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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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Contents

Page

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}
β	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 β is:

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

where

μ_g is the mean value of g;

σ_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

μ is the mean value;

α is the sensitivity index;

β is the reliability index;

σ 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 β
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
β is based on a 50 year design life.			

4.3 Sensitivity index, α

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	α_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. 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. 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

σ_{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;

ε_{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

σ_{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, σ_{max}, and comparing with the elementary formula, the following expressions are found.

