E-CFW ENGINEERING HANDBOOK

TOPFIBRA

EFFECTIVE FILAMENT WINDING® PIONEERS

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GENERAL DESIGN SPECIFICATION FOR THE GLASS/BASALT-FIBER-REINFORCED THERMOSETTING REISIN PIPE (RTRP) AND THE GLASS/BASALT-FIBER-REINFORCED PLASTIC MORTAL PIPE (RPMP)

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1. INTRODUCTION

The Reinforced Thermosetting Resin Pipe (RTRP) is also known as the GRP (glass reinforced plastic) pipe or the FRP (fiberglass reinforced plastic) pipe or BRP pipe (basalt reinforced pipe). Due to its unique characteristics, it offers a range of advantages over the pipes made from the traditional materials. When it is properly designed and installed, it gives the system the required performance at the minimal costs. This Design Specification chapter aims at assisting the Engineer in the development and the selection of an RTR piping system, to meet the required operational needs.

1.1. Composite materials

The fiberglass reinforced plastic is a "composite" material. Composites are an engineering material that consists of a thermosetting resin (the matrix) and a fiber reinforcement.

During the manufacturing process, the liquid resin is combined with a fiber reinforcement, which is then cured into a solid laminate. There are many types of resins and reinforcements and each of them imparts specific properties to the composite FRP product.

1.2. Resins

There are at least 6 major family groups of resins used in the fabrication of the composites: polyester; vinylester; modified acrylic; epoxy; phenolic resin; urethane resin systems and so on. It is important to note that each of these resins possesses specific performance characteristics.

Three ordinary examples will help us illustrate that choosing the correct resin is the same as, for example, choosing the right vehicle: if you want to go fast, you buy a sports car; to haul loads, you use a truck; and to go off-road, you drive a 4x4. Let's translate this to choosing the correct resins. If the corrosion resistance characteristic is a priority, a vinylester resin should be used. If high strength is critical, the epoxy is recommended. If cost vs. performance is the issue, the polyester resin is used most commonly.

Just choosing between the different polyester resins alone, will give you the specific formulations. Some are used for attaining aesthetic properties; others for enhanced corrosion resistance; the resistance to the elevated temperatures; or for the consideration of the cost.

The resin system is selected on the basis of the functional and cost requirements of the product.

1.3. The reinforcements

A number of different reinforcement fibers are used in the composites. Glass fiber is used in over 90% of the cases. However, to reach a specific high level performance, advanced fibers such as Basalt, Kevlar or Carbon Fiber are used. They offer good properties at a price that is quite high.

When it comes to the glass fibers, there are many "styles" of reinforcement. Many production options exist, depending on the moulding process and the strength requirements of the product. Glass fibers can be applied with a random fiber orientation in the form of a chopped strand mat. There are also lightweight textile fabrics, heavy woven materials, knitted fabrics and unidirectional fabrics. All of them serve specific purposes in the composite design.

To maximize the benefit to cost ratio of the composite products, the component materials must be custom tailored to the application.

For the production of the TOPFIBRA FRP pipes and fittings, the main materials that are used are the polyester resins, Basalt and Fiberglass in the form of the continuous roving and in different tissues, as better specified on the next pages.

1.4. Aggregates and fillers

In addition to the polyester resin and the glass fibers, aggregates and/or fillers can be used in the production of the GRP-BRP pipes. The aggregate that is added to the fiberglass/resin laminate is generally a siliceous sand, complying with the special requirements. Such pipe is called the Reinforced Plastic Mortar Pipe (RPMP).

The filler is a compound, generally added directly to the matrix to build the laminate It serves to improve the different properties of the pipe (thixotropic agents, fire retardant, pigment, etc.).

1.5. Manufacturing techniques

For the production of the composite products, many different process methods can be used.

Composites are moulded by an array of process methods that range from the very simple and low-cost methods, to the complex and capital intensive ones.

The selection of the moulding process is usually based on two major factors:

- the required end-use properties of the product;
- the volume of the product to be manufactured.

The open moulding hand lay-up (HLU) process is suitable for producing the small to medium quantities of parts. The capital investment in the open mould tooling is relatively low, while the production labour costs are relatively high.

The various options for the closed moulding require a higher capital investment and the labour costs become progressively lower. Closed mouldings are used for the tubular products, which are most commonly made with the **filament winding** process.

TOPFIBRA offers the continuous filament winding and the discontinuous filament winding processes for the production of the FRP pipes.

This handbook prescribes the requirements for the design of the RTRP-RPMP piping systems and the reference documents that can be used, when necessary, to fulfil these requirements.

The following manufacturing techniques will be described in separate documents:

- Continuous Filament Winding;
- Reciprocal Filament Winding;
- Open Mould HLU.

2. REFERENCE STANDARDS

Please see the chapter: "THE LIST OF THE STANDARD SPECIFICATION AND THE STANDARD TEST METHODS" for the list of the main reference standards for the GRP pipe and the related raw materials.

3. PIPE WALL COMPOSITION

The RTRP/RPMP pipe wall consists of three layers, perfectly adherent one to another and each having different characteristics and properties in relation to their function.

For each layer, the different reinforcements and resins are used.

3.1. Internal Liner

The liner or the chemically resistant layer is the internal layer of the pipe. It is in direct contact with the conveyed fluid. This layer has the function of guaranteeing the maximum resistance to the chemical corrosion and securing the impermeability of the whole pipe, due to:

- the higher content of the resin;

- the special kind of the resin used;
- the special kind of the glass reinforcement used.

The liner is generally made of two monolithic sub-layers:

- the inner layer, which is in direct contact with the fluid. It is reinforced with 1 or more layers of the chemically resistant "C" glass surfacing veil (20÷33 g/m^2) with the resin/glass ratio about 90/10 by weight;
- the outer layer is reinforced with the plies of the "E" glass mat of 375÷450 g/m^2, or with an equivalent amount of the chopped "E" glass roving, with the resin/glass ratio of about 70/30 by weight.

The standard liner thickness is about 0.8÷1.2 mm. This thickness can be increased when needed.

3.2. Mechanically Resistant Layer (Also called "the structural layer")

The high content of the reinforcing glass fiber guarantees:

- the mechanical resistance of the whole pipe to the stresses due to the internal and/or external pressure;
- the resistance to the external loads due to handling and the installation;
- the resistance to the soil loads, traffic loads, thermal loads, beam loads, etc.
    - The structural layer is obtained in different ways, which depend on the manufacturing technology and on the application of the following materials on the previous partly cured liner, using:
        - the thermosetting resin;
        - the continuous "E" glass roving, wound on the pipe with a controlled tension at different winding angles, depending on the production process;
        - the chopped "E" glass roving;
        - the silica sand (aggregate).

The first two elements are always present in the fiberglass pipe, produced with the TOPFIBRA technologies.

This layer can contain aggregates (inert granular materials, such as the silica sand) in order to increase the stiffness of the whole pipe. The thickness of the mechanical resistant layer depends on the design conditions.

For more details on the manufacturing of the structural layer please see the documents concerning the particular manufacturing technology.

3.3. Outer Liner

The top coat or the gel coat is the outer layer of the pipe, with a minimum thickness of 0.2÷0.3 mm or more, depending on the design requirements. Normally, it consists of the pure resin with an added UV inhibitor, in order to protect the pipe from the sun exposure.

