TECHNICAL REPORT

ISO/TR 10465-2

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Underground installation of flexible glass-reinforced thermosetting resin (GRP) pipes —

Part 2:
Comparison of static calculation methods

Installation enterrée de canalisations flexibles en plastique renforcé de fibres de verre/résine thermodurcissable (PRV) —

Partie 2: Comparaison de méthodes de calcul statique

Reference number
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Contents

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Foreword

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

The main task of ISO technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 10465-2, which is a Technical Report of type 2, was prepared by Technical Committee ISO/TC 138, *Plastics pipes, fittings and valves for the transport of fluids*, Subcommittee SC 6, *Reinforced plastics pipes and fittings for all applications*.

The reasons which led to the decision to publish this document in the form of a type 2 Technical Report are explained in the introduction.

ISO/TR 10465 consists of the following parts, under the general title *Underground installation of flexible glass-reinforced thermosetting resin (GRP) pipes:*

— *Part 1: Installation procedures*

— *Part 2: Comparison of static calculation methods*

— *Part 3: Installation parameters and application limits*

This document is not to be regarded as an International Standard. It is proposed for provisional application so that experience may be gained on its use in practice. Comments should be sent to the secretariat of TC 138/SC 6.

Introduction

Work in ISO/TC 5/SC 6 (now ISO/TC 138) on writing standards for the use of glass-reinforced plastics (GRP) pipes and fittings was approved at the subcommittee meeting in Oslo in 1979. An *ad hoc* group was established and the responsibility for drafting various standards was later given to a Task Group (now ISO/TC 138/SC 6).

At the SC 6 meeting in London in 1980, Sweden proposed that a working group be formed to develop documents regarding a code of practice for GRP pipes. This was approved by SC 6, and Working Group 4 (WG 4) was formed for this purpose. Since 1982, twenty-eight WG 4 meetings have been held which have considered the following areas:

— procedures for the underground installation of GRP pipes;

— pipe/soil interaction with pipes having different stiffness values;

— minimum design features;

— an overview of various static calculation methods.

During the work of WG 4, it became evident that unanimous agreement could not be reached within the working group on the specific methods to be employed. Therefore WG 4 agreed that all documents should be made into a three-part type 2 Technical Report, of which this is part 2.

Part 1 describes procedures for the underground installation of GRP pipes. It concerns particular stiffness classes for which performance requirements have been specified in at least one product standard, but it can also be used as a guide for the installation of pipes of other stiffness classes.

Part 2 presents a comparison of the two primary methods used internationally for static calculations on underground GRP pipe installations.

These methods are:

a) the ATV method given in ATV-A 127, *Guidelines for Static Calculations on Drainage Conduits and Pipelines*;

b) the AWWA method given in AWWA's *Fiberglass pipe design manual M-45*.

Part 3 gives additional information, which is useful for static calculations when using an ATV-A 127 type design system in accordance with part 2 of this Technical Report, on items such as:

— parameters for deflection calculations;

— soil parameters, strain coefficients and shape factors for flexural-strain calculations;

— soil moduli and pipe stiffnesses for buckling calculations with regard to elastic behaviour;

— parameters for rerounding and combined-loading calculations;

— the influence of traffic loads;

— the influence of sheeting;

— safety factors.

Underground installation of flexible glass-reinforced thermosetting resin (GRP) pipes —

Part 2:
Comparison of static calculation methods

1 Scope

This part of ISO/TR 10465 presents a comparison of the ATV and AWWA methods for static calculations on underground GRP pipe installations. It is intended that this comparison will encourage the use of both procedures for GRP pipes conforming to International Standards.

It is not the intent of this part of ISO/TR 10465 to cover all the details of the two methods. Some aspects are, of necessity, very complex, and for a full understanding the original documents need to be studied in detail. Rather, the intention is to give a general overview and comparison of the key elements so that the user can more easily understand and appreciate the differences between the two procedures and their similarities.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO/TR 10465. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO/TR 10465 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ATV-A 127, *Guidelines for static calculations on drainage conduits and pipelines* (December 1988).

AWWA M-45, *Fiberglass pipe design manual M-45* (1997).

ISO/TR 10465-1:1993, *Underground installation of flexible glass-reinforced thermosetting resin (GRP) pipes — Part 1: Installation procedures.*

ISO/TR 10465-3:1999, *Underground installation of flexible glass-reinforced thermosetting resin (GRP) pipes — Part 3: Installation parameters and application limits.*

3 Terminology

Pipeline installation terminology can vary around the world so, where such terms are used in this part of ISO/TR 10465, they will either be described or reference will be made to part 1 or 3, where the relevant descriptions can be found.

4 Symbols and abbreviated terms

For the purposes of this Technical Report, the following symbols apply:

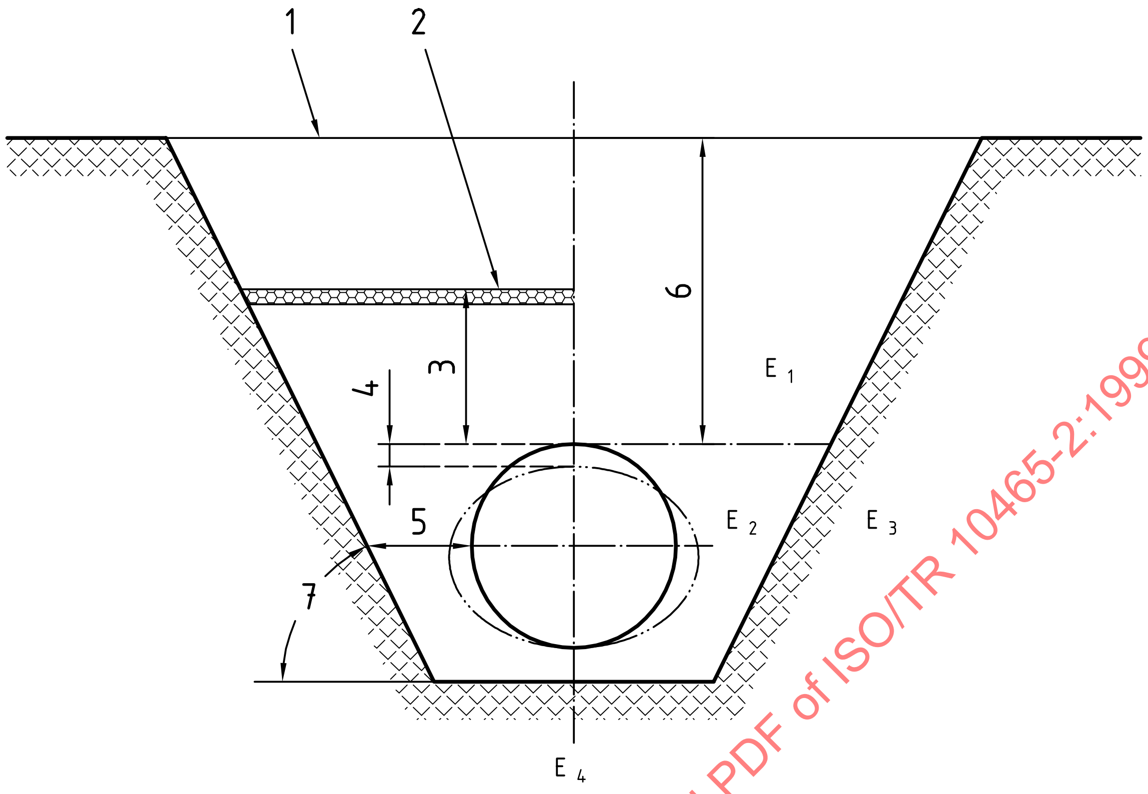
NOTE This clause also contains symbols and abbreviations from parts 1 and 3 for completeness.

Symbol	Unit	Meaning
a_f	—	Ageing factor
a_f	—	Distribution factor
B'	—	Support factor
b	m	Trench width at spring-line
b'	m	Distance from trench wall to pipe (see Figure 1)
c_4	—	Reduction factor
c_f	—	Creep factor
c_h, c_v	—	Deformation coefficients
D_f	—	Shape factor
D_g	—	Shape adjustment factor
D_L	—	Deflection lag factor
d_e	m	External pipe diameter
d_m	mm	Mean pipe diameter $[(d_e \times 1\,000) - e]$
d_v	mm	Vertical deflection
d_{vA}	m	Maximum permissible long-term deflection
d_{vR}	mm	Vertical deflection at rupture
$(d_v/d_m)_{permissible}$	%	Maximum permissible relative vertical deflection
$(d_v/d_m)_{initial}$	%	Initial vertical deflection
$(d_v/d_m)_{50}$	%	Long-term (50-year) vertical deflection
$(d_v/d_m)_{ult}$	%	Ultimate long-term vertical deflection
E, E_o, $E_{t,wet}$	N/m^2	Apparent flexural moduli of pipe wall
E', E_1, E_2, E_3, E_4, E'_s, E'_t, E_s	N/mm^2	Soil deformation moduli
E_{TH}	N/m^2	Tensile hoop modulus
e	mm	Pipe wall thickness
e	—	Base of natural logarithms (2,718 281 8)
F	—	Compaction factor
F_A, F_E	kN	Wheel loads
FS	—	Safety factor
FS_b	—	Bending safety factor
FS_{pr}	—	Pressure safety factor
HDB	—	Extrapolated pressure strain at 50 years
H_{EVD}	m	Environmental depth of cover
h	m	Depth of cover to top of pipe
h_w	m	Height of water surface above top of pipe

Symbol	Unit	Meaning
I	m^4/m	Second moment of area in longitudinal direction per unit length (of a pipe)
i_o	—	Initial ovalization
i_f	N/mm^2	Installation factor
K^*	—	Coefficient for bedding reaction pressure
K_1, K_2	—	Ratio of horizontal to vertical soil pressure in soil zones 1 and 2
K_3	—	Ratio of horizontal to vertical soil pressure in pipe-zone backfill, when backfill is at top of pipe (see ISO/TR 10465-3, annex A)
k_x	—	Bedding coefficient
M	—	Sum of bending moments
M_s	N/mm^2	Constrained-soil modulus
m_{qv}, m_{qh}, m^*_{qh}	—	Moment factors
N	—	Sum of normal forces
n_{10}	—	Number of blows
P	bar	Internal pressure
PN	—	Nominal pressure
$P(x)$	—	Probability function
P_f	—	Probability of failure
P_v	MPa (N/mm^2)	Internal underpressure
P_W	N/m^2	Working pressure
p_a	N/m^2	External water pressure
p_E	N/mm^2	Pressure due to prismatic soil load
p_F	N/m^2	Pressure due to traffic load according to Boussinesq
p_o	N/mm^2	Soil pressure due to distributed load
p_v	N/mm^2	Soil pressure resulting from traffic load
q_a	MPa (N/mm^2)	Permissible buckling pressure
q_c	MPa (N/mm^2)	Critical buckling pressure
q_{cs}	MPa (N/mm^2)	Short-term critical buckling pressure
q_{cl}	MPa (N/mm^2)	Critical buckling pressure under sustained load
q_{cw}	MPa (N/mm^2)	Critical buckling pressure due to water
q_h, q_v	N/mm^2	Horizontal and vertical soil pressure on pipe
$q_h{}^*$	N/mm^2	Horizontal bedding reaction pressure
$q_{h,50}$	N/mm^2	Long-term (50-year) horizontal soil pressure
q_{hLT}	N/mm^2	Reduced long-term horizontal soil pressure
q_{c^*w}	N/mm^2	Horizontal bedding reaction for pipe and contents
$q_{v,50}$	N/mm^2	Long-term (50-year) vertical soil pressure
q_{vLT}	N/mm^2	Reduced long-term vertical soil pressure
q_{vwa}	N/mm^2	Vertical load due to pipe and contents
R_w	—	Water buoyancy reduction factor
r	—	Rerounding factor

