GENERAL ANNEX A2

BURIED PIPINGS

(Non-mandatory annex)

A2.1 - GENERAL

This annex describes the applicable requirements for buried pipings, supplementing those of the different Divisions of the Code.

A2.2 - MATERIALS

The requirements specified in the different Divisions apply without any restriction.

However, one shall remind that the corrosion phenomena occurring in the case of buried pipings may be significantly different from those to which pipings above-ground, in ducts or tunnels are subjected.

Note: The protection of buried pipings against corrosion may be obtained by means of different types of coating and/or by cathodic protection (see annex MA4 of Division1).

A2.3 – DESIGN AND CALCULATION

A2.3.1 - Calculation procedure

a) Determination of the required thicknesses from the formulas given in the different Divisions of the Code when the piping is subjected only to internal pressure.

b) Determination of the loads due to backfill and to live loads.

c) Checking of the thicknesses defined in *a*) for the different operating conditions under which the loads defined in *b*) are applicable.

d) Checking of the global stability of the buried piping system.

A2.3.2 - Determination of the loads due to backfill

A2.3.2.1 - General

Different installation methods may be considered for buried pipings:

- Piping in narrow trench.
- Piping in wide trench or in positive projecting embankementcondition.

Note: Other arrangements needing special consideration may be envisaged: pipings installed in a negative projecting embankment condition, pipings in a same trench at the same level or at different levels, pipings installed in particular trench. These cases will be dealt with later.

A2.3.2.2 - Notation

For the purposes of this annex the following notation shall apply:

C_{tass} = Settlement ratio (see A2.3.2.5.1*b*)

C_{dyn} = Coefficient for taking into account the dynamic effect of the live loads

D_e = External piping diameter. For standardized tubes, D_e is the theoretical external diameter, tolerances excluded.

e = Piping thickness defined in C1.6

E_t = Backfill material modulus (see Division 1 C3.2.2)

E = Modulus of elasticity for the piping material

H_t = Total height from the top of the piping to natural ground surface

H_e = Distance from the plane of equal settlement to the top of pipe

k = Ratio of lateral pressure to vertical pressure for the backfill material (Rankine coefficient) :

$$k = \left\{ tg\left(\frac{\pi}{4} - \frac{\varphi}{2} \right) \right\}^2$$

L_t = width of the trench in the horizontal plane containing the top of the piping

P = Internal calculation pressure(s) defined in the different Divisions of the Code

Pd_t = Unit weight of backfill material

φ = Angle of internal friction for the material used to fill the trench.

μ = Coefficient of internal friction of backfill material

μ' = Coefficient of sliding friction between the backfill material and the trench walls.

μ' is always less than or equal to μ and μ' may be taken as μ provided that backfilling material of proper quality (homogeneity) is used

A2.3.2.3 - Soil properties

In the absence of specific data, the values given in the table hereafter may be used for the design and calculation of buried pipings.

[1] Calcul des sollicitations extérieures agissant sur les conduites enterrées (*Calculation of external loadings acting on buried pipings*)

CERIB 1970

[2] The theory of external loads on closed conduits in the ligth of the latest experiments

MARSTON 1930

[3] Stabilité des canalisations enterrées (*Stability of buried pipelines*)

E.M.YASSINE et V.I. TCHERNIKINE

Moscow 1968

Table A2.3.2.3

		Weight daN/m^3	**Phi °**	**μ = Tg (Phi)**	**k**	**μ' = Tg (Phi')**	**k μ**	**k μ'**
Topsoil	[1]	1450	22	0,404			0,184	0,184
Partially compacted (moist) topsoil	[2]	1440			0,330	0,500		0,165
Saturated topsoil	[2]	1760			0,370	0,400		0,150
Sandy clay	[3]		25		0,406			
Clay	[3]		22					
Silty clay	[1]	2000	20	0,364			0,178	0,178
Plastic clay - Sandy clay	[1]	1800	14	0,249			0,152	0,152
Moist clay	[1]	2000	12	0,213			0,139	0,139
Yellow clay, moist and partially compated	[2]	1600			0,330	0,400		0,130
Saturated yellow clay or loam	[2]	2080			0,370	0,300		0,110
Coarse - gravely sand	[3]		43					
Medium sand	[3]		40					
Fine sand	[3]		38					
Silty sand	[3]		36					
Uncompacted sand	[1]	1700	31	0,601			0,192	0,192
Sand - Gravel	[1]	2000	33	0,649			0,191	0,191

		Poids daN/m³	Phi °	μ = Tg (Phi)	k	μ' = Tg (Phi')	k μ	k μ'
Clayey sand	[1]	1800	22	0,404			0,184	0,184
Sarurated clayey sand	[2]	2110			0,350	0,400		0,140
Dry sand	[2]	1600			0,330	0,500		0,165
Moist sand	[2]	1920			0,330	0,500		0,165
Sludge	[3]		18					
Marshy ground - Peat	[1]	1700	12	0,213			0,139	0,139
Loamy loess (al-luvial deposits)	[1]	2100	18	0,325			0,172	0,172
Loam - Marl - poor clay	[1]	2100	22	0,404			0,184	0,184
Sandy silt	[1]	1800	25	0,466			0,189	0,189
Gravel - Pebbles	[1]	1900	37	0,754			0,187	0,187
Loose - gravelly backfilling mate-rial	[2]	1700			0,330	0,580		0,192
Stony-sandy backfilling mate-rial	[2]	1900			0,330	0,500		0,165
Moist-loamy backfilling mate-rial	[2]	2000			0,330	0,450		0,150

A2.3.2.4 - Piping in narrow-trench condition

A2.3.2.4.1 - Definition

A piping is considered as piping in narrow-trench condition (figures A2.3.2.4.1-1 to -4) if one of the following conditions is satisfied:

$$\frac{L_t}{D_e} < 2 \quad \text{and} \quad \frac{H_t}{L_t} \geq 1{,}5$$

or

$$2 \leq \frac{L_t}{D_e} \leq 3 \quad \text{and} \quad \frac{H_t}{L_t} \geq 3{,}5$$

If neither of these conditions is satisfied, the piping is considered as piping in wide-trench condition.

