BRITISH STANDARD

BS EN 1295-1 : 1998

Structural design of buried pipelines under various conditions of loading

Part 1. General requirements

The European Standard EN 1295-1 : 1997 has the status of a British Standard

ICS 23.040.01

National foreword

This British Standard is the English language version of EN 1295-1 : 1997 published by the European Committee for Standardization (CEN).

The UK participation in its preparation was entrusted by Technical Committee B/505 to Subcommittee B/504/505/1, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

The European Standard EN 1295-2 will in due course incorporate the calculation procedures for structural design of buried pipelines of all CEN member countries. As the UK mirror committee is in agreement on the format and content of the UK calculation procedure it has been decided to include it as an informative national annex in this Part. This will allow the UK pipe industry an early opportunity to view the procedure.

NOTE. The terms and clause numbers in the key to figure 1 refer to EN 1610.

The attached national annex comprises the calculation procedure for the structural design of buried pipelines as practised in the UK. In due course this annex will be incoporated in EN 1295-2, together with other CEN member countries' procedures. As the UK submission has been agreed, the BSI committee has included it to allow the UK pipe industry an early opportunity to view the calculation procedure.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled 'International Standards Correspondence Index', or by using the 'Find' facility of the BSI Standards Electronic Catalogue.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 34, an inside back cover and a back cover.

Amendments issued since publication

Amd. No.	Date	Text affected

This British Standard, having been prepared under the direction of the Sector Board for Building and Civil Engineering, was published under the authority of the Standards Board and comes into effect on 15 June 1998

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EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 1295-1

July 1997

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Descriptors: Sanitation, water supply, water removal, water pipelines, buried pipes, pressure pipes, sewage, computation, mechanical strength, loads: forces

English version

Structural design of buried pipelines under various conditions of loading — Part 1: General requirements

Calcul de résistance mécanique des canalisations enterrées sous diverses conditions de charge — Partie 1: Prescriptions générales

Statische Berechnung von erdverlegten Rohrleitungen unter verschiedenen Belastungsbedingungen — Teil 1: Allgemeine Anforderungen

This European Standard was approved by CEN on 1997-06-29. CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CEN

European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung

Central Secretariat: rue de Stassart 36, B-1050 Brussels

Ref. No. EN 1295-1 : 1997 E

Foreword

This European Standard has been prepared by Technical Committee CEN/TC 165, Waste water engineering, the Secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement at the latest by January 1998, and conflicting national standards shall be withdrawn at the latest by January 1998.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

This standard is intended for use in conjunction with the series of product standards covering pipes of various materials for the water industry.

This standard comprises two Parts:

- Part 1: *General requirements*, dealing with the requirements for structural design of pipelines and giving the basic principles of the nationally established methods of design;
- Part 2: *Summary of the nationally established methods of design*, giving an overview of these methods as prepared by the various countries where they are in use.

Contents

0 Introduction

The structural design of buried pipelines constitutes a wide ranging and complex field of engineering, which has been the subject of extensive study and research in many countries over a period of many years.

Whilst many common features exist between the design methods which have been developed and established in the various member countries of CEN, there are also differences reflecting such matters as geological and climatic variations, as well as different installation and working practices.

In view of these differences, and of the time required to develop a common design method which would fully reflect the various considerations identified in particular national methods, a two stage approach has been adopted for the development of this European Standard.

In accordance with this two stage approach, the joint working group, at its initial meeting, resolved 'first to produce an EN giving guidance on the application of nationally established methods of structural design of buried pipelines under various conditions of loading, whilst working towards a common method of structural design'. This standard represents the implementation of the first part of that resolution.

This guidance is an important source of design expertise, but it cannot include all possible special cases, in which extensions or restrictions to the basic design methods may apply.

Since in practice precise details of types of soil and installation conditions are not always available at the design stage, the choice of design assumptions is left to the judgement of the engineer. In this connection the guide can only provide general indications and advice.

This Part of the standard specifies the requirements for structural design and indicates the references and the basic principles of the nationally established methods of design (see annexes A and B).

1 Scope

This standard specifies the requirements for the structural design of water supply pipelines, drains and sewers, and other water industry pipelines, whether operating at atmospheric, greater or lesser pressure.

In addition, this standard gives guidance on the application of the nationally established methods of design declared by and used in CEN member countries at the time of preparation of this standard.

2 Normative references

This European Standard incorporates, by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of the publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references, the latest edition of the publication referred to applies.

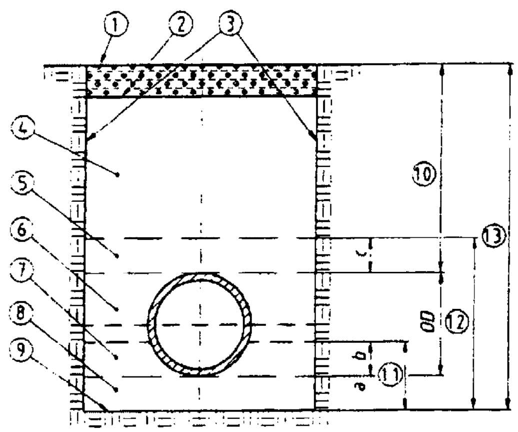
prEN 1610 *Construction of pipelines for drains and sewers*

3 Definitions

For the purposes of this standard, the following definitions apply (see also annex A).

3.1 Installation terms

Installation terms are given in figure 1. The same terms apply for embankment installations and for trenches with sloping sides.



1 Surface
2 Bottom of road or railway construction, if any
3 Trench walls
4 Main backfill (**3.6**)
5 Initial backfill (**3.5**)
6 Sidefill (**3.12**)
7 Upper bedding
8 Lower bedding
9 Trench bottom
10 Depth of cover (**3.3**)
11 Depth of bedding (**3.1**)
12 Depth of embedment (**3.4**)
13 Trench depth (**3.13**)
a *Depth of lower bedding*
b *Depth of upper bedding*
c *Depth of initial backfill*

NOTE. The terms in figure 1 are the same as in prEN 1610.

Figure 1. Trench installation

3.1.1 compaction

Deliberate densification of soil during the construction process.

3.1.2 consolidation

Time-dependent densification of soil by processes other than those deliberately applied during construction.

3.1.3 embedment

Arrangement and type(s) of material(s) around a buried pipeline which contribute to its structural performance.

3.2 Design terms

3.2.1 bedding factor

Ratio of the maximum design load for the pipe, when installed with a particular embedment, to the test load which produces the same maximum bending moment.

3.2.2 design pressure (DP)

Maximum operating internal pressure of the system or of the pressure zone fixed by the designer considering future developments but excluding surge.

3.2.3 load bearing capacity

Load per unit length that a particular combination of pipe and embedment can sustain without exceeding a limit state.

3.2.4 maximum design pressure (MDP)

Maximum operating internal pressure of the system or of the pressure zone fixed by the designer considering future developments and including surge, where:

- MDP is designated MDPa when there is a fixed allowance for surge;
- MDP is designated MDPc when the surge is calculated.

3.2.5 silo effect

Effect whereby lateral earth pressure in trench backfill causes friction at the trench wall to carry part of the weight of the backfill.

3.2.6 soil-structure interaction

Process whereby the deformations of soil and/or pipe caused by the contact and reaction pressures between a pipe and the surrounding soil distribute the pressures to achieve equilibrium.

3.2.7 system test pressure (STP)

Hydrostatic pressure applied to a newly laid pipeline in order to ensure its integrity and tightness.

4 Requirements

4.1 All pipelines shall be designed to withstand the various loadings to which they are expected to be subjected, during construction and operation, without detriment to their function and to the environment.

4.2 The future owner of the pipeline is free to specify the appropriate method of design to be adopted.

4.3 The designer shall determine whether or not the pipeline comes within the scope of the methods covered by this standard.

4.4 The design adopted shall be such that construction may be carried out safely and so as to ensure that the design assumptions regarding the influence of construction procedures and soil characteristics will be satisfied.

4.5 Subject to the other requirements of clause **4**, design should be carried out preferably using in its entirety one of the methods in annex B of this standard.

4.6 Methods of design, in accordance with annex B, when presented in the form of tables, charts or computer programmes, shall be deemed equivalent to a full calculation, provided that any simplification does not reduce the level of safety to below that which would be obtained by full design. Outputs from computer programmes shall be capable of verification.

4.7 Where a design method other than one of those in annex B is employed, the designer shall satisfy himself that the method constitutes a coherent system and provides the level of safety required.

4.8 Account shall be taken of the probable consequences of pipeline failure in establishing the acceptable level of safety.

4.9 The values adopted for all variables, including factors of safety, shall be in accordance with the method used.

5 Basis of design procedures

5.1 General

Whilst there are differences between some of the established national design procedures, there are no differences in respect of the fundamental basis of design, which is the interactive system consisting of the pipe and the surrounding soil.

The external loadings to be considered shall include that due to the backfill, that due to the most severe surface surcharge or traffic loading likely to occur, and those due to any other causes, producing a loading of significant magnitude such as self weight of the pipe and water weight, as appropriate. The internal pressure in the pipeline, if different from atmospheric, shall also be treated as a loading.

The design of the pipeline, and its embedment, shall provide an adequate level of safety against the appropriate ultimate limit state being exceeded. In addition, the design loading shall not result in any appropriate serviceability limit state being exceeded.

5.2 External loads

Account shall be taken of the effect of the stiffness of the pipe and the stiffness of the surrounding soil.

Where appropriate, account shall be taken of the effects of trench construction, of groundwater and of time dependent influences. The design should take into consideration, however, the possible effect on trench conditions of any further planned works.

The effective pressure due to the backfill and any distributed surface loads shall be calculated on the basis of the principles of soil-structure interaction.

The pressure exerted on pipelines by concentrated surface surcharges, such as vehicle wheels, shall be calculated in accordance with a method based on Boussinesq, and account shall be taken of impact.

5.3 Limit states

The ultimate limit state for all types of pipe is reached when the pipe ceases to behave in the manner intended in the structural design.

Serviceability limit states may be dictated by effects either on the performance of pipelines or on their durability (for example leakage, deformation or cracking beyond allowable limits).

Additional serviceability limit states may apply to particular pipe materials, and reference shall be made to the relevant standards.

The design of the pipeline shall ensure that these above limit states are not reached. This will include consideration of one or more of the following factors:

- strain, stress, bending moment and normal force or load bearing capacity, in the ring or longitudinal direction as appropriate;
- instability (e.g. buckling);
- annular deformation;
- watertightness.

Where fluctuating loads of significant magnitude and frequency will exist, appropriate consideration should be given to their cumulative effects.

5.4 Longitudinal effects

Longitudinal effects include bending moments, shear forces and tensile forces resulting for example from non-uniform bedding and thermal movements and, in the case of pressure pipelines (see **6.5**), from Poisson's contraction and thrust at change of direction or cross-section.

These effects may be accommodated by the angular deflection and/or the shear resistance of flexible joints and by the flexural strength of pipes, the serviceability limits of which should be obtained from the different product standards.

The designer shall check that these provisions, together with the embedment design, are sufficient for the project and, where needed, specify adequate additional measures.

6 Additional considerations for pressure pipelines

6.1 General

Pipelines operating at internal pressures above or below atmospheric are subjected to loadings in excess of those at atmospheric pressure.

The application of internal pressure not only introduces additional stresses and strains in the circumferential direction, but can also modify the deformation of flexible and semi-rigid pipes. In addition, pressure pipelines, containing changes of direction or other discontinuities, shall be designed for the longitudinal tensile loading, or the thrusts at the discontinuities.

Special consideration shall be given to pipelines which will be subject to transient surge pressures. Both positive and negative transient pressures shall be considered, but it may not be appropriate for these to be taken in combination with the full vehicle surcharge load.

The design shall take account of the design pressure, the maximum design pressure, and the system test pressure (see **3.2**).

Pressure pipelines shall also satisfy the design criteria which would apply if they were non-pressure pipelines, in order to ensure their satisfactory structural performance for the initial period between construction and the application of the internal water pressure, and subsequently when emptied for maintenance.

6.2 Stresses and strains resulting from simultaneous loads

Internal pressures above or below atmospheric produce circumferential stresses and strains which act simultaneously with bending stresses and strains due to external loadings.

Design cases to be considered depending on pipe material and/or type and respective load intensities, can be one or more of the following:

- circumferential stresses resulting from combined loads;
- circumferential strains resulting from combined loads;
- separate analysis of circumferential stresses or strains.

Similar cases shall be considered for the longitudinal direction, when appropriate.

NOTE. If the cross-section of the pipe is truly circular, circumferential stresses and strains due to internal pressure will be purely tensile or compressive, but if the pipe cross-section is not truly circular or has been deformed there will also be bending stresses and strains due to internal pressure.

