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Design method for ductile iron pipes

Méthode de calcul des tuyaux en fonte ductile

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Contents

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 10803 was prepared by Technical Committee ISO/TC 5, *Ferrous metal pipes and metallic fittings*, Subcommittee SC 2, *Cast iron pipes, fittings and their joints*.

Annexes A to D of this International Standard are for information only.

Design method for ductile iron pipes

1 Scope

This International Standard covers the design of ductile iron pipes used for conveying water, sewage and other fluids:

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

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 2531:1998, *Ductile iron pipes, fittings, accessories and their joints for water or gas applications.*

ISO 6708:1995, *Pipework components — Definition and selection of DN (nominal size).*

ISO 7186:1996, *Ductile iron products for sewage applications.*

ISO 7268:1983/Amd.1:1984, *Pipe components — Definition of nominal pressure — AMENDMENT 1.*

ISO 10802:1992, *Ductile iron pipelines — Hydrostatic testing after installation.*

3 Terms and definitions

For the purposes of this International Standard, the term and definition given in ISO 7268:1983/Amd.1:1984 and the following apply.

3.1
allowable operating pressure
internal pressure, excluding surge, that a component can safely withstand in permanent service

3.2
allowable maximum operating pressure
maximum internal pressure, including surge, that a component can safely withstand in service

3.3
allowable test pressure
maximum internal hydrostatic pressure which can be applied on site to a component in a newly installed pipeline

NOTE This test pressure is different from the system test pressure, which is related to the design pressure of the pipeline and is intended to ensure its integrity and leak tightness.

3.4
embedment
arrangement and type(s) of material around a buried pipeline which contribute to its structural performance

See Figure 1.

3.5
bedding
lower part of the embedment, made of the lower bedding (if necessary) and the upper bedding

See Figure 1.

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, as defined in AASHTO T99 using a 2,5 kg rammer and a 305 mm drop

4 Design procedure

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 traffic.

Using the equations given in clauses 5 and 6, the design of buried pipes can be performed either by calculating the pipe wall thickness from the expected internal pressure and external loads, or by determining for each available pipe wall thickness class the allowable pressures and heights of cover; these are shown in annex A and annex B respectively.

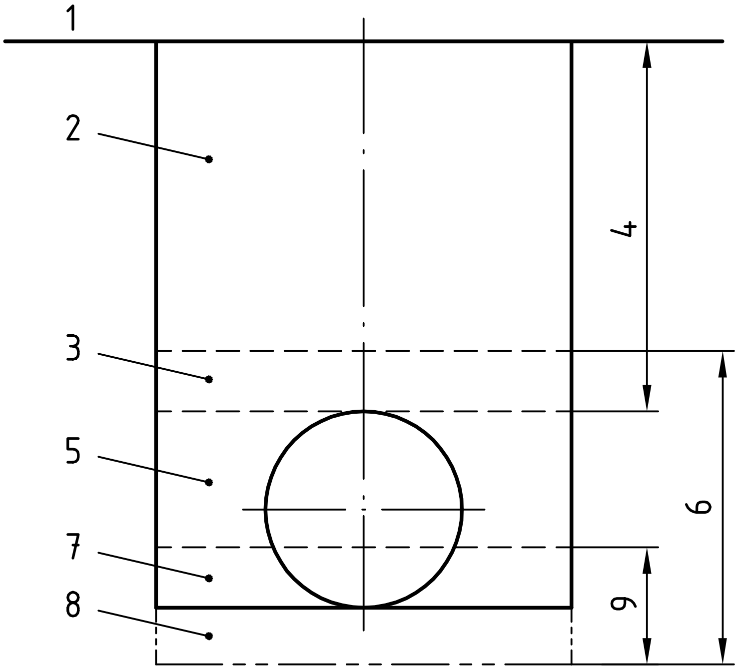
The design equations allow the calculation of the minimum pipe wall thickness t as the larger of t_1 and t_2:

- t_1 to resist hoop stresses due to internal pressure (see clause 5);
- t_2 to limit the diametral deflection and bending stresses caused by external loads (see clause 6).

