



**International  
Standard**

**ISO 10803**

**Design method for ductile iron pipes**

*Méthode de calcul des tuyaux en fonte ductile*

**Third edition  
2024-11**

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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

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This document was prepared by Technical Committee ISO/TC 5, *Ferrous metal pipes and metallic fittings*, Subcommittee SC 2, *Cast iron pipes, fittings and their joints*.

This third edition cancels and replaces the second edition (ISO 10803:2011), which has been technically revised.

The main changes are as follows:

- considering various applicable standards in different countries for the traffic loading, common new formulae have been developed to enable the calculation of the pressure on pipe due to traffic loads for any country;
- the previous formula to calculate the pressure on pipe due to traffic loads and the earth loads has no provision to consider the effect of the settlement of side fill and the effect of native soil; the modified formula now takes into account the effect of settlement of soil in terms of deflection lag factor and the effect of native soil by considering the soil modulus of native soil;

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

# Design method for ductile iron pipes

## 1 Scope

This document specifies the design of ductile iron pipes used for conveying water, sewerage and other fluids

- with or without internal pressure, and
- with or without earth and traffic loading.

The design method defined in this document is applicable to ductile iron pipes conforming to ISO 2531, ISO 7186 and ISO 16631.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

ISO 2531, *Ductile iron pipes, fittings, accessories and their joints for water applications*

ISO 7186, *Ductile iron products for sewerage applications*

ISO 7268, *Pipe components — Definition of nominal pressure*

ISO 10802, *Ductile iron pipelines — Hydrostatic testing after installation*

ISO 16631, *Ductile iron pipes, fittings, accessories and their joints compatible with plastic (PVC or PE) piping systems, for water applications and for plastic pipeline connections, repair and replacement*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 7268 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

### 3.1 allowable operating pressure

**PFA**

$P_{FA}$

maximum internal pressure, excluding surge, that a component can safely withstand in permanent service

[SOURCE: ISO 2531:2009, 3.2, modified — The symbol  $P_{FA}$  has been added.]

### 3.2 maximum allowable operating pressure

**PMA**

$P_{MA}$

maximum internal pressure, including surge, that a component can safely withstand in service

[SOURCE: ISO 2531:2009, 3.17, modified — The symbol  $P_{MA}$  has been added.]

**3.3**  
**allowable site test pressure**

**PEA**

$P_{EA}$

maximum hydrostatic pressure that a newly installed component can withstand for a relatively short duration, when either fixed above ground level or laid and backfilled underground, in order to ensure the integrity and leak tightness of the pipeline

Note 1 to entry: This test pressure is different from the system test pressure, which is related to the *design pressure* (3.11) of the pipeline.

[SOURCE: ISO 2531:2009, 3.3, modified — The symbol  $P_{EA}$  has been added.]

**3.4**  
**embedment**

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

Note 1 to entry: See [Figure 2](#).

**3.5**  
**bedding**

lower part of the *embedment* (3.4), composed of the lower bedding (if necessary) and the upper bedding

Note 1 to entry: See [Figure 2](#).

**3.6**  
**bedding reaction angle**

conventional angle used in the calculation model to account for the actual soil pressure distribution at pipe invert

**3.7**  
**compaction**

deliberate densification of soil during the installation process

**3.8**  
**standard proctor density**

degree of soil *compaction* (3.7) using a 2,5 kg rammer and a 305 mm drop

Note 1 to entry: The degree of soil compaction is defined in AASHTO T99.

**3.9**  
**deflection lag factor**

factor that takes account of the settlement of the sidefill over time resulting in further deflection of the pipe, till the final equilibrium is reached after pipe installation

**3.10**  
**operating pressure**

**OP**

$P_0$   
highest pressure that occurs at a time and at a point in the pipeline when operating continuously under stable conditions, without surge

**3.11**  
**design pressure**

maximum *operating pressure* (3.10) of the pipeline system or of the pressure zone fixed by the designer, considering future developments but excluding surge

## 4 Design procedure

### 4.1 General

The pipe wall thickness shall provide adequate strength against the internal pressure of the fluid and against the effects of external loads due to backfill and surcharge, i.e. traffic loadings.

Ductile iron pipes in conformity with ISO 2531 are classified according to their allowable operating pressure for use in water applications. Ductile iron pipes in conformity with ISO 7186 are for sewerage applications either under pressure or under gravity. Ductile iron pipes in conformity with ISO 16631 are for water applications with joints compatible with plastic (PVC or PE) piping systems either under pressure or without pressure. Using the formulae given in [Clauses 5](#) and [6](#), the design of buried pipes is performed by determining:

- a) the minimum pipe wall thickness for the allowable operating pressure (PFA); and
- b) the allowable depths of cover for the external loads as per procedure given in [Clause 7](#).

NOTE National standards or established calculation methods can be used instead of this document.

### 4.2 Design steps

The steps for the design procedure for the pipes are given below.

- a) Based on the design pressure of the pipeline system, select pressure class of pipe as appropriate in accordance with ISO 2531 or ISO 7186 or ISO 16631 such that PFA of selected pipe class is higher than the design pressure.
- b) Check the safety against the external loads for the selected pipe class by using appropriate method for calculating the allowable depth of cover as defined in [Clause 7](#).
- c) If the allowable depth of cover is not adequate, select higher pressure class of pipe and repeat steps [4.2 a\)](#) and b) until the allowable depth of cover is acceptable.

NOTE When installed and operated under the conditions for which they are designed, ductile iron pipes, fittings, accessories and their joints maintain all their functional characteristics over their operating life, due to constant material properties, to the stability of their cross-section and to their design with high safety factors.

## 5 Design for internal pressure

### 5.1 Design formulae for wall thickness

The minimum wall thickness of pipes,  $e_{\min}$ , shall be not less than 3 mm (as specified in ISO 2531) or 2,4 mm (as specified in ISO 7186) or 2,2 mm (in accordance with ISO 16631) and shall be determined using [Formula \(1\)](#):

$$e_{\min} = \frac{P_{FA} \cdot S_{FH} \cdot D_E}{2 \cdot R_m + (P_{FA} \cdot S_{FH})} \quad (1)$$

where

- $e_{\min}$  is the minimum pipe wall thickness to resist hoop stress due to internal pressure, in mm;
- $P_{FA}$  is the allowable operating pressure, in MPa (see [5.2](#));
- $S_{FH}$  is the design safety factor against hoop stress (see [5.2](#));
- $D_E$  is the nominal pipe external diameter (DE), in mm (see [Annex A](#));

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$R_m$  is the minimum ultimate tensile strength of the ductile iron, in MPa ( $R_m = 420$  MPa as defined in ISO 2531 or ISO 7186 or ISO 16631).

Nominal wall thickness,  $e_{nom}$ , of the pipe is calculated as given in [Formula \(2\)](#) for pipes conforming to ISO 2531, ISO 7186 and ISO 16631:

$$e_{nom} = e_{min} + (1,3 + 0,001D_N) \quad (2)$$

where  $D_N$  is the nominal diameter (DN) of pipe, in mm, as defined in [Annex A](#).

Nominal pipe wall thicknesses for various classes in accordance with ISO 2531 are given in [Table A.1](#) and nominal pipe wall thicknesses for pressure and gravity pipe classes in accordance with ISO 7186 are given in [Table A.2](#).

Nominal pipe wall thicknesses for various sizes in accordance with ISO 16631 are given in [Table A.3](#).

### 5.2 Design safety factors

The minimum pipe wall thickness,  $e_{min}$ , shall be calculated with a design safety factor of 2,5 for the maximum allowable operating pressure (i.e. PMA as indicated in ISO 2531 and ISO 7186) and a design safety factor of 3 for the allowable operating pressure (i.e. PFA as indicated in ISO 2531 and ISO 7186).

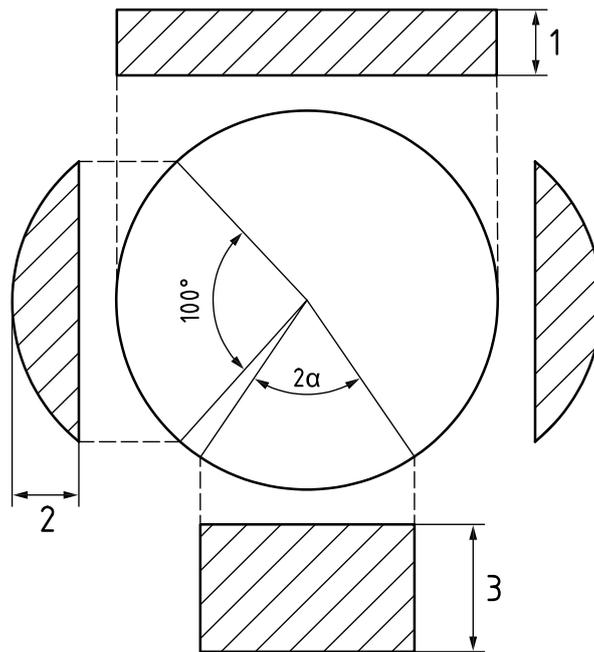
Field testing of installed ductile iron pipelines shall be done in accordance with ISO 10802 by application of test pressures up to the allowable site test pressures (i.e. PEA given in ISO 2531 and ISO 7186).

