

BS 9295:2010



BSI Standards Publication

Guide to the structural design of buried pipelines

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Foreword

Publishing information

This British Standard is published by BSI and came into effect on 31 March 2010. It was prepared by Technical Committee B/505, *Wastewater engineering* in consultation with Technical Committee B/504, *Water supply*. A list of organizations represented on these committees can be obtained on request to their secretaries.

Relationship with other publications

This British Standard is complementary to BS EN 1295-1:1997 and PD CEN/TR 1295-2:2005.

BS EN 1295-1:1997 specifies general requirements for the structural design of buried pipelines 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 summarised in **B.2.12**, and National Annex A describes the calculation procedure in more detail.

PD CEN/TR 1295-2:2005 summarizes the nationally established methods of design made available to CEN and the United Kingdom method is described in **A.9**, which is consistent with BS EN 1295-1:1997, National Annex A, as corrected by Corrigendum No. 1 on 31 May 2006.

This British Standard gives further information to facilitate in full the structural design of buried pipelines under various conditions of loading using the established United Kingdom method; it does not alter any of the provisions of BS EN 1295-1:1997.

Whilst recognizing that the UK National Annex to EN 1295-1 might be reviewed in the future in respect of possible changes to current practice for the design of thermoplastics pipelines, it was agreed that this first edition of BS 9295 is specifically required to be a guide to the existing BS EN 1295-1.

Use of this document

As a guide, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it was a specification or a code of practice and claims of compliance cannot be made to it.

Presentational conventions

The provisions in this standard are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is "should".

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

Introduction

The established United Kingdom method for the structural design of buried pipelines under various conditions of loading ("the UK method") is based on the "Marston" or "Computed load" method developed at the Iowa Engineering Experiment Station in the USA by Professor Anson Marston and his colleagues Professors Merlin G. Spangler and W.J. Shlick in the first half of the twentieth century. In 1951, at the request of the then Ministry of Housing and Local Government, a 10-year programme of experimental work was carried out at Garston by the Building Research Station (later the Building Research Establishment). The work was led by N.W.B. Clarke, supported by Oliver C. Young and J.H. Smith and in 1962 resulted in the publication of *Simplified tables of external loads on buried pipelines* [1], followed in 1966 by *Loading charts for the design of buried rigid pipes* [2] and in 1967 by *High-strength beddings for unreinforced concrete and clayware pipes* [3]. In 1970 an updated and revised *Simplified tables of external loads on buried pipelines* [4] was published.

Throughout the 1960s the Marston work was complemented by a programme of research on rigid pipe beddings at the British Ceramic Research Association at Stoke-on-Trent, sponsored by the Clay Pipe Development Association and led by John H. Walton. This phase of the Stoke-on-Trent investigations culminated in 1970 with the publication of *The structural design of the cross-section of buried vitrified clay pipelines* [5], but by then the work had moved on into minimum beddings for small diameter pipes. That research was led by Colin E.G. Bland, whose work in chairing the B/505 project group that developed this British Standard is acknowledged by both B/504 and B/505. In 1975 the use of minimum beddings for rigid pipes not exceeding DN225 was endorsed by the Department of the Environment's Working Party on Sewers and Water Mains in its First Report [6].

By 1983 the United Kingdom central role in this field had passed from the Building Research Station to the Transport and Road Research Laboratory (now the Transport Research Laboratory) and, based on work by Oliver C. Young and Myles P. O'Reilly, it published *A guide to design loadings for buried rigid pipes* [7]; there was no longer any limit on the size of rigid pipes that could be used with minimal bedding. In 1986 a further edition of *Simplified tables of external loads on buried pipelines* [8] was published, based on work by the same authors and Guy Brennan. BSI gratefully acknowledges the permission kindly granted by Her Majesty's Stationery Office to draw heavily on the texts of these two publications in the preparation of this British Standard.

In 1989 a joint working group of CEN/TC 164 *Water supply* and CEN/TC 165 *Wastewater engineering*, led by the latter, was created to develop a common method for the structural design of buried pipelines. The varying practices throughout Europe and the huge task of agreeing a common method led the group to adopt what became a three-stage approach. The first stage was to produce an EN specifying general requirements and giving guidance on the application of nationally established methods; this was achieved in 1997 and implemented by BSI as BS EN 1295-1:1997. The second stage was to collate and summarize the various nationally established methods of design that had been reported in Europe and this was published by BSI as PD CEN/TR 1295-2:2005.

It proved impossible to agree a common method and so in 2003 it was decided to stop work on an EN, since the human and financial resources necessary were no longer available. By then the draft had been distilled into two separate methods, broadly speaking those used in France and the Germanic countries, and so it was decided to publish these as what became CEN/TR 1295-3:2007. The United Kingdom recorded opposition to the proposed Technical Report at CEN formal vote stage because the two methods not only give widely varying results for the same input data for both rigid and flexible pipes, but neither produces equivalent results to the UK method described in BS EN 1295-1:1997, which has been proven both by research and practice correlating theory and practice for both rigid and flexible pipes.

More recent research work indicates a possible need for revision of the design method for buried thermoplastics pipes to be included in a future revision of BS EN 1295-1.

BSI is not obliged to publish CEN Technical Reports and so, on the advice of B/505, supported by B/504, did not do so in the case of CEN/TR 1295-3:2007.

The method for semi-rigid pipes in BS EN 1295-1:1997 was taken from published and unpublished work by C. Barrie Greatorex at Stanton plc.

The aim of this British Standard, therefore, is to consolidate and update the various documents that together describe the UK method. The opportunity has also been taken to expand on the published information and in this connection both B/504 and B/505 acknowledge the kind permission of MWH (Montgomery Watson Harza) UK Ltd. to incorporate work developed by the late Jonathan L. Olliff, for many years a member of both committees and principal UK expert in the CEN joint working group.

1 Scope

This British Standard gives information and guidance for the use of BS EN 1295-1:1997, National Annex A, the UK established method for the structural design of buried pipelines under various conditions of loading. The procedures are explained and, for situations where general assumptions can be made, loading tables are given.

NOTE The scope of BS EN 1295-1:1997 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.

The design for longitudinal effects is not covered (see BS EN 1295-1:1997, 5.4).