6.3 Effect of pressure on deformation

When positive internal pressure is applied to a not truly circular pipe, it tends to re-round the deformed pipe, i.e. to reduce the out-of-circle deformations.

The re-rounding process may have the beneficial effect of reducing the bending stresses and strains in the pipe wall. The extent to which the re-rounding process reduces pipe deformation depends on pipe properties and on other various factors, such as the ratio of the internal pressure to the external pressure and the amount of consolidation of the soil which has taken place around the pipe. Thus, the beneficial effects of re-rounding are likely to be greater if the pressure is applied soon after backfilling, and less if there is a longer delay until the first pressurization.

Although the application of internal positive pressure will always produce some degree of re-rounding, the magnitude is difficult to predict. Also, although pipe ovalization benefits from internal pressure, stresses and strains may not benefit to the same extent (e.g. when the deflected shape is not elliptical).

6.4 Buckling of pressure pipes

Positive internal pressure assists pipes which are not rigid to resist any tendency to buckle, but since there can never be complete certainty that the pressure may not be removed at some time during the life of the pipeline, it is normal to design pipelines to resist buckling without this assistance.

Pipelines subject to hydraulic transients may experience sub-atmospheric pressures, and, although these are usually of very short duration, they tend to increase the tendency to buckle.

Proper account shall be taken of this possibility in the design of such pipelines, and it is preferable to rely on a conservative estimate of the sub-atmospheric pressure. When calculating stability, the sub-atmospheric pressure shall be added to the external pressure caused by sustained loading.

6.5 Thrusts and longitudinal stresses

A further effect of the application of internal pressure in pipes is the generation of thrusts at bends and other discontinuities. Depending on the type of provision made for resisting these thrusts, the pipes and fittings may be subjected to additional longitudinal bending and/or tensile stresses, and to excessive movement which could cause dislocation of joints.

7 Influence of construction procedures

7.1 General

Of the various factors to be considered in the structural design process, some, such as pipe diameter and depth of cover, can be regarded as entirely under the control of the designer. Other factors, such as the methods adopted for trench excavation and for filling around and above the pipeline, are only under the control of the designer to the extent that they are specified in advance, and supervised during construction.

7.2 Trenching procedures

The width of the trench can influence the extent to which the backfill load may be reduced by the silo effect, and this effect is taken into account for certain applications.

The width of the trench can also influence the quality of the lateral soil support at the sides of the pipes. This effect is variously covered in the design procedures, via the coefficient of lateral earth pressure, the bedding factor, the soil modulus, etc.

The slope of the trench sides can affect the magnitude of the backfill load, and, if vertical trench sides are employed, consideration shall also be given to the method of support.

If the trench supports are withdrawn after embedding and/or backfilling, voids are left which can cause loosening of the soil, reducing the quality of the embedment and the friction on which the silo effect relies, and also promote long term settlement.

The presence of groundwater, and the use of measures such as groundwater lowering to remove it during construction, can have important effects. The absence of groundwater assists in the compaction of backfill, but the subsequent return of groundwater after completion of backfilling can cause movements of soil particles, possibly leading to increased loads and reduction of support to the sides of the pipe.

7.3 Pipe bedding

If the nature of the ground at the base of the trench is such that it will not itself provide adequate support, then, for all types of pipe, the thickness of lower bedding shall be designed to ensure adequate support along the length of the pipeline.

Where pipes are installed in soft ground, the thickness of the lower bedding may need to be increased in order to prevent excessive settlement of the pipeline.

The thickness of upper bedding should be such as to ensure that the bending moments in the pipe (as calculated directly or covered by the bedding factor) are acceptable.

7.4 Filling procedures

In the vicinity of the pipe, the placing and compaction of the fill material have great influence on structural performance. They affect the distribution of soil pressure around the circumference of the pipe, and hence the response of the pipe. The amount of compaction applied initially during installation also affects the amount of settlement which will take place later, as a result of natural consolidation, or consolidation accelerated by traffic. Usually, the larger such settlements, the greater the load which will be transferred to the pipe.

When the soil around the pipe is being compacted in order to improve its structural quality, some of the energy is diverted into the pipe (as strain energy of deformation) and some into the native soil. The extent to which the total compaction energy is so diverted depends upon the pipe-soil stiffness ratio and the type of native soil.

Prediction of these effects is difficult and is further complicated by the sensitivity of some soils to moisture content. The use of soils which are easy to compact, and which have low sensitivity to moisture content, can therefore greatly reduce the magnitude of strains developed in pipes as a result of installation.

8 Design philosophies and factors of safety

Field and experimental studies of pipelines show variations in observed earth pressures and pipe deformations, stresses and strains. The main cause of these variations is the inevitable inconsistency of soil characteristics and construction practices, already described in clause **7** of this standard. The magnitude of the variation can be reduced by good supervision, control measurement and by the use of fill materials which are easily placed and treated, but some degree of variation is inevitable.

Variations in pipe characteristics, such as strength or elasticity, also occur in practice.

Appropriate allowance for these variations should be made at the design stage and should be in accordance with one of the following design philosophies.

a) The design procedure shall aim to predict the mean values of loads, and shall compare these with the load bearing capacity of the pipeline based on mean values of pipe strength or stiffness (for example as derived by calculation), and on average earth pressure distribution assumptions.

b) The design procedure shall aim to predict the maximum possible (high fractile or upper bound) values of loads, and shall compare these with estimates of the load bearing capacity of the pipeline based on lower bound (or low fractile) values of pipe strength or stiffness (for example as established by testing), and on unfavourable earth pressure distribution assumptions.

The factors of safety to be employed with designs following philosophy b) will be lower than those used in a), to achieve the same probability of failure.

Annex A (informative)

Pipe definition according to cross-sectional behaviour

The definition according to cross-sectional behaviour of pipes as rigid, semi-rigid or flexible, is essentially based on consideration of the structural performance of the pipe cross-section under external loads.

Some nationally established methods of design distinguish between 'flexible', 'semi-rigid' and 'rigid' pipes on the basis of the relative pipe and surrounding soil stiffnesses. This distinction is particularly useful in the evaluation of the backfill load for which the pipeline should be designed.

In other nationally established methods of design, the distinction between 'flexible' and 'rigid' is based on the type of material from which the pipe is made, and the way in which the material is used. Thus pipes whose material would fracture at only small deformations of the pipe cross-section are regarded as 'rigid', whilst pipes whose cross-sections can deform substantially without fracture are regarded as 'flexible'.

Designers should take account of both considerations, and recognize that the definition of a pipe as 'rigid' or 'flexible' according to one approach may not invariably be associated with the same definition in the other approach. Having selected the design procedure to be employed, designers should use the method of definition incorporated in that procedure.

Whilst materials can be defined as flexible or rigid according to their failure strain, a pipe made from a material with a low failure strain will not necessarily be defined as rigid. Materials which fail at low elongations, if used in thin-walled pipe, may produce very flexible pipes, because the deformation of the pipe cross-section corresponding to the limiting strain in the pipe wall is large. This aspect of material and pipe performance is usually dealt with by calculating the pipe deformation corresponding to the limiting strain, and using this as a basis for establishing an absolute limit on permissible pipe deformation.

Annex B (informative)

Nationally established methods of design

This annex includes the nationally established methods of design declared, submitted by and used in member countries and collated by the joint working group. The documents listed in **B.1** have been submitted to the joint working group except those in **B.1.4**, **B.1.9** and **B.1.11**.

B.1 Identification of methods and addresses where they are available

B.1.1 *Austria*

The Austrian nationally established methods for structural design of buried pipeline are given in:

– Standards ÖNORM B 5012-1 and 2.

These standards may be obtained from:

Österreichisches Normungsinstitut

Heinestraße 38

A-1021 Wien

Phone: +43-222-21-300

Telefax: +43-222-21-300-818

Telex: 115 960

B.1.2 *Belgium*

The Belgian nationally established method for calculation of asbestos-cement pipes is given in:

– ISO 2785 *Directives for selection of asbestos-cement pipes subject to external loads with or without internal pressure*, second edition 1986-07-01 (Ref. No. ISO 2785 : 1986 (E))

This standard may be obtained from:

International Organization for Standardization

Case Postale 56

S-1211 Genève 20

B.1.3 *Denmark*

The Danish nationally established methods for design of buried pipelines are given in:

– DS 430 *Dansk Ingeniørforenings norm for lægning af fleksible ledninger af plast i jord* (Dansk Ingeniørforenings Code of practice for the laying of underground flexible pipelines of plastic)

– DS 437 *Dansk Ingeniørforenings norm for lægning af stive ledninger af beton mv i jord* (Dansk Ingeniørforenings Code of practice for the laying of underground rigid pipelines of concrete, etc.)

These standards may be obtained from:

Dansk Standard

Danish Standards Association

Baunegaardsvej 73

DK-2900 Hellerup

Phone: +45-39-77-01-01

Telefax: +45-39-77-02-02

B.1.4 *Finland*

The Finnish methods are given in:

– *Suomen kuntaliitto: Vesijohtojen ja viemäreiden suunnittelu*, 1979 (Design of water supply and wastewater pipelines).

– *Suomen kuntaliitto: Kunnallisteknisten töiden yleinen työselitys*, 1990 (General work specification for municipal engineering).

– *Suomen rakennusinsinöörien Liitto: Maahan ja veteen asennettavat kestomuoviputket*, 1990 (Thermoplastic pipes buried in ground and under water).

– *Suomen kunnallisteknillinen yhdistys: Betoiputkinormit*, 1990 (Concrete pipe rules).

These documents may be obtained from:

Suomen Standardisoimisliitto

PO box 116

FIN-00241 Helsinki

B.1.5 *France*

The French nationally established methods are given in:

– General title: *Cahier des clauses techniques générales applicables aux marchés publics de travaux* (Book of general technical requirements applicable to public procurements).

– Fascicule 70: *Ouvrages d'assainissement* (Sewerage works).

  – See chapitre III: *Règles de conception et de calcul des ouvrages* (Design and calculation rules for sewerage works).

– Fascicule 71: *Fourniture et pose de canalisations d'eau, accessoires et branchements* (Supply and installation of water pipelines, accessories and fittings).

  – See chapitre II: *Prescriptions particulières aux tuyaux, raccords et leurs accessoires* (Special requirements for pipes, fittings and accessories).

  – See chapitre IV: *Matériaux et fournitures d'un type non-courant ou nouveau* (Materials and products of a non-traditional or new type).

These regulations may be obtained from:

Direction des Journaux Officiels

26, rue Desaix

F-75727 Paris cedex 15

B.1.6 *Germany*

The German nationally established methods are:

– ATV A 161 *Statische Berechnung von Vortriebsrohren* (Standard code of practice of the ATV-Abwassertechnische Vereinigung, work sheet A 161 Structural design for jacking pipes) first edition 1990.

– *Richtlinie für die statische Berecnung von Entwässerrung kanälen un-leitungen* Arbertsblatt A 127 (Standard code of practice of the ATV-Abwassertechnische Vereinigung, work sheet A 127. Guidelines for the statical analysis of sewage channels and pipelines) second edition 1988.

These standards may be obtained from:

Gesellschaft zur Förderung der Abwassertechnik (GFA)

Postfach 1165

D-53758 Hennef

B.1.7 ***Netherlands***

The Dutch nationally established method for concrete pipes is based on the following documents:

– CUR report no. 122 (a) *Pipes in the ground. Design of plain and reinforced concrete pipes.* CUR, 1985.

– NEN 7126 (b) *Circular unreinforced, reinforced and steel fibre reinforced concrete pipes and unreinforced pipes with a base. Requirements and test methods*, NNI, first print, September 1991.

– NEN 3218 (b) *Drainage and sewerage gravity systems outside buildings. Installation and Maintenance.* NNI, first print, 1984.

A summary of the procedure is given in: *Design procedure for plain and reinforced pipes to be laid into the ground*, according to CUR report no. 122 (a).

These standards may be obtained from:

a) CUR
PO Box 420
NL-2800 AK Gouda

b) Nederlands Normalisatie-Instituut (NNI)
Kalfjeslaan, 2
PO Box 5059
NL-2600 GB Delft

B.1.8 ***Norway***

The Norwegian method for concrete pipes is based on the following documents:

– *Design loads on concrete pipes in road construction*

Internal report No. 1521

Norwegian Road Research Laboratory

– *Earth pressure on concrete pipes*

Internal report No. 1554

Norwegian Road Research Laboratory

These documents may be obtained from:

Norwegian Road Research Laboratory

Postbox 8142 DEP

N-0033 OSLO

The Norwegian method for plastics pipes is based on the following document:

– VAV P70 *Markavloppsrör av plast för självfallsledningar i jord* (Buried gravity sewer plastics pipes) Stockholm 1992.