## 6 Design for external loads

### 6.1 Spangler formula

The design formula is based on Spangler model ([Figure 1](#)), where the vertical pressure,  $q$ , is acting downward and:

- is uniformly distributed at the pipe crown over a diameter;
- is in equilibrium with a pressure, acting upward at the pipe invert, uniformly distributed over the bedding reaction angle  $2\alpha$ ;
- causes a pipe deflection, which gives rise to a horizontal reaction pressure at pipe sides, parabolically distributed over an angle of  $100^\circ$ .



**Key**

- 1 vertical pressure
- 2 lateral reaction pressure distribution
- 3 vertical reaction pressure distribution

**Figure 1 — Spangler model**

The pipe diametral deflection and vertical pressure at pipe crown based on Spangler model are calculated from [Formulae \(3\)](#) and [\(4\)](#):

$$\Delta = 100 \frac{K_x q}{8S + 0,061E'} \quad (3)$$

$$q = D_{LY} \cdot q_1 + q_2 \quad (4)$$

where

- $\Delta$  is the pipe diametral deflection, in per cent of external diameter, DE;
- $K_x$  is the deflection coefficient depending on bedding reaction angle, given in [Table 1](#) for each trench type and soil group;
- $q$  is the vertical pressure at pipe crown due to all external loads, in MPa;
- $q_1$  is the vertical pressure at pipe crown due to earth load, in MPa;
- $q_2$  is the vertical pressure at pipe crown due to traffic load, in MPa;
- $S$  is the pipe diametral stiffness, in MPa;
- $E'$  is the modulus of soil reaction, in MPa;
- $D_{LY}$  is the long-term deflection factor.

Long-term deflection factor ( $D_{LY}$ ) and pipe soil stiffness factor are obtained from [Formula \(5\)](#) and [\(6\)](#):

$$D_{LY} = [1 + 0,8n(D_L - 1)] \cdot D_R \quad (5)$$

$$n = \frac{\left(\frac{E'}{D_L}\right)}{\left(105 \cdot S + 0,8 \frac{E'}{D_L}\right)} \quad (6)$$

where

$D_L$  is the deflection lag factor given in [Table 1](#) for each trench type and soil group;

$n$  is the pipe-soil stiffness factor;

$D_R$  is the reduction factor on long-term deflection due to internal pressure  $D_R = 1$ , except if the pipeline is to be pressurised to at least 0,3 MPa within one year of buried depth at a depth of less than 2,5 m. In such a case:

$$D_R = 1 - \frac{P_0}{4}, \text{ where } P_0 \text{ is the operating pressure (OP) in pipe in MPa.}$$

$S$  and  $E'$  are obtained from [Formulae \(7\)](#) and [\(8\)](#):

$$S = \frac{E \left(\frac{e_{\text{stiff}}^3}{12}\right)}{D^3} \quad (7)$$

$$E' = E_2' \cdot C_L \quad (8)$$

where

$S$  is the pipe diametral stiffness, in MPa ( $S$  can also directly taken from the relevant annexes of ISO 2531 and ISO 7186);

$E$  is the modulus of elasticity of the pipe wall material, in MPa (170 000 MPa for ductile iron);

$D$  is the mean diameter of pipe ( $D_E - e_{\text{stiff}}$ ), in mm;

$D_E$  is the nominal pipe external diameter (DE) as specified in ISO 2531 and ISO 7186, in mm;

$e_{\text{stiff}}$  is the average of the minimum pipe wall thickness of the pipe and nominal wall thickness of pipe, in mm, [ $e_{\text{stiff}} = (e_{\text{nom}} + e_{\text{min}}) / 2$ ];

$E'$  is the modulus of soil reaction, in MPa;

$E_2'$  is the embedment modulus of soil reaction for the selected pipe surround material at the chosen level of compaction (see [Table 1](#));

$C_L$  is the Leonhardt's coefficient to calculate the effective pipe soil stiffness factor.

$C_L$  is obtained by [Formula \(9\)](#):

$$C_L = \frac{0,985 + \left(0,544 \cdot \frac{W_t}{D_E}\right)}{\left[1,985 - 0,456 \cdot \left(\frac{W_t}{D_E}\right)\right] \cdot \left(\frac{E_2'}{E_3'}\right) - \left[\left(1 - \frac{W_t}{D_E}\right)\right]} \quad (9)$$

where

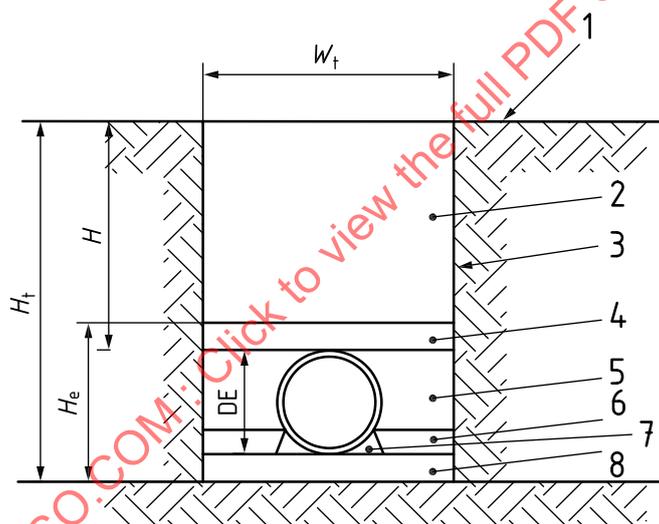
$W_t$  is the width of trench in mm;

$E_3'$  is the native soil modulus in MPa, given in [Table 2](#).

## 6.2 Pipe embedment

### 6.2.1 Types of embedment

There are various types of embedments, which are designated into different classes based on configuration, bedding and side fills. A typical embedment and its various parameters are defined in [Figure 2](#).



#### Key

- 1 surface
- 2 main fill
- 3 wall of trench
- 4 direct cover zone (initial backfill)
- 5 lateral fill (side fill)
- 6 upper bedding layer
- 7 haunch zone
- 8 lower bedding layer
- $H_t$  depth of trench
- $H$  height of cover
- $H_e$  height of embedment
- $D_E$  outside diameter of pipe
- $W_t$  width of trench

Figure 2 — Typical trench embedment

6.2.2 Types of trenches

There are following types of trenches.

- a) Trench type 1: embedment dumped.
- b) Trench type 2: embedment with very light compaction, greater than 75 % standard proctor density.
- c) Trench type 3: embedment with light compaction, greater than 80 % standard proctor density.
- d) Trench type 4: embedment with medium compaction, greater than 85 % standard proctor density.
- e) Trench type 5: embedment with high compaction, greater than 90 % standard proctor density.

6.2.3 Embedment properties

Embedment properties depend on the type of embedment and compacted density (see 6.2.2 for type of trenches). Embedment properties i.e. value of deflection coefficient ( $K_x$ ), compaction density, embedment soil modulus ( $E_2'$ ) and deflection lag factor ( $D_L$ ) for various embedment classes are given in Table 1.

The bedding reaction angle depends on the installation conditions (bedding, sidefill compaction) and on the pipe diametral deflection. The embedment modulus of soil reaction,  $E_2'$ , depends on the selected pipe surround material at the chosen level of compaction and the trench type.

In the absence of the applicable standards or other data, the values of  $E_2'$  indicated in Table 1 can be used at the design stage for five trench types and for six soil groups as defined in Annex D for the pipe surround material. A preliminary geotechnical survey should be carried out to facilitate identification of the soil and proper selection of  $E_2'$  values. The final value of modulus of soil reaction,  $E'$  is calculated as per the formulae defined in 6.1.

Table 1 — Pipe embedment properties (values of  $K_x$ ,  $D_L$  and  $E_2'$ )

Trench type	1		2		3		4		5	
Placement of embedment	Dumped		Very light compaction		Light compaction		Medium compaction		High Compaction	
Standard proctor density of sidefill, %	a		>75		>80		>85		>90	
Bedding reaction angle ( $2\alpha$ )	30°		45°		60°		90°		150°	
$K_x$	0,108		0,105		0,102		0,096		0,085	
$E_2'$ (MPa) and $D_L$	$E_2'$ (MPa)	$D_L$	$E_2'$ (MPa)	$D_L$	$E_2'$ (MPa)	$D_L$	$E_2'$ (MPa)	$D_L$	$E_2'$ (MPa)	$D_L$
Soil group A	4	1,5	4	1,5	5	1,25	7	1,0	10	1,0
Soil group B	2,5	3,0	2,5	2,5	3,5	2,0	5	1,5	7	1,25
Soil group C	1	3,0	1,5	2,5	2	2,0	3	1,5	5	1,25
Soil group D	0,5	4,5	1	4,0	1,5	3,5	2,5	3,0	3,5	2,0
Soil group E	b	-	b	-	b	-	b	-	b	-
Soil group F	b	-	b	-	b	-	b	-	b	-

<sup>a</sup> Depending on the type of test of soil and its moisture content, a standard proctor density of 70 % to 80 % should normally be achieved by simply dumping the soil in the trench.

