®

ZPU MIĘDZYRZECZ
PREINSULATED PIPE SYSTEM

TO BE USED IN UNDERGROUND THERMAL UTILITIES

Static and Design Calculations
[Guidelines]

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1. Introduction

1.1 Study Subject

The subject of this study is to provide methods of making calculations and designs of preinsulated pipeline structures laid directly on ground.

1.2 Scope of Application

Methods of making calculations and designs have to be followed in drawing up of technical specifications of structures of pipelines made from preinsulated pipe and fittings and subsequently put into operation in networks carrying heating media with maximal working temperature of 152°C predicted for thirty-year lifetime.

1.3 Construction Plans and Specifications

Construction plans and specifications should be drawn up in accordance with the Building Law and methods presented in the study.

2. Basic Parameters

2.1 Geometric Properties

A	carrier pipe cross section area
DN	carrier pipe nominal diameter
D_z	carrier pipe external diameter
D_{zp}	jacket pipe nominal diameter
g	carrier pipe wall thickness
g_p	jacket pipe wall thickness
H	pipeline axis over full height of backfill
Hp	pipeline backfill height
L, C, D	compensating arm lengths
L	pipeline segment length
L_{max}	pipeline assembly length
ε	pipeline unit elongation
ΔL	buried pipeline L long elongation
ΔL_n	elongation of unburied pipeline [L_n] long heated up to a temperature of [T_p], free elongation
ΔL_z	buried elongation (shortening) of pipeline heated up to a temperature of [T]
L_n	length of unburied pipeline
l	preinsulated pipe length
r	preinsulated pipe bend radius
β	preinsulated pipe bend angle

2.2 Loads, Shearing Force, Load Bearing Capacity

V	jacket pipe unit soil stress
F	jacket pipe surface side friction
N	axial force
N_{max}	maximal axial force
N_{PS}	fixed point axial force
N_{RC}	rated load bearing capacity at compaction
p	carrier pipe pressure

2.3 Stresses and Strengths

σ	axial stress
τ	tangential stress
R_e	yield point specified by manufacturer (rated)
R_m	tensile strength specified by manufacturer
R_r	breaking strength
R_s	crushing strength
σ_{tr}	compressive stress at transport
σ_H	hoop stress
σ_x	axial stress
f_d	reduced rated steel strength
f_{dT}	reduced rated steel strength at increased temperatures
$f_{d'}$	rated steel strength

2.4 Material Constants, Factors and Others

E	Young's modulus
E_T	Young's modulus corrected to temperature
ν	Poisson's ratio
α	coefficient of linear expansion
λ	thermal conductivity
γ	load factor
μ	friction factor
ρ	backfill soil density
T	service temperature
T_0	assembly temperature
T_p	preheating temperature
ΔT	temperature difference
A_5	percent of minimal elongation
ρ_S	steel density
ρ_{PE}	hard polyethylene density
ψ	rated cross section load reductibility ratio
k	coefficient accounting for friction force between pipe and subgrade

3. Materials and Products

3.1 Carrier Pipe

Carrier pipe is a certified steel seamless pipe manufactured in compliance with DIN-1629, steel grade St 37.0, or PN-EN 10216-2 with steel grade P235GH, PN-EN 10216-1/A1 with steel grade P235TR1 and P235TR2 or certified seamed steel pipe in compliance with DIN-1626, steel St 37.0, as per PN-EN 10217-2/A1 and PN-EN 10217-5/A2 from steel P235GH, PN-EN 10217-1 with steel grade P235TR1 and P235TR2.

If these pipes are to be used in the transmission of potable hot water, then seamless pipe is to be used, manufactured in compliance with steel grade St 37.0 in accordance with DIN 1629, for pipes from steel grade P235GH per PN-EN 10216-2, P235TR1/P235TR2 according to PN-EN 10216-1 and galvanised in accordance with PE-EN 10240, PN-EN 1461, PN-EN 1179.

Product	Steel marking	Mechanical properties			
		R_e	R_m	A_5	f_{d}'
		MPa	MPa	%	MPa
Spiral or longitudinal seam pipe	St 37.0 P235GH	235	350	25	210
Rolled pipe	St 37.0 P235GH	235	345	25	210
Rolled pipe galvanised	St 37.0 P235GH	235	345	25	210

Steel material constants:

E = 205 GPa
ν = 0,3
α = 1,2 · 10^{-5}/°C
ρ_S = 7850 kg/m^3

Other types of carrier pipe:

copper pipe
polyethylene pipe
polypropylene pipe
post-chlorinated PVC pipe

3.2 Jacket Pipe

Jacket pipe made in accordance with standard PN-EN 253 from high density polyethylene (PEHD):

Product	Marking	Mechanical properties			
		σ_H	R_r	R_S	σ_{tr}
		MPa	MPa	MPa	MPa
Rigid polyethylene pipe	PEHD	4,0	24,0	37,0	3,0

PEHD material constants:

$\boldsymbol{E}$ = 1,0 GPa
λ = 0,43 W/mK
α_t = 0,2 · 10^{-5}/°C
ρ_{PE} = 950 kg/m^3

friction force between pipe and subgrade coefficient μ = 0,3÷05

Other types of carrier pipe:

SPIRO galvanized sheet or aluminium pipe (for overhead networks), PVC or steel pipe

3.3 Rigid Polyurethane Foam

Rigid polyurethane foam meets the requirements of standard	EN-253
density	min 60 kg/m^3
radial compression strength at a 10% relative strain	min 0,3 MPa
MDI index	min 130
Thermal conductivity index at λ_{50}:	
CO_2 foaming system (without freon)	max 0,030 W/mK
CO_2/cC5 foaming system (panthane)	max 0,029 W/mK

3.4 Pipe Unit

Pipe unit – preinsulated pipe complies with standard	EN-253/A1:2007/A2:2006(U)
thermal conductivity index at carrier pipe temperature - 70°C-90 °C	max 0,029 W/mK
expected life duration	min 30 years
axial shear strength	
(at 20°C)	min 0,12 MPa
(at 140°C)	min 0,08 Mpa
circumferential shear strength (at 20°C)	min 0,20 MPa

ZPU Międzyrzecz Sp. z o. o. uses preinsulated pipe up to a nominal diameter of DN 1000. Tables present geometric dimensions of preinsulated pipe up to DN 600.

Unit heat losses for a preinsulated pipeline are presented in Table 2.

Soil temperature = 8°C Hp = 0,6 m

Preinsulated Pipe Dimensions

Table 1

Steel Carrier Pipe					PEHD Jacket Pipe		PEHD Jacket Pipe	
DN	Dz	R-35	St 37.0	P235GH	*Standard Insulation*		*Insulation Plus*	
		g	g	g	Dzp	gp	Dzp	gp
mm	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*
20	26,9	2,9	2,6	Min. 2,6	75	3,0	90	2,5
25	33,7	2,9	2,6	Min. 2,6	90	3,0	110	2,5
32	42,4	2,9	2,6	Min. 2,6	110	3,0	125	2,5
40	48,3	2,9	2.6	Min. 2,6	110	3,0	125	2,5
50	60,3	3,2	2,9	Min. 2,9	125	3,0	*140*	3,0
65	76,1	3,2	2,9	Min. 2,9	140	3,0	160	3,0
80	88,9	3,6	3,2	Min. 3,2	160	3,0	200	3,2
100	114,3	4,0	3,6	Min. 3,6	200	3,2	225	3,5
125	139,7	4,0	3,6	Min. 3,6	225	3,4	250	3,9
150	168,3	4,5	4,0	Min. 4,0	250	3,6	315	4,9
200	219,1	6,3	4,5	Min. 4,5	315	4,1	400	6,3
250	273,0	7,1	5,0	Min. 5,0	400	4,8	450	7,0
300	323,9	7,1	5,6	Min. 5,6	450	5,2	500	7,8
350	355,6	8,0	5,6	Min. 5,6	500	5,6	520	8,2
400	406,4	8,8	6,3	Min. 6,3	520	5,8	560	8,8
450	457,0	10,0	6,3	Min. 6,3	560	6,0	630	9,8
500	508,0	11,0	6,3	Min. 6,3	630	6,6	710	11,1
600	610,0	–	7,1	Min. 7,1	800	7,9	–	–

Unit Heat Losses for a Preinsulated Pipeline [W.m]

Table 2

D_z	D_{ZP}	Pipeline Temperature					
mm	*mm*	150°C	130°C	110°C	90°C	70°C	50°C
26,9	75	20,2	17,3	14,5	11,7	8,8	6,0
33,7	90	24,7	21,2	17,7	14,3	10,8	7,3
42,4	110	25,5	21,9	18,3	14,7	11,1	7,5
48,3	110	29,3	25,2	21,1	16,9	12,8	8,7
60,3	125	33,0	28,3	23,7	19,0	14,4	9,8
76,1	140	39,3	33,8	28,2	22,7	17,2	11,6
88,9	160	40,7	35,0	29,2	23,5	17,8	12,0
114,3	200	42,7	36,7	30,7	24,7	18,6	12,6
139,7	225	49,9	42,8	35,8	28,8	21,8	14,7
168,3	250	59,6	51,2	42,8	34,4	26,0	17,6
219,1	315	65,1	56,0	46,8	37,6	28,4	19,3
273,0	400	62,5	53,7	44,9	36,1	27,3	18,5
323,9	450	72,3	62,1	52,0	41,8	31,6	21,4
355,6	500	70,1	60,2	50,4	40,5	30,6	20,7
406,4	560	74,6	64,1	53,6	43,1	32,6	22,1
457,0	630	74,7	64,2	53,7	43,2	32,6	22,1
508,0	710	72,0	61,9	51,8	41,6	31,5	21,3
610,0	800	88,6	76,1	63,6	51,2	38,7	26,2

4. Design Input Data

In the calculations of friction force [F], axial force [N], maximal assembly length [L_{max}] and elongations [ΔL] for ***ZPU Międzyrzecz Sp. z o. o.*** pipelines the following loads and material constants were used:

pipeline depth	H = 1m
compacted backfill density	ρ =1650 kg/m^3
jacket pipe-soil friction factor	μ = 0,35
passive soil pressure	K = 0,6
pipeline working pressure	p = 1,6 MPa
reduced calculated steel strength	f_d = 150 MPa
service temperature	
input	T = 135°C
return	T = 80°C
assembly temperature	T_0 = 8°C
Young's modulus accounted for temperature	E_T = 204 GPa
coefficient of linear elongation	
for 0÷100°C range	a_T = $1{,}2 \cdot 10^{-5}$/°C
for 0÷150°C range	a_T = $1{,}22 \cdot 10^{-5}$/°C
load factors	
load upper point	γ = 1,1
service upper point	γ = 1,0
Poisson's ratio	v = 0,3

5. Design Principles

5.1 Dimensioning Method

Dimensioning is performed by means of finite element method for loads and use in compliance with standard PN-76/B-03001, PN-EN 13941 showing that in service the pipeline will meet the load condition.