A2.3.2.4.2 - Calculation of the load due to backfill

The load per unit length the piping is subjected to is given by the formulas A2.3.2.4.1-1 and -2 :

$$F_1 = C_1 \, P d_t \, L_t \, H_t \qquad \text{(A2.3.2.4.1-1)}$$

$$C_1 = \frac{L_t}{2\,k\,\mu'\,H_t}\left\{1 - \exp\left(\frac{-2\,k\,\mu'\,H_t}{L_t}\right)\right\} \qquad \text{(A2.3.2.4.1-2)}$$

The value of C_1 may be derived directly from graph A2.3.2.4.2 as a function of the ratio H_t / L_t and of the product $k\mu'$.

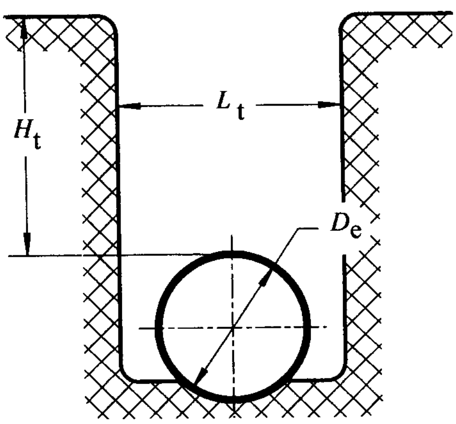


Figure A2.3.2.4.1-1

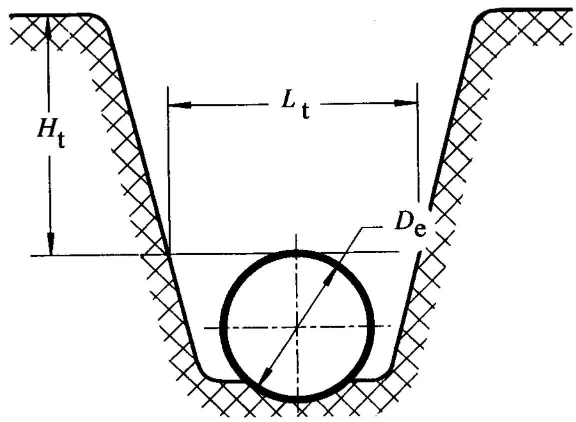


Figure A2.3.2.4.1-2

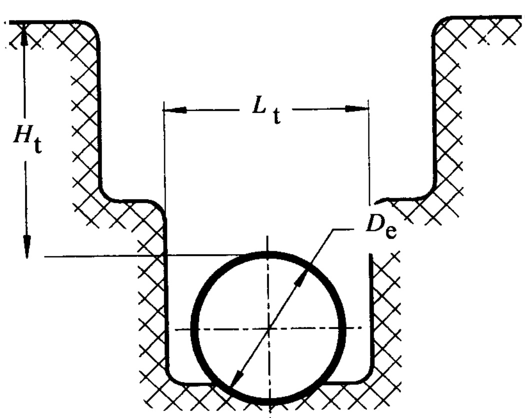


Figure A2.3.2.4.1-3

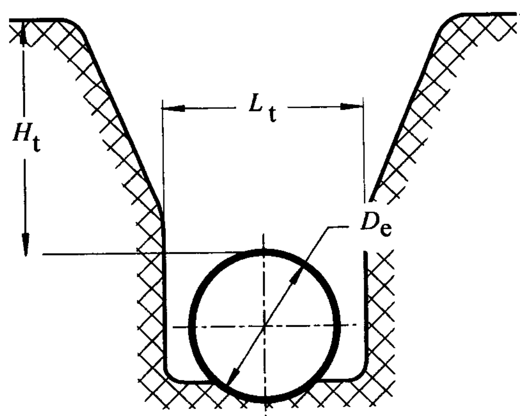
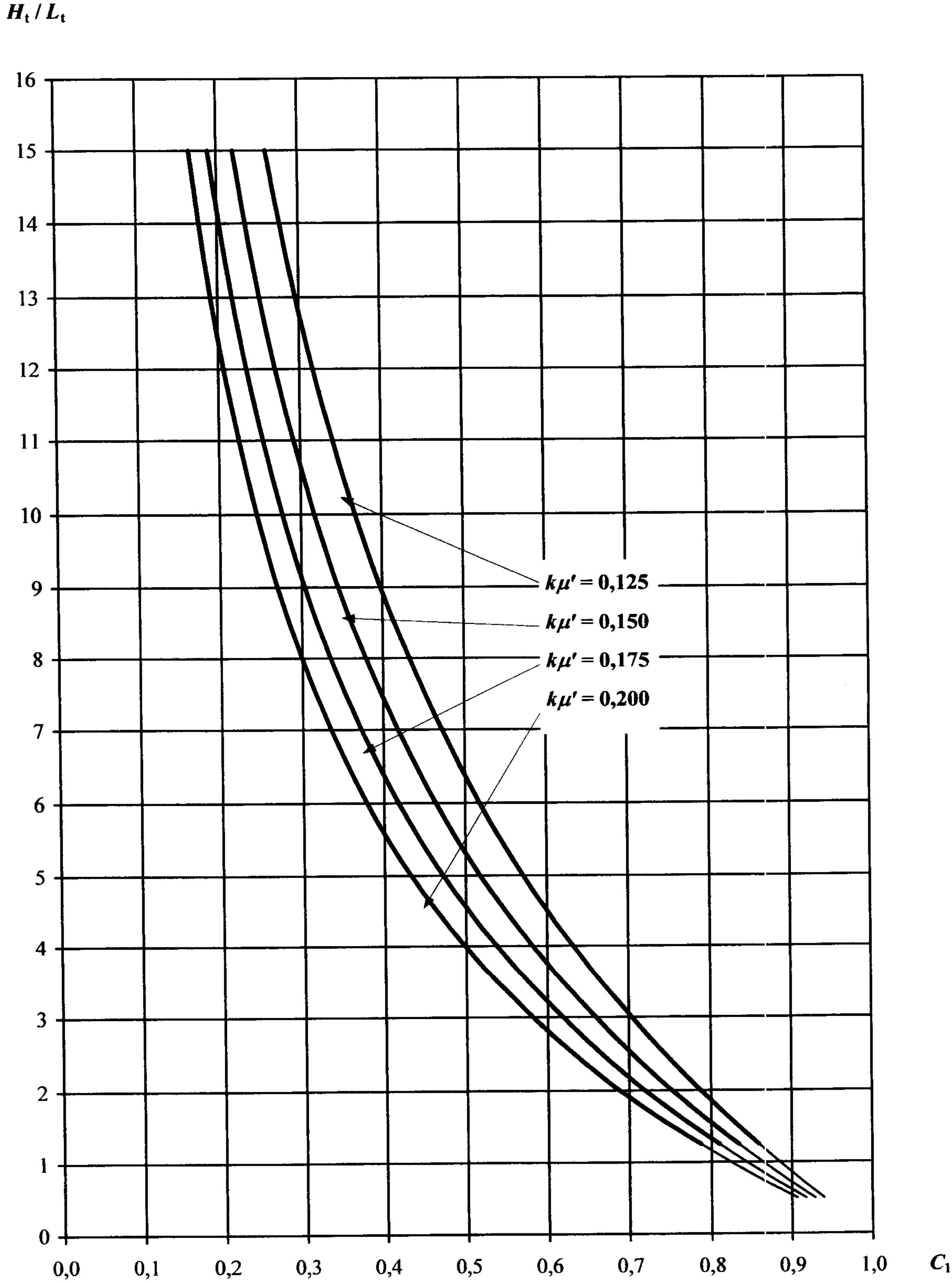


Figure A2.3.2.4.1-4



Graph A2.3.2.4.2

A2.3.2.5 - Piping in wide-trench conditions or positive projecting embankment conditions

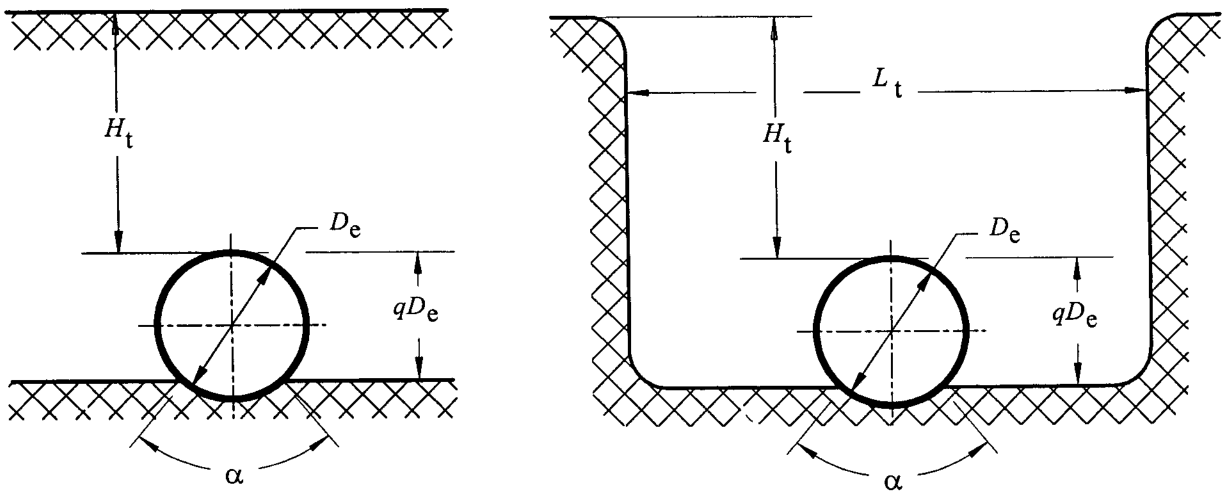
A2.3.2.5.1 - Definitions

a) Projection ratio

The projection ratio, q, is defined in figures A2.3.2.5.1-1 and -2 and the most commonly used values are given in table A2.3.2.5.1-1.

Table A2.3.2.5.1-1

Angle α	q
0°	1
30°	0,98
60°	0,93
90°	0,85
120°	0,75



Figures A2.3.2.5.1-1 and -2

b) Settlement ratio

The settlement ratio, C_{tass}, is defined as follows:

$$C_{tass} = \frac{\Delta S_1 + \Delta S_2 - \Delta T_1 - \Delta T_2}{\Delta S_1} \qquad \text{(A2.3.2.5.1)}$$

where (Figure A2.3.2.5.1-3) :

ΔS_1 = Settlement of the backfill adjacent to the piping, measured between the natural ground plane and the horizontal plane containing the top of the piping

ΔS_2 = Settlement of the natural ground under the backfill adjacent to the piping

ΔT_1 = Settlement of the piping into the natural ground

ΔT_2 = Deflection of vertical height of the pipe

Note 1: Two cases may be envisaged after back-filling:

- The backfill above the piping settles less than the rest of the backfill. In this case, which corresponds to a « rigid » piping, (see Note 2), the shearing forces at the boundaries will tend to increase the load on the piping and the settlement ratio will be positive.

