INTERNATIONAL STANDARD

ISO 21052

First edition
2021-11

Restrained joint systems for ductile iron pipelines — Calculation rules for lengths to be restrained

Systèmes d'assemblages verrouillés pour canalisations en fonte ductile — Règles de calcul pour les longueurs à verrouiller

Reference number
ISO 21052:2021(E)

Contents

Page

Foreword ..... **v**

1 Scope **1**

2 Normative references **1**

3 Terms, definitions and symbols **1**
- 3.1 Terms and definitions 1
- 3.2 Symbols 3

4 Thrust restraint principles, calculation rules and general specification **4**
- 4.1 Thrust forces 4
- 4.2 Calculation rules and general specification 4
- 4.3 Standard jointing systems offer no longitudinal restraint 5
- 4.4 Restrained joint systems 5
- 4.5 Length to be restrained 5
- 4.6 Restrained design method 5
- 4.7 Gravity thrust blocks 6

5 Thrust force **6**
- 5.1 Internal hydrostatic pressure in straight pipes 6
- 5.2 Internal hydrostatic pressure in bends 6
- 5.3 Internal hydrostatic pressure in other configurations 7

6 Restrained joints **8**
- 6.1 Principle 8
- 6.2 Conservative design 8
- 6.3 Required prevailing site conditions 8

7 Unit frictional force, F_s **8**
- 7.1 Static frictional force 8
- 7.2 Values of soil cohesion 9

8 Polyethylene encasement and PU coating and other extruded organic coatings **10**

9 Unit bearing resistances, R_s **10**
- 9.1 Lateral resistance, passive soil pressure 10
- 9.2 Design value of passive soil pressure 10
- 9.3 Empirical values of passive soil pressure 11

10 Application to common situations **14**
- 10.1 Horizontal bends 14
- 10.2 Vertical down bends 15
- 10.3 Vertical up bends 15
- 10.4 Tees 16
- 10.5 Reducers 17
- 10.6 Dead ends 17
- 10.7 Encroaching restrained lengths 17
- 10.8 Equal angle vertical offset (θ) 18
- 10.9 Combined horizontal equal angle bends (θ) 19
- 10.10 Combined horizontal unequal angle bends 20
- 10.11 Combined vertical equal angle offsets (θ) 21
  - 10.11.1 Pipeline under obstruction 21
  - 10.11.2 Pipeline over obstruction 22

11 Restrained lengths **22**

12 Installation and laying instruction **22**
- 12.1 Select backfill considerations 22
  - 12.1.1 Backfill material versus native soil support characteristics 22
  - 12.1.2 Swamps or marshes 22
- 12.2 Combining thrust blocks/anchor blocks and restrained joints 22

12.3 Pipe in a casing 23
12.3.1 Restrained lengths inside casing 23
12.3.2 Balancing the thrust force with restraining lengths outside the casing 23
12.4 Future excavations 23

Annex A (informative) **Dimensions and unit weights of pipes filled with water for preferred class** **24**

Annex B (informative) **Soil classification chart** **25**

Bibliography **26**

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 documents 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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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*.

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.

Restrained joint systems for ductile iron pipelines — Calculation rules for lengths to be restrained

1 Scope

This document specifies a computation method used to determine the length of the ductile iron pipes to be restrained, when used for conveying raw water, drinking water, sewerage under pressure.

This computation method takes into account all common pipeline route changes, including changes in the diameter of the pipeline itself and dead ends at the extremity of the pipeline, the outside diameter of the pipe, the system test pressure (to estimate the thrust), depth of cover, the characteristics of the soil surrounding the pipe and trench backfilling methods for a worldwide usage. The characteristics of the restrained joint are not covered by this document but can also be considered to determine the restraining length using any appropriate method.

The computation method defined in this document is applicable to all types of restrained joint systems, with their operating pressure ratings of ductile iron pipelines complying with ISO 2531, ISO 7186 and ISO 16631.

NOTE 1 ISO 10804 deals with actual design of the joint for various operating pressures of the pipeline.

NOTE 2 National standards or established calculation methods can be used instead of this ISO standard.

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 10804, *Restrained joint systems for ductile iron pipelines — Design rules and type testing*

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, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 2531, ISO 10804 and the following apply.

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1.1
mechanical flexible joint
flexible joint in which sealing is obtained by applying pressure to the gasket by mechanical means

3.1.2
push-in flexible joint
flexible joint assembled by pushing the spigot through the gasket into the socket of the mating component

3.1.3
restrained joint
joint in which a means is provided to prevent longitudinal separation of the assembled joint

3.1.4
maximum design pressure
MDP
P_{MD}
maximum operating pressure of the system or of the pressure zone fixed by the designer considering future developments and including surge

Note 1 to entry: It is the maximum pressure considering the design pressure and surge together, where:

— MDP is designated MDPa, P_{MDa}, fixed allowance for surge (secondary distribution networks);

— MDP is designated MDPc, P_{MDc}, surge is calculated (pumping & water mains).

[SOURCE: ISO 10802:2020, 3.6]

3.1.5
system test pressure
STP
P_{ST}
pressure to which a pipeline or a pipeline section is subjected for testing purposes

Note 1 to entry:

— PST = 1,5 × PD (when PMD ≤ 10 bar), or

— PST = PD + 5 (when PMD > 10 bar)

where P_D is the design pressure.

Note 2 to entry: 1 bar is equivalent to 0,1 MPa.

[SOURCE: ISO 10802:2020, 3.7, modified — The original note 2 to entry has been replaced by a new one.]

3.1.6
thrust force
unbalanced hydrostatic force developed at the locations of a pipeline, changing diameter or direction

3.1.7
bearing resistance
passive pressure that is generated as the pipeline attempts to separate and move into the soil

3.1.8
frictional resistance
resisting force resulting from the interaction of the pipeline with the soil encountered on the project site and the pipeline laying conditions

3.1.9
passive soil pressure
maximum pressure that the soil imparts on a structure at the prescribed depth

Note 1 to entry: The passive soil pressure is dependent upon the compaction of the soil.