Symbol	Unit	Meaning
r_A, r_E	m	Wheel radii
r_c	—	Rerounding coefficient
S_{Bh}	N/mm^2	Horizontal bedding stiffness
S_{Bv}	N/mm^2	Vertical bedding stiffness
S_b	—	Long-term strain
S_c	—	Soil support combining factor
S_k	N/mm^2	Characteristic stress
S_p	N/m^2	Initial pipe stiffness
$S_{p,50}$	N/m^2	Long-term pipe stiffness
S_R	N/mm^2	$S_p \times 8 \times 10^{-6}$
$S_{R,50}$	N/mm^2	$S_{p,50} \times 8 \times 10^{-6}$
s_{Res}	N/mm^2	Standard deviation of strength of pipe
$s_{Res,A}$	N/mm^2	Standard deviation of strength of pipe above ground
$s_{Res,B}$	N/mm^2	Standard deviation of strength of pipe below ground
s_S	N/mm^2	Standard deviation of stress in pipe
$s_{S,A}$	N/mm^2	Standard deviation of stress in pipe above ground
$s_{S,B}$	N/mm^2	Standard deviation of stress in pipe below ground
SPD	%	Standard Proctor density
V_{RB}	—	System stiffness
V_S	—	Stiffness relation
W_c	N/m^2	Vertical soil load on pipe
W_L	N/m^2	Traffic load
X	—	Safety index
y_R	%	Coefficient of variation for tensile strength
y_{ult}	%	Coefficient of variation for ultimate deflection
α	° (degrees)	Half the bedding angle (see Figure 2)
β	° (degrees)	Half the horizontal support angle (see Figure 2)
χ	—	Reduction factor applied to prismatic soil load to allow for friction
χ_β	—	Reduction factor applied to prismatic soil load to allow for friction and taking into account trench angle (β in ATV and ω in this part of ISO/TR 10465)
χ_o	—	Reduction factor applied to a uniformly distributed load to allow for friction
$\chi_{o\beta}$	—	Reduction factor applied to a uniformly distributed load to allow for friction and taking into account trench angle (β in ATV but ω in this part of ISO/TR 10465)
δ	° (degrees)	Trench wall friction angle
δ_d	mm	Maximum permitted long-term installed deflection
δ_v	%	Relative vertical deflection
δ_{vio}	%	Relative vertical deflection due to backfilling in pipe zone
δ_{viv}	%	Relative vertical deflection due to installation irregularities

Symbol	Unit	Meaning
δ_{vs}	%	Relative vertical deflection due to soil load
δ_{vw}	%	Relative vertical deflection due to weight of pipe
δ_W	%	Relative vertical deflection due to traffic load
ε_{comp}	—	Compressive strain due to vertical load
ε, ε_t, ε_f	—	Calculated flexural strains in pipe wall
ε_{max}	—	Maximum permissible strain due to pressure
ε_{pr}	—	Calculated strain in pipe wall due to internal pressure
ε_v	—	Flexural strain due to total vertical load
ε_{vio}	—	Flexural strain due to backfilling in pipe zone
ε_{vw}	—	Flexural strain due to weight of pipe
ε_W	—	Flexural strain due to pipe contents
γ_b	MN/m^3	Bulk density of backfill material
γ_w	MN/m^3	Density of pipe contents
η, η_t, η_f, η_{ff}	—	Safety factors
η_{haf}	—	Combined flexural safety factor
η_{hat}	—	Combined tensile safety factor
φ	° (degrees)	Soil internal friction angle
κ, κ_ω	—	Reduction factor for distributed load according to silo theory when trench angle (ω) is 90°
κ_o, $\kappa_{o\omega}$	—	Reduction factor for distributed load according to silo theory when trench angle (ω) is not 90°
λ_B	—	Concentration factor in soil next to pipe
λ_{max}	—	Maximum concentration factor
λ_R, λ_{RG}, λ_{max}	—	Concentration factors for soil above pipe
μ_{Res}	N/mm^2	Mean value of pipe strength (resistance)
$\mu_{Res,A}$	N/mm^2	Mean value of strength (resistance) of pipe above ground
$\mu_{Res,B}$	N/mm^2	Mean value of strength (resistance) of pipe below ground
μ_S	N/mm^2	Mean value of stress in pipe
$\mu_{S,A}$	N/mm^2	Mean value of stress in pipe above ground
$\mu_{S,B}$	N/mm^2	Mean value of stress in pipe below ground
ρ	MN/m^3	Density of pipe-wall material
ρ_D	g/cm^3	Density
σ_c	N/mm^2	Calculated compressive stress in pipe wall
σ_t	N/mm^2	Calculated tensile stress in pipe wall
ν_s	—	Poisson's ratio for soil
ω	° (degrees)	Trench wall angle (see Figure 1) (designated β in ATV-A 127)
ξ	—	Correction factor for horizontal bedding



Key

1 Ground level
2 Water table
3 Height of water surface above top of pipe, h_w
4 Vertical deflection, d_v
5 Distance from trench wall to pipe, b'
6 Depth of cover to top of pipe, h
7 Trench wall angle, ω

NOTE 1 The AWWA M-45 design manual uses E'_b in zone E_2.

NOTE 2 The AWWA M-45 design manual uses E'_n in zone E_3 and E_4.

NOTE 3 E_1 is the backfill above the pipe zone (E_2) material.

NOTE 4 E_2 is the embedment material to the side of the pipe.

NOTE 5 E_3 is the *in situ* trench wall material.

NOTE 6 E_4 is the *in situ* material underlying the pipe zone material (foundation material).

NOTE 7 In ATV-A 127, β is used for the trench wall angle instead of ω.

Figure 1 — Symbols and terminology

5 Soil-load distribution

The assumed soil-load distributions used in ATV-A 127 and AWWA M-45, which are based on those made by M.G. Spangler, are shown in Figure 2. The main difference between the two assumptions is that ATV-A 127 considers the active horizontal pressure, whereas AWWA M-45, like Spangler, assumes the value to be zero. In ATV, the influence of active horizontal pressure is accounted for by using a value for K_2 which is in the range 0,1 to 0,4, depending on the type of soil in the pipe zone (zone E_2 in Figure 1).

Both ATV-A 127 and AWWA M-45 use vertical deflection.

When, in the ATV system, the appropriate coefficients are used to calculate horizontal deflection using Spangler's assumption for soil-load distribution, the same deflection is obtained as with Spangler's system provided Spangler's E' is multiplied by 0,6 (coefficient c_4 in ATV).