- The backfill above the piping settles more than the rest of the backfill. In this case, which corresponds to a « semi-rigid » or « flexible » piping (see Note 2), the shearing forces at the boundaries will tend to lower the load on the piping and the settlement ratio will be negative.

Note 2: A piping may be considered as a rigid » piping if :

$$\left(\frac{E}{E_t}\right)\left(\frac{2\,e}{D_e}\right)^3 \geq 1$$

Note 3: In the case of a « rigid » piping which does not undergo any deformation and if the foundation soil is incompressible, the settlement coefficient is equal to 1.

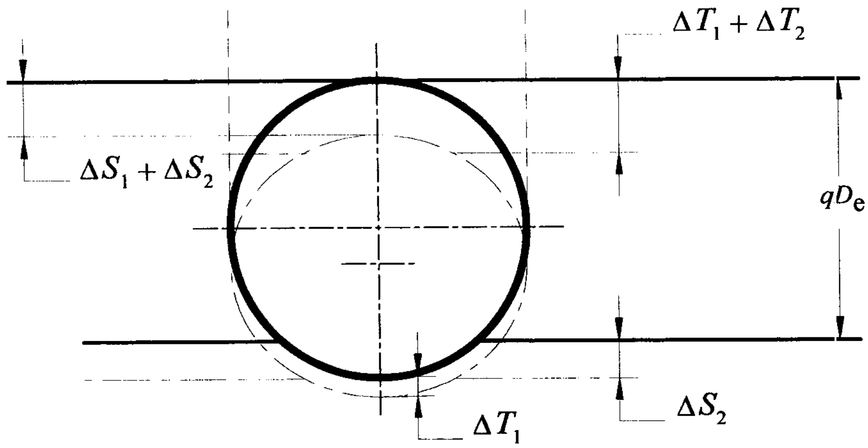


Figure A2.3.2.5.1-3

Table A2.3.2.5.1-2 gives a set of values recommended for this settlement coefficient for the most current cases:

Table A2.3.2.5.1-2 – Settlement coefficient C_{tass}

"Rigid" piping on rock or firm soil	+ 1,0
"Rigid" piping on ordinary soil	+ 0,8 to + 0,5
"Rigid" piping on unconsolidated soil	+ 0,5 à 0

"Flexible" piping with non-compacted backfill on each side	- 0,4 to – 0,2
"Flexible" piping with slightly compacted backfill on each side	- 0,2 à 0
"Flexible" piping with well compacted backfill on each side	0 à + 0,4
"Flexible" piping with optimally compacted backfill on each side	+ 0,4 à + 0,8

c) Plane of equal settlement

The plane of equal settlement is defined as the plane above which the settlement of the backfill above the piping and that of the backfill adjacent to the piping are identical. The distance, H_e, from the plane of equal settlement to the top of the pipe may be determined from the following formulas:

$C_{tass} > 0$

$$\exp\left(\frac{+2\,k\,\mu\,H_e}{D_e}\right) - \frac{2\,k\,\mu\,H_e}{D_e} = +2\,k\,\mu\,q\,C_{tass} + 1$$

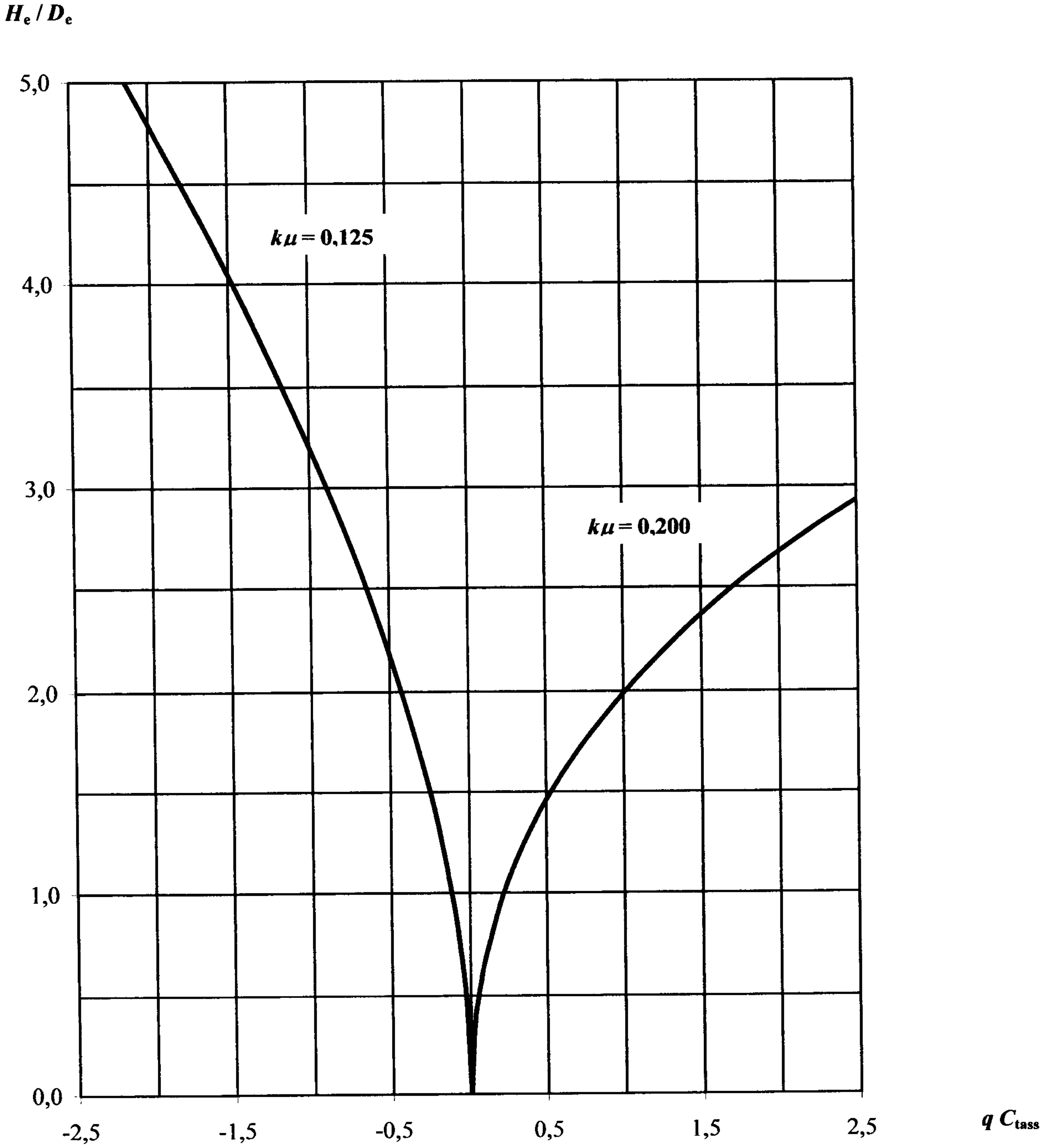
(A2.3.2.5.1-1)