3.1.10
restrained length
minimum length to be restrained in order to balance *thrust forces* (3.1.6) and prevent disassembly or separation of the pipeline

3.2 Symbols

A	cross-sectional area of pipe, in m^2
A_p	surface area of the pipe bearing on the soil, in m^2/m
C	pipe-soil cohesion, equals $f_c C_s$, in kN/m^2;
C_s	soil cohesion, in kN/m^2 (see Table 2)
D_e	outside diameter of pipe spigot, in m (see Annex A)
f_c	ratio of pipe-soil cohesion to soil cohesion (see Table 2)
F_f	unit frictional resistance, in kN/m
F_s	unit frictional force assuming 1/2 the pipe circumference bears against the soil, in kN/m
$(F_s)_b$	unit frictional force assuming the entire pipe circumference contacts the soil, in kN/m
f_φ	ratio of pipe-soil friction angle to soil friction angle (see Table 2)
h	thrust block height, in m
H	depth of cover to top of pipe, in m
H_c	depth of cover to pipe centreline, in m
K_n	trench condition modifier (see Table 2)
L	minimum required restrained pipe length, in m
N_φ	$= \tan^2 (45° + \varphi/2)$
P	system test pressure, in kN/m^2
P_p	passive soil pressure, in kN/m^2
R_s	unit bearing resistance, in kN/m
T	resultant thrust force, in kN
γ	backfill soil density, in kN/m^3 (see Table 2)
W	unit normal force on pipe = $2\ W_e + W_p + W_w$, in kN/m
W_e	earth prism load = $\gamma\ HD_e$, in kN/m
W_p	unit weight of pipe, in kN/m (see Annex A)
W_w	unit weight of water, kN/m (see Annex A)
θ	bend angle, in degrees
δ	pipe-soil friction angle, equals $f_\varphi\ \varphi$, in degrees;

φ soil internal friction angle, in degrees (see Table 2)

S_f safety factor (see 4.2)

4 Thrust restraint principles, calculation rules and general specification

4.1 Thrust forces

When underground or above-ground pipelines are in operation, unbalanced hydrostatic or hydrodynamic forces are developed at many locations under the internal pressure of the fluid in the pipeline, this is known as thrust forces. Unless the pipe joints in these areas are restrained against longitudinal movement, joint separation can result. These thrust forces are developed at locations where the pipeline changes either in diameter or in direction. Such locations include horizontal and vertical bends, tees, wyes, reducers, offsets, pipe bifurcations and valves.

At these locations the thrust forces are resisted with thrust blocks at the focus of the thrust force, or by installing a group of restrained joint pipes, in such a way that the unbalanced force is transmitted to the surrounding soil or pedestals (above-ground installation, without overstressing the pipeline wall and without subjecting the pipeline to joint separation).

The present standard studies and provides formulae which enable to balance thrust forces with the adequate quantity of restrained joint pipes.

Proper care shall be taken by the designer when chambers are installed within the restrained length of the pipeline.

The manufacturer's recommendations for selecting the type of restrained joint shall also be taken into account.

4.2 Calculation rules and general specification

The following parameters shall be taken into account: the cross-sectional area of the pipe (Table A.1), the pipeline changes generating the thrust force (Clause 5), the outside diameter of the pipe (Table A.1), the depth of cover of the pipe (see Figure 6), the characteristics of the soil surrounding the pipe and the trench backfilling methods (Clauses 7 and 9), the pipeline external coating system (bituminous, epoxy and acrylic paints or polyethylene encased pipe, PU and other extruded coatings - Clause 8).

The system test pressure (STP) of the pipeline is calculated from the maximum design pressure (MDP) and shall be used to estimate the thrust forces (Clause 5); and a safety factor of 2 is recommended.

For each pipeline changes and their combination, a specific formula is provided to calculate the length of pipes to be restrained. The list of common situations is provided in Table 1 together with the subclause number:

Table 1 — Type of common situation

Description	Subclause number
Horizontal bends	10.1
Vertical down bends	10.2
Vertical up bends	10.3
Tees	10.4
Reducers	10.5
Dead ends	10.6
Encroaching restrained lengths	10.7
Equal angle vertical offset (θ)	10.8

Table 1 *(continued)*

Description	Subclause number
Combined horizontal equal angle bends (θ)	10.9
Combined horizontal unequal angle bends	10.10
Combined vertical equal angle offsets (θ)	10.11
Pipeline under obstruction	10.11.1
Pipeline over obstruction	10.11.2

4.3 Standard jointing systems offer no longitudinal restraint

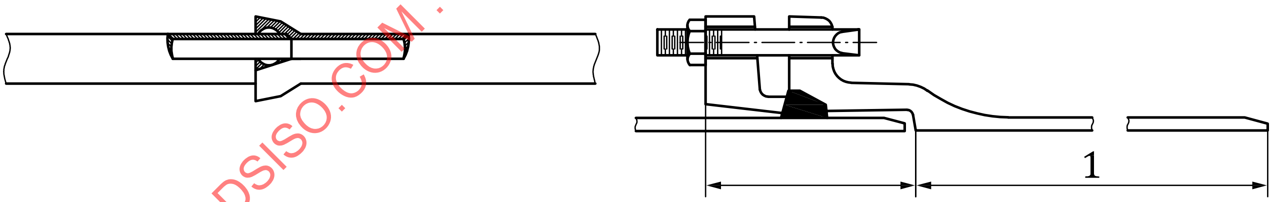
Ductile iron pipes and fittings are most often joined with push-in or mechanical flexible joints (Figure 1). Neither of these joints provide significant restraint against longitudinal separation other than the friction, between the gasket and the plain end of the pipe or fitting. Tests have shown that this frictional resistance of these joints are unpredictable. Thus, these joints should be considered as offering no longitudinal restraint for design purposes.

4.4 Restrained joint systems

The primary objective of the restrained joint system is to design a system to transmit the unbalanced forces to the surrounding soil without overstressing the pipeline wall and without subjecting the pipeline to joint separation. In order to accomplish the transfer of the unbalanced forces, the friction and passive resistance have been relied upon.

4.5 Length to be restrained

The length of the pipe, with restrained joints on each side of the focus of a thrust force, is calculated using the sum of the components of the unbalanced forces in the direction of the corresponding leg. The objective of the thrust restraint design using a restrained joint system is to extend the side of the fitting with inseparable joints so that the fitting can transmit the unbalanced forces to the surrounding soil.



a) Push-in flexible joint b) Mechanical flexible joint

Key

1 nominal laying length

Figure 1 — Push-in and mechanical flexible joints

4.6 Restrained design method

This document shows the method to calculate the quantum of thrust forces for the most common situations and the approaches to the design of restrained joint systems for balancing these forces. The suggested design approaches are conservatively based on accepted principles of soil mechanics.

4.7 Gravity thrust blocks

The design of gravity thrust blocks to counter the thrust forces in pipeline systems is not covered by this document. Thrust blocks/anchor blocks should not interfere with the angular deflection and axial movement of restrained joints as prescribed by the manufacturer.

5 Thrust force

5.1 Internal hydrostatic pressure in straight pipes

The internal hydrostatic pressure acts perpendicularly on any plane with a force equal to the pressure (P) times the area (A) of the plane. All components of these forces acting radially within a pipe are balanced by circumferential tension in the wall of the pipe. Axial components acting on a plane perpendicular to the pipe through a straight section of the pipe are balanced internally by the force acting on each side of the plane (Figure 2).