This standard may be obtained from:

VAV

Regeringsgatan 86

S-111 39 Stockholm

B.1.9 ***Spain***

The Spanish methods for reinforced concrete and prestressed concrete pressure pipes cylinder and non-cylinder type are given in:

– *Instrucción del Instituto Eduardo Torroja para tubos de hormigón armado o pretensado* (Guideline of the Instituto Eduardo Torroja for reinforced and prestressed concrete pipes).

This document may be obtained from:

I.C.C. 'Eduardo Torroja'

Apdo. Correos 19002

SP-28080 Madrid

The Spanish nationally established methods for asbestos-cement and for plastics (uPVC and HDPE) pipelines are given in:

– UNE 88211 *Asbestos-cement pipelines.* (Guide for selection of asbestos cement pipes subject to external loads with or without internal pressure).

– UNE 53331 *Plasticos. Tuberías policloruro de vinilo (PVC-U) y polietileno de alta densidad (PE-HD). Criterio para la comprobación de los tubos a utilizar en conducciones con y sin presión sometidas a cargas externas* (Plastics-uPVC and HDPE pipes — Guide for selection of gravity and pressure pipelines subjected to external load).

These standards may be obtained from:

AENOR

Fernández de la Hoz, 52

SP-28010 Madrid

B.1.10 ***Sweden***

The Swedish nationally established methods are given in:

– VAV P70	*Markavloppsrör av plast för självfallsledningar i jord* (Buried gravity sewer plastic pipes) Stockholm 1992
– VAV P43	*Trafiklast pårörledning med jordöverfyllning*, September 1982 (Traffic load on buried pipelines)
– VAV P48	*Hålfasthetsdimensionering av rörledning av armerad beton med jordöverfyllning*, July 1986 (Strength calculation of buried pipeline of reinforced concrete pipes)
– VAV P56	*Anvisningar för provning av armerade betonrör*, April 1993 (Instructions for quality control of reinforced concrete pipes)
– VAV P9	*Anvisningar för oarmerade betongrör*, April 1991 (Instructions for non-reinforced concrete pipes)

These standards may be obtained from:

VAV

Regeringsgatan 86

S-111 39 Stockholm

B.1.11 ***Switzerland***

The Swiss nationally established method is given in:

– SIA V 190, *Kanalisationen* (Sewage system), Edition 3/1993

– SIA Dokumentation D 01000, *Kanalisationen 4* (Sewage system 4), Edition 25/3/1993.

These documents may be obtained from:

Schweizerisher Ingenieur-und Architekten-Verein (SIA)

Selnaustrasse 16, Postfach

CH-8039 ZURICH

Telefon: + 41 1 283 15 60
(Normen-und Drucksachenverkauf)

Telefax: + 41 1 201 63 35.

B.1.12 ***United Kingdom***

The following publications are regarded as the primary sources of information regarding the standard UK procedures:

1) BS 8005 : Part 1 *Guide to new sewerage construction*

Published by the British Standards Institution

Scope: Recommends that all sewerage design should normally use the 'computed load method based on the work of Marston, Spangler and others'. Bedding factors are recommended for use in rigid pipe design, and references to other documents are provided for details of design procedures for rigid and flexible pipe sewers.

2) BS 8301 *Building drainage*

Published by the British Standards Institution.

Scope: Limited to pipes of DN 300 and smaller sizes. Provides simplified design recommendations for rigid and flexible pipes in normal installation circumstances.

3) *Simplified tables of external loads on buried pipelines*

Published by The Stationery Office.

Scope: Provides simplified design procedure for rigid pipes, ranging in diameter from DN 100 to DN 3000, installed in trench conditions.

4) *A guide to design loadings for buried rigid pipes*

Published by The Stationery Office

Scope: Provides detailed design procedure for rigid pipes installed in trench and embankment conditions. Pressure and non-pressure pipelines are covered.

5) *Pipe materials selection manual — Water mains : UK Edition*

Published by the Water Authorities Association and the Water Research Centre.

Scope: Provides detailed design procedures for pressure and non-pressure GRP pipelines, and for pressure pipelines in PVC and polyethylene. Trench and embankment installations are covered. Provides general guidance on the design of pipelines using other materials, and provides references to other documents for guidance on their detailed design.

6) *Guide to the water industry for the structural design of underground non-pressure uPVC pipelines* (Document ER201 E).

Published by the Water Research Centre.

Scope: Provides detailed design procedure for non-pressure PVC pipelines in trench and embankment installations.

7) *Ductile iron pipelines: Embedment design* (Document PJF268 Section 5).

Published by Stanton and Staveley.

Scope: Provides detailed design procedures for pressure and non-pressure ductile iron pipeline in trench and embankment installations, provides simplified design procedure for pipes in the range DN 80 to DN 1600.

8) The Building Regulations 1985: *Drainage and Waste Disposal: Approved Document H.*

Published by The Stationery Office.

Scope: Provides simplified design procedures for non-pressure pipelines of DN 150 and smaller sizes.

9) *Revised bedding factors for vitrified clay drains and sewers*

(Information and Guidance Note No. 04-11-02).

Published by the Water Research Centre.

Scope: Provides guidance relating to bedding factors for all rigid pipes at an appropriate time.

10) *Directive for selection of asbestos-cement pipes subject to external loads with or without internal pressure* (ISO 2785)

Scope: Detailed design procedures for pressure and non-pressure asbestos-cement pipelines in trench and embankment installations.

NOTES

i) A review of bedding factors and factors of safety for rigid pipes is currently being undertaken by the water industry in the UK. Amendments may be introduced from time to time in the light of experience, research and development.

ii) The documents listed above make reference to certain further documents for detailed guidance on design, and these further documents may themselves be regarded as representative of the established methods used in the UK.

iii) Also published in the UK, by various pipe manufacturing organizations, are design guides and manuals covering the application of the established methods to specific types of pipe.

Loads on buried concrete pipelines: Tables of total design loads in trench (Concrete Pipe Association).

Design tables for determining the bedding construction of vitrified clay pipelines (Clay Pipe Development Association)

These documents may be obtained from:
British Standards Institution
389 Chiswick High Road
London W4 4AL

The Stationery Office
PO Box 276
London SW8 5DT

WRc Publications
PO Box 16
Marlow Sl7 2HD

Stanton plc
PO Box 72
Nottingham NG10 5AA

The Concrete Pipe Association
60 Charles Street
Leicester LE1 1FB

Clay Pipe Development Association Ltd
Copsham House
53 Broad Street
Chesham
Bucks HP5 3EA

B.2 Description of methods

B.2.1 *Austria*

B.2.1.1 *Application*

The Austrian method enables the calculation of both types of pipes, pressure and non-pressure pipes.

B.2.1.2 *Basic input data*

Besides the geometrical data for the structural calculation, data describing the structural properties of the pipe as well as of the soil have to be used, which are measurable and controllable by standard measurement techniques.

The most important data additional to the geometric data are the ultimate stress or strain, the modulus of elasticity and the specific weight as input data for the pipe and the self weight, the stiffness-modulus as a result of the consolidation test and the friction-angle for the soil.

The dependence of the soil stiffness-modulus upon the stress intensity is taken into account.

B.2.1.3 *Structural design*

The pipe bedding and load distribution are assumed to be constant in the longitudinal direction. Therefore, the design can be handled as a two-dimensional problem. The structural model of the pipe consists of an elastically embedded circular ring.

B.2.1.4 *Loading*

The following load cases can be taken into account:

- vertical and horizontal earth pressure;
- horizontal bedding reaction pressure;
- traffic loads;
- static uniformly distributed surcharge;
- partial surcharges;
- self weight of the pipe;
- internal water load;
- internal pressure of pressure pipes;
- external water pressure.

The load distribution is assumed to be uniform, except for the horizontal embedment reaction pressure which is assumed to be parabolically distributed.

The distribution range of the vertical and horizontal pressures can be chosen optionally in correspondence with the actual embedment conditions. The distribution of the horizontal reaction pressure is proposed by the ÖNORM B 5012 as corresponding to an angle of 120°.

For the practical calculation, the forces are decomposed in their vertical and horizontal components.

B.2.1.5 *Types of pipes*

As a function of the elastic characteristics of the pipe in relation to the surrounding soil, the pipes are subdivided into three deformation classes:

- rigid pipes;
- semi-rigid pipes;
- flexible pipes.

There are different manners for the calculation of these types of pipes.

B.2.1.6 *Method of calculation*

The calculation consists of the structural analysis of the embedded circular ring under the given loading.

The vertical earth load for flexible pipes is prescribed by the weight of the soil: for semi-rigid and rigid pipes, however, this load has to be increased.

The horizontal bedding reaction pressure of semi-rigid and flexible pipes has to be calculated by the help of the compatibility of the horizontal displacements of the pipe and the soil.

The ÖNORM suggests certain distribution angles of the vertical reaction stress which are dependent on the installation type, the bedding type and the deformation class together with structural calculation according to first order theory and for flexible pipes under certain conditions according to second order theory.

B.2.1.7 *Required analysis*

The required analysis according to the installation type, the soil group and the elastic property of the pipe are as follows:

- stress analysis according to first and second order theory;
- deformation analysis according to first and second order theory;
- stability analysis.

The stress analysis for pressure pipes has to be calculated according to first order theory for rigid pipes and according to second order theory in consideration of the re-rounding effect for semi-rigid and flexible pipes.

B.2.2 ***Belgium***

B.2.2.1 *Application*

The ISO 2785 standard covers the calculation of pressure and non-pressure asbestos cement pipes, in both trench and embankment conditions.

B.2.2.2 *Basic input data*

The calculation method takes into account for the pipe the geometrical data and the material parameters, such as modulus of elasticity, bursting strength and crushing strength. Besides this, the soil parameters such as type of soil and degree of compaction should be known. This is given in the standard for four types of soil. Also the trench and foundation conditions should be indicated together with the traffic and other surface loads.

B.2.2.3 *Structural design*

The pipe embedment and load distribution is assumed to be constant in the longitudinal direction. The structural system of the pipe consists of an elastically embedded circular ring.

B.2.2.4 *Loading*

The following load cases are considered:

- a vertical earth pressure, taking into account the concentration factor of vertical earth pressure, a coefficient of lateral earth pressure and the distribution of the reaction forces depending on the pipe-soil system stiffness;
- a lateral earth pressure, composed of a uniformly distributed pressure resulting from the vertical earth pressure and the lateral soil reaction due to the deformation of the pipe;
- vertical superimposed concentrated and distributed traffic loads, taking into account the road structure;
- internal water load.

B.2.2.5 *Type of pipes*

Asbestos-cement pipes are classified amongst semi-rigid pipes. Therefore, as a function of the pipe-soil system stiffness, different soil pressure distributions are suggested.

B.2.2.6 *Method of calculation*

The structural calculation method derives the maximum ring bending moments in the wall of the buried pipe. A distinction is made between the crown, the spring line and the invert of the pipe.

In the equation, the following is taken into account:

- total vertical pressure on the pipe, composed of the earth pressure and the traffic load pressure;
- lateral earth pressure;
- lateral reaction;
- internal water load.

The influence of each of these pressures on the ring bending moment is determined by means of so-called ring bending moment factors. These are chosen out of a table as a function of the bedding angle, the bedding type and the pipe-soil stiffness.

B.2.2.7 *Safety factors*

Three safety factors are determined, the values of which depend upon the diameter and the application as pressure or non-pressure pipes.

The safety factors are:

- a safety factor against crushing when a combined internal hydraulic pressure is applied together with a ring-bending moment;
- a safety factor against bursting when a ring-bending moment is applied together with an internal hydraulic pressure;
- a safety factor against crushing of a pipe loaded externally without any internal pressure.

The stress analysis for pressure pipes has to be calculated according to first order theory for rigid pipes and according to second order theory in consideration of the re-rounding effect for semi-rigid and flexible pipes.

B.2.3 ***Denmark***

B.2.3.1 *Loads*

- Types of loads

Permanent loads:

- earth load;
- self weight of pipe.

Variable loads:

- uniformly distributed surface load;
- traffic load;
- load from external and internal water pressure.

- Distribution of load and bedding reactions

The vertical load is assumed uniformly distributed over a width equal to the external width of the pipe.

The bedding reaction is assumed to be a vertical action uniformly distributed over a width depending on the bedding class for circular pipes or the width of the base for pipes with a base.

In the longitudinal direction of the pipe the bedding reaction is assumed to be uniformly distributed. If the length of the pipe is large in relation to its diameter, due consideration shall be given as to the validity of this assumption.

– Determination of loads

The permanent and the variable loads are determined as follows.

– Earth load

The characteristic vertical load on a pipe is:

$v_j = \lambda \gamma h_d$ kN/m^2

where λ is the earth load coefficient, γ is the specific weight of the backfill (kN/m^3) and h_d is the height of earth cover (m) with the relieving effect of the lateral pressure being included in λ.

