iniziative industriali

Engineering Guide

sarplast

SISTEMA DI GESTIONE INTEGRATO
UNI EN ISO 9001:2000
UNI EN ISO 14001:2004
SINCERT DNV

ENGINEERING GUIDE

Release 001/2008

INDEX

1. FOREWORD

The *SARPLAST* filament-wound glass reinforced thermosetting resin pipe systems (Polyester and Vinylester) offer superior corrosion resistance and a combination of high mechanical and physical properties which have been proved in the most severe operating conditions all over the world.

The purpose of the *Iniziative Industriali Engineering Guide* is to provide engineers with a useful tool for the design, specification of *SARPLAST PLASTIWIND* (glass-fiber-reinforced thermosetting-resin pipe) and *SARPLAST PLASTISAND* (glass-fiber-reinforced plastic-mortar pipe), pipes and together with the Installation Manual the guidelines for their installation for aboveground, below-ground and submarine installations.

The information provided by this *Engineering Guide* are widely applicable to diameter size ranging from 25 to 3000 mm. Anyway, for diameter larger than ND1200 or for not standard applications it is suggested to contact the technical department of Iniziative Industriali to identify the appropriate solutions.

As a result of experience, gained in over 30 years of engineering GRP piping systems, we are able to suggest solutions to a wide variety of service conditions and to find the most suitable solution to new technical requirements.

Fields covered by *SARPLAST GRP* products are the following:

a. Water Distribution (civil and industrial)
b. Sewer Systems (urban and industrial)
c. Irrigation Networks
d. Water Intakes for Cooling Water Systems
e. Waste Water Outfalls to sea
f. Sub-sea Pipelines
g. Process Lines for Industrial plants
h. Fire Fighting Networks
i. Corrosive Fluids and Vent Gas Stacks
j. Wells Casing, Wells Pump Risers and Screen
k. Penstocks
l. Pipes for Ships and Offshore applications

Important Notice

It is intended that this document be used by personnel having specialized training according to standard industry practice and normal operating conditions.

All information was correct at the time of issue of the document. Variations of any products or systems, described in this brochure, can be done without prior warning.

We do not accept any responsibility for the accuracy of statements made.

2. CODES AND STANDARDS

The governing documents commonly used in specifying, testing and applying GRP piping are the following:

- ***Product Specifications and Classifications***

ANSI/AWWA C950-95	Standard for Fiberglass Pressure Pipe
ASTM D2310	Standard Classification for Machine-Made Reinforced Thermosetting-Resin Pipe
ASTM D2996	Standard Specification for Filament-Wound "Fiberglass" (Glass-Fiber Reinforced Thermosetting-Resin) Pipe
ASTM D3262	Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer Pipe
ASTM D3517	Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pressure Pipe
ASTM D3754	Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer and Industrial Pressure Pipe
ASTM D4161	Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe Joints Using Flexible Elastomeric Seals
BS 5480 - 90	British Standard Specification for Glass reinforced plastics (GRP) pipes, joints and fittings for use for water supply or sewerage.
BS 7159 - 89	Design and construction of glass reinforced plastics (GRP) piping systems for individual plants or sites
UNI 9032	Tubi di resine termoindurenti rinforzate con fibre di vetro (PRFV) con o senza cariche. Tipi, dimensioni e requisiti.
ISO 14692	Petroleum and natural gas industries – Glass reinforced plastics (GRP) piping

- ***Recommended Practices***

ASTM C581	Standard Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass-Fiber-Reinforced Structures Intended for Liquid Service
ASTM D2488	Standard Practice for Description and Identification of Soils
ASTM D2563	Standard Practice for Classifying Visual Defects in Glass-Reinforced Plastic Laminate Parts
ASTM D2992	Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Fittings Procedure B - Steady pressure
ASTM D3567	Standard Practice for Determining Dimensions of Reinforced Thermosetting Resin Pipe (RTRP) and Fittings

ASTM D3839	Standard Practice for Underground Installation of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe
BS 8010	B.S. Code of practice for Pipelines - Section 2.5 Glass reinforced thermosetting plastics
ISO 14692	Petroleum and natural gas industries – Glass reinforced plastics (GRP) piping

- ***Test Methods***

ASTM D1598	Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure
ASTM D1599	Standard Test Method for Short Term Hydraulic Failure Pressure of Plastic Pipe, Tubing and Fittings
ASTM D2412	Standard Test Method for Determination of External Loading Characteristics of Plastics Pipe by Parallel-Plate Loading
ASTM D2924	Standard Test Method for External Pressure Resistance of Reinforced Thermosetting-Resin Pipe
ASTM D3681	Standard Test Method for Chemical Resistance of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe in a Deflected Condition
BS 5480-90	British Standard Specification for Glass reinforced plastics (GRP) pipes, joints and fittings for use for water supply or sewerage
UNI 9033	Tubi di resine termoindurenti rinforzate con fibre di vetro (PRFV) con o senza cariche. Metodi di prova.
ISO 14692	Petroleum and natural gas industries – Glass reinforced plastics (GRP) piping

Fittings and Flanges

Fittings and flanges comply with the following standard:

U.S. Department of Commerce, National Bureau of Standard Voluntary Product Standard PS 15-69, Custom Contact-Molded Reinforced Polyester Chemical-Resistant Process Equipment.

3. QUALITY ASSURANCE

Iniziative Industriali Quality Assurance System is in accordance with **ISO 9001** Quality System certified by Det Norske Veritas Italia for quality assurance in design, production, installation and servicing, and **ISO 14001** for the Management of Environmental issues.

SARPLAST GRP products have been also certified by the following institutes:

- **BUREAU VERITAS**
- **DNV** Det Norske Veritas
- **FM** Factory Mutual
- **MAFIRE L3**
- **KIWA**
- **WRAS**
- **Lloyd's Register**
- **NSF** National Sanitation Foundation
- **RINA** Registro Navale Italiano

4. CLASSIFICATION OF PIPES AND FITTINGS

Nominal Diameter

Nominal size of pipe and fitting is based on internal diameter. The complete list of the available size produced by *Iniziative Industriali* is in table 4.1.

Nominal Pressure Classes

Pipes and fittings are classified according to nominal pressure. Standard pressure classes are 4, 6, 10, 16, 20 and 25 bar. Intermediate or higher pressure classes are considered on request or depending on the design conditions.

Specific Pipe Stiffness Classes

Pipes are also classified according to specific pipe stiffness. Standard stiffness classes are 1250, 2500, 5000 and 10000 Pa. Intermediate or higher stiffness classes are available on request or depending on the design conditions.

The standard GRP pipes and fittings produced by *Iniziative Industriali* are described in the document *GRP PIPING PRODUCT LIST.*

Tab 1 - List of Nominal sizes (ND) produced by Iniziative Industriali

Mm	inch	Mm	Inch	mm	inch	mm	inch	mm	inch
25	1	200	8	600	24	1000	40	1900	76
40	1 1/2	250	10	650	26	1100	44	2000	80
50	2	300	12	700	28	1200	48	2200	88
65	2 1/2	350	14	750	30	1300	52	2400	96
75	3	400	16	800	32	1400	56	2500	100
100	4	450	18	850	34	1500	60	2600	104
125	5	500	20	900	36	1600	64	2800	112
150	6	550	22	950	38	1800	72	3050	120

5. RAW MATERIALS

Basic raw materials used for manufacturing of SARPLAST GRP PIPES are the following:

- Resins
- Glass reinforcements
- Auxiliary raw materials

5.1 RESINS

Sarplast pipes can be manufactured using the following types of resin:

- Isopthalic Polyester
- Vinylester (epoxy bisphenol-A, vinyl- urethanic, epoxy novolac)
- Bisphenol Polyester
- Special resins (for high temperatures, fire retardance, abrasive resistance, etc.)