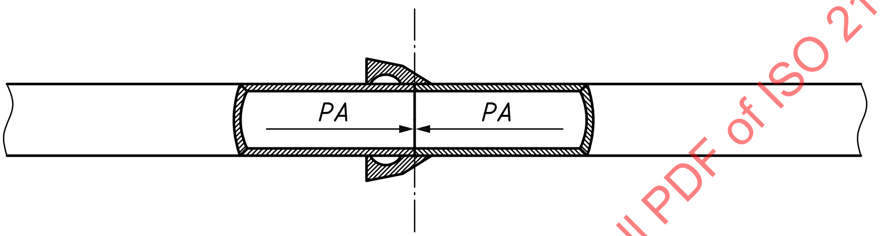


Figure 2 — Internally balanced force

5.2 Internal hydrostatic pressure in bends

In the case of a bend as shown in Figure 3, the forces PA acting axially along each side of the bend are not balanced. The vector sum of these forces is shown as T. This is the thrust force. In order to prevent separation of the joints, a reaction equal to and in the opposite direction of T, shall be established.

$$T = 2PA\sin\frac{\theta}{2} \tag{1}$$

where

- T is the resultant thrust force, in kN;
- P is the system test pressure, in kN/m^2;
- A is the cross-sectional area of pipe, in m^2;
- θ is the bend angle, in degrees.

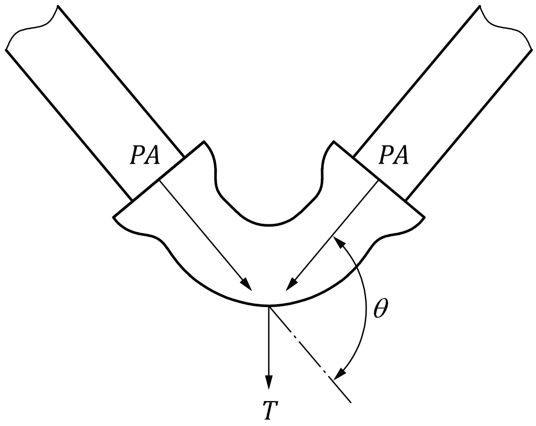
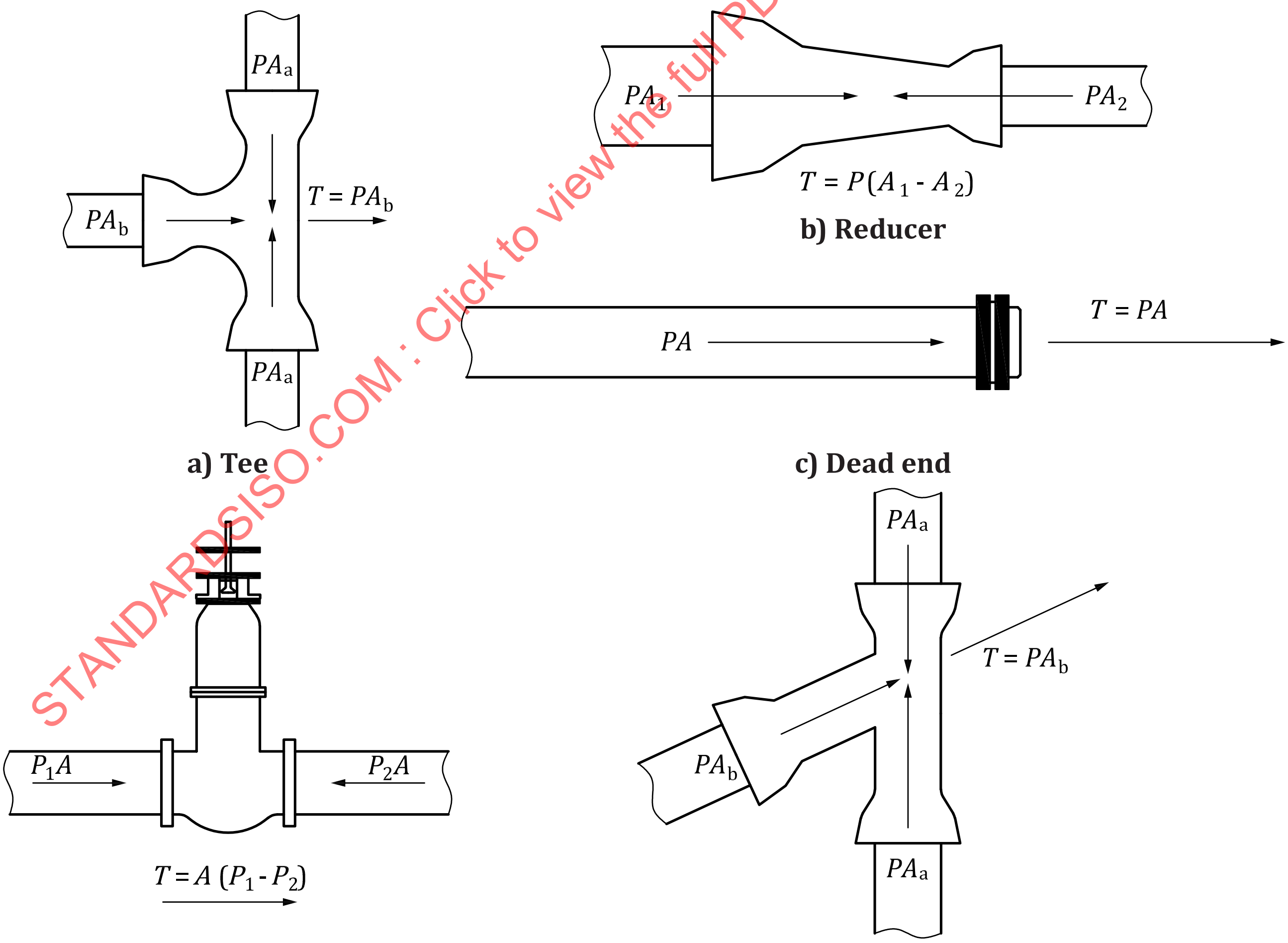


Figure 3 — Thrust force

5.3 Internal hydrostatic pressure in other configurations

Figure 4 depicts the net thrust force at various other configurations. In each case the expression for T can be derived by the vector addition of the axial forces.



a) Tee **b) Reducer** **c) Dead end** **d) Closed valve** **e) Wye**

Key

A_a is the cross-sectional area of the pipe a, in m^2

A_b is the cross-sectional area of the pipe b, in m^2

A_1 is the cross-sectional area of the pipe n°1, in m^2

A_2 is the cross-sectional area of the pipe n°2, in m^2

P_1 is the system test pressure of the pipe section n°1, in kN/m^2

P_2 is the system test pressure of the pipe section n°2, in kN/m^2

Figure 4 — Thrust force for various configurations

6 Restrained joints

6.1 Principle

The method of providing thrust restraint in the pipe itself is by the use of restrained joints. Restrained joint systems function, in a manner similar to thrust blocks, in so far as the reaction of the entire restrained lengths of piping with the soil balances the thrust forces.