The standard gives values for λ depending on the installation conditions (e.g. $\lambda = 1{,}6$ for normal laying class and $\gamma = 21$ kN/m^3) which can be used instead of a closer examination according to Marston.

– Self weight of pipe

The loading effect of the self weight of the pipe shall be included, either as a reduction in the load bearing capacity of the pipe or as an equivalent addition to the vertical load.

– Uniformly distributed surface load

The action on the pipe is $v_q = \lambda q$ kN/m^2 from a uniformly distributed characteristic surface load q kN/m^2.

– Traffic loads

The action from any wheel loads is determined in accordance with Boussinesq's theory.

For roads, a three-axle load group is assumed in which each axle load consists of two wheel loads of 65 kN for normal and 100 kN for heavy road traffic. These loads include an impact factor which is independent of the earth cover.

– Load from external and internal water pressure

The effect on a pipe due to its water-filled state shall normally be included, either as a deduction in the load bearing capacity of the pipe or as an equivalent addition to the vertical load.

B.2.3.2 *Safety*

The safety shall be evaluated in accordance with the partial coefficient method. The load bearing capacity of a pipe can either be determined arithmetically or by a combination of calculation and testing.

In the safety analysis both the serviceability limit state and the ultimate limit state shall be considered.

B.2.3.3 *Partial safety factors*

– Design loads

The design load is determined as the sum of the characteristic permanent load and the characteristic variable load, both multiplied by the actual partial safety factor γ_f.

For the serviceability limit state γ_f is 1,0 for both types of loads and for the ultimate limit state γ_f is 1,0 for the permanent load and 1,3 for the variable load.

– Design material parameters

The design value of the load bearing capacity of the pipe is determined as the characteristic value divided by the actual partial safety factor γ_m.

γ_m is 1,3 to 1,5 depending on the factory production control, when estimating the load bearing capacity on the basis of full scale tests.

For reinforced pipes which are structurally analysed solely on the basis of calculations, partial safety factors for the reinforcement, respectively the concrete, shall be fixed according to the standard for design of concrete structures.

B.2.3.4 *Calculations*

It shall be proved that the design load bearing capacity of a pipe is greater than the design effect of actions considered.

– Determination of effects of actions

When determining the internal forces with a view to evaluating the serviceability limit state, the elasticity theory shall be used with the commonly accepted approximations.

When determining the internal forces with a view to evaluating the ultimate state, the elasticity theory shall be applied in the case of unreinforced pipes, and either the elasticity theory or the plasticity theory in the case of reinforced pipes.

– Determination of load bearing capacity

For unreinforced pipes the load bearing capacity is determined by a calculation on the basis of the actual laying conditions and the declared design strength based on the crushing test load.

For reinforced pipes the load bearing capacity may be determined on the basis of tests or calculations. If calculations are applied, the rules of the standard for design of concrete structures shall be applied.

– Determination of laying depths

The maximum and possibly minimum acceptable laying depths for a pipe shall be determined by a load estimation in such a way that the actual design loads are equal to the design load bearing capacity of the pipe.

B.2.4 ***Finland***

No text available.

B.2.5 *France*

The French structural design method for buried pipes (Fascicule 70), firstly, lists the relevant parameters:

– pipe characteristics;

– geotechnical data on the surrounding soil;

– installation conditions: embedment and backfilling materials, degree of compaction, water table influence, withdrawal of trench wall support.

In a second step, after evaluation of the rigidity criterion of the buried pipe, loads acting on the pipe are defined: earth loads (vertical and horizontal), surface loads, hydraulic pressure (external and internal), etc. Marston theory is used with, for a flexible pipe, a lower bound value corresponding to the weight of the column of soil above it. For concentrated surface loads Boussinesq's theory, modified by Froelich, is used.

In a third step, deflections, bending moments, normal forces and strains are calculated through a model which can be applied in a consistent way from rigid to flexible pipes. This model is based on a cylindrical shell placed in an elastic medium, which represents the surrounding soil, itself modelled by an infinite number of elastic springs normal to the pipe wall.

Results are calculated through second order theory. This means that equilibrium equations are written for the displaced position (and not for the initial position). This is important for flexible pipes. Amplification effects due to the external hydrostatic pressure or to the compressive mean pressure (also called spherical component of initial soil stresses tensor) are taken into account. The form of the ovalization equation is similar to Spangler's one, but with a second additive term. Moreover, the second order approach shows a non-linear result increasing with pressure, asymptotically when critical buckling pressure is reached. This enables the strains associated with non-elliptical deformed shapes (e.g. three wave or squaring effects) to be predicted.

In the case of pressure pipes, the internal pressure in this model leads to an increase in system stiffness, instead of a decrease as is the case with external pressure.

Three types of verification are to be performed:

1) against instability due to buckling;

2) ultimate limit state against failure;

3) serviceability limit state for durability during intended service life. The design service life is at least 50 years.

The limit states considered are in accordance with the general principles of Eurocode I: thus, for a given level of safety, all materials are treated equally.

Moreover, for pressure pipes, Fascicule 71 gives the basis for designing pressure pipes: either it refers to standards when they exist or it gives the data for designing those pipes when design is not covered in standards or regulations.

B.2.6 *Germany*

The calculation method given in ATV-A 127 standard of the Abwassertechnische Vereinigung (ATV), *Guideline for the structural design of sewerage and drainage pipelines*, applies for the structural calculation of buried pipes of all standardized pipe materials.

The calculation method can be used for rigid and flexible pipes with different pipe stiffnesses and installation conditions with a smooth transition from trench to embankment, in which the loading of the pipes is dependent on the deformation properties of pipe and soil and their mutual influence.

The spectrum of the existing soils and their deformation moduli is mostly represented by four types of soil, characterized through different friction angles and grades of compaction. Solutions for the influence of road, railway and airplane traffic loads are given, including the effect of fluctuating loads.

The material properties of the pipes are determined by appropriate DIN standards.

Different installation methods on site, trench shapes, installation and earth fill condition depending on trench sheeting or embankment, soil compaction and ground water influence are considered.

The load concentration above the pipe is calculated by means of the theory of the shear resistant beam, depending on different soil and pipe deformation and caused by the embedment reaction.

For extreme conditions, e.g. very high earth covers or sloping sides or special conditions, e.g. pipeline supported on piles or high internal pressures for flexible pipes, additional considerations are necessary.

Solutions are obtained for the soil pressure distribution on rigid and flexible pipes from which bending moments, axial forces, pipe deformations, strains and stresses are calculated. All parameters necessary for this are given in tables and diagrams.

The analysis and its verification is made by calculating bearing capacity, stresses, strains and deformation. Additional checks are made for fatigue strength under traffic loads and for buckling.

The global safety factors for certain defined probabilities of failure are associated with the calculation model with probabilistic assumptions for the influence of the scatter of each important influence factor resulting from soil, installation conditions and strength properties of the pipes.

For the design of jacking pipes ATV-standard A161 is valid.

B.2.7 ***Netherlands***

The Dutch structural design method for buried concrete pipes firstly lists the relevant parameters:

- pipe characteristics;
- geotechnical data on the surrounding soil;
- installation conditions: embedment and backfill materials, degree of compaction, ground water conditions, withdrawal of trench wall support.

In a second step, loads acting on the buried pipe are defined: earth loads (vertical and horizontal), surface loads, traffic load, self weight of pipe, internal load due to weight of water, hydraulic pressures (external and internal) and temperature differences. Earth loads are calculated through a model which can be applied in a continuous way from the rigid pipe to the flexible one. This model is based on theories published by G. Leonhardt.

For the earth loads the rules in CUR report No. 122 correspond to those in the ATV-standard A 127. Different concentration factors are used for surface and earth loads. For concentrated loads due to traffic, Boussinesq's theory is used but modified by a specific concentration factor to take into account the stiffness of the pipe with respect to the surrounding soil. The traffic load on the pipe is further averaged according to the theory of Braunstorfinger.

In a third step, bending moments, normal forces and stresses are calculated by the rules of mechanics.

The following assessment criteria are given.

- For unreinforced pipes:

  Ultimate limit state. The flexural tensile strength is determined from crushing load tests. A reduction factor of 0,9 is used to take into account the possible long-term nature of some loads.

The partial load factors and material parameters to be used are given in CUR report No. 122.

- For reinforced pipes:

  The design is based on calculations using basic data such as concrete grade, steel grade and reinforcement percentage. One serviceability limit state (allowable crack width) and three failure criteria are used. Failure criteria are given for bending, shear (diagonal tension) and radial tension.

  The partial load factors and material parameters to be used are given in CUR report No. 122.

B.2.8 ***Norway***

B.2.8.1 *Design of rigid pipes according to internal reports 1521 and 1554*

B.2.8.1.1 *Earth load*

The earth load on a rigid pipe is calculated from:

$Q = C\gamma D^2$ (kN/m)

where:

C is the earth load coefficient;

γ is the unit weight of the backfill (kN/m^3);

D is the outer diameter of the pipe (m).

The calculation of the earth load coefficient C is based on a theory developed by Vaslestad based on classical soil mechanics.

This is a theoretically more sound concept than the Marston theory, but yields similar results. Embankment theory is applied and lateral earth pressure is taken into account.

B.2.8.1.2 *Traffic load*

The design traffic load is based on an axle load of 2×130 kN which includes a dynamic impact factor.

The wheel loads are assumed to act on an area 0,2 m $\times$ 0,6 m and the pressure distribution is calculated according to the theory of Boussinesq.

B.2.8.2 *Design of buried plastic pipes according to VAV P 70 (Swedish standard)*

See **B.2.10.1**.

B.2.9 ***Spain***

B.2.9.1 *Concrete pipes*

The Spanish structural design method for reinforced concrete and prestressed concrete pressure pipes considers Marston's theory to evaluate soil actions on the pipe.

The theoretical method for calculation of a pipe is according to T. Turazza's book on large diameter reinforced and prestressed concrete pipes.

Basic input data includes geometrical characteristics, concrete and steel characteristics, type of soil, depth and overloads, pressure and safety factors to be considered.

B.2.9.2 *Asbestos-cement pipes*

For asbestos-cement pipelines, UNE 88211 is based on ISO 2785 with some modifications which increase the safety of the method:

- distance between axes for standard vehicles has been reduced;
- lateral soil reaction pressure due to deformation of pipe is always disregarded;
- the recommended minimum safety factor for non-pressure pipes has been increased from 1,5 to 1,6.

Scope

UNE 88211 covers the calculation of pressure and non-pressure asbestos-cement pipes, in both trench and embankment conditions.

Basic input data

The calculation method takes into account the geometrical data and the mechanical parameters for the pipe such as modulus of elasticity, bursting pressure and crushing load. Besides this, the soil parameters such as type of soil and degree of compaction should be known. Also the trench dimensions and bedding conditions should be taken into account together with the traffic and other surface loads.

Structural design

The pipe embedment and load distribution is assumed to be constant in the longitudinal direction. The structural system consists of an elastic embedded circular ring.

Loads

The following loads are considered:

- a vertical earth pressure, taking into account the concentration factor of vertical earth pressure depending on the pipe-soil system stiffness;
- a lateral earth pressure resulting from the vertical earth pressure;
- vertical superimposed concentrated and distributed traffic loads, taking into account the road structure;
- internal water load.

Load distribution

Different soil pressure distributions are suggested depending on the bedding conditions.

Method of calculation

The structural calculation method derives the maximum ring bending moments in the wall of the buried pipe. A distinction is made between the crown, the spring line and the invert of the pipe.

In the equation to calculate the ring bending moment, the following is taken into account:

- total vertical pressure on the pipe composed of the earth pressure and the traffic load pressure;
- lateral earth pressure;
- internal water load.

The influence of each of these pressures on the ring bending moment is determined by means of so-called ring bending moment factors. These are chosen out of a table as a function of the bedding angle and the type of bedding.

Safety factors

Three safety factors are determined:

- a safety factor against crushing of a pipe loaded externally without any internal pressure;
- a safety factor against crushing when an internal hydraulic pressure is applied together with a ring bending moment;
- a safety factor against bursting when a ring bending moment is applied together with an internal hydraulic pressure.

Minimum values for the safety factors are recommended according to the applications (non-pressure or pressure) and the diameter of the pipes.

B.2.9.3 *Plastic pipes*

For plastic pipes, uPVC and HDPE, UNE 53331 calculates pipes as flexible units, considering passive co-operation of soil to pipe resistance. Basic input data includes characteristics of pipe, installation, soil and surcharges. The calculation also requires vertical and horizontal soil pressure as well as external and internal water pressure.

Safety coefficients take into account variations in resistance and dimensions of pipes, loads, soil characteristics and pipe laying procedures.

B.2.10 *Sweden*

B.2.10.1 *Design of buried plastics pipes according to VAV P 70*

B.2.10.1.1 Soil load

The soil load can be determined according to the embankment or to the trench theory. In Sweden, plastics pipes have traditionally been designed according to the embankment theory.