The required nominal pipe wall thickness is then determined by adding the casting tolerance specified in ISO 2531 to the minimum pipe wall thickness t; the appropriate standard thickness class can thus be selected.

This procedure is based on separate design for internal pressure and for external loads; this is due to the marginal effect of the combination of stresses for ductile iron pipes which is amply covered by the high design safety factors (see 5.2).

NOTE National standards and regulations may specify other design methods.



Key

1	Surface
2	Main backfill
3	Initial backfill
4	Depth of cover
5	Side fill
6	Embedment
7	Upper bedding
8	Lower bedding
9	Bedding

Figure 1 — Trench diagram

5 Design for internal pressure

5.1 Design equation

$$t_1 = \frac{p(D - t_1)\mathrm{SF}}{2R_\mathrm{m}}$$

where

t_1 is the minimum pipe wall thickness to resist hoop stresses due to internal pressure, in millimetres;

p is the internal pressure, in megapascals (see 5.2);

D is the pipe external diameter as specified in ISO 2531, in millimetres;

R_m is the minimum ultimate tensile strength of the material, in megapascals (420 MPa according to ISO 2531);

SF is the design safety factor (see 5.2).

5.2 Design safety factors

The minimum pipe wall thickness, t_1, shall be calculated with a design safety factor of 2,5 for the maximum allowable operating pressure and a design safety factor of 3 for the allowable operating pressure.

NOTE This allows field testing of installed ductile iron pipelines in compliance with ISO 10802 by application of test pressures up to the allowable test pressures shown in annex A.

6 Design for external loads

6.1 Design equation

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

where

Δ is the pipe diametral deflection, in percent of external diameter D;

K_x is a deflection coefficient depending on the bedding reaction angle;

q is the vertical pressure at pipe crown due to all external loads, in megapascals;

$S = \dfrac{EI}{(D - t_m)^3}$ is the pipe diametral stiffness, in megapascals (see ISO 2531 and ISO 7186);

E' is the modulus of soil reaction, in megapascals;

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

$I = \dfrac{(t_2 + 0{,}65 + 0{,}000\,5\text{DN})^3}{12}$ is the second moment of area of the pipe per unit length, in millimetres to the third power;

D is the pipe external diameter as specified in ISO 2531, in millimetres;

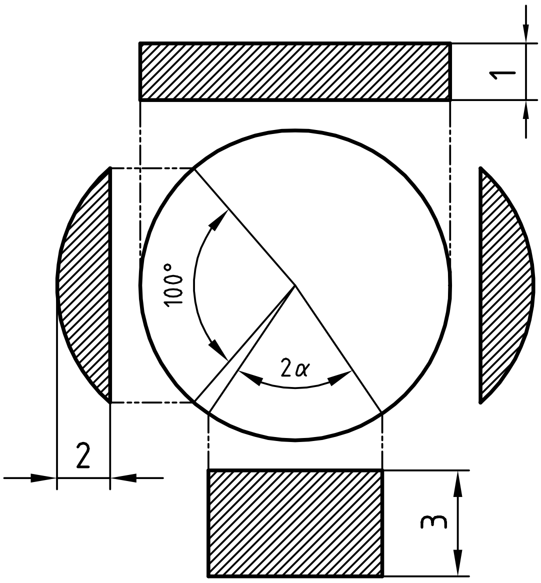
$t_m = \dfrac{t_2 + t}{2}$ is the calculation thickness for the diametral stiffness of the pipe, in millimetres;

t_2 is the minimum pipe wall thickness to limit the diametral deflection and bending stress caused by external loads, in millimetres;

t is the nominal pipe wall thickness (see 6.4, note 2), in millimetres.

NOTE This design equation is based on the Spangler model (see Figure 2) where the vertical pressure q acting downward:

- 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 2α;
- causes a pipe deflection which gives rise to an horizontal reaction pressure at pipe sides, parabolically distributed over an angle of 100°.