6.2 Conservative design

A practical design procedure has been adopted in this document, based on valid assumptions. The assumptions considered in the design procedure are on the conservative side.

6.3 Required prevailing site conditions

Attention is drawn to the fact that all parameters considered in the formulae shall be validated by the prevailing site conditions as taken into consideration by the project designer/owner.

The thrust force shall be restrained or balanced by the reaction of the restrained pipe lengths with the surrounding soil, taking into account:

a) the static friction between the pipe length and the soil;

b) the restraint provided by the pipe as it bears against the side fill soil along each side of the fitting.

The use of restrained joint pipes, adjacent to the fittings, actually increases the lengths of all the arms of the fitting.

7 Unit frictional force, F_s

7.1 Static frictional force

The static frictional force acting on a body is equal in magnitude to the applied force, up to a maximum value. In the conventional analysis, the maximum static friction is proportional to the normal force between the surfaces which provide the friction. The constant of proportionality, in this case called the coefficient of friction, depends upon the nature of the surfaces. Experimental work indicates that for friction between pipes and soils, the force is also dependent upon the cohesion of the soil.

Thus,

$$F_s = A_p C + W \tan \delta \quad (2)$$

where

A_p is the surface area of the pipe bearing on the soil, in m^2/m:

$\pi D_e/2$ (for bends, assume 1/2 the pipe circumference bears against the soil);

πD_e (for tee branches, dead end conditions, and reducers, assume the full pipe circumference bears against the soil);

C is the pipe-soil cohesion, which equals $f_c C_s$, in kN/m^2;

f_c is the ratio of pipe-soil cohesion to soil cohesion;

W is the unit normal force, in kN/m;

C_s is the soil cohesion, in kN/m^2 (see Table 2);

δ is the pipe-soil friction angle, which equals $f_\varphi \varphi$, in degrees;

f_φ is the ratio of pipe-soil friction angle to soil friction angle;

φ is the internal friction angle of the soil, in degrees (see Table 2).

7.2 Values of soil cohesion

Values of soil cohesion (C_s) and internal friction angle of the soil φ, shall be known or conservatively estimated for the soil at a particular installation. f_c and f_φ are related to soil types and pipe material. Table 2 presents conservative values of these parameters, for ductile iron pipe in seven general classifications of soils.

The unit normal force W is given by

$$W = 2\,W_e + W_p + W_w \quad (3)$$

where the earth load (W_e) is taken as the prism load on the pipe in kN/m. The earth load is doubled, to account for the forces acting on both the top and the bottom of the pipe (see Figure 5). The unit weight of the pipe and water ($W_p + W_w$) is given in Annex A.

Then

— for bends:

$$F_s = \frac{\pi D_e}{2} C + \left(2W_e + W_p + W_w\right) \tan\delta \quad (4)$$

— for tee branches, dead-end conditions and reducers:

$$(F_s)_b = \pi D_e C + \left(2W_e + W_p + W_w\right) \tan\delta \quad (5)$$

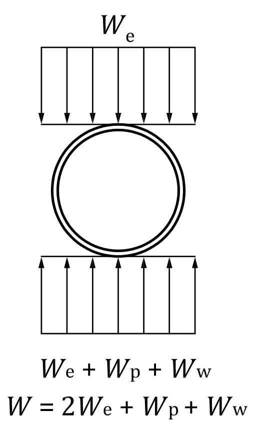


Figure 5 — Unit normal forces on pipe

Extraordinary installations can result in lesser loads and frictional resistance on the pipes than that calculated by Formulae (4) and (5) and as shown in Figure 5. When such conditions exist, this shall be provided for in the design.

8 Polyethylene encasement and PU coating and other extruded organic coatings

Limited experimental data suggest that the frictional resistance terms (F_s) and $(F_s)_b$ should be multiplied by a factor of 0,7, for pipe encased in polyethylene film, PU coatings and other extruded organic coatings to determine the appropriate value of F_f to be used in the formulae.

9 Unit bearing resistances, R_s

9.1 Lateral resistance, passive soil pressure

The maximum unit lateral resistance R_s, at the bend is limited, so as not to exceed a rectangular distribution of the passive soil pressure, P_p, which is generally less than the ultimate capacity of the soil to resist pipe movement. Passive soil pressure is a term generally defined as the maximum horizontal pressure that is resisted by the soil structure, without shearing failure of the soil. Horizontal sub grade pressure results in a deformation of the soil structure. The resistance offered by the sub grade soil increases with this deformation or strain for pressures less than the passive soil pressure.

In soils having a density that exceeds the critical void ratio (this condition is usually obtained in stable, undisturbed soil and in backfill compacted to approximately 80 % or more of the Proctor density), the movement or deformation that occurs in developing the full passive soil pressure is very small, in relation to the allowable, or available, movement at the bend in restrained push-in or mechanical joint systems used with ductile iron pipe.

The passive soil pressure for a particular soil is given by the Rankine formula:

$$P_p = \gamma H_c N_\varphi + 2C_s\sqrt{N_\varphi} \quad (6)$$

where

P_p is the passive soil pressure, in kN/m²;

γ is the backfill soil density, in kN/m³ (see Table 2);

H_c is the mean depth from surface to the plane of resistance (centreline of a pipe), in m;

C_s is the soil cohesion, in kN/m² (see Table 2);

N_φ equals $\tan^2(45°+\varphi/2)$;

φ is the internal friction angle of the soil, in degrees (see Table 2).

9.2 Design value of passive soil pressure

As shown in 9.1, the full Rankine passive soil pressure, P_p can be developed with insignificant movement, in well-compacted soils. For some of the standard laying conditions (see Figure 7) for ductile iron, the design value of passive soil pressure shall be modified by a factor K_n to ensure that excessive movement does not occur.

Therefore,

$$R_s = K_n P_p D_e \quad (7)$$

where

R_s is the unit bearing resistance, in kN/m;

K_n is the trench condition modifier (see Table 2);

P_p is the passive soil pressure, in kN/m^2;

D_e is the outside diameter of pipe spigot, in m (see Annex A).

9.3 Empirical values of passive soil pressure

Empirically determined values for K_n can be found in Table 2. In this context, the value chosen for K_n depends on the compaction achieved in the trench, the back-fill materials and the undisturbed earth.

