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Plastics piping systems - Validated design parameters of buried thermoplastics piping systems

Systèmes de canalisations en matières plastiques - Paramètres de calcul validés pour les systèmes enterrés de canalisations en matières thermoplastiques

Kunststoff-Rohrleitungssysteme - Gültige Berechnungsparameter von erdverlegten thermoplastischen Rohrleitungssystemen

This draft Technical Specification is submitted to CEN members for second formal vote. It has been drawn up by the Technical Committee CEN/TC 155.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
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Contents

Foreword

This document (prCEN/TS 15223:2007) has been prepared by Technical Committee CEN/TC 155 “Plastics pipesing systems and ducting systems”, the secretariat of which is held by NEN.

This document is currently submitted to the second Formal Vote.

Introduction

In Europe several design methods exist and some are still under development. The plastics pipes industry has carried out a lot of research with full-scale trials. From these research graphs have been made that shows the deflection in the pipes immediately after installation. Also the so-called settlement period is measured. This settlement will always take place. In case that heavy traffic is present, the final deflection will be reached faster.

It is strongly advised to check any calculated deflection with the values in the two design graphs.

The information compiled is meant to be used by designers. The values given are meant for general guidance.

1 Scope

This document covers thermoplastics pipe material related properties and design topics to be taken into account when carrying out any static pipe calculation. It also provides *guidance to* applying structural design of thermoplastics piping systems for pressure and non-pressure applications. It furthermore provides documentation based on long term experience, to be *used in justifying and / or verification of* any structural design method.

NOTE For piping systems for the conveyance of gaseous fluids additional guidance is given in EN 12007-2.

2 Normative references

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

EN 476, *General requirements for components used in discharge pipes, drains and sewers for gravity systems*

EN 773:1999, *General requirements for components used in hydraulically pressurized discharge pipes, drains and sewers*

EN 805:2000, *Water supply — Requirements for systems and components outside buildings*

CEN/TR 1295-2, *Structural design of buried pipelines under various conditions of loading — Part 2: Summary of nationally established methods of design*

prCEN/TR 1295-3, *Structural design of buried pipelines under various conditions of loading — Part 3: Common method*

EN 1446, *Plastics piping and ducting systems — Thermoplastics pipes — Determination of ring flexibility*

EN 12007-2, *Gas supply systems — Gas pipelines for maximum operating pressure up to and including 16 bar — Part 2: Specific functional recommendations for polyethylene (MOP up to and including 10 bar)*

EN ISO 9080, *Plastics piping and ducting systems — Determination of the long-term hydrostatic strength of thermoplastics materials in pipe form by extrapolation (ISO 9080:2003)*

EN ISO 12162, *Thermoplastics materials for pipes and fittings for pressure applications — Classification and designation — Overall service (design) coefficient (ISO 12162:1995)*

3 Terms, definitions, symbols and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1
constant load
load on a pipe, e.g. from internal pressure, that is not changing with time

3.1.2
constant deformation
deformation due to deflection of the pipe that is not changing with time, e.g. due to constraint from the soil

3.1.3
design stress
$\boldsymbol{\sigma}_{\mathbf{s}}$
allowable stress, in megapascals, for a given application. It is derived from the MRS by dividing it by the overall service coefficient C

3.1.4
minimum required strength
MRS
value of σ_{LPL}, rounded down to the next smaller value of the R10 series or of the R20 series depending on the value of σ_{LPL}

NOTE R10 and R20 series are the Renard number series according to ISO 3 [1] and ISO 497 [2]

3.1.5
overall service coefficient
$\boldsymbol{C}$
overall service coefficient with a value greater that one, which takes into consideration service conditions as well as properties of the components of a piping system others than those represented in the lower confidence limit

3.1.6
nominal pressure
PN
numerical designation used for reference purposes related to the mechanical characteristics of the component of a piping system. It corresponds to the maximum continuous operating pressure in bars

3.1.6
pipe stiffness
$\boldsymbol{S}_{\mathbf{p}}$
theoretical pipe stiffness determined with the Young's modulus and the Poisson ratio

3.1.7
critical buckling pressure
$\boldsymbol{q}_{\mathbf{crit}}$
critical internal pressure causing buckling of the pipe

3.1.8
nominal stiffness
SN
numerical designation of the ring stiffness of a pipe or fitting, which is a convenient round number indicating the minimum required ring stiffness of the pipe or fitting

NOTE It is designated by the letters "SN" followed by the appropriate number.

3.2 Symbols

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

C	overall service coefficient
$ß$	deflection correction factor
C_{100}	100 year overall service coefficient
C_{50}	50 year overall service coefficient
C_f	deflection factor, in percent

d_n	nominal outside diameter of the pipe, in millimetres
δ	deflection of the pipe, in millimetres
d_{em}	mean outside diameter of the pipe, in millimetres
D_m	the midwall diameter, in millimetres
D_u	outerside diameter of the pipe, in millimetres
e	wall thickness of the pipe, in millimetres
ε	strain
E_p	the Young's modulus of the pipe, in megapascals
E_t	tangent modulus, in kilopascals
f_a	application rating factor
$F_{fitting}$	maximum tensile force, in Newton
f_T	temperature rating factor
g	gravity, in m/s^2
K	value of the measured molecular weight
k	absolute roughness, in millimetres
k_{water}	viscosity of water, in m^2/s
v	poisson ratio
q_{crit}	critical buckling pressure, in kilopascals
ρ	density, in kilograms per cubic meter
R	bending radius of the pipe, in millimetres
R_{max}	maximum bending radius of the pipe, in millimetres
ρ	density of water
S	geometrical pipe characteristic defined as: $S = (d_n - -e)/(2e)$
S_p	pipe stiffness value determined by $(1 - v^2)/E_p \cdot (d_{em}/e - 2)$, in [MPa^{-1}]
σ_s	design stress, in Newtons per square millimetre
$\sigma_{tensile\ strength}$	tensile strength, in megapascals

