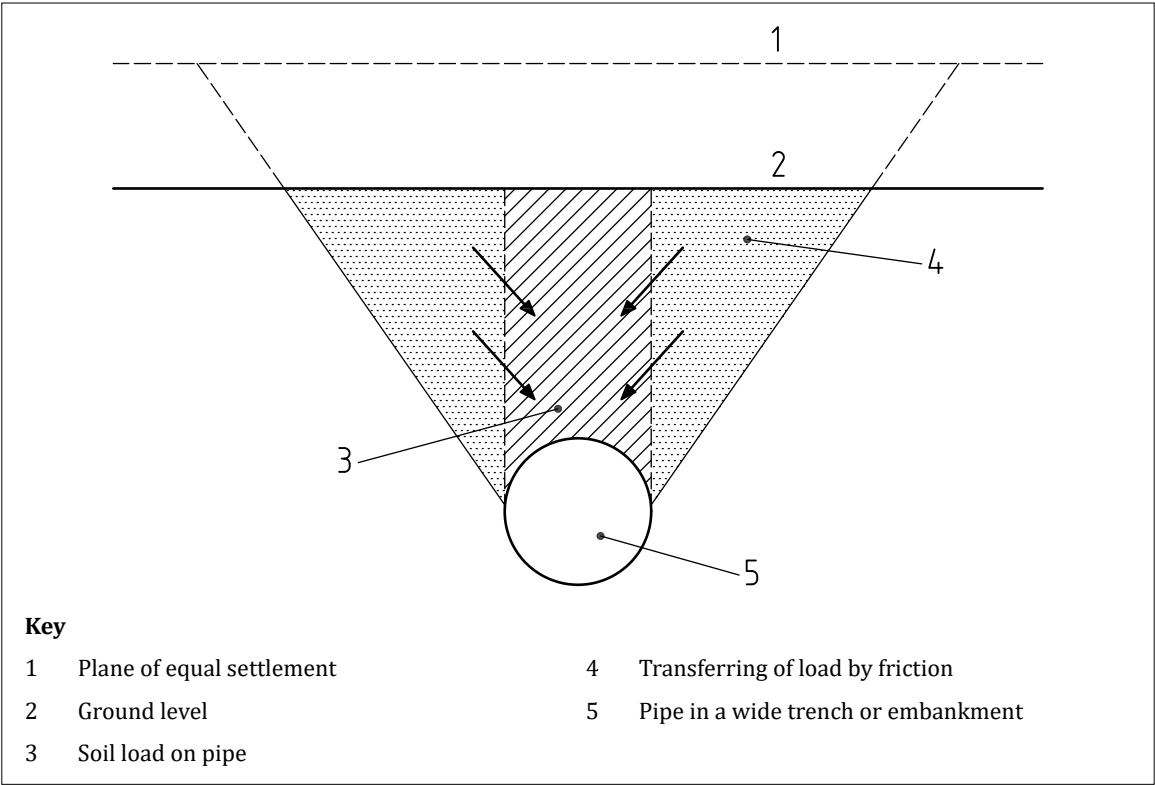
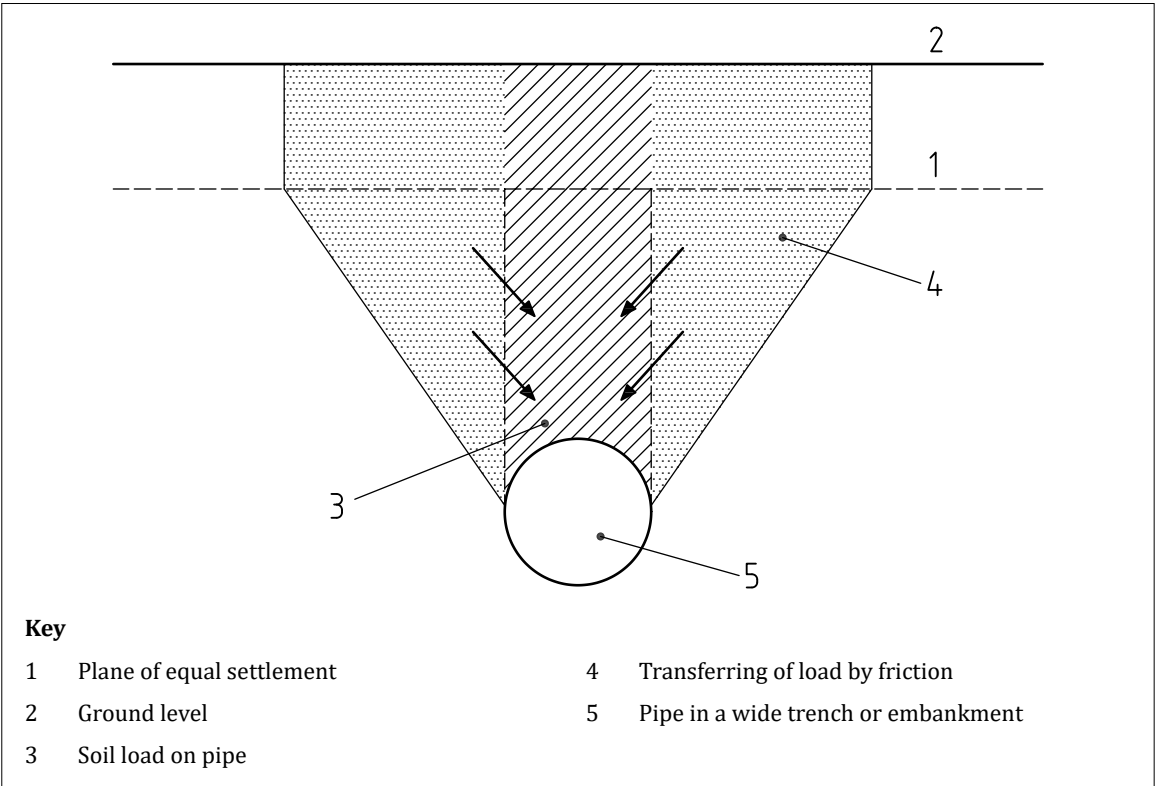