The above resins show several interesting characteristics such as:
- curing at room temperature
- low toxicity during handling and curing
- high chemical resistance
- good adhesion to glass fibers.

Isophthalic Polyester has a good corrosion resistant to water and fluids with low acid content up to a maximum operating temperature of about 60 °C.

Bisphenol Polyester resin shows a high chemical inertness to both strong acids and bases also at elevated temperature.

Vinylester resin combines a very good chemical inertness to strong acids and bases with high mechanical properties of the laminates. The suggested uses are applications where either chemical resistance and toughness are needed.

For equipment where higher temperature resistance or specific properties like flame retardance, conductivity or enhanced abrasion resistance are needed, special formulated vinylester resins are used.

Some typical properties of liquid resins are:

Tab 2 – Typical properties of liquid resins

Property	**Isophtalic**	**Vinylester**
Styrene level, %	48	45-48
Brookfield viscosity, mPa.s at 25 °C	400	500
Specific gravity uncured at 25 °C [g/cm^3]	1.07	1.02
Storage stability months	6	6

The cured resin has the following properties at room temperature:

Tab 3 – Typical properties of liquid resins

Test	Isophtalic	Vinylester
Tensile strength, MPa	80-90	81-83
Tensile modulus, GPa	3.0-3.9	3.3-3.5
Flexural strength, MPa	-	124 -153
Flexural modulus, GPa	-	3.1-3.5
Heat distortion temperature, °C	95-115	102-115
Barcol hardness	35-40	35-40

Resin properties are checked on each single batch according to Iniziative Industriali Quality Control and Inspection Test Plan.

5.2 GLASS REINFORCEMENTS

Types of glass used for manufacturing GRP are the following:

- "C" glass chemical-resistant hydrolytic grade III DIN 12111
- "E" glass with excellent mechanical and electrical properties acc. to ISO 2078

Typical glass reinforcements used are:

- - surfacing "C" veil, consisting of randomly dispersed glass fibers bonded into sheet by a polyester resin generally used as reinforcement for the first layer of the laminate
- - CSM (chopped strand mat) "E" glass, made of chopped strands bonded in mat form with a powder binder and used in hand lay-up or contact molding processes.
- - CR (continuous roving) "E" glass specially designed for fast wet-out, good processing and handling characteristics as well as excellent adhesion with polyester and Vinylester used in filament winding processes.
- - WR (woven roving) "E" glass composed of direct roving woven into a fabric and designed to be compatible with most polyester hand lay-up resins.

The more significant mechanical properties of fiberglass used as reinforcement are the following:

Tab 4 – Typical properties of fiberglass

Property	Value
Ultimate tensile strength, Mpa	1.400
Modulus of elasticity, Gpa	70

The glass fiber surface is treated with agents to prevent damages to the fiber and to improve the compatibility with the resin. These agents are Silan-organic substances.

5.3 AUXILIARY RAW MATERIALS

Auxiliary raw materials are all the technological additives used for processing of reinforced resins such as promoters, accelerators, catalysts, inhibitors, viscosity and density additives, aggregates, filler and pigments .

6. FABRICATION

6.1 PIPES

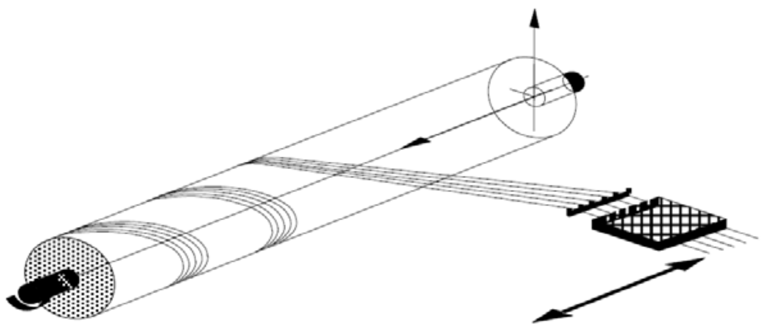
6.1.1 Fabrication methods

Pipes are manufactured using the discontinuous filament winding process on computer controlled machines (CAM).

By adjusting the relative speed of mandrel rotation and glass distribution head movement, helical reinforced layers with different angles can be wound.

The inside diameter of the finished pipe is defined by the mandrel outside diameter and the designed wall thickness is achieved by repeated winding passes. In such a way the outside diameter of pipe (OD) is determined by the pipe wall thickness.

In order to increase the pipe stiffness, specially on large diameter pipes, silica sand can be added to parallel layers of the mechanical wall.



Main characteristics of this process are the following:

- Bell and spigot ends are monolithic with the pipe wall
- Optimisation of axial and hoop characteristics can be obtained by changing winding angles
- Axial strength normally higher than pipes produced with other processes
- Pipe stiffness is not related to joint stiffness that in any case is higher than the pipe stiffness

Pipes manufactured using the Discontinuous Filament Winding process are used both for above ground and underground installations, for gravity flows, or for medium and high internal pressures.

6.1.2 Wall structure

GRP pipe wall consists of three layers perfectly adherent one to the other and each having different characteristics and properties according to their function.

- ***Liner***

Liner or chemically resistant layer is the internal layer of the pipe; it is in direct contact with the conveyed fluid. This layer has the function to guarantee the resistance to the chemical corrosion and the impermeability of the whole pipe.

The Liner has the internal surface, i.e. the one in contact with the conveyed fluid, particularly smooth. This smoothness characteristic reduces to minimum the fluid and pumping head losses and prevents the growth of mineral deposits and algae. The Liner is made of two monolithic sub layers: the inner one, in direct contact with the fluid, is reinforced with glass veil "C" 33 g/m^2, with ratio resin content in a range of 80% - 90% in weight, the outer one is reinforced with plies of glass mat "E" of 375 g/m^2 , with a resin content in a range of 60% - 70% in weight. Standard liner thickness is about 0.8 - 1.2 mm, higher thickness can be produced on request.

- ***Mechanically resistant layer***

Glass reinforced layers guarantee the mechanical resistance of the whole pipe against stresses due to internal and/or external pressure, external loads due to handling and installation, thermal loads.

The layer is obtained by applying, on the previous partly cured liner, continuous rovings of glass impregnated with resin, under controlled tensioning. This layer can contain aggregates (inert granular material such as silica sand) in order to increase the stiffness of the whole pipe.

The thickness of mechanical resistant layer depends on the design conditions.

- ***Top coat***

The top coat or gel coat is the outer layer of the pipe which consists of pure resin added with UV protectors to protect the pipe from sun exposure.