Table 2 — Suggested values for soil parameters and reduction constant, K_n

Soil designation	Soil description	Internal friction angle of the soil φ	Ratio of pipe friction to soil f_φ	Soil cohesion C_s	Ratio of pipe cohesion to soil cohesion f_c	Backfill soil density γ	Factor for laying condition K_n			
		°		kN/m^2		kN/m^3	2[a]	3	4	5
Clay 1	Clay of medium to low plasticity, LL < 50, < 25 % coarse particles (CL and CL-ML)	0	0	14,37	0,80 (0,50[a])	14,139	0,2	0,4	0,6	0,85
Silt 1	Silts of medium to low plasticity, LL < 50, < 25 % coarse particles (ML and ML-CL)	29	0,50[a] 0,75	0	0	14,139	0,2	0,4	0,6	0,85
Clay 2	Clay of medium to low plasticity w/sand or gravel, LL < 50, 25-50 % coarse particles (CL)	0	0	14,37	0,80 (0,50[a])	14,139	0,4	0,6	0,85	1
Silt 2	Silt of medium to low plasticity w/sand or gravel, LL < 50, 25-50 % coarse particles (ML)	29	0,50[a] 0,75	0	0	14,139	0,4	0,6	0,85	1
Coh-gran	Cohesive granular soils, > 50 % coarse particles (GC and SC)	20	0,40[a] 0,65	9,58	0,4	14,139	0,4	0,6	0,85	1
Sand silt	Sand or gravel w/silt, > 50 % coarse particles (SC and SM) (GM and SM)	30	0,50[a] 0,75	0	0	14,139	0,4	0,6	0,85	1
Clean sand or clean gravel	Clean sand or clean gravel, > 95 % coarse particles (SW, SP and GW)	36	0,75[a] 0,80	0	0	15,71	0,4	0,6	0,85	1

[a] These values shall be used for laying condition type 2.

NOTE 1 Laying types are as follows:

— type 1 omitted since no compaction is not suitable for restrained joint;

— type 2 very light compaction Proctor density 75 %;

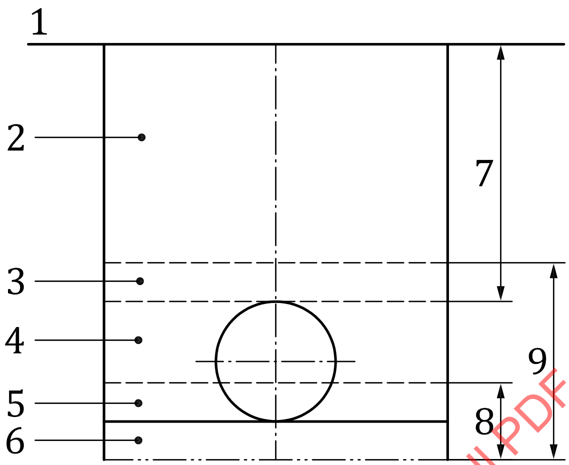
— type 3 light compaction Proctor density 80 %;

— type 4 medium compaction Proctor density 85 %;

— type 5 high compaction Proctor density 90 %.

NOTE 2 Laying types 1 and 6 (refer to Figure 7) require full pipeline to be restrained and are therefore not included in Table 2.

NOTE 3 Characteristics of soil are given in Annex B.



Key

1 surface

2 main backfill

3 initial backfill

4 side fill

5 upper bedding

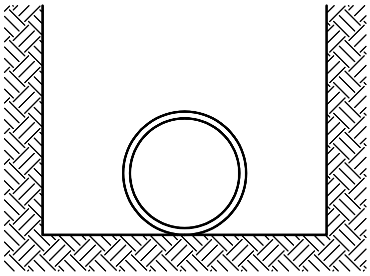
6 lower bedding

7 depth of cover

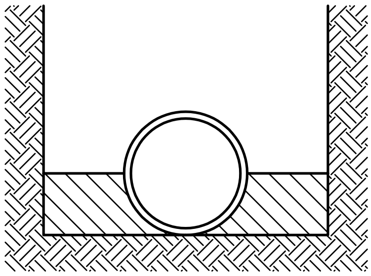
8 bedding

9 embedment

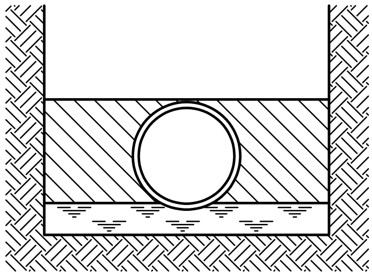
Figure 6 — Trench diagram



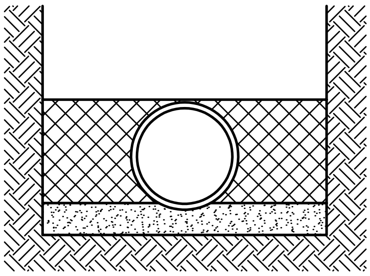
a) Laying type-1[a]



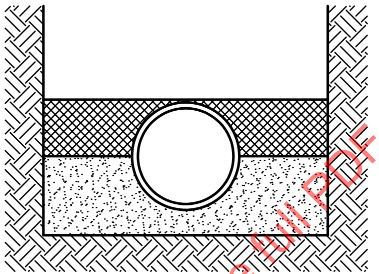
b) Laying type-2[b]



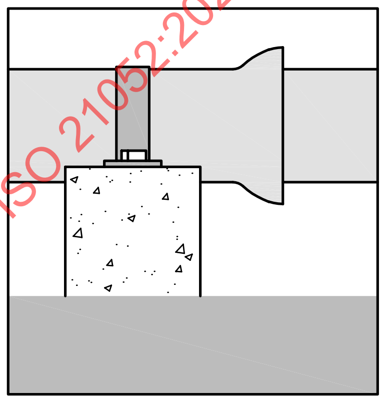
c) Laying type-3[c]



d) Laying type-4[d]



e) Laying type-5[e]



f) Laying type-6[f]

a Loose backfill.

b Backfill lightly consolidated to centreline of pipe.

c Pipe bedded in 100-mm minimum loose soil. Backfill lightly consolidated to top of pipe.

d Pipe bedded in sand gravel, or crushed stone to depth of 1/8 pipe diameter, 100 mm minimum. Backfill compacted to 80 % Proctor density top of pipe, 80 % standard.

e Pipe bedded to its centreline in compacted granular material, 100 mm minimum under pipe. Compacted granular or select material to top of pipe (approximately 90 % Proctor density).

f Pipes on support.

Figure 7 — Laying conditions 1 to 6 for ductile iron pipe

For DI pipes of any diameter, type 1 is not recommended.

NOTE 1 “Loose soil” or “select material” is defined as “native soil excavated from the trench, free of rocks, foreign material, and frozen earth”.

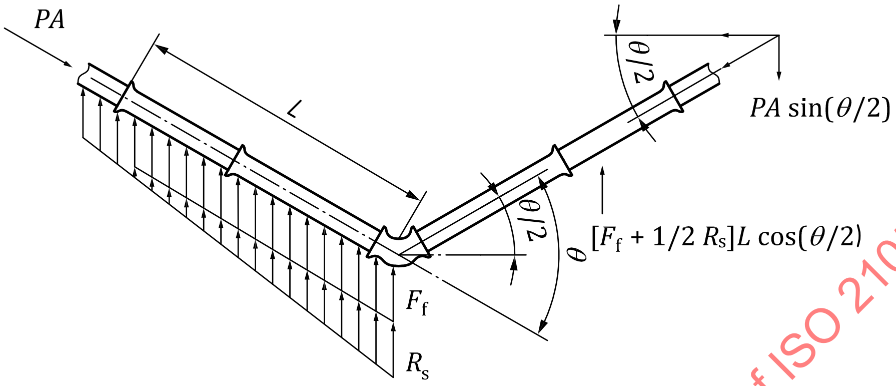
NOTE 2 Granular materials are unified soil with the exception that gravel bedding/backfill adjacent to the pipe is limited to 50 mm maximum particle size. For details, see Annex B.