5.2 Loads

Preinsulated pipe laid down directly on ground is loaded by:

- friction forces affecting pipe side surface;
- soil pressure on jacket pipe;
- internal carrier pipe pressure response,

and is additionally subject to heating medium temperature changes inside the carrier pipe.
Thus, a static system of a limited degree of free elongation, where carrier pipe temperature drops and rises generate axial forces dependent on friction forces and internal carrier pipe pressure.

5.2.1 Soil-induced Load on a Buried Pipe

The unit passive soil pressure exerted on a buried pipe should be determined in accordance with standard PN-83/B-03001 from the formula:

- vertical component: $V_z = \gamma \cdot H \cdot \rho \cdot g$ $[N/m^2]$
- horizontal component: $V_x = \gamma \cdot H \cdot \rho \cdot g \cdot K_0$ $[N/m^2]$

where:

γ	load factor	
H	pipeline axis depth	$[m]$
ρ	backfill density	$[kg/m^3]$
g	gravitational acceleration	$[m/s^2]$
K_0	passive pressure coefficient	

To determine the unit soil pressure evenly distributed circumferentially an average value is taken into calculation and calculated from the formula:

$$V = 0.5 \cdot (V_z + V_x)$$

5.2.2 Friction Force on Side Surface

Friction force per pipe length unit [F] is calculated from the formula:

$$F = \mu \cdot V \cdot \pi \cdot D_{zp}$$

where:

μ friction coefficient between jacket pipe and soil	
V jacket pipe unit soil pressure	$[N/m^2]$
D_{zp} jacket pipe external diameter	$[m]$

5.2.3 Carrier Pipe Axial Force [N]

Axial force [N] in carrier pipe of a length of [L] generated by friction forces is calculated from the formula:

$$N = F \cdot L$$

where:

F friction coefficient between jacket pipe and soil	$[N/m]$
L jacket pipe unit soil pressure	$[m]$

5.3 Forces Resulting from Carrier Pipe Internal Pressure

It is assumed that the load generated by the heating medium is taken over by the carrier pipe, where the following stresses will appear:

- hoop stresses: $$\sigma_H = \frac{p \cdot (D_z \cdot g)}{2 \cdot g} \qquad [\mathrm{N/m^2}]$$
- axial stresses: $$\sigma_x = \frac{p \cdot (D_z \cdot g)}{4 \cdot g} \qquad [\mathrm{N/m^2}]$$

where:

p	carrier pipe pressure	$[\mathrm{N/m^2}]$
D_z	jacket pipe external diameter	[m]
g	carrier pipe wall thickness	[m]

Axial force derived from internal pipe pressure, being the axial stress here is:

$$N_x = \sigma_x \cdot A$$

where:

A	carrier pipe cross section area	$[\mathrm{m^2}]$

The impact of the axial force resulting from the internal carrier pipe pressure on the computed cross section loading is minimal, hence it can be neglected in further calculations.

5.4 Computed Loading Capacity of a Carrier Pipe Cross Section

If standard PN-90/B-03200 is to be complied with, then the pipe axial force cannot exceed the pipe computed loading capacity, namely:

$$N - N_x \leq N_{RC} \qquad [\mathrm{N}]$$

Once $N = F \cdot L$, $N_x = \sigma_x \cdot A$ and $N_{RC} = \psi \cdot A \cdot f_d$, the resultant equation is:

$$F \cdot L - \sigma_x \cdot A \leq \psi \cdot A \cdot f_d$$

where:

F	unit friction force	[N/m]
L	pipeline section length	[m]
ψ	rated cross section load reductibility ratio	
A	carrier pipe cross section	$[\mathrm{mm^2}]$
f_d	reduced rated steel strength	[MPa]
σ_x	axial stress	$[\mathrm{N/m^2}]$

6. Designing ZPU Międzyrzecz Sp. z o. o. Systems

Designing consists in determining:

- pipeline assembly section $[L_{max}]$, for which the maximal axial force in a carrier pipe $[N_{max}]$ does not exceed its rated load $[N_{RC}]$;
- pipeline extension $[\Delta L]$ and its compensation in a natural way using changes in the pipeline routing (expansion joints) or using compensators.

6.1 Method 1 - Natural

A pipeline having been assembled and tested is buried.

6.1.1 Maximal straight assembly length [L_{max}] of straight pipeline section

In accordance with Point 5.4 the rated load of a cross section of pipe is determined by the formula:

$$F \cdot L - \sigma_x \cdot A \leq \psi \cdot A \cdot f_d$$

where:

F	unit friction force	[N/m]
L	pipeline section length	[m]
ψ	rated cross section load reductibility ratio	
A	carrier pipe cross section	[mm^2]
f_d	reduced rated steel strength	[MPa]
σ_x	axial stress	[N/m^2]

If $L = L_{max}$ and providing $\psi = 1$ (class 1 of cross section), then the maximal assembly length [L_{max}] equals:

$$L_{max} = \frac{A \cdot (f_d + \sigma_x)}{F}$$

Maximal assembly lengths [L_{max}] for the carrier pipe diameters and wall thickness specified in Table 3 and 4 assume that a pipeline axis is buried at H = 1.0 m and at the initial data assumed in design.

Table 3

Seamless Carrier Pipe			Jacket Pipe	Friction Force	Assembly Length
Dz	g	A	Dzp	F	L_{max}
mm	*mm*	*mm^2*	*mm*	*N/m*	*m*
26,9	2,9	219	75	1410	24
33,7	2,9	281	90	1410	31
42,4	2,9	360	110	1723	32
48,3	2,9	414	110	1723	38
60,3	3,2	574	125	1958	46
76,1	3,2	733	140	2193	53
88,9	3,6	965	160	2506	61
114,3	4,0	1386	200	3132	71
139,7	4,0	1705	225	3524	79
168,3	4,5	2316	250	3916	97
219,1	6,3	4212	315	4934	140
273,0	7,1	5931	400	6265	156
323,9	7,1	7066	450	7048	168
355,6	8,0	8736	500	7831	187
406,4	8,8	10992	560	8144	211
457,0	10,0	14043	630	8771	239
508,0	11,0	17175	710	9867	260

Table 4

Welded Carrier Pipe			Jacket Pipe	Friction Force	Assembly Length
Dz	g	A	Dzp	F	L_{max}
mm	*mm*	*mm^2*	*mm*	*N/m*	*m*
26,9	2,6	198	75	1410	22
33,7	2,6	254	90	1410	28
42,4	2,6	325	110	1723	29
48,3	2,6	373	110	1723	34
60,3	2,9	523	125	1958	42
76,1	2,9	667	140	2193	49
88,9	3,2	862	160	2506	55

114,3	3,6	1252	200	3132	65
139,7	3,6	1539	225	3524	72
168,3	4,0	2065	250	3916	88
219,1	4,5	3034	315	4934	104
273,0	5,0	4210	400	6265	115
323,9	5,6	5600	450	7048	137
355,6	5,6	6158	500	7831	138
406,4	6,3	7919	560	8144	158
457,0	6,3	8920	630	8771	161
508,0	6,3	9930	710	9867	162
610,0	7,1	13448	800	12530	197

The assembly length $L_{max}^{H_i}$ and unit friction force F^{Hi} for a pipeline laid at a depth of H_i can be determined from the formula:

$$L_{max}^{H_i} = \frac{L_{max}}{H_i} \qquad F^{Hi} = F \cdot H_i$$

e.g. for: $D_z = 26.9\ mm$ $g = 2.9\ mm$
$L_{max} = 24\ m$ $F = 1410\ N/m$ as per Table 3

for $H_i = 0.6$ m $L_{max}^{0.6} = \frac{24}{0.6} = 40m$ $F^{0.6} = 1410 \cdot 0.6 = 846\ N/m$

In the case when a steel carrier pipe of a cross section area of [A] different than the dimensions specified in Tables 3 and 4 is used, L_{max} has to be pro rata changed.

6.1.2 Pipeline Expansion

The expansion by [ΔL] of a preinsulated buried pipeline whose assembly length is [L] is defined as a difference between free thermal expansion and expansion due to friction forces, and is calculated from the formula:

$$\Delta L = a_t \left(T - T_0\right) \cdot L - \frac{F \cdot L^2}{2 \cdot E_T \cdot A}$$

where:

α_T	coefficient of linear expansion	[1/°C]
T	service temperature	[°C]
T_0	assembly temperature	[°C]
L	pipeline segment length	[m]
F	unit friction force	[N/m]
E_T	coefficient of elasticity of elongation	[N/m^2]
A	carrier pipe cross section area	[m^2]

Once initial data are input (see Table 4) a simplified formula determining elongation, expressed in millimetres, [ΔL] is obtained:

for $T = 80^{\circ}C$ $[\Delta L] = 0.864 \cdot L - W \cdot H \cdot L^2$ [mm]
for $T = 135^{\circ}C$ $[\Delta L] = 1.549 \cdot L - W \cdot H \cdot L^2$ [mm]

where:

0.864 and 1.549	are constant	[mm/m]
W	coefficient dependent on carrier pipe cross section specified in Tables 3 and 4	[mm/m^3]
H	pipeline buried at	[m]
L	pipeline segment length	[m]

"W" Coefficient to determine the extension of the pipeline

Table 5

Seamless Carrier Pipe			**Insulation STANDARD**	**Insulation PLUS**
			Coeffcient	Coefficient
Dz	g	A	W	W
mm	*mm*	*mm^2*	*mm/m^3*	*mm/m^3*
26,9	2,9	219	0,0144	0,0176
33,7	2,9	281	0,0112	0,0137
42,4	2,9	360	0,0107	0,0121
48,3	2,9	414	0,0093	0,0105
60,3	3,2	574	0,0076	0,0085
76,1	3,2	733	0,0067	0,0076
88,9	3,6	965	0,0058	0,0072
114,3	4,0	1386	0,0050	0,0057
139,7	4,0	1705	0,0046	0,0051
168,3	4,5	2316	0,0038	0,0047
219,1	6,3	4212	0,0026	0,0029
273,0	7,1	5931	0,0024	0,0026
323,9	7,1	7066	0,0022	0,0025
355,6	8,0	8736	0,0020	0,0021
406,4	8,8	10992	0,0017	0,0018
457,0	10,0	14043	0,0014	0,0016
508,0	11,0	17175	0,0013	0,0014

Table 6

Welded Carrier Pipe			Insulation STANDARD	Insulation PLUS
			Coefficient	Coefficient
Dz	g	A	W	W
mm	*mm*	*mm^2*	*mm/m^3*	*mm/m^3*
26,9	2,6	198	0,0158	0,0193
33,7	2,6	254	0,0124	0,0151
42,4	2,6	325	0,0118	0,0134
48,3	2,6	373	0,0103	0,0117
60,3	2,9	523	0,0083	0,0093
76,1	2,9	667	0,0073	0,0084
88,9	3,2	862	0,0065	0,0081
114,3	3,6	1252	0,0056	0,0063
139,7	3,6	1539	0,0051	0,0057
168,3	4,0	2065	0,0042	0,0053
219,1	4,5	3034	0,0036	0,0041
273,0	5,0	4210	0,0033	0,0037
323,9	5,6	5600	0,0028	0,0310
355,6	5,6	6158	0,0028	0,0029
406,4	6,3	7919	0,0023	0,0025
457,0	6,3	8920	0,0022	0,0025
508,0	6,3	9930	0,0022	0,0025
610,0	7,1	13448	0,0021	0,0000

6.2 Method 2 - Initial Stresses

A pipeline having been assembled and tested prior to burying is subjected to a preheating. Once the requested elongation has been achieved, the pipeline is buried.
The preheating temperature [T_p] is set at such a point that when the buried pipeline is cooled down to the assembly temperature [T_0] and heated up to the service temperature [T], the axial stress [σ] does not exceed the computed compressive and tensile [f_d] strength of a steel pipe.