In case of severe exposure conditions, i.e. aggressive soils or very corrosive environment, the gel-coat can be reinforced with a surfacing veil or added with fillers or pigments.

6.2 FITTINGS

6.2.1 Fabrication methods

Fittings are manufactured by the hand lay-up, contact molding and spray-up process.

In hand lay-up and contact molding processes veil and alternate layers of mat and woven roving saturated with resin are applied on the mold. The operation is repeated until the required thickness is achieved.

In spray up process continuous strand roving is fed through a chopper gun, combined with catalyzed resin, and sprayed onto the mould surface. The operation is repeated to reach the required thickness.

6.2.2 Wall structure

The wall of a GRP fitting similarly to the pipe’s wall, consists of three layers perfectly adherent one to the other in order to have a monolithic structure, each having different characteristics and properties in relation to their function.

The liner and top coat are the same as the pipe. The difference consists in the mechanical resistant layer due to the type of reinforcement used.

7. SYSTEM DATA

The raw materials and the manufacturing method for discontinuous filament winding grp pipes are described in the following paragraphs, though for general considerations on the design parameters for the standard pipe series PPW, the following formulae and graphs can be used.

7.1 PIPES

7.1.1 Total wall thickness *(T_W)*

The thickness of the PPW pipe will change according to the winding angle and can be calculated as:

$$T_W = T_M + T_L + T_G \qquad (1)$$

Where:

T_W :Total wall thickness (mm)

T_M: Minimum wall thickness (mm)

T_L: Liner thickness (Standard = 0.8 – 1 mm)

T_G: Gel Coat thickness (Standard = 0.3 mm)

Note :For production technical reasons the real wall thickness may by greater than the theoretical value

The structural calculations are to be considered valid only for thickness to diameter ratios that are in accordance with the following:

$$\left(\frac{t_r}{D}\right) \leq 0{,}1 \qquad (2)$$

Where:

t_r : Average wall thickness of mechanical layer (mm)

D: Mean Diameter (mm)

7.1.2 Minimum reinforced wall thickness (T_M)

The minimum reinforced wall thickness can be calculated according to the following formula :

$$T_M = \frac{PN * ID}{2\sigma_H - PN} = \frac{PN * Dm}{2\sigma_H} = \frac{PN * OD}{2\sigma_H + PN} \qquad (4)$$

Where:

T_M: Minimum reinforced wall thickness (mm);

PN: Nominal Pressare (Mpa) ;

ID: Internal Diameter (mm) ;

σ_H: Allowable hoop stress (N/mm^2)

Dm: Mean Diameter

OD: External Diameter (mm)

7.1.3 Mass of the pipe (M_P)

The mass of the pipe is calculated as follows:

$$M_P = \frac{\pi}{4} * \left(OD^2 - ID^2\right) * S_L * 10^{-6} \qquad (5)$$

Where:

M_P: Linear mass of pipe (kg/m)

ID: Internal Diameter (mm)

OD: Outer Diameter (mm) (*)

S_L: Specific gravity of the laminate (kg/m^3)

*(*) Note: OD = ID+2*T_W*

7.1.4 Structural wall area (A)

The structural wall is calculated as follows:

$$A = \frac{\pi}{4} * (DO^2 + DI^2) \qquad (6)$$

Where:

A :Structural wall area (mm^2)

DO: Structural Outer Diameter (mm) (*)

DI: Structural Internal Diameter (mm) (*)

(*) Note: DO = ID+2(T_L+ T_E) ; : DI = ID+2*T_L*

7.1.5 Linear moment of Inertia (I_Z)

The Linear Moment of Inertia can be calculated from the following:

$$I_Z = \frac{\pi}{64} * (DO^4 - DI^4) \qquad (7)$$

Where:

I_Z :Linear moment of Inertia (mm^4)

DO: Structural Outer Diameter (mm)

DI: Structural Internal Diameter (mm)

7.1.6 Radius of Inertia (I_R)

The radius of Inertia is obtained from the formula:

$$I_R = \sqrt{\frac{I_Z}{A}} \qquad (8)$$

Where:

I_R *: Radius of Inertia (mm)*

I_Z *:Linear moment of Inertia (mm^4)*

A :Structural wall area (mm^2)

7.1.7 Bore area (A_B)

$$A_B = \frac{\pi}{4} * ID^2 \qquad (9)$$

Where:

A_B *:Bore area (mm^2)*

ID: Internal Diameter (mm)

7.1.8 Moment of Resistance to Bending (W_B)

$$W_B = \frac{\pi}{32} * \frac{DO^4 - DI^4}{DO} \qquad (10)$$

Where:

W_B*: Moment of resistance to bending (mm^3)*

DO: Structural Outer Diameter (mm)

DI: Structural Internal Diameter (mm)

Note: The Moment of resistance to bending can also be calculated from $W_B = W_W/2$
With W_W*= moment of resistance to torsion*

7.1.9 Mass of the Pipe content

It is possible to calculate the mass of the pipe content by means of the following:

$$M_V = \frac{\pi}{4} * ID^2 * S_V * 10^{-6} \qquad (11)$$

Where:

M_V *:Linear mass of the pipe content (kg/m)*

ID: Internal Diameter (mm)

S_V *: Specific gravity of the fluid (kg/m^3)*

7.2 ALLOWABLE HOOP STRESS

To calculate the minimum reinforced wall thickness (T_F) related to the different fittings one must refer to the minimum wall thickness of pipes (T_M) by the ratio allowable hoop stress s_H of pipes divided by the allowable hoop stress of fittings.

For pipes the s_H allowable hoop stress can be calculated according to the winding angles from the following table where the main Hydrostatic properties are shown, considering the Long Term Hydrostatic Strength at 50 years. The same can be used also at higher temperature by applying the correction factors for the E Moduli.

Table 5: Mechanical Properties(*) = Biaxial Stress ; (#) = Uniaxial Stress

Property		**Test**	**55° Angle**	**63° Angle**	
Ultimate Hoop Strength (rupture)	-	ASTM D2290	430	500	N/mm^2
Ultimate Hoop Stress (weeping)	-	ASTM D1599	250 (*)	300 (#)	N/mm^2
RTRP : Long Term Hydrostatic Strength (50 years)	-	ASTM D2992 B	174 (*)	-	N/mm^2
RTMP : Long Term Hydrostatic Strength (50 years)	-	ASTM D2992 B	96 (*)	-	N/mm^2
Axial Tensile Stress	$E_{X,d}$	ASTM D2105	75	55	N/mm^2
Axial Tensile Modulus			12000	11500	N/mm^2
Hoop Tensile Stress	-	ASTM D2290	480	500	N/mm^2
Hoop Tensile Modulus			20500	27500	N/mm^2
Shear Modulus	E_S	-	11500	9000	N/mm^2
Axial Bending Stress	$E_{X,f}$	ASTM D2925	140	100	N/mm^2
Axial Bending Modulus			12000	10000	N/mm^2
Hoop Bending Strength	$E_{H,f}$	ASTM D2412	350	500	N/mm^2
Hoop Bending Modulus			18000	24000	N/mm^2
Poisson Ratio axial/hoop	E_{xy}	-	0.58	0.56	
Poisson Ratio hoop/axial	E_{yx}		0.35	0.24	

For Fittings the allowable hoop stress for Pressure is:

- *Tee, Reducers:* $\sigma_H = 21 \div 24\ N/mm^2$
- *Elbows:* $\sigma_H = 21 \div 24\ N/mm^2$

8. QUALIFICATION PROGRAM

8.1 GENERAL

The qualification program is the standard method for quantifying component performance taking in consideration the static internal pressure, elevated temperature, chemical resistance, electrostatic and fire performance properties. According to kind of installation optional methods can be followed to quantify potable water, impact, low temperature or cycle performance.