Figure 19 — Incomplete projection



6.4 Settlement deflection ratio, r_{sd}

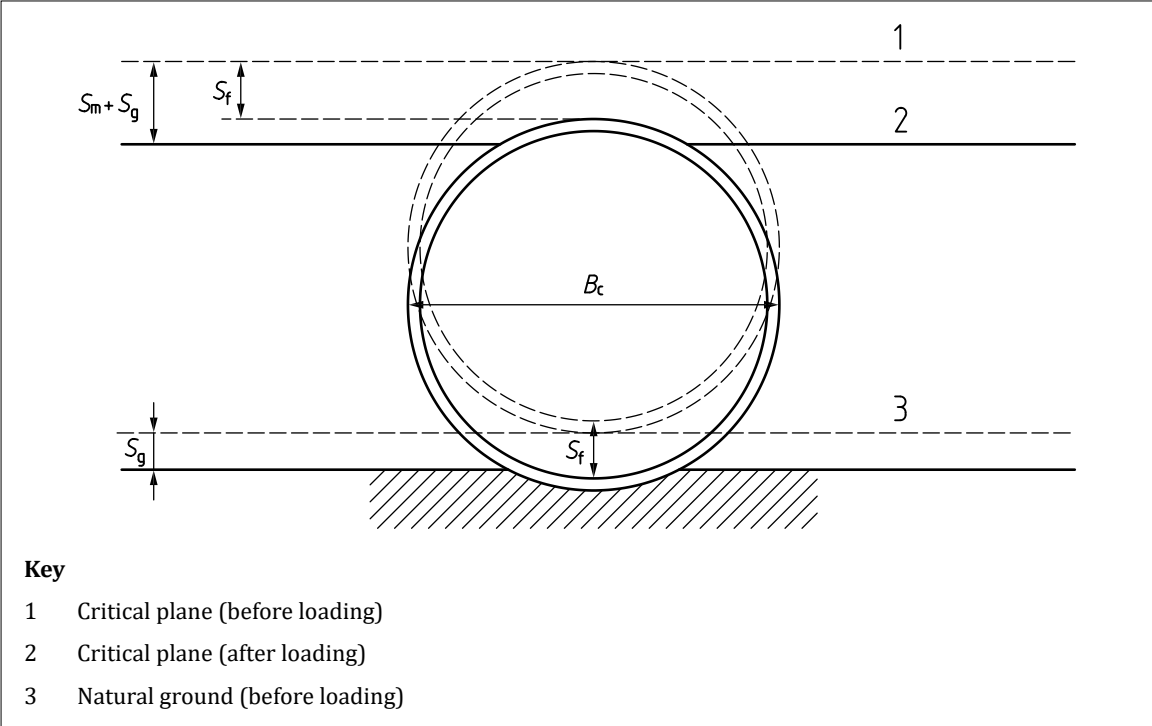
The settlement deflection ratio for a positively projecting pipe, r_{sd} , i.e. in a wide trench or embankment, is given by:

$$r_{sd} = \frac{(S_m + S_g) - S_f}{S_m}$$

where S_m , S_g and S_f are as shown in Figure 20.

NOTE Values of settlement deflection ratio have been determined experimentally and are taken from the TRRL's "Guide to design loadings for buried rigid pipes" [N1] and reproduced in Table 4.

Figure 20 — Settlement deflection ratio



The settlement deflection ratio is evaluated by examining the situation of a pipe being laid on the surface of the ground, with the critical plane being at the pipe crown. Once loading occurs, the natural ground level goes down an amount, S_g , the pipe goes down by the settlement of the pipe invert, S_f , and the critical plane goes down by the settlement of the fill, S_m , plus the settlement of the natural ground, S_g .

The recommended values of the settlement deflection ratio, r_{sd} , and ranges for the native soil modulus, E'_3 , are given in Table 3.

A1

Table 3 — Recommended values for r_{sd} and E'_3

Foundation	r_{sd}	E'_3 MN/m ²
Unyielding (e.g. rock)	1.0	>14
Normal	0.5 to 0.8	3 to 14
Yielding (e.g. soft ground)	0 to 0.5	<3

NOTE Guidance on the relationship between native soil moduli and soil types is given in Table 4.

A1

Table 4 — *Guide values of Spangler modulus for native soils, E'_3*

Soil type	Spangler modulus for soils in various conditions (MN/m ²)				
	Very dense	Dense	Medium dense	Loose	Very loose
Gravel	Over 40	15 to 40	9 to 15	5 to 9	3 to 5
Sand	15 to 20	9 to 15	4 to 9	2 to 4	1 to 2
Clayey, silty sand	10 to 15	6 to 10	2.5 to 6	1.5 to 2.5	0.5 to 1.5
Clay	Very hard	11 to 14			
	Hard	10 to 11			
	Very stiff	6 to 10			
	Stiff	4 to 6			
	Firm	3 to 4			
	Soft	1.5 to 3			
	Very soft	0 to 1.5			

NOTE Further guidance on the use of lightweight aggregates is given in [A.11.4](#).

6.5 Projection ratio, ρ

The projection ratio, ρ , is calculated as the proportion of the pipe external diameter that is above firm bedding level or the natural ground level. For classes D, N and F beddings (see [6.7](#), [Table 6](#)) the value of ρ is unity, and for other granular and concrete beddings ρ is 0.7.

In calculation, the settlement deflection and projection ratios are used in combination, and design values of their product, $r_{sd}\rho$, are often taken as 0.7 for bedding classes D, N and F (see [6.7](#), [Table 6](#)) and 0.5 for bedding classes B and S.

6.6 Soil properties

In the absence of data on the soil type supporting the use of other values it is normal practice to assume the following:

- a) $K\mu = 0.19$;
- b) $K\mu' = 0.13$; and
- c) $\gamma = 19.6 \text{ kN/m}^3$.

The combinations $K\mu$ and $K\mu'$ are generally used as single design parameters, rather than determining values of K , μ and μ' separately.

Where soils are more precisely identified, the values given in [Table 5](#) may be used.

Table 5 — *Values of $K\mu$ and $K\mu'$ for specific soil types*

Type of soil	$K\mu$ or $K\mu'$
Granular soils without cohesion	0.190
Maximum for sand and gravel	0.165
Saturated top soil	0.150
Maximum for ordinary clay	0.130
Maximum for saturated clay	0.110

The value of $K\mu'$ is taken as the lower of the values for the backfill material and the native soil in the trench sides.