Design Formulae (10) to (27) for vertical bends, tees, reducers, and dead ends are derived with assumptions, similar to those used in the derivation of the horizontal bend formula [Formula (9)]. This document doesn't include a full discussion of the derivations or discussion of all possible fittings and thrust configurations.

10 Application to common situations

10.1 Horizontal bends

Figure 8 is a free body diagram of a restrained pipe unit where L is the length of the restrained pipe on each side of the bend. The unit frictional resistance is shown as a distributed force of unit value F_f. The total frictional resistance on each side of the bend is then $F_f\,L\cos(\theta/2)$.



Key

$F_f = F_s$ for standard bituminous, epoxy or acrylic paint coated pipes

$F_f = 0{,}7\ F_s$ for polyethylene encased pipe, PU and other extruded coatings

Figure 8 — Force diagram of horizontal bend

The bearing resistance is shown as a distributed force with a maximum unit value of R_s at the bend, diminishing linearly to 0 at L. This assumption is based on the fact that the bearing resistance (passive resistance of the soil) is proportional to deformation or movement. As the restrained joints take load, maximum movement occurs at the bend. The total assumed bearing resistance on each side of the bend is $1/2R_sL\cos(\theta/2)$.

The equilibrium formula for the free body is then:

$$PA\sin\frac{\theta}{2} = F_f L\cos\frac{\theta}{2} + \frac{1}{2}R_s L\cos\frac{\theta}{2} \tag{8}$$

Employing a safety factor and solving for L,

$$L = \frac{S_f PA\tan\frac{\theta}{2}}{F_f + \frac{1}{2}R_s} \tag{9}$$

As to the design methodology, it is important to ensure that all sides resist the unbalanced force component along the length of the pipe leg, while satisfying overall equilibrium of the joint. Therefore, the length of the pipe with restrained joints in all sides should satisfy the following conditions.

— The resultant of the components of the thrust forces, in the direction of the leg, should be safely transferred to the soil along the pipe-soil interface to avoid joint separation.

— The resultant of the un-balanced thrust forces should be safely transmitted to the soil through friction and bearing.

The safety factor shall be chosen in accordance with 4.2 for the design of thrust restraint systems. Care should be exercised in the selection of the soil parameters used in the design, especially when the designer wants to take advantage of the adhesive and passive resistances from the soil (Clause 9).

10.2 Vertical down bends

See Figure 9.

NOTE For conservatism, the weight of the earth, pipe, and water directly opposing the thrust force is ignored; however, the weight of the earth, pipe, and water is used in calculating the unit frictional force, F_s.

Summation of forces in the “Y” direction:

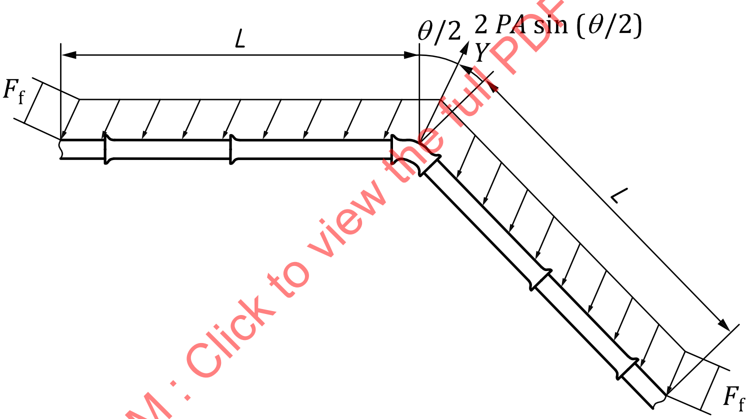
$$\Sigma F_Y = 0 \tag{10}$$

yields:

$$2PA\sin\frac{\theta}{2} - 2F_f L\cos\frac{\theta}{2} = 0 \tag{11}$$

employing a safety factor and solving for L,

$$L = \frac{S_f PA\tan\frac{\theta}{2}}{F_f} \tag{12}$$



Key

$F_f = F_s$ for standard bituminous, epoxy or acrylic paint coated pipes

$F_f = 0,7\ F_s$ for polyethylene encased pipe, PU and other extruded coatings

Figure 9 — Force diagram of vertical down bends

10.3 Vertical up bends

See Figure 8.

$$L = \frac{S_f PA tan\frac{\theta}{2}}{F_f + \frac{1}{2}R_s} \tag{13}$$

NOTE Force diagram is identical to that for horizontal bends (see Figure 8).

As the bend system in this case attempts to move in the direction of thrust, and against the bottom of the trench, the values of K_n in this case should be chosen to reflect the conditions of the trench bottom on which the pipe rests, assuming adequate socket holes are provided. In most cases, values representing those of type 4 or type 5 laying conditions may be used, as the trench bottom is normally relatively undisturbed.

10.4 Tees

See Figure 10.

$$PA_b = L_b F_f + \frac{1}{2} R_s L_r \tag{14}$$

Employing a safety factor and solving for L_b,

$$L_b = \frac{S_f PA_b - \frac{1}{2} R_s L_r}{F_f} \tag{15}$$

where

- R_s equals $K_n P_n D'_r$;
- A_b is the cross-sectional area of branch, in m^2;
- L_b is the length of branch to be restrained, in m;
- L_r is the total length between first joints on either side of tee on the run, in m;
- D'_r is the diameter of run, in m;
- F_f equals $(F_s)_b$; for standard bituminous, epoxy or acrylic paint coated pipes, in kN/m;
- F_f equals 0,7 $(F_s)_b$; for polyethylene encased pipe, PU coated pipes and other extruded organic coatings, in kN/m;
- $(F_s)_b$ is the unit frictional force (in kN/m) on branch:

  $\pi(D_e)C + (2W_e + W_p + W_w) \tan\delta$ (used for tee branches, dead end conditions and reducers);