3.3 Abbreviations

HDS hydrostatic design stress

MRS minimum required strength

PE Polyethylene

PEA allowable site test pressure

PFA allowable operating pressure

PMA allowable maximum operating pressure

PN nominal pressure

PP polypropylene

PVC poly(vinyl chloride)

SDR standard dimension ratio

4 General material properties

4.1 General material properties

Plastics pipe properties related to design are given in Table 1.

Table 1 — Material properties: values [a] typical for calculations

Material	Poisson ratio [-]	Coefficient of linear expansion [1/ °C]	Young's modulus [MPa]	Relaxation coefficient [-]	Tensile strength [MPa]
PVC-HI	0,4	6×10^{-5}	2 500	0,06	40
PVC 250	0,4	8×10^{-5}	3 200	0,05	50
PVC 315	0,4	8×10^{-5}	3 500	0,05	60
PVC 355	0,4	8×10^{-5}	3 500	0,05	60
PVC 400	0,4	8×10^{-5}	3 500	0,05	60
PVC 450	0,4	8×10^{-5}	3 500	0,05	60
PVC 500	0,4	8×10^{-5}	3 500	0,05	60
PE 63	0,45	19×10^{-5}	800	0,06	17
PE 80	0,45	19×10^{-5}	850	0,07	19
PE 100	0,45	19×10^{-5}	1 100	0,08	21
PP-B	0,42	12×10^{-5}	1 250	0,07	27
PP-HM	0,42	$12x10^{-5}$	1 700	0,07	31
PP-H	0,42	12×10^{-5}	1 250	0,07	30
PP-R	0,42	12×10^{-5}	950	0,07	23

[a] If specific values are needed related to specific products, these shall be acquired from the manufacturer or specific standards.

4.2 Pressure pipes (stress design basis)

4.2.1 Minimum Required Strength (MRS)

The minimum required strength shall be classified according to EN ISO 12162. The classification shall be determined out of the lower confidence limit tangential stress, which divides the MRS values into ranges. In the pressure test according to EN ISO 9080 the LCL-value shall be determined for the pipe material. This LCL-value gives the classification for the MRS value. For classification reasons 50 year have been taken and the relevant design coefficient is applied. In practise the lifetime will be longer. Therefore also the remaining design factor 100 year is given. For the different thermoplastics materials used in buried pipes, the MRS values are given in Table 2.

Table 2 — Material properties relevant for pressure pipes at 20 °C

Material [a]	MRS σ classification [MPa]	Overall service design coefficient [b] C_{50} [-]	Overall design coefficient [c] C_{100} [-]	Allowable approximately one hour stress [MPa]
PVC-HI	18	1,4	1,38	35
PVC 250	25,0	2,0	1,94	42
PVC 315	31,5	1,6	1,58	45
PVC 355	35,5	1,6	1,58	51
PVC 400	40,0	1,6	1,58	57
PVC 450	45,0	1,4	1,38	64
PVC 500	50,0	1,4	1,38	71
PE 63	6,3	1,25	—	10
PE 80	8,0	1,25	1,23	12,6
PE 100	10,0	1,25	1,23	12,5

[a] If specific values are needed related to specific products, these shall be acquired from the manufacturer or specific standards.

[b] The overall design coefficient is determined in EN ISO 12162 and the values shown in the table are minimum values. The values may be increased by users when specific fluids which are harmful for the environment or mankind.

[c] Based on regression curves it is shown that the C_{100} coefficients slightly differ from the C_{50} values.

NOTE At temperatures below 20 °C the values will be higher than those shown.

4.2.2 Overall service (design) coefficient C

Minimum overall service design coefficients shall be determined in accordance with EN ISO 12162. The overall service design coefficient lowers the nominal pressure (PN) as given in the following equation:

$$\mathrm{PN} = \frac{10\sigma_s / S}{C} \quad e \qquad \ldots(1)$$

where

$$S = (d_\mathrm{n} - e)/2e \qquad \ldots(2)$$

4.2.3 Design stresses

The design stress of the pipe is determined with the MRS divided by the overall service coefficient.

4.2.4 Pressure rating PN

The pressure rating shall be determined using Equation (1).

4.3 Non-pressure pipes (strain design based)

Non-pressure pipes do not require a stress analysis because of the visco-elastic behaviour and redistribution of stresses. Studies of Moser [3] and Janson [4] have discussed whether thermoplastics are strain limited or not. In these studies strain by bending as well as through-wall strains have been evaluated. It was shown that for all practical purposes these materials are not strain limited. Nevertheless, Moser [3] has proposed rather conservative values that are not based on the occurrence of a failure. If one wishes to calculate the material strain value then the table below supplies conservative guidance about the levels that can be accepted.

The combination of pipe construction and integrity shall be tested by means of a ring flexibility test up to 30 % deflection as described in EN 1446. Passing this test ensures stability against buckling.