6.7 Bedding factors

The loadbearing capacity of a rigid pipe when buried is the crushing strength of the pipe [determined in accordance with European Standards, e.g. [BS EN 295](#) (all parts) for clay; [BS EN 1916](#) for concrete] multiplied by the bedding factor, $\langle A_1 \rangle F_m \langle A_1 \rangle$. The crushing strength is determined by line load testing which produces the most onerous pipe wall circumferential bending moment.

The safe crushing strengths specified in European Standards are statistically determined from these tests.

[Table 6](#) shows that the bedding factor increases with the bedding angle, $\langle A_1 \rangle \propto \langle A_1 \rangle$. Higher bedding angles result in greater load distribution. Furthermore, horizontal soil loads can have a bending moment-relieving effect that is also reflected in the values of bedding factors.

The purpose of the embedment is to distribute the vertical loads (and the corresponding support reaction) around the pipe. By effectively distributing these loads the pipe can withstand higher loadings than the crushing strength of the pipe alone. For example, a 360° embedment (bedding class S – see [Table 6](#)) has historically been given a bedding factor of 2.2, whereas a non-existent or minimal bedding (bedding class D or N) hardly distributes the loads at all, and results in a bedding factor of only 1.1.

A series of 240 physical tests on clay pipes over a 13-year period at British Ceramic Research Ltd. and the Water Research Centre demonstrated that higher bedding factors were achieved in practice, even using lower than normal levels of workmanship [3]. This was attributable to the bending moment-relieving effect of lateral soil loading in the wide trench conditions of the tests. The tests also demonstrated that it was the amount of support to the bottom half of the pipe that was the critical determinant of the bedding factor. Hence, the same bedding factor of 2.5 is adopted for wide trench conditions to both class B and class S beddings. The only exception is where trench widths are less than the minima specified in [BS EN 1610](#), in which case the bedding factor for classes B and S revert to 1.5, as for class F, because filling of the upper bedding (under the haunches of the pipe – see [Figure 1](#)) cannot be assured in practice. These different values are reflected in [Table 6](#).

Bedding factors are extensively discussed in *Guide to design loadings for buried rigid pipes* [N1], *Bedding construction and flow capacity of vitrified clay pipelines* [4] and *Revised bedding factors for vitrified clay pipes* [3].

6.8 Crushing strength adjustments for pressure pipes

Some rigid pipe materials, such as specially designed concrete, can be used for pressure applications. In this case it is necessary to make an adjustment to the crushing strength of the pipe to account for the fact that, in addition to the backfill and traffic loading, some of the pipe's strength will also be required to contain the internal pressure within the pipe.

6.9 Minimum bedding factor and factor of safety

The process of structural design involves effectively matching the imposed loads to the loadbearing capacity of the pipe and its embedment to achieve an overall and appropriate factor of safety. As rigid pipes are available in few crushing strength classes (one for concrete, up to three for clay), design typically involves establishing that the required minimum bedding factor, when multiplied by the selected pipe strength, at least equals the total imposed design load (see [6.11](#)).

The minimum factors of safety are given in [6.12](#), [Table 9](#).

Recommended design values of the bedding factor required can be obtained from [6.15.6](#), [Table 12](#), and [6.16](#), [Table 13](#). The applicable design values of crushing and proof strengths, W_t and W_p , should be obtained from the applicable product standards.

Where a limit state design is used, the partial safety factors given in [6.13.4](#), [Table 10](#), should be used. The use of a minimum factor of safety is no longer required.