<sup>b</sup> Use an  $E_2'$  value of 0 unless it can be ensured that a higher value is achieved consistently.

## 6.2.4 Spangler modulus of native soils

The stiffness of the native soil in which the pipeline trench is excavated is important for the design of ductile iron pipes. The stiffness of the native soil is measured in terms of the Spangler modulus  $E_3'$  (see [Table 2](#)), which in combination with the soil modulus,  $E_2'$ , is used to calculate the overall modulus of soil reaction,  $E'$ .

**Table 2 — Guide values of Spangler modulus of native soils ( $E_3'$ , in MPa)**

Soil type	Very dense	Dense	Medium dense	Loose	Very loose
Gravel	> 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			
SOURCE: BS 9295:2020, Table 27, reproduced with permission.					

## 7 Safety check against internal pressure and external loads

### 7.1 Principle

#### 7.1.1 General

Two methods can be used for safety check of pipe class against external loads and internal pressure. Both the methods are based on Spangler formula ([6.1](#)) and their results are valid for the following conditions:

- minimum allowable depth of cover is equal to 2 times DN;
- for calculated depth of cover more than 6 meters, adequate structural pipeline design engineer recommendations should be considered as per the actual site conditions;
- the pipe deflection in percentage shall not exceed the value defined in [7.5](#).

In method 1, the allowable depth of cover is calculated based on the maximum allowable pipe deflection. In method 2, the actual deflection of the pipe is calculated based on the actual depth of cover. Examples of calculation with methods 1 and 2 are given in [Annex B](#). Examples of national traffic load systems are given in [Annex C](#).

In any case, it is presupposed that the height of cover complies with the project specifications and local regulations for traffic loading (type of load and lading pattern), the safety of people and shielding, and anti-freeze prevention.

### 7.1.2 Method 1: calculate maximum allowable depth of cover from maximum allowable pipe deflection

From Spangler [Formula \(3\)](#), the value of  $q$  can be re-formulated as below:

$$q = \frac{\Delta \times (8S + 0,061E')}{100 K_x} \quad (10)$$

Where  $q$  is basically a function of  $H$  (allowable depth of cover) after all other constants are known. The method consists in calculating  $q$  with all terms on the right-side equation, then extracting the maximum allowable depth of cover ( $H_{\max}$ ) from  $q$ , in the following steps:

- calculate the value of  $S$ ;
- calculate the value of  $E'$ ;
- calculate the maximum allowable pipe deflection,  $\Delta_{\max}$ ;
- calculate the value of  $q$ ;
- formulate  $q_1$ ,  $q_2$  and  $q$  as a function of  $H$ ;
- calculate the value of  $H_{\max}$ .

### 7.1.3 Method 2: calculate the actual pipe deflection from the actual depth of cover

From spangler [Formula \(3\)](#) the actual pipe deflection is calculated as below:

$$\Delta = \frac{100 K_x q}{8S + 0,061E'}$$

The method consists in calculating the actual deflection  $\Delta_{\text{actual}}$  with all terms on the right-side formula, then checking if the actual deflection is lower than the allowable pipe diametral deflection, in the following steps:

- calculate the values of  $q_1$ ,  $q_2$  and  $q$ ;
- calculate the value of  $E'$ ;
- calculate the value of  $S$ ;
- calculate the value of  $\Delta_{\text{actual}}$ ;
- calculate the value  $\Delta_{\text{allowable}}$ ;
- check if  $\Delta_{\text{actual}}$  is lower or equal to  $\Delta_{\text{allowable}}$ . If not, use higher class pipe and repeat till the calculated value in step d) is lower than the value in step e).

## 7.2 Total vertical pressure on the pipe

The total vertical pressure,  $q$ , acting at pipe crown is the sum of the components shown in [Formula \(11\)](#):

$$q = D_{LY} \cdot q_1 + q_2 \quad (11)$$

where

- $q_1$  is the pressure from earth loads;
- $q_2$  is the pressure from traffic loads;
- $D_{LY}$  is the long-term deflection factor as defined in [6.1](#).

NOTE Special considerations are required in case the pressure from traffic loads,  $q_2$ , is greater than that from normal static loads applied to the ground surface or in the case of any abnormal surface loading.

### 7.3 Pressure from earth loads

Pressure from earth load,  $q_1$  shall be calculated using [Formula \(12\)](#) from the weight of the earth prism immediately above the pipe:

$$q_1 = 0,001 \gamma H \quad (12)$$

where

$q_1$  is the pressure at pipe crown, in MPa;

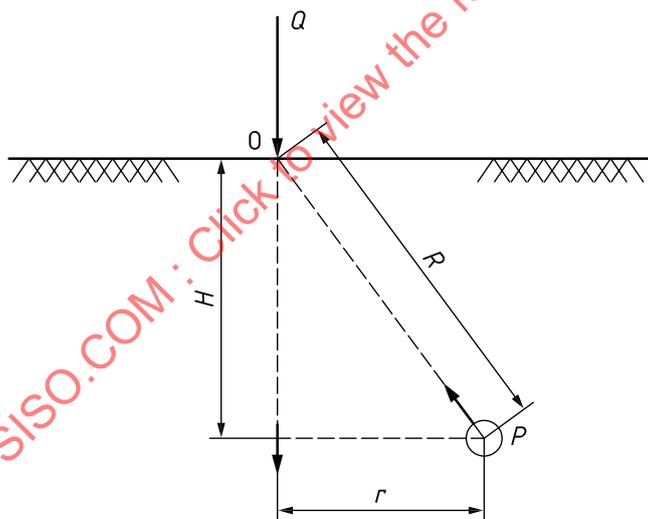
$\gamma$  is the unit weight of the backfill, in kN/m<sup>3</sup>;

$H$  is the height of cover (distance from pipe crown to ground surface), in m.

A preliminary geotechnical survey should be carried out to determine the actual unit weight of the backfill. The unit weight of the soil of 20 kN/m<sup>3</sup> is covering a vast majority of soils. In the absence of other data, it can be used for general design purposes.

### 7.4 Pressure from traffic loads

The design formula is based on the Boussinesq model ([Figure 3](#)).



#### Key

$H$  height of cover

$Q$  pressure of wheel

$P$  pressure on pipe

Figure 3 — Boussinesq model

The value of  $q_2$  shall be calculated using [Formula \(13\)](#). This formula has been derived from Boussinesq theory and further approximation.

$$q_2 = 0,001 \cdot \varphi \cdot a_f \cdot p_f \quad (13)$$

where

$q_2$  is the pressure at pipe crown, in MPa;

$\varphi$  is the dynamic impact coefficient, given in [Table 3](#).

$a_f$  is a correction factor to take into account the pressure spread over the pipe cross-section;

$p_f$  is an approximation for the maximum stress under wheel loads and wheel contact areas.

**Table 3 — Suggested values of  $\varphi$  for various types of vehicle**

Vehicle	$\varphi$
Heavy vehicle	1,2
Medium vehicle	1,4
Light vehicle	1,5

$a_f$  and  $p_f$  are obtained using [Formula \(14\)](#) and [\(15\)](#):

$$a_f = 1 - \frac{0,9}{0,9 + \frac{4 \cdot H^2 + H^6}{1,1(D)^{\frac{2}{3}}}} \quad (14)$$

$$p_f = \frac{F_A}{r_A^2 \cdot \pi} \left\{ 1 - \left[ \frac{1}{1 + \left( \frac{r_A}{H} \right)^2} \right]^{\frac{3}{2}} \right\} + \sum_i \frac{3}{2} \cdot \frac{F_E}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{r_E}{H} \right)^2} \right]^{\frac{5}{2}} \quad (15)$$

where

$H$  is the height of cover, in m;

$D$  is the mean diameter of pipe in m;

$i$  is the wheel number;

$F_A$  the load of the wheel passing directly above the pipe crown;

$F_E$  the load of the wheel passing at a distance  $r_E$  from the vertical of the pipe crown;

$r_A, r_E$  are auxiliary radii for the traffic loads, in m.

NOTE The parameters  $r_A$  and  $r_E$  are based on wheel loads of national and/or local applicable standards and regulations. Examples are given in Annex C.

