# TECHNICAL SPECIFICATION

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# Plastics piping systems — General rules for structural design of glass-reinforced thermosetting plastics (GRP) pipes —

## Part 1:
## Buried pipes

*Systèmes de canalisation en matières plastiques - Règles générales pour la conception structurelle des*

*tubes et raccords plastiques thermodurcissables renforcés de verre (PRV) —*

*Partie 1: Tubes enterré*



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# Foreword

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This document was prepared by ISO/TC 138, *Plastics pipes, fittings and valves for the transport of fluids*, SC 6, *Reinforced plastics pipes and fittings for all applications*.

A list of all the parts in the ISO 20656- series, can be found on the ISO website.

# Introduction

This document provides general rules for structural design of buried glass-reinforced thermosetting plastics (GRP) pipes. It provides the necessary link between the requirements for safety, serviceability and durability of GRP pipe construction products and the technical provisions for civil works. The basis for design of structures, as specified in ISO 2394 and Eurocode EN 1990, are addressed in this document by providing partial factors for effects of actions and resistance for buried GRP pipes.

# Plastics piping systems — General rules for structural design of glass-reinforced thermosetting plastics (GRP) pipes —

## Part 1: Buried pipes



## 1 Scope

This document describes how partial factors for buried GRP pipes are developed, and are primarily intended to define the necessary safety measures for GRP pipes that meet the requirements of ISO 10639, ISO 10467 and ISO 25780, and EN 1796 and EN 14364. The same methodology can be utilised for other pipe product standards, although other parameters would apply.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 2394:2015, *General principles on reliability for structures*

ISO 10639, *Plastics piping systems for pressure and non-pressure water supply — Glass-reinforced thermosetting plastics (GRP) systems based on unsaturated polyester (UP) resin*

ISO 10467, *Plastics piping systems for pressure and non-pressure drainage and sewerage — Glass-reinforced thermosetting plastics (GRP) systems based on unsaturated polyester (UP) resin*

ISO 25780, *Plastics piping systems for pressure and non-pressure water supply, irrigation, drainage or sewerage — Glass-reinforced thermosetting plastics (GRP) systems based on unsaturated polyester (UP) resin — Pipes with flexible joints intended to be installed using jacking techniques*

EN 1796, *Plastics piping systems for water supply with or without pressure — Glass-reinforced thermosetting plastics (GRP) based on unsaturated polyester resin (UP)*

EN 1990:2002, *Eurocode — Basis of structural design*

EN 14364, *Plastics piping systems for drainage and sewerage with or without pressure — Glass-reinforced thermosetting plastics (GRP) based on unsaturated polyester resin (UP) — Specifications for pipes, fittings and joints*

EN/TS 14632, *Plastics piping systems for drainage, sewerage and water supply, pressure and non-pressure — Glass-reinforced thermosetting plastics (GRP) based on unsaturated polyester resin (UP) — Guidance for the assessment of conformity*

## 3 Terms and definitions

For the purposes of this document the terms and definitions given in ISO 2394 and EN 1990 apply.

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

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

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

# 4 Partial factor method

## 4.1 General

The procedures used here follow the methodology for establishing partial factors for effects of actions and structural resistance as specified in ISO 2394 and EN 1990. The procedure followed is the semi-probabilistic method (ISO 2394:2015, Clause 9 and EN 1990, Clause 6), where characteristic values of actions are defined, and these design values are determined based on the uncertainties involved, both in terms of actions, material properties and environment. The partial factors are the ratio between the characteristic values and the design values. The process consists of minimising the risk involved compared with perceived costs, and defined probability of failure, using level II of the first order reliability method (FORM, Level II).

In this Clause the method is described briefly as it applies for buried flexible pipes. For a full explanation of the methodology, refer to ISO 2394 and EN 1990.

The method for establishing partial factors for resistance is based on ISO 2394, 9.4.2 (with reference to Annex C), as EN 1990, 6.3.3, 6.3.4 and 6.3.5 (with reference to Annex D). The principles are the same in both standards.

## 4.2 Reliability index, *β*

The measure of reliability is conventionally defined by the reliability index, *β*, which is related to the probability of failure, $P_f$, by:

$$P_f = \times(-\beta) \tag{1}$$

where *Φ* is the cumulative distribution function of the standardised normal distribution.

The relation between the probability of failure, $P_f$, and the reliability index, *β*, is given in Table 1.

**Table 1 — Relationship between probability of failure and reliability index**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $P_f$ | $10^{-1}$ | $10^{-2}$ | $10^{-3}$ | $10^{-4}$ | $10^{-5}$ | $10^{-6}$ | $10^{-7}$ |
| $\beta$ | 1,28 | 2,32 | 3,09 | 3,72 | 4,27 | 4,75 | 5,20 |

The probability of failure, $P_f$, is expressed through a performance function, *g*, such that a structure is considered to survive if $g > 0$ and fail if $g \leq 0$:

$$P_f = \text{Prob}(g \leq 0) \tag{2}$$

where *g* is the performance function with:

$$g = R - E \tag{3}$$

where

*R* is the resistance;

*E* is the effect of actions;

*R*, *E* and *g* are random variables.

For a normal distribution the reliability index $\beta$ is:

$$\beta = \frac{\mu_g}{\sigma_g} \tag{4}$$

where

$\mu_g$ is the mean value of $g$;

$\sigma_g$ is the standard deviation.

We thus have:

$$\mu_g - \beta \times \sigma_g = 0$$

and

$$P_f = \text{Prob}(g \leq 0) = \text{Prob}(g \leq \mu_g - \beta \times \sigma_g).$$

Using this function, the partial factors are established, based on the uncertainties associated with the effects of actions and the uncertainties of resistance.