In case of the severe exposure conditions, i.e. the aggressive soils or a very corrosive environment, the gel-coat can be reinforced with the "E" glass mat; or the chopped roving and the "C" glass surfacing veil; or the flakes of different thicknesses.

The outer liner can also have a white or coloured pigment on request.

4. RAW MATERIALS REQUIREMENTS

4.1. Resin

The resin system in a filament-wound composite serves the same purpose as it does in the composite structures, fabricated by other means. These functions are:

- keeping the filaments in the proper position;
- helping distribute the load;
- protecting the filaments from abrasion (during the winding and in the composite);
- controlling the electrical and chemical properties;
- providing the interlaminar shear.

Resin properties that should be considered in a cured composite are:

- the strength of adhesion to the fiber. It is important for the most systems and is a function of a fiber's surface finish. It is important for the effectiveness of the bond between the resin and the surface finish. The adhesive strength should be known, since it controls the shear and compressive strengths and influences the flexural strength;
- the heat resistance is critical only for the special applications of the FRP pipe. The choice of a high-heat-distortion resin system should be made only after a thorough study of the operating environment of the filament-wound component;

- the fatigue strength, the chemical resistance, and the moisture resistance of the composite are the key selection criteria. But these characteristics should be evaluated only in the relation to the mechanical properties that are required by the operational environment. The fatigue strength of a composite will generally be dominated by the fiber, its surface finish and its ply orientations;
- the high strain-to-failure capability of the resin system is important in order to be able to transfer loads from one fiber to the other. The fibers have a high strength and a high modulus and generally, the first failure in a composite laminate occurs in the resin transversely to the fiber orientation. Higher strain to failure of the resin can reduce the stress at which this failure occurs.

A high strain to failure is also necessary in order to overcome the differences in the CTE (Coefficient of Thermal Expansion) between the matrix and the reinforcement. Brittle fibers lead to a highly micro-cracked structure. These micro-cracks weaken the shear properties of the laminate and render the CTE calculations (which are based on the rule of mixtures) useless.

Other requirements for the resin used for the Filament Winding manufacture processes are:

- low-temperature cure;
- long pot life;
- high heat distortion temperature;
- high elongation or strain-to-failure;
- low toxicity.

These five specific key factors may result exclusively in respect to each other (i.e. a low-temperature cure does not result in the high-heat-distortion properties, and a high heat distortion general1y rules out the high strain capability).

Filament winding is one of the few composite manufacturing techniques that allow the composite fabricator (winder) to formulate or modify the resin system. Together with the advantages of the increased local control of the resin system, there are some added responsibilities, such as an increased concern for the safety and the environmental controls; a need for training and the certifications for the wet chemical procedures. Most fabricators do not have the required background to select and/or modify the resin systems and thus, must follow the indications of the suppliers. There are some optimum handling criteria for a wet resin system that are peculiar to the wet filament winding. These are:

- the viscosity should be 500 cP or lower;
- the toxicity should be low;
- the pot life should be as long as possible.

For the wet filament winding, it is generally desirable to use the resin with the lowest possible viscosity. This will prevent the resin from carrying air bubbles that cause voids and delaminations. Low viscosity promotes fiber wetting, band spreading, and low friction over guides, which can result in a smoother outer surface and a denser structure after curing.

When the resin viscosity is too high, the pot life can be traded for viscosity by heating the resin system to the convenient elevated temperature. Thus, a system that has several hours' pot life at a room temperature can, sometimes, be slightly heated to reduce the viscosity to approximately half of its room-temperature value. That will, however, substantially reduce the pot life. It is practical to sacrifice the pot life for the resin viscosity because at a reasonable fiber application rates, the resin in the heated bath will be used within its pot life.

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

- Orthophthalic Polyester;
- Isophthalic Polyester;
- Vinylester (epoxy bisphenol-A, vinyl-urethanic, epoxy novolac);
- Bisphenolic Polyester;
- Special resins (for the high temperatures, fire retardant, abrasive resistant, etc.).

The mentioned resins, display several interesting characteristics, such as:

- curing at a room temperature;
- low toxicity during the handling and curing;
- high chemical resistance;
- good adhesion to the glass fibers.

Orthophthalic resins are the general-purpose resins, for water conveying and sewerage application at an ambient temperature. They are used for the manufacturing of the laminates, which are not supposed to undergo strong chemical attacks or weathering. The orthophthalic resins should not be used for making the internal liner of a fiberglass pipe.

Isophthalic Polyester resin is characterized by a good corrosion resistance to water and fluids with the low acid content, up to a maximum operating temperature of about 80°C.

Bisphenolic Polyester resin shows a high chemical inertness to both, the strong acids and the bases, also at an elevated temperature.

Vinylester resin combines very good chemical inertness to the strong acids and bases with the high mechanical properties of the laminates. It is recommended to use both, when the chemical resistance and toughness are needed.

The specially formulated vinylester resins are recommended to be used for the equipment, where higher temperature resistance is needed or to achieve specific properties like flame retardancy, conductivity or enhanced abrasion resistance.

Some typical properties of the liquid resins are:

Property	Orthophthalic	Isophthalic	Bisphenolic	Vinylester
Styrene level in %	40	48	48÷50	45÷48
Brookfield viscosity in mPa s at 25 °C	400	400	450	500
Specific gravity, uncured at 25 °C [g/cm3]	1.1	1.02	1.03	1.04
Storage stability in months	4	6	6	6

The cured resins have the following properties at a room temperature:

Property	ASTM Test	Isophthalic	Bisphenol	Vinylester
Specific gravity	D792	1.2	1.12	1.12
Tensile strength in MPa	D638	>90	>60	>80
Tensile E-modulus in MPa	D638	>3,900	3,100	3,300
Elongation at break in %	D638	>2	>3	>3
Flexural strength in MPa	D790	>130	>120	>120
Flexural E-modulus in GPa	D790	>3,000	3,100	>3,000
Heat distortion temperature in °C		>95	>90	>98
Barcol hardness	D2583	40	35÷40	35÷40
Water absorption in %	D570	<0.2	<0.1	<0.1

The resin properties should be checked for each single batch, according to the Quality Control and the Inspection Test Plan.

For more details on resins, see the relevant section of the Raw Materials Handbook.

4.2. Fiberglass

When the glass is drawn into the fine fibers, usually 8÷12 µm in diameter, the tensile strength increases substantially, compared to that of the massive glass. Laboratory-drawn fibers reach the strengths of more than 6.9×10^6 kPa. The commercial glass reaches the strengths of $2.75 \div 4.83 \times 10^6$ kPa. On the strength-to-weight basis it is one of the strongest commonly used structural materials.

4.2.1. Types

Two most commonly used fiberglass types are the "E" and the "C" glass.

The "E" glass (or the Electrical Grade) is best for the general-purpose structural uses, to provide a good heat resistance and an extremely high electrical property.

The "C" glass (or the Chemical Grade) is best for the resistance to the chemical corrosion.

The "ECR" glass is similar to the E-glass but it does not contain boron and fluorine. Due to the removal of these components, the chemical resistance (including the water-resistance, acid-resistance and the alkali-resistance) is greatly improved. When compared to the E-glass fibers, the ECR-glass shows a higher temperature resistance, better dielectric strength, lower electrical leakage, and a higher surface resistance.