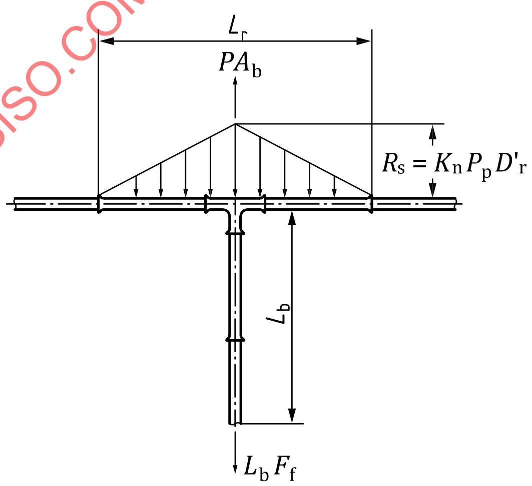


Figure 10 — Tee(s)

10.5 Reducers

See Figure 11.

$$L_1 = \frac{S_f P(A_1 - A_2)}{F_{f1}} \quad (16)$$

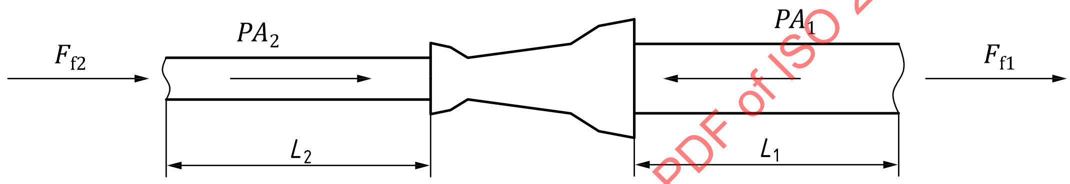
where

A_1 is the cross-sectional area of larger pipe;

A_2 is the cross-sectional area of smaller pipe;

NOTE If straight run of pipe on small side of reducer exceeds L_2, then no restrained joints are necessary.

$$L_2 = \frac{S_f P(A_1 - A_2)}{F_{f2}} \quad (17)$$



Key

$F_{f2} = (F_s)_{b2}$ and $F_{f1} = (F_s)_{b1}$ for standard bituminous, epoxy or acrylic paint coated pipes

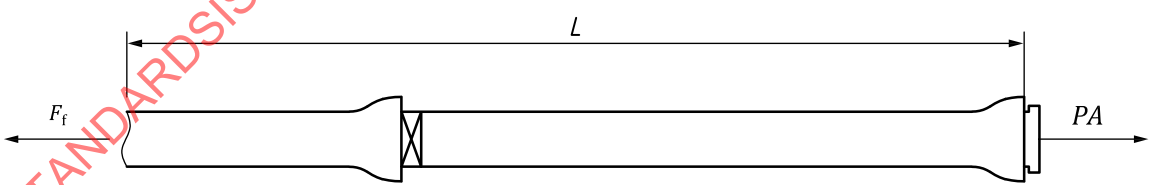
$F_{f2} = 0{,}7(F_s)_{b2}$ and $F_{f1} = 0{,}7(F_s)_{b1}$ for polyethylene encased pipe, PU and other extruded coatings

Figure 11 — Reducers

10.6 Dead ends

See Figure 12.

$$L = \frac{S_f PA}{F_f} \quad (18)$$



Key

$F_f = (F_s)_b$ for standard bituminous, epoxy or acrylic paint coated pipes

$F_f = 0{,}7(F_s)_b$ for polyethylene encased pipe, PU and other extruded coatings

Figure 12 — Dead ends

10.7 Encroaching restrained lengths

Both horizontal and vertical offsets are commonly encountered in restrained sections of a line. These offsets should be made with as small a degree bend as possible in order to minimize the thrust loads and restrained length required. Also, in these configurations an increase in line segment length can be detrimental to the pipeline or surrounding structures due to over deflection of the joints; therefore, the restrained joints should be fully extended (if applicable) during installation. In certain configurations, fittings may be close enough to one another that adjacent calculated restrained lengths overlap. In situations of this type, one approach is to:

— restrain all pipes between the two fittings;

— assume 1/2 of the restrained pipe length between the two fittings acts to resist the thrust force of each fitting;

— use the appropriate formulae, calculate the additional restrained length required on the outer legs of the fittings. 10.8 and 10.9 offer two such examples.

10.8 Equal angle vertical offset (θ)

See Figure 13.

As the bend angle approaches 90°, lateral movement of the outer legs approaches zero. For this condition, restrain all pipes between the fittings and restrain the outer legs as dead ends.

For L_1:

$$\Sigma F = 0$$

$$2PA\sin\frac{\theta}{2} = F_f L\cos\frac{\theta}{2} + F_f L_1\cos\frac{\theta}{2} \tag{19}$$

Employing a safety factor and solving for L_1,

$$L_1 = \frac{S_f 2PA\tan\frac{\theta}{2}}{F_f} - L \tag{20}$$

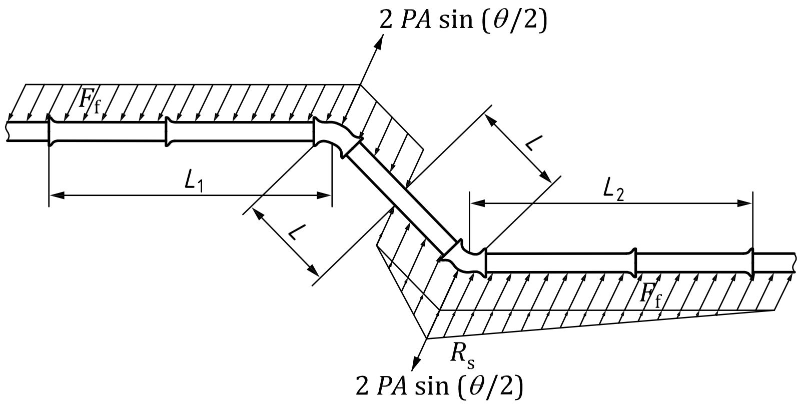
For L_2:

$$\Sigma F = 0$$

$$2PA\sin\frac{\theta}{2} = F_f L\cos\frac{\theta}{2} + \frac{1}{2}R_s L\cos\frac{\theta}{2} + F_f L_2\cos\frac{\theta}{2} + \frac{1}{2}R_s L_2\cos\frac{\theta}{2} \tag{21}$$

Employing a safety factor and solving for L_2,

$$L_2 = \frac{S_f 2\mathrm{PA}\tan\frac{\theta}{2}}{F_f + \frac{1}{2}R_s} - L \tag{22}$$



Key

$F_f = F_s$ for standard bituminous, epoxy or acrylic paint coated pipes

$F_f = 0{,}7F_s$ for polyethylene encased pipe, PU and other extruded coatings

Figure 13 — Force diagram of equal angle vertical offset (θ)

10.9 Combined horizontal equal angle bends (θ)

See Figure 14.

As the bend angle approaches 90°, lateral movement of the outer legs approaches zero. For this condition, restrain all pipes between the fittings and restrain the outer legs as dead ends.