Table 6 — *Rigid pipe embedment*

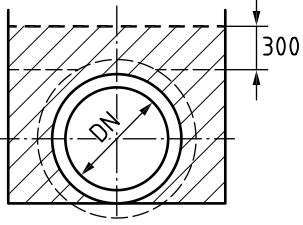
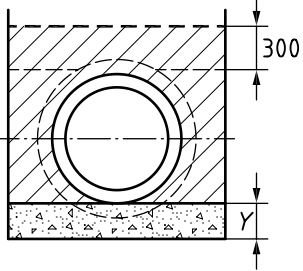
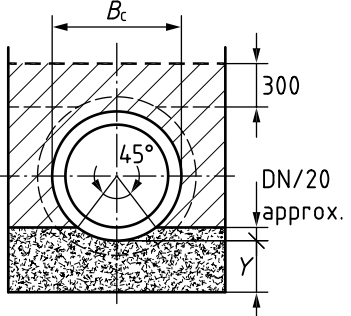
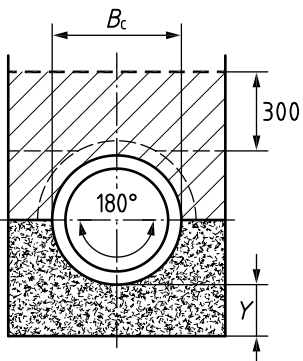
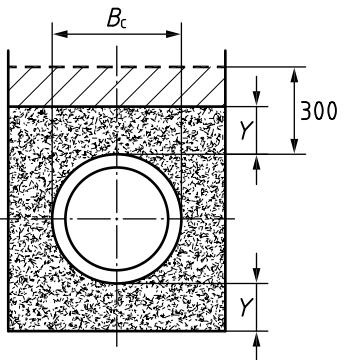
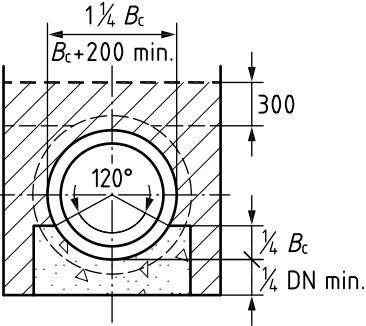
Bedding detail $Y = 1/6 B_c$	Bedding class	Dimensions in millimetres	
		Bedding factors, F_m	
		Narrow trench	Wide trench/ embankment ^{A)}
	D	1.1	1.1 to 1.3 (see [N1])
	N	1.1	1.1 to 1.3 (see [N1])
	F	1.5	1.9 (see [4])
	B	1.9 ^{B)}	2.5 (see [4])
	S	2.2 ^{B)}	2.5 (see [4])

Table 6 — Rigid pipe embedment (continued)

Dimensions in millimetres							
Bedding detail $Y = 1/6 B_c$		Bedding class		Bedding factors, F_m			
				Narrow trench		Wide trench/ embankment ^{A)}	
		A Unreinforced		2.6		Wide trench: 2.6 (see [N1]) Embankment: 2.6 to 3.7 (see [N1])	
		Reinforced		3.4		Wide trench: 3.4 (see [N1]) Embankment: 3.4 to 5.7 (see [N1])	
	In situ concrete		Granular bedding material		Selected backfill material		All-in granular material

NOTE 1 The TRRL guide [N1] provides:

- guidance on use of embankment bedding factors; and
- details of class A bedding reinforcement.

NOTE 2 The source of this material is reference [4] and further detail can be found there if required.

A1) NOTE 3 Bedding factors for concrete surround are given in A.14, Figure A.13. **A1)**

A) Applicable to pipes less than 900 mm outside diameter. For outside diameters ≥ 900 mm, see 6.10.1, Table 7.

B) Subject to conformity with minimum trench widths specified by BS EN 1610. For narrower trench widths the bedding factors for classes B and S should be taken as 1.5 for design.

6.10 Design loads for rigid pipes

6.10.1 General

Where designers have sufficient control over the installation stage to ensure conformity with the temporary works specification (trench support, compaction and overall trench width), the load-reducing effect of narrow trenches can be incorporated within the design. In all other cases (typically where the temporary works are likely to be determined by the installation contractor or subject to uncertain site conditions, e.g. proximity of other trenches), the design should be based on the more conservative wide trench model. The bedding factors for the wide trench condition given in Table 6 already take account of relieving lateral pressure, but only for outside diameters up to 900 mm as verified by testing in the UK [4]. For larger diameters, **A1)** in the case of bedding classes, B and S **A1)** design bedding factors are given in Table 7. **A1)** For other bedding classes, see Table 6. **A1)**

Table 7 — Design bedding factors for pipes laid in wide trench and embankment conditions with bedding classes B and S and outside diameter greater than or equal to 900 mm^{A)}

H/B_c	0.5	1.0	1.5	2.0	3.0	5.0	10	15
$F_m^{B)}$	2.8	2.58	2.44	2.39	2.36	2.35	2.33	2.33

A) Assumes $\rho = 0.7$; $r_{sd}\rho = 0.5$; refer to 6.5.

B) From Concrete Pipe Design Manual published by American Concrete Pipe Association [5].