The "S" glass (or the High-Silica) is a special glass with the highest heat resistance, characterized by the enhanced structural properties.

The "E" glass and the "C" glass are the only ones commonly used in the fabrication of the pipes, the latter only for the making of the internal liner.

4.2.2. Manufacture

Continuous glass fibers are produced by drawing the molten glass in a clusters or strands of 50 to 400 (usually 200) filaments simultaneously, through the platinum bushings at the rates of 30÷60m per second. Staple fibers which are 200÷380 mm long, are formed by pulling the fibers from a furnace by jets of air. The fibers are then gathered into strands.

4.2.3. Sizing

Sizing, or the surface treatments, are applied to the glass fibers when they are drawn and before they are gathered into strands.

The sizing can be of two types: "the textile sizing" and "the reinforcement sizing". Both aim to protect the glass from the damage during the processing. The textile sizings are the oil-starch emulsions and essentially act as lubricants, which prevent the glass from being damaged when it is being twisted into the yarns and weaved into the fabrics. They are removed later by heat cleaning or burning, before the treatment with "finishes".

Reinforcement sizings are complexes of the film formers combined with the wetting agents and the surface-active ingredients. They are compatible with the further treatments or "finishes", and may serve to improve the bonding of the fiber with the resin matrix that has been used in the reinforced plastic.

4.2.4. Finishes

Finishes are the chemical complexes applied to the fabrics after the weaving and heat cleaning. They provide a good bond between the glass and the resin matrix and are especially useful with the commonly-used unsaturated polyesters, which otherwise may not readily wet and bond the glass.

The finishes commonly used for polyesters and epoxies are:

- Finish 112 – it is the heat cleaning, which is the first step and makes the fabric ready for the further treatment;
- Finish 114 - it is a chrome complex, applied after the Finish 112, and prepares the glass for the polyesters. Where a high wet strength is needed, a variant of the Finish 114 (methacrylate chromic chloride) is employed;
- Finish 136 and Finish 301 – are the silane treatments, applied after the Finish 112, leaving a vinyl-silane finish on the glass that provides the outstanding dry and wet strengths with polyester resins;
- Finish A-I72 – it is a vinyl-silane treatment, which provides good wet-out properties with the polyesters, epoxies, and phenolics;
- Finish A-ll00 – it is an amine type vinyl-silane, which is especially good for the temperature-resistant epoxies and phenolics, but not recommended for the polyesters.

4.2.5. Binders

In glass mats and when the spray-up is preformed, the fibers must be kept in a fixed position during the fabrication. This is achieved by the binders, which are applied to the virgin blown fibers or to the previously "sized" strands. Binders are selected to be compatible with the resin matrices, such as the polyesters and the epoxies used for building up the final product.

4.3. Types of the Glass Reinforcements

Glass fibers are employed in the following forms:

- continuous strands (roving, yarns);
- mats;
- chopped strands;
- milled fibers;
- fabrics (including tapes and woven roving).

Continuous strands: Many (commonly 50 to 400) continuous filaments are formed into the **roving**, i.e. strands of the parallel filaments or the yarn, comprised of fibers formed into the strands by twisting, plying, or both.

Continuous roving is the basis for the reinforcement of the continuous and discontinuous filament wound TOPFIBRA fiberglass pipe. The type of the glass that is used for the filament-wound pipe is the "E" Type continuous roving, with the weight ranging from 300 to 4800 tex (grams per km).

Mats: Mats don't contain the woven strands. Instead, the strands are applied in a random pattern to provide an equal distribution of fibers in all directions in the plane of the mat. Strands are fixed by the binders or by "needling". Mats cost less than the woven fabrics. Two general categories of this material are **the reinforcing mats** and **the surfacing mats**.

Reinforcing mats: The chopped-strand mat is made from the strands that are chopped to the various lengths and dispersed with a random pattern, which is used mostly for the contact moulding. The continuous-strand mat is made from the continuous strands, which are deposited in a swirl pattern to provide a random distribution. This is recommended for the matched-die moulding with deep draws. The combined mat is made from the chopped and continuous strands.

Surfacing mats: These fine lightweight mats are employed as resin-rich surface layers to provide a good appearance and the resistance to weathering. They do not provide reinforcement characteristics. These mats help prevent the underlying glass reinforcing fibers from protruding through the surface. Such protruding fibers can act as the wicks to draw in water or other liquids and cause serious deteriorations. Two common types are:

- **the standard surfacing veil** is made of the type "C" glass mono-filaments, which are transformed into a thin, highly-porous mat that helps provide the smooth surfaces and compensates for the shrinkage that might otherwise occur in a resin-rich surface;

In the fiberglass pipes, the "C" glass surfacing veil is widely used for the reinforcing of the innermost layer that is directly in contact with the conveyed fluid.

- **the overlay mat** is similar to the surfacing veil and is commonly used in the matched-die moulding.

Chopped strands: Continuous strands, such as roving, are frequently chopped into pieces of shorter length, usually 6 to 76 mm, and used as reinforcement (as in the chopped-strand mat described earlier). In the spray-up and preform processes, and in the *TOPFIBRA continuous filament winding machine*, chopping is happening simultaneously with the deposition. In other cases, the chopped strands are incorporated into the matrix (as in bulk moulding).

Milled Fibers: In a hammer mill, the fibers are broken into the short length pieces of 1/32 in. to 1/8 in. (0.8÷3.2mm), and used, for example, in the reinforced thermosetting moulding compounds and in the reinforced foams.

Reinforcement fabrics: Many different patterns can be produced on the weaving machine by various combinations of longitudinal (or warp yarns) and cross yarns (also called fill, pick, or weft). Moreover, the yarns can be heavy or light; scarcely spaced or tightly packed; and equal or unequal in number in two directions. The number of yarns, or picks, per unit length provides some indications of the tightness of the weave.

Fabrics can be characterized according to the kind of the yarn employed and the pattern of the weave. According to how the yarns are processed, the principal classes are:

- the continuous filament yarns, consisting of the continuous filaments. The fabrics of these yarns are stronger and thinner than the staple-yarn fabrics, but they do not drape as well;
- the staple yarns, consisting of the twisted short-length (staple) fibers. Fabrics are thicker and not as strong, but compared to the continuous-filament yarn fabrics the drape is easier;
- the roving contains characteristically heavy strands. Fabrics woven from the roving are correspondingly heavy. Fewer plies of this material are needed to achieve a certain thickness than in the case of the continuous-filament or the staple yarn fabrics.

The reinforcement fabrics are commonly used in the form of the **woven roving,** in the fabrication of the fiberglass pipe fittings and the laminated pipe joints in conjunction with the reinforcing mats.

4.3.1. Mechanical Properties

The main mechanical properties (the strand properties) of the roving are shown in the following table:

Property	the "E" glass
Specific gravity	2.6
Tensile strength in MPa	3500
Tensile E-modulus in GPa	72.5
Ultimate Strain in %	4.8

It is impossible to define the similar properties for the glass fibers of other forms (mats, woven roving, etc.).

Fiberglass keeps being used for the filament winding, despite the increase in the number of the new reinforcement fibers. This is due to the low cost of the fiberglass; its dimensional stability; good impact properties; moderate strength and modulus; and the ease of handling.