Table 3 (taken from Janson [4]) — Strainability, ε, for non-pressure pipes

Material	ε [%]
PVC-U	2,5
PE	5,0
PP	5,0

4.4 Piping systems for gaseous fluids

For guidance for the design of gas supply systems EN 12007-2 shall apply.

5 System and operation related aspects

5.1 General

According to EN 476, EN 773 and EN 805 the information on following aspects, when relevant, shall be provided in product standards.

5.2 Tightness

5.2.1 Non pressure pipes

For elastomeric sealing ring joints in non-pressure pipes the tightness is normally tested for deformation of the socket and spigot and angular deflection. Table 4 gives an overview of typical values:

Table 4 — Typical parameter values for tightness testing

Deflection	Socket: ≥ 5 [%] Spigot: ≥ 10 [%] Difference: ≥ 5 [%]
Angular deflection	$d_e \leq 315$: 2° $315 < d_e \leq 630$: 1,5° $630 < d_e$: 1°
Special cases	Manufacturer's recommendation

For joints using fusing techniques and adhesive bonding are considered to be leak tight. The test for evaluating the jointing quality is defined in the product standards by pressure or tensile testing.

All lines of the system have to be tested in commissioning.

5.2.2 Pressure pipes

For elastomeric sealing ring joints in pressure pipes the tightness is normally tested for deformation of the socket and spigot in combination with angular deflection. Test conditions are done for infiltration and ex-filtration.

For joints using fusing techniques and adhesive bonding are considered to be leak tight. The test for evaluating the jointing quality is defined in the product standards by pressure or tensile testing.

All lines of the system have to be tested in commissioning.

5.3 Flow capacity

5.3.1 General

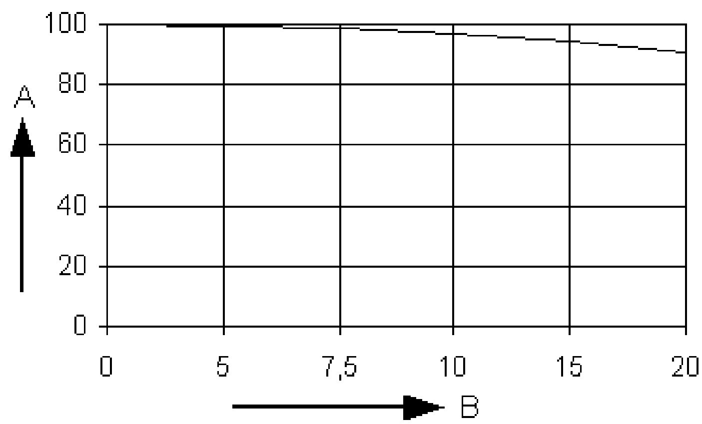
The flow capacity is dependent on both the material of the pipe and of the design of the system. Plastic piping system with their narrow tolerances for diameters and wall thickness for pipe joint fittings and chambers reduce considerably the influence on the flow capacity.

The flow capacity is influenced by the change of wall roughness and the pipe deformation. For thermoplastics pipes, wear and corrosion are non-relevant phenomena and hence ageing of the pipe has no effect on flow performance.

Table 5 [1] — Typical values of K to determine the flow capacity

Pipe	K [a] [mm]
Plastics d < 100 mm	0,01
Plastics pipe d > 100 mm	0,05
[a] Values are valid for straight pipes without connections and other fittings.	
NOTE 1 The so-called system roughness is considerably higher then the values mentioned in the table. NOTE 2 Prof. Janson recommends the use of a K-value of 0,1 for plastics water piping systems. NOTE 3 For sewer systems a K-value of 0,4 seems to be more appropriate for plastics.	

As far as the deformation is concerned, it is a fact that the discharge capacity is decreasing with 2 % when at the same time the pipe is deflected up to an average deflection of 10 %. Figure 1 shows the effect of deformation on discharge capacity.



Key
A discharge capacity, in percent
B pipe deflection, in percent

Figure 1 — Discharge capacity as a function of average pipe deflection

5.3.2 Flow capacity for non pressure pipes

In some regions, one is more used to utilise the Manning approach instead of the Colebrook procedures.

Although there is no clear relation between the two, from practical experience the following values for k (Colebrook) and n (Manning) are coincide with each other.

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[1] Values are taken from “Stromingsweerstanden in leidingen, Prof. Ir. L. Huisman, KIWA 1969”.

Table 6 — Relation between Colebrook and Manning values

Colebrook *k*	Manning *n*
0,2	100
1,0	80
5,0	60

5.4 Temperature

In case where the pipe material is exposed to temperatures other than 20 °C, rating factors shall be used.

NOTE Normally this is only done when the temperature is higher than 20 °C. When the temperature is lower than 20 °C, such a rating is not applied. It should be realised that in most situations the temperature is lower than 20 °C, meaning that a higher factor of safety is achieved.

5.4.1 Temperature dependence of PE

The temperature dependence of PE is given in Table 7, where the values are taken from EN 12201-1 [5].

Table 7 — Pressure rating for PE

Temperature [°C]	f_t
20	1,0
30	0,87
40	0,74

NOTE 1 For other temperatures between each step a linear interpolation is allowed. The coefficients mentioned are valid for PE 80 and PE 100. For other PE types see ISO 13761 [6].