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

BS EN 598:2007+A1:2009, *Ductile iron pipes, fittings, accessories and their joints for sewerage applications – Requirements and test methods*

BS EN 622-4:1997, *Fibreboards – Specifications – Part 4: Requirements for softboards*

BS EN 1295-1:1997, *Structural design of buried pipelines under various conditions of loading – Part 1: General requirements*

BS EN 1610:1998, *Construction and testing of drains and sewers*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this British Standard, the terms and definitions given in BS EN 1295-1:1997 apply.

3.2 Symbols

For the purposes of this British Standard, the following symbols apply.

B_c	outside diameter of pipe
B_d	effective width of trench
C_c	soil load coefficient in wide trench (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
D	mean diameter of pipe
D_f	strain factor
D_L	deflection lag factor
D_{Lsr}	lag deflection factor for semi-rigid pipes
E	flexural modulus of elasticity of pipe material
E_h	hoop tensile modulus of elasticity of pipe material
E'	overall modulus of soil reaction
E'_2	embedment soil modulus
E'_3	native soil modulus
F_m	bedding factor
F_s	factor of safety
F_{se}	factor of safety for rigid pipe material (external load design)
F_{si}	factor of safety for rigid pipe (internal pressure design)
H	depth of cover to top of pipe
H_e	height of plane of equal settlement above top of pipe
I	second moment of area of unit length of pipe wall
K	coefficient of active lateral earth pressure
K_x	deflection coefficient
M_p	modified Proctor density

m	Poisson's ratio
n	pipe-soil stiffness factor
P	vertical pressure due to soil and surcharge
P_{cr}	critical pressure for buckling of flexible pipes
P_{cra}	short-term critical pressure in air
P_{crl}	long-term critical pressure
P_{crs}	short-term critical pressure
P_e	vertical soil pressure
P_i	internal water pressure
P_s	surcharge pressure
P_u	ultimate bursting pressure
P_v	transient vacuum pressure from surge analysis
P_w	working pressure
ρ	projection ratio
r_{sd}	settlement deflection ratio
S_f	settlement of pipe invert
S_g	settlement of the natural ground
S_m	settlement of fill
t	pipe wall thickness
W_c	soil load per unit length of pipe in narrow trench conditions
W'_c	soil load per unit length of pipe in embankment or wide trench conditions
W''_c	load on a rigid pipe where there is no friction at the backfill/trench wall interface
W_{csu}	concentrated surcharge load per unit length of pipe
W_e	total design external load per unit length of pipe
W_p	proof crushing strength
W_t	crushing strength of rigid pipes (maximum load for concrete pipes)
W'_t	crushing strength of rigid pipes with internal pressure per unit length of pipe
W_w	equivalent external load due to weight of water in unit length of pipe
γ	unit weight of soil
γ_w	unit weight of water
Δ	pipe diameter change
ε_b	bending strain in pipe wall
ε_c	combined strain in pipe wall
μ	coefficient of friction within soil mass
μ'	coefficient of friction at trench wall
σ_{bs}	bending stress in pipe wall
σ_c	combined stress

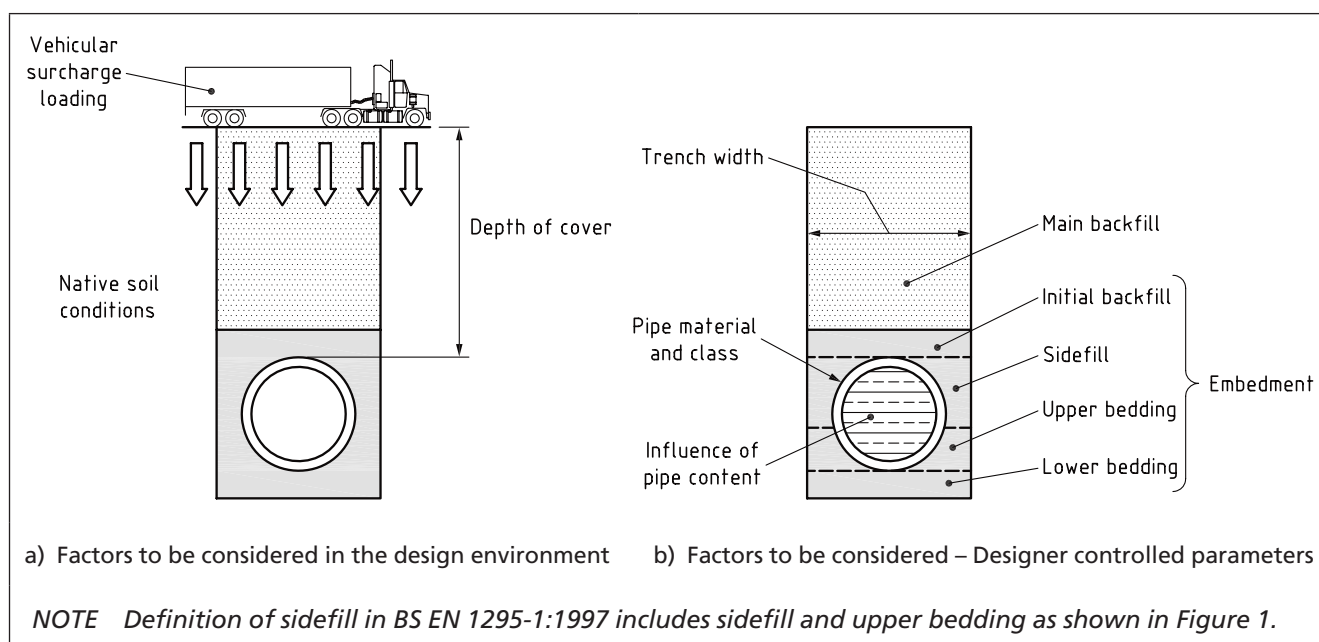
For ease of reference to BS EN 1295-1:1997, National Annex A, the equation numbers given in that standard are also used in this British Standard.

4 The structural design of pipelines

4.1 General

The purpose of the structural design of the cross-section of buried pipelines is to ensure that they are designed so that the optimum materials and embedments are selected for the given installation, whilst meeting all the necessary design criteria. For design considerations see Figure 1.

Figure 1 Design considerations



4.2 Categories of structural behaviour

Pipe materials are divided for structural design purposes into three categories.