B.2.10.1.2 *Traffic load*

The influence of traffic load is calculated by applying the pressure distribution according to the theory of Boussinesq. The most common design traffic load recommended in Sweden is presently defined as an axle load of 2 × 130 kN, which includes a dynamic impact factor.

B.2.10.1.3 *Short-term deflection*

According to the Swedish method, the maximum vertical deflection is determined in the following way. First, the theoretical deflection is calculated. To this value are added empirical allowances for deformation effects caused by the installation method used (installation factor) and by the effect of uneven pipe bed conditions (bedding condition factor).

According to experience the average deflection is in most cases estimated by just excluding the bedding condition factor.

The theoretical deflection caused by loads is calculated according to the Molin equation (modified Spangler formula). In this equation, consideration is given to the load factor, the load distribution factor and the lateral soil pressure coefficient.

B.2.10.1.4 *Long-term deflection*

The calculated pipe deflection gives the short-term value immediately after completed installation and backfilling.

A simplified calculation of the long-term pipe deflection is used which, based on comprehensive field studies, has been verified to correspond to the short-term value multplied by a factor of 1,5 to 2,0.

B.2.10.1.5 *Strain*

When bending strain in the pipe wall has to be calculated, a coefficient $D_f = 6$ is used according to Molin.

B.2.10.1.6 *Buckling*

The permissible external pressure due to the risk of buckling is calculated according to classical formulae.

The risk of buckling gives the ultimate lower limit for the ring stiffness of the pipe.

B.2.10.1.7 *Nomographs for simplified design*

In order to illustrate how situations of load, ring stiffness, side fill type, compaction, etc. will influence the pipe deflection, simplified design nomographs are given. In practice, routine design is usually carried out with the aid of these graphs.

B.2.10.2 *Design of rigid pipes according to VAV P 48*

Minimum crushing strengths for reinforced concrete pipes are stipulated in the Swedish Code VAV 56.

The safety factor used in the Swedish Code with respect to the ultimate strength is 1,5.

B.2.10.2.1 The vertical loads considered are:

Soil weight

The calculation of the soil load has long been based on Marston's formulas for trench and embankment conditions. The present National Code recommends empirical formulae obtained from extensive field investigations performed in Sweden, but basically developed from the Marston theory. They are considered to give an upper limit of the loads obtained under the worst installation conditions accepted by the authorities. Normally embankment theory is applied.

Traffic

The traffic load is specified as a number of concentrated wheel loads, which may be assumed to act on an area 0,2 m in the road direction and 0,6 m in the lateral direction (see **B.2.10.1.2**).

B.2.10.2.2 *Horizontal loads*

The ratio between horizontal and vertical earth pressures is assumed to be for an uncracked concrete pipe $k = 0,3$ and in cracked condition $k = 0,5$. In a trench, with a width $B < 4d_y$, no horizontal earth pressure is considered.

B.2.11 ***Switzerland***

The 3/1993 edition of the SIA Empfehlung V 190, Kanalisationen, contains amongst other things the requirements valid in Switzerland for the planning, structural design, construction, approval and work safety of buried sewerage pipes made of all standardized materials.

In the structural design of sewerage constructions, a distinction is made between proof of load bearing capacity and safety against buckling, on the one hand, and proof of serviceability, on the other.

Proof of the load bearing capacity and safety against buckling of a buried sewerage pipe is obtained on the basis of most critical conditions during its construction and operation. For this, the partial safety factors for load and reaction are superimposed accordingly with the usual safety coefficients from the old Swiss standard SIA 190 (1977). Compared with the previous standard, the new SIA Empfehlung V 190 has higher degrees of safety.

The proof of serviceability of a buried sewerage pipe is obtained on the basis of the stress and deformation proof for the limit states under carefully selected conditions. Using three critical calculation models taken from ATV Arbeitsblatt A 127 (1988), the maximum circumferential bending stresses are determined in the pipe cross-section with a distinction being made between the long-term and short-term effects. In this way, it is intended to limit crack development in the pipes and to ensure the allowable pipe deformation is adhered to.

B.2.12 ***United Kingdom***

B.2.12.1 *General description*

B.2.12.1.1 *Classification of pipes*

Pipes of different materials are classified in the UK according to the strength criterion required to be proven in testing, or otherwise established for use in design.

Thus, pipes whose strength is established in crushing tests are classified as 'rigid'. Clay, concrete and reinforced concrete pipes are thus invariably classed as rigid, whilst asbestos cement pipes, which also have specified minimum crushing strengths, are normally regarded as rigid. It is, however, also permissible to design asbestos cement pipes as 'semi-rigid', in accordance with ISO 2785.

The normal procedure for ductile iron pipes treats them as semi-rigid (see below).

Thermoplastic, glass reinforced plastic, and thin walled steel pipes are treated as 'flexible' for structural design purposes.

B.2.12.1.2 *Design aids*

In practice, routine design is usually carried out with the aid of tables or charts, which have themselves been compiled in accordance with the principles described above, using the procedures and formulae set out below.

B.2.12.1.3 *Calculation of loads*

Soil loads are effectively calculated from the geostatic earth pressure. Concentration factors increasing the value are applied in the case of rigid and semi-rigid pipes, but reduction factors are not used in the case of flexible pipes. Load reductions due to the silo effect in trenches, and other favourable installations, are only considered in the cases of rigid and semi-rigid pipes, and the reduction factors are conservatively calculated, using Rankine's active lateral earth pressure coefficient.

Consequently, for both trench and embankment conditions, the soil load on flexible pipes is taken as the geostatic earth pressure, and on rigid and semi-rigid pipes as greater than the geostatic pressure.

Surcharge loads are calculated using Boussinesq's theory, for various vehicle wheel loading patterns, representing the most severe loadings which might apply in various locations.

External loads on flexible and semi-rigid pipes are normally expressed as vertical pressures, and for rigid pipes as loads per unit length of pipeline.

B.2.12.1.4 *Flexible pipe response*

Pipe deflection and buckling stability are calculated in all cases. In the case of thermoplastic pipes, the bending stress is only calculated for pressure pipelines, where it is added to the hoop tensile stress.

Pipe deflection is calculated using Spangler's equation, but using values of the soil modulus and deflection lag factor derived from UK research and experience. Leonhardt's procedure is used for adjusting the soil modulus to take account of the influence of the native soil.

The bending strain in the walls of GRP pipes is calculated using Molin's equation, but with values of the strain factor which are varied to take account not only of pipe and soil stiffnesses, but also of the energy applied in compacting the soil.

B.2.12.1.5 *Semi-rigid pipe response*

Pipe wall bending stress is calculated for pressure and non-pressure ductile iron pipes but it is not added to the hoop tensile stress in pressure pipes. Deflection is checked using similar procedures to those for flexible pipes. Bending stress in the walls of ductile iron pipes is calculated using the Spangler stress equation. Large diameter asbestos-cement pipes are regarded as semi-flexible and may be designed according to ISO 2785.

B.2.12.1.6 *Rigid pipe response*

Pipelines of clay, concrete, reinforced concrete and small diameter asbestos-cement pipes are designed using the 'bedding factor' method. This method is favoured not only because it is convenient and quick to use, but also because the bedding factor can readily be investigated experimentally. Because of this, extensive research programmes have established recommended bedding factor values for various standard types of installation.

B.2.12.1.7 *Factors of safety*

The procedures used for calculating the design loads on all types of pipes predict values close to the upper bound.

Because of the crushing test compliance requirements, design strengths for rigid pipes are close to the lower bound. Bedding factor values are also regarded as conservative in the light of experimental data. For these reasons, a factor of 1,25 is normally used in rigid pipe design, though designers are recommended to consider whether there are any particular circumstances warranting the use of a higher value.

In the design procedures for flexible and semi-rigid pipes, conservative design is primarily ensured by the use of soil modulus values regarded as close to the lower bound. The allowable stress and strain values used in design incorporate various specified safety factors.

B.2.12.2 *Calculation procedures*

Three basic calculation procedures are used, covering rigid, semi-rigid and flexible pipes. These three categories normally include the following pipe materials:

rigid:	asbestos cement, clay, concrete and reinforced concrete.
semi-rigid:	ductile iron.
flexible:	steel, thermoplastics, reinforced thermosetting plastics (GRP).

It is also permissible to treat pipelines of asbestos-cement pipes as semi-rigid, and to design according to ISO 2785.

National annex A (informative) Calculation procedure for UK established method

NA.1 General

The three basic calculation procedures cover rigid, semi-rigid and flexible pipes. These three categories normally include the following pipe materials:

rigid:	asbestos cement, clay, concrete and reinforced concrete;
semi-rigid:	ductile iron;
flexible:	steel, thermoplastics, reinforced thermosetting plastics (GRP).

This annex gives the design formulae, identified by equation numbers which are referred to in the flowcharts setting out design procedures for rigid, semi-rigid and flexible pipes (figures NA.1 to NA.5). Also included here are 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.

NA.2 Symbols

B_c	Outside diameter of pipe
B_d	Effective width of trench
C_c	Soil load coefficient in embankment conditions
C_d	Soil load coefficient in trench conditions
C_L	Soil modulus adjustment factor
C_w	Water load coefficient
D	Mean diameter of pipe
D_f	Strain factor
D_L	Deflection lag factor
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_{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
p	Projection ratio
r_{sd}	Settlement deflection ratio
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_{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

NA.3 Native soil

The stiffness of the native soil in which a pipeline trench is excavated can be particularly important for the design of pipelines using flexible pipes, and also influences the settlement deflection ratio for rigid pipes. Guide values are given in table NA.1.

NA.4 Rigid pipes

NA.4.1 *Design loads for rigid pipes*

NA.4.1.1 Soil load W'_c in wide trench and embankment installation:

$$W'_c = C_c \gamma B_c^2 \qquad (1)$$

The value of C_c is taken as the lower of the values derived from equations (2) and (3). If the lower value is given by equation (2), then complete projection conditions exist, whilst if the lower value is given by equation (3), then incomplete projection conditions apply.

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

$$C_c = \left\{ \frac{e^{2K\mu H_e/B_c}}{2K\mu} + \left(\frac{H}{B_c} - \frac{H_e}{B_c} \right) e^{2K\mu H_e/B_c} \right\} \qquad (3)$$

In which H_e is the height of the plane of equal settlement above the top of the pipe. With $K\mu$ set at 0.19, the values in table NA.2 are obtained for C_c.

Table NA.2 Load coefficients for incomplete projection condition

$r_{sd}p$	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	$C_c = 2.28\ (H/B_c) - 0.22$

NOTE. See **NA.4.3** for guidance on values of r_{sd} and p.

NA.4.1.2 Soil load W_c in narrow trench installations:

$$W_c = C_d \gamma B_d^2 \qquad (4)$$

where

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

For pipelines in trenches, the backfill load is calculated according to equation 1 and equation 4 and the lower value is used for the pipeline design.

NA.4.1.3 For details of soil load in negative projection conditions, see **B.1.12**.

NA.4.1.4 Concentrated surcharge load, W_{csu}:

$$W_{csu} = P_s B_c \qquad (5)$$

where the value of the surcharge pressure, P_s, is obtained from figure NA.6, NA.7, NA.8 or NA.9.

Table NA.1 Guide values of Spangler modulus for native soils

Soil type	Spangler modulus for soils in various conditions (MN/m²)				
	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			

NA.4.1.5 Equivalent load due to weight of water in pipe, W_w:

$$W_w = C_w \gamma_w \pi (d - t)/4 \quad (6)$$

in which the value of C_w is normally taken as 0.75.

NA.4.1.6 Total design external load, W_e:

$$W_e = W_c + W_{csu} + W_w \quad (7)$$

NA.4.2 *Supporting strength of rigid pipes*

The supporting strength of rigid pipes is the product of the pipe strength and the bedding factor, and must be at least equal to the total design load calculated from equation 7.

Minimum recommended bedding factor, F_m:

$$F_m \geq W_e F_{se}/W_t \text{ (or } W'_t) \quad (8)$$

Recommended design values of the bedding factor can be obtained from table NA.7. Refer to product standards for design values of crushing strength (W_t).

NOTE 1. For pressure pipelines a reduction factor has to be applied to the crushing strength to take account of the effect of the internal water pressure.

NOTE 2. Refer to table NA.5 for recommended values of factor of safety.

Crushing strength adjustment W'_t for reinforced concrete pressure pipes:

$$W'_t = W_t(1 - P_w/P_u) \quad (9)$$

The working pressure P_w should not exceed:

$$P_u(1 - W_c/W_t F_m)/F_{si}$$

Crushing strength adjustment W'_t for asbestos cement pressure pipes:

$$W'_t = W_t (1 - P_w/P_u)^{0.5} \quad (10)$$

NOTE. The working pressure P_w should not exceed

$P_u(1 - (W_c/W_t F_m)^2)/F_{si}$.