Related to the question of soil distribution is the influence of the modulus of passive soil resistance. ATV introduces the term S_{Bh} equal to $0,6 \times \zeta \times E_2$ where ζ is the Leonhardt factor which accounts for the influence of the *in situ* (native) soil (zone E_3) and trench width (see Figure 1) and E_2 corresponds to Spangler's E'.

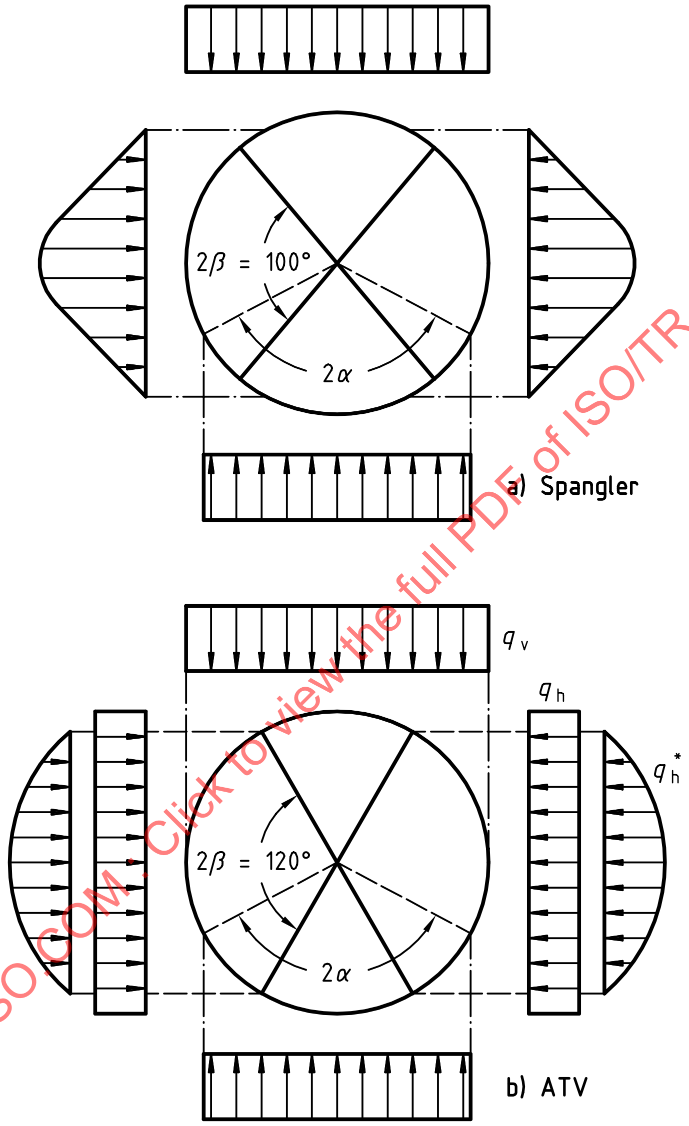


Figure 2 — Soil distribution according to Spangler and ATV-A 127

6 Soil load

6.1 General

The calculation of soil loads needs to consider both initial and long-term loadings. Short-term loading can be related to the initial pipe deflection which is a property that is often used as a measure of installation quality. Long-term loading defines the expected long-term deflection of the pipe and is therefore related to service life.

6.2 Initial loadings

6.2.1 AWWA procedure

In the AWWA procedure, the soil loading is assumed to be a soil prism in all cases. The prism has a height equal to the depth of cover and its width is equal to the outside diameter of the pipe. The prismatic equation is always used, and arching or silo theory is not considered.

The vertical soil load W_c is calculated using equation (1):

$$W_c = \gamma \times h \tag{1}$$

where

W_c is the vertical soil load, in N/m²;

γ is the bulk density of the soil (i.e. its weight per unit volume), in N/m³;

h is the depth of cover, in m.

6.2.2 ATV procedure

The ATV procedure for calculating soil loads is more detailed than that used by AWWA. The procedure is based on silo theory which assumes that frictional forces against the trench walls will lead to a reduction in the pressure acting on the pipe due to the soil. It is assumed that these friction conditions are maintained for the whole life of the pipe.

Trench and embankment conditions are considered, as well as the angle of the trench walls and the relationship between the horizontal and vertical soil pressures.

When the trench width is four times the pipe diameter or greater, then ATV assumes that embankment conditions exist and consequently the soil load is a prismatic load.

The remainder of this subclause is an outline of the ATV procedure for calculating the soil load. Because of the detailed nature of this approach, the reader is strongly recommended to read ATV-A 127 in detail very carefully.

The vertical pressure p_E due to the prismatic soil load is modified by a factor χ_β in equation (2) to take into account the friction effects mentioned above:

$$p_E = \chi_\beta \times \gamma \times h \tag{2}$$

Similarly, friction effects change the soil pressure p_o applied by a uniformly distributed load acting over a limited area, and this is expressed using the factor $\chi_{o\beta}$:

$$p'_o = \chi_{o\beta} \times p_o \tag{3}$$

NOTE Subscripts have been used above to indicate that χ is the reduction factor for soil load, χ_o is the reduction factor for a uniformly distributed load (UDL), χ_β is the reduction factor for soil loads which take into account the trench angle β or ω (see Figure 3) and $\chi_{o\beta}$ is the reduction factor for a UDL which takes into account the trench angle.

To use these reduction factors, the procedures require that:

a) $E_1 \leqslant E_3$ (for χ)

b) $E_1 < E_3$ (for χ_o)

If either of these conditions is not met or if the installation is considered to be of the embankment type, then the factors χ and χ_o are taken to be equal to 1.

The reduction factors are derived using equations (4) and (5):

$$\chi = \frac{1 - e^{\left(-2 \times \frac{h}{b} \times K_1 \times \tan\delta\right)}}{2 \times \frac{h}{b} \times K_1 \times \tan\delta} \quad (4)$$

$$\chi_o = e^{\left(-2 \times \frac{h}{b} \times K_1 \times \tan\delta\right)} \quad (5)$$

where

- e is the base of natural logarithms (2,718 281 8);
- p_E is the vertical soil pressure due to the soil load, in N/m^2;
- χ_β is the reduction factor for silo theory;
- γ is the bulk density of the soil (i.e. its weight per unit volume), in N/m^3;
- h is the depth of cover, in m;
- $\chi_{o\beta}$ is the silo theory reduction factor for UDL (uniformly distributed load);
- p_o is the soil pressure due to the UDL, in N/m^2;
- b is the trench width, in m;
- δ is the trench wall friction angle, in degrees;
- K_1 is the ratio of the horizontal to the vertical soil pressure.