- Rigid (see Clause 5);
- Semi-rigid (see Clause 6);
- Flexible (see Clause 7).

The behaviour of these materials depends upon both their inherent response to external loading and their interaction with surrounding soils.

Rigid pipe materials have a small deflection on loading, which is too small to develop any lateral earth pressures. Load is taken by the pipeline 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. Semi-rigid pipe materials tend to exhibit a range of behaviour from rigid to flexible. 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. BS EN 1295-1:1997, National Annex A uses the terms “soil load” and “backfill load” synonymously to describe the load imposed from the backfill after burial of the pipeline.

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

Table 1 **Pipe classification**

Type of pipe	Classification
Clay	Rigid
Concrete	Rigid
Reinforced concrete	Rigid
Ductile iron	Semi-rigid
Thick walled steel	Semi-rigid
Thermoplastics	Flexible
Glass reinforced plastics	Flexible
Thin walled steel	Flexible

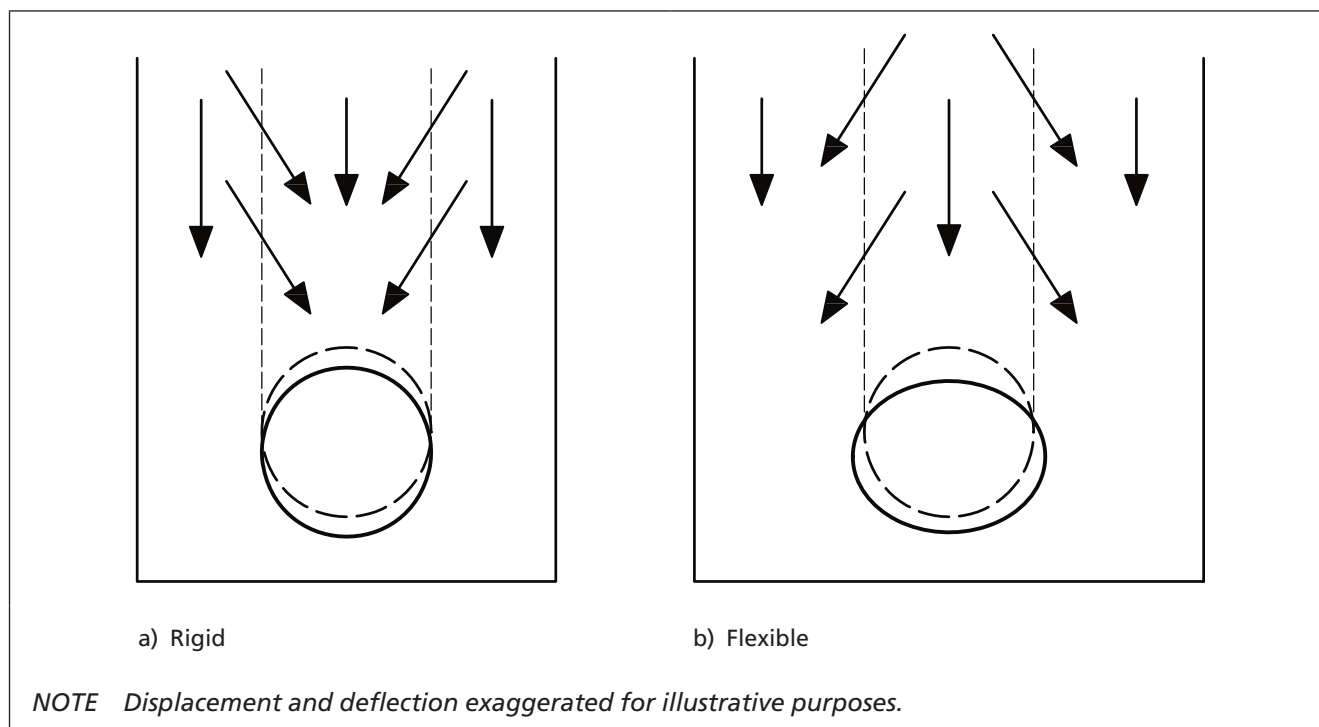
When a pipeline is installed, the ground is disturbed. Settlement of the disturbed soil occurs in the pipe trench even after backfilling is complete.

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 (geostatic load, γH) meaning that the pipe is attracting more load than just the geostatic load. 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. The effect of this is that the flexible pipe will deflect on loading, but will also tend to shed load away from itself. Figure 2 illustrates rigid and flexible pipe behaviour.

The set of equations for rigid and semi-rigid pipe given in BS EN 1295-1:1997 (equations 1, 2, 4, 12 and 14) and equation A.7 in this standard (Annex A, subclause A.5) together provide continuity of calculation for loads from fully flexible to fully rigid pipe.

Figure 2 Rigid and flexible pipe behaviour



Over time all these effects within the trench tend to disappear. From a backfill load point of view, the worst loading condition for a rigid pipe is when it is newly installed in the ground and the columns of soil to the sides of the pipe are transferring load onto the pipe. These factors are taken into account by the use of the coefficient C_c in the wide trench condition, equation 1, and C_d in the narrow trench condition, equation 4 (a description of wide and narrow trench conditions is given in 5.2).