The scope of a qualification program is to determine a qualified pressure P_q that then becomes the basis of the structural design described in Section 3.

8.2 QUALIFICATION PRESSURE AND TEMPERATURE

The pressure rating provided in product literature is not the same as the qualified pressure P_q defined as in or the system design pressure and assigned to all components.

$$NPR_{man} = f_2 \times f_{3man} \text{ x } P_q \qquad (12)$$

Where:

$P_{q:}$: Qualified Pressure (Mpa)

f_2 : load factor

f_{3man} : factor chosen to consider the axial load capability of GRP, it is not a fixed parameter and depends on application

A component in a complex piping system where significant non-pressure stresses may be produced f_3 may have a value about of 0,5. Conversely f_3 may have a value of 0,9 or more where the component is well supported and part of a long pipe run.

Please contact Technical Department of Iniziative Industriali S.p.A. to define these parameters.

The Qualification Procedure is used to verify the proposed qualified pressure of each component.

8.3 TEST REQUIREMENTS

In order to keep the burden of the testing within acceptable limits but at the same time to control the use of test data beyond their limits of applicability, the use of a product family and its subdivisions is applied. The product family representative to be tested is the component chosen to represent a particular component product family.

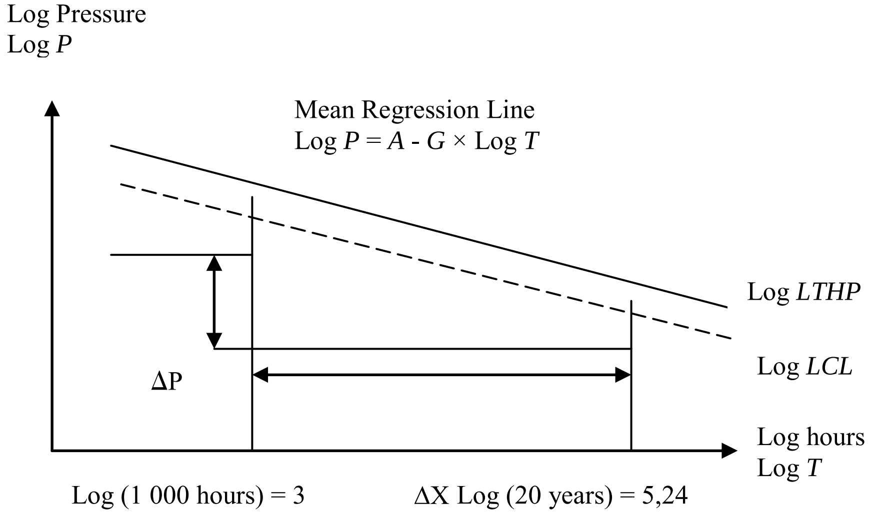
Qualification tests are proof tests of specific representatives of a given product family and do not need to be repeated for each order or project. Though changes in the product family characteristics need re-qualification.

Please contact Technical Department of Iniziative Industriali S.p.A. for further details.

8.4 TEST METHODOLOGY

The basis for defining a qualified pressure of the family representative on the design basis of 20 years is given by full regression tests (ASTM D2992:1996) that according to the typology of the same allows the use of gradients *(G)* to apply to the 1000 h survival test necessary to determine the qualified pressure. This is identified in the Lower Confidence Limit (LCL) pressure of the product sector representative and can be used for all kinds of joints.

The applied pressure shall not be less than the predicted lower confidence limit for the product sector representative at 1000 h. Successful completion of the test results when the product sector representative survives, i.e. does not weep, the test duration. The Figure below graphically shows how to calculate the 1000 h test pressure using the regression line for the product family representative



$$Log(TP_{100}) = \Delta P + Log(f_1 \times LTHP) \qquad (13)$$

or

$$TP_{1000} = f_1 \times LTHP \times 10$$

and

$$\Delta P = G \times \Delta X = G \times [Log(20 years) - Log(1000 hours)] = 2{,}24 \times G$$

$$TP_{1000} = f_1 \times LTHP \times 10^{2{,}24 \times G}$$

8.5 DESIGN LIFETIMES OTHER THAN 20 YEARS

The standard or default life time according to this procedure is 20 years. To convert the qualified pressure, *LCL* (20 years) obtained according to this qualification procedure to a qualified pressure at a different life time, LCL (T years), the following equations are used;

$$LCL(20\text{ years}) = LCL(T\text{ years}) \times 10^{\Delta P}$$

$$\Delta P = G \times (1{,}3 - \mathrm{Log}(T))$$

where *G* is the appropriate gradient of the regression line for the component variant of interest.

8.6 EFFECT OF TEMPERATURE AND CHEMICAL RESISTANCE

Partial factors shall be taken in consideration, A_1 and A_2, to take in account the reduction in performance capability caused by long term exposure to temperatures above 65 ^{o}C and chemicals other than water. To identify the procedures on determining A_1 and A_2, please contact the Technical Department of Iniziative Industriali S.p.A. The Maximum design pressure can be calculated as:

$$P_{MAXD} = A_1 \; x \; A_2 \; x \; f_1 \; x \; f_2 \; x \; f_3$$

9. STRUCTURAL DESIGN

The aim of structural design for GRP piping systems is to ensure that they shall perform satisfactorily and sustain all stresses and deformations during construction/installation and throughout their service life. This section identifies the service design criteria and the loads to which GRP may be subjected.

9.1 QUALIFIED PRESSURE

The qualified pressure P_q for pipes and fittings shall be determined using the procedure described in Paragraph 2 above. The qualified pressure is based on a design life of 20 years and is equivalent to the *LCL*.

9.2 FACTORED QUALIFIED PRESSURE

The factored qualified pressure is defined as the pressure to be used in determining the safe operating envelope of the GRP pipe or piping system. It takes account of specific service conditions that could not be considered in the qualification programme.

The factored qualified pressure, P_{qf}, for pipe and fittings shall be calculated using equation:

$$P_{qf} = A_1 \times A_2 \times A_3 \times P_q \quad (14)$$

where:

P_q is the qualified pressure (Mpa)

A_1 is the partial factor for temperature

A_2 is the partial factor for chemical resistance

A_3 is the partial factor for cyclic service

To identify the procedures to determine these factors please contact the Technical Department of Iniziative Industriali S.p.A.