6.2.1 Elongation [ΔL_n] of an Unburied Pipe

A preheated [T_0] and unburied pipeline:

Elongation [ΔL] of a pipeline [L_n] long preheated to [T_p], and **unburied** – in other words free elongation is computed according to the formula:

$$\Delta L_n = k\cdot\alpha_1\cdot(Tp - T_0)\cdot L_n$$

where:

k	coefficient accounting for friction forces between pipe and soil	k = 0,7÷0,8
α_1	linear elongation coefficient	[1/°C]
T_p	preheating temperature	[°C]
T_0	actual assembly temperature	[°C]
L_n	unburied pipeline length	[m]

Free elongation of a preheated pipeline can be determined as a product of unit elongation [ε] and pipeline length [L_n]:

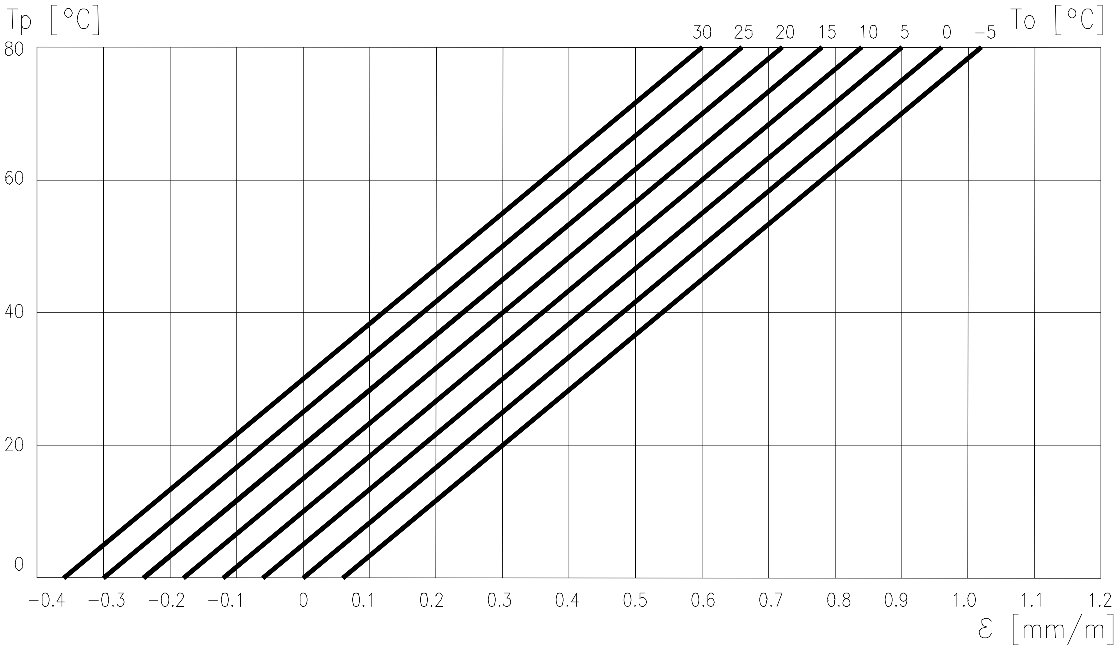
$$\Delta L_n = \varepsilon\cdot L_n \qquad \text{[mm]}$$

Pipeline unit elongation:

$$\varepsilon = \alpha_1\cdot(T_p - T_0) \qquad \text{[mm/m]}$$

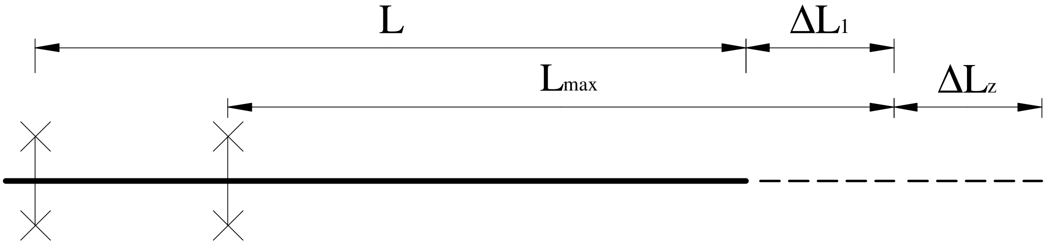
Pipeline unit elongation

Diagram 1



6.2.2 Elongation (Shortening) [ΔL_z] of an Unburied Pipe

A buried and service temperature [*T*] preheated pipeline:



Elongation, or shortening [ΔL_z], of a **buried** pipeline is calculated from the formula:

$$\Delta L_z = a_t \cdot \left(T - T_p\right) \cdot L_{max} - \frac{F \cdot L_{max}^2}{2 \cdot E_T \cdot A} \qquad \text{[m]}$$

where:

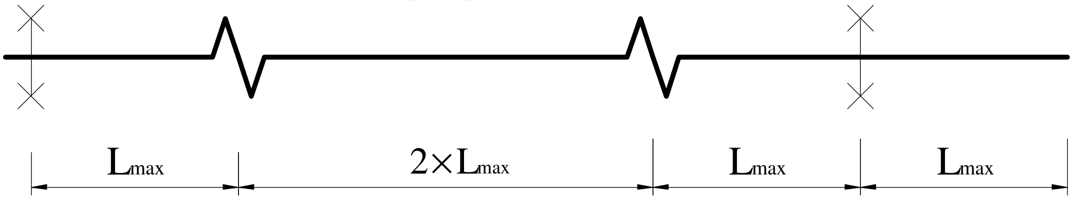
α_t	coefficient of linear expansion	[1/°C]
T	service temperature	[°C]
T_p	preheating temperature	[°C]
L_{max}	pipeline assembly length	[m]
F	unit friction force	[N/m]
E_T	coefficient of elasticity of elongation accounted for temperature	[N/m^2]
A	carrier pipe cross section area	[m^2]

When shortening is calculated from the above presented formula, proper temperature values have to be applied, while pipeline assembly length [L_{max}] has to be calculated from the formula presented in Point 6.1.1.

6.3 Method 2a - Initial Stresses If Single Use Elongation Joints Are Considered

A pipeline with elongation joints on it, having been subjected to tests, is subsequently buried except for places where the joints are, and then is preheated.

Spacing between joints should not exceed twice the maximal assembly length [$2 \cdot L_{max}$] determined as specified in Point 6.1, while the distance of the joints from either the actual or virtual fixed point should not exceed the assembly length [L_{max}] calculated from the formula in 6.1.1.



Elongation joint setting, allowing the joint to accommodate pipe elongation [ΔL_z], once the pipe has been preheated and put into operation at [*T*] is calculated from the formula:

$$\Delta L = a_t \cdot (T - T_0) \cdot L - \frac{F \cdot L^2}{4 \cdot E_T \cdot A} \qquad \text{[m]}$$

where:

α_t	coefficient of linear expansion	[1/°C]
T	service temperature	[°C]
T_0	preheating temperature	[°C]
L	pipeline assembly length	[m]
F	unit friction force	[N/m]
E_T	coefficient of elasticity of elongation accounted for temperature	[N/m^2]
A	carrier pipe cross section area	[m^2]

6.4 Change in Pipeline Routing

Pipeline rerouting can be effected by means of:

- pipe end scarfing at the joint;
- assembling using preinsulated elbows;
- elastic bending of pipe at the site;
- preinsulated bend pipes.

Where the pipe is bent at an angle less than 10°, such section is treated as a straight one.

6.4.1 Pipe Rout Alteration By Scarfing Steel Pipe At a Joint

Maximal temperatures difference	Maximal angle of refraction	Notice:
90 K	2°	The maximum angular tolerance without the tolerance after assembly should not exceed ± 0.25
100 K	1°	
110 K	0,5°	The minimum distance between beveled couplings should be 6.00 m
> 110 K	0°	

6.4.2 Pipe Route Alteration By Using Preinsulated Elbow Units

Changes in a pipeline routing by inset elbows at angles of: 15°, 30°, 45°, 60°, 75° and 90° for the whole range of diameters.
Elbow radii:

Diameter	Steel Grade	r (bend radius)
DN 20÷DN 80	P235GH	3×Dz
DN 100÷DN 300	St 37.0	1,5×DN

D_z - steel pipe external diameter

6.4.3 Pipe Route Alteration By Elastic Bending of Pipe

Assembled preinsulated pipe 6,00 or 12,00 m long is lowered into trench and subjected to elastic bending. A minimal bending radius and the corresponding pipe bend angle [β], dependent on pipe diameter and pipe sections used, is specified in Table 7.

Table 7

Steel Carrier Pipe		Jacket Pipe		Bend angle	
				Pipe Length	
Nominal Diameter	External Diameter	External Diameter	Bend Radius	6.00 m	12.00 m
DN	Dz	Dzp	r	β	β
mm	*mm*	*mm*	*m*	*deg*	*deg*
20	26,9	75	17	20,0	–
25	33,7	90	20	17,0	–
32	42,4	110	24	14,0	28,0
40	48,3	110	28	12,0	24,0
50	60,3	125	34	10,0	20,0
65	76,1	140	42	8,0	16,4
80	88,9	160	49	7,0	14,0
100	114,3	200	65	5,3	10,6
125	139,7	225	76	–	9,0
150	168,3	250	97	–	7,1
200	219,1	315	123	–	5,6
250	273,0	400	153	–	4,5
300	323,9	450	182	–	3,8
350	355,6	500	200	–	3,4
400	406,4	560	224	–	3,1
450	457,0	630	251	–	2,7
500	508,0	710	283	–	2,4
600	610,0	800	343	–	2,0

6.4.4 Rerouting by Means of Preinsulated Bend Pipe

Straight preinsulated sections 6,00 and 12,00 m long are bent on special machines at a requested angle. Preinsulated bent pipes have to be used where routing optimisation is sought and can substitute elbows.