To help in other parts of the procedures, there are four classes of installation for the zone of material above the pipe zone (see Table 1)

Table 1 — Installation conditions

Class	Description
A1	Compacted fill against undisturbed native soil without assessing degree of compaction. These conditions also apply to sheet piles left in after installation.
A2	Vertical timber sheeting or lightweight sheet piles or shields which are gradually removed in stages during installation or uncompacted fill or soaking of the fill (valid for soil group G1).
A3	Vertical sheeting or shields withdrawn in one operation after all the fill material has been put in place.
A4	Same as A1 but degree of compaction is assessed. These conditions shall not be used with soil group G4.

For all the installation conditions detailed in Table 1, the lateral soil pressure acting on the trench walls, expressed in terms of the vertical to horizontal soil pressure ratio K_1, is assumed to be 0,5. Under these conditions, equations (4) and (5) reduce to equations (4a) and (5a):

$$\chi = \frac{1 - e^{\left(-\frac{h}{b} \times \tan\delta\right)}}{\frac{h}{b} \times \tan\delta} \quad (4a)$$

$$\chi_o = e^{\left(-\frac{h}{b} \times \tan\delta\right)} \quad (5a)$$

The wall friction angle is derived from one of the equations given in Table 2, depending on the fill conditions.

Table 2 — Wall friction angle δ

Class	Equation	
A1	$\delta = 0{,}66 \times \varphi^*$	(6a)
A2	$\delta = 0{,}33 \times \varphi^*$	(6b)
A3	$\delta = 0$	(6c)
A4	$\delta = \varphi^*$	(6d)
NOTE φ^* is the internal friction angle, in degrees, of the soil.		

In the case where $\delta = 0$, the reduction factors χ and χ_o are taken to be equal to 1.

The other reduction factors χ_β and $\chi_{o\beta}$ are adjusted to take into account the trench angle, as shown by equations (7) and (8):

$$\chi_\beta = 1 - \frac{\omega}{90} + \left(\chi \times \frac{\omega}{90}\right) \quad (7)$$

$$\chi_{o\beta} = 1 - \frac{\omega}{90} + \left(\chi_o \times \frac{\omega}{90}\right) \quad (8)$$

The horizontal soil pressure q_h is calculated using equation (9):

$$q_h = K_2\left[(\chi \times \gamma \times h) + (\chi_o \times p_o) + \left(\gamma \times \frac{d_e}{2}\right)\right] \quad (9)$$

where

d_e is the outside diameter of the pipe, in m;

K_2 is the ratio of the horizontal to the vertical pressure at the pipe spring-line (see ATV).

When the pipe installation work is to be checked by measurement of the pipe deflection, calculate the concentration factor in the soil above the pipe, λ_R, as described in ATV and the concentration factor in the soil next to the pipe, λ_B, together with the concentration factor above the pipe, λ_{RG}, using equations (10) and (11):

$$\lambda_B = \frac{4 - \lambda_R}{3} \quad (10)$$

$$\lambda_{RG} = \left(\frac{\lambda_R - 1}{3} \times \frac{b}{d_e}\right) + \frac{4 - \lambda_R}{3} \quad (11)$$

In such cases, calculate the vertical soil pressure q_v using equation (12):

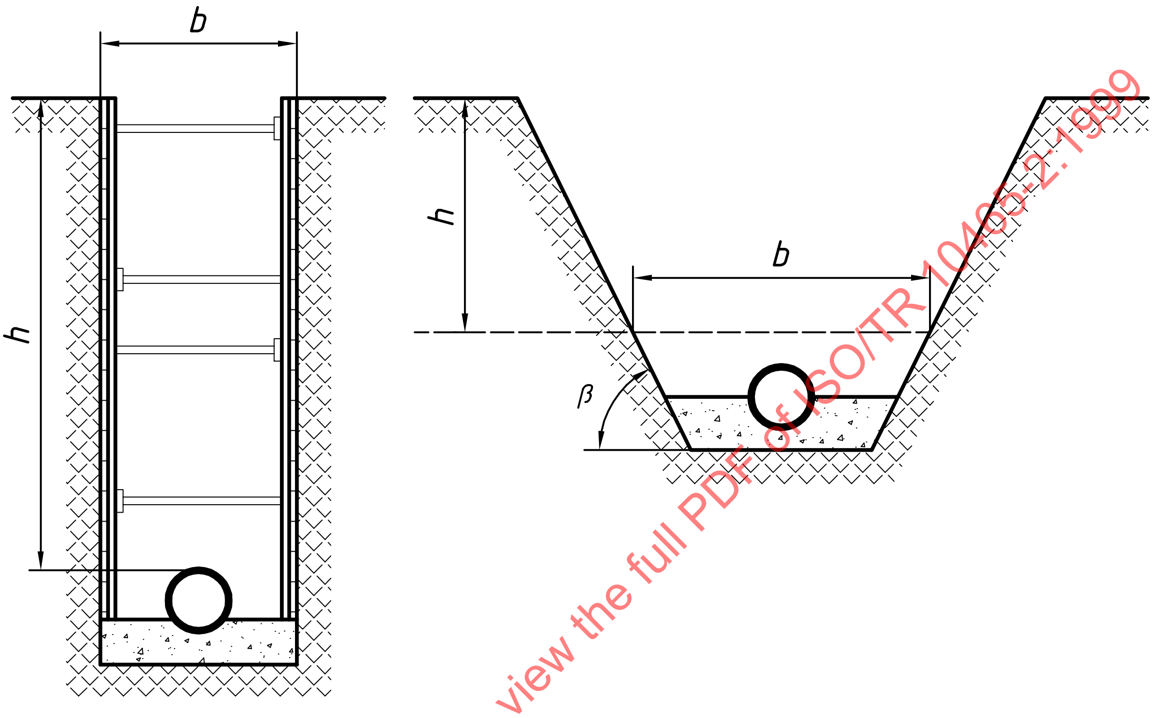
$$q_v = \lambda_{RG}\left[(\chi \times \gamma \times h) + (\chi_o \times p_o)\right] + p_v \quad (12)$$