$$W'_c = C_c \gamma B_c^2 \quad (\text{BS EN 1295-1:1997, equation 1})$$

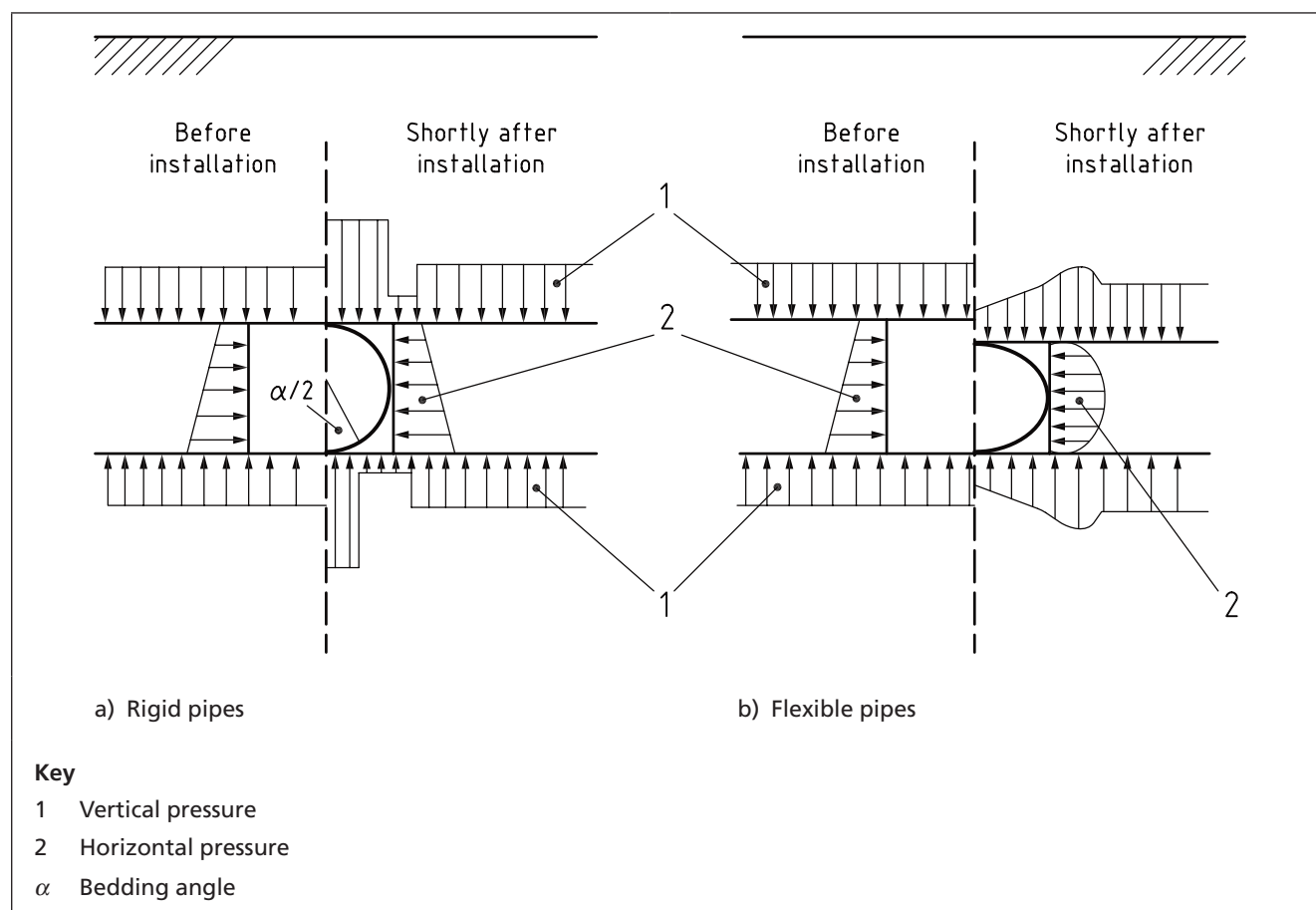
$$W_c = C_d \gamma B_d^2 \quad (\text{BS EN 1295-1:1997, equation 4})$$

Conversely, the highest predicted backfill load for a flexible pipe, according to BS EN 1295-1:1997, is after all the beneficial shedding of load has taken place, so the load used is just the geostatic value γH with no coefficients.

$$P_e = \gamma H \quad (\text{BS EN 1295-1:1997, equation 20})$$

Figure 3 shows a schematic diagram of the changes in the soil pressures following the burial of rigid and flexible pipes.

Figure 3 Soil pressure changes



4.3 Native soil

The stiffness of the surrounding soil is measured in terms of the Spangler modulus E' , which is known as the modulus of soil reaction. This parameter is not a fundamental engineering property of the soil and cannot be directly measured. It is a semi-empirical parameter which is a function of the pipe and soil system (and not the soil alone).

The Spangler moduli for various native soils are given in BS EN 1295-1:1997, Table NA.1. Table NA.1 modulus values apply to shallow depths and with groundwater present; they are likely to be conservative for depths exceeding 1 m or above groundwater, or both.

Although it is not mentioned in Table NA.1, the values given are the E'_3 moduli for various native soils and are used in the calculation of the soil modulus adjustment factor C_L (Leonhardt's coefficient [9]).

$$C_L = \frac{0.985 + (0.544B_d / B_c)}{\{1.985 - 0.456(B_d / B_c)\}(E'_2 / E'_3) - \{1 - (B_d / B_c)\}}$$

(BS EN 1295-1:1997, equation 17)

The E'_3 moduli are also referenced in BS EN 1295-1:1997, Table NA.4. Leonhardt's coefficient is a factor used to adjust the value of the embedment modulus, in order to establish an overall soil modulus value for design purposes (see 6.5).

4.4 Vehicle loading

The vehicle loadings used in BS EN 1295-1:1997, National Annex A are given in BS 5400-2:1978. BS 5400-2:1978 has been revised, but the original loadings are still used in pipeline design and give a more conservative result than loadings derived from the newer standard. The loading configurations considered are shown in Figure 4 and Figure 5 and these are converted to pressure at the pipe crown using Newmark's integration of Boussinesq's formula, to give the resultant load at pipe crown level at a certain depth and distance away from the wheel loading.

Figure 6 and Figure 7 indicate how backfill load increases with depth of cover whereas traffic load decreases. Further information on traffic loading, including simplified tables of vehicular loading, can be found in Annex A.

Graphs of surcharge pressure due to vehicle loads illustrated in Figure 4 are shown in BS EN 1295-1:1997, Figure NA.6. Similar graphs for other vehicles and railways are shown in BS EN 1295-1:1997, Figures NA.7, NA.8 and NA.9.

The maximum loading on a pipeline will depend upon its depth and diameter.