5. PHYSICAL PROPERTIES AND THE DESIGN VALUES OF THE TOPFIBRA GLASS FIBER REINFORCED RESIN PIPE AND FITTINGS

The following is the summary of the physical properties and the design values applicable to the piping and the fittings which are used in determining the performance of the RTRP in the various system applications. Additional data is available upon request from the TOPFIBRA Engineering Department.

5.1. Physical Properties

5.1.1. Hand Lay-Up Laminates

Specific gravity in kg/dm^3	1.3 ÷ 1.7
Impact strength in $kJoule/m^2$	8
Machinability	Good

Barcol hardness	25 ÷ 45
Rockwell "M" scale D785-51	90 ÷ 105

5.1.2. Structural Layer

Specific gravity in kg/dm3	1.8 ÷ 2.0
Impact strength in kJoule/m2	12
Machinability	Good
Barcol hardness	25÷45

5.1.3. Thermal Properties

Thermal conductibility in kcal m/m2 h °C	0.2
Linear coefficient of the thermal expansion in m/m °C It is highly variable with the reinforcement content and the orientation	21x10-6
Heat distortion temperature (at 264 psi) in °C It depends on the resin	100÷110

5.2. Electrical Properties

Dielectric strength in kV/mm	450÷500
Electrical resistivity in ohm/cm	10^{14}
Dielectric constant in ohm/cm	3÷4

5.3. Viscoelastic Behaviour

The relationship between the stress and the strain, or the structural response of the plastics, varies from viscous to elastic. Most structural plastics and reinforced plastics display a structural response which is intermediate between the viscous and the elastic states, which means they are the viscoelastic materials. The type of the plastic compound, stress, strain, time, temperature, and the environment all play a significant role in determining whether the response is predominantly viscous, elastic or viscoelastic.

Viscoelasticity is a complex subject. Rigorous approaches are not usually needed for the practical structural design; hence, simple models and analogies are used later to demonstrate the viscoelastic behaviour.

5.3.1. Terminology

To characterize the viscoelastic behaviour of plastics, including the idealized components of the viscoelastic models, a special terminology is needed, which is explained here:

Elastic response: An elastic body is represented by the Hookean solid, as modelled by the linear spring. The stress is proportional to the strain and independent of time; the response to stress is instantaneous. There is no permanent or irrecoverable deformation, all energy used to deform the spring is accumulated and is fully recoverable.

Viscous response: A viscous body is represented by the Newtonian fluid as modelled by the dashpot. The stress is proportional to the strain rate, making the behaviour time-dependent. The recovery is nil when the stress is removed. The energy to deform the dashpot is completely dissipated during the deformation process.

Creep: Creep is the time-dependent increase in strain of a viscous or viscoelastic material under the sustained stress. The time-dependent deformation is partially recoverable with time after the release of the stress.

The creep experiments are usually performed under the constant load conditions. When stresses are high, the sample may "neck" and the cross-section supporting the load may be significantly reduced at some point during the test. Unless otherwise indicated, the creep stress (or "an engineering" stress), based on the original cross-sectional area, will be used, rather than the "true" creep stress which is based on the reduced cross-sectional area, that occurs on necking. This reflects the typical practice, which is to report the engineering stress rather than the true creep stress in creep experiments. This practice is not universal, particularly in scientific behavioural investigations.

Relaxation is the time-dependent decay in stress of a viscoelastic material under the sustained strain. Some of the deformation is recoverable with time after the release of the sustained strain. Unless the imposed initial strain is above the yield point, the cross-section remains fairly close to the original one, throughout the test. This differs from the creep behaviour as noted earlier.

Recovery is the extent to which an element returns to its original configuration after the release of the stress or strain.

The linear viscoelastic response refers to the viscoelastic response in which the stress and strain are related by a single modulus, which depends only on the duration of the applied stress and strain at a given temperature. This differs from the non-linear viscoelastic response in which the modulus depends on the value and duration of the stress or strain.

The viscoelastic stiffness response has been traditionally expressed in terms related to the manner of loading. That is, to the time dependent apparent modulus or to the ratio of the (decaying) stress to the (constant) strain, imposed during the relaxation experiments. This is defined as the "relaxation modulus" $E(t)$. If the test is performed in creep, the "creep compliance" or the ratio of (increasing) strain to the applied stress $D(t)$, is used to define the response. This observation is extremely useful for the study of the non-linear viscoelastic behaviour, which occurs at the stresses and the temperatures above the range of the interest in the structural engineering.

It can be shown that for the small strains at the temperatures within the useful range, $E(t) \approx 1/D(t)$. Thus, provided that one knows the range over which this assumption can be made, a single modulus can be used to describe the time-dependent stiffness response under both the creep and the relaxation loading conditions.

A new term, the "Viscoelastic Modulus" E_v, is coined here, which defines the ratio between the stress and the strain after any duration of the stress or strain. This ratio is frequently referred to as the "Apparent Modulus". The "Viscoelastic Modulus" terminology, however, appears to be a more descriptive and appropriate companion to the term "elastic modulus", which is well known to the Structural Designer.

5.3.2. The Viscoelastic Behaviour of the Fiberglass Pipe and the Design Factors

The mechanical properties (stiffness and strength) of the fiberglass are time dependant, which is the characteristic that most of the plastic materials have.

The TOPFIBRA fiberglass pipe (as all the GRP-BRP pipes) shows both the creep and the relaxation. Several performed tests ascertain and measure these phenomena according to the relevant international standards.

Creep was studied through the long term pressure tests according to ASTM D2992. Several specimens were loaded with the constant internal pressure (i.e. the **constant stress**) at different levels. For the creep phenomenon, the **strain** in the pipe wall **increases** continuously over the time, leading to the pipe failure (leaking) after several hours. The failure points were recorded and analysed according to the standard.

The result of the test is a decay of approximately 35% in the failure stress after 10,000 hours, which is extrapolated to 45% after 50 years.

The design stress for the internal pressure is generally taken at the ½ of the failure stress at 50 years and thus ¼ of the short term failure stress. This is also reflected by most of the standards that require a short time strength of the pipe wall in the hoop direction, which is exactly 4 times the hoop stress for the pressure class. For an example of this, see the Table 8 of the ASTM D3517 Standard Specification or the equivalent Table 10 of the AWWA C950 Standard.

The long-term failure stress due to the internal pressure is called the ***"Hydrostatic Design Basis"*** **(*HDB*)**, and it is often expressed as a **strain** rather than a stress. The long or short time failure stress varies considerably in the fiberglass pipes, due to the variability of the wall structures that can be realized, with different reinforcement content and arrangement. On the contrary, the failure strain is more constant. The excess strain causes most of the failures of the pipe, resulting in the micro-cracks in the resin; debonding of the reinforcement; and weeping of the pipe, without catastrophic ruptures of the reinforcement.

The design strain, applying the Safety Factor of 1.8÷2 as required by the Specifications, generally ranges between 0.18% and 0.35%. The starting value conservatively suggested by TOPFIBRA is 0.25÷0.30%, even if the results of the tests are often quite higher.