## 7.5 Allowable pipe diametral deflection

The allowable pipe diametral deflection,  $\Delta_{\max}$ , can be taken from relevant annexes of ISO 2531, ISO 7186 and ISO 16631. These values provide sufficient safety against yield bending strength of the pipe wall, lining deformation, joint leak tightness and hydraulic capacity of the pipe. However, national standards and/or the manufacturer's catalogues can introduce more stringent limitations, for instance 3 % for cement mortar linings.

For each DN, the allowable pipe diametral deflection,  $\Delta_{\max}$ , is the lowest of the following:

a)  $\Delta_1$ , which provides a safety factor of 2 against irreversible damage of the lining, is defined in [Table 4](#):

— for cement mortar linings:

**Table 4 —  $\Delta_1$  according to DN for cement mortar linings**

DN range	$\Delta_1$ in %
DN $\leq$ 300	3 %
300 < DN $\leq$ 700	$\Delta_1 = 3 + [(D_N - 300)/500]$
DN > 800	4 %

— for flexible linings:

$$\Delta_1 = 5 \%$$

b)  $\Delta_2$ , which provides a safety factor of 1,5 against the yield bending strength of the ductile iron pipe wall is calculated using [Formula \(16\)](#):

$$\Delta_2 = 100 \cdot \frac{R_f \cdot (D_E - e_{\text{nom}})}{S_{\text{FB}} \cdot E \cdot e_{\text{nom}} \cdot D_F} \quad (16)$$

where

$R_f$  is the yield bending strength of the pipe wall material ( $R_f = 500$  MPa for ductile iron);

$D_E$  is the pipe external diameter (DE) as defined in ISO 2531, ISO 7186 and ISO 16631, in mm;

$e_{\text{nom}}$  is the nominal pipe wall thickness, in mm;

$S_{\text{FB}}$  is the safety factor against the yield bending strength (1,5 for ductile iron pipes);

$E$  is the modulus of elasticity of the pipe wall material (170 000 MPa for ductile iron material);

$D_F$  is the deformation factor which depends mainly on the pipe diametral stiffness (3,5 for ductile iron pipes).

**Annex A**  
(informative)

**Dimensions of preferred and other class pipes**

**A.1 Dimensions of preferred and other class pipes for pipes conforming to ISO 2531**

Dimensions of preferred and other class pipes with flexible joints classified by the allowable operating pressure, in bar (PFA), prefixed by the letter C, i.e. C20, C25, C30, C40, C64 and C100 are given in this annex. These are derived from [Formula \(1\)](#) and the data of [Clause 5](#), and are in conformity with ISO 2531.

**Table A.1 — Dimensions of preferred and other class pipes for pipes conforming to ISO 2531**

DN	DE <sup>a</sup> mm	Nominal iron wall thickness, $e_{nom}$ mm <sup>b</sup>						
		C20	C25	C30	C40	C50	C64	C100
40	56				4,4 <sup>c</sup>	4,4	4,4	4,4
50	66				4,4 <sup>c</sup>	4,4	4,4	4,4
60	77				4,4 <sup>c</sup>	4,4	4,4	4,4
65	82				4,4 <sup>c</sup>	4,4	4,4	4,4
80	98				4,4 <sup>c</sup>	4,4	4,4	4,8
100	118				4,4 <sup>c</sup>	4,4	4,4	5,5
125	144				4,5 <sup>c</sup>	4,5	4,8	6,5
150	170				4,5 <sup>c</sup>	4,5	5,3	7,4
200	222				4,7 <sup>c</sup>	5,4	6,5	9,2
250	274				5,5 <sup>c</sup>	6,4	7,8	11,1
300	326			5,1	6,2 <sup>c</sup>	7,4	8,9	12,9
350	378		5,1	6,3 <sup>c,d</sup>	7,1	8,4	10,2	14,8
400	429		5,5	6,5 <sup>c,d</sup>	7,8	9,3	11,3	16,5
450	480		6,1	6,9 <sup>c</sup>	8,6	10,3	12,6	18,4
500	532		6,5	7,5 <sup>c</sup>	9,3	11,2	13,7	20,2
600	635		7,6	8,7 <sup>c</sup>	10,9	13,1	16,1	23,8
700	738	7,3	8,8 <sup>c,d</sup>	9,9	12,4	15,0	18,5	27,5
800	842	8,1	9,6 <sup>c</sup>	11,1	14,0	16,9	21,0	
900	945	8,9	10,6 <sup>c</sup>	12,3	15,5	18,8	23,4	
1 000	1 048	9,8	11,6 <sup>c</sup>	13,4	17,1	20,7		
1 100	1 152	10,6	12,6 <sup>c</sup>	14,7	18,7	22,7		
1 200	1 255	11,4	13,6 <sup>c</sup>	15,8	20,2			
1 400	1 462	13,1	15,7 <sup>c</sup>	18,2				
1 500	1 565	13,9	16,7 <sup>c</sup>	19,4				
1 600	1 668	14,8	17,7 <sup>c</sup>	20,6				

<sup>a</sup> A tolerance of +1 mm applies.

<sup>b</sup> For pipes with weld beads, see ISO 10804.

<sup>c</sup> Preferred classes.

<sup>d</sup> For preferred classes, thicknesses are greater than the thicknesses calculated for “smoothing” between C40 and C30, and also between C30 and C25.

Table A.1 (continued)

DN	DE <sup>a</sup> mm	Nominal iron wall thickness, $e_{nom}$ mm <sup>b</sup>						
		C20	C25	C30	C40	C50	C64	C100
1 800	1 875	16,4	19,7 <sup>c</sup>	23,0				
2 000	2 082	18,1	21,8 <sup>c</sup>	25,4				
2 200	2 288	19,8	23,8 <sup>c</sup>					
2 400	2 495	21,4	25,8 <sup>c</sup>					
2 600	2 702	23,1	27,9 <sup>c</sup>					

<sup>a</sup> A tolerance of +1 mm applies.

<sup>b</sup> For pipes with weld beads, see ISO 10804.

<sup>c</sup> Preferred classes.

<sup>d</sup> For preferred classes, thicknesses are greater than the thicknesses calculated for “smoothing” between C40 and C30, and also between C30 and C25.

## A.2 Dimensions of pressure and gravity sewer pipes conforming to ISO 7186

Table A.2 — Dimensions of pressure and gravity sewer pipes conforming to ISO 7186

DN	DE <sup>a</sup> mm	Nominal iron wall thickness, $e_{nom}$ mm		Pressure pipe: corresponding preferred pressure class of ISO 2531
		Pressure pipe	Gravity pipe	
80	98	4,4	3,4	C40
100	118	4,4	3,4	C40
125	144	4,5	3,4	C40
150	170	4,5	3,4	C40
200	222	4,7	3,4	C40
250	274	4,9	4,1	C30
300	326	5,1	4,8	C30
350	378	5,7 <sup>b</sup>	5,5	C30
400	429	6,3 <sup>b</sup>		C30
450	480	6,4		C25
500	532	6,5		C25
600	635	7,5		C25
700	738	8,5 <sup>b</sup>		C25
800	842	9,6		C25
900	945	10,6		C25
1 000	1 048	11,6		C25
1 100	1 152	12,6		C25

<sup>a</sup> A tolerance of +1 mm applies.

<sup>b</sup> For preferred classes, thicknesses are greater than the thicknesses calculated for “smoothing” between C40 and C30, and also between C30 and C25.

Table A.2 (continued)

DN	DE <sup>a</sup> mm	Nominal iron wall thickness, $e_{nom}$ mm		Pressure pipe: corresponding preferred pressure class of ISO 2531
		Pressure pipe	Gravity pipe	
1 200	1 255	13,6		C25
1 400	1 462	15,7		C25
1 500	1 565	16,7		C25
1 600	1 668	17,7		C25
1 800	1 875	19,7		C25
2 000	2 082	21,8		C25
2 200	2 288	23,8		C25
2 400	2 496	25,8		C25
2 600	2 702	27,9		C25

<sup>a</sup> A tolerance of +1 mm applies.

<sup>b</sup> For preferred classes, thicknesses are greater than the thicknesses calculated for “smoothing” between C40 and C30, and also between C30 and C25.

### A.3 Dimensions of pipes conforming to ISO 16631

Table A.3 — Dimensions of pipes conforming to ISO 16631

DN	DE <sup>a</sup> mm	Nominal iron wall thickness, $e_{nom}$ mm
50	50	3,0
63	63	3,0
75	75	3,0
90	90	3,0
110	110	3,0
125	125	3,0
140	140	3,1
160	160	3,2
180	180	3,3
200	200	3,4
225	225	3,5

<sup>a</sup> A tolerance of +1 mm applies.

## Annex B (informative)

### Examples of calculations for safety check with methods 1 and 2

#### B.1 General

The calculation of allowable depth of cover requires calculation of earth load as per [7.3](#), traffic load as per [7.4](#), long term deflection factor,  $D_{LY}$  and other embedment properties and embedment modulus of soil reaction  $E_2'$ .