For L_1:

$$2PA\sin\frac{\theta}{2} = F_f L\cos\frac{\theta}{2} + \frac{1}{2}R_s L\cos\frac{\theta}{2} + F_f L_1\cos\frac{\theta}{2} + \frac{1}{2}R_s L_1\cos\frac{\theta}{2} \quad (23)$$

Employing a safety factor and solving for L_1,

$$L_1 = \frac{S_f\, 2PA\tan\frac{\theta}{2}}{F_f + \frac{1}{2}R_s} - L \quad (24)$$

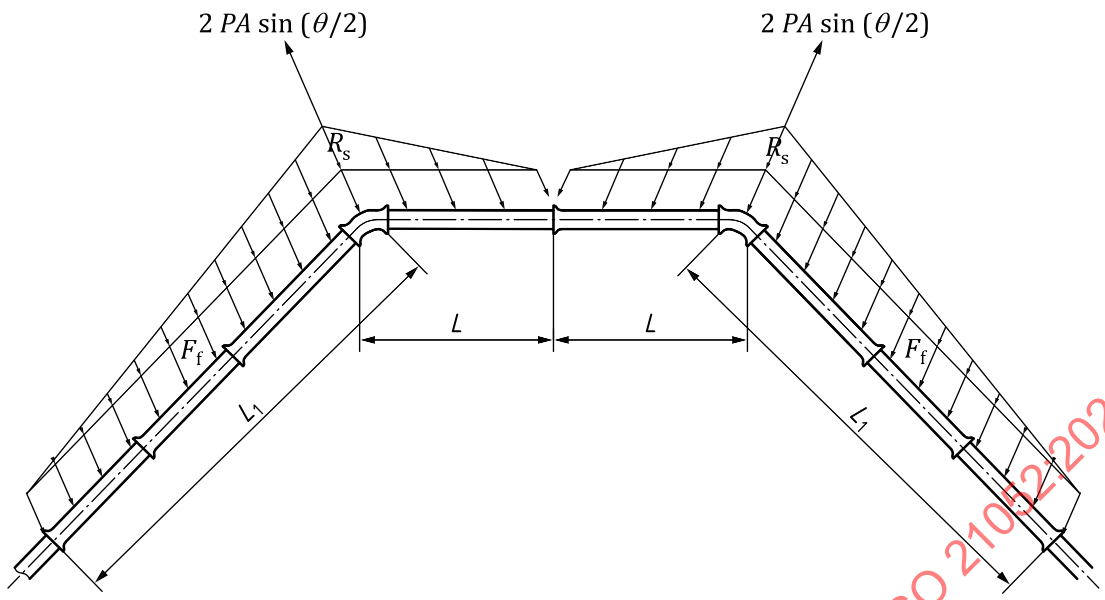


Figure 14 — Force diagram of combined horizontal equal angle bends (θ)

10.10 Combined horizontal unequal angle bends

See Figure 15.

For L_1:

$$2PA\sin\frac{\theta_1}{2}=F_f L\cos\frac{\theta_1}{2}+\frac{1}{2}R_{S1}L\cos\frac{\theta_1}{2}+F_f L_1\cos\frac{\theta_1}{2}+\frac{1}{2}R_{S1}L_1\cos\frac{\theta_1}{2} \quad (25)$$

Employing a safety factor and solving for L_1,

$$L_1=\frac{S_f\,2PA\tan\frac{\theta_1}{2}}{F_f+\frac{1}{2}R_{S1}}-L \quad (26)$$

For L_2:

$$2PA\sin\frac{\theta_{tot}}{2}=F_f L\cos\frac{\theta_{tot}}{2}+\frac{1}{2}R_{S2}L\cos\frac{\theta_{tot}}{2}+F_f L_2\cos\frac{\theta_{tot}}{2}+\frac{1}{2}R_{S2}L_2\cos\frac{\theta_{tot}}{2} \quad (27)$$

Employing a safety factor and solving for L_2,

$$L_2=\frac{S_f\,2PA\tan\frac{\theta_{tot}}{2}}{F_f+\frac{1}{2}R_{S2}}-L \quad (28)$$

With $\theta_{tot}=\theta_1+\theta_2$.

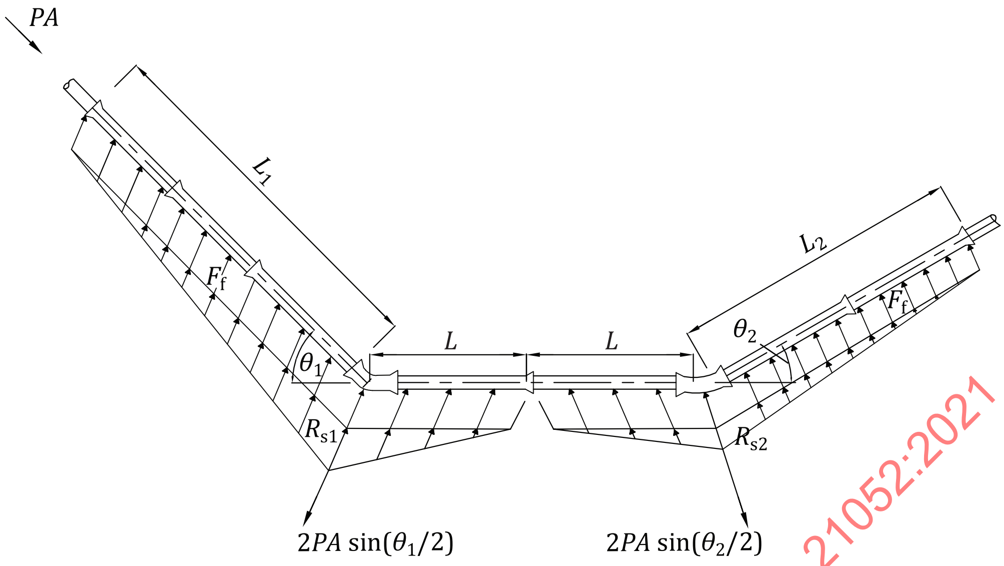


Figure 15 — Force diagram of combined horizontal unequal angle bends

10.11 Combined vertical equal angle offsets (θ)

10.11.1 Pipeline under obstruction

See Figure 16.

Vertical offsets are often combined to route a pipeline under an obstruction or existing utility. If the required restrained lengths of the vertical up bends do not overlap, the system may be treated as two individual vertical offsets (Figure 16). If the required restrained lengths do overlap, one approach is to:

— restrain all pipe between the outer-most two fittings;

— assume that the thrust forces of the middle two fittings (vertical up bends) are counteracted due to opposing forces;

— assume 1/2 of the restrained pipe length between the vertical down and vertical up bends acts to resist the thrust force of the vertical down bends;

— use the appropriate formulae, calculate the additional restrained length required on the outermost legs of the offset system (vertical down bends). The resulting formula is the same as for the vertical down bend in the single vertical offset [Formula (20)]:

$$L_1 = \frac{S_f\, 2PA \tan\dfrac{\theta}{2}}{F_f} - L \qquad (29)$$