Since the short-term resistance of plastics is considerably higher than the long-term resistance, the partial factors for effects of actions need to be determined for both cases, i.e. both for incidental actions and sustained actions. Partial factors for resistance are determined for short-term material properties and are converted to long-term material properties as described in Clause 6.

The design value for a normal distribution is (see EN 1990:2002, Table C.3 and ISO 2394:2015, Clause E.6):

$$X_d = \mu - \alpha \times \beta \times \sigma = \mu \times (1 - \alpha \times \beta \times V) \tag{5}$$

where

$\mu$ is the mean value;

$\alpha$ is the sensitivity index;

$\beta$ is the reliability index;

$\sigma$ is the standard deviation;

$V$ is the coefficient of variation.

Both EN 1990 and ISO 2394 define target reliabilities based on consequences of failure. In addition, the ISO 2394 includes the relative cost of safety measure as part of the assessment. Table 2 shows the consequence classes as defined in EN 1990.

**Table 2 — Consequence classes as defined in EN 1990:2002, Table B.1**

| Consequence class | Description | Examples of pipelines | Minimum value for $\beta$ |
|---|---|---|---|
| CC3 | High consequence for loss of human life, or economic, social or environmental consequences very great. Significant damage to the qualities of the environment contained at national scale but spreading significantly beyond the surroundings of the failure event and which can only be partly restored in a matter of months. | Major water supply and sewerage pipes within cities, transmission lines without back-up, oil and gas pipelines. | 4,2 |
| CC2 | Medium consequence for loss of human life, economic, social or environmental consequences considerable. Damage to the qualities of the environment limited to the surroundings of the failure event and which can be restored in a matter of weeks. | Major water supply and sewerage pipes within cities, transmission lines with back-up, penstocks where flooding can wreak havoc. | 3,7 |
| CC1 | Low consequence for loss of human life and economic, social or environmental consequences small or negligible. Damage to the environment of an order which can be restored completely in a matter of weeks. | Irrigation, small and remote penstocks. | 3,1 |
| $\beta$ is based on a 50 year design life. | | | |

## 4.3 Sensitivity index, $\alpha$

The FORM analysis as defined in ISO 2394 includes a sensitivity factor for the independent random variables for actions and resistance. The sensitivity factors are summarised in ISO 2394:2015, Table E.3, and repeated here in Table 3.

**Table 3 — Sensitivity factors for actions and resistance**

| $X_i$ | $\alpha_i$ |
|---|---|
| Dominating resistance parameter | 0,8 |
| Other resistance parameters | 0,4 × 0,8 = 0,32 |
| Dominating load parameter | −0,7 |
| Other load parameters | −0,4 × 0,7 = −0,28 |

For non-pressure or low pressure pipes the deflection will be the dominating load parameter. For high pressure pipes the pressure will be the dominating load parameter. The corresponding resistance parameters apply.

## 4.4 Quality management

Quality management shall follow the rules in ISO 2394:2015, Annex A. These can be directly related to the consequence classes, as shown in Table 4.

In case of buildings, engineering works and engineering systems where high consequence for loss of human life or economic, social, or environmental consequences are involved, i.e. public buildings where consequences of failure are high (e.g. a concert hall, grandstand, high-rise building, critical bearing elements), a quality level QL3 shall be applied. The choice of the required quality level can be based on reliability-based methods. See Table 4 for quality levels based on consequence class.

**Table 4 — Quality levels**

| Quality level (QL) | Consequence class | Description | Control organism for specification of requirements and checking |
|---|---|---|---|
| QL3 | CC3 | Extensive quality level associated to extended measures for quality management, inspection, and control | Besides self-control and systematic control, independent party control shall also be executed: specification of requirements for quality management, assurance, and control, as well as the checking performed by an organisation different from that which has prepared the stage of the life cycle involved.<br>Intensive supervision and inspection during construction of the structural main bearing system by well-qualified people with an expert knowledge (e.g. with respect to design and/or execution of structures). |
| QL2 | CC2 | Increased quality level | Specification of requirements for quality management, assurance, and control, as well as the systematic checking performed by self-control, as well as by different persons than those who prepared the stage of the life cycle involved and in accordance with the procedure of the organisation.<br>Increased effort with respect to supervision and inspection during the construction of the structural key elements. |
| QL1 | CC1 | Basic quality level | Self-control: specification of requirements for quality management, assurance, and control, as well as the checking performed by the person who has prepared the stage of the life cycle involved. |

To establish default partial factors for GRP pipe product standards, consequence class 2 and quality level 2 will be assumed in this document. If the requirements for a project deviate from that assumption, the reliability index and uncertainties shall be revised, to determine the appropriate partial factors.

## 5 Partial factors for effects of actions

### 5.1 General

Buried pipelines may be subject to sustained actions from internal (or external) pressure, soil load and live load from traffic, as well as incidental actions, such as surge or water hammer loads. The resulting strains (or stresses) shall be compared with the strength of the materials, long-term or short-term as appropriate. The uncertainties associated with each of these need to be established to compute the partial factors for effects of actions.

For convenience, the effects of actions are expressed in terms of strain (stress could also be used). The effects of internal pressure are computed from the elementary hoop stress formula. The effects of soil load and traffic load are considerably more complex, and involve many variables. There are three well recognised methods for computing these: the ATV 127 (German), Fascicule 70 (French) and AWWA M45 (USA).

The effects of external pressure are not addressed in this document, but are given in the documents mentioned above.

### 5.2 Partial factors for internal pressure

#### 5.2.1 General

Plastic pipes are commonly classified for a pressure level, standardised pressure class or nominal pressure. This classification makes logistics and manufacturing simpler, and aids the designer in selecting the suitable product. To determine the effects of actions, the pressure needs to be converted into strains.