#### B.2 Assumptions on pipe and installation conditions

Assumption parameters for calculation of allowable depth of cover for examples of method 1 and method 2 are given in [Table B.1](#).

**Table B.1 — Assumption parameters for calculation of allowable depth of cover for pipes conforming to ISO 2531**

Assumption parameter	Designation of parameter	Values
Cement lined ductile iron pipe	ISO 2531	--
Pipe diameter	DN	800
Class of pipe	Class	C25
External diameter	DE	842 mm
Nominal wall thickness	$e_{nom}$	9,6 mm
Minimum wall thickness	$e_{min}$	7,5 mm
Trench type from <a href="#">Table 1</a>	Type	5
Soil type from <a href="#">Annex D</a>	Group	A
Native soil type from <a href="#">Table 2</a>	--	Dense sand
Width of trench according to <a href="#">Figure 2</a>	$W_t$	1 442 mm
Density of soil (to see <a href="#">subclause 7.3</a> )	$\gamma$	20 kN/m <sup>3</sup>
Operating pressure	OP	2 MPa
Type of vehicle (heavy vehicle, see <a href="#">7.4</a> )	$\varphi$	1,2
Traffic load system	--	according to national load system

#### B.3 Safety check for traffic load system, method 1

##### B.3.1 Calculate the value of $S$

Value of  $S$  is obtained from [Formula \(7\)](#):

$$S = \frac{E \times \left( \frac{e_{stiff}^3}{12} \right)}{(D)^3}$$

$$S = \frac{170\,000 \times \left( \frac{8,55^3}{12} \right)}{833,45^3} = 0,015\,3 \text{ MPa}$$

where

$S$  is the pipe diametral stiffness, in MPa ( $S$  can be also directly taken from the relevant annexes of ISO 2531);

$E$  is 170 000 MPa, the modulus of elasticity of ductile iron material;

$e_{\text{stiff}}$  is 8,55 mm [(9,6+7,5)/2];

$D$  is 833,45 mm, the mean diameter of pipe, [ $D_E - e_{\text{stiff}}$ ];

$D_E$  is 842 mm, the nominal diameter (DE) of pipe, as specified in [Annex A](#).

### B.3.2 Calculate the value of $E'$

Value of  $E'$  from [Formula \(8\)](#):

$$E' = E_2' \cdot C_L$$

$$E' = 10 \cdot C_L$$

where it is assumed:  $E_2'$  is 10 MPa according [Table 1](#).

Using [Formula \(9\)](#):

$$C_L = \frac{0,985 + \left( 0,544 \cdot \frac{W_t}{D_E} \right)}{\left[ 1,985 - 0,456 \cdot \left( \frac{W_t}{D_E} \right) \right] \cdot \left( \frac{E_2'}{E_3'} \right) - \left[ \left( 1 - \frac{W_t}{D_E} \right) \right]}$$

$$C_L = \frac{0,985 + \left( 0,544 \times \frac{1\,442}{842} \right)}{\left[ 1,985 - 0,456 \left( \frac{1\,442}{842} \right) \right] \left( \frac{10}{9} \right) - \left[ 1 - \frac{1\,442}{842} \right]} = 0,935$$

where

$E_3'$  is 9 MPa according to [Table 2](#);

$D_E$  is 842 mm;

$W_t$  is 1 442 mm.

Finally:

$$E' = 10 \times 0,935 = 9,35 \text{ MPa}$$

### B.3.3 Calculate the value of $\Delta_{\text{max}}$

$\Delta_1$  is obtain from [7.5](#), that gives 4 % for DN 800

$\Delta_2$  is obtain from [Formula \(16\)](#):

$$\Delta_2 = 100 \cdot \frac{R_f \cdot (D_E - e_{nom})}{S_{FB} \cdot E \cdot e_{nom} \cdot D_F}$$

$$\Delta_2 = 100 \times \frac{500 \times (842 - 9,6)}{1,5 \times 170\,000 \times 9,6 \times 3,5} = 4,857\%$$

$\Delta_{max}$  is the lower of  $\Delta_1$  and  $\Delta_2$ , i.e. 4 %.

### B.3.4 Calculate the value, $q$

Value of  $q$  is calculated using [Formula \(10\)](#):

$$q = \frac{\Delta \times (8S + 0,061E')}{100 K_x}$$

$$q = \frac{4 \times (8 \times 0,0153 + 0,061 \times 9,35)}{100 \times 0,085} = 0,326 \text{ MPa}$$

where  $K_x$  is 0,085 from [Table 1](#) for trench type 5.

### B.3.5 Formulate $q_1, q_2$ and $q$ as a function of $H$

#### B.3.5.1 Formulate $q_1$ as a function of $H$

Formula the value of  $q_1$  using [Formula \(12\)](#):

$$q_1 = 0,001 \gamma H$$

$$q_1(H) = 0,001 \times 20 \times H$$

where  $\gamma$  is 20 kN/m<sup>3</sup>.

#### B.3.5.2 Formulate $q_2$ as a function of $H$

Formula the value of  $q_2$  using [Formula \(13\)](#):

$$q_2 = 0,001 \cdot \varphi \cdot a_f \cdot p_f$$

$$q_2(H) = 0,001 \times 1,2 \times a_f \times p_f$$

where  $\varphi$  is 1,2.

Calculate  $a_f$  using [Formula \(14\)](#):

$$a_f = 1 - \frac{0,9}{0,9 + \frac{4 \cdot H^2 + H^6}{2}}$$

$$a_f = 1 - \frac{0,9}{0,9 + \frac{4 \times H^2 + H^6}{2}}$$

$$a_f = 1 - \frac{0,9}{1,1 \times 0,833^3}$$

where  $D$  is 0,833 m.

Calculate  $p_f$  using [Formula \(15\)](#):

$$p_f = \frac{F_A}{r_A^2 \cdot \pi} \left\{ 1 - \left[ \frac{1}{1 + \left( \frac{r_A}{H} \right)^2} \right]^{\frac{3}{2}} \right\} + \sum_i \frac{3}{2} \cdot \frac{F_E}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{r_E}{H} \right)^2} \right]^{\frac{5}{2}}$$

The values of  $p_f$  for various traffic load system, are given in [Table B.2](#), [Table B.3](#) and [Table B.4](#).

**Table B.2 — Calculation of  $p_f$  – Method 1 for traffic load system ATV-DVWK-A 127E:2000, HGV 60 loading**

Wheel	$F_E$ , kN	$F_A$ , kN	$r_E$ , m	$r_A$ , m	$p_f$
1	100	-	2,5	-	$p_{f_1} = \frac{3}{2} \cdot \frac{100}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{2,5}{H} \right)^2} \right]^{\frac{5}{2}}$
2	100	-	2	-	$p_{f_2} = \frac{3}{2} \cdot \frac{100}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{2,0}{H} \right)^2} \right]^{\frac{5}{2}}$
3	100	-	2,5	-	$p_{f_3} = \frac{3}{2} \cdot \frac{100}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{2,5}{H} \right)^2} \right]^{\frac{5}{2}}$
4	100	-	1,5	-	$p_{f_4} = \frac{3}{2} \cdot \frac{100}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{1,5}{H} \right)^2} \right]^{\frac{5}{2}}$
5	-	100	0	0,254	$p_{f_5} = \frac{100}{0,254^2 \cdot \pi} \cdot \left\{ 1 - \left[ \frac{1}{1 + \left( \frac{0,254}{H} \right)^2} \right]^{\frac{3}{2}} \right\}$
6	100	-	1,5	-	$p_{f_6} = \frac{3}{2} \cdot \frac{100}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{1,5}{H} \right)^2} \right]^{\frac{5}{2}}$

$$p_f = p_{f_1} + p_{f_2} + p_{f_3} + p_{f_4} + p_{f_5} + p_{f_6}$$

$$p_f = \frac{3}{2} \cdot \frac{100}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{2,5}{H} \right)^2} \right]^{\frac{5}{2}} + \frac{3}{2} \cdot \frac{100}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{2,0}{H} \right)^2} \right]^{\frac{5}{2}} + \frac{3}{2} \cdot \frac{100}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{2,5}{H} \right)^2} \right]^{\frac{5}{2}} +$$

$$\frac{3}{2} \cdot \frac{100}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{1,5}{H} \right)^2} \right]^{\frac{5}{2}} + \frac{100}{0,254^2 \cdot \pi} \cdot \left\{ 1 - \left[ \frac{1}{1 + \left( \frac{0,254}{H} \right)^2} \right]^{\frac{3}{2}} \right\} + \frac{3}{2} \cdot \frac{100}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{1,5}{H} \right)^2} \right]^{\frac{5}{2}}$$

Table B.3 — Calculation of  $p_f$  – Method 1 for traffic loads system IRC-6:2017, Class AA Loading