NA.4.3 *Design data for rigid pipes*

NA.4.3.1 *Soil properties*

In the absence of specific data supporting the use of other values, it is normal practice to assume the following:

$K\mu = 0.19$

$K\mu' = 0.13$

$\gamma = 19.6$ kN/m^3

Where soils are more precisely identified, the values given in table NA.3 may be used.

Table NA.3 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.

NA.4.3.2 *Settlement deflection ratio*

The recommended values of the settlement deflection ratio r_{sd} and ranges for the native soil modulus E'_3 are given in table NA.4.

Table NA.4 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 NA.1.

NA.4.3.3 *Projection ratio*

The projection ratio, p, is calculated as the proportion of the pipe external diameter that is above firm bedding level or the natural ground level. For class D, F and N beddings (see table NA.7) the value of p is unity, and for other granular and concrete beddings p is 0.7.

NOTE. In calculation, the settlement deflection and projection ratios are used in combination, and design values of their product ($r_{sd}p$) are often taken as 0.7 for class D, N or F beddings (see table NA.7) and 0.5 for classes B and S.

NA.4.3.4 *Factors of safety*

The recommended minimum values of safety factors F_{se} and F_{si} are given in table NA.5.

Table NA.5 Minimum values of F_{se} and F_{si}

Pipe material	F_{se}		F_{si}	
	Non-pressure	Pressure	Pressure	
Clay	1.25	—	—	
Concrete	1.25	1.60	2.0	
			DN	F_{si}
Asbestos cement	1.30	1.50	175 to 225 250 to 500 600 to 1000	3.5 3.0 2.5

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

NA.5 Semi-rigid pipes

NA.5.1 *Design pressures for semi-rigid pipes*

NA.5.1.1 The pipe surround material, and its degree of compaction, must first be selected to permit calculation of the relative pipe-soil stiffness factor, n:

$$n = \frac{E'/D_L}{(105EI/D^3) + (0.8\,E'/D_L)} \qquad (11)$$

Design values of E' are obtained using tables NA.1 and NA.6, and equations 16 and 17. Design values of D_L are obtained using table NA.6.

NA.5.1.2 Soil pressure P_e in embankment installations:

$$P_e = C_c \gamma B_c \qquad (12)$$

where C_c has the lower of the values derived from equations 2 and 3. Equation 3 is solved using table NA.2, with the settlement deflection ratio r_{sd} evaluated as follows:

$$r_{sd} = 0.7\,(1 - n) \qquad (13)$$

NA.5.1.3 Soil pressure P_e in trench installations:

$$P_e = \frac{C_d \gamma B_d^2}{nB_d + (1 - n)B_c} \qquad (14)$$

with the value of C_d obtained from equation 4.

The design value of soil pressure P_e is the lower of the values obtained from equations 12 and 14.

NA.5.1.4 Total vertical external pressure, P:

$$P = P_e + P_s \qquad (15)$$

NOTE. The value of the surcharge pressure P_s can be obtained directly from figure NA.6, NA.7, NA.8, or NA.9.

NA.5.2 *Supporting strength of semi-rigid pipes*

NA.5.2.1 The modulus of soil reaction (E'_2) for the selected pipe surround material, at the chosen level of compaction, is obtained from table NA.6. Guidance on evaluation of the corresponding modulus for the native soil (E'_3) can be found in table NA.1, taking account of site investigation data. The effective overall modulus (E') may then be obtained using equation 16, for a particular trench width.

NA.5.2.2 Overall modulus of soil reaction, E':

$$E' = E'_2\,C_L \qquad (16)$$

where

$$C_L = \frac{0.985 + (0.544B_d/B_c)}{\{1.985 - 0.456(B_d/B_c)\}(E'_2/E'_3) - \{1 - (B_d/B_c)\}} \qquad (17)$$

NOTE. If the trench width is more than 4.3 times the external pipe diameter, the value of E' can be taken as equal to the value of E'_2.

NA.5.2.3 Ovalization Δ/D:

$$\frac{\Delta}{D} = \frac{K_x\,(D_L P_e + P_s)}{8EI/D^3 + 0.061E'} \qquad (18)$$

NOTE. The initial deflection is obtained with the value of D_L set at 1.0, and the long term deflection with the D_L value from table NA.6. If the working pressure is 3 bar[1)] or more, and if the depth of cover does not exceed 2.5 m, the long term deflection can be reduced by the factor D_R, where $D_R = 1 - (P_i/40)$, where P_i is the internal pressure in bars.

NA.5.2.4 Bending stress σ_{bs}:

$$\sigma_{bs} = ED_f(\Delta/D)\,(t/D) \qquad (19)$$

NA.5.3 *Design data for semi-rigid pipes*

It is normal practice to assume the following:

$K\mu = 0.19$

$K\mu' = 0.13$

Values of the deflection coefficient (K_x), deflection lag factor (D_L) and strain factor (D_f) for use in equations 18 and 19 can be obtained from table NA.6.

The allowable ovalizations for ductile iron pipes given in EN 545 and EN 598 are intended to ensure that the allowable bending stress is not exceeded.

NA.6 Flexible pipes

NA.6.1 *Design pressures for flexible pipes*

Vertical soil pressure P_e:

$$P_e = \gamma H \qquad (20)$$

The total external pressure for design purposes, P, is obtained from equation 15, with the value of surcharge pressure P_s being obtained directly from figure NA.6, NA.7, NA.8 or NA.9.

[1)] 1 bar = 100 kPa.

Table NA.6 Flexible and semi-rigid pipe embedment properties

Embedment class as table NA.8 and deflection coefficient K_x	Compaction M_P %	Modulus of soil reaction E'_2 MN/m²	Deflection lag factor D_L[2)]	Strain factor D_f for various pipe stiffnesses[1)] kN/m²					
				1.25	2.5	5.0	10	15	30 or more
Class S1	Uncompacted	5	1.5	4.7	4.5	4.3	4.0	3.75	3.0
K_x = 0.083	80	7	1.25	4.7	4.5	4.3	4.0	3.75	3.0
	85	7	1.0	4.7	4.5	4.3	4.0	3.75	3.25
	90	10	1.0	4.7	4.5	4.3	4.0	3.75	3.5
	95	14	1.0	—	—	—	—	3.75	3.5
Class S2	Uncompacted	3	1.5	4.7	4.5	4.3	4.0	3.75	3.0
K_x = 0.083	80	5	1.25	4.7	4.5	4.3	4.0	3.75	3.0
	85	7	1.0	4.7	4.5	4.3	4.0	3.75	3.25
	90	10	1.0	4.7	4.5	4.3	4.0	3.75	3.5
	95	20	1.0	—	—	—	—	3.75	3.5
Class S3	85	5	1.5	6.2	5.5	4.75	4.25	4.0	3.25
K_x = 0.100	90	7	1.25	7.75	6.6	5.5	4.7	4.25	3.5
	95	14	1.0	—	—	—	—	4.75	3.5
Class S4	85	3	1.5	6.2	5.5	4.75	4.25	4.0	3.5
K_x = 0.100	90	5	1.25	7.75	6.6	5.5	4.7	4.25	3.5
	95	10	1.0	—	—	—	—	4.75	3.5
Class S5	85	1	3.0	—	—	—	—	4.0	3.5
K_x = 0.100	90	3	2.0	—	—	—	—	4.25	3.5
	95	7	1.25	—	—	—	—	4.5	3.5
Class B1	85	5	1.5	—	—	—	5.0	4.0	3.5
K_x = 0.083	90	7	1.25	—	—	—	5.5	4.25	3.5
Class B2	85	3	2.0	—	—	—	5.5	4.25	3.5
K_x = 0.083	90	5	1.75	—	—	—	6.0	5.0	3.5

1) Pipe stiffnesses referred to in this table are initial values.

2) Where the designer can be certain that initial pressurization will take place within one year of backfilling, a value of 1.0 may be taken for the deflection lag factor.

NOTE 1. For construction details of embedment classes see table NA.8.

NOTE 2. Quoted values of E'_2 assume pipeline will be installed below groundwater.

NOTE 3. M_P indicates modified Proctor density and corresponds to the heavy compaction test in BS 1377.

NA.6.2 ***Supporting strength of flexible pipes***

NA.6.2.1 The modulus of soil reaction (E'_2) for the selected pipe surround material, at the chosen level of compaction, is obtained from table NA.6. Guidance on evaluation of the corresponding modulus for the native soil (E'_3) can be found in table NA.1, taking account of site investigation data.

NA.6.2.2 The effective overall modulus of soil reaction (E') is obtained from equations 16 and 17.

NOTE. If the trench width is more than 4.3 times the external pipe diameter, the value of E' can be taken as being equal to the value of E'_2.

NA.6.2.3 Factor of safety against buckling, F_s:

a) *With soil support (applies in all cases):*

$$F_s = 1/\{(P_e/P_{crl}) + (P_s + P_v)/P_{crs}\} \quad (21)$$

where

$$P_{cr} = 0.6\,(EI/D^3)^{0.33}\,(E')^{0.67} \quad (21a)$$

NOTE. In equation 21a, the long and short term values of the modulus (E) are used to calculate P_{crl} and P_{crs} respectively. (For metal pipes, the long and short term moduli are identical.)

b) *Without soil support:*

This case need only be considered when $H < 1.5$ m to cover the possible temporary situation of adjacent excavations:

$$F_s = P_{crs}/(P_e + P_v) \quad (22)$$

where

$$P_{crs} = 24EI/D^3 \quad (22a)$$

NOTE. In equation 22a, the short term value of the modulus (E) is used to calculate P_{crs}.

NA.6.2.4 Ovalization Δ/D:

$$\Delta/D = \frac{K_x\{(D_L P_e) + P_s\}}{8EI/D^3 + 0.061E'} \quad (23)$$

NOTE. The initial deflection is obtained with the value of D_L set at 1.0, and the long term deflection with the value of D_L from table NA.6. The pipe stiffness (EI/D^3) should be calculated using the long or short term value of the modulus (E) as appropriate.

NA.6.2.5 Re-rounding of pressure pipes reduces the initial deflection (Δ/D) to a lower value $(\Delta/D)_R$, given by equation 24:

$$(\Delta/D)_R = (1 - P_i/40)(\Delta/D) \quad (24)$$

where

P_i is the internal pressure in bars.

NOTE. It is recommended that re-rounding is only included in the design if water pressure is not less than 3 bar[1)] and will be applied within one year of back-filling, and if the depth of cover does not exceed 2.5 m.

NA.6.2.6 Combined stress in thermoplastics, σ_c:

$$\sigma_c = (P_i - P)\,D/2t + ED_f(\Delta/D)_R(t/D) \quad (25)$$

NOTE 1. In equation 25 the long term value of E should be used.

NOTE 2. The value of P is obtained from equation 15.

NOTE 3. Equation 25 applies to pipes buried with not less than 0.75 m cover.

NOTE 4. The form of equation 25 differs from the version appearing in the second edition of the Pipe Materials Selection Manual, in that the total vertical external pressure is deducted from the internal water pressure, not solely the soil pressure.

NA.6.2.7 Strain in GRP pipes.

a) Bending strain in non-pressure pipes, ε_b:

$$\varepsilon_b = D_f(\Delta/D)\,(t/D) \quad (26)$$

where

(Δ/D) is obtained from equation 23.

b) Combined strain in pressure pipes, ε_c:

$$\varepsilon_c = D_f(\Delta/D)_R(t/D) + P_i D/2E_h t \quad (27)$$

NOTE. In equation 27, the long term value of E_h should be used.

NA.6.3 ***Design data for flexible pipes***

In the absence of specific data supporting the use of other values, it is normal to assume a value for the unit weight of soil, γ, of 19.6 kN/m^3.

Values of the deflection coefficient (K_x), deflection lag factor (D_L) and strain factor (D_f) for use in equations 23, 25, 26 and 27 can be obtained from table NA.6.

1) 1 bar = 100 kPa.