which, in embankment situations, simplifies to equation (13):

$$q_v = \lambda_R \left[(\gamma \times h) + p_o \right] + p_v \quad (13)$$

and the horizontal pressure q_h using equation (14):

$$q_h = K_2 \times \left[\lambda_B \left(\chi \times \gamma \times h + \chi_o \times p_o \right) + \left(\gamma \times \frac{d_e}{2} \right) \right] \quad (14)$$



a) Trench with parallel walls b) Trench with sloping walls

Figure 3 — Trench walls

6.3 Long-term loading

6.3.1 AWWA procedure

AWWA does not differentiate between short-term and long-term loading. However, to take into account the effects of time on deflection, a deflection lag factor is used (see 8.1.1.2).

6.3.2 ATV procedure

For all soil loads, the silo theory is used and the short-term and long-term loads are equal.

7 Traffic loads

7.1 General

Basically, the design methods used in both documents are related to the Boussinesq theory which converts a surface wheel load into a soil pressure load applied to the pipe at the crown. The magnitude of the load applied to the pipe is a function of wheel load, burial depth and the angle of pressure dissipation.

While only traffic loads due to lorry traffic are discussed here, AWWA also discusses rail loading and ATV has extensive guidance on aircraft and rail loadings.

7.2 AWWA procedure

The AWWA approach is based on an AASHTO H-20 truck (16 000 lb = 71 300 N wheel load) centred in each lane of a four-lane highway (lanes 3,7 m wide) (see Figure 4).

The pipe may be perpendicular or parallel to the direction of truck travel, or any intermediate position. Other design truck loads can be specified if required.

The traffic load W_L is calculated using equation (15):

$$W_L = \frac{P I_f}{L_1 \times L_2} \qquad (15)$$

where

W_L is the live load at the pipe crown, in N/m²;

L_1, L_2 are the lengths of the sides of the pressure rectangle (see Figure 4), in m;

P is the wheel load, in N;

I_f is an impact factor (dimensionless):

= 1,1 for depths of cover $>$ 0,6 m but $<$ 0,9 m,

= 1,0 for depths of cover $\geqslant$ 0,9 m.

The values of L_1, the load width parallel to the direction of travel, and L_2, the load width at right angles to the direction of travel, are calculated from equation (16) and equation (17) or (18), respectively:

$$L_1 = 0{,}25 + 1{,}75h \qquad (16)$$

where h is the burial depth, in m (see Figure 3).

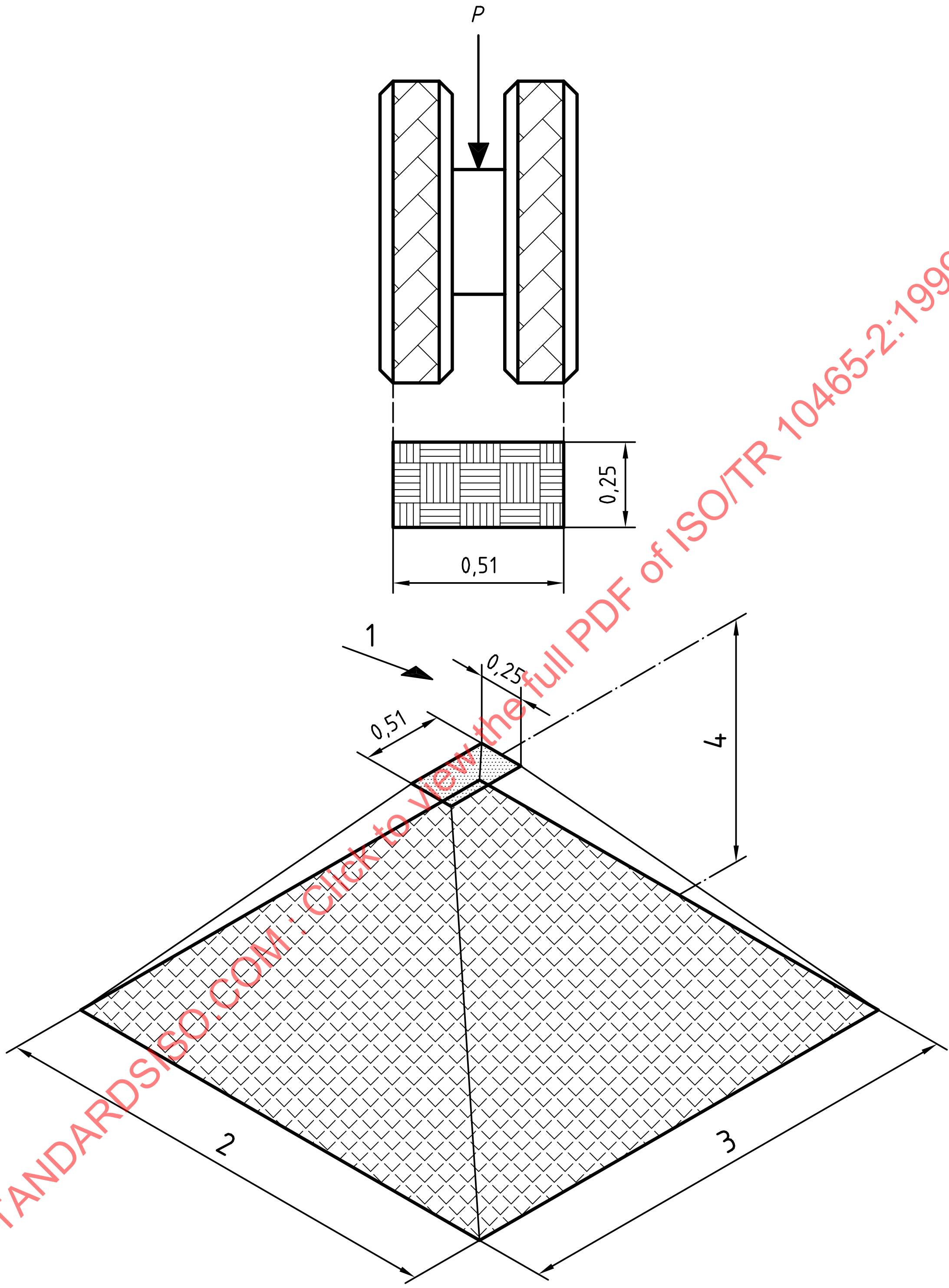
When the depth of cover h is between 0,6 m and 0,745 m, then

$$L_2 = 0{,}5 + 1{,}75h \qquad (17)$$

When the depth of cover h is 0,745 m or more, then

$$L_2 = (13{,}1 + 1{,}75h)/8 \qquad (18)$$

Dimensions in metres



Key

1 Direction of travel
2 Load width parallel to direction of travel, L_1
3 Load width at right angles to direction of travel, L_2
4 Burial depth, h