$C_{tass} < 0$

$$\exp\left(\frac{-2\,k\,\mu\,H_e}{D_e}\right) + \frac{2\,k\,\mu\,H_e}{D_e} = -2\,k\,\mu\,q\,C_{tass} + 1$$

(A2.3.2.5.1-2)

Note: The value of H_e may be derived directly from graph A2.3.2.5.1.



Graph A2.3.2.5.1 - Plane of equal settlement - Determination of H_e

A2.3.2.5.2 - Calculation of the load due to the back-fill

The load per unit length the piping is subjected to is given by equation A2.3.2.5.2-1.

$$F_2 = C_2 \, Pd_t \, D_e \, H_t \qquad \text{(A2.3.2.5.2-1)}$$

The coefficient C_2 is given by the following formulas:

a) $H_e > H_t$:virtual plane of equal settlement

$C_{tass} > 0$

$$C_2 = \frac{\exp\left(\frac{+2\,k\,\mu\,H_t}{D_e}\right) - 1}{+2\,k\,\mu} \frac{D_e}{H_t} \qquad \text{(A2.3.2.5.2-2)}$$

$C_{tass} < 0$

$$C_2 = \frac{\exp\left(\frac{-2\,k\,\mu\,H_t}{D_e}\right) - 1}{-2\,k\,\mu} \frac{D_e}{H_t} \qquad \text{(A2.3.2.5.2-3)}$$