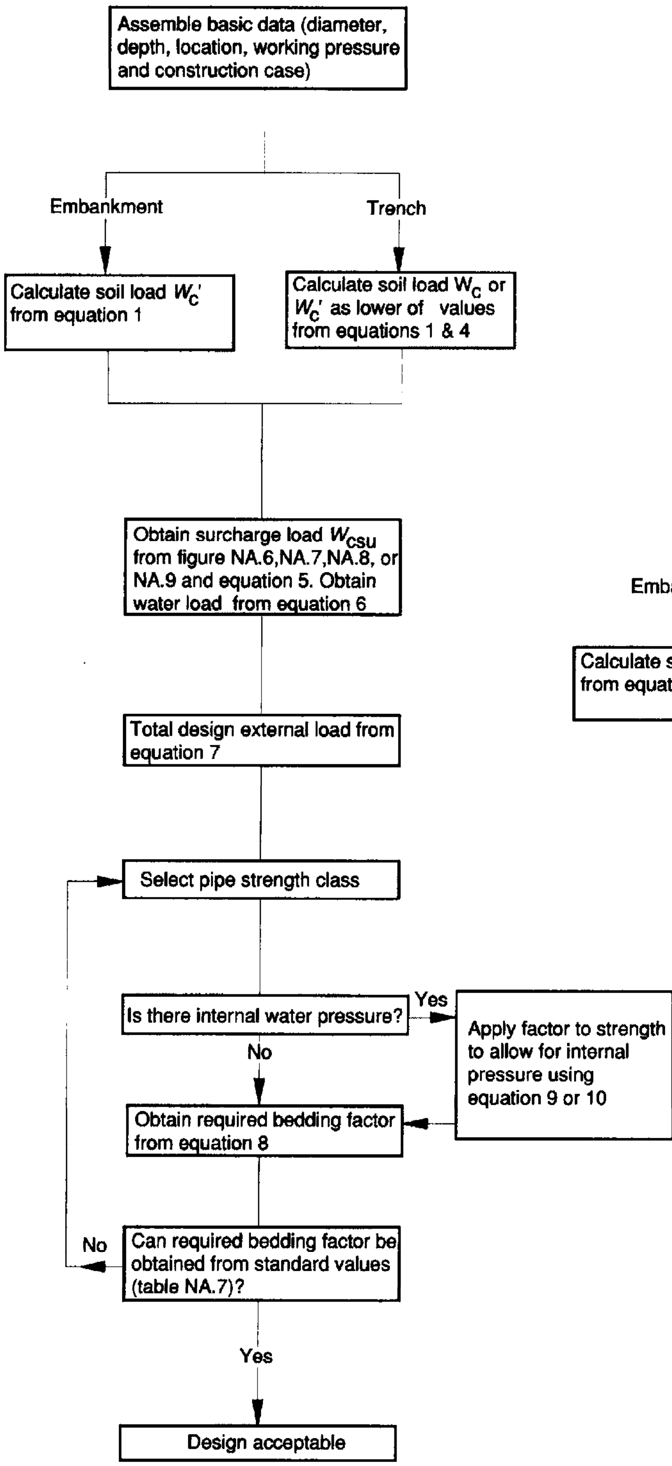


Figure NA.1 Flowchart for pipeline design with rigid pipes

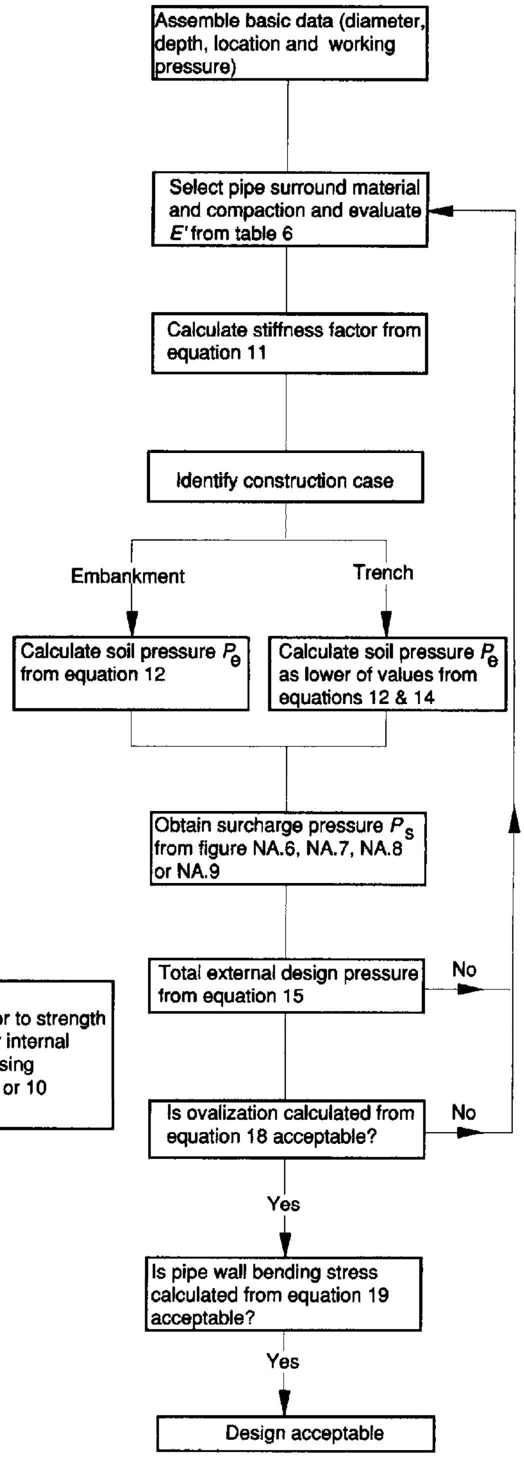
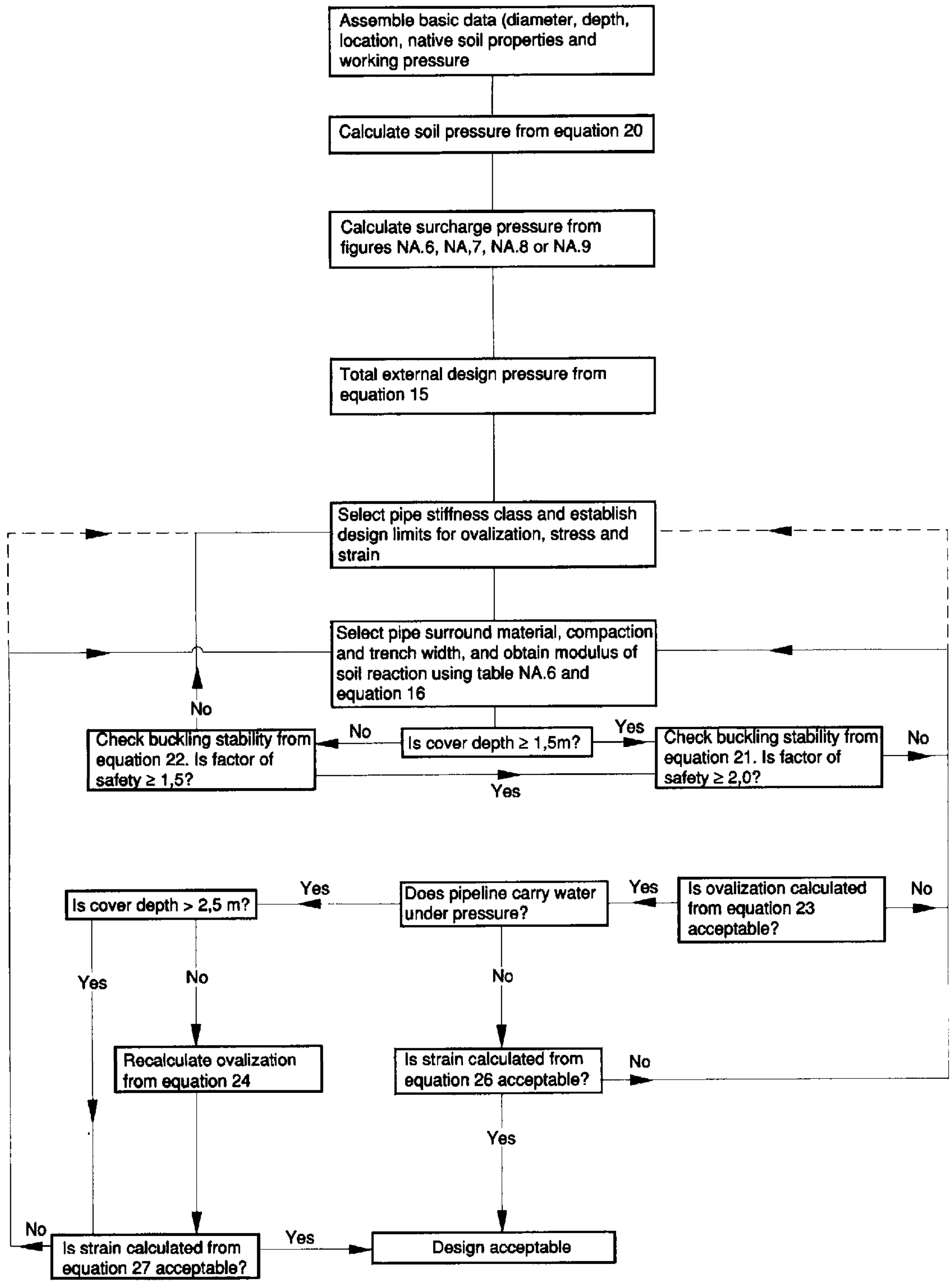
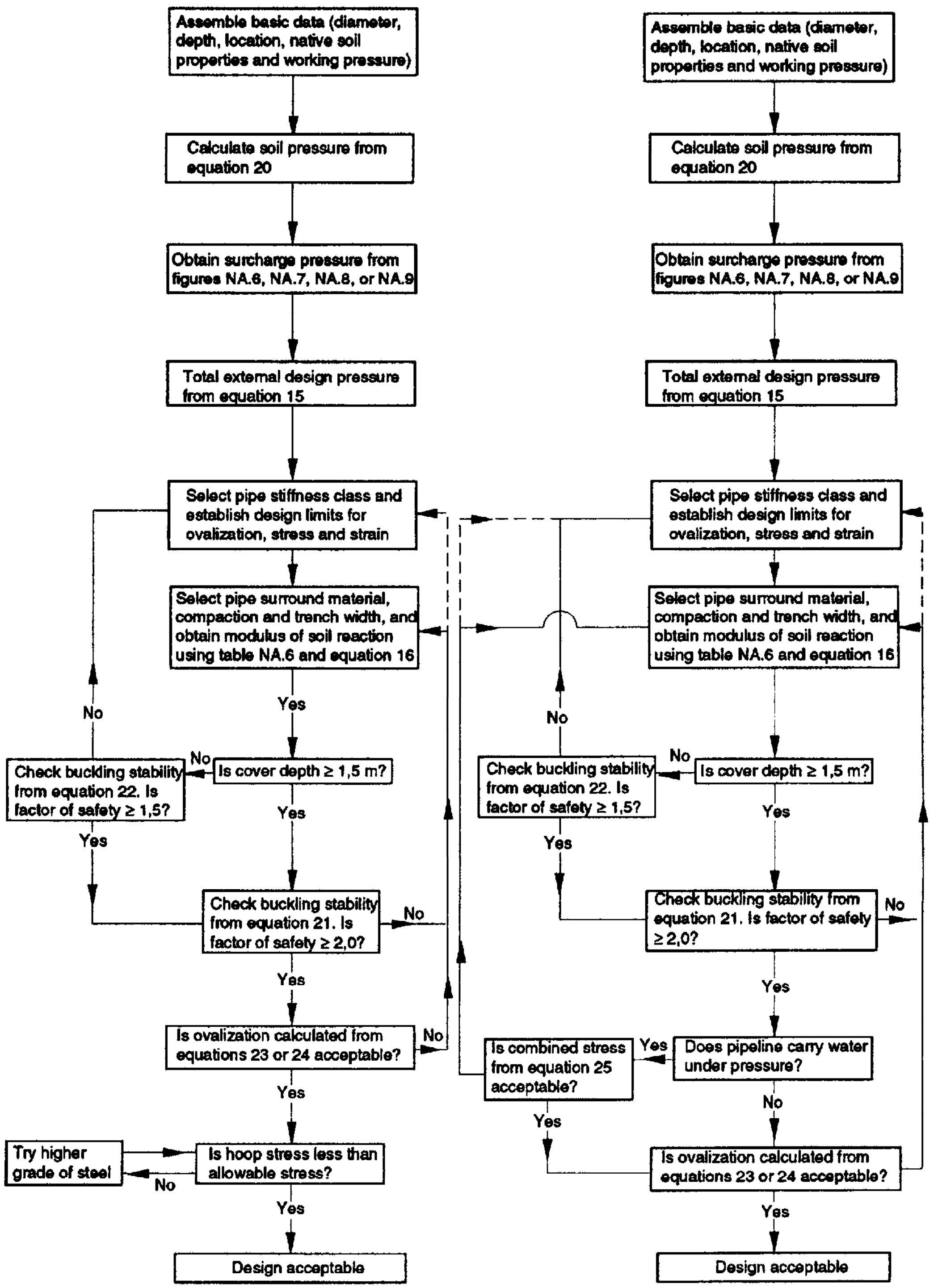


Figure NA.2 Flowchart for pipeline design with ductile iron pipes



NOTE. The solid line represents the preferred route.

Figure NA.3 Flowchart for pipeline design with GRP pipes



NOTE. The solid line represents the preferred route.