The effect of internal pressure of a pipe in service is usually computed through the elementary hoop stress formula:

$$\sigma_{ht} = \frac{p \times D}{2 \times t_R} \tag{6}$$

or, in terms of strain:

$$\varepsilon_{ht} = \frac{p \times D}{2 \times t_R \times E_{ht}} \tag{7}$$

where

$\sigma_{ht}$ is the hoop tensile stress;

$p$ is the internal pressure;

$D$ is the diameter;

$t_R$ is the thickness of the load bearing layers (i.e. excluding liner and protective layers) of the laminate of the pipe in service;

$\varepsilon_{ht}$ is the circumferential tensile strain in the laminate;

$E_{ht}$ is the circumferential tensile modulus of the laminate.

Of the three parameters defining the effects of this action, one, the pressure, is the action itself. The other parameters, diameter and thickness, are geometric properties of the pipe. Each has uncertainty associated with it.

### 5.2.2 Model uncertainty

In the elementary hoop stress formula the diameter, *D*, is either taken as the inner diameter or the mean diameter, depending on convention, or standards. The product standards ISO 10639, ISO 10467, EN 1796, EN 14364 and ISO 25780, as well as AWWA M45 use mean diameter.

There are several assumptions made in this model. The stress is assumed to be evenly distributed, the material is assumed to be linear, homogeneous and isotropic.

In Lamé's solution for thick walled cylinders the stress is not assumed to be evenly distributed:

$$\sigma_{ht} = \frac{p \times \left( r_i^2 + \frac{r_i^2 \times r_o^2}{r^2} \right)}{r_o^2 - r_i^2} \tag{8}$$

where

$\sigma_{ht}$ is the hoop tensile stress;

$p$ is the internal pressure;

$r_i$ is the inner radius;

$r_o$ is the outer radius;

$r$ is the radius where the stress is computed.

Putting $r = r_i$ into this formula to compute the maximum hoop tensile stress, $\sigma_{max}$, and comparing with the elementary formula, the following expressions are found.

Taking $D$ as inner diameter:

$$\frac{\sigma_{max}}{\sigma_{ht}} = \frac{r_i^2 + r_o^2}{(r_o + r_i) \times r_i} \qquad (9)$$

Taking $D$ as mean diameter:

$$\frac{\sigma_{max}}{\sigma_{ht}} = 2 \times \frac{r_i^2 + r_o^2}{(r_o + r_i)^2} \qquad (10)$$

These can now be compared for various aspect ratios, as shown in Table 5.

**Table 5 — Model error related to aspect ratio, $\sigma_{max}/\sigma_{ht}$**

| $r_o/r_i$ | 1 030 | 1 032 | 1 034 | 1 036 | 1 038 | 1 040 | 1 045 | 1 050 | 1 100 |
|---|---|---|---|---|---|---|---|---|---|
| $D = D_i$ | 1 0152 | 1 0163 | 1 0173 | 1 0183 | 1 0194 | 1 0204 | 1 0230 | 1 0256 | 1 0524 |
| $D = D_m$ | 1 0002 | 1 0002 | 1 0003 | 1 0003 | 1 0003 | 1 0004 | 1 0005 | 1 0006 | 10023 |

The error in the elementary model using inner diameter, compared with Lamé's equation for these aspect ratios ranges from 1,5 % to over 5 %. If the average diameter is used, the inaccuracy is a small fraction, i.e. 0,02 % to 0,2 %.

For GRP pipes a more accurate model would also include the effects of orthotrophy. Numerical analysis of several types of pipes suggests that the inaccuracy of the elementary formula is closer to 1,0 %, for orthotropic materials.

Based on the above, a partial factor proportional to the aspect ratio for the pipes should be applied, whenever the elementary hoop stress formula is used in design. It should be noted that this is not uncertainty in the sense that it is an unknown variable with a normal or Gumbel distribution. It is an inaccuracy of the model, which can be accounted for by multiplying the computed strain (or stress) by the appropriate factor.

The suggested correction factor, when using the mean diameter for the calculation, is thus 1,01, which accounts for both orthotropy and thin wall approximation.

### 5.2.3 Uncertainty of pressure

Unlike stochastic loads governed by nature, such as wind, snow and earthquake, the pressure in pipes is controllable. The system designer usually decides which pressure to design his piping system for, and the components and conditions that govern the pressure, such as pumps and elevation, are specified accordingly. The installer then needs to ensure that the specifications are met, and the owner of the pipeline to ensure that it is operated according to specifications.

All of these factors carry with them a degree of uncertainty, depending on the quality of the work, and the efforts put in inspections and quality control. Sources of errors could be system analysis, writing of specifications (e.g. typographical errors), communications, mounting and assembly of components, operation, start-up and closure of pumps, closing of valves etc.

### 5.2.4 Uncertainty of long-term pressure

Internal pressure will vary widely throughout the lifetime of a pipeline, from zero pressure during transport and installation, and during maintenance or inspection periods, to pressure levels exceeding the design pressure during pressure testing before commissioning.

To determine the partial factor for long-term effects, variations in sustained pressure need to be addressed. Sustained pressure is the maximum service pressure at which the design engineer expects the pipeline to be operated, for long time periods. The pressure will usually fluctuate, in some cases considerably, during normal operation (depending on the application), but the sustained pressure is the maximum pressure expected on a regular basis, be that daily, or weekly. This is the pressure on which the designer bases his choice of pressure class for the pipe, the expected pressure in the pipe throughout its expected lifetime.

The uncertainties related to the sustained pressure depend on how thoroughly the system is designed and analysed. A carefully designed pipeline, using sophisticated software for transient analysis, where the effects of all components, such as pumps, pressure relief valves, governors, etc. are included, would reduce the uncertainty related to pressure. If the analysis is also carefully checked by an independent expert, the uncertainties are further reduced.