9.3 SYSTEM DESIGN PRESSURE

The system design pressure P_d (MPa) shall be less than the maximum allowable pressure for a component given by following equation:

$$P_d \leq f_2 \times f_3 \text{ x } P_{qf}$$

where:

f_2 is defined as part factor for loading

f_3 is defined

P_{qf} is defined

9.4 LOADING REQUIREMENTS

9.4.1 Applied loads

The design of pipe systems shall represent the most severe anticipated conditions experienced during installation and within the service life of the system, that include both operational **sustained loadings** (internal, external or vacuum pressure, hydrotest, piping self weight, piping insulation weight, fire protection weight, transported medium weight, buoyancy, other system loads, inertia loads due to motion during operation, displacement of supports caused by flexing of the hull during operations, thermal induced loads, electric surface heating, environmental loads, ice, encapsulation in concrete, soil loads) and **occasional loads** (water hammer, equipment vibrations, pressure safety valve releases, impact, inertia loads due to motion during transportation, earthquake-induced horizontal and vertical forces, installation loads, lifting loads, transportation loads, adiabatic cooling loads, wind, blast over-pressures. soil subsidence), as well as their duration and will all influence the value of factor f_2.

9.5 QUALIFIED STRESS.

The qualified stress, σ_{qs} (Mpa) for plain pipe is the maximum hoop stress that the system is designed to operate at under sustained conditions. The qualified stress, σ_{qf}, for plain pipe shall be calculated using following equation:

$$\sigma_{qs} = p_q * \frac{D}{2t_r} \qquad (15)$$

where:

P_{qf} is the factored qualified pressure in MPa

D is the average diameter of the pipe in mm.

t_r is the minimum reinforced wall thickness of the pipe in mm.

The qualified service stress, σ_{qs}, for fittings shall be calculated using following equation:

$$\left(\frac{\sigma_{qs}}{p_q}\right)_{fitting} = \left(\frac{\sigma_{qs}}{p_q}\right)_{pipe} \qquad (16)$$

Similarly as calculated previously with the Qualified Pressure, the value of Factored Qualified Stress σ_{fs} must now take into account partial factors for temperature (A1), chemical resistance (A2) and cyclic service (A3) according to the following:

$$\sigma_{fs} = A_1 \times A_2 \times A_3 \times \sigma_{qs} \qquad (17)$$

where:

σ_{qs} is the qualified stress (Mpa)

A_1 is the partial factor for temperature

A_2 is the partial factor for chemical resistance

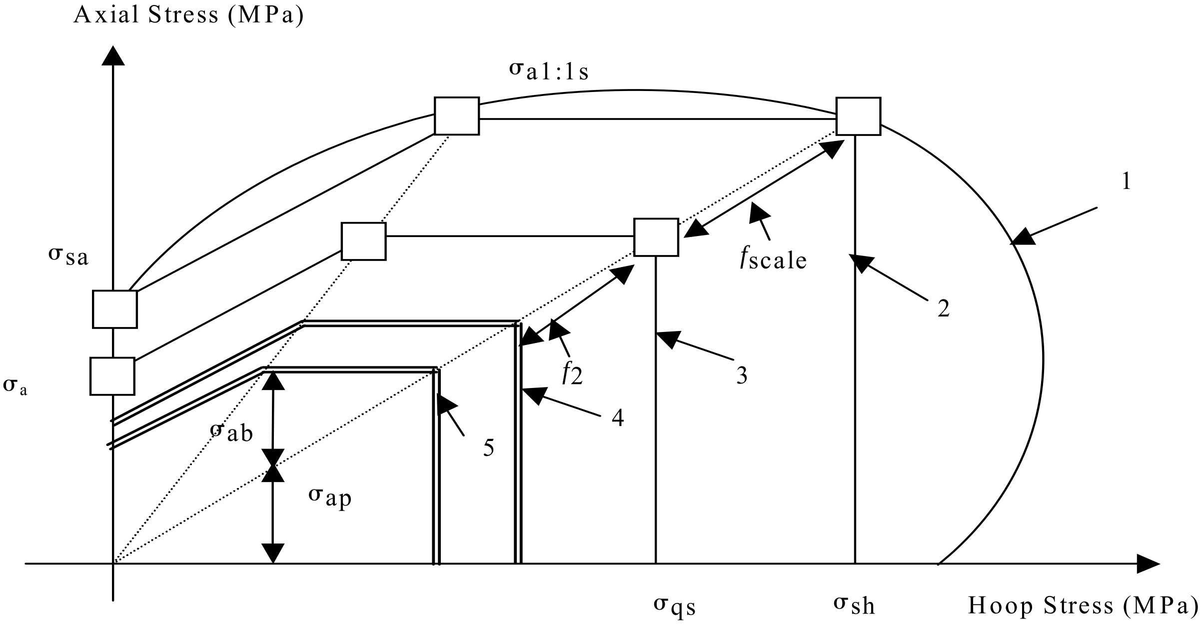
A_3 is the partial factor for cyclic service

The general requirement is that the sum of all hoop stresses, $\sigma_{h\ sum}$, and the sum of all longitudinal stresses, $\sigma_{a\ sum}$, in any component in a piping system due to pressure, weight, and other sustained loadings, and of the stresses produced by occasional loads such as wind, blast or earthquake shall not exceed values defined by the long term design envelope.

9.6 DETERMINATION OF FAILURE ENVELOPE

This section describes how the failure envelope of the GRP pipe components can be determined to meet the requirements of design, by means of the Short Term Envelope. Simplified envelopes are available yet the fully measured envelope is the least conservative procedure and described below.

The long term envelope previously discussed as the basis for design is derived from a fully measured short term envelope according specific procedures. The ideal long term envelope shown in figure below is calculated for a single wound angle ply GRP pipe with winding angles in the range between 45° to 75°.



σ_{qs}	Qualified stress (in MPa)
σ_a	Idealised long term longitudinal (axial) strength in MPa at 0:1 stress ratio
σ_{sa}	Short term longitudinal (axial) strength in MPa at 0:1 stress ratio
σ_{sh}	Short term hoop stress in MPa at 2:1 stress ratio
$\sigma_{a1:1s}$	Short term strength in MPa at 1:1 stress ratio in MPa
σ_{ab}	Non-pressure induced axial stress in MPa
σ_{ap}	Axial stress due to internal pressure in MPa

KEY:

1. *Schematic representation of the short term failure envelope*
2. *idealized short term envelope*
3. *idealized long term envelope*
4. *non factored long term design envelope*
5. *factored long term design envelope*

By calculating values where ratio s hoop to s axial is respectively (2:1), (1:1) and (0:1) by means of short term testing one can build the curve 1 shown above. From these values and therefore after having built the schematic representation of the short term failure envelope one starts applying the scaling factors, f_{scale} calculated as per equation below and f_2 depending on loading type.

$$f_{scale} = \frac{\sigma_{qs}}{\sigma_{sh(2:1)}} \qquad (18)$$

The factored long term design envelope can then be defined as:

$$g_{LONG}(\sigma_{h,sum}, \sigma_{a,sum}) \leq f_2 \cdot f_{scale} \cdot A_1 \cdot A_2 \cdot A_3 \cdot g_{SHORT}(\sigma_{sh(2:1)}, \sigma_{sa(0:1)}) \qquad (19)$$

Where:

$\sigma_{a\ sum}$ = sum of all axial stresses (MPa),

$\sigma_{h\ sum}$ = sum of all hoop stresses in MPa (pressure plus system design)

A_1 = partial factor for temperature

A_2 = partial factor for chemical resistance

A_3 = partial factor for cyclic service

$g_{LONG}(\sigma_{h,sum}, \sigma_{a,sum})$ = shape of the factored long term design envelope

$g_{SHORT}(\sigma_{sh(2:1)}, \sigma_{sa(0:1)})$ = shape of the idealized short term design envelope.