Figure 4 Loading configurations

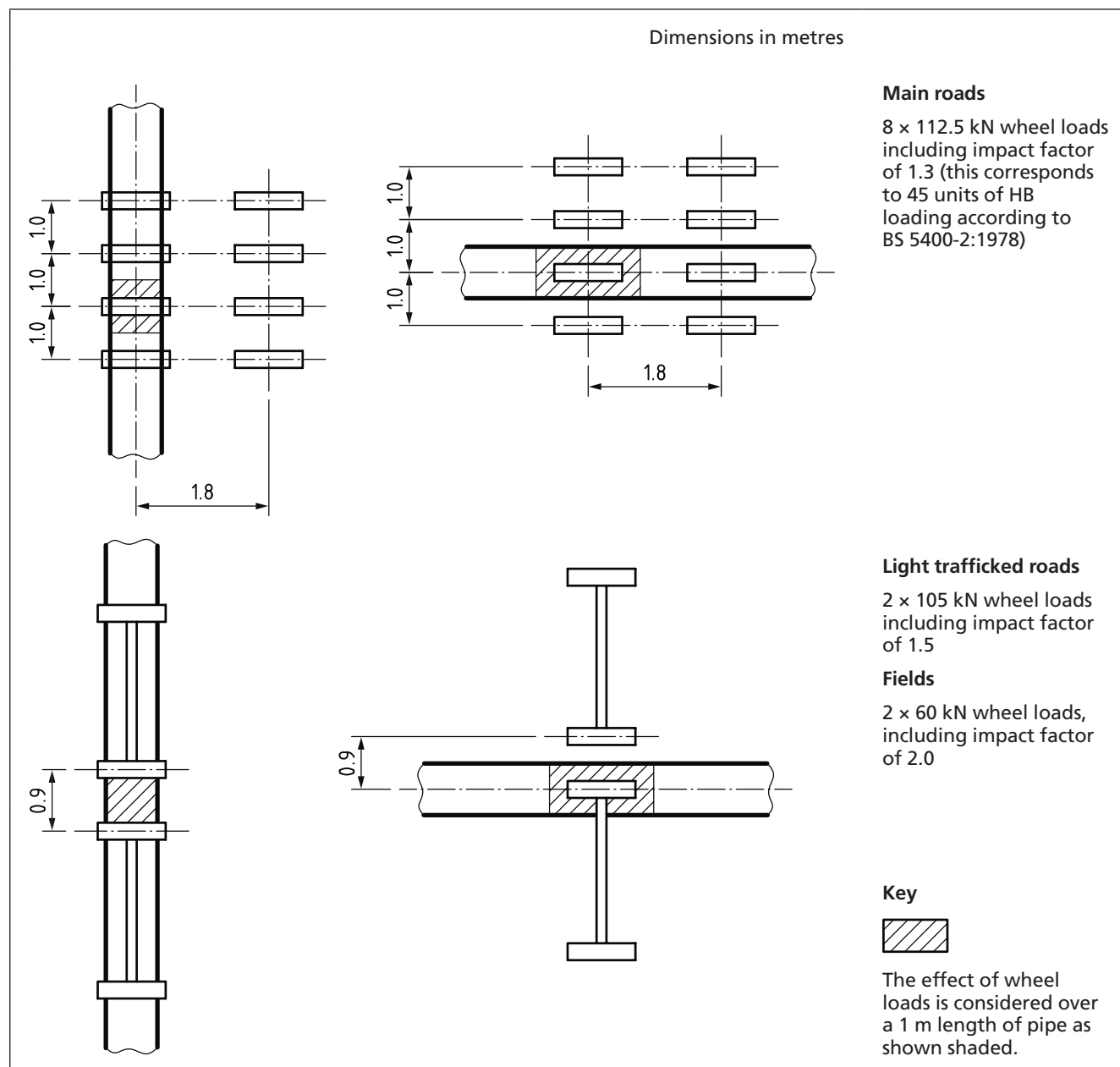


Figure 5 Schematics of the main road loading case

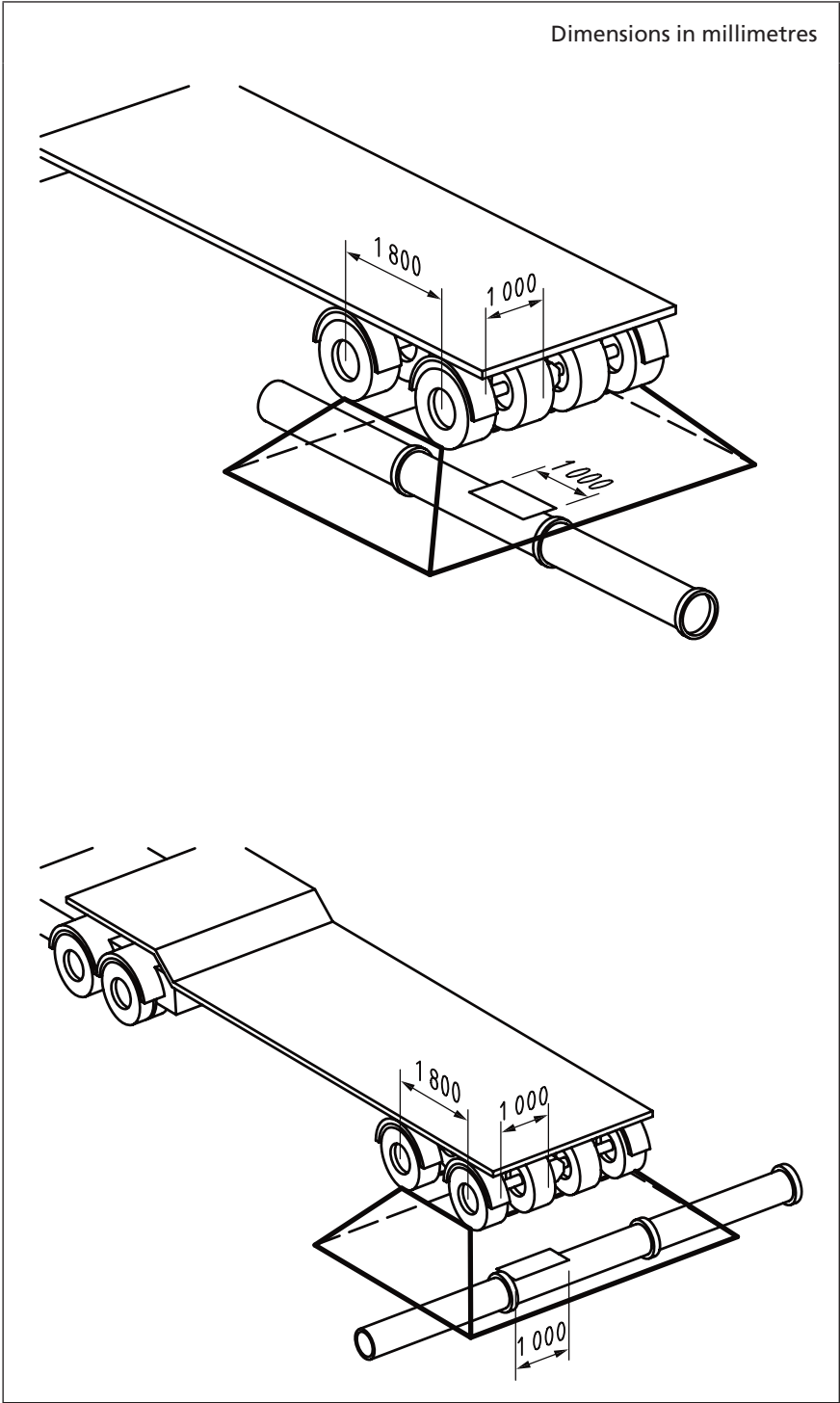