Another creep test is conducted according to the ASTM D5365 "Standard Test Method for Long-Term Ring-Bending Strain of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe". Several pipe ring specimens are subject to the constant loads of different values, up to a catastrophic failure or to a significant reduction in the mechanical properties. The parameter resulting from this test is called the ***"Strain basis"*** **(**S_b**)** and is the long term failure strain of the pipe in a deflected condition. This value is used, for example, to calculate the allowable vertical deflection for a buried pipe (AWWA M45, Section 5.7.2).

Relaxation is measured with another long-term test, similar to ASTM D5365, but with the pipe ring specimens subject to the **constant deformations** of different extent during the test. The guiding standard is ASTM D3681 "Standard Test Method for Chemical Resistance of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe in a Deflected Condition", also called the **"strain corrosion test"**, i.e. *failure of the pipe wall caused by the exposure of the inside surface, while in strained condition, to a corrosive environment for a period of time*. Generally, the used testing solution contains 5% of the sulphuric acid.

The strain corrosion test is especially required for the sewer pipes, mainly in the warm climatic conditions. The design parameter derived from the test is the ***"Strain Basis"***, which is used alternatively to the one derived from the creep test to ASTM D5365.

The elastic modulus would also require a similar analysis.

5.4. Long Term Design Strength

The values given in the following tables provide the general information, because of an almost infinite sort of structures that can be produced. This infinity is attributed to the fiberglass being a composite material and also to the flexibility of the TOPFIBRA machines.

PROPERTY	**Unit**	**FW55**	**CWH**	**CWL**	**HLU**
Hoop Modulus	N/mm2	24,500	28,000	10,000	6,600
Hoop Allowable Stress[1]	N/mm2	60	70	25	20
Axial Modulus	N/mm2	12,000	8,000	8,000	6,600
Axial Allowable Stress	N/mm2	30	10	10	20
Compressive Strength	N/mm2	60	40	40	40
Hydrostatic Design Basis (strain basis)	%	0.7 for all			
Strain basis (Strain corrosion tests)	%	0.9 for all			

FW55	Reciprocal filament wound - 55° winding angle
CWH	Continuous filament wound high pressure
CWL	Continuous filament wound low pressure / gravity
HLU	Open mould hand lay up

6. PIPE DESIGN PARAMETERS AND CLASSIFICATION

The fiberglass pipe is defined through a number of higher parameters, compared to the traditional materials like steel or cast-iron. On the other hand, nothing is required to define and specify the corrosion protection systems.

The main parameters required to define, classify and manufacture a fiberglass pipe are:

1 4:1 safety factor against elongation at first crack or design strain 0.25%.

Construction type	Continuous Filament Winding; Discontinuous Filament Winding.
Resin system	Many types of the resins can be used (see subchapter 4.1 on resin). Different resins can be used for the internal liner; the structural layer; the outer layer; the fittings etc. Defining the resin system is generally the responsibility of the manufacturer.
Liner type and thickness	The standard liner is reinforced and the reinforcement includes at least an innermost layer, which is reinforced with the "C" glass veil.
Size	The inside diameter normally corresponds to the nominal size. When it comes to the outside diameter (OD) series pipe (pipe produced by continuous filament winding and with a sleeve joint) the outer diameter is the same as for the standard cast-iron pipe, with the the inside diameter being rather close to the nominal size.
Joint type	Joints are mainly divided in the restrained (the ones that can transfer the axial load from one section of the pipe to the other) and the unrestrained joints. The type of the joint has a big influence on the design of the pipe. Since the fiberglass is a composite material, the reinforcing material can be placed where it is required. In a pipe with the unrestrained joints, a lower axial load is expected and less reinforcement can be placed in the axial direction, realizing considerable savings.
Pressure class	Pressure class is generally defined considering the long term behaviour of the fiberglass (see later chapters how the pressure class is specified). The standard pressure classes (*Pc*) are defined differently by the International Standards (most common are the 2.5 bar or gravity and 6, 12, 18, 24 bar). Due to the flexibility of the manufacturing technologies, any pressure class can be specified and manufactured (for more details see section 6.1 – Pressure Class)
Hoop tensile strength	Hoop tensile strength is strictly dependent from the pressure class. It is generally defined as strength per unit of width in a pipe ring and tabled by the International Standards as a short term property.

Axial tensile strength	Depending on the type of the joint (restrained or unrestrained), the requirements for the axial strength of the pipe will vary considerably. According to the International Standards table, there is a minimum short term requirement for the unrestrained joints, as well as for the strength per unit of circumference. A pipe with the restrained joint should have at least the axial strength to resist the stress induced by the internal pressure with the due safety factor. The pipes for the above ground installation should have an additional axial strength to resist the thermal stresses and the beam load.
Beam strength	The beam strength is linked to the axial tensile strength and the beam test can be used to calculate the initial tensile strength of a pipe (the BS5480 App. B).
Stiffness class	once the strength (and the thickness) of the pipe wall, required to fulfil the pressure requirements are defined (if the project requires a stiffness higher than the stiffness obtained for the chosen reinforcement), it is possible to increase the stiffness in different ways. The most common way is to add silica sand in the laminate structure of layers of fiberglass or to add solid or hollow ribs. For more details see the section 0-Stiffnes, where the pipe transversal stiffness is better defined.
Section length	Section length has a minimal influence on the design of the pipe wall structure. Standard section lengths are defined by the International Standards, by the Manufacturer or by the Client. The continuously filament wound pipe can be easily cut to pieces of any length. The discontinuous filament wound pipe generally has a fixed length which corresponds to the length of the mandrel (or it can have a shorter length, but it results in a certain loss in the productivity).

6.1. Pressure Class

Due to the viscoelastic behaviour of the fiberglass pipe (see Section 5.3 – Viscoelastic Behaviour) almost all of the International Standards define the Pressure Class (*Pc*) as the maximum internal pressure that can be sustained continuously for a given amount of time and a given Safety Factor (*SF*).

Generally *Pc* is referred to as a period of 50 years with *SF* of 1.8÷2.

A reduction of the Pressure Class may be required for the elevated temperatures or for the corrosive fluids.

The Pressure Class of a pipe must be defined with the respect to the type of the joint (restrained or unrestrained). The pipe with the restrained joint is subjected to the full axial load due to the internal pressure. Only in the long buried pipelines, the axial stress in the pipe load is transferred to the soil by the friction.

The stresses (the hoop and the axial stress) caused by the internal pressure, are calculated with the classical Mariotte's equation, which is valid for the ratio thickness-to-diameter lower than 1/20, as in case of all the fiberglass pipes:

$$\sigma_h = \frac{P \cdot d}{2t} = \frac{P \cdot r}{t}$$

Stress σ generates a deformation ε, equalling:

$$\varepsilon_h = \frac{\sigma_h}{E_h}$$

Safety coefficient at the design conditions with the regard to the short term strength is:

$$\frac{\sigma_r}{\sigma_h} \geq 4$$

and, with regard to the long term strength it is:

$$\frac{HDB_{stress\ basis}}{\sigma_h} \geq 1.8$$

or:

$$\frac{HDB_{strain\ basis}}{\varepsilon_h} \geq 1.8$$

Where:

σ_h = the hoop stress;

σ_r = the short time rupture/weeping stress;

P = design pressure;

d = mean diameter;

t = thickness;

r = mean radius;

ε_h = deformation (strain) in mm/mm;

E_h = hoop modulus of elasticity.