NOTE 2 Unless analysis according to EN ISO 9080 demonstrates that less reduction is applicable, in which case higher factors and hence higher pressures can be applied.

5.4.2 Temperature dependence of PVC

For PVC-O the same values can be used as for PVC-U (EN 1452-2 [7]).

Table 8 — Pressure rating for PVC

Temperature [°C]	f_t
25	1,0
30	0,9
35	0,8
40	0,7
45	0,6

NOTE 1 For other temperatures between each step a linear interpolation is allowed.

NOTE 2 Unless analysis according to EN ISO 9080 demonstrates that less reduction is applicable, in which case higher factors and hence higher pressures can be applied.

5.5 Design procedure of pressure pipes

5.5.1 Procedure

Pressure pipes are buried in soils after which they will be pressurised. Therefore the response to external and internal pressure has to be verified in the design.

For thermoplastics materials, with its visco-elastic behaviour, it is not the combination of internal and external load that provides the worse case condition.

Thermoplastics pressure pipes, such as those made out of PE and PVC-U, shall be designed in the following way.

a) The pipe shall be considered without pressure and with a surge pressure of –0,8 bar, as required in EN 805. The design shall be based on buckling resistance.

b) The pipe shall be designed as for a free creeping condition. The value to refer to is the Hydrostatic Design Stress (HDS). The HDS is the stress referring to the Minimum Required Strength (MRS) of the raw material using the Overall Service Design Coefficient (C) as given by the product standards.

5.5.2 PFA, PMA and PEA

Following the request given by EN 805, relation between product related pressure classification and PFA, PMA and PEA are given.

The product related pressure classification for thermoplastics is based on the worst condition under pressure, which is free creep.

The following equation applies:

$$[\text{PFA}] = f_{\text{T}} \times f_{\text{a}} \times [\text{PN}]$$

For product standards the value of the application rating factor f_{a} in the equation can be set to 1 in case potable water, gas and sewage is transported under normal condition. When chemicals are transported then advice shall be sought at the manufacturer to obtain specific values for f_{a}.

The maximum allowable transient pressure including surge:

$$[\text{PMA}] = 2 \times [\text{PN}]$$

The maximum test pressure:

$$[\text{PEA}] = 1{,}5 \times [\text{PN}]$$

5.6 Water hammer (pressure pipes)

The maximum pressure occurring in pipelines is caused by unsteady flow, so-called water hammer The maximum pressure occurring in a pipeline systems can be calculated by the Joukowski equation:

$$D_{\text{p}} = \sqrt{\frac{\rho(\frac{1}{k_{\text{water}}} + S_{\text{p}})}{g}} \times D_{\text{u}} \qquad \ldots(3)$$

where

k_{water} is the stiffness of water (2 000 MPa);

S_p is the water hammer related stiffness value determined by $(1 - \nu^2) / E_p \cdot (D_m / e - 2)$

where

E_p is the Young's modulus of the pipe, in megapascals [MPa];

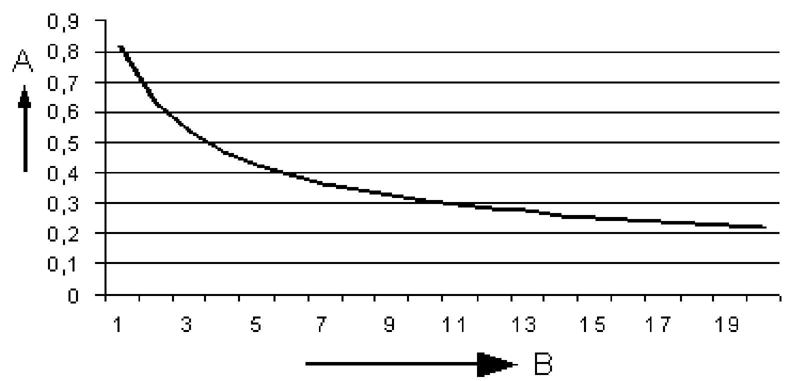
ρ is the density of water, which equals 1 000 kg·m^3;

D_m is the midwall diameter, in millimetres [mm];

e is the wall thickness, in millimetres [mm].

Figure 2 shows the pressure increase as a function of the water hammer related stiffness S_p.

The figure is valid for a steady flow of 1 m/s.



Key
A pressure increase
B water hammer related stiffness × 1 000

Figure 2 — Pressure increase versus water hammer related stiffness

Table 9 shows S_p values for common plastics pipes.

Table 9 — Typical material related values for S_p

Material	S_p [(kN/m^2)$^{-1}$]
PVC-U, SDR 41	11
PVC-U, SDR 26	6,8
PE, SDR 17	15
PE, SDR 11	9
Non-thermoplastics for reference purposes	0,3

For systems where extreme transient conditions are unlikely, it may be safely assumed that the peak surge pressure will never have a value more than twice the rated steady state pressure.