Figure 6 Typical calculated backfill and main road traffic loadings on a DN300 rigid pipeline with an external diameter of 358 mm

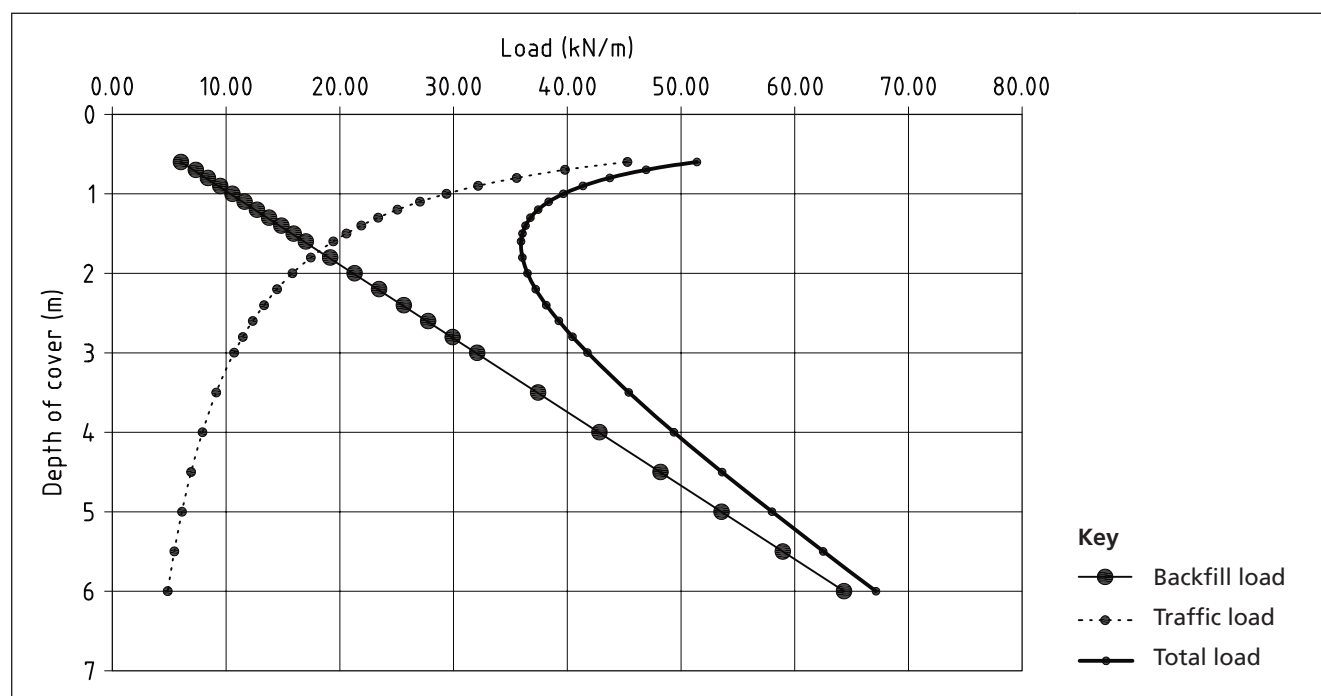
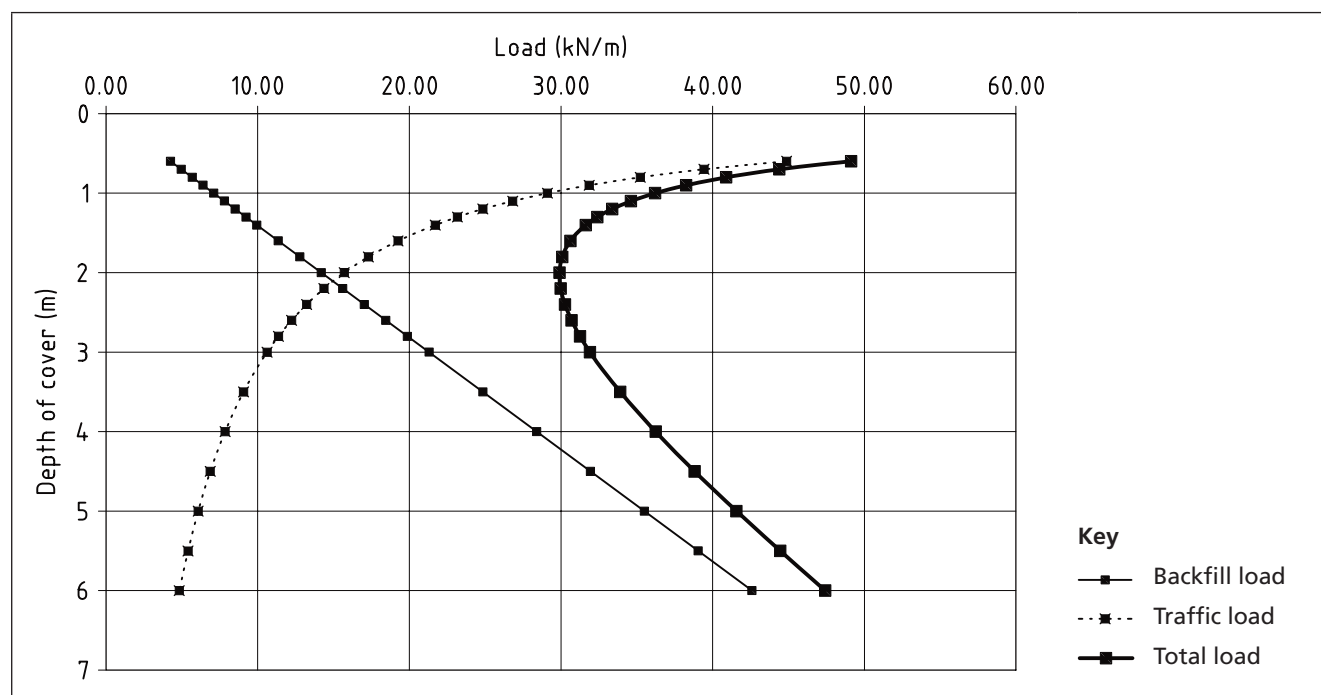