If the pipeline is subjected to the occasional ***pressure surge***, the earlier design factor can be reduced by a factor 1/1.4, according to the AWWA recommendation (see Section 7.5 – Water Hammer).

Therefore, the Pressure Class can be defined as (stress basis):

$$P_c = \left(\frac{HDB_\sigma}{SF}\right)\left(\frac{2t}{d}\right)$$

or (strain basis):

$$P_c = \left(\frac{HDB_\varepsilon E_h}{SF}\right)\left(\frac{2t}{d}\right)$$

SF being the required safety factor.

It is generally recommended to use the strain basis approach. This approach is also used if the tests always give a long term stress or pressure, since the elastic modulus can vary substantially. Same is true for the fiberglass pipes made with the same technology and materials but with a different percentage and distribution of the reinforcements.

The calculation and verification of the E-modulus of a new pipe structure is quite easy, since the already available long term strain can be used, provided that the resin and the liner structures are the same or proven to be better.

If, for example, the long term test result (100 MPa; stress) for a pipe with a short term E-modulus of 20,000 MPa is available, the long term strain is defined as:

$$HDB_{strain} = \frac{HDB_{stress}}{E_h} = \frac{100}{20000} = 0.005$$

For a pipe of the same category (the same resin, the same liner, the same production technology) but with a slightly different structure (different winding angle, different percentage of the reinforcement) and thus a different E-modulus (18,000 MPa, for example), the long term stress is calculated as:

$$HDB_{stress} = HDB_{strain} E_H = 0.005 \cdot 18000 = 90MPa$$

For the major changes in the pipe characteristics and changes in the more complex structure, such as skin + core + skin wall, with the variable thickness ratio, a new long term test or a reconfirmation medium term test (1000 hours – 6 weeks) is required. See the chapter: "TESTING PROGRAM FOR THE RECONFIRMATION OF THE HYDOSTATIC DESIGN BASIS ACCORDING TO THE ASTM D2992 STANDARD PRACTICE" for more details on the subject.

Special considerations should be made, when the is pipe subjected to the axial load, either because of the internal pressure or in addition to the other external loads. The pipe wall structure can be tailored in order to exactly match the design requirements, however, an accurate stress analysis should be carried out for the complex, above ground piping systems in order to find the more stressed sections.

The test for determining the long term or the short term strength is generally made with the free-end closures, which are closures that are mechanically fixed at the ends of the specimens or chemically welded end-caps, so that the axial load on the closures is transferred to the pipe wall. This test is meant for the pipes that are intended to sustain the full axial loads and for the pipes that have the restrained end closures. For the pipes that are not intended to sustain the axial load, or for the pipes that are only able to sustain limited axial loads, the externally tied end closures have to be used.

6.2. Stiffness

The fiberglass pipe "stiffness", if not specified, always stands for the transversal stiffness of the pipe, i.e. the capacity to resist the loads that tend to deform, compress or implode the pipe in the section transversal to the pipe axis.

According to the AWWA or ASTM, the ***pipe stiffness*** or the ***stiffness class*** is defined as:

$$PS = \frac{F}{\Delta y}$$

The F stands for the force applied to a pipe ring of the unit length, to produce the deflection Δy, equal to the 5% of the diameter (parallel plate test according to ASTM D2412).

Generally, the pipe stiffness is shown in *psi*.

According to the BS, ISO and other European standards, the specific stiffness (STIS or S) is defined as:

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

Where:

E = the ring flexural modulus of elasticity;

I = the second moment of inertia of the pipe wall;

D = mean diameter.

For a plain wall, the second moment of inertia is $I = \frac{t^3}{12}$.

Generally, the specific stiffness is given in N/m^2 (Pa).

6.2.1. Relation Between the Pipe Stiffness and the Specific Stiffness

Both parameters measure "the resistance of the pipe to the circumferential deflection in response to the external loading applied along one diametric plane" (BS 5480).

Since the pipe stiffness (the ASTM or AWWA) is related to the quantity EI, also called the stiffness factor (SF) by the equation:

$$EI = 0.149 \cdot r^3 \cdot PS$$

the relation between the PS and S can be calculated as:

$$EI = 0.149 \cdot \left(\frac{8}{8} r^3 \right) \cdot PS = 0.149 \cdot \frac{1}{8} D^3 \cdot PS$$

$$\frac{EI}{D^3} = S = 0.018625 \cdot PS$$

Considering different units that are generally used, the Pa for the European standard and the psi for the US standard, the formula becomes:

$$\frac{EI}{D^3} = S \quad [Pa] = 0.018625 \cdot PS \cdot \kappa \, [psi]$$

where κ is the conversion factor from psi to Pa (1 psi = 6895 Pa), and $0.018625 \cdot 6895 = 128$.

The relation between the standard USA and the European stiffness classes is:

USA (AWWA and ASTM)	**European**
$PS = \frac{EI}{0.149 \cdot r^3}$ (psi)	$S = \frac{EI}{D^3} = 128 \cdot PS$ (Pa)
9	1250
18	2500
36	5000
72	10000

Note that the figures for the European stiffness are rounded.

7. HYDRAULIC CHARACTERISTICS

The interior surfaces of all the pipes and components have a smooth glass-like finish. Due to their zero water absorption and excellent resistance to the corrosion, as well as due to the fact that they are not subjected to the attacks of the micro-organisms, the pipes and the components do not undergo the increase in roughness or the reduction of their cross sectional area, that are otherwise caused by sediments over a long period of time.

Therefore, the designer of a piping system has one or more of the following options in comparison with the other traditional materials:

- smaller pipe size for the equal flow volume;
- reduced horsepower requirement for the pumped system;
- larger flow volume for the equal size and the hydraulic head.

7.1. Maximum Velocity

The suggested maximum fluid velocity for the TOPFIBRA fiberglass pipe for the clean fluids is:

$$v = \frac{40}{\sqrt[3]{\rho}} \text{, m/s}$$

Where ρ stands for the fluid density [kg/m^3].

This results in the maximum velocity of a 4 m/s for clear water at an ambient temperature.

The maximum velocity is generally reduced by ½ for the corrosive or erosive fluids, but because each fluid has to be analysed, this reduction is not easy and it is not allowed to be generalised, for a variety of conditions that can occur. For the severe working conditions, special liners with an increased thickness and special additives in the resin can be chosen.

The variety and complexity of the conditions will be the subject of a separate design specification.

Urban sewers and drainage are not considered corrosive or erosive fluids for the TOPFIBRA fiberglass pipe. Here, the maximum velocity of a 4 m/s is allowed.

7.2. Pressure Loss Calculation

The most commonly used equations for calculating the pressure losses in a fiberglass pipe are:

- The Hazen-William equation;
- The Manning's equation;
- The Darcy-Weisbach equation.

7.2.1. The Hazen-William Equation

The Hazen-William equation has a good applicability for the conditions of the full turbulent flow.

The basic equation is:

$$h_m = \left(\frac{1.176 \times v}{C \times R^{0.63}} \right)^{1.852}$$

Where:

h_m = friction loss, meters of liquid column per unit length;

C = the HW friction factor, 145÷150 for the fiberglass pipe;

R = the pipe hydraulic radius ($D/4$) in meters;

D = the inside diameter in m;

v = velocity in m/s.