Wheel	$F_E$ , kN	$F_A$ , kN	$r_E$ , m	$r_A$ , m	$p_f$
1	37,5	-	2,0	-	$p_{f_1} = \frac{3}{2} \cdot \frac{37,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{2,0}{H} \right)^2} \right]^{\frac{5}{2}}$
2	62,5	-	1,56	-	$p_{f_2} = \frac{3}{2} \cdot \frac{62,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{1,56}{H} \right)^2} \right]^{\frac{5}{2}}$
3	62,5	-	1,2	-	$p_{f_3} = \frac{3}{2} \cdot \frac{62,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{1,2}{H} \right)^2} \right]^{\frac{5}{2}}$
4	37,5	-	1,34	-	$p_{f_4} = \frac{3}{2} \cdot \frac{37,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{1,34}{H} \right)^2} \right]^{\frac{5}{2}}$
5	37,5	-	0,6	-	$p_{f_5} = \frac{3}{2} \cdot \frac{37,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{0,6}{H} \right)^2} \right]^{\frac{5}{2}}$

Table B.3 (continued)

Wheel	$F_E$ , kN	$F_A$ , kN	$r_E$ , m	$r_A$ , m	$p_f$
6	-	62,5	--	0,143	$p_{f_6} = \frac{62,5}{0,143^2 \cdot \pi} \cdot \left\{ 1 - \left[ \frac{1}{1 + \left( \frac{0,143}{H} \right)^2} \right]^{\frac{3}{2}} \right\}$
7	62,5	-	1,0	-	$p_{f_7} = \frac{3}{2} \cdot \frac{62,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{1,0}{H} \right)^2} \right]^{\frac{5}{2}}$
8	37,5	-	1,6	-	$p_{f_8} = \frac{3}{2} \cdot \frac{37,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{1,6}{H} \right)^2} \right]^{\frac{5}{2}}$

$$p_f = p_{f_1} + p_{f_2} + p_{f_3} + p_{f_4} + p_{f_5} + p_{f_6} + p_{f_7} + p_{f_8}$$

$$p_f = \frac{3}{2} \cdot \frac{37,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{2,0}{H} \right)^2} \right]^{\frac{5}{2}} + \frac{3}{2} \cdot \frac{62,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{1,56}{H} \right)^2} \right]^{\frac{5}{2}} + \frac{3}{2} \cdot \frac{62,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{1,2}{H} \right)^2} \right]^{\frac{5}{2}} +$$

$$\frac{3}{2} \cdot \frac{37,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{1,34}{H} \right)^2} \right]^{\frac{5}{2}} + \frac{3}{2} \cdot \frac{37,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{0,60}{H} \right)^2} \right]^{\frac{5}{2}} +$$

$$\frac{62,5}{0,143^2 \cdot \pi} \cdot \left\{ 1 - \left[ \frac{1}{1 + \left( \frac{0,143}{H} \right)^2} \right]^{\frac{3}{2}} \right\} + \frac{3}{2} \cdot \frac{62,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{1,0}{H} \right)^2} \right]^{\frac{5}{2}} + \frac{3}{2} \cdot \frac{37,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{1,6}{H} \right)^2} \right]^{\frac{5}{2}}$$

Table B.4 — Calculation of  $p_f$  - Method 1 for HB loading as per BS 5400-2:2006

Wheel	$F_E$ , kN	$F_A$ , kN	$r_E$ , m	$r_A$ , m	$p_f$
1	112,5	-	2,7	-	$p_{f_1} = \frac{3}{2} \cdot \frac{112,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left(\frac{2,7}{H}\right)^2} \right]^{\frac{5}{2}}$
2	112,5	-	2,06	-	$p_{f_2} = \frac{3}{2} \cdot \frac{112,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left(\frac{2,06}{H}\right)^2} \right]^{\frac{5}{2}}$
3	112,5	-	1,8	-	$p_{f_3} = \frac{3}{2} \cdot \frac{112,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left(\frac{1,8}{H}\right)^2} \right]^{\frac{5}{2}}$
4	112,5	-	2,06	-	$p_{f_4} = \frac{3}{2} \cdot \frac{112,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left(\frac{2,06}{H}\right)^2} \right]^{\frac{5}{2}}$
5	112,5	-	1,0	-	$p_{f_5} = \frac{3}{2} \cdot \frac{112,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left(\frac{1,0}{H}\right)^2} \right]^{\frac{5}{2}}$
6	-	112,5	0	0,18	$p_{f_6} = \frac{112,5}{0,18^2 \cdot \pi} \cdot \left\{ 1 - \left[ \frac{1}{1 + \left(\frac{0,18}{H}\right)^2} \right]^{\frac{3}{2}} \right\}$
7	112,5	-	1,0	-	$p_{f_7} = \frac{3}{2} \cdot \frac{112,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left(\frac{1,0}{H}\right)^2} \right]^{\frac{5}{2}}$
8	112,5	-	2,0	-	$p_{f_8} = \frac{3}{2} \cdot \frac{112,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left(\frac{2,0}{H}\right)^2} \right]^{\frac{5}{2}}$

$$p_f = p_{f_1} + p_{f_2} + p_{f_3} + p_{f_4} + p_{f_5} + p_{f_6} + p_{f_7} + p_{f_8}$$

$$p_f = \frac{3}{2} \cdot \frac{112,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left(\frac{2,7}{H}\right)^2} \right]^{\frac{5}{2}} + \frac{3}{2} \cdot \frac{112,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left(\frac{2,06}{H}\right)^2} \right]^{\frac{5}{2}} + \frac{3}{2} \cdot \frac{112,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left(\frac{1,8}{H}\right)^2} \right]^{\frac{5}{2}} +$$

$$\frac{3}{2} \cdot \frac{112,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left(\frac{2,06}{H}\right)^2} \right]^{\frac{5}{2}} + \frac{3}{2} \cdot \frac{112,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left(\frac{1,0}{H}\right)^2} \right]^{\frac{5}{2}} +$$

$$\frac{112,5}{0,18^2 \cdot \pi} \left\{ 1 - \left[ \frac{1}{1 + \left(\frac{0,18}{H}\right)^2} \right]^{\frac{3}{2}} \right\} + \frac{3}{2} \cdot \frac{112,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left(\frac{1,0}{H}\right)^2} \right]^{\frac{5}{2}} + \frac{3}{2} \cdot \frac{112,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left(\frac{2,0}{H}\right)^2} \right]^{\frac{5}{2}}$$

**B.3.6 Calculate the value of  $H_{\max}$**

**B.3.6.1** Calculate the value of  $H_{\max}$  for traffic load system for ATV-DVWK-A 127E:2000, Clause 3.2.1 HGV 60.

Calculate the value of  $H_{\max}$  using [Formula \(11\)](#):

$$q(H) = D_{LY} \cdot q_1(H) + q_2(H)$$

where it is assumed:  $D_{LY}$  is 1 from [Formula \(5\)](#), [Table 1](#) and [6.1](#).

The formula above becomes:

$$0,326 = 0,001 \times 20 \times H + 0,001 \times 1,2 \times \left( 1 - \frac{0,9}{0,9 + \frac{4 \times H^2 + H^6}{1,1 \times 0,833^{\frac{2}{3}}}} \right) \times \left\{ \frac{3}{2} \cdot \frac{100}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left(\frac{2,5}{H}\right)^2} \right]^{\frac{5}{2}} + \frac{3}{2} \cdot \frac{100}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left(\frac{2,0}{H}\right)^2} \right]^{\frac{5}{2}} + \frac{3}{2} \cdot \frac{100}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left(\frac{1,5}{H}\right)^2} \right]^{\frac{5}{2}} + \frac{100}{0,254^2 \cdot \pi} \cdot \left\{ 1 - \left[ \frac{1}{1 + \left(\frac{0,254}{H}\right)^2} \right]^{\frac{3}{2}} \right\} + \frac{3}{2} \cdot \frac{100}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left(\frac{1,5}{H}\right)^2} \right]^{\frac{5}{2}} \right\} \quad (B.1)$$