Figure 4 — Distribution of HS-20 live load through fill

The calculation is independent of pipe diameter, and with the H-20 (71 300 N) wheel load it gives the values given in Table 3.

Table 3 — H-20 live loads

Depth of cover m	Traffic load W_L kN/m^2
0,6	41,4
0,8	26,9
0,9	22,8
1,1	17,9
1,2	15,2
1,8	10,3
2,7	6,9
3,0	5,5
3,7	4,1
4,9	3,4
6,1	2,8
8,2	1,4
12,2	0,7

7.3 ATV procedure

ATV also follows the Boussinesq theory, but uses different pressure dissipation angle, wheel load and impact factor assumptions from those used by AWWA.

According to Boussinesq, the maximum pressure p_F is calculated using equation (19):

$$p_F = \frac{F_A}{r_A^2 \times \pi}\left\{1 - \left[\frac{1}{1+\left(\frac{r_A}{h}\right)^2}\right]^{\frac{3}{2}}\right\} + \frac{3 \times F_E}{2 \times \pi \times h^2}\left[\frac{1}{1+\left(\frac{r_E}{h}\right)^2}\right]^{\frac{5}{2}} \quad (19)$$

and the pressure (i.e. traffic load) acting on the pipe is calculated using equation (20):

$$p_V = a_F \times p_F \times \varphi \quad (20)$$

where

p_F is the soil pressure due to the traffic load according to Boussinesq, in N/m^2;

F_A, F_E are the wheel loads, in kN;

r_A, r_E are the wheel radii, in m;

h is the depth of cover, in m;

p_V is the soil pressure acting on the pipe, in N/m²;

a_F is the distribution factor, given by:

$$a_F = 1 - \frac{0{,}9}{0{,}9 + \frac{4h^2 + h^6}{1{,}1 \times d_m^{\frac{2}{3}}}} \tag{21}$$

d_m being the mean pipe diameter, in m;

φ is the impact factor.

The term p_F is an approximation to the pressure according to Boussinesq under wheel loads.

The distribution factor a_F takes into account the pressure distribution over the pipe cross-section and pipe length at various depths of fill. It is based on a pressure spread at an inclination of 2:1. Equation (21) is considered valid for the limits:

$h \geqslant 0{,}5$ m

$d_m \leqslant 5{,}0$ m

The design loads F_A and F_E as well as the design radii r_A and r_E given in Table 4 are taken from DIN 1072:1985, *Road and foot bridges; design loads*.

Table 4 — Design wheel loads and radii for standard vehicles

Standard vehicle	F_A kN	F_E kN	r_A m	r_E m
SLW 60	100	500	0,25	1,82
SLW 30	50	250	0,18	1,82
LKW 12	40	80	0,15	2,26

Horizontal pressures due to traffic loads are not considered.

The pressures due to traffic loads are multiplied by the impact factor φ given in Table 5.

Table 5 — Impact factor φ

Standard vehicle	φ
SLW 60	1,2
SLW 30	1,4
LKW 12	1,5

For convenience, ATV presents the loads graphically as a function of burial depth.

8 Deflections

8.1 Resulting from vertical load

8.1.1 AWWA procedure

The AWWA system is based on Spangler's work and modifications made to it by Spangler/Watkins, commonly known as the "modified Iowa" formula:

$$\frac{d_\text{v}}{d_\text{m}} = \frac{\left(D_\text{L} \times W_\text{c} + W_\text{L}\right) \times k_\text{x}}{8\dfrac{EI}{{d_\text{m}}^3} + 0{,}061E'} \times 100 \qquad (22)$$

where

d_v is the vertical deflection, expressed as a percentage of the mean pipe diameter;

k_x is the bedding coefficient (dimensionless);

E is the apparent flexural modulus of the pipe, in N/m^2;

I is the second moment of area in the longitudinal direction, in m^4/m;

d_m is the mean diameter of the pipe, in m;

E' is the composite modulus of the soil reaction, in N/m^2;

D_L is the deflection lag factor to allow for long-term soil consolidation (dimensionless);

W_c is the soil pressure, in N/m^2;

W_L is the traffic pressure, in N/m^2;

AWWA has modified the formula and introduced additional considerations to allow for the effects of native-soil properties and the width of the trench.

8.1.1.1 Bedding coefficient k_x

The bedding coefficient reflects the degree of support provided by the soil at the bottom of the pipe and over which the bottom reaction is distributed. Assuming an inconsistent haunch (typical direct-bury condition), a k_x value of 0,1 should be used. For support provided by a shaped trench bottom, a value of 0,083 is appropriate.

8.1.1.2 Deflection lag factor D_L

The deflection lag factor is used to convert short-term to long-term deflection. Long-term deflection will be higher due to a potential increase in overburden load as soil arching is gradually lost. Other causes of increased deflection can be time-related consolidation of pipe-zone embedment and/or creep of native soil. For prediction of long-term deflection, a value greater than 1,0 shall be used for D_L. The value shall be chosen carefully, taking into account the stiffness of the native and pipe-embedment soils.