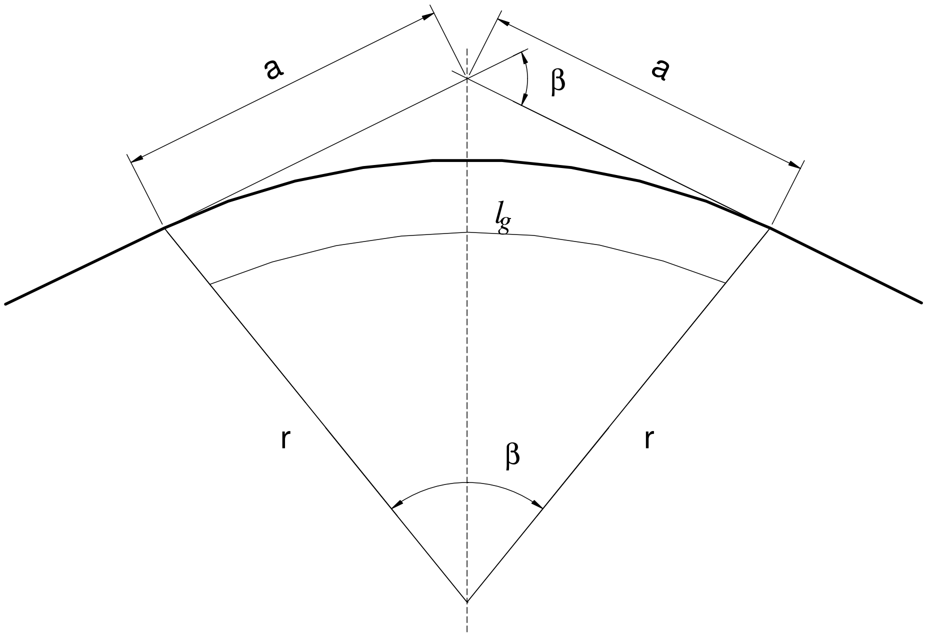
The permissible minimal radius [r_{min}] and the corresponding bend angle [β] for a pipe 12,00 m long depending on steel carrier pipe diameter [D_z] and depth of trench [H], provided steel pipe stress does not exceed $f_d = 150$ MPa, is presented in the Table.

Table 8

Steel Carrier Pipe		Jacket Pipe	Soil Layer Depth [m]											
Nominal Diameter	External Diameter	External Diameter	0,5		0,6		0,7		0,8		0,9		1,0	
DN	Dz	Dzp	r	β	r	β	r	β	r	β	r	β	r	β
mm	*mm*	*mm*	*m*	*grad*	*m*	*grad*	*m*	*grad*	*m*	*grad*	*m*	*grad*	*m*	*grad*
20	26,9*)	75	6,5	–	5,4	–	4,7	–	4,1		3,6	–	3,3	–
25	33,7*)	90	8,4	–	7,0	–	6,0	–	5,3		4,7	–	4,2	–
32	42,4	110	8,8	–	7,3	–	6,3	–	5,5		4,9	–	4,4	–
40	48,3	110	10,1	–	8,4	–	7,2	–	6,3		5,6	–	5,0	–
50	60,3	125	12,3	–	10,3	–	8,8	–	7,7		6,9	–	6,1	–
65	76,1	140	14,0	–	11,7	–	10,1	–	8,8		7,8	–	7,0	–
80	88,9	160	16,2	–	13,5	–	11,6	–	10,2		9,0	–	8,1	–
100	114,3	200	18,5	37	15,5	44	13,3	52	11,7	59	10,4	66	9,3	74
125	139,7	225	20,3	34	16,9	41	14,6	47	12,7	54	11,4	61	10,1	68
150	168,3	250	24,8	28	20,7	33	17,8	39	15,6	44	13,9	50	12,4	56
200	219,1	315	25,8	27	21,6	32	18,5	37	16,2	42	14,4	48	12,9	53
250	273,0	400	28,2	24	23,6	29	20,2	34	17,7	39	15,8	43	14,1	49
300	323,9	450	33,3	21	27,9	25	23,9	29	21,0	33	18,7	37	16,7	41

*) bend radii refer to 6.0 m long pipes.

Auxiliary formulas and guidelines on pipe routing if bend pipe or elastic bending is used.



The β rerouting angle is determined from the design.

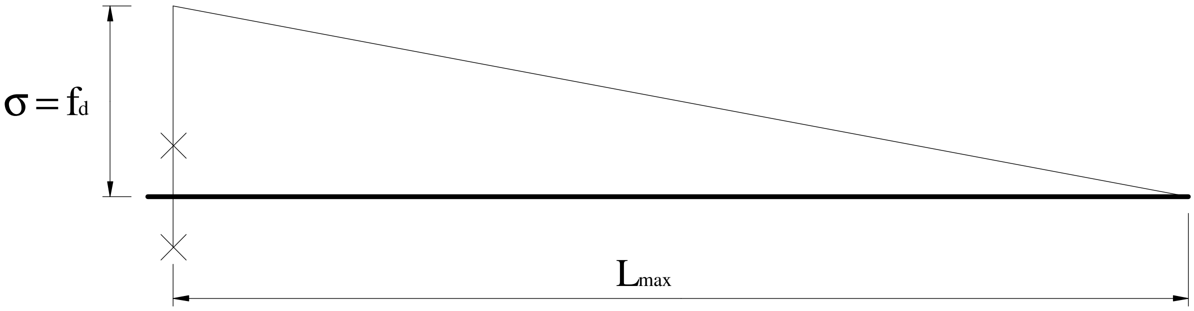
Tangent length is obtained from: $a = r \cdot tg\,\frac{\beta}{2}$ [m]

bend radius from: $r = \frac{360 \cdot l_g}{2 \cdot \pi \cdot \beta}$ [m]

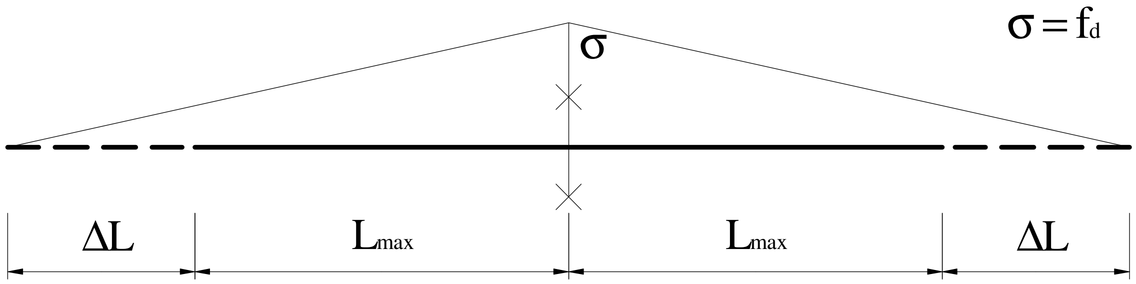
The pipe length [l_g] over the arch section has to be treated as a multiple of preinsulated pipe section 6.00 m long for nominal diameter of 20 and 25, and 12.00 m long for diameters 32 and more, respectively. In the case of elastic bending the arch pipe length [l_g] is determined once the rerouting angle has been specified in the design.

7. Elongation Compensation

The state of axial stress [σ] and pipeline elongation [ΔL] when buried and operated at temperature [T], and having an assembly length [L_{max}] at which the carrier pipe cross section reduced rated steel strength [f_d] is not exceeded is shown in the diagram below:



length of straight pipe sections should not exceed twice the maximal length [L_{max}], the elongation [ΔL] being zero in the span middle, and a virtual (conventional) fixed point is set up - the pipe is fixed - and the free pipe ends will extend by [ΔL].

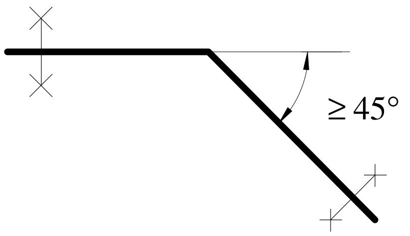


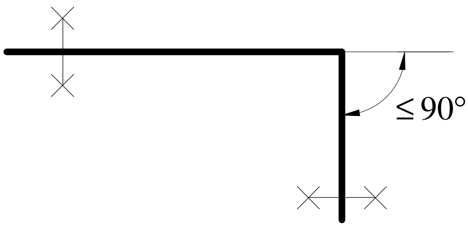
Pipe elongation is set off by pipe rerouting (natural compensation) or by mounting elongation joints. Depending on the geometric configuration of a route, natural compensation is achieved through:

- an L-shape system;
- a Z-shape system;
- a U-shape system.

7.1 The L-Shape System

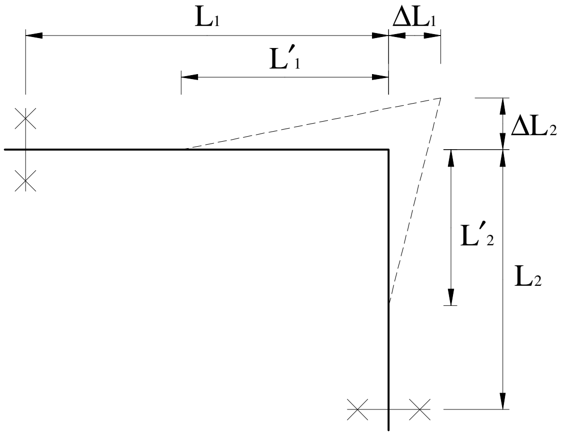
L-Shape Systems alter a route by an angle of 45° to 90°.





Elongation and compensation arm calculation

The L90 System - rerouting by 90°



$L_1 < L_{max}$
$L_2 < L_{max}$

Compensation arm length is calculated from:

$$L_1' = 1.2 \cdot \sqrt{\frac{1.5 \cdot E_T}{f_d}} \cdot \sqrt{D_z \cdot \Delta L_2} \qquad [m]$$

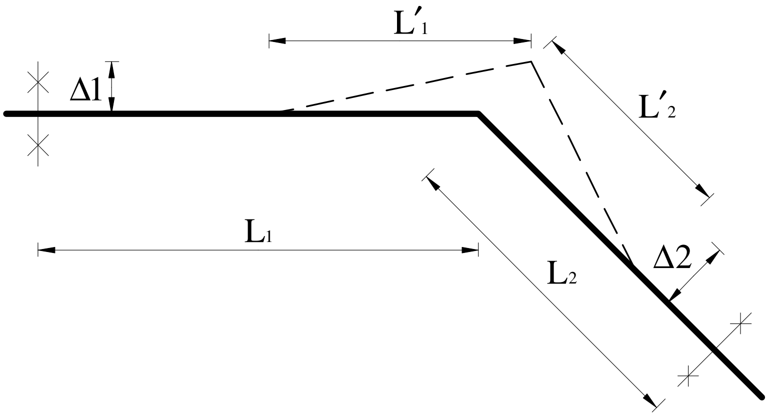
$$L_2' = 1.2 \cdot \sqrt{\frac{1.5 \cdot E_T}{f_d}} \cdot \sqrt{D_z \cdot \Delta L_1} \qquad [m]$$

where:

D_z	external carrier pipe diameter	[m]
f_d	reduced rated steel strength	[MPa]
E_T	coefficient of elasticity of elongation	
ΔL_1	L_1 section elongation (as per 6.1.2)	[m]
ΔL_2	L_2 section elongation (as per 6.1.2)	[m]

[L'] compensation arm lengths for carrier pipe diameters [D_z] to be used and conditions in which the pipeline is to be laid depending on elongation [ΔL] can be obtained from Diagram 2.