5.7 Deflection

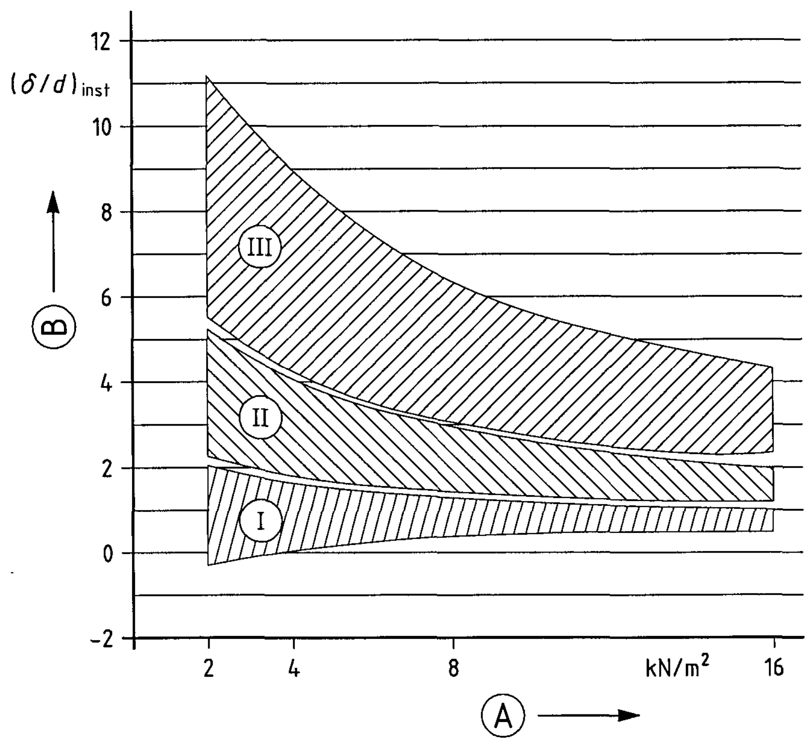
For the deflection conditions see 6.1. For the limits see 6.3.

6 Design approach

6.1 Design approach based on experience

6.1.1 General

For the design of a system of flexible pipes in the stiffness range of 2 kN/m^2 to 16 kN/m^2 use is made of the graph in Figure 3. On the vertical axis, the pipe deflection is shown and at the horizontal the pipe stiffness classes. For each installation group (as defined in ENV 1046 [8] into well, moderate and none and described in Annex C) an area is given in which the deflection after installation is expected. The upper edge of the area represents the maximum deflection to be expected. The lower edge of the area shows the average deflection to be expected.



Key

A nominal ring stiffness

B initial deflection, as a percentage

I well compacted

II moderate compaction

III non-granular

Figure 3 — Design graph for determining the pipe deflections immediately after installation

The graph shows the deflections immediately after installation. It does not include the effect of traffic load, depth of cover and groundwater.

The soil will further compact in the course of time. This further compaction is caused by the own weight of the soil, the percolation of rain and ground water through the soil and by traffic load.

In order to obtain the final deflection including the effect of traffic, one shall add a consolidation value to the initial deflection. These consolidation values are listed in the table in the graph.

Hence the final deflection becomes:

Final deflection = Initial deflection + C_f

For C_f values see Annex C.

In most cases it takes 10 to 40 days for the soil to consolidate, depending on traffic load etc. When cohesive soils like clay are used it might take a few years.

The graph is applicable when the following conditions are fulfilled.

Table 10 — Application of the design graph; checking pipe installations within this design graph fulfils 4.2 of EN 1610:1997 [13]

Parameter	Value (range)	Remark
Installed depth	0,80 m to 6,0 m	Cover depth to crown
Soils	Granular-cohesive	
Installation type	Well, moderate, none	Combination of soil, compaction, and degree of care
Pipe stiffness, SN (EI/D^3)	≥ 2 kN/m^2	
Pipe types, structured and solid wall	Solid wall pipes Structured wall pipes fulfilling the 30 % ring flexibility test	Also applies to solid wall pressure pipes
Traffic load	all cases	
Diameter	≤ 1 100 mm	
Depth of cover / diameter ratio	≥ 2	
Ground water table	No limitation	
NOTE 1 National calculation methods and regulations might put additional limitations. See therefore the national foreword. NOTE 2 Pipe stiffness less than 4 kN/m^2 is sometimes used for pipes with diameters bigger then 800 mm.		

NOTE In the industry and amongst users there is an ongoing discussion about what is the best pipe stiffness to be used. The choice of pipe stiffness can be based on many ideas, emotional or rational and it is certainly not the intention here to provide a single answer. However, the following might be of help to make a good choice.

When installations are carried out using well graded soils which do not require a lot of compaction energy, then low stiffness pipes (≤ 2 KN/m^2) can in theory be used.

The combination of poor graded soils and low stiffness pipes (< 2 KN/m^2), creates the danger that the application of a lot of compaction energy might deform the pipe in such a way that squaring could be encountered. Especially with high groundwater tables this might reduce the resistance against buckling significantly.

Pipes with stiffness in the range of 4 KN/m^2 to 8 KN/m^2 provide a good choice for most installations. In relation to this it should however be noted that poor installations are mostly not recommendable.

They create a kind of uncontrolled situation which can cause high deflection or huge longitudinal settlements which latter becomes especially relevant in case of the more rigid pipes (> 8 KN/m^2). Irrespective of pipe stiffness or pipe material, poor installations born the potential of obtaining high future infra structure costs, as they will result in subsidence of the surface. In agricultural land such subsidence might affect the harvest and in the street or footpath it will result in the need for rehabilitation of the street after some years.

For the above reasons it is advised to use good to moderate compaction and pipe stiffness in the range of 4 KN/m^2 to 16 KN/m^2. However, as discussed before, it is possible to utilise pipes outside this window in specific circumstances which do not result in the before mentioned drawbacks. It should also be mentioned that the subsidence of the pipe will increase with higher pipe stiffness.