The same equation can be used to calculate the velocity and the flow rate when the available head is known:

$$v = 0.85 \times C \times R^{0.63} \times h^{0.54}$$

7.2.2. The Manning's equation

The Manning's equation is traditionally used for the gravity flow with a free surface (the pipe is partially full). The Manning roughness coefficient (*n*) for the fiberglass pipe is 0.009.

The basic equation is:

$$v = \frac{1}{n} \times R^{0.667} \times h^{0.5}$$

It is very similar to the Hazen-William equation (0.85x145=123; 1/0.009=111).

In case of a flow with a free surface the hydraulic radius is:

$$R = \frac{A}{W_p}$$

Where:

A = the cross-section area of the liquid profile in m2;

W_p = the wetted perimeter of pipe in m.

7.2.3. The Darcy-Weisbach Equation

The Darcy-Weisbach equation with the Colebrook friction factor is the most universal equation, because it is valid for any diameter, velocity and fluid, both in laminar and turbulent flow.

The equation is:

$$h = \frac{f \cdot v^2}{2 \cdot g \cdot D}$$

Where:

f = the Colebrook friction factor;

g = the gravitational constant.

The friction factor also depends on the Reynolds number R_e and on the roughness of the internal pipe surface, measured as length (ε).

The Reynolds number is:

$$R_e = \frac{v \cdot D}{\mu}$$

μ is the kinematic viscosity [m^2/s], which depends on the fluid and on the temperature.

For $R_e > 4000$ (in most cases) the Colebrook friction factor is:

$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{\varepsilon}{3.71\cdot D} + \frac{2.51}{R_e\sqrt{f}}\right)$$

The equation requires a trial and error iterative solution (or the TOPFIBRA computer program) since it is implicit in the f.

The value of the absolute roughness (ε) of the interior surface of the TOPFIBRA GRP-BRP pipes is estimated at 5μm. For use in the Darcy-Weisbach formula with the Colebrook coefficient, the value of the 25÷100μm can be used, depending on the type of the joints and the distance between them.

The TOPFIBRA computer programs automatically record the section length and the losses due to the joints, depending on the type of joint used.

7.3. Head Loss in the Fittings

The Head loss in the fitting can be calculated as the equivalent length of the pipe that is added to the straight run of the pipe or by using the loss coefficient (*K* factors), like for the other piping materials:

$$H_f = K\frac{v^2}{2g}$$

The typical K factors for the fiberglass fittings are given in the following table:

Type of Fitting	K Factor
45° elbow, std. (R=1.5D)	0.3
45° elbow, 1 mitre	0.5
90° elbow, std. (R=1.5D)	0.5
90° elbow, 3 mitres	0.6
90° elbow, 2 mitres	0.8
90° elbow, 1 mitre	0.9
180° return bend, std.	1.8
Tee, straight flow	0.4

Tee, flow to branch	1.4
Tee. flow from branch	1.7
Reducer, single size reduction	0.7
Reducer, double size reduction	3.3

Standard elbows are moulded on a mandrel with the continuous bending radius equal to the 1.5x diameter.

The coefficient used for the steel can be also used for the fittings not mentioned in the table.

7.4. The Energy Consumption Calculation

If required, the energy consumption can be calculated with the following equations:

- the equation to calculate the total head loss (H_T) in the system, according to the earlier equations and including the head loss in the fittings, is:

$$H_T = h_f \times L + \sum_1^n H_F \quad \text{[meters of liquid column]}$$

- the equation to calculate the required pump power is:

$$h_p = H_T \times Q \times \rho \times 9.81 \quad \text{[W]}$$

- the equation to calculate the annual energy consumption is:

$$E_y = \frac{\rho \times W \times H_T}{\eta_p \times \eta_m} \quad \text{[W h / year]}$$

where:

Q	= total flow volume in m3/s;
W	= total flow in 1 year in m3;
ρ	= density of the fluid in kg/m3;
η_p	= pump efficiency;

η_m = motor efficiency.

7.5. Water Hammer

The magnitude of the water hammer is a function of:

- the fluid properties, i.e. the bulk modulus of the compressibility of the fluid;
- change in the flow velocity;
- modulus of the elasticity of the pipe material;
- thickness-to-diameter ratio of the pipe.

A relatively low modulus of elasticity of the fiberglass pipe contributes to a self-dampening effect as the pressure wave travels through the piping system. The value of the pressure wave in a metal piping system is much higher due to a higher modulus of the elasticity of these materials.

Except for the rapid valve closure or opening, the water hammer can be caused by a sudden air release or a pump start up or shut down.

The water hammer is seldom a problem in the buried fiberglass piping systems because of the compliance of the pipe, due to the relatively low modulus and the restraining effect of the surrounding soil. A good design practice usually prevents the water hammer in most systems. The installation of valves, which cannot open or close rapidly, is one simple precaution. In addition, the pumps should never be started at the empty discharge lines, unless the slow-opening, mechanically actuated valves can increase the flow.

Depending on the speed of the fluid and the time of the closure of the downstream end in a pipeline of a significant length, the generated over-pressure may easily lead to the critical values for the pipe.

The pipeline designer must take all the necessary precautions to avoid or to compensate the effect of the water hammer.

However, in a fiberglass pipe this effect is 2÷3 times lower than in the comparable steel or cast iron pipes due to a lower elastic modulus and a high elongation of the GRP-BRP pipe.

Moreover, the standards generally allow an increase in the pipe pressure class when the pressure surge is not a normal working condition, i.e. the pipe system is not subjected to the rapid and frequent cyclic service.

For example, according to the AWWA Standard (Manual M45 – Sections 4.7 and 5.7.1.3) the pressure class (P_c) can be increased by 40%, when checking the sum of the working pressure (P_w) plus the surge pressure (P_s):

$$P_w + P_s \leq 1.4 P_c$$

Obviously, the requirement $P_w \leq P_c$ remains valid.

According to the AWWA, the surge pressure allowance of 0.4 P_c is based on the increased strength of the fiberglass pipe for a rapid strain rate.

The surge pressure is calculated as follows (the Talbot equation).

The pressure wave celerity ***(c)*** is given by the classical equation:

EQUATION **(a)**: $$c = \frac{C}{\sqrt{1 + \frac{e}{E} \times \frac{D}{t}}}$$

Where:

C = the sound speed in water in 1420 m/s;

e = the water bulk modulus of elasticity in 2000 MPa;

E = the pipe wall modulus of elasticity in MPa;

D = the pipe diameter in mm;

t = the pipe wall thickness in mm.

Since the pipe thickness is linked to the pressure class by the equation (the Mariotte equation):

EQUATION **(b)**: $$\frac{1}{Pc} = \frac{D}{2t\sigma_{all}} = \frac{1}{2\varepsilon_{all} E} \times \frac{D}{t}$$

EQUATION **(c)**: $$\frac{D}{t} = \frac{2\varepsilon_{all} E}{Pc}$$

Where:

ε_{all} = the allowable strain in the pipe wall;

σ_{all} = the allowable stress in the pipe wall ($\sigma = \varepsilon \times E$).

Changing the expression **(c)** of $\frac{D}{t}$ in the equation **(a)**, we obtain an expression on the pressure wave speed function of the pressure class:

EQUATION **(d)**: $$c = \frac{C}{\sqrt{1 + \frac{2e\varepsilon_{all}}{Pc}}}$$

The allowable strain being known, which is in the 0.2%÷0.3% range for most of the GRP-BRP pipe construction types, the required pressure class can be calculated with few iterations combining the equation **(d)** and the equation (M45-5.4).