L-45°-plus compensation: rerouting at an angle ≥ 45°



The length of compensation arms $[L'_1]$ and $[L'_2]$, provided the reduced elongations $\Delta 1$ and $\Delta 2$ have been accounted for, is obtained from the formula:

$$L'_1 = 1.2 \cdot \sqrt{\frac{1.5 \cdot E_T}{f_d}} \cdot \sqrt{D_z \cdot \Delta 2} \qquad [\mathrm{m}]$$

$$L'_2 = 1.2 \cdot \sqrt{\frac{1.5 \cdot E_T}{f_d}} \cdot \sqrt{D_z \cdot \Delta 1} \qquad [\mathrm{m}]$$

where:

D_z	external carrier pipe diameter	[m]
f_d	reduced rated steel strength	[MPa]
E_T	coefficient of elasticity of elongation	[MPa]
ΔL_1	reduced elongation of section L_1	[m]
ΔL_2	reduced elongation of section L_2	[m]

Reduced elongation is obtained from:

$$\Delta 1 = \frac{\Delta L_2}{tg\,a} + \frac{\Delta L_1}{\sin a} \qquad [\mathrm{mm}]$$

$$\Delta 2 = \frac{\Delta L_2}{\sin a} + \frac{\Delta L_1}{tg\,a} \qquad [\mathrm{mm}]$$

where:

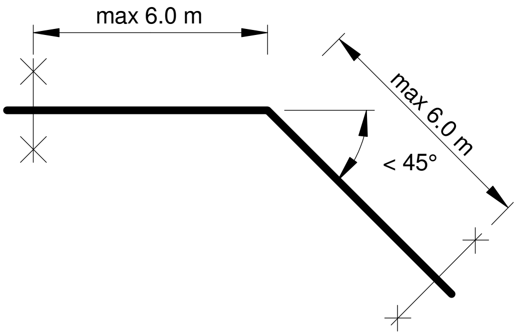
a	obtuse angle	
ΔL_1	L_1 section elongation (as per 6.1.2)	[m]
ΔL_2	L_2 section elongation (as per 6.1.2)	[m]

The length of compensation arms $[L'_1]$ and $[L'_2]$ for applicable carrier pipe diameters $[D_z]$ depending on reduced elongations $[\Delta 1]$ and $[\Delta 2]$ can be determined from Diagram 2.

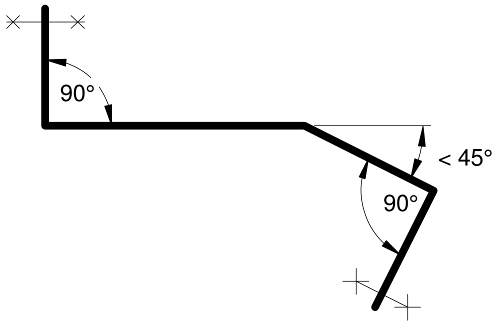
Specific requirements

A system needs no compensation if its route is altered by an angle between 8° and 45°. Such a system should be protected against overloads by means of a fixed point at a distance of maximum L = 6,0 m or by an L-90 system at a distance not exceeding $0{,}5 \cdot L_{max}$.

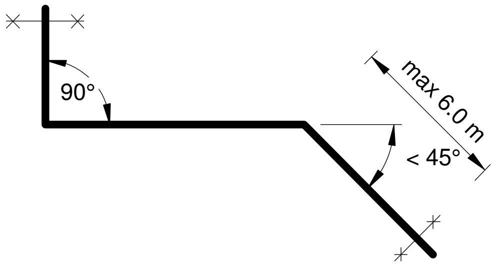
a)



b)

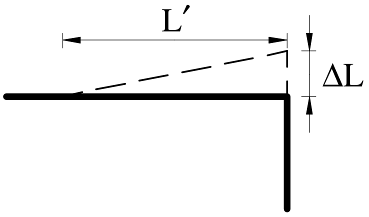


c)



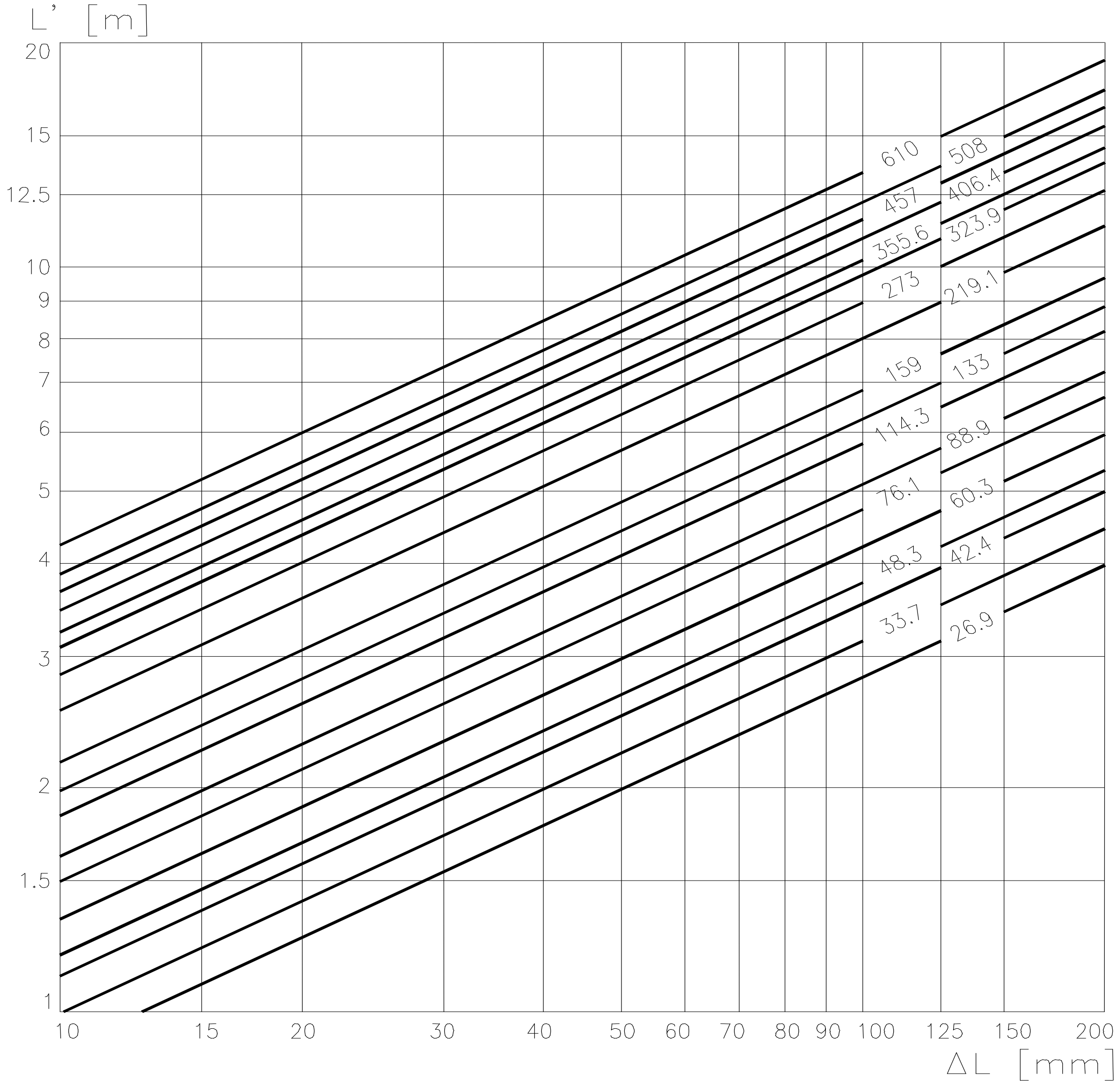
L-Shape System

The compensation arm length [L'] in relation to elongation [ΔL]

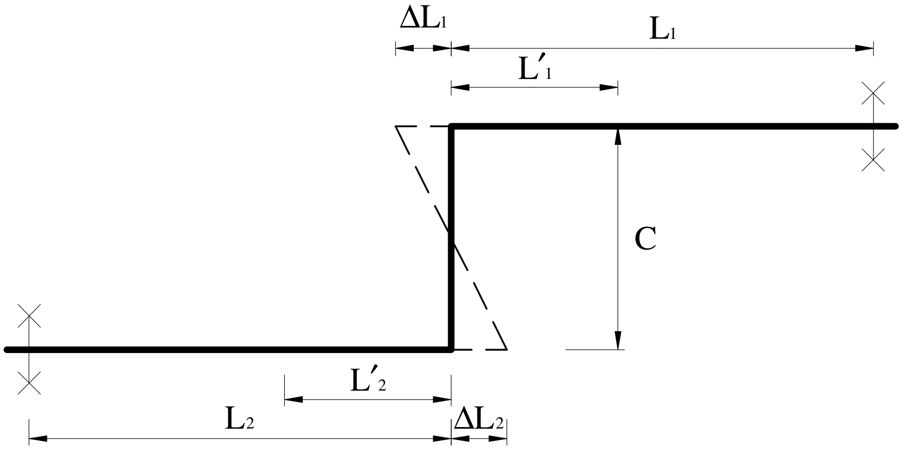


E = 204 GPa
f_d = 150 MPa

Diagram 2



7.2 The Z-Shape System



For a Z-Shape System, the length of compensation arms [*C*] is obtained from:

$$C = \sqrt{\frac{1.5 \cdot E_T}{f_d}} \cdot \sqrt{D_z \cdot \Delta L} \qquad [\mathrm{m}]$$

where:

D_z	external carrier pipe diameter	[m]
f_d	reduced rated steel strength	[MPa]
E_T	coefficient of elasticity of elongation	[MPa]

$$\Delta L = \Delta L_1 + \Delta L_2$$

ΔL_1	L_1 section elongation (as per 6.1.2)	[m]
ΔL_2	L_2 section elongation (as per 6.1.2)	[m]

The length of [*L*’] compensation arms in a Z-Shape System for applicable carrier pipe diameters and initial data depending on elongation [*ΔL*] can be obtained from Diagram 3.