6.1.2 Ring buckling

The critical buckling pressure of a buried pipe can be calculated and verified against the sustained load at the outside of the pipe. For buried pipes, sustained load is the load exerted by groundwater and part of the soil load. The load to be taken into account is given by the relevant standards. The resistance against buckling can be calculated for flexible pipes using the following equations (see [9]).

Soft soils / mud: Condition [SN] > 0,0275E_t

$$q_{crit} = 24 \times [SN] + \frac{2}{3} E_t \qquad (4)$$

Other soils:

$$q_{crit} = 5,63 \sqrt{E_t \times [SN]} \qquad (5)$$

where

q_{crit} is the critical buckling pressure, in kilopascals;

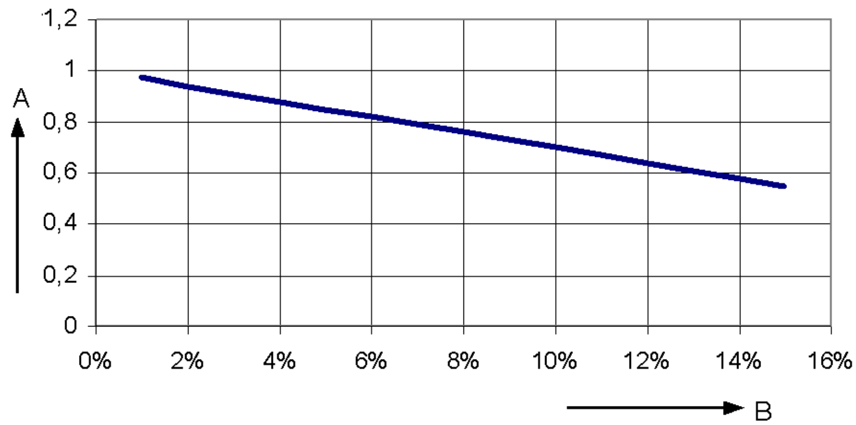
[SN] is the value of the nominal ring stiffness, expressed in kilonewtons per square meter;

E_t is the tangent modulus (E_s), in kilopascals.

When a pipe is deflected, it will result in a lower buckling resistance of the pipe.

The value found shall then be corrected with β:

$$\beta = (1 - 3 \cdot (\delta / d_n)) \qquad (6)$$



Key
A reduction factor ß
B deflection δ/d_n, in percent

Figure 4 — Reduction factor for the buckling resistance as a function of the deflection of the pipe

EXAMPLE

Pipe (SN4) buried in granular soil at 5 m depth and with 4 m groundwater. The installation has been well done and the deflection stays below 2,2 %.

Sustained load due to groundwater; 4 × 1 000 × 10 = 40 000 N/m^2. The soil load is not the same as used for the deflection calculations in most methods. If methods discriminate between the hydrostatic load component and the shear related component the hydrostatic component shall be taken into account.

In this example the buckling will be checked for groundwater only.

$q_{crit} = 5{,}63 \sqrt{(2\,800 \times 4)}$

$q_{crit} = 595$ kN/m^2

The safety factor F is calculated by dividing the critical pressure by the load as given by the groundwater table. F becomes then: 14,8.

In most cases a factor of safety of 2,5 is required.

6.2 Longitudinal effects

6.2.1 General

An essential part of the design of a pipeline is to evaluate the longitudinal effects, which is not covered in most of the recognised structural design methods as listed in EN 1295-1 [10]. Therefore guidance is given to this issue here.

6.2.2 Axial bending

When bending a pipe in the field, either caused during installation or by the occurrence of settlement differences along the pipeline after installation, the following phenomena have to be checked:

Strain:

The strain due to bending of a straight pipe can be calculated by:

$$\varepsilon = \frac{d_{\text{n}}}{2R} \times 100 \qquad \text{...(7)}$$

where

ε is the tangential strain, as a percentage;

d_{n} is the nominal outside diameter of the pipe, in millimetres;

R is the bending radius, in millimetres.

The allowable strain values are listed in Table 3.

6.2.3 Bending limits

When pipes are bent they might buckle (sometimes called kinking). The limiting bending radius shall be calculated using the following equation:

$$R = \frac{d_{\text{n}}^2}{1{,}12e} \qquad \text{...(8)}$$

where

R is the bending radius, in millimetres;

d_{n} is the nominal outside diameter of the pipe, in millimetres;

e is the wall thickness of the pipe, in millimetres.

In pressure pipes product standards more limiting values are given. They are shown below and should irrespective the results of Equation (7) [or Equation (8)], taken as covering:

Table 11 — Recommended limiting bending radii for pressure pipes

Diameter DN	PVC (ENV 1452-6 [11])	PE
≤ 200	R > 300 × [DN]	R > 250 × [DN]
> 200	R > 500 × [DN]	R > 400 × [DN]

6.3 Joints

Certain joints may offer extra bending capability to the piping system. The manufacturer's documentation or the relevant EN standards should be consulted for these possibilities.

Where appropriate, allowable pull-out forces and bending moments may be found in the manufacturer's documentation.

The allowable maximum values are given in this subclause. Users might require lower values in certain applications. The evaluation against Limit State is shown in Table 12 and in Table 13.