Nevertheless, there will always be some uncertainty involved. Full knowledge of all components, and how they operate cannot be expected. The computational models are based on certain hypotheses and have limited accuracy. Topography may not be fully known, the effects of collection of air bubbles in the pipeline may not be included, etc.

These uncertainties can be difficult to quantify, so certain assumptions, preferably based on experience, must be made.

If the analysis is mediocre or simplified, the variation will be greater. A common mistake, for example, is to analyse the pipe based on nominal diameter, rather than the actual diameter of the pipe.

Table 6 provides a guideline to select the expected variation of the computed sustained pressure from the actual.

**Table 6 — Variation of computed pressure from actual pressure**

| Accuracy of analysis for computing pressure — Quality level | Expected variation from actual pressure |
|---|---|
| Detailed – QL3 | 5 % |
| Medium – QL2 | 10 % |
| Simplified – QL1 | 15 % |

Whether and how the pressure is monitored when the pipeline is in service is also of importance. If the pressure is not monitored there is greater likelihood that it will deviate from assumed value. The better it is monitored, the less likely it will diverge. Table 7 provides an estimate of the variation of the assumed service pressure and the actual service pressure.

**Table 7 — Variation of assumed service pressure from actual pressure**

| Effort of monitoring service pressure – Quality level | Expected variation from actual pressure |
|---|---|
| Careful – QL3 | 3 % |
| Medium – QL2 | 5 % |
| Basic– QL1 | 10 % |

### 5.2.5 Uncertainty of short-term pressure

Short-term pressures include test pressure(s), computed surge pressure from valve closing or opening, or pump start-up or shut-down, as well as other incidental pressure fluctuations, that may, or may not, be foreseen. Each of these pressure occurrences will last a certain time period, from a few seconds or minutes in case of surges, to several hours or even a few days in case of hydrotesting.

Test pressure is usually predefined, often as a percentage of the pressure rating of the pipe (e.g. 150 % of the pressure rating), and its time period also defined. The accuracy of the actual pressure is not always as clear. The pump will usually have ample capacity, the accuracy of the pressure gauge may be limited and it may not necessary be placed at the intended elevation. The engineer must account for such uncertainties.



 

Surge pressures can also deviate considerably from the presumed or calculated values, depending on the sophistication of the analysis and modelling. Wave celerity may be underestimated, as some parts of the pipeline may be cast in concrete or otherwise restricted from expansion. The operation of the pipeline may be different from the intended, resulting in increased pressure.

In lieu of better information, the variations in Table 7 may also be used for short-term pressure.

### 5.2.6 Uncertainty of thickness and E-modulus

For fibre-reinforced material, the total amount of reinforcement rather than the thickness per se controls the design. The thickness is a by-product of the wettability of the glass-fibres and the viscosity of the resin. The amount of fillers used further distort the picture.

The effects of the thickness and the E-modulus need to be examined combined; a thinner pipe may have higher pressure capacity if it has more reinforcement, but less resin and filler, i.e. a higher reinforcement percentage. The greater the reinforcement percentage, the higher the E-modulus.

An important quality check is thus to check for the amount of reinforcement, by observation during manufacturing or direct measurement.

The uncertainty of thickness depends on the manufacturing process and the quality control.

Statistical analysis of data from several manufacturers suggests that the variation of the combined thickness and E-modulus is approximately 5 %.

### 5.2.7 Uncertainty of diameter

The diameter of the pipe is determined by the manufacturing process. The three main processes for GRP pipes, crosswinding, centrifugal cast, and filament winding, use, respectively, fixed inside mandrel, fixed outside form, and variable inside steel-band mandrel. For a fix inside mandrel the variation in diameter will be negligible.

For outside-form or variable inside mandrel the accuracy of the diameter will depend on how well controlled the manufacturing process is.

Irrespective of process, checking the diameter is part of the daily quality control, where deviations from the specified value are noted.

Statistical analysis of data from several manufacturers reveals that the variation of the measured diameter is approximately 0,3 % for small diameter pipes and less than 0,1 % for large diameter pipe.

When the pipe is pressurised the diameter increases, and as the material creeps with time the diameter increases even further. Assuming an initial strain of approximately 0,3 % and 20 % creep, the additional error of the diameter will be 0,3 % for short-term pressure and 0,36 % for sustained long-term pressure.

### 5.2.8 Combined uncertainty and partial factor for effects of pressure

The combined uncertainty and the partial factor can now be determined.

For normally distributed functions, the combined standard uncertainty is the positive square root of the combined variance, which is given by Formula (11) (see[4]):

$$u_\sigma^2 = \sum_{i=1}^{N} \left[ \frac{\partial f}{\partial x_i} \right]^2 u^2 (x_i) \tag{11}$$

where

$u_\sigma$ is the combined uncertainty;

$f$ is the function to be evaluated;

$x_i$ are the variables;

$u\ (x_i)$ are the uncertainties associated with each variable.

Using this formula the combined standard uncertainty of the parameters that determine the effects of pressure can be computed. The function is the strain, as defined by Formula (7). Taking the derivative with respect to each variable (taking the thickness times the E-modulus as one variable), the following expression for the uncertainty of the strain is obtained:

$$u_\varepsilon^2 = \left(\frac{r}{t_R \times E_{ht}}\right)^2 \times u_p^2 + \left(\frac{p}{t_R \times E_{ht}}\right)^2 \times u_r^2 + \left(\frac{p \times r}{(t_R \times E_{ht})^2}\right)^2 \times u_{tE}^2 \quad (12)$$

where

$u_\varepsilon$ is the combined uncertainty;

$u_p$ is the uncertainty of internal pressure;

$u_r$ is the uncertainty of pipe radius;

$u_{tE}$ is the uncertainty of pipe wall thickness and modulus;

$r$ is the mean pipe radius;

$p$ is the internal pressure;

$t_R$ is the thickness of the load bearing layers (i.e. excluding liner and protective layers) of the laminate of the pipe in service;

$E_{ht}$ is the circumferential tensile modulus of the laminate.