Z-Shape System

The compensation arm length [*C*] in relation to elongation [*ΔL*]

E = 204 GPa
f_d = 150 MPa

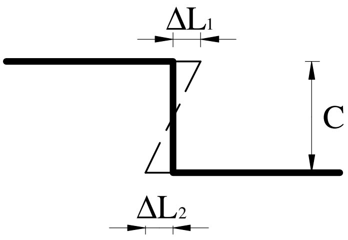
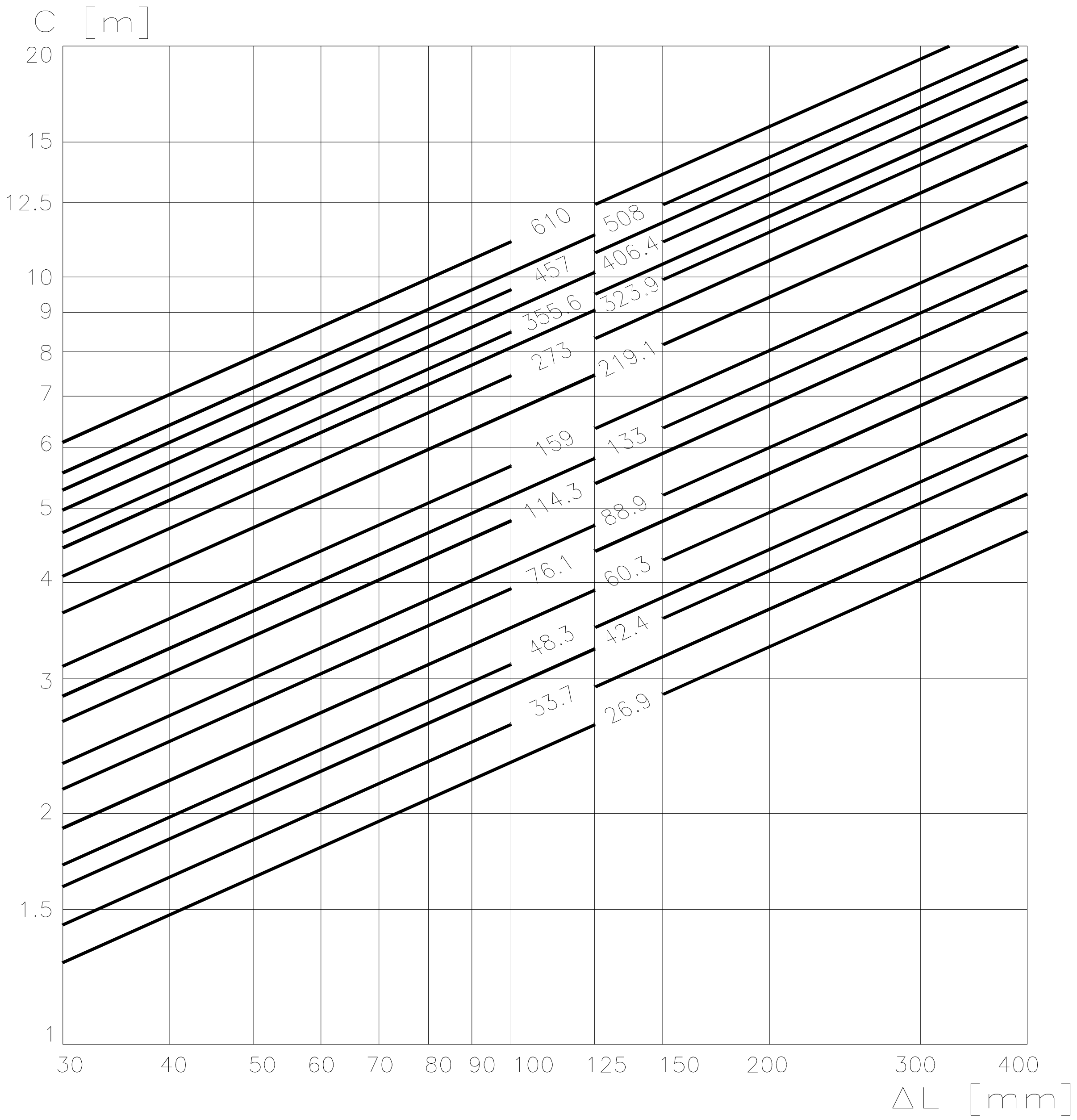


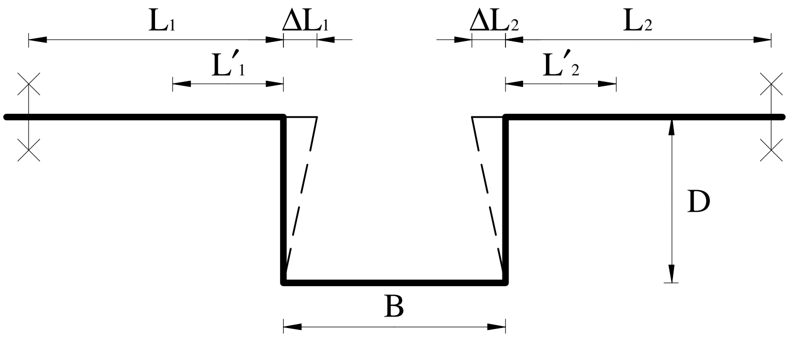
Diagram 3


C [m]
20
15
12.5
10
9
8
7
6
5
4
3
2
1.5
1
610
508
457
406.4
355.6
323.9
273
219.1
159
133
114.3
88.9
76.1
60.3
48.3
42.4
33.7
26.9
30
40
50
60
70
80
90
100
125
150
200
300
400
ΔL [mm]

7.3 The U-Shape System

A U-Shape System is seen as a system where the arms length remains within the following limits:

$$B \le D \le 2 \cdot B$$



For a Z-Shape System, the length of compensation arms [*D*] is obtained from:

$$D = 0.7 \cdot \sqrt{\frac{1.5 \cdot E_T}{f_d}} \cdot \sqrt{D_z \cdot \Delta L} \qquad [\mathrm{m}]$$

where:

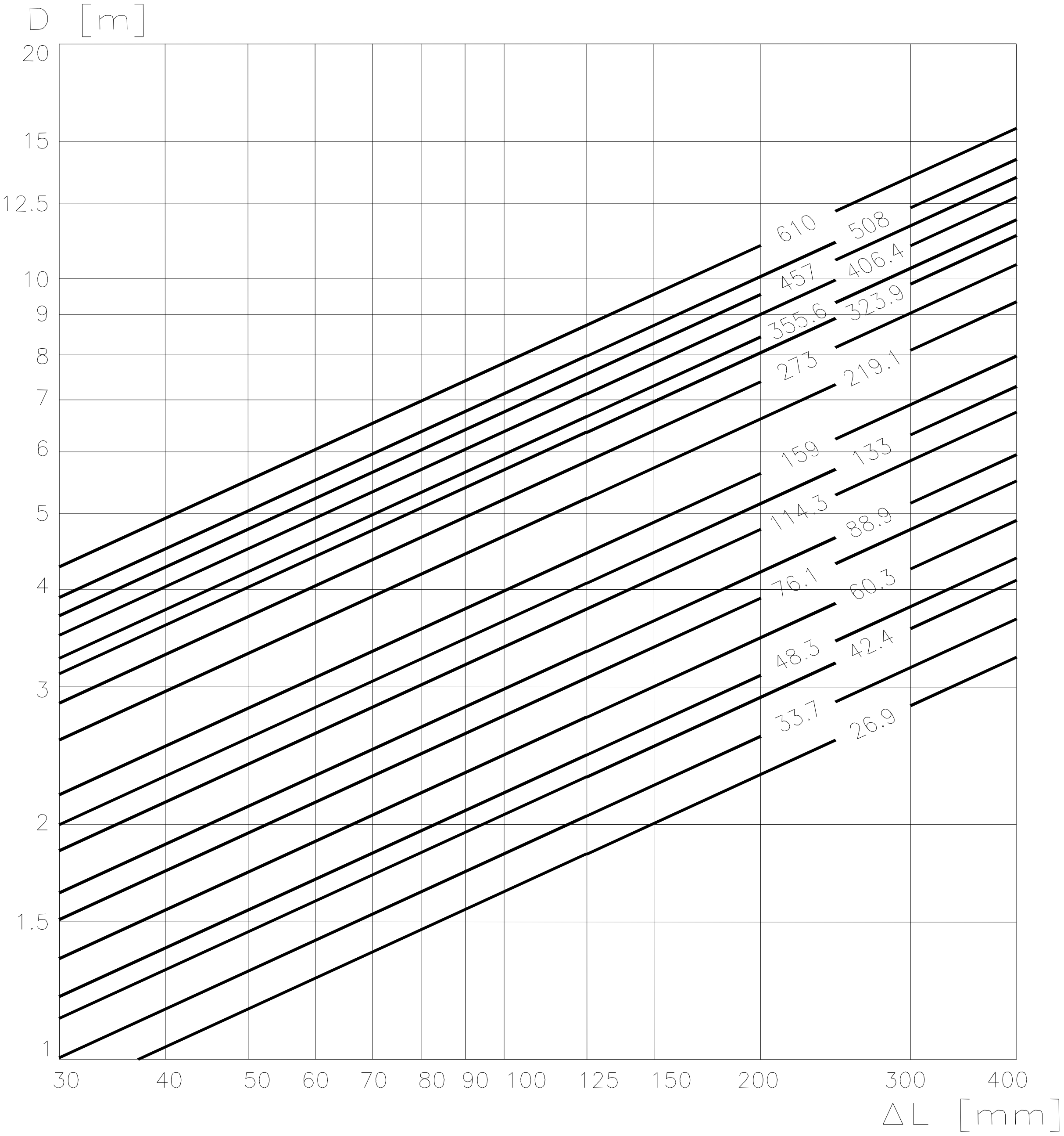
D_z	external carrier pipe diameter	[m]
f_d	reduced rated steel strength	[MPa]
E_T	coefficient of elasticity of elongation	[MPa]

$$\Delta L = \Delta L_1 + \Delta L_2$$

ΔL_1	L_1 section elongation (as per 6.1.2)	[m]
ΔL_2	L_2 section elongation (as per 6.1.2)	[m]

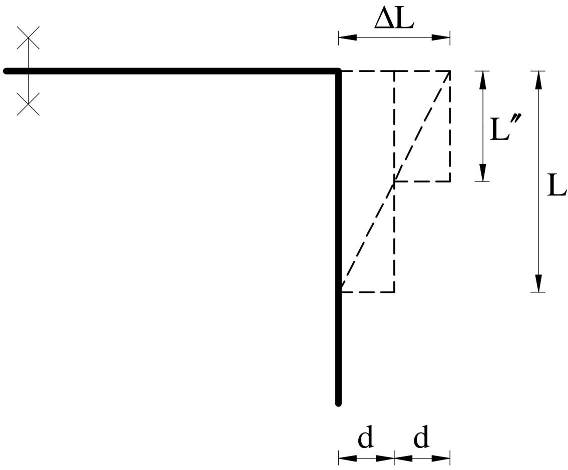
The length of [*D*] compensation arms in a U-Shape System for applicable carrier pipe diameters and initial data depending on elongation [ΔL] can be obtained from Diagram 4.