Table 12 — Verification against limit states for non-pressure pipes

Type of loading / deformation	Verify	Remark
Short term: Pulling force during insertion Initial average deflection Initial maximum deflection	 0,5 × $\sigma_{tensile\_strength}$ ≤ 8 % PVC-U ≤ 9 % PP and PE ≤ 10 % PVC-U ≤ 12 % PE and PP	Deflection values mentioned do not result in failure, but limiting values are suggested for reason of serviceability. Deflection shall be calculated by CEN/TR 1295-2, prCEN/TR 1295-3, methods and verified with design graph in Figure 3
Long term: Final average deflection Final maximum deflection Settlement and cold bends	 ≤ 10 % PVC-U ≤ 12 % PE ad PP ≤ 15 % PVC-U ≤ 15% PE and PP $R \geq R_{max}$	Deflection values mentioned do not result in failure, but limiting values are suggested for reason of serviceability. Deflection shall be calculated by CEN/TR 1295-2, prCEN/TR 1295-3, methods and verified with design graph in Figure 3
Stability	Allowable buckling pressure	CEN/TR 1295-2, prCEN/TR 1295-3 or 6.1.2
NOTE Thermoplastics pipes allow high deflection because of the huge strainability of those materials. Strainability and pipe wall stability are checked in the ring flexibility test at which the pipes are deformed up to 30 % deflection. Therefore the deflections mentioned in the table are still very safe values as far as structural integrity is concerned		

Table 13 — Verification against limit states for pressure pipes

Type of loading	Verify	Remarks
Non-pressure conditions	See non-pressure issues and stability as in Table 12	A pressure pipe needs first to be verified as for a short-term non-pressure pipe. See Table 12 In accordance with EN 805 the maximum deflection shall be limited to 8 %
Transient: Water hammer Negative pressure	 $0{,}9 \times \sigma_{tensile\_strength}$ Buckling at –0,08 MPa	Water hammer is an extremely quick process. Rapid loading increases the apparent strength considerably. See 5.6
Sustained: Sustained internal pressure Settlement and cold bends Contraction forces Bend forces at joints Cyclic pressure	 [PN] $R \geq R_{max}$ $\leq F_{fitting}$ $\leq F_{fitting}$ See 5.6	Effects of internal pressure shall not be combined with those from other loading types as the other loading types exhibit stress relaxation. $F_{fitting}$ Ability of fitting to accommodate or withstand contraction forces when applicable.

Design shall not only be limited to the pipe and its cross-section.

NOTE In most European standards as for instance partly described in CEN/TR 1295-2 there is no guidance on how to deal with fittings and axial loading effects. Sound engineering judgement should be used here. For situations with sustained loading due to internal pressurisation, performance verification should utilise the long-term strength values. For all other situations short term verification should be carried out.

7 Guidance for verification of installation

When designing piping systems, field surveys shall be done and the installation verified.

The soil group to be used needs to be determined. In the situation that soils are imported to the site, the soil group is well known. Historical information about the site can be used, or soil sampling shall be used. All this shall be done in advance when calculation methods are used. The information needs to be accurate known, in order to obtain a reliable calculation result.

When using the graph in Clause 6 the soil type, granular or cohesive, should be known. With the soil type, the anticipated installation procedure and pipe stiffness the expected pipe deflection can directly be determined.

The graph can be easily used by the contractor and pipeline owner to adjust the installation or decide to accept a slightly different deflection level, in case the true conditions deviate from the expected.

Simple tests can be used to check the quality of the installation during the progress of the work. The best tools are those that give a direct result, like the impact cone and accelerator device. In both case one drops a weight from a certain height and the number of blows needed for 30 cm penetration or the stopping speed of the hammer is measured.

8 Commissioning

8.1 Non pressure pipe

Reference is made to EN 476 and EN 1610:1997.

8.2 Pressure pipe

Reference is made to EN 805.

Annex A
(informative)

Time dependency of stress and strain in buried flexible piping systems

Flexible pipes buried in the ground have the ability to follow the settlement of the soil as long as the material is able to follow the strain. For thermoplastics this strainability is relatively high.

The speed of deformation is dictated by the speed of soil settlement. Visco-elastic behaviour is the way in which thermoplastics can be described. The stress and strain are time and history dependent. Pipes that are loaded in a sustained way will exhibit creep. In internal pressure testing where the pipe is completely free to expand, such a creep condition is met. The pipe is in a state of prescribed deformation, not in a state of sustained load when buried in the soil. The deformation is prescribed by the soil. For the more rigid pipes, which are not able to follow the soil settlement, load will be developed instead of deformation.

In several design methods in which effects of loading on pipe performance are calculated, a time dependent Young's modulus is used. In reality however the modulus is not time dependant, but it is a way to satisfy the observed data with Hook's law. The material responds to every new load with its true modulus.

For thermoplastics pipes the following applies:

a) buried gravity pipes develop stress relaxation, meaning that the stress will decrease in the course of time. The strain will increase slightly with the increase of deformation caused by soil settlement. Annex B gives more information on soil-pipe interaction;

b) when pipes are buried in soil, such condition is only met when the soil is of a very weak type;

c) the pipe stiffness to account for is the initial pipe stiffness, previously called STIS;

d) pressure pipes buried in weak soils will develop and maintain a constant stress due to the fact that weak soils are not able to consolidate and therefore are not able to support the pipe;

e) pressure pipes in other soils will develop stress relaxation again. First a certain stress depending on the soil stiffness will be developed and with that a certain shape of the pipe created. From that moment onwards the stress will not increase further. The stress is lower than the free creep stress.