**B.3.6.2** Calculate the value of  $H_{\max}$  for traffic load system for IRC6: Class AA loading.

$$\begin{aligned}
 0,326 &= 0,001 \times 20 \times H + 0,001 \times 1,2 \times \left( 1 - \frac{0,9}{0,9 + \frac{4 \times H^2 + H^6}{1,1 \times 0,833^3}} \right) \times \\
 &\left\{ \frac{3}{2} \cdot \frac{37,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{2,0}{H} \right)^2} \right]^{\frac{5}{2}} + \frac{3}{2} \cdot \frac{62,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{1,56}{H} \right)^2} \right]^{\frac{5}{2}} + \right. \\
 &\frac{3}{2} \cdot \frac{62,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{1,2}{H} \right)^2} \right]^{\frac{5}{2}} + \frac{3}{2} \cdot \frac{37,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{1,34}{H} \right)^2} \right]^{\frac{5}{2}} + \frac{3}{2} \cdot \frac{37,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{0,6}{H} \right)^2} \right]^{\frac{5}{2}} + \frac{62,5}{0,143^2 \cdot \pi} \cdot \\
 &\left. \left\{ 1 - \left[ \frac{1}{1 + \left( \frac{0,143}{H} \right)^2} \right]^{\frac{3}{2}} \right\} + \frac{3}{2} \cdot \frac{62,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{1,0}{H} \right)^2} \right]^{\frac{5}{2}} + \frac{3}{2} \cdot \frac{37,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{1,6}{H} \right)^2} \right]^{\frac{5}{2}} \right\}
 \end{aligned} \tag{B.2}$$

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**B.3.6.3** Calculate the value of  $H_{\max}$  for traffic load system for HB loading, BS 5400-2:2006.

$$\begin{aligned}
 0,326 = & 0,001 \times 20 \times H + 0,001 \times 1,2 \times \left( 1 - \frac{0,9}{0,9 + \frac{4 \times H^2 + H^6}{1,1 \times 0,833^{\frac{2}{3}}}} \right) \times \left\{ \frac{3}{2} \cdot \frac{112,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{2,7}{H} \right)^2} \right]^{\frac{5}{2}} \right. \\
 & + \frac{3}{2} \cdot \frac{112,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{2,06}{H} \right)^2} \right]^{\frac{5}{2}} + \frac{3}{2} \cdot \frac{112,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{1,8}{H} \right)^2} \right]^{\frac{5}{2}} + \frac{3}{2} \cdot \frac{112,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{2,06}{H} \right)^2} \right]^{\frac{5}{2}} \\
 & \left. + \frac{3}{2} \cdot \frac{112,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{2,0}{H} \right)^2} \right]^{\frac{5}{2}} \right\} \\
 & + \frac{112,5}{0,18^2 \cdot \pi} \cdot \left\{ 1 - \left[ \frac{1}{1 + \left( \frac{0,18}{H} \right)^2} \right]^{\frac{3}{2}} \right\} + \frac{3}{2} \cdot \frac{112,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{1,0}{H} \right)^2} \right]^{\frac{5}{2}} + \frac{3}{2} \cdot \frac{112,5}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{2,0}{H} \right)^2} \right]^{\frac{5}{2}} \right\}
 \end{aligned}$$

(B.3)

Finally, as per the assumption parameters of [Table B.1](#), the value of  $H_{\max}$  is calculated using iteration by equating  $q = 0,326$  MPa, with [Formulae \(B.1\)](#), [\(B.2\)](#) and [\(B.3\)](#) and the final value is given below:

- $H_{\max}$  is 16,24 m for traffic load system according to [C.2](#) for HGV 60 load as per ATV-DVWK-A 127E, Clause 3.2.1 (Germany);
- $H_{\max}$  is 16,25 m for traffic load system according to [C.3](#) for IRC - 6 - Load, Type Class AA Loading (India);
- $H_{\max}$  is 16,21 m for traffic load system according to [C.4](#) for loading BS 5400-2, clause 6.3 (UK).

## B.4 Safety check with method 2

### B.4.1 Calculate the values of $q_1$ , $q_2$ and $q$

Calculate the value of  $q_1$  using [Formula \(12\)](#):

$$q_1 = 0,001 \gamma H$$

$$q_1 = 0,001 \times 20 \times 20 = 0,04 \text{ MPa}$$

where

$H$  is 2 m;

$\gamma$  is 20 kN/m<sup>3</sup>.

Calculate the value of  $q_2$  using [Formula \(13\)](#):

$$q_2 = 0,001 \cdot \phi \cdot a_f \cdot p_f$$

$$q_2 = 0,001 \times 1,2 \times a_f \times p_f$$

where  $\varphi$  is 1,2.

Calculate the value of  $a_f$  using [Formula \(14\)](#):

$$a_f = 1 - \frac{0,9}{0,9 + \frac{4 \cdot H^2 + H^6}{1,1(D)^3}}$$

$$a_f = 1 - \frac{0,9}{0,9 + \frac{4 \times 2^2 + 2^6}{1,1 \times 0,833^3}} = 0,989$$

where

$H$  is 2 m;

$D$  is 0,833 m.

Calculate the value of  $p_f$  using [Formula \(15\)](#):

$$p_f = \frac{F_A}{r_A^2 \cdot \pi} \left\{ 1 - \left[ \frac{1}{1 + \left( \frac{r_A}{H} \right)^2} \right]^{\frac{3}{2}} \right\} + \sum_i \frac{3}{2} \cdot \frac{F_E}{\pi \cdot H^2} \cdot \left[ \frac{1}{1 + \left( \frac{r_E}{H} \right)^2} \right]^{\frac{5}{2}}$$

The values of  $p_f$  for various traffic load system, are given in [Table B.5](#), [Table B.6](#) and [Table B.7](#).

Table B.5 — Calculation of  $p_f$  – Method 2 for traffic load system ATV-DVWK-A 127E:2000, Clause 3.2.1 HGV 60 loading

Wheel	$F_E$ , kN	$F_A$ , kN	$r_E$ , m	$r_A$ , m	$p_f$
1	100	-	2,5	-	$p_{f_1} = \frac{3}{2} \cdot \frac{100}{\pi \cdot 2^2} \cdot \left[ \frac{1}{1 + \left(\frac{2,5}{2}\right)^2} \right]^{\frac{5}{2}} = 1,14$
2	100	-	2	-	$p_{f_2} = \frac{3}{2} \cdot \frac{100}{\pi \cdot 2^2} \cdot \left[ \frac{1}{1 + \left(\frac{2,0}{2}\right)^2} \right]^{\frac{5}{2}} = 2,11$
3	100	-	2,5	-	$p_{f_3} = \frac{3}{2} \cdot \frac{100}{\pi \cdot 2^2} \cdot \left[ \frac{1}{1 + \left(\frac{2,5}{2}\right)^2} \right]^{\frac{5}{2}} = 1,14$
4	100	-	1,5	-	$p_{f_4} = \frac{3}{2} \cdot \frac{100}{\pi \cdot 2^2} \cdot \left[ \frac{1}{1 + \left(\frac{1,5}{2}\right)^2} \right]^{\frac{5}{2}} = 3,91$
5	-	100	0	0,254	$p_{f_5} = \frac{100}{0,254^2 \cdot \pi} \cdot \left\{ 1 - \left[ \frac{1}{1 + \left(\frac{0,254}{2}\right)^2} \right]^{\frac{3}{2}} \right\} = 11,71$
6	100	-	1,5	-	$p_{f_6} = \frac{3}{2} \cdot \frac{100}{\pi \cdot 2^2} \cdot \left[ \frac{1}{1 + \left(\frac{1,5}{2}\right)^2} \right]^{\frac{5}{2}} = 3,91$

$p_f = p_{f_1} + p_{f_2} + p_{f_3} + p_{f_4} + p_{f_5} + p_{f_6} = 23,917$  (for HGV 60 loading)

Table B.6 — Calculation of  $p_f$  - Method 2 for traffic loads system IRC-6:2017, Class AA Loading

Wheel	$F_E$ , kN	$F_A$ , kN	$r_E$ , m	$r_A$ , m	$p_f$
1	37,5	-	2,0	-	$p_{f_1} = \frac{3}{2} \cdot \frac{37,5}{\pi \cdot 2^2} \cdot \left[ \frac{1}{1 + \left(\frac{2,0}{2}\right)^2} \right]^{\frac{5}{2}} = 0,792$
2	62,5	-	1,56	-	$p_{f_2} = \frac{3}{2} \cdot \frac{62,5}{\pi \cdot 2^2} \cdot \left[ \frac{1}{1 + \left(\frac{1,56}{2}\right)^2} \right]^{\frac{5}{2}} = 2,269$
3	62,5	-	1,2	-	$p_{f_3} = \frac{3}{2} \cdot \frac{62,5}{\pi \cdot 2^2} \cdot \left[ \frac{1}{1 + \left(\frac{1,2}{2}\right)^2} \right]^{\frac{5}{2}} = 3,460$
4	37,5	-	1,34	-	$p_{f_4} = \frac{3}{2} \cdot \frac{37,5}{\pi \cdot 2^2} \cdot \left[ \frac{1}{1 + \left(\frac{1,34}{2}\right)^2} \right]^{\frac{5}{2}} = 1,77$
5	37,5	-	0,6	-	$p_{f_5} = \frac{3}{2} \cdot \frac{37,5}{\pi \cdot 2^2} \cdot \left[ \frac{1}{1 + \left(\frac{0,6}{2}\right)^2} \right]^{\frac{5}{2}} = 3,610$
6	-	62,5	0,0	0,143	$p_{f_6} = \frac{62,5}{0,143^2 \cdot \pi} \cdot \left\{ 1 - \left[ \frac{1}{1 + \left(\frac{0,143}{2}\right)^2} \right]^{\frac{3}{2}} \right\} = 7,417$
7	62,5	-	1,0	-	$p_{f_7} = \frac{3}{2} \cdot \frac{62,5}{\pi \cdot 2^2} \cdot \left[ \frac{1}{1 + \left(\frac{1}{2}\right)^2} \right]^{\frac{5}{2}} = 4,273$
8	37,5	-	1,6	-	$p_{f_8} = \frac{3}{2} \cdot \frac{37,5}{\pi \cdot 2^2} \cdot \left[ \frac{1}{1 + \left(\frac{1,6}{2}\right)^2} \right]^{\frac{5}{2}} = 1,30$