Diagram 4


D [m]
20
15
12.5
10
9
8
7
6
5
4
3
2
1.5
1
610
508
457
406.4
355.6
323.9
273
219.1
159
133
114.3
88.9
76.1
60.3
48.3
42.4
33.7
26.9
30
40
50
60
70
80
90
100
125
150
200
300
400
ΔL [mm]

7.4 Compensation Zones

A compensation zone has to be seen as a space along a pipeline, limited by the length of a compensation arm [**L'**] and existing elongations [ΔL] where a pipeline section or elbows are to be relieved from the pressure a pipeline exerts on the soil. We suggest filling the compensation zone over a stretch equaling $L = 2/3\,L'$



We suggest:

In order to have a compensation zone properly filled in with for instance mineral wool mats or foam claddings, subsequent layers have to be stepped, assuming that if one mat layer of thickness [d] is to take over part of elongation [ΔL] over length [L'], then the following mat should be [L''] long equaling:

$$L = \frac{\Delta L - d}{\Delta L} \cdot L' \qquad \text{[m]}$$

8. An Actual Preinsulated Fixed Point

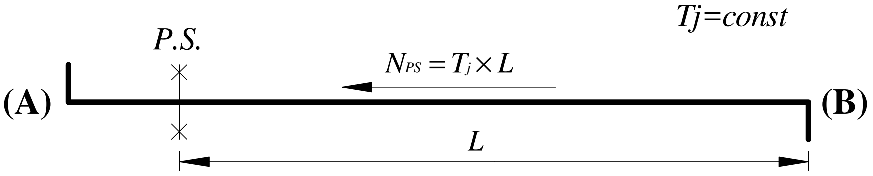
Preinsulated fixed points in thermal networks are used to:

- relieve other preinsulated structural members not fitted to carry loads, that is for instance preinsulated tees, wall transition sleeves, points where traditional transmission modes are replaced with preinsulated solutions;
- form desired elongations within thermal networks, for example where a preinsulated elbow compensation arm, calculated basing on actual elongation does not carry over such an elongation due to topographic conditions.

8.1 Calculation of Forces Affecting a Fixed Point

8.1.1 Relieved Fixed Point

A fixed point completely and on one side relieved is such which is subjected to axial force acting on one side. A case of a one side load on a fixed point is when there runs a straight section on one side, whilst on the other the route is altered by means of for instance a 90° elbow. It is essential that this straight section between the 90° compensation elbow [*A*] and the fixed point is negligibly short, which is illustrated below:



The axial force [N_{PS}] affecting the fixed point is expressed by:

$$N_{PS} = T_j \times L \qquad \text{[N]}$$

where:

T_j	unit friction force affecting preinsulated pipe	[N/m]
L	pipe length between f.p. and compensation elbow [*B*]	[m]

8.1.2 Partially Relieved Fixed Point

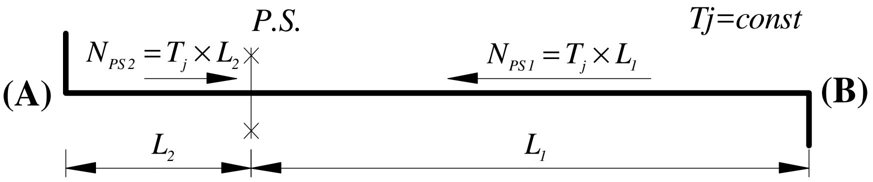
A partially relieved fixed point is a one where axial force resulting from friction between a preinsulated pipe jacket and the sand surround, and affecting the fixed point:

$$N_{PS1} = T_j \times L_1 \qquad [N]$$

and taken over from an L_1 length between the fixed point and the compensation elbow at [*B*] is a partially reduced axial force which acts in an opposite direction to soil friction forces affecting the point:

$$N_{PS2} = T_j \times L_2 \qquad [N]$$

taken over from an L_2 length between the fixed point and the compensation elbow at [*A*]
This situation is shown in the diagram below:



A total axial force [N_{PS}] affecting the fixed point is expressed as:

$$N_{PS} = N_{PS1} - N_{PS2} \qquad [N]$$
$$N_{PS} = T_j \times (L_1 - L_2) \qquad [N]$$

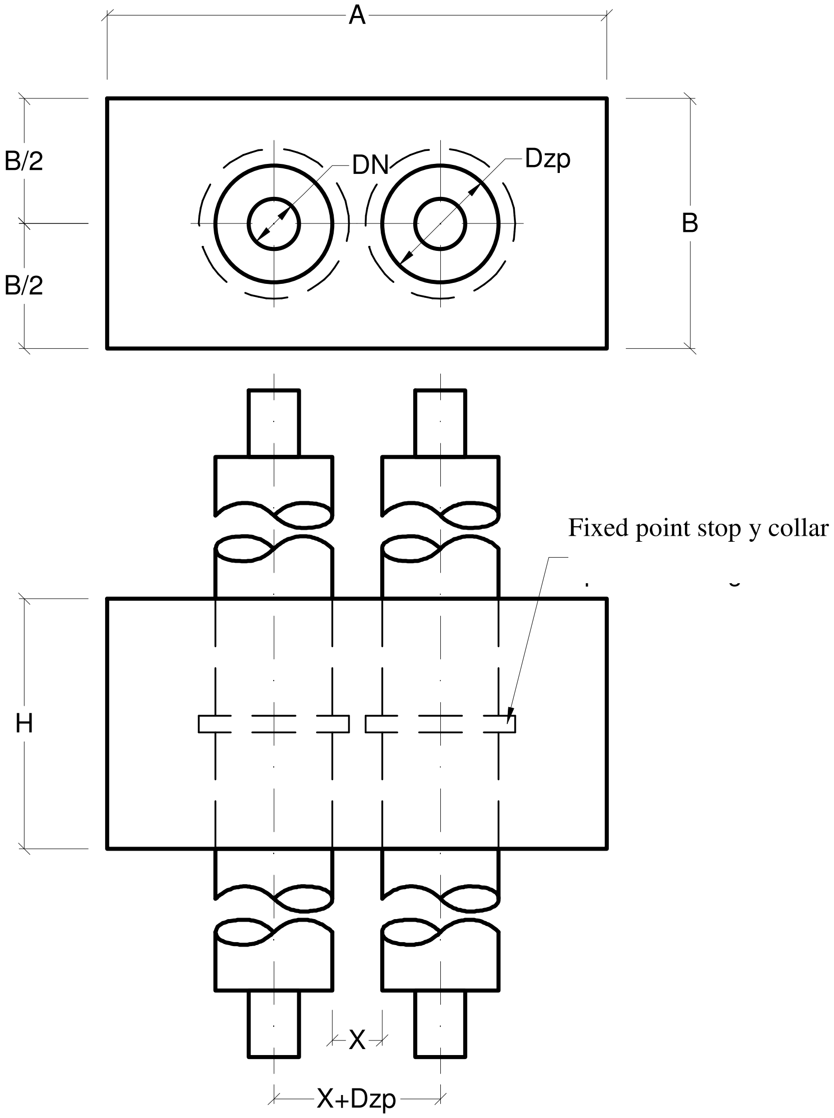
(indexes as in the previous diagram)

Table 12 shows maximal dimensions of fixed point concrete blocks. Axial forces acting on a fixed point were derived from the following assumptions:

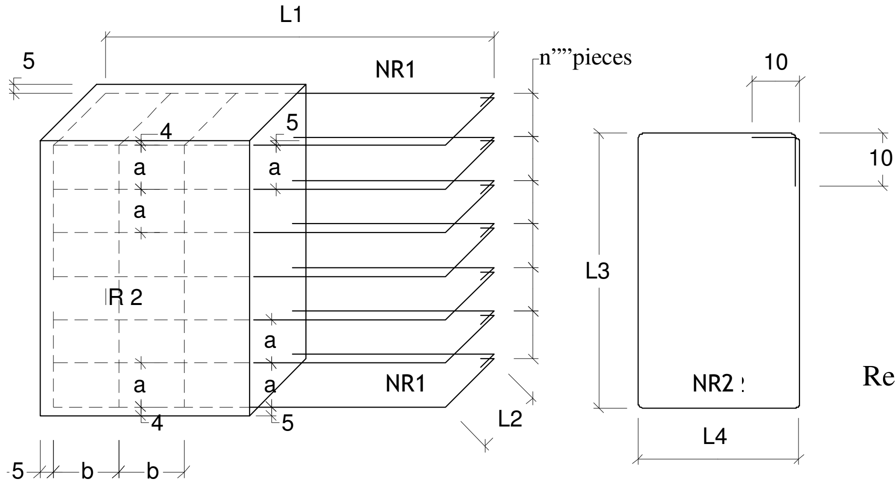
- pipe axis depth is below soil level H = 1,0 m;
- fixed point is totally relieved on one side;
- the section length over which axial forces affecting the fixed point were collected is L_{max}, steel grade is St-3.0, insulation STANDARD;
- in dimensioning concrete blocks the axial force assumed was twice that of [N_{PS}] due to the action of the feeding and return carrier pipe on the concrete block;
- in dimensioning a concrete block the unit passive soil pressure was assumed to be 150 kPa in accordance with standard PN-81/B-3020.

Fixed point foundation blocks have to be designed and cast in concrete of class at least B-15, reinforced with rebars grade A-III, 34 GS.

Fixed Point Concrete Block Dimensions



Concrete Block Reinforcement



Rebar dimensions in cm

Maximal Dimensions of Fixed Point Concrete Blocks

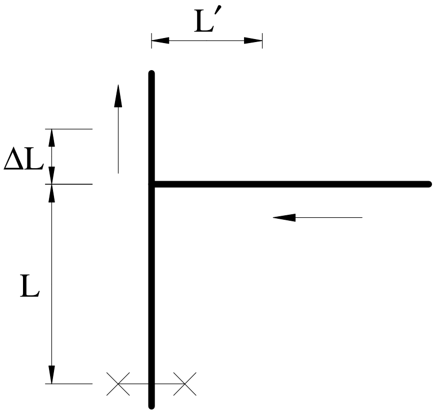
	Steel Pipe External Diameter/Wall Thickness	Jacket Pipe External Diameter	Maximal Force Transmitted by Concrete Block	Fixed Point Concrete Block Dimensions			Fixed Point Concrete Block Reinforcement						
	Dz/g	Dzp	[NPS]	A	B	H	Rebar No	Diameter	Quantity	L1	L2	L3	L4
	mm/mm	mm	Dn	cm	cm	cm		mm	pcs	cm	cm	cm	cm
1	**26,9/2,6**	**75**	6030	80	50	30	1	8	4	70	20		
							2	6	5			42	22
2	**33,7/2,6**	**90**	7530	105	50	30	1	8	4	95	20		
							2	6	6			42	22
3	**42,4/2,6**	**110**	10800	110	60	30	1	8	4	100	20		
							2	6	5			52	22
4	**48,3/2,6**	**110**	11730	130	60	30	1	8	4	120	20		
							2	6	5			52	22
5	**60,3/2,9**	**125**	15870	150	70	40	1	10	5	140	30		
							2	6	6			62	32
6	**76,1/2,9**	**140**	20580	165	80	40	1	10	6	155	30		
							2	6	7			72	32
7	**88,9/3,2**	**160**	27520	170	100	50	1	10	8	160	40		
							2	6	7			92	42
8	**114,3/3,6**	**200**	40970	205	120	70	1	10	10	195	60		
							2	6	8			112	62
9	**139,7/3,6**	**225**	48430	240	125	70	1	10	10	230	60		
							2	6	9			117	62
10	**168,3/4**	**250**	65050	280	140	100	1	12	10	270	90		
							2	8	11			132	92
11	**219,1/4,5**	**315**	90760	390	150	100	1	1	12	380	90		
							2	8	15			142	92
12	**273,0/5**	**400**	124863	446	180	100	1	14	14	435	90		
							2	10	17			172	92
13	**323,9/5,6**	**450**	173730	541	190	150	1	14	16	530	140		
							2	10	20			182	142

Note: Foundation dimensions have to be customized accounting for pipeline axial force value, computational passive soil upper limit pressure and stability of the foundation-subgrade conditions as specified by standard PN-81/B-3020.