Figure 7 Typical calculated backfill and main road traffic loadings on a DN355 external diameter flexible pipeline (for comparison purposes)



5 The design of rigid pipelines

5.1 General

Rigid pipes rely on their embedment to distribute the loads imposed by backfill and traffic in order to reduce the circumferential bending moments in the pipe walls. Their response to the loading is to settle marginally into their supporting material until sufficient reaction is achieved (see 4.2).

5.2 Wide and narrow trenches

In BS EN 1295-1:1997, **NA.4.1**, there are two broad sections: pipes installed in wide trenches or embankments (see BS EN 1295-1:1997, **NA.4.1.1**) and pipes installed in narrow trenches (see BS EN 1295-1:1997, **NA.4.1.2**). For all pipeline installations both conditions should be calculated and the lower of the two loads used in the design. In the absence of specific information it is safer to assume the trench is wide. The effective trench width is illustrated in Figure 8.

Figure 8 Effective trench width, B_d

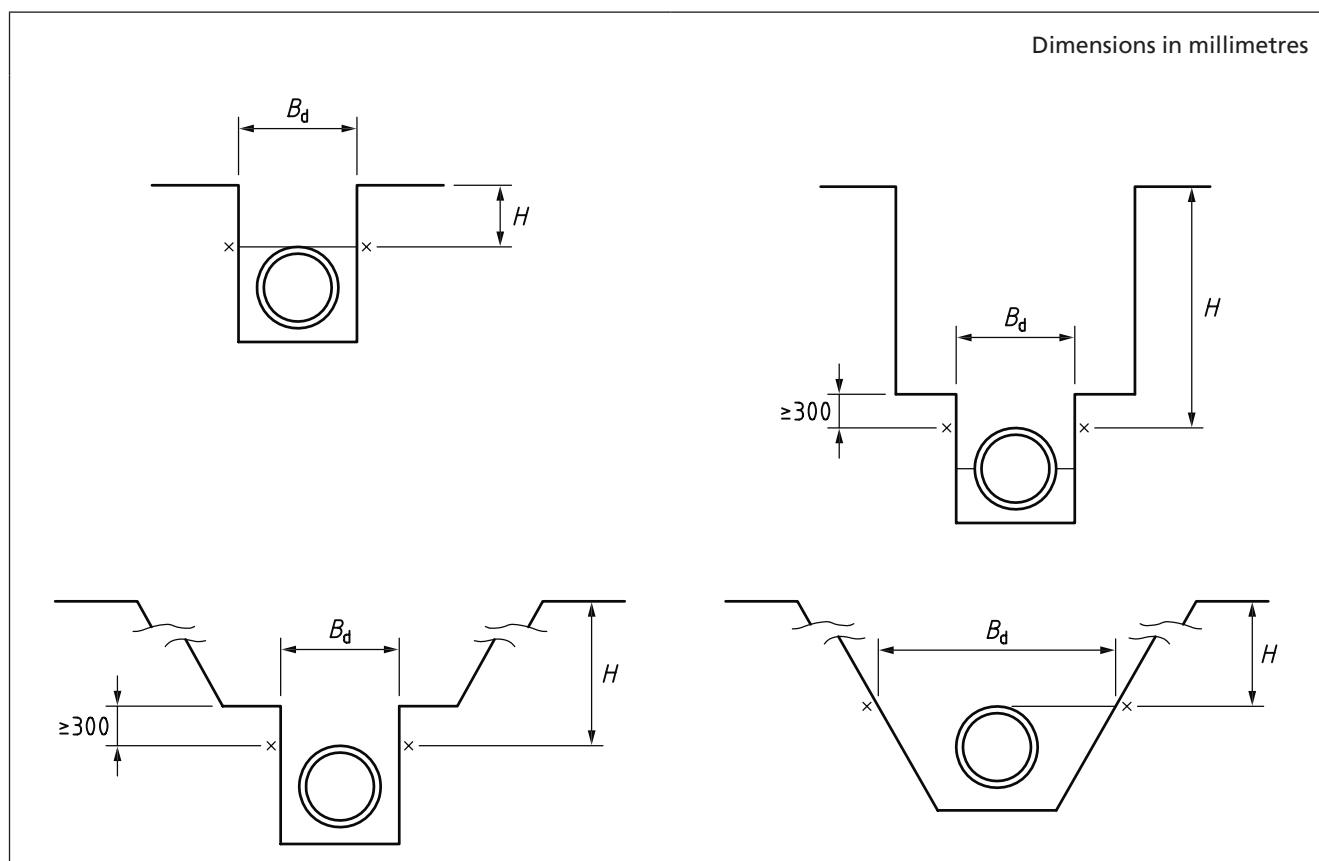


Figure 9 and Figure 10 illustrate what is known as the “transition width” and “transition depth”. In the case of a narrow trench at a particular depth, the load W_c increases as the trench width increases, up to a maximum value of that given by the wide trench formula.

When the loads calculated by the two methods are equal, then the “transition width” is reached. Although the load calculated by the narrow trench formula increases beyond that width, in reality the pipeline will not 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 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 will prevail (see Annex A and Annex B).