$p_f = p_{f_1} + p_{f_2} + p_{f_3} + p_{f_4} + p_{f_5} + p_{f_6} + p_{f_7} + p_{f_8} = 24,891$  (for IRC 6 -AA loading)

Table B.7 — Calculation of  $p_f$  - Method 2 for HB loading as per BS 5400-2:2006

Wheel	$F_E$ , kN	$F_A$ , kN	$r_E$ , m	$r_A$ , m	$p_f$
1	112,5	-	2,7	-	$p_{f_1} = \frac{3}{2} \cdot \frac{112,5}{\pi \cdot 2^2} \cdot \left[ \frac{1}{1 + \left(\frac{2,7}{2}\right)^2} \right]^{\frac{5}{2}} = 1,004$
2	112,5	-	2,06	-	$p_{f_2} = \frac{3}{2} \cdot \frac{112,5}{\pi \cdot 2^2} \cdot \left[ \frac{1}{1 + \left(\frac{2,06}{2}\right)^2} \right]^{\frac{5}{2}} = 2,203$
3	112,5	-	1,8	-	$p_{f_3} = \frac{3}{2} \cdot \frac{112,5}{\pi \cdot 2^2} \cdot \left[ \frac{1}{1 + \left(\frac{1,8}{2}\right)^2} \right]^{\frac{5}{2}} = 3,048$
4	112,5	-	2,06	-	$p_{f_4} = \frac{3}{2} \cdot \frac{112,5}{\pi \cdot 2^2} \cdot \left[ \frac{1}{1 + \left(\frac{2,06}{2}\right)^2} \right]^{\frac{5}{2}} = 2,203$
5	112,5	-	1,0	-	$p_{f_5} = \frac{3}{2} \cdot \frac{112,5}{\pi \cdot 2^2} \cdot \left[ \frac{1}{1 + \left(\frac{1,0}{2}\right)^2} \right]^{\frac{5}{2}} = 7,691$
6	-	112,5	0	0,18	$p_{f_6} = \frac{112,5}{0,18^2 \cdot \pi} \cdot \left\{ 1 - \left[ \frac{1}{1 + \left(\frac{0,18}{2}\right)^2} \right]^{\frac{3}{2}} \right\} = 13,301$
7	112,5	-	1,0	-	$p_{f_7} = \frac{3}{2} \cdot \frac{112,5}{\pi \cdot 2^2} \cdot \left[ \frac{1}{1 + \left(\frac{1,0}{2}\right)^2} \right]^{\frac{5}{2}} = 7,691$
8	112,5	-	2,0	-	$p_{f_8} = \frac{3}{2} \cdot \frac{112,5}{\pi \cdot 2^2} \cdot \left[ \frac{1}{1 + \left(\frac{2,0}{2}\right)^2} \right]^{\frac{5}{2}} = 2,375$

$$p_f = p_{f_1} + p_{f_2} + p_{f_3} + p_{f_4} + p_{f_5} + p_{f_6} + p_{f_7} + p_{f_8} = 39,516 \text{ (for BS 5400-2 HB loading)}$$

Finally, as per the assumption parameters of [Table B.1](#), the value of  $q_2$ ,  $p_f$  and  $q$  are summarised for all three traffic loading systems in the [Table B.8](#).

Table B.8 — Summary of  $p_f$  and  $q_2$  - Method 2 for all loadings

Type of loading	Value of $p_f$	Calculation of $q_2$ using <a href="#">Formula (13)</a>	Calculation of $q$ using <a href="#">Formula (11)</a>
ATV-DVWK-A 127E:2000, HGV 60	$p_f = 23,917$	$q_2 = 0,001 \times 1,2 \times 0,989 \times 23,917$ $= 0,028\ 4\ \text{MPa}$	$q = D_{LY} \cdot q_1 + q_2$ $= 1 \times 0,040 + 0,028\ 4$ $= 0,068\ 4\ \text{MPa}$
IRC-6:2017, Class AA Loading	$p_f = 24,891$	$q_2 = 0,001 \times 1,2 \times 0,989 \times 24,891$ $= 0,029\ 5\ \text{MPa}$	$q = D_{LY} \cdot q_1 + q_2$ $= 1 \times 0,040 + 0,029\ 5$ $= 0,069\ 5\ \text{MPa}$
HB loading, BS 5400-2:2006	$p_f = 39,516$	$q_2 = 0,001 \times 1,2 \times 0,989 \times 39,516$ $= 0,046\ 9\ \text{MPa}$	$q = D_{LY} \cdot q_1 + q_2$ $= 1 \times 0,040 + 0,046\ 9$ $= 0,086\ 9\ \text{MPa}$

NOTE  $D_{LY}$  is 1 from [Formula \(5\)](#) and [Table 1](#).

#### B.4.2 Calculate the value of $E'$ (for all three traffic load systems)

Calculate the value of  $E'$  using [Formula \(8\)](#):

$$E' = E_2' \cdot C_L$$

$$E' = 10 \cdot C_L$$

where  $E_2'$  is 10 MPa according to [Table 1](#).

Calculate the value of  $C_L$  using [Formula \(9\)](#):

$$C_L = \frac{0,985 + \left(0,544 \cdot \frac{W_t}{D_E}\right)}{\left[1,985 - 0,456 \cdot \left(\frac{W_t}{D_E}\right) \cdot \left(\frac{E_2'}{E_3'}\right) - \left[1 - \frac{W_t}{D_E}\right]\right]}$$

$$C_L = \frac{0,985 + \left(0,544 \times \frac{1\ 442}{842}\right)}{\left[1,985 - 0,456 \left(\frac{1\ 442}{842}\right)\right] \left(\frac{10}{9}\right) - \left[1 - \frac{1\ 442}{842}\right]} = 0,935$$

where

$E_3'$  is 9 MPa according to [Table 2](#);

$D_E$  is 842 mm;

$W_t$  is 1 442 mm.

Finally:

$$E' = 10 \times 0,935 = 9,35\ \text{MPa}.$$

**B.4.3 Calculate the value of  $S$  (for all three traffic load systems)**

The value of  $S$  is obtained from [Formula \(7\)](#):

$$S = \frac{E \left( \frac{e_{\text{stiff}}^3}{12} \right)}{D^3}$$

$$S = \frac{170\,000 \times \left( \frac{8,55^3}{12} \right)}{833,45^3} = 0,015\,3 \text{ MPa}$$

where

- $S$  is the pipe diametral stiffness, in MPa ( $S$  can be also directly taken from the relevant annexes of ISO 2531);
- $E$  is 170 000 MPa, the modulus of elasticity of ductile iron material;
- $e_{\text{stiff}}$  is 8,55 mm [(9,6+7,5)/2];
- $D$  is 833,45 mm, the mean diameter of pipe, [ $D_E - e_{\text{stiff}}$ ];
- $D_E$  is 842 mm, the external diameter (DE) of pipe, as specified in [Annex A](#).

**B.4.4 Calculate the value of  $\Delta_{\text{allowable}}$  (for all three traffic load systems)**

$\Delta_1$  is obtain from [7.5](#), that gives 4 % for DN 800.

$\Delta_2$  is obtain from [Formula \(16\)](#):

$$\Delta_2 = 100 \cdot \frac{R_f \cdot (D_E - e_{\text{nom}})}{S_{\text{FB}} \cdot E \cdot e_{\text{nom}} \cdot D_F}$$

$$\Delta_2 = 100 \times \frac{500 \times (842 - 9,6)}{1,5 \times 170\,000 \times 9,6 \times 3,5} = 4,857 \%$$

$\Delta_{\text{allowable}}$  is the lesser of  $\Delta_1$  and  $\Delta_2$ , i.e. 4 %.

**B.4.5 Calculate the value of  $\Delta_{\text{actual}}$  and comparison with  $\Delta_{\text{allowable}}$**

Based on the value of  $q$  calculated in [Table B.8](#), the values of  $\Delta_{\text{actual}}$  and  $\Delta_{\text{allowable}}$  for all three traffic load system are given in [Table B.9](#).