6.10.2 Soil load, W'_c , in wide trench and embankment conditions

Soil load, W'_c , in the wide trench and embankment conditions is given by:

$$W'_c = C_c \gamma B_c^2 \quad (3)$$

The value of C_c is taken as the lower of the values derived from [equations \(4\) and \(5\)](#). If the lower value is given by [equation \(4\)](#), complete projection conditions exist. If the lower value is given by [equation \(5\)](#), incomplete projection conditions apply.

$$C_c = \frac{e^{2K\mu H/B_c} - 1}{2K\mu} \quad (4)$$

$$C_c = \left[\frac{e^{2K\mu H_e/B_c} - 1}{2K\mu} + \left(\frac{H}{B_c} - \frac{H_e}{B_c} \right) e^{2K\mu H_e/B_c} \right] \quad (5)$$

where H_e is the height of the plane of equal settlement above the top of the pipe. Derivation of H_e is complex, but [Table 8](#) provides simplified equations for obtaining C_c .

The full formulae from which the equations in [Table 8](#) are derived are given in the TRRL's *Guide to design loadings for buried rigid pipes* [N1], Clauses 2.4 and 2.5, assuming $K_\mu = 0.19$ (see [6.6](#)).

Table 8 — Load coefficients for incomplete projection condition

$r_{sd}\rho$	Equation for C_c
0	$C_c = H/B_c$
+0.1	$C_c = 1.23 (H/B_c) - 0.02$
+0.3	$C_c = 1.39 (H/B_c) - 0.05$
+0.5	$C_c = 1.50 (H/B_c) - 0.07$
+0.7	$C_c = 1.59 (H/B_c) - 0.09$
+1.0	$C_c = 1.69 (H/B_c) - 0.12$
+2.0	$C_c = 1.93 (H/B_c) - 0.17$
+3.0	$C_c = 2.08 (H/B_c) - 0.20$
+4.0	$C_c = 2.19 (H/B_c) - 0.21$
+5.0	$C_c = 2.28 (H/B_c) - 0.22$

6.10.3 Soil load, W_c , in the narrow trench condition

For the narrow trench condition soil load, W_c , is given by:

$$W_c = C_d \gamma B_d^2 \quad (6)$$

where:

$$C_d = \frac{1 - e^{-2K\mu' H/B_d}}{2K\mu'}$$

For pipes in trenches, the backfill load is given by [equation \(3\)](#) and [equation \(6\)](#) and the lower value is used for the pipe design.

6.10.4 Concentrated surcharge load, W_{csu}

The concentrated surcharge load, W_{csu} , is given by:

$$W_{\text{csu}} = P_s B_c \quad (7)$$

where the value of the surcharge pressure, P_s , is obtained from [Clause 5](#).

6.10.5 Internal water load, W_w

Equivalent load due to weight of water in pipe, W_w , is given by [equation \(8\)](#):

$$W_w = C_w \gamma_w \pi (D - t)^2 / 4 \quad (8)$$

where the value of C_w is normally taken as 0.75.

6.10.6 Total design external load, W_e

Total design external load, W_e , is given by [equation \(9\)](#):

$$W_e = W_c + W_{\text{csu}} + W_w \quad (9)$$

NOTE Substitute W'_c for W_c for the wide trench or embankment conditions.

6.11 Supporting strength of rigid pipes

The supporting strength of rigid pipes is the product of the pipe strength and the bedding factor and should be at least equal to the total design external load, W_e , given by [equation \(9\)](#).

The minimum recommended bedding factor, F_m , is given by [equation \(10\)](#):

$$F_m \geq W_e F_{se} / W_t \quad (\text{or } W'_t) \quad (10)$$

Recommended design values of the bedding factor can be obtained from [Table 6](#), with the design values of crushing strength, W_c , obtained from product standards.

For pressure pipes a reduction factor should be applied to the crushing strength, W'_c , to take account of the effect of the internal water pressure.

a) for reinforced concrete pressure pipes:

$$W'_t = W_t (1 - P_{op} / P_{ult}) \quad (11)$$

in which case, the working pressure in kilonewtons per square metre (kN/m²), P_w , should not exceed:

$$P_{ult} (1 - W_e / W_t F_m) / F_{si} \quad (12)$$

b) for asbestos cement pressure pipes:

$$W'_t = W_t (1 - P_{op} / P_{ult})^{0.5} \quad (13)$$

in which case, the working pressure, P_{op} , should not exceed:

$$P_{ult} \left[1 - (W_e / W_t F_m)^2 \right] / F_{si} \quad (14)$$

6.12 Factors of safety

The recommended minimum values of safety factors, F_{se} and F_{si} , for the equations in 6.11 are given in Table 9.