EXAMPLE Using this expression with the uncertainty parameters in 5.2.3 to 5.2.7, the combined uncertainty for any given product can be computed. For a typical DN600-PN 10-SN 5000-pipe the numbers would be:

r = 303 mm

t = 10 mm

E = 13000 MPa

ε = 0,00233



 

$$u_{\epsilon}^{2}(y)=\left(\frac{303}{10\times 13000}\right)^{2}\times(1\times 0{,}1)^{2}+\left(\frac{1}{10\times 13000}\right)^{2}\times(0{,}004\times 303)^{2}+\left(\frac{303\times 1}{(10\times 13000)^{2}}\right)^{2}\times$$
$$\times(0{,}05\times 10\times 13000)^{2}=54{,}3\times 10^{-9}+0{,}087\times 10^{-9}+13{,}6\times 10^{-9}=68{,}0\times 10^{-9}$$

or:

$$u_{\varepsilon}=0{,}00026\,.$$

With a strain of 0,003 the variation becomes:

$v$ = 0,00026/0,00233 = 0,112.

The error in the model is not part of the uncertainty, but needs to be included in the partial factor as a pure correction factor.

The design value for pressure is computed as follows:

$$E_{\mathrm{d}}=\mu\times(1-\alpha\times\beta\times V) \quad (13)$$

For the sensitivity factor, $\alpha$, see Table 3.

To determine the partial factor, the error in the model – a factor of 1,015 –, must also be included (see 5.2.2). A correction factor for increased diameter under pressure of 1,004 is also recommended.

If pressure is the dominating action the sensitivity factor (see Table 3) is:

$$\alpha=-0{,}7$$

For consequence class 2 the probability of failure is:

$$p_{\mathrm{f}}=10^{-4}$$

and the corresponding reliability index:

$$\beta=3{,}7$$

For probability of failure of $10^{-4}$ and a sensitivity factor of –0,7 the partial factor will thus be:

$\gamma_{\mathrm{P}}$=(1+0,7×3,7×0,11)×1,01×1,004

$$\gamma_{\mathrm{P}}=1{,}3 \quad (14)$$

The partial factors for long-term failure pressure for the other consequence classes are computed similarly, with reliability index from Table 2. Partial factor for long-term pressure for all three consequence classes are computed similarly, and shown in Table 8.

**Table 8 — Partial factor for long-term pressure with pressure as dominating action (α = –0,7)**

| Consequence class | Probability of failure $p_f$ | Reliability index $\beta$ | Partial factor for pressure $\gamma_p$ |
|---|---|---|---|
| CC3 | $10^{-5}$ | 4,2 | 1,36 |
| CC2 | $10^{-4}$ | 3,7 | 1,3 |
| CC1 | $10^{-3}$ | 3,1 | 1,28 |

See Annex A for default values and corresponding minimum safety factor.

Whether the action of pressure or deflection creates the dominating effect, depends on the computed strains (or stresses). For most GRP pipe designs, the changeover will be for pressure classes PN2 – PN4, depending on stiffness class.

If the pressure is not the dominating load the sensitivity factor from Table 3 becomes:

$$\alpha = -0{,}4 \times 0{,}7 = -0{,}28$$

with the corresponding partial factors as shown in Table 9.

**Table 9 — Partial factor for long-term pressure with deflection as dominating action (α = –0,28)**

| Consequence class | Probability of failure $p_f$ | Reliability index $\beta$ | partial factor for pressure $\gamma_p$ |
|---|---|---|---|
| CC3 | $10^{-5}$ | 4,2 | 1,16 |
| CC2 | $10^{-4}$ | 3,7 | 1,15 |
| CC1 | $10^{-3}$ | 3,1 | 1,13 |

The partial factor for short-term pressure (one day) is assumed to be the same as for long-term pressure.

For pipes with end-thrust the same partial factors and safety factors apply, since the same uncertainties are involved.

## 5.3 Partial factors for soil and traffic load

### 5.3.1 General

The engineering parameters associated with installation of buried pipe cannot be treated the same way as for pressure, since these essentially depend on the quality of field work, rather than work in a factory.

The AWWA M45 design method provides a model for determining stresses and strains that result from ring bending in the deflected, buried pipe. In the following, this method will be used as an example to estimate the partial factors for soil and traffic load. Other methods will yield similar results, since the same variations and uncertainties apply. It must be noted, however, that the characteristic material values might originate from a different source, and might thus have already been treated for uncertainty. This shall be ascertained in each case.

There is considerable uncertainty associated with computing deflection. It is therefore required to measure the initial deflection after installation, to ensure the integrity of the installation. The difference between the measured and computed deflection reflects the uncertainty, and therefore the associated partial factor. If there is great difference between the two, it is advised to re-evaluate the installation parameters, to assure the accuracy of the long-term deflection calculation.

According to AWWA M45 the stresses and strains are linked to the deflection of the pipe as follows.

In terms of stress:

$$\sigma_b = D_f \times E \times \left(\frac{\Delta y}{D}\right) \times \left(\frac{t_t}{D}\right) \tag{15}$$

In terms of strain:

$$\varepsilon_b = D_f \times \left(\frac{\Delta y}{D}\right) \times \left(\frac{t_t}{D}\right) \tag{16}$$

where

$\sigma_b$ is bending stress due to deflection;

$\varepsilon_b$ is the bending strain due to deflection;

$D_f$ is the shape factor, which depends on installation parameters and pipe stiffness;

$E$ is ring flexural modulus of the pipe;

$\Delta y$ is the deflection of the pipe;

$D$ is the diameter of the pipe;

$t_t$ is the total wall thickness of the pipe.

The uncertainties of all these parameters are examined separately in the following clauses.