10. PROPERTIES OF LAMINATES

The following tables refer to laminated obtained by the filament winding process having a winding angle of 55 degrees.

10.1 MECHANICAL PROPERTIES

Tab 6 – Mechanical Properties

Property	Pipes	Fittings	
Ultimate Hoop Tensile Strength	250	150	N/mm^2
Ultimate Axial Tensile Strength	130	150	N/mm^2
Ultimate Hoop Flexural Strength	370	170	N/mm^2
Hoop Tensile Modulus (Eh)	22.000	13.000	N/mm^2
Axial Tensile Modulus (El)	12.000	13.000	N/mm^2
Hoop Flexural Modulus (Ef)	25.000	13.000	N/mm^2
Poisson's Ratio for applied Hoop Stress, ν_{hl}	0.58	0.3	
Poisson's Ratio for applied Axial Stress, ν_{lh}	ν_{hl} *El/Eh	0.3	

10.2 THERMAL AND OTHER PHYSICAL PROPERTIES

Tab 7 – Thermal and Physical Properties

Property	Pipes	Fittings	
Glass Content (by weight)	65 - 75	35 - 50	%
Specific Gravity	1.850	1.650	kg/m^3
Coefficient of Linear Thermal Expansion	$1.8*10^{-5}$ - $2.2*10^{-5}$	$1.8*10^{-5}$ - $2.2*10^{-5}$	1/°C
Thermal Conductivity	0.26	0.26	W/m*K
Electrical Resistivity (standard pipe)	10^9	10^9	Ohm/m
Electrical Resistivity (conductive pipe)	$<10^5$	$<10^5$	Ohm/m

11. HYDRAULIC CHARACTERISTICS

GRP pipes, thanks to their smooth internal surface, their resistance to corrosion and to the absence of fouling, have excellent hydraulic characteristics and provide economic advantages over other material pipes.

11.1 PRESSURE LOSS CALCULATIONS

A number of different calculation methods help to determine the head loss for pipes and fittings. The most common are the Darcy-Weisbach formula with Colebrook friction factor, Hazen-Williams and Manning formulae.

The inner surface of GRP pipe has an absolute roughness of 25 µm.

When the joint system is B/2R or B/2RLJ the equivalent absolute roughness of the pipeline is 70 µm.

- ***Darcy-Weisbach formula***

$$J = \frac{fv^2}{2gD} \qquad (20)$$

where:

g = gravity constant, 9.81 m/s^2
J = head loss, m/m
v = velocity, m/s
D = inside diameter, m
f = friction factor (from the Colebrook equation):

$$\frac{1}{\sqrt{f}} = -2\mathrm{Log}\left(\frac{\varepsilon}{3.71D} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right) \qquad (21)$$

where:

ε = long term absolute roughness, (70 µm for GRP)
Re = vD / ν = Reynold's number, dimensionless
ν = kinematic viscosity, m^2*/s (1.14 * 10*$^{-6}$ *at 15°C for water)*

- ***Hazen-Williams formula***

$$v = 0.85CR^{0.63}J^{0.54} \qquad (22)$$

where:
v = velocity, m/s
C = Hazen-Williams coefficient, (145 for GRP)
R = hydraulic radius, m
J = hydraulic gradient, m/m

- ***Manning formula***

$$v = \frac{1}{n} R^{0.667} J^{0.5} \qquad (23)$$

where:

v	*= velocity, m/s*
n	*= Manning's coefficient, (0.01 for GRP)*
R	*= hydraulic mean radius, m*
J	*= hydraulic gradient, m/m*

- ***Max recommended fluid velocity***

Clear fluid	up to 4.0 m/s max
Corrosive or erosive fluids	up to 2.0 m/s max

- ***Head loss in fittings***

The head loss H (m) in fittings can be determined using K factor:

$$H = K \frac{v^2}{2g} \qquad (24)$$

where typical K factors for fiberglass fittings are illustrated in following table 3.

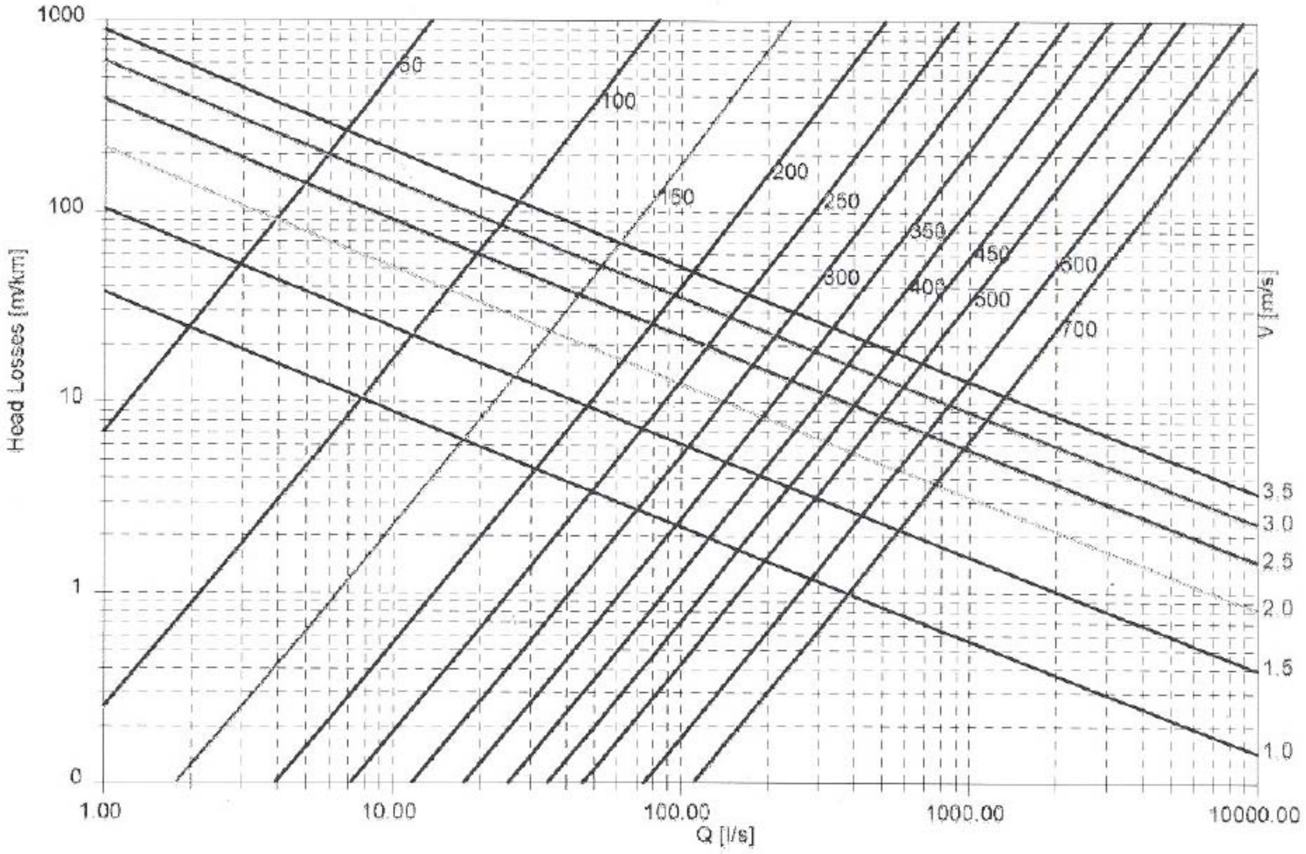
Tab 8 – Typical K factors for GRP fittings