Key

1	q
2	$0{,}01\Delta E'$
3	$\dfrac{q}{\sin\alpha}$

Figure 2 — Spangler model

6.2 Loads applied to the pipe

The total vertical pressure q acting at pipe crown is the sum of two pressures:

$$q = q_1 + q_2$$

where

q_1 is the pressure from earth loads;

q_2 is the pressure from traffic loads.

NOTE The pressure from traffic loads q_2 is greater than that from normal static loads applied to the ground surface; however any abnormal surface loading may require special consideration.

6.2.1 Pressure from earth loads

The following equation shall be used to calculate q_1 from the weight of the earth prism immediately above the pipe:

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

where

q_1 is the pressure at pipe crown, in megapascals;

γ is the unit weight of the backfill, in kilonewtons per cubic metre;

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

In the absence of other data, the unit weight of the soil shall be taken equal to 20 kN/m^3, to cover the vast majority of cases. However, if a preliminary geotechnical survey determines that the actual unit weight will be less than 20 kN/m^3, the actual value may be used for determining q_1; or, if the actual value will be greater than 20 kN/m^3, the actual value shall be used.

6.2.2 Pressure from traffic loads

The value of q_2 shall be calculated in compliance with national and/or local applicable standards and regulations.

However, the following simplified formula may be used to calculate q_2 as it covers most of the regulations and types of traffic:

$$q_2 = 0{,}04 \frac{\beta}{H} (1 - 2 \times 10^{-4} \text{ DN})$$

where

q_2 is the pressure at pipe crown, in megapascals;

β is a traffic load factor;

H is the height of cover, in metres;

DN is the nominal size.

NOTE 1 This formula is not applicable when $H < 0{,}3$ m.

Three types of traffic loading shall be considered:

- main roads, $\beta = 1{,}5$: this is the general case, except access roads;
- access roads, $\beta = 0{,}75$: roads where truck traffic is prohibited;
- rural areas, $\beta = 0{,}5$: all other cases.

NOTE 2 In certain countries, national regulations require the use of higher values for β.

All pipelines shall be designed for at least $\beta = 0{,}5$ and pipelines laid adjacent to roads shall be designed to withstand the full road loading. Finally, for pipelines which may be exposed to particularly high traffic loading, a factor β of 2 or more may be adopted.

NOTE 3 For pipelines under railroads or airports or subjected to heavy construction traffic, special requirements will apply.

6.3 Soil-pipe interaction

The bedding reaction angle depends on the installation conditions (bedding, sidefill compaction) and on the pipe diametral deflection (especially for large sizes).

The modulus of soil reaction E' of the sidefill depends upon the type of soil used for the embedment and upon the trench type (see annex C). In the absence of applicable standards or other data, the values of E' indicated in Table 1 may be used at the design stage for five typical trench types and for six soil groups (see annex D for the classification of soils).

NOTE 1 These data are valid for pipes laid under embankments as well as in trenches.

NOTE 2 A preliminary geotechnical survey will allow classification of the soil and proper selection of E' values.

NOTE 3 E' values given in Table 1 apply when trench shoring is left in place or removed in such a way as to allow compaction of sidefill against the native trench wall; otherwise, reduced E' values will apply.

NOTE 4 In very poor ground, it may be necessary to use a soil stabilisation matting to prevent migration of the embedment with resultant loss of soil reaction modulus E'.

Table 1 — Modulus of soil reaction E'

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 (2α)	30°	45°	60°	90°	150°
K_x	0,108	0,105	0,102	0,096	0,085
E' (MPa)					
Soil Group A	4	4	5	7	10
Soil Group B	2,5	2,5	3,5	5	7
Soil Group C	1	1,5	2	3	5
Soil Group D	0,5	1	1,5	2,5	3,5
Soil Group E	[b]	[b]	[b]	[b]	[b]
Soil Group F	[b]	[b]	[b]	[b]	[b]

[a] Depending on the type of soil and its moisture content, a standard proctor density of 70 % to 80 % will normally be achieved by simply dumping the soil in the trench.

[b] Use an E' value of 0 unless it can be ensured that a higher value will be achieved consistently.