b) $H_e < H_t$: realal plane of equal esttlement

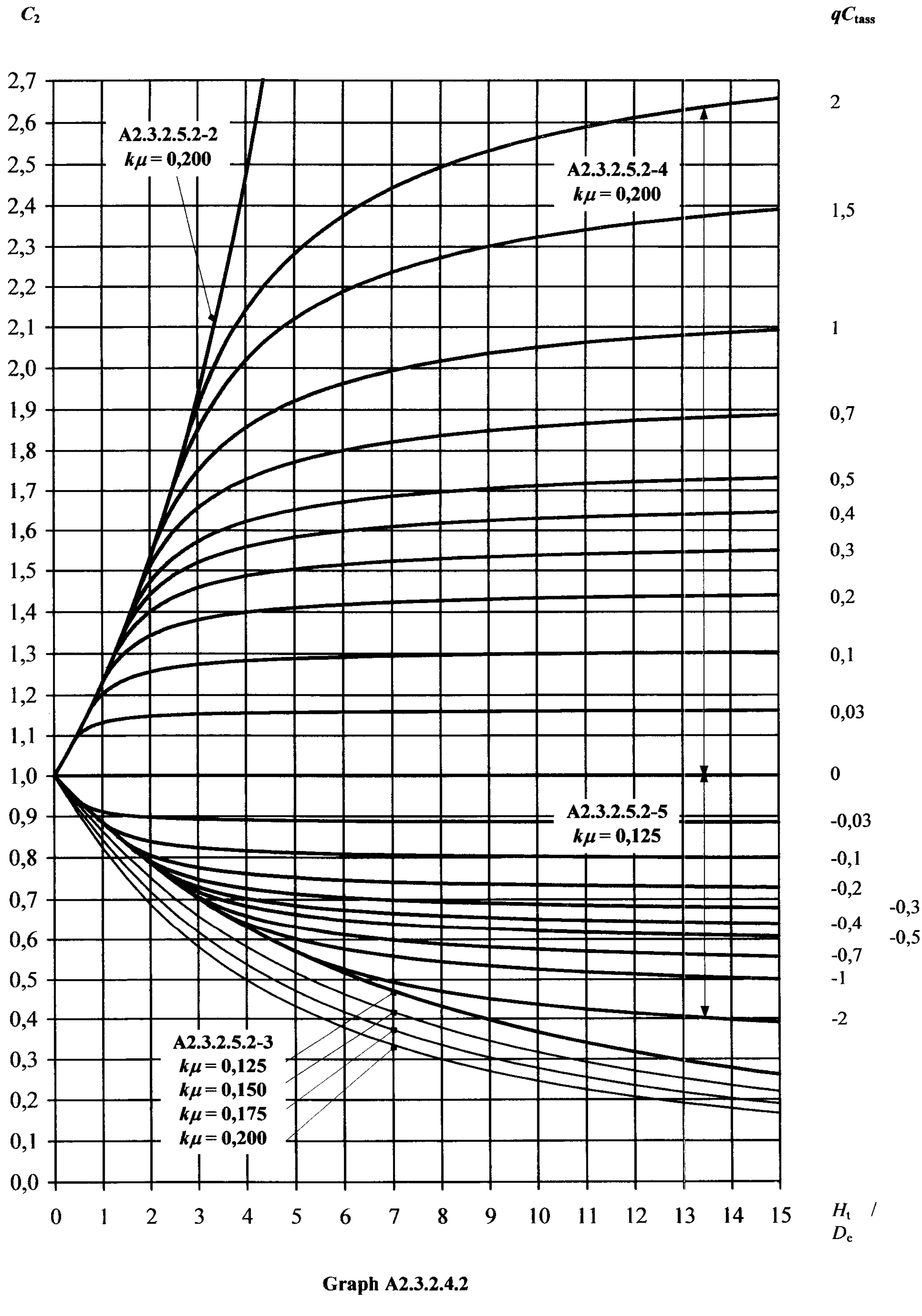
$C_{tass} > 0$

$$C_2 = \frac{\exp\left(\frac{+2\,k\,\mu\,H_e}{D_e}\right) - 1}{+2\,k\,\mu'} \frac{D_e}{H_t} + \left(1 - \frac{H_e}{H_t}\right) \exp\left(\frac{+2\,k\,\mu\,H_e}{D_e}\right) \qquad \text{(A2.3.2.5.2-4)}$$

$C_{tass} < 0$

$$C_2 = \frac{\exp\left(\frac{-2\,k\,\mu\,H_e}{D_e}\right) - 1}{-2\,k\,\mu} \frac{D_e}{H_t} + \left(1 - \frac{H_e}{H_t}\right) \exp\left(\frac{-2\,k\,\mu\,H_e}{D_e}\right) \qquad \text{(A2.3.2.5.2-5)}$$

The value of C_2 may be derived directly from graph A2.3.2.5.2 for different values of $k\mu$.



Graph A2.3.2.4.2

A2.3.3 - Determination of the loads due to live loads

A2.3.3.1 - Concentrated live load

In the case of a concentrated live load, the load per unit length the piping is subjected to is given by equation A2.3.3.1-1:

$$F_7 = C_7 \frac{F_c}{L} C_{dyn} \qquad \text{(A2.3.3.1-1)}$$

$$C_7 = \frac{2}{\pi} \{ C_{71} + C_{72} \}$$

$$C_{71} = arc\,tg \left(\frac{B}{H_t} \frac{A \{ A^2 + B^2 \} - 2\,A\,H_t \{ R - H_t \}}{\{ A^2 + B^2 \} \{ R - H_t \} - H_t \{ R - H_t \}^2} \right)$$

$$C_{72} = \left(\frac{B\,H_t}{\{ B^2 + H_t^2 \}} \frac{A \{ R^2 + H_t^2 \}}{\{ A^2 + H_t^2 \} R} \right)$$

The coefficient C_7 may be obtained directly from the graphs A2.3.3.1-1 and -2 with:

A	=	$L/2$	
B	=	$D_e/2$	
C_{dyn}	=	$1 + \frac{0{,}3}{H_t}$	Streets and roads
	=	$1 + \frac{0{,}6}{H_t}$	Railways and airports
L	=	Piping length (equal to 1 if the actual length of the piping under consideration exceeds 1)	
F_c	=	Concentrated live load	
R	=	$\sqrt{A^2 + B^2 + H_t^2}$	

A2.3.3.2 - Distributed live load

In the case of a distributed live load, the load per unit length the piping is subjected to is given by equation A2.3.3.2-1:

$$F_8 = C_8\,p_r\,D_e\,C_{dyn} \qquad \text{(A2.3.3.2-1)}$$

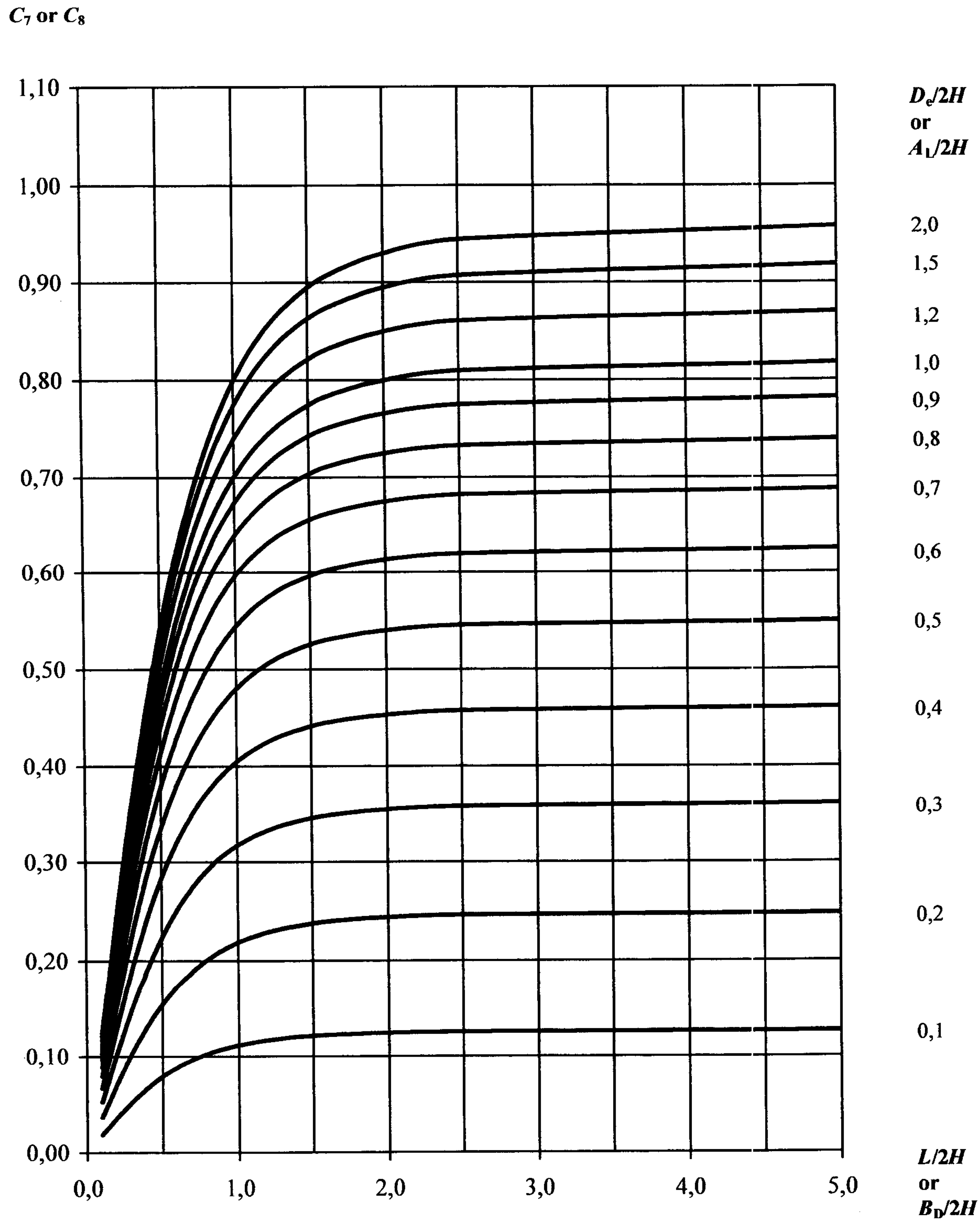
$$C_8 = \frac{2}{\pi} \{ C_{81} + C_{82} \}$$

$$C_{81} = arc\,tg \left(\frac{B}{H_t} \frac{A \{ A^2 + B^2 \} - 2\,A\,H_t \{ R - H_t \}}{\{ A^2 + B^2 \} \{ R - H_t \} - H_t \{ R - H_t \}^2} \right)$$

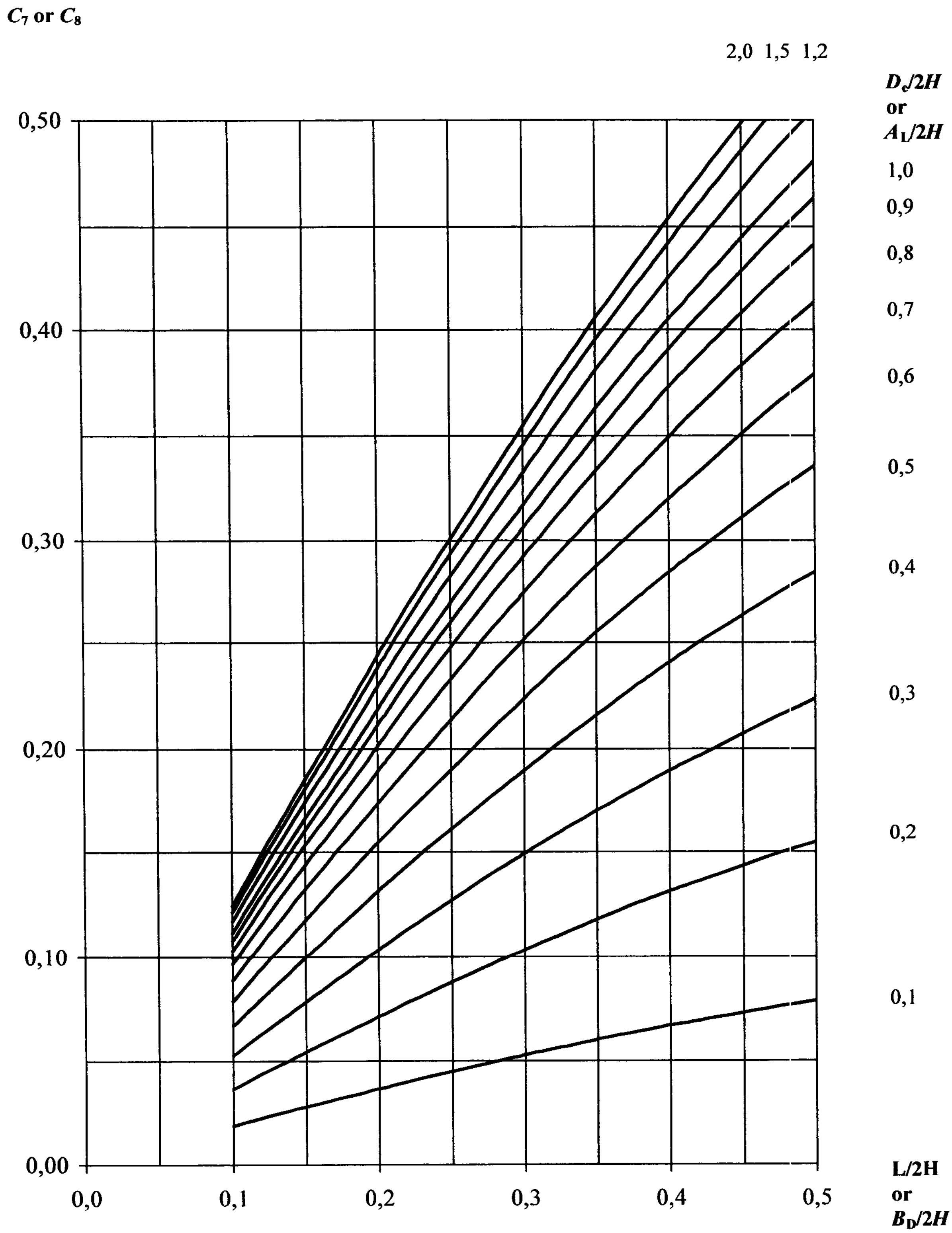
$$C_{82} = \left(\frac{B\,H_t}{\{ B^2 + H_t^2 \}} \frac{A \{ R^2 + H_t^2 \}}{\{ A^2 + H_t^2 \} R} \right)$$