Type of fitting	K factor
90° elbow, std.	0.5
90° elbow, single miter	1.4
90° elbow, double miter	0.8
90° elbow, triple miter	0.6
45° elbow, std.	0.3
45° elbow, single miter	0.5
Tee, straight flow	0.4
Tee, flow to branch	1.4
Tee, flow from branch	1.7
Reducer, single size reduction	0.7

The graphs in the following pages give quick methods to obtain the head losses of a pipeline for a selected velocity of fluid, for the range of size ND 50 - ND 700, the graph at page 26, and ND 800 - ND 2800, the graph at page 27.

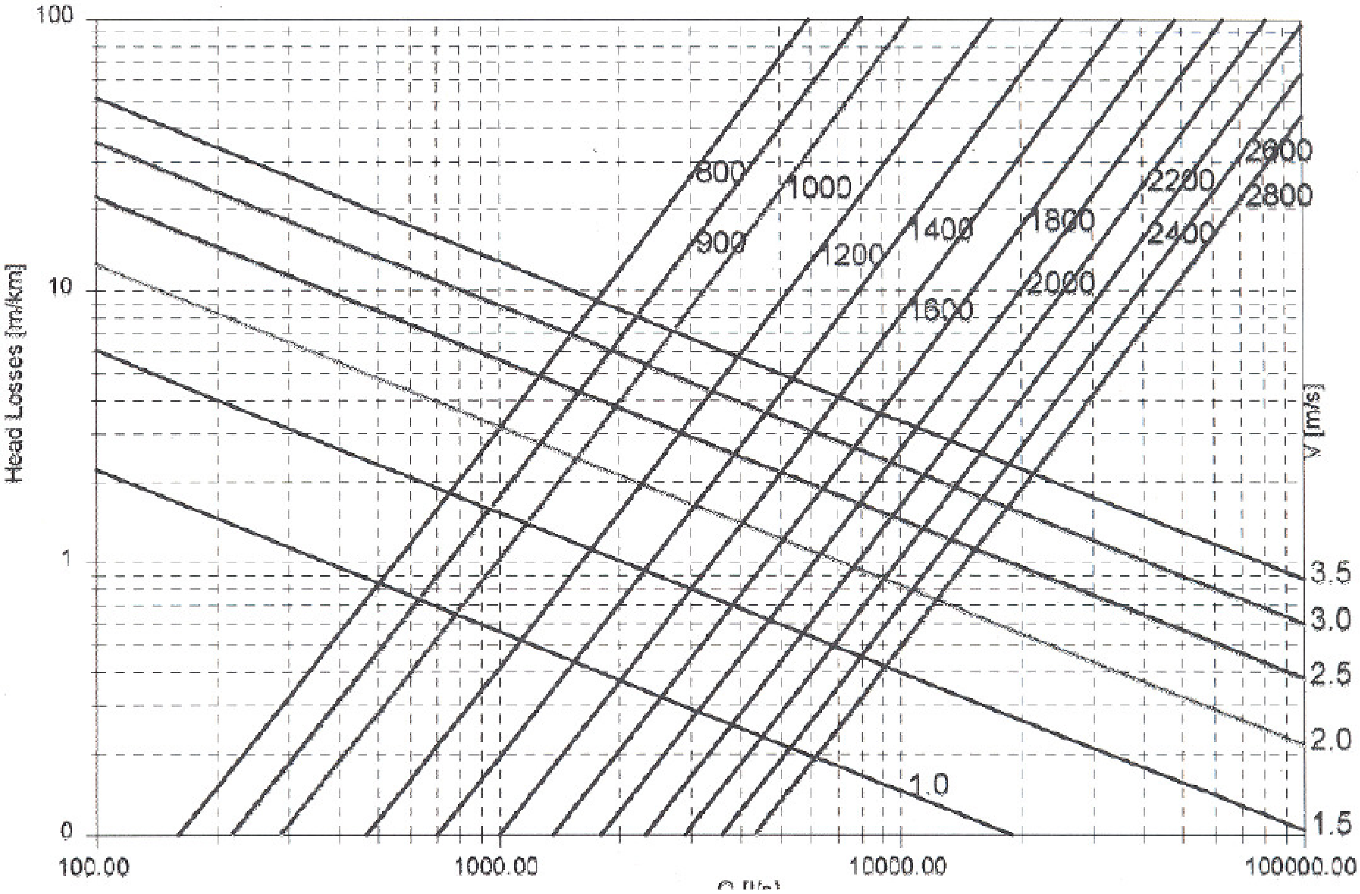
HEAD LOSS CHART

ND 50 -700 mm



HEAD LOSS CHART

ND 800 -2800 mm



11.2 SURGE PRESSURE (WATER HAMMER)

The magnitude of surge pressure is highly depending on the hoop tensile modulus of elasticity and on the thickness-to-diameter (t/D) ratio of the pipe.

The smaller the modulus , the lower the surge pressures; because of this, the designer should generally expect lower calculated surge pressures for GRP pipe than for pipe materials with higher modulus or thicker wall or both.

Changes of flow velocity increase the maximum pressure. The parameter to calculate the theoretical value of the maximum pressure is the wave velocity "c", which depends on the pipe characteristics and flow properties of the fluid.

The value of "c" is given by:

$$c = \sqrt{\frac{K/\rho}{1 + \frac{K}{E}\frac{D}{t}}} \qquad (25)$$

where:

ρ = water density = 1000 N s^2 / m^4
K = water bulk modulus = 2200 x 10^6 Pa (at 15 ^oC and up to 10 bar pressure)
D = inside diameter of pipe, mm
E = hoop modulus of elasticity of the pipe, Pa
t = mechanical thickness, mm

The theoretical value of the maximum/minimum surge pressure is obtained from the following formula:

$$\Delta H = \pm c \Delta v/g \qquad (26)$$

where:
ΔH = surge pressure, m
Δv = change in liquid velocity, m/s

If the operation has a sudden change in the flow rate (i.e. pump start-up or shut-down, valve quick closure,.), Δv is equal to the fluid mean velocity.

The following allowance is commonly accepted for GRP pipe (AWWA C 950/95):
$P_w < NP$
$P_w + P_s < 1.4\ NP$

where:
P_w = working pressure
P_s = surge pressure
NP = nominal pressure

This means that the surge pressure tolerated in GRP piping system can exceed by 40% the pressure class.