8.1.1.3 Composite soil-reaction modulus E'

The vertical loads on a flexible pipe cause a decrease in its vertical diameter and an increase in its horizontal diameter. The horizontal movement develops in the soil a passive soil resistance that provides support for the pipe. The magnitude of the soil's passive resistance varies depending upon the soil type, the degree of compaction of the pipe-zone backfill material, the native-soil characteristics, the cover depth and the trench width. To determine E' for a buried pipe, separate E' values for the native soil, E'_n, and the pipe backfill surround, E'_b, shall be determined and then combined using equation (23):

$$E' = S_c \times E'_b \quad (23)$$

where

E'_b is the modulus of the pipe-zone embedment, in N/m^2;

S_c is the soil support combining factor (dimensionless).

Values of S_c are obtained from a table (see Table 6), where S_c is a function of trench width and the ratio of the native-soil to pipe-embedment moduli. This table was developed considering the work of Leonhardt, as used in ATV, along with additional studies.

Table 6 — Values of soil support combining factor S_c

E'_n/E'_b	b/d					
	1,5	**2**	**2,5**	**3**	**4**	**5**
0,1	0,15	0,30	0,60	0,80	0,90	1,00
0,2	0,30	0,45	0,70	0,85	0,92	1,00
0,4	0,50	0,60	0,80	0,90	0,95	1,00
0,6	0,70	0,80	0,90	0,95	1,00	1,00
0,8	0,85	0,90	0,95	0,98	1,00	1,00
1,0	1,00	1,00	1,00	1,00	1,00	1,00
1,5	1,30	1,15	1,10	1,05	1,00	1,00
2,0	1,50	1,30	1,15	1,10	1,05	1,00
3,0	1,75	1,45	1,30	1,20	1,08	1,00
⩾ 5,0	2,00	1,60	1,40	1,25	1,10	1,00

where

b is the trench width at the spring-line, in m;

d is the pipe diameter, in m;

E'_n is the native-soil modulus, in N/m^2;

E'_b is the embedment modulus, in N/m^2.

NOTE 1 Tabulated values for E'_b and E'_n are given in AWWA.

NOTE 2 Intermediate values of S_c may be determined by linear interpolation between adjacent values.

8.1.2 ATV procedure

The relative vertical deflection δ_v, given by $\delta_v = \frac{d_v}{d_m}$ (% deflection when multiplied by 100), is determined using equation (24):

$$\delta_v = \frac{d_v}{d_m} = \left[c_{v1} + \left(c_{v2} \times K^*\right)\right] \times \left(q_v - q_h\right) \times \frac{1}{S_R} \quad (24)$$

where

$$K^* = \frac{c_{h1}}{V_{RB} - c_{h2}} \quad (25)$$

c_{v1}, c_{v2}, c_{h1}, c_{h2} are deflection coefficients (see Tables 7 and 8);

$$V_{RB} = S_R / S_{Bh} \tag{26}$$

$$S_{Bh} = 0,6 \times \xi \times E_2 \tag{27}$$

E_2 is the modulus of the pipe-zone soil, in N/mm^2 (see Figure 1);

ξ is a correction factor for the horizontal bedding stiffness, given by:

$$\xi = \frac{1,44}{f + (1,44 - f) \times E_2 / E_3} \tag{28}$$

in which $$f = \frac{b/d_a - 1}{1,154 + 0,444 \times (b/d_a - 1)} \leqslant 1,44 \tag{29}$$

The correction factor ξ allows for the difference between the moduli of the pipe-embedment material and the native soil, and also for the width of the trench.

The relationship between the bedding angle 2α and the coefficients c_{v1} and c_{h2} is shown in Table 7.

The values of c_{v2} and c_{h2} for a bedding reaction angle of 120° are given in Table 8.

Table 7 — Values of c_{v1} and c_{h1} in relation to the bedding angle 2α

Bedding angle 2α	c_{v1}	c_{h1}
60	−0,105 3	0,102 6
90	−0,096 6	0,095 6
120	−0,089 3	0,089 1
180	−0,083 3	0,083 3

Table 8 — Values of c_{v2} and c_{h2} for a bedding reaction angle of 120°

Bedding reaction angle	c_{v2}	c_{h2}
120	0,064 0	−0,065 8

8.1.2.1 Short-term versus long-term deflection

In ATV, the difference between short-term and long-term deflection is addressed largely by determining which short-term and long-term pipe stiffness is to be assessed for the product being considered.

In addition, for very weak soils the soil modulus is reduced by 50 %

8.2 Aspects not covered by AWWA or ATV

8.2.1 Deflection due to weight of pipe

Neither AWWA nor ATV include deflection due to the weight of the pipe.

8.2.2 Initial ovalization

When a trench is backfilled, the compaction of the side fill can lead to the pipe having an increased vertical diameter (initial ovalization), the extent of which will depend on the type of soil used for the pipe embedment, its degree of compaction and the stiffness of the pipe. Neither AWWA nor ATV includes initial ovalization in the deflection calculations.

8.3 Irregularities in the installation

8.3.1 General

The accuracy of any deflection calculation will depend on the input parameters and the ability of the operators installing the pipe to achieve the specified conditions. Typical potential causes of variations in deflection include:

— an uneven pipe bed;

— variations in the trench width;

— variations in the depth of burial;

— variations in native-soil properties;

— the fact that the degree of soil compaction is different from that specified;

— unplanned surface loading.

Such irregularities can increase (or decrease) pipe deflection and pipe strain compared to the calculated values.

8.3.2 AWWA procedure

There are no formal methods given in AWWA to address irregularities in the installation. However, it is implied that one could consider the effects of different native-soil and pipe-embedment moduli and/or levels of compaction from those used in design.

8.3.3 ATV procedure

ATV requires that the pipe-embedment modulus be reduced to 2/3 of the design value to allow for variations in installation.

9 Circumferential bending strain

NOTE Circumferential bending strain is determined at the top and bottom inside surfaces of the pipe. Compressive strains are negative and tensile strains are positive.

9.1 AWWA procedure

The long-term circumferential strain is calculated using equation (30):

$$\varepsilon = D_\mathrm{f} \times \frac{d_\mathrm{vA}}{d_\mathrm{m}} \times \frac{e}{d_\mathrm{m}} \tag{30}$$

where

D_f is the shape (deformation) factor (dimensionless);

d_vA is the maximum permissible long-term vertical pipe deflection, in mm.

Values of D_f are given in Table 9 as a function of pipe stiffness and embedment compaction.