The coefficient C_8 may be derived directly from graphs A2.3.3.1-1 and -2 with:

A	=	A_L	Dimensions of the sides of the area affected by the distributed live load
B	=	B_D	
C_{dyn}	=	$1 + \frac{0{,}3}{H_t}$	Streets and roads
	=	$1 + \frac{0{,}6}{H_t}$	Railways and airports
p_r	=	Surface pressure due to distributed live load	
R	=	$\sqrt{A^2 + B^2 + H_t^2}$	



Graph A2.3.3.1-1



Graph A2.3.3.1-2

A2.3.4 - Determination of the moments acting upon the piping

A2.3.4.1 - General

The formulas given hereafter permit the determination of the moments at any point of the piping wall for different loading cases. The superposition of these different cases make it possible to account for the behaviour of this piping.

The stresses may be derived from the values of the resultant moments using the following equation:

$$\sigma(\alpha) = \frac{M(\alpha)}{I/v}$$

A2.3.4.2 - Moments due to backfill

A2.3.4.2.1 - Load per unit length

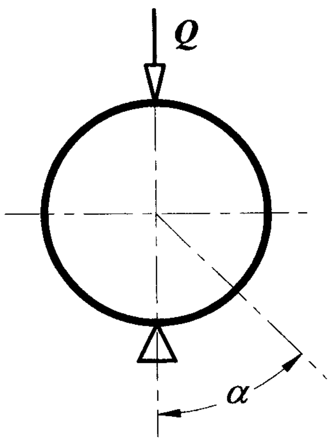


Figure A2.3.4.2.1

$$M(\alpha) = \left(\frac{1}{\pi} - \frac{\sin\alpha}{2}\right) Q \frac{D_m}{2} \qquad \text{(A2.3.4.2.1-1)}$$

where:

Q = Load per unit length

D_m = Mean diameter

A2.3.4.2.2 - Distributed load

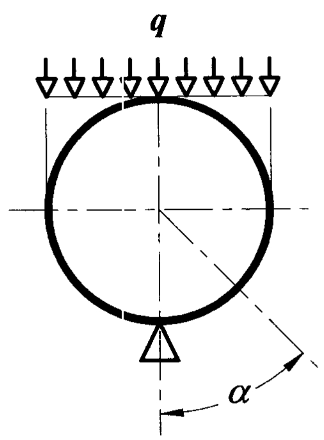


Figure A2.3.4.2.2

$0 \leq \alpha \leq \pi/2$

$$M(\alpha) = q\left(\frac{D_m}{2}\right)^2 \left(\frac{1}{\pi} + \frac{3}{8} - \sin\alpha - \frac{\cos\alpha}{3\pi}\right)$$

(A2.3.4.2.2-1)

$\pi/2 \leq \alpha \leq \pi$

$$M(\alpha) = q\left(\frac{D_m}{2}\right)^2 \left(\frac{1}{\pi} - \frac{1}{8} - \frac{(\sin\alpha)^2}{2} - \frac{\cos\alpha}{3\pi}\right)$$

(A2.3.4.2.2-2)

where:

q = Load per unit length, distributed along the diameter

$$q = \left(\frac{Q}{D_m}\right)$$

D_m = Mean diameter

A2.3.4.3 - Dead load

$$M(\alpha) = p\left(\frac{D_m}{2}\right)^2 \left(-(\pi-\alpha)\sin\alpha + \frac{\cos\alpha}{2} + 1\right)$$

(A2.3.4.3-1)

p = Weight per circumferential unit length

A2.3.4.4 - Hydrostatic pressure

$$M(\alpha) = \frac{p}{2}\left(\frac{D_m}{2}\right)^3 \left(-(\pi-\alpha)\sin\alpha + \frac{\cos\alpha}{2} + 1\right)$$

(A2.3.4.4-1)

p = Unit weight

A2.3.4.5 - Taking account of the bedding condition (continuous supporting on sand bed e.g.)

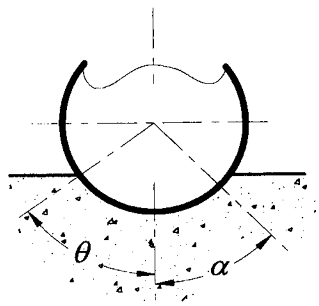


Figure A2.3.4.5

$\alpha \leq \theta$

$$M(\alpha) = \frac{q}{2\pi}\left(\frac{D_m}{2}\right)^2 \left(2U + K\cos\alpha + 2\pi\{(\theta-\alpha)\sin\alpha - \cos\alpha + \cos\theta\}\right)$$ (A2.3.4.5-1)

$\alpha \leq \theta$

$$M(\alpha) = \frac{q}{2\pi}\left(\frac{D_m}{2}\right)^2 \left(2U + K\cos\alpha\right)$$ (A2.3.4.5-2)

with:

$U = 2\sin\theta - \theta(\cos\theta + 1)$ (A2.3.4.5-3)

$K = \theta - \sin\theta\cos\theta$ (A2.3.4.5-4)

and

q = distributed total load