Annex B
(informative)

Soil / pipe behaviour

Several design methods and approaches exist to describe the soil-pipe interaction for pressure and non pressure pipes. Most approaches have been adopted from rather rigid pipes and some have been checked and developed further for flexible pipes. The design is also dedicated to the deformations, stresses and strain for the tangential direction. That means that the behaviour of the ring is mostly considered.

Design of pipe installations involves:

— the interpretation of the site and the anticipated installation approach;

— the transformation of this into soil, loading and pipe parameters and the choice of the appropriate models;

— the execution and interpretation of the calculated results;

— the proposed execution of the installation;

— the verification of the assumed parameters.

Extensive studies performed by the Plastics Pipes industry in Europe (TEPPFA / APME) and by verification of other studies performed in various countries has shown that flexible pipes behave differently then rigid pipes. The current theories describing the performance of flexible pipes do not reflect the true physics of the process of pipe deflection.

In the TEPPFA / APME project, an explanation for the fact that depth and traffic loads, as examples of increased load, has hardly any influence on the final pipe deflection.

Looking at the installation at its different phases and the measurements, it was concluded that the soil undergoes significant changes during and after installation. Janson [4] referred already to this phenomenon in 1990. In case of good soil and or less good soils in combination with proper compaction, these changes are very small. In case of loose soils however, these changes are considerable. More details can be found Alferink [12].

These soil changes are however not considered in the current design methods. They all work with constant soil stiffness independent of the changes occurring in the soil. Some reflect that higher in-situ stress results in higher grain stresses and hence higher soil stiffness. Nevertheless, they do not consider the change of volume in the soil by settlement.

As a result of the TEPPFA / APME study a graph was produced. This gives the deflection of the pipe immediately after installation and compaction factors are used to reflect the increase in deflection after the soil has consolidated. In this effect of consolidation, also the effect of high loads as those exerted by traffic is included.

The determining factor for the prediction of the deflection is the amount of free volume around the pipe. This is the volume that can be decreased due to grain movements. When compaction around the pipe has been completed then there are no possibilities to further compact the soil and the pipe will not deflect further. The pipe is now in a condition of stress relaxation, irrespective of the quality of installation.

For pressure pipes the same thing happens. First the pipe is buried as a gravity pipe and the same applies as described before. When afterwards pressure is added, the pipe will try to re-round. The vertical diameter will like to increase slightly, but the soil is preventing this. Two extreme situations as follows can be recognised now:

The soil is firm

In such a case, re-rounding will not develop or only to a very limited extent and any remaining bending stresses continue to relax. Also the internal pressure will not be able to develop the full creep stresses. As a consequence the bending stress, however it is calculated, shall not be added to the (calculated free creep) hoop stress.

The soil is soft

Then the internal shear resistance of the soil is so low that re-rounding will fully develop and therefore bending strains and stresses will vanish.

Design approach based on experience

Ring effects

Some design methods are rather transparent where others are more complicated.

Some tend to be more precise for good installations where others are better in predicting the effects of poor installation. Extensive research has been undertaken by the industry. The results have been discussed with European design experts and have been presented at many conferences. For the design of pipes, the dominating factors are judgement of soils and quality of workmanship. Therefore for most common installations the usage of soil judgement in combination with a graph reflecting results of actual installations is sufficient.

The outcome of the above research as mentioned is reflected in the graph and table below.

The graph shows three areas. The lower edge of each area represents that average pipe deflection along the pipeline when utilising the specific installation method. The upper line represents the 95 % confidence maximum value that can be expected along the pipeline when considering the same type of installation.

Annex C
(informative)

Soil and installation parameters

Soil surrounds the pipe and therefore plays an important role in the design of any buried product. The soil properties depend largely on the level of consolidation / compaction (artificial consolidation). Consolidation takes time and hence soils have time dependant properties.

This means that stresses and strains in the more rigid pipes and deflection in flexible pipes are also time dependant.

For the purpose of design using simple methods, two soil groups are used, granular and cohesive. For more detailed and sophisticated design, more soil groups are used, for which reason reference is made to EN 1295-1 [10] and to national methods.

In the design described in Clause 6, the initial deformation is achieved from a graph. This graph is the result of an extensive and detailed study performed in co-operation with the European design experts as working in CEN/TC 165.

The deformation shown in the graph is the deflection immediately found after installation.

The effects of groundwater, depth of cover and traffic load are covered by the consolidation factor 'C_f'.

For the purpose of using the graph, three types of installation have been defined.

Well (C_f = 1)

The embedment soil of a granular type is placed carefully in the haunching zone and compacted, followed by placing the soil in shifts of maximum 30 cm, after which each layer is compacted carefully. A layer of 15 cm of soil shall at least cover the pipe before the trench is further filled with soil of any type and compacted. Typical values of standard Proctor are above 94 %.

Moderate (C_f = 2)

The embedment soil of a granular type is placed in batches a maximum of 50 cm deep, after which each layer is compacted carefully. A layer of 15 cm shall at least cover the pipe before the trench is further filled with soil of any type. Typical values for the Proctor density are in the range of 87 % to 94 %.

None (C_f = 3 for granular soil, C_f = 4 for cohesive soils)

The embedment soil of any type is added without compaction. However, big dry lumps of clay or rocks with excessive sizes shall not be placed directly on the pipe.

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