9. Pipe Laterals and Wall Transitions

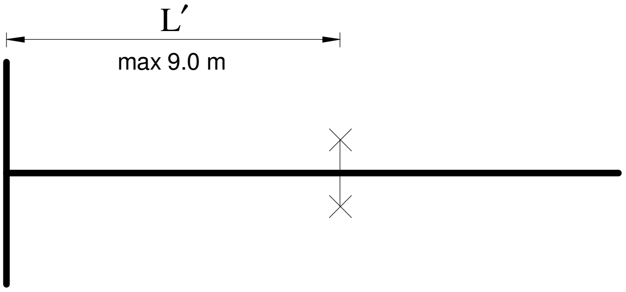
Pipelines in ***ZPU Międzyrzecz Sp. z o. o.*** have to be branched off by means of tees. Laterals are affected by mains elongation (as in the diagram); moreover, a lateral will be subject to thermal elongation, affecting this way the mains.

The length of a compensation zone [***L'***] and elongation [***ΔL***] are calculated as for an L-90 Compensation System.

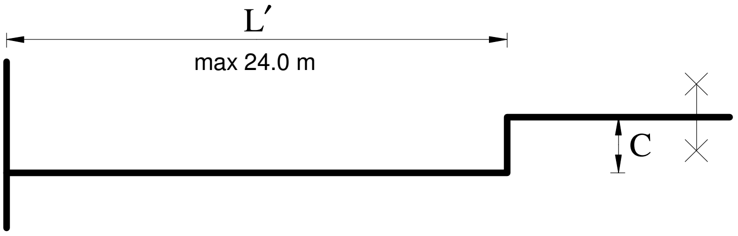


Thermal elongation exerted by a lateral on the mains can be set off by:

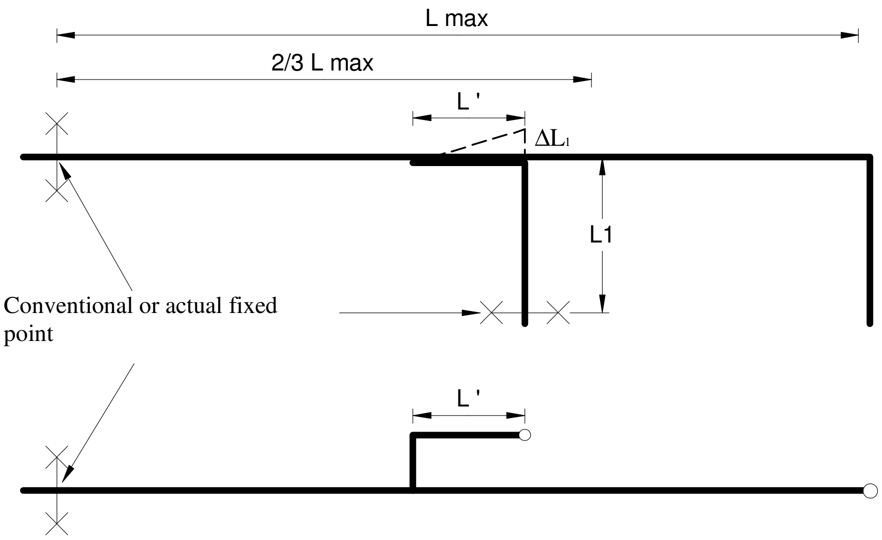
1. Setting up a fixed point within the lateral no more than 9,0 m away from the mains axis:



2. Fitting in a Z-Shape Compensation System within the lateral no more than 24,`0 m away from the mains axis:

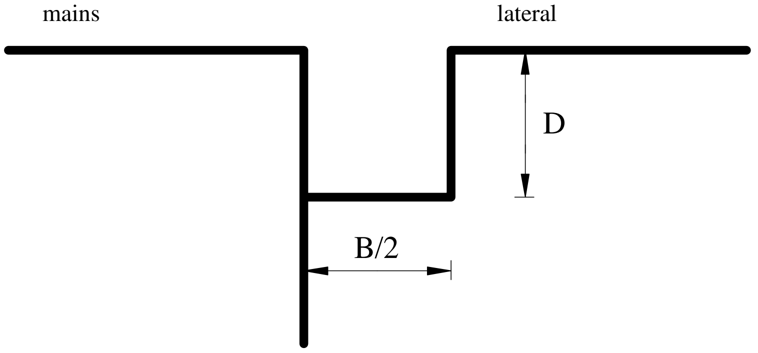


3. Fitting in a lateral parallel to the mains over a 2/3 L_{max} from the fixed point (or a conventional one):

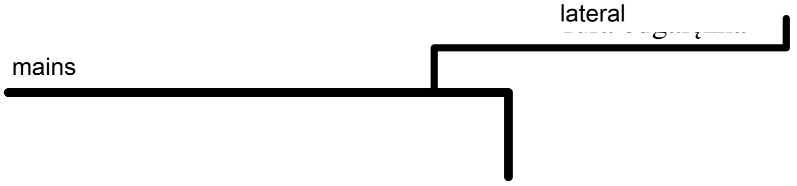


The compensation arm length [*L'*] of parallel branch is calculated in the same way as for the L-Shape Compensation, i.e. elongations [*ΔL*] over the section L_1 are calculated and the compensation arm length [*L'*] is read out from the [Δ*L*] axis acc. **Diagram 2** on page 20.

4. If a branch makes an extension of the mains, a half of a U-Shape Compensation System should be considered in designing.



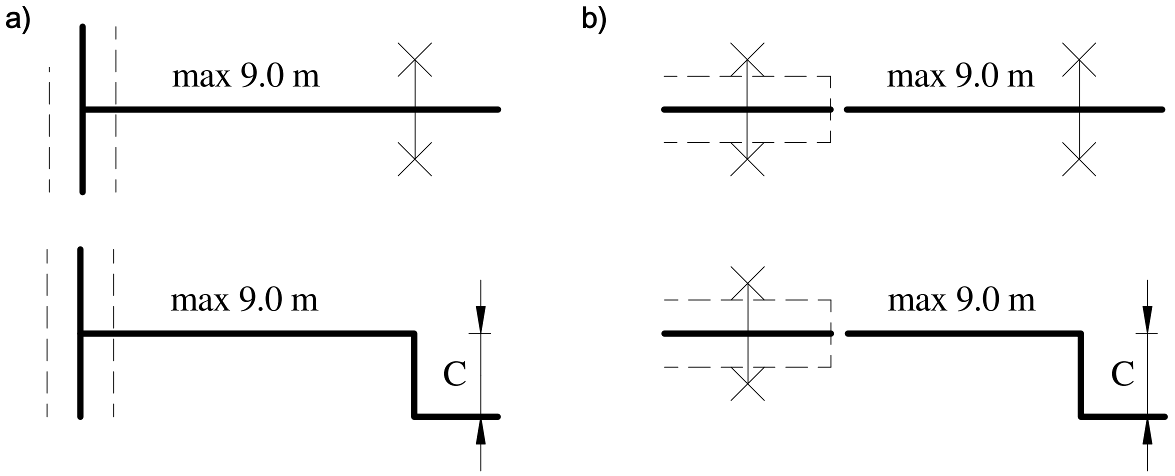
A preinsulated section parallel to a thermal network cannot be worked out as a mains extension by means of a parallel tee.
The diagram below shows an incorrectly designed thermal network section.



5. No shutoff, venting, strain nor preinsulated laterals can be included in compensation zones.

10. Preinsulated Pipe Connected To a Traditional Pipe (Underground Utilities)

Effect of preinsulated pipe elongation are set off by fitting in a fixed point or a Z-Shape System distanced no more than 9.0 m from the traditional pipeline axis or connection.



11. Steel Fittings and Fixtures

When designing preinsulated steel fittings and fixtures like: shutoff valves, shutoff valves with a single venting (straining) valves, shutoff valves with straining and venting functions the following should be observed:

- fittings should not be located in the vicinity of compensation elbows (L-, Z-, and U-compensating joints);
- shutoff vent spindle should be accessible from a street box and jacket pipe or a man-hole should be built in concrete tube at least 600 mm in diameter;
- the spindle of a buried shutoff valve should be protected with compensation mats;
- straining and venting shutoff valves should be in concrete tube manholes of a diameter at least 10000 mm or in concrete chambers;

Steel shutoff fittings and fixtures are used to cut off the flow of a medium in a given section or thermal utilities. Strain valves should be fitted in the lowest network points, while venting ones in the topmost sections and next to straining, aerating and venting shutoff valves.

12. Technical Information

The application of preinsulated pipe and fittings has been specified in general above, whilst details referring to design, execution and take over of networks are presented in:

1.	Guidelines	Static and Design Calculations ***ZPU Międzyrzecz Sp. z o. o.*** System
2.	Manual	Detection of Pipe Leaks Connection of Pulse Monitoring System in Thermal Utilities ***ZPU Międzyrzecz Sp. z o. o.*** System
3.	Manual	Manual of Execution and take Over ***ZPU Międzyrzecz Sp. z o. o.*** System
4.	Manual	Joint Unit Assembly Insulation and Sealing ***ZPU Międzyrzecz Sp. z o. o.*** System
5.	Manual	Manual of Steel Pipe Welding ***ZPU Międzyrzecz Sp. z o. o.*** System
6.	Manual	Steel Pipe Connection Welding Quality Inspection ***ZPU Międzyrzecz Sp. z o. o.*** System
7.	Manual	DX Joints electrically welded ***ZPU Międzyrzecz Sp. z o. o.*** System
8.	Manual	DT Type Heat Shrinkable Joints Electrically Welded ***ZPU Międzyrzecz Sp. z o. o.*** System

Note: We convert heat system specifications so that they could meet the requirements of the *ZPU Międzyrzecz Sp. z o. o.* technology solutions.

13. Trade Information

Manufacturer and Seller:

ZAKŁAD PRODUKCYJNO USŁUGOWY
Międzyrzecz
Polskie Rury Preizolowane
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Trade Service: +095 742 33 23, 742 33 38
Supplies: +095 742 33 46, 742 33 56
e-mail: zpu@zpum.pl www.zpum.pl

When placing orders please specify carrier pipe steel grade (St 37.0, or P235GH), type of heat insulation, type of polyurethane embedded moisture detection system or its lack, and for pipes specify their length and quote Catalogue Number. If products are to be made-to-order, dimensions have to be agreed separately.