Figure 9 Narrow to wide trench conditions (transition width)

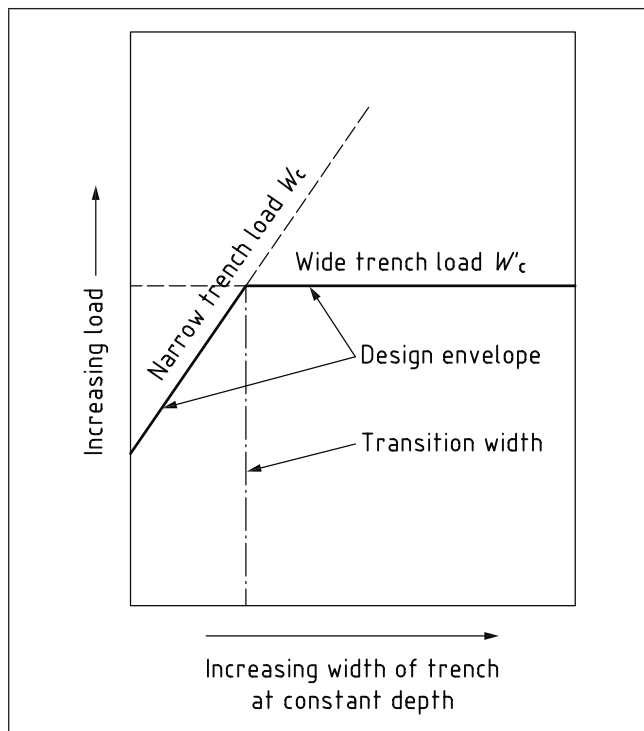
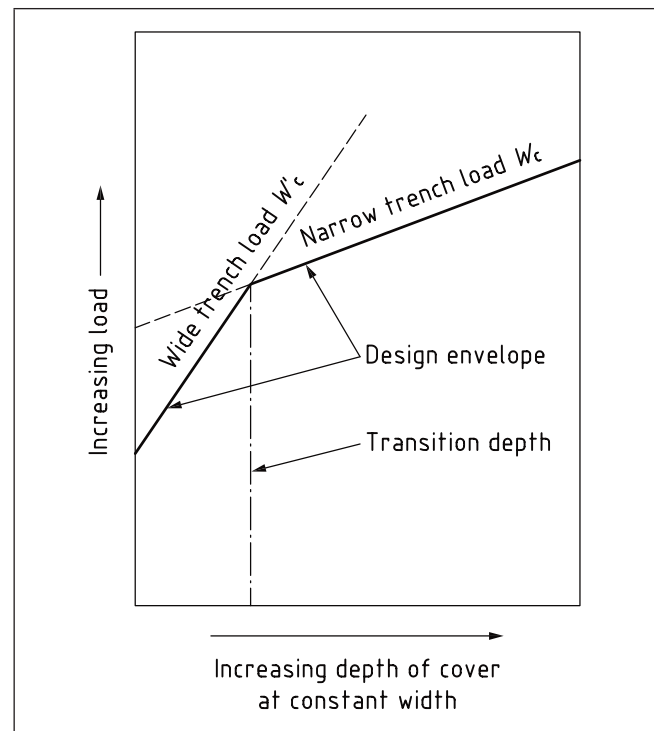


Figure 10 Wide to narrow trench conditions (transition depth)



For the wide trench condition (see Figure 9) the soil load coefficient C_c is used and takes into account the amplification of the backfill load on rigid pipes. There are two equations given, equation 2 for the wide trench complete projection case and equation 3 for the wide trench incomplete projection case (see 5.3 for descriptions of complete and incomplete projection). In the latter case, however, values for C_c are given in BS EN 1295-1:1997, Table NA.2, rather than being calculated using equation 3.

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

(BS EN 1295-1:1997, equation 2)

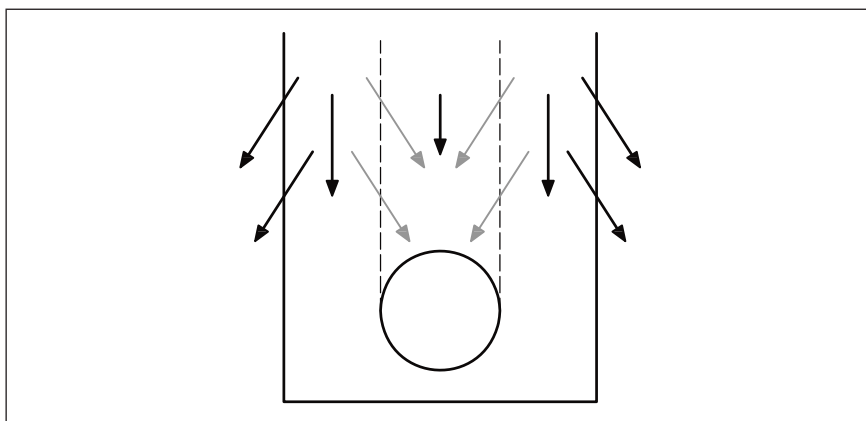
$$C_c = \left\{ \frac{e^{2K\mu H_e/B_c} - 1}{2K\mu} + \left(\frac{H}{B_c} - \frac{H_e}{B_c} \right) e^{2K\mu H_e/B_c} \right\}$$

(BS EN 1295-1:1997, equation 3)

NOTE See Annex A, subclause A.5, for elaboration of equation 3, and equation A.7 for alternative calculation of C_c for the incomplete projection case.

For the narrow trench condition (see Figure 10) the soil load coefficient C_d is used and takes account of what is known as the “silo effect” (see Figure 11). It is so called because the phenomenon was first observed in grain silos during the 19th century, where failures were occurring in the walls of these structures. The reason for this was that load was being transferred into the silo walls by the friction created from settling grain within. It was recognized that the same thing would happen in trenches when backfilled. This would have a beneficial effect in design if the walls of the trench were sufficiently close to the pipeline.

Figure 11 The silo effect



If, however, the walls of the trench are not close enough to have a beneficial effect, then the pipeline 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 or not site supervision will be such that a narrow trench design can be relied upon (see Annex A and Annex B).

5.3 Complete and incomplete projection

Within the wide trench design, there is introduced the idea of complete and incomplete projection. These refer to a line known as the “plane of equal settlement” and to whether or not this line falls above ground level (complete projection, see Figure 12) or below (incomplete projection, see Figure 13). The plane of equal settlement refers to the point at which the settlements of soil to the sides of the pipeline and over the pipeline are equal (see 4.2).