Table 9 — Minimum values of F_{se} and F_{si}

Pipe material	F_{se} ^{A)}		F_{si}
	Non-pressure	Pressure	Pressure
Clay	1.25	—	—
Concrete	1.25	1.60	2.0

^{A)} For reinforced concrete pipes, F_{se} should be not less than W_t/W_p .

6.13 Limit state design

6.13.1 Introduction

The traditional approach for rigid pipe design is set out in 6.10. The method provides a minimum bedding factor, based on factor of safety values given in Table 9.

A limit state design approach can be used with verification by the partial factor method as an alternative to global factors of safety. Similar principles are used for the assessment of the minimum bedding factor required.

6.13.2 Limit states

The pipe crushing strength, W_t , is used to determine the ultimate limit state, ULS. Product standards specify this strength as an absolute minimum, which can also be used in place of characteristic strength for the purposes of the ULS design checks.

The serviceability limit state, SLS, is assessed using the proof load, W_p . The proof load is only applicable for reinforced products where a maximum crack width is specified in product standards. The crack width is generally considered to be an SLS for durability issues.

Ultimate limit state (ULS):	Pipe crushing strength (W_t)
Serviceability limit state (SLS):	Proof load (W_p)

6.13.3 Design loads

Design loads are calculated for the following, using the methodology set out in 6.10:

- soil load: W_c for the narrow trench and W'_c for the wide trench or embankment condition;
- concentrated surcharge load, W_{csu} ; and
- internal water load, W_w .

6.13.4 Partial safety factors

To calculate the total design load required, partial factors are applied to the respective loads. The partial factors consistent with BS EN 1990:2002+A1:2005 and BS EN 1991-4:2006 are given in Table 10, along with values for the ULS and SLS.

Table 10 — *Design factors of actions*

Action	Type		Limit state		Reference
			ULS	SLS	
Permanent	Soil	γ_G	1.35	1.0	NA to BS EN 1990:2002+A1:2005, Table NA.A2.4(B)
Variable	Traffic/Surcharge	γ_Q	1.35	1.0	NA to BS EN 1990:2002+A1:2005, Table NA.A2.4(B)
Permanent	Internal water	$\gamma_{G,intw}$	1.2	1.0	BS EN 1991-4:2006, NA.A.2.1

6.13.5 Design value of actions

The total design external load in kN/m, $W_{e,Ed}$, is given by [equation \(15\)](#):

$$W_{e,Ed} = \gamma_G W'_c + \gamma_Q W_{csu} + \gamma_{G,intw} W_w \quad (15)$$

NOTE Substitute W_c for W'_c in narrow trench conditions.

6.13.6 Minimum recommended bedding factor, F_m

The minimum bedding factor is calculated for both ULS and SLS as follows.

$$ULS = F_m \geq W_{e,Ed} / W_t \quad (16)$$

$$SLS = F_m \geq W_{e,Ed} / W_p \quad (17)$$

For reinforced pipes the minimum F_m required for both limit states should be calculated and the critical or higher value used to specify the bedding class.

For unreinforced pipes only the ULS is applicable and the resulting minimum F_m is used.