Figure NA.4 Flowchart for pipline design with steel pipes

NOTE. The solid line represents the preferred route.

Figure NA.5 Flowchart for pipeline design with thermoplastic pipes

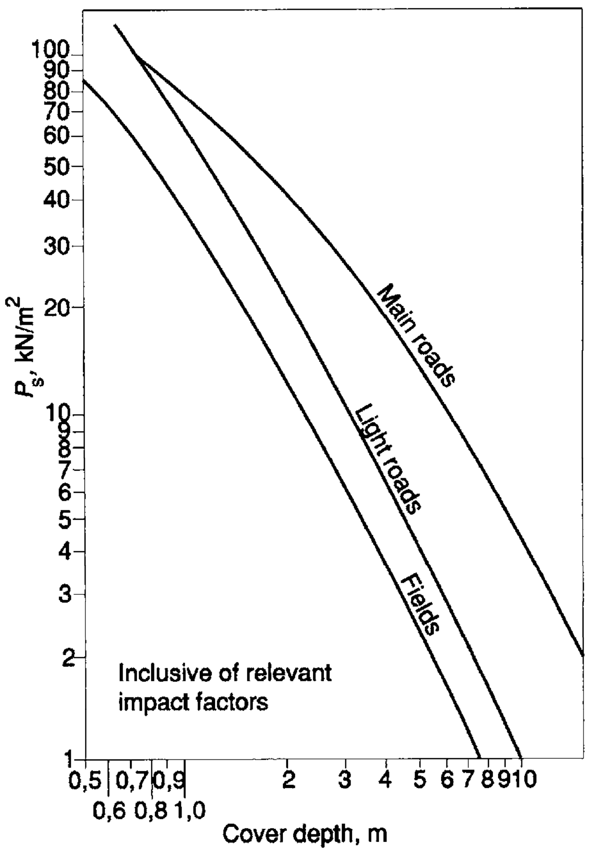


Figure NA.6 Surcharge pressure P_s due to vehicle wheels

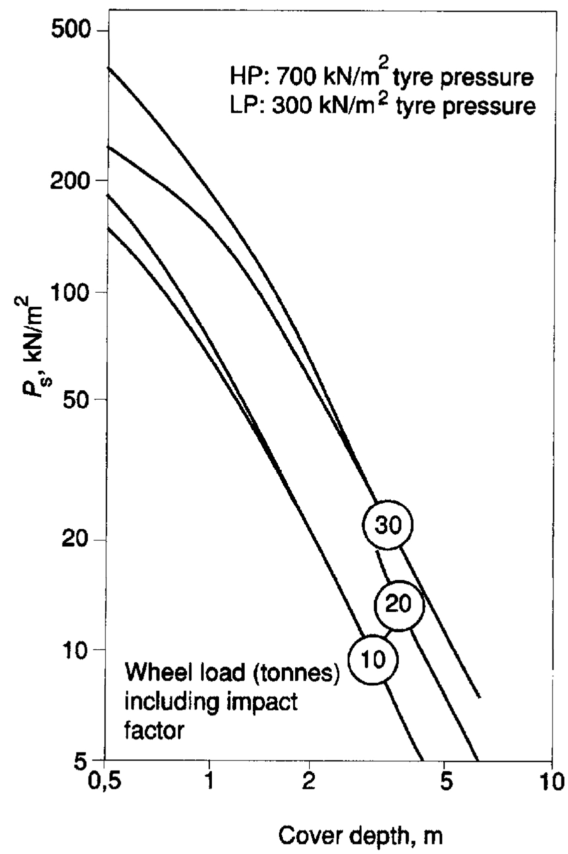


Figure NA.7 Surcharge pressure P_S due to construction vehicles

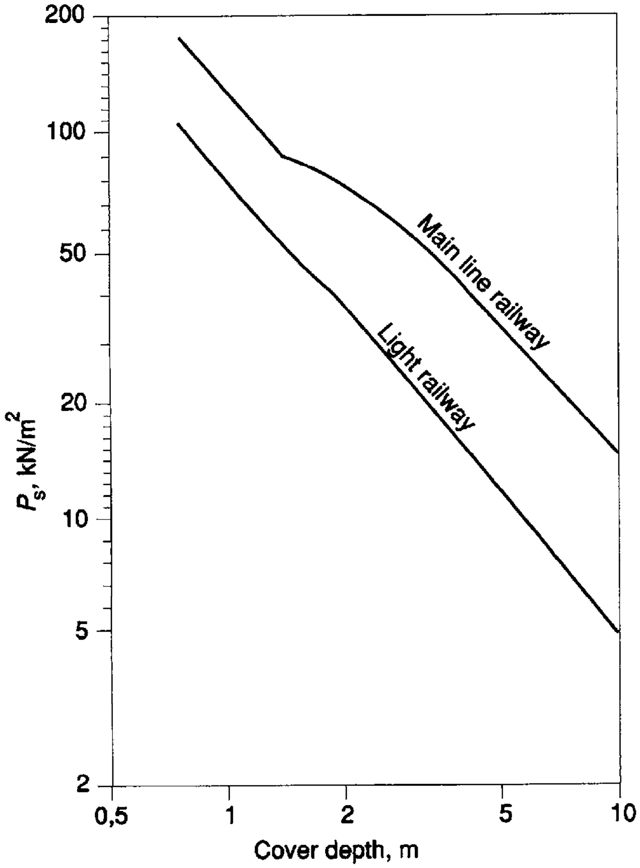


Figure NA.8 Surcharge pressure P_S due to single track railway

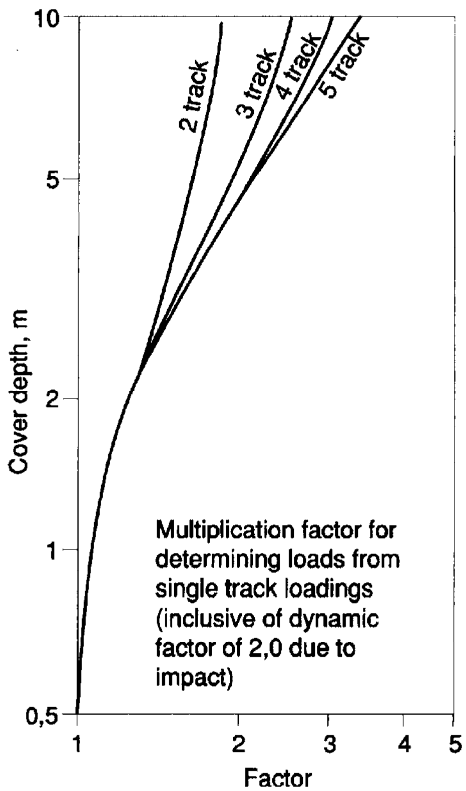


Figure NA.9 Factor for calculating multi-track railway loadings

Table NA.7 Rigid pipe embedments

Dimensions in millimetres

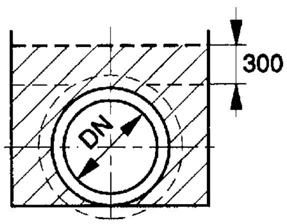
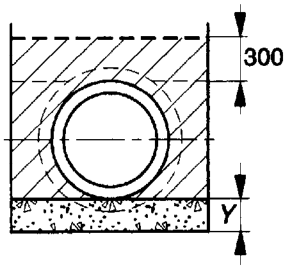
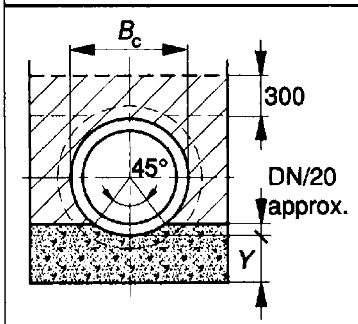
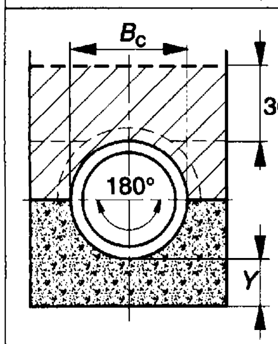
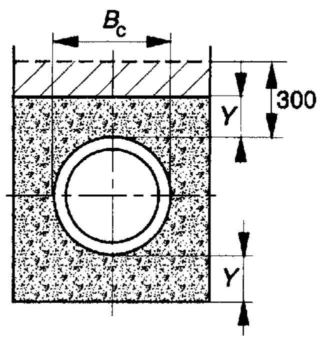
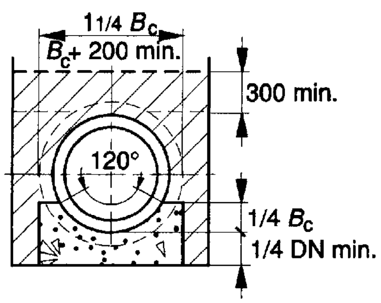
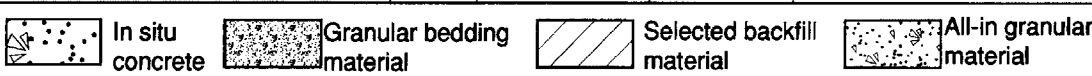
Bedding detail $Y = 1/6\ B_c$	**Bedding class**	**Bedding factors** **Narrow trench**	 **Wide trench and embankment**
	D	1.1	Wide trench 1.1 (See ref 4, **B.1.12**) Embankment 1.1 to 1.3 (See ref 4, **B.1.12**)
	N	1.1	Wide trench 1.1 (See ref 4, **B.1.12**) Embankment 1.1 to 1.3 (See ref 4, **B.1.12**)
	F	1.5	Wide trench 1.5 (See ref 4, **B.1.12**) 1.9 (See ref 9. **B.1.12**) Embankment 1.5 to 1.9 (See ref 4, **B.1.12**)
	B	1.9	Wide trench 1.9 (See ref 4, **B.1.12**) 2.5 (See ref 9, **B.1.12**) Embankment 1.9 to 2.3 (See ref 4, **B.1.12**)

Table NA.7 Rigid pipe embedments *(continued)*

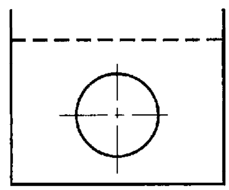
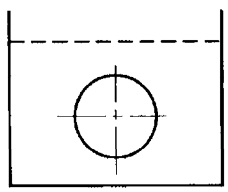
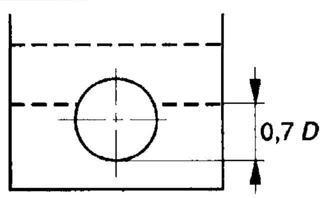
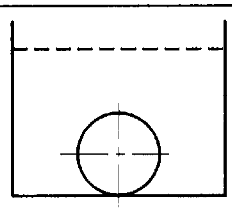
Dimensions in millimetres

Bedding detail $Y = 1/6\ B_c$	Bedding class		Bedding factors Narrow trench	Bedding factors Wide trench and embankment
	S		2.2	Wide trench 2.2 (See ref 4, **B.1.12**) 2.5 (See ref 9, **B.1.12**) Embankment 2.2 (See ref 4, **B.1.12**)
	A	Unreinforced	2.6	Wide trench 2.6 (See ref 4, **B.1.12**) Embankment 3.4 to 5.7 (See ref 4, **B.1.12**)
	A	Reinforced	3.4	Wide trench 3.4 (See ref 4, **B.1.12**) Embankment 3.4 to 5.7 (See ref 4, **B.1.12**)



NOTE. Ref 4 provides additional information on:
- guidance on use of embankment bedding factors;
- details of Class A bedding reinforcement;
- information on Class A Arch.

Table NA.8 Semi-rigid and flexible pipe embedments

Embedment class	Embedment configuration	Bed and sidefill materials	Notes
S1 and S2		Class S1: Gravel (single size) Class S2: Gravel (graded)	Normally processed granular materials
S3 - S5		Class S3: Sand and coarse grained soil with more than 12 % fines	These represent 'as dug' soils, and require particularly close control when used with low stiffness pipes.
		Class S4: Coarse grained soil with more than 12 % fines OR Fine grained soil, liquid limit less than 50 %, medium to no plasticity and more than 25 % coarse grained material.	
		Class S5: Fine grained soil, liquid limit less than 50 %, medium to no plasticity and less than 25 % grained material	Class S5 only recommended for use with semi-rigid pipes.
B1 and B2		Class B1: Upper surround as for S3 or S4 Lower surround as for S1 or S2	Class B embedments not recommended for use with pipes of less than 10 kN/m^2 stiffness.
		Class B2: Upper surround as for S5 Lower surround as for S1 or S2	
D		As for S3, S4 or S5	Only suitable for semi-rigid pipes with high beam strength. Soil properties from table NA.6, except K_x = 0.110

NOTE 1. See Table NA.6 for design parameters for embedment classes.

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