It should be noted that the designer may always choose a conservative value for a parameter, thereby reducing the probability of overloading.

In AWWA M45 the deflection can be expressed by a modified Iowa formula:

$$\frac{\Delta y}{D} = \frac{(D_l \times W_c + W_L) \times K_x}{8 \times STIS + 0{,}061 \times M_s} \tag{17}$$

where

$\Delta y$ is the deflection of the pipe;

$D$ is the diameter of the pipe;

$D_l$ is deflection lag factor;

$W_c$ is vertical soil load on pipe;

$W_L$ is vertical traffic load on pipe;

$K_x$ is the bedding coefficient;

$STIS$ is the pipe stiffness;

$M_s$ is the composite soil constrained modulus.

Typical values for the composite soil modulus are in the range 1 MPa for weak soil to 30 MPa for good soil or backfill. With pipe stiffness classes SN 2500, SN 5000 and SN 10000, the contribution of the soil to resisting the vertical load is thus in the range of being equal to the contribution from the pipe to being 100 times that of the pipe.

NOTE The effects of external pressure are not addressed in this document, but are given in e.g. ATV 127 (German), Fascicule 70 (French) and AWWA M45 (USA).

### 5.3.2 Uncertainty of installation parameters

For buried pipe the uncertainties of installation parameters are the dominating factors for determining the total uncertainty of the effects of bending action. Thus, as with all geotechnical installations, they will depend on the quality of the work of the engineer, the contractor and the inspector.

The composite constrained soil modulus, $M_S$, combines the stiffness of the native soil and the backfill through the ratio of the pipe diameter and the trench width. Other factors included in the model for the modulus are stress level (burial depth), compaction, and presence of ground water. With all these parameters known the soil modulus can be determined with a reasonable accuracy.

The main uncertainties are associated with lack of information about the parameters affecting the soil modulus. The most important of these is the knowledge, or the lack thereof, about the composition of the native soil. The usual approach is to dig investigating holes along the trajectory of pipeline and analyse the unearthed material. The inherent variation of the native soil within each hole, and from one hole to the next, is a source of uncertainty. During excavation of the trench better knowledge can be acquired and additional analyses conducted. This will, however, not provide full knowledge of the supporting native soil, since it is the soil at the trench walls, rather than soil from the trench itself, which provides the support. Direct measurement of the soil stiffness by soil stiffness gauge would provide additional information, but this method is seldom used.

Since the type of backfill is usually clearly specified, the uncertainty of the soil modulus associated with the backfill is mainly related to the compaction. With the standard Proctor test, the compaction can be easily measured, so it is the extent and frequency of the tests which determines the uncertainty.

The bedding coefficient, $K_X$, according to the AWWA M45 varies from 0,083 for uniform shaped bottom support to 0,1 inconsistent haunch. The uncertainty in this coefficient depends mainly on the quality of the workmanship of the pipe installer, and how well the installation is monitored. This in turn will depend on the quality level of the project.

The soil load is a multiple of the burial depth and the unit weight of the soil overburden. The uncertainty of these parameters is dependent on how well the project is planned and prepared, including land surveying and soil analysis.

The shape factor in Formula (15) and Formula (16) is in the range 3,3 to 6,5, depending on pipe stiffness class and compaction of backfill (3,3 for SN 10000 pipe and poor compacted gravel, 6,5 for SN 2500 pipe and well compacted sand backfill).

### 5.3.3 Uncertainty of deflection model

The Iowa formula for computing deflection of flexible buried pipe, or the Spangler formula as it is also called, was first published by Spangler and Handy in 1941.[1] It was originally created as a means to predict deflection of Flexible Pipe Culverts for the United States Federal Works Agency and the Public Roads Administration. Extensive full-scale experiments on flexible corrugated-metal pipes, ranging from 900 mm to 1500 mm in diameter were conducted, with various soil fills extending more than 5 m over the crown of the pipe. A derived soil parameter, $E'$, which depends on the pipe radius was part of the analyses.

Over the years the Iowa formula has received wide recognition, and has been adopted by many industries. In 1977 the U.S. Bureau of Reclamation published a report by A. Howard, titled *Modulus of soil reaction (E') for buried flexible pipe*,[2] presenting measurements of deflection in more than 100 pipe installations, with fills of various soils extending up to 13 m above the pipes, made of materials such as corrugated metal, cast iron, smooth iron, ductile iron, straight steel, reinforced plastic mortar, fibreglass reinforced plastic, PVC and pretensioned concrete, ranging in diameters from 300 mm to 4 570 mm. Based on the measured data the E' modulus was back calculated, and a range of values were suggested for various soil groups as a function of compaction effort. Further refinement of the approach was presented by McGrath,[3] where two suggestions for improvements were made: the $E'$ modulus of soil reaction is replaced by the constrained soil modulus $M_S$, and the modulus is dependent on the stress level. These improvements are based on rigorous theoretical and numerical analyses, as well as comparisons with previously published data. The resulting values for the modulus are in much narrower categories, with considerably greater accuracy. This approach was adopted in the 2005 version of the AWWA M45 manual. With this improvement in the formulation the soil parameter is also detached from the calculation model, and thus the uncertainties and partial factors can be treated separately.

It should be noted that the deflection model is susceptible to the same uncertainties as the installation parameters, since it is based on observations of installations with the same inherent factors, i.e. the quality of the work of the engineer, installer and controller.

### 5.3.4 Uncertainty in traffic load

The accuracy of the traffic load depends on the location of the pipeline. Traffic in cities and on public highways is well monitored in most countries by road authorities and police, with associated minor uncertainty. Smaller country roads are less well monitored, but may on the other hand not be able to carry heavy trucks. Pipelines in fields or alongside roads may be more vulnerable, sometimes with unplanned traffic by tractors and other agricultural machinery. Unless a pipeline is protected from traffic by fences or other means, the engineer should always assume traffic load that can be carried by the soil.