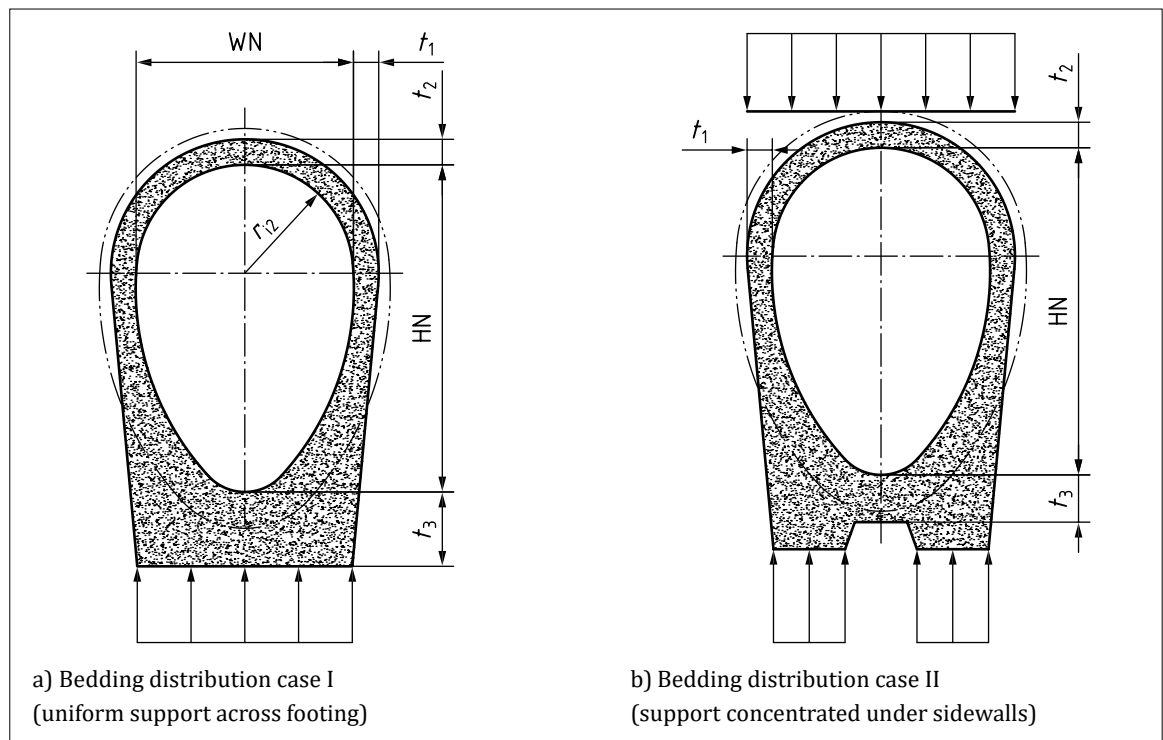
6.14 Design of egg-shaped pipes**6.14.1 Design approach**

The design method described in this subclause is based on PD CEN/TR 1295-3:2007, as updated in the (forthcoming) German standard DWA-A 127-2 [6], utilizing bending moments at crown, springing and invert level to determine flexural tensile stress and to compare with permissible stress in unreinforced concrete pipes.

6.14.2 Design method**6.14.2.1** Establish values for the following dimensions, in metres (m):

- WN – internal width;
- HN – internal height;
- r_{i2} – internal radius at crown (generally = WN/2);
- t – wall thickness (which can vary with location around cross-section);
- t_1 – wall thickness at springings;
- t_2 – wall thickness at the crown;
- t_3 – wall thickness at the invert; and
- r_m – mean pipe radius at springing level ($= r_{i2} + t_1/2$),

and for the applicable bedding distribution case dependent on the footing design of the pipe cross-section, as defined by [Figure 21](#).

Figure 21 — Dimensions and bedding distribution cases for egg-shaped pipes

- 6.14.2.2** For embedment of egg-shaped pipes, use only bedding class B or S; the choice between these two does not affect structural design.
- 6.14.2.3** Determine external loading by calculating soil load (W_c for narrow trench, W'_c for wide trench) and surcharge load, W_{csu} , in accordance with 6.10.
- 6.14.2.4** Determine external pressure components, expressed in kN/m^2 , as follows:
- vertical pressure due to soil load, $[A_1] P_{vwc} [A_1] = W_c/B_c$ or $[A_1] P_{vw,c} [A_1] = W'_c/B_c$, as applicable;
 - vertical pressure due to surcharge (traffic) load, P_s , in accordance with Clause 5;
 - horizontal pressure due to soil load, P_h , given by:

for narrow trench condition: $[A_1] P_{h,wc} = 0 [A_1]$ (18)

for wide trench condition: $[A_1] P_{h,w'c} = 0.3 \left(\frac{\gamma H B_d - W'_c}{B_d - B_c} \right) [A_1]$ (19)

- external water pressure at pipe springing level, $[A_1] P_{h,w} [A_1]$.

NOTE 1 Horizontal pressure due to variable (traffic) load may be ignored for conservative design.

NOTE 2 Stresses developed from self-weight and internal water in the pipe are typically so small they can be ignored.