6.4 Allowable pipe diametral deflection

The allowable pipe diametral deflection Δ_{max} is indicated in Table 2 for the most frequently used pipes. These values provide sufficient safety against yield bending strength of the pipe wall, lining deformation, joint leaktightness, and hydraulic capacity of the pipe. However, national standards and/or the manufacturer's catalogues may introduce more stringent limitations, e.g. 3 % for cement mortar linings.

NOTE 1 For each DN, the allowable pipe diametral deflection, Δ_{max}, is the lowest of the three following limits:

a) $\Delta_1 = 5$ %;

b) Δ_2 which provides a safety factor of 2 against irreversible damage of the lining:

- for cement mortar linings (DN ⩾ DN 300):

$$\Delta_2 = 3 + \frac{\mathrm{DN} - 300}{500}$$, with a maximum of 4 %;

- for flexible linings:

$\Delta_2 = 2\Delta_3$, with a maximum of 10 %;

c) Δ_3 which provides a safety factor of 1,5 against the yield bending strength of the ductile iron pipe wall

$$\Delta_3 = 100\,\frac{R_f\,(D - t)}{\mathrm{SF} \cdot E \cdot t \cdot \mathrm{DF}}$$

where

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

D is the pipe external diameter as specified in ISO 2531 and ISO 7186, in millimetres;

t is the nominal pipe wall thickness, in millimetres;

SF is the safety factor (=1,5);

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

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

NOTE 2 The nominal pipe wall thickness, t, is as specified in ISO 2531 for pipes complying with ISO 2531. For pipes complying with ISO 7186, t is equal to the minimum pipe wall thickness given in ISO 7186 plus the manufacturing tolerance (1,3 + 0,001 DN, in millimetres).

Table 2 — Allowable pipe diametral deflection

DN	Δ_{max} (%)					
	Pipes complying with ISO 7186		Pipes complying with ISO 2531			
			K9		K10	
	Cement-mortar lining	Flexible lining[a]	Cement-mortar Lining	Flexible lining[a]	Cement-mortar lining	Flexible lining[a]
40	—	—	0,45	0,45	0,45	0,45
50	—	—	0,55	0,55	0,55	0,55
60	—	—	0,65	0,65	0,65	0,65
65	—	—	0,70	0,70	0,70	0,70
80	—	—	0,85	0,85	0,85	0,85
100	1,65	1,65	1,05	1,05	1,05	1,05
125	2,00	2,00	1,30	1,30	1,20	1,20
150	2,30	2,30	1,55	1,55	1,40	1,40
200	2,70	2,70	1,90	1,90	1,70	1,70
250	2,95	2,95	2,20	2,20	2,00	2,00
300	3,00	3,20	2,50	2,50	2,25	2,25
350	3,10	3,50	2,70	2,70	2,45	2,45
400	3,20	3,75	2,90	2,90	2,60	2,60
450	3,30	3,95	3,05	3,05	2,75	2,75
500	3,40	4,20	3,25	3,25	2,90	2,90
600	3,60	4,55	3,55	3,55	3,20	3,20
700	3,80	4,25	3,75	3,75	3,40	3,40
800	4,00	4,50	4,00	4,00	3,55	3,55
900	4,00	4,65	4,00	4,15	3,75	3,75
1 000	4,00	4,85	4,00	4,30	3,85	3,85
1 100	4,00	4,45	4,00	4,45	4,00	4,00
1 200	4,00	4,55	4,00	4,55	4,00	4,10
1 400	4,00	4,75	4,00	4,75	4,00	4,25
1 500	4,00	4,80	4,00	4,80	4,00	4,35
1 600	4,00	4,90	4,00	4,90	4,00	4,40
1 800	4,00	5,00	4,00	5,00	4,00	4,50
2 000	4,00	5,00	4,00	5,00	4,00	4,60
2 200	4,00	5,00	4,00	5,00	4,00	4,70
2 400	4,00	5,00	4,00	5,00	4,00	4,75
2 600	4,00	5,00	4,00	5,00	4,00	4,85

[a] Flexible linings are those linings which can withstand without cracking a pipe diametral deflection of two times Δ_{max}.