It should also be noted that allowable wheel or axle load on roads and highways may change with time.

Military traffic is usually not considered in design of buried pipelines.

### 5.3.5 Uncertainty in pipe stiffness

Manufacturers following the assessment of conformity procedures of EN/TS 14632 conduct regular tests to determine initial pipe stiffness. By using the nominal stiffness in the deflection calculation the associated uncertainty will be minimal.

### 5.3.6 Uncertainty of deflection measurement

There are several tools available to measure deflection of buried pipes, such as lasers, measuring rods, LVDTs, digital close range photogrammetry, etc. The accuracy of these measurements depends on the method. It could be as low as 0,5 % for the most accurate to 5 % for rough methods. If the accuracy is not known, 5 % uncertainty should be assumed.

For best accuracy the internal diameter should first be measured after backfilling of the embedment zone, i.e. to crown level, and again after backfilling to ground level.

### 5.3.7 Deflection lag factor

The greatest uncertainty is perhaps associated with the deflection lag factor. The AWWA M45 does not provide specific guidelines on how to determine this factor. It only states that it should be chosen between 1 and 1,5. Without detailed geotechnical investigation it is recommended to use a conservative value of 1,5.

### 5.3.8 Uncertainty of model – Stress and strain calculation

The model for computing strains from deflection (Formula (15) and Formula (16)) includes a shape factor, which depends on the installation conditions and the pipe stiffness. This factor varies from 3,3 to 4,5 for SN 10000 pipe (depending on compaction of backfill) and 4,5 to 6,5 for SN 2500 pipe.

It is common practice to take a conservative approach and design the pipes for the highest shape factor for the stiffness class of interest, irrespective of backfill compaction, without evaluating the uncertainties involved.

### 5.3.9 Strain assessment through curvature measurement

The most accurate way of establishing the strain in the pipe is to measure the change in curvature, rather than resorting to derivatives from deflection. Sophisticated equipment, with accompanying software to do such evaluations is readily available in the market, and should be used for all major pipelines.

### 5.3.10 Combined uncertainty of installation parameters

The deviation between the measured and computed initial deflection becomes an indicator of both how good the installation is and how accurately the long-term deflection can be determined. Measured deflection considerably greater than the computed deflection indicates a poor installation practice, or poor knowledge of installation parameters. In either case the installation should be further analysed. If the measured deflection is less than computed the installation is acceptable.

Experience has shown that in most cases the initial deflection is between 1 % and 3 %, and that for proper installation the deviation from the computed is within ± 0,5 % deflection. Since initial deflection less than 3 % will seldom lead to excessive long-term deflection, it is only necessary to study the uncertainties associated with 3 % deflection.

The uncertainty of the installation parameters, i.e. choice of backfill, backfill compaction, bedding coefficient, shape factor, and native soil stiffness, depends primarily on the quality of the work of the engineer, the contractor and the installation inspector. The required partial factors will thus depend on the accuracy of their work, i.e. the quality of the engineer's preparation and field surveys, the contractor's skills and experience, and the inspector's attention to detail. These parameters are not easily quantified, but still need to be estimated.

Most countries maintain rules and regulations for certifying engineers, and in many countries contractors are required to demonstrate their skills and experience for all major projects. Other countries have less control over such work. The level of quality assurance of civil works, including buried pipes, can thus vary considerably from one nation to the other. As a guideline the combined uncertainties related to the uncertainty related to installation are shown in Table 10. It should be noted that these uncertainties are rough estimates, and should be treated as such.



**Table 10 — Estimated variation of effects of bending action, resulting from quality of installation**

| Quality level | Combined uncertainty related to the work of the engineer, contractor and inspector |
|---|---|
| Detailed – QL3 | 10 % |
| Medium – QL2 | 25 % |
| Simplified – QL1 | 50 % |

### 5.3.11 Partial factors for effects of bending

The effects of actions in buried pipes are stresses (or strains) resulting from pressure and deflection. How these are combined is addressed in design documents, such as AWWA M45, ATV A 127, and Fascicule 70.

In EN 1990 and ISO 2394 it is expected that these stresses are combined depending on the dominating action. If the action of pressure is dominating, one set of partial factors is used; if the action of deflection is dominating another set of partial factors is used. A similar approach is taken in AWWA M45. For GRP pipes the transition is generally between PN3 and PN6, i.e. for higher pressures than this pressure will be the dominating action, while for lower pressures bending will be the dominating action.

The partial factors for bending are computed from Formula (1), for the cases of the effects of pressure being dominating, and deflection being dominating, according to Table 3. These are shown in Table 11 and Table 12 respectively.

 

**Table 11 — Partial factor for bending as non-dominating action ($\alpha$ = −0,28)**

| Consequence class | Quality level | Probability of failure $p_f$ | Reliability index $\beta$ | Combined uncertainty | Partial factor for effects of bending |
|---|---|---|---|---|---|
| CC3 | Detailed – QL3 | $10^{-5}$ | 4,4 | 0,10 | 1,12 |
| CC2 | Medium – QL2 | $10^{-4}$ | 3,8 | 0,25 | 1,27 |
| CC1 | Simplified – QL1 | $10^{-3}$ | 3,3 | 0,50 | 1,46 |

**Table 12 — Partial factor for bending as dominating action ($\alpha$ = −0,7)**

| Consequence class | Quality level | Probability of failure $p_f$ | Reliability index $\beta$ | Combined uncertainty | Partial factor for effects of bending |
|---|---|---|---|---|---|
| CC3 | Detailed – QL3 | $10^{-5}$ | 4,4 | 0,10 | 1,31 |
| CC2 | Medium – QL2 | $10^{-4}$ | 3,8 | 0,25 | 1,66 |
| CC1 | Simplified – QL1 | $10^{-3}$ | 3,3 | 0,50 | 2,16 |



## 5.4 Combined effects of pressure and bending

For the computation of the combined effects of pressure and bending in the pipe wall, the partial factors in Tables 11 and 12 shall be used in conjunction with Tables 8 and 9. If pressure is the dominating action then Tables 8 and 11 are used; if bending is the dominating action, Tables 9 and 12 are used.