12. SYSTEM DESIGN

12.1 DESIGN PHILOSOPHY

Rational and experimental methods used in designing GRP systems are followed for *SARPLAST* pipes design. Most of performance limits are determined from long-term strength characteristics. Design factors are used to ensure adequate system over the intended system life of the pipe by providing for unforeseen variations in materials properties and loads.

The structural design procedure involves establishing of the design conditions, selection of the pipe classes and corresponding pipe properties, selection of installation parameters, and performing pertinent calculations to satisfy the design requirements. The procedure usually requires iterative calculation that can be simplified with the aid of the computer. *Iniziative Industriali* has developed dedicated software for the calculations of stresses, strains and deformations for underground and aboveground applications.

12.2 DESIGN CONDITIONS

Before selecting a *GRP* pipe, the following design conditions should be established:

- Nominal pipe diameter
- Working pressure P_W
- Surge pressure P_S
- Internal vacuum pressure P_V
- Installation conditions: aboveground, underground, subaqueous, ...
- Average service temperature and range

12.3 PIPE PROPERTIES

Preliminary pipe pressure and stiffness classes selection is made on the basis of the design conditions.

Pipe properties necessary for performing calculation include:

- Reinforced wall thickness *t* and liner thickness t_L, in mm
- Hoop modulus of elasticity, tensile E_H and flexural E in MPa
- Hydrostatic design basis HDB or allowable strain ε
- Poisson's ratios ν_{hl}, ν_{lh}

12.4 INTERNAL PRESSURE CLASS

The nominal pressure should be the most severe internal operating pressure that the system will be subjected to under all modes of operation, including starts-up, shut-downs, deflection for undergriund and aboveground installation, etc., throughout the entire life time of the system. As previously described, the Nominal Pressure NP should be:

$$P_w \leq NP \qquad \text{and} \qquad P_w + P_s < 1.4\ NP$$

The pressure class Pc according to AWWA C950-95 is related to the long term strength, HDB, of the pipe as follows:

On strain basis HDB

$$P_c \leq \left(\frac{HDB}{FS} \frac{2E_H t}{D} \right) \tag{27}$$

where:

FS = *minimum design factor, 1.8*
D = *mean pipe diameter, mm*

The hydrostatic design basis (HDB) for internal pressure class is based on a long-term test performed in accordance with ASTM D2992 Procedure B.

12.5 STIFFNESS CLASSES

The Stiffness of a pipe is defined as the resistance of a pipe to circumferential deflection in response to external loading applied along one diametric plane.

The Stiffness of the pipe S (in N/m^2) is given by the following formula:

$$S = \frac{EI}{D^3} \tag{28}$$

where:

E = *hoop flexural modulus of elasticity, Pa*
I = *moment of inertia of pipe wall calculated as* $I = t^3/12$, *in* mm^3, *with t = pipe wall thickness*
D = *mean pipe diameter, mm,*

12.6 MINIMUM BENDING RADIUS

In many cases it is useful to know the minimum bending radius of a pipe when subjected to bending loads.

The formula applied for the calculation of the minimum allowable bending radius is the following:

$$R_m = \frac{E_b * D}{2/\sigma_b} = \frac{D}{2/\varepsilon} \tag{29}$$

where:

R_m = *minimum allowable bending radius, mm*

E_b = *bending modulus of elasticity,* N/mm^2

D = *mean diameter of pipe, mm*

σ_b = *maximum allowable bending stress,* N/mm^2

ε = *maximum allowable strain, mm/mm*

13. OTHER CONSIDERATIONS

13.1 EARTHQUAKE

Earthquake displays its action along the three space directions, but only two of them (vertical and parallel directions to pipeline) have practical effects.

Vertical action

Earthquake action is converted into an increased value of gravity acceleration, that means an higher soil load on pipeline and a shear action on the pipe.

Parallel action

Soil movement along the pipeline determines, because of the friction between soil and pipeline, the sliding of pipeline joints if they are bell and spigot double O-ring type, or an axial stress if joints are bell and spigot double O-ring key lock type.

Earthquake action along the direction normal to pipeline and parallel to ground is negligible.

Seismic acceleration calculation

Vertical and horizontal accelerations, due to earthquake, are calculated as follows:

$$a_v = m\ C\ I\ g \quad (47)$$

$$a_h = R\ C\ I\ g \quad (48)$$

where :

- a_v = *vertical acceleration,* m/s^2
- a_h = *horizontal acceleration,* m/s^2
- m = *dimensionless coefficient, usually = 2*
- C = *seismic intensity coefficient = (S-2)/100*
- I = *seismic protection coefficient, usually = 1.2*
- R = *response coefficient of structure*
- g = *gravity acceleration, 9.81* m/s^2
- S = *seismic grade (S>=2), usually = 9*

R (response coefficient) is assumed as a function of the fundamental period T_O of the structure, for oscillations along the considered direction:

when $T_O > 0{,}8$ s $\quad R = 0.862 / T_O^{0.667}$

when $T_O <= 0.8$ s $\quad R = 1$

In case of indetermination of T_O a value of R equal to 1 (maximum value) shall be assumed.

Vertical and horizontal accelerations, due to earthquake, are:

$$a_v = 2 * (9 - 2) / 100 * 1.2 * g = 0.17\ g = 1.65\ m/s^2 \quad (49)$$

$$a_h = 1 * (9 - 2) / 100 * 1.2 * g = 0.084\ g = 0.82\ m/s^2 \quad (50)$$

Acceleration during earthquake shall be:

Vertical action

$a_v + g = 1.17\ g = 11.5\ \ m/s^2$

Horizontal action

$a_h = 0.08\ g = 0.82\ \ m/s^2$

Check of pipe buckling during earthquake

Vertical action increases the weights of ground and live load operating on the pipeline. This condition determines a reduction of the safety factor to buckling.

Buckling is checked at depth foreseen by the design through the following formulae (AWWA C950-88):

$q_a = (1/FS)(32\ R_w B'\ E'\ S)^{1/2}$ (see 11.3)

$$q_{ex} = \left(R_W \frac{W_C}{D} + \frac{W_L}{D} \right) \frac{a_v + g}{g} \qquad (51)$$

q_{ex} = external loads, N/mm^2

$q_a / q_{ex} \geq 1$

13.1.1 Seismic strain of ground

In order to calculate the seismic action along the direction parallel to pipe it is necessary to consider the strain of ground during earthquake:

$$\varepsilon_g = (T_g a_h)/(2\pi v_s) \qquad (52)$$

where:

T_g = seismic wave period, s

a_h = horizontal acceleration, m/s^2

v_s = propagation speed of the seismic wave, m/s

13.1.2 Axial strain of pipe

- **Bell and Spigot Double O-ring Lock Joint**

Bell and Spigot Double O-ring Lock Joint transmits axial stresses and allows rotation between a pipe length and its adjacent.

We have to determine the pipe's axial strain due to earthquake, add the strain due to working pressure and verify that the total strain is less than the axial allowable strain.

- **Bell and Spigot Double O-ring**

Bell and Spigot Double O-ring Joint does not transmit axial stresses and allows rotation between a pipe length and its adjacent.

The pipe's axial strain due to earthquake must be determined and checked that joint sliding does not allow the slipping of the spigot out of the bell.

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