# 6 Partial factors for resistance

## 6.1 Concept

The design value of the resistance, $R_d$, is determined from:

$$R_d = \frac{R(X_d, a_d)}{\gamma_R} \tag{18}$$

where

$X_d$ are design values of a material property;

$a_d$ are design values for the geometry;

$\gamma_R$ is a partial factor related to the model uncertainty for the resistance model – including possible uncertainty related to the transformation from laboratory to real structure and bias in the resistance model

The procedures in EN 1990:2002, Annex D shall be followed.

NOTE The characteristic value and partial material factors are determined in accordance with EN 1990:2002, Clauses D.7.2 and D.7.3, using Formulae D.1 and D.4.

The design value, $X_d$, based on 5 % characteristic value (lower confidence level) is thus (EN 1990:2002, Formula D.1):

$$X_d = \eta \times \frac{X_{kn}}{\gamma_m} = \frac{\eta}{\gamma_m} \times m_x \times \{1 - k_n \times V_x\} \tag{19}$$

where

$\eta$ is the conversion factor for short to long term properties (design life of minimum 50 years);

$X_{kn}$ is the characteristic value of the material or product property

$\gamma_m$ is the partial factor for the material property to take account of the possibility of an unfavourable deviation of a material or product property from its characteristic value and the random part of the conversion factor $\eta$;

$m_x$ is the mean value;

$k_n$ 1,64;

$V_x$ is the variation.

For the ultimate limit state the design value is (EN 1990:2002, Formula D.4):

$$X_d = \eta \times m_x \times \{1 - k_{d,n} \times V_x\} \quad (20)$$

where:

$$k_{d,n} = \alpha \times \beta$$

For a sensitivity factor equal to 0,8 and a reliability index 3,8:

$$k_{d,n} = \alpha \times \beta = 0,8 \times 3,8 = 3,04$$

The properties of GRP pipes are determined by testing, both short term and long term. The test results, along with the desired design life time of the pipeline and assessment of consequences of failure, are used to establish the partial factor for the material property and the conversion factor for the product through Formulae (18) and (19).

## 6.2 Design value for resistance

### 6.2.1 General

The pressure resistance of GRP pipe is determined through both long-term tests and short-term tests.

### 6.2.2 Long-term resistance and conversion factor, $\eta$

The conversion factor shall take into account load duration effects, moisture, temperature, scale effects etc. For GRP pipe products this factor is established through long-term tests of several specimens, whereby the relationship between short-term tests and long-term performance is established. These tests are conducted under the appropriate environmental conditions for each property, i.e. pressure resistance and deflection resistance, and comprise typically 18 samples with at least one sample passing 10 000 hours in test. By regression analysis to the specified design life of the pipeline the long term property is determined. The design life is specified by the owner of the pipeline. For municipal works the design life is typically set as 50 years, but could be any other time frame.

This value is compared with the strength measured in the short-term test to establish the conversion factor, $\eta$.

$$= \sigma_{50} / \sigma_0 \quad (21)$$

where:



 

$\sigma_{50}$ is the 50 year resistance value;

$\sigma_0$ is the initial resistance value.

The long-term resistance for GRP pipes is determined through type tests, using at least 18 pipe, or pipe ring, samples, with failure times to over 10 000 hours. Through covariance analysis of the data a regression line is created, and used to extrapolate the data to the desired life-time of the product, usually 50 years (see ISO 10928). These tests determine the conversion factor, $\eta$, to be used in design.

The pipe manufacturer shall conduct such tests for pressure, deflection in water, and for sewer pipe: deflection in acid.

#### 6.2.2.1 Long-term pressure resistance

The requirements for this test are described in EN 1796, EN 14364, ISO 10639 and ISO 10467.

#### 6.2.2.2 Long-term deflection resistance in water (water supply pipes)

The requirements for this test are described in EN 1796, EN 14364, ISO 10639 and ISO 10467.

#### 6.2.2.3 Long-term deflection resistance in acid (sewer pipes)

The requirements for this test are described in EN 14364 and ISO 10467.

### 6.2.3 Short-term resistance

The short-term resistance is established by testing of pipe samples or rings. These tests are part of daily quality control (batch release tests) at the manufacturing facility. These tests are performed on material coupons or pipe rings, and provide the initial ultimate strength of the material.

#### 6.2.3.1 Short-term pressure resistance

The product standards specify several different methods to determine short-term pressure resistance. The reference method is burst pressure, while coupon tests (or test on narrow rings – split disc tests) are commonly used for quality control purposes. The relationship between the burst test and the coupon tests needs to be established by testing samples using both methods. If the coupon test provides lower values, it can be used in quality control as means of proving conformance with minimum requirements.

The variation in the product strength is determined from the quality control in the factory, using the procedures described in Annex B. A value lower than 0,09 for the coefficient of variation should not be used. The manufacturer shall, through analysis of his quality control data, establish the coefficient of variation for his products.

For a probability of failure $p_f = 10^{-4}$, and assuming a coefficient of variation of 0,09, the partial material factor for pressure is:

$$\gamma_{mp} = (1 - 1{,}64 \times 0{,}09) / (1 - 0{,}8 \times 3{,}72 \times 0{,}09) = 1{,}16$$

$$\gamma_{mp} = 1{,}16 \tag{22}$$

For other reliability classes the partial factors are shown in Table 13.