The maximum anticipated over-pressure for a sudden change in the flow velocity (time of flow velocity variation = 0) is:

$$\Delta H = \frac{c \times \Delta V}{g}$$

Where:

ΔH = overpressure in mlc (meters of liquid column);

ΔV = the change in the flow velocity in m/s;

g = the gravitational constant in m/s2.

In many cases, this (simple but conservative) approach to the calculation of the transient pressure can be followed, due to a lower pressure surge in the fiberglass pipe and to the pressure surge allowance according to the recommendation of the AWWA standard. In other words, the pressure surge calculated in this way is the maximum surge that can be anticipated.

A more sophisticated analysis and computer programs are required in complex piping systems.

8. DESIGN PARAMETERS

The design of the RTRP and the RTMP piping systems must be done in such a way, that they resist all the loads, including the transient loads, with an adequate safety factor.

The logic used by TOPFIBRA in calculating the fiberglass pipes is:

- the RTRP is an anisotropic material, in which the reinforcement can be oriented in such a way that it has the maximum strength in the direction of the stress;
- the modulus of elasticity tends to increase with ageing;
- the tensile strength diminishes by an average of 30÷50% after 50 years; however, there is no loss of strength due to the corrosion;
- the creep phenomenon becomes very noticeable under the loads greater than 50% of the ultimate load; therefore, a safety coefficient of ≥ 3 is imposed as a binding condition;
- the elastic deformation tends to diminish over periods of time; therefore, when calculating a structure which has to ensure a watertight seal, it is best to consider the creep as a precaution and not stresses as the binding factor;
- failure does not take place in the form of a collapse, but happens with a slow weakening of the fibres and is generally displayed at the limit of elasticity of the fiber/matrix bond;
- one-piece items can be made, even in very complex shapes, due to the ability to vary the arrangement of the material.

9. BASIS OF THE DESIGN FOR THE UNDERGROUND (U/G) PIPES

Due to their mechanical/elastic characteristics, the fiberglass pipes are considered to be flexible conduits. Thus, when designing them, it is useful to take into account the contribution of the soil to the restraining deformation.

All calculations given hereinafter take into the consideration this fact, which was initially emphasized and quantified by Spangler in the 1930's and verified through many practical experiments. Spangler's deflection theory is the basis for the calculation method adopted by the ASTM and the AWWA recommendations.

In this part of the handbook, you will find only a few concepts and warnings. A more detailed analysis and guidance can be found in the chapter: "THE BURIED PIPE DESIGN SPECIFICATION".

Three important parameters, besides the resistance to the internal pressure, are calculated in order to verify the safety conditions of a buried GRP-BRP pipe:

- the vertical deflection;
- strain in the pipe wall;
- elastic stability (buckling).

It is obvious that the designer of the pipes should know the data that concerns the soil and the burial conditions, so they are able to draw up the best design project.

Therefore, the primary factor affecting the design and performance of the installed piping system is the stiffness of the soil surrounding the pipe, both the native soil and the bedding, side-filling and back-filling soil.

The stiffness of the native soil can be determined by means of a geological survey and calculating the modulus of the soil reaction (*E'*) by means of the test borings taken from the proposed installation site.

The method for determining the in-situ soil modulus is the CRD-C 655-95, "Standard Test Method for Determining the Modulus of Soil Reaction", which replaces the MIL-STD-621 (method 104).

The stiffness of the backfilling can be determined and specified by defining the soil type, the compaction degree and the trench width.

9.1. Deflection Analysis

Deflection is the elastic (or the elastic-plastic) deformation (shortening of the vertical diameter) of the soil-pipe system under the vertical load of the soil cover and the superimposed loads.

Deflection is mainly dependent on the soil stiffness. The AWWA deflection equation that originates from the Spangler's equation is:

$$\frac{\delta y}{D} = \frac{(D_L W_c + W_L) K_x}{8S + 0.061 M_s}$$

Where:

δy = the shortening of the vertical diameter in m;

D = the pipe diameter in m;

D_L = the deflection lag factor (1.25 to 1.5), [-];

K_x = bedding constant (0.08 ÷ 0.1), [-];

W_c = the vertical permanent load (the soil load) per surface unit in kN/m2;

W_L = the live load per unit surface in kN/m2;

S = pipe stiffness in kN/m2;

M_s = the composite soil constrained modulus in kN/m2;

The term at the denominator of the equation is the stiffness of the elastic system made by the pipe and the soil. The contribution of the pipe ($8S$) and of the soil ($0.061M_s$) are summed up.

The pipe stiffness and the soil stiffness are generally expressed in different units, in N/m^2 and N/mm^2. If we compare the two quantities in the congruent units, we can see that the soil stiffness is always many times bigger than the pipe stiffness.

For example, the contribution of a very stiff pipe (*S*=10,000 N/m^2) is $8 \times 10{,}000 \times 10^{-3} = 80$ kN/m^2, while the contribution of a very soft soil (having a composite soil modulus of 2.8 N/mm^2) can be $0.061 \times 2.8 \times 10^6 \times 10^{-3} = 170$ kN/m^2, which is more than double the contribution of the pipe stiffness. With a medium stiffness pipe (*S*=2500 N/m^2) and a medium installation (*E'*=6.9 N/mm^2), the ratio is 20/420=1/20. The stiffness of the soil can be 20 times the stiffness of the pipe.

For this reason, it is often useless to recur to a high pipe stiffness in order to allow for a poor installation or to compensate for the risk of a bad installation.

Furthermore, a stiff pipe always has a thicker wall, and therefore a higher strain in the pipe wall at a comparable deflection.

The requirements for a stiff or a very stiff pipe are reasonable only in the case of the internal vacuum and/or high external hydrostatic load. For more details, please see the section 9.4 - The Buckling Analysis.

9.2. Strain in the Pipe Wall Due to the Deflection

Deflection causes strain in the pipe wall, which depends on the extent of the deflection, the thickness of the pipe wall, and the installation conditions (the embedment material and the compaction).

According to AWWA M45, the maximum anticipated strain is:

$$\varepsilon_b = D_f \frac{\Delta y}{D} \frac{t_t}{D}$$

where t_t is the total thickness of the pipe wall and D_f a "shape factor", which depends on the pipe stiffness and the installation condition (Table 5.1 of AWWA M45).

The bending strain multiplied by the safety factor (1.5 according to AWWA M45) must be lower than the long term ring bending failure strain (S_b - from ASTM D5365, or ASTM D3681).

In this case, as well as for the deflection, it is quite useless to increase the pipe stiffness in order to reduce the strain in the pipe wall. Increasing the stiffness gives a minimum deflection reduction and it is counterbalanced by the increase in the thickness.

As an example, one can compare two ND 1000 pipes buried in the sand with a medium compaction degree (E'=6.8 MPa - D_L= 1.5 – K_x=0.1) with a soil cover of 4 meters (soil load W_c=70.632 kN/m^2).

The differences in the calculated deflection and in the pipe wall strain for 1250 Pa and 10,000 Pa stiffness, are as follows:

Pipe Stiffness in Pa	1250	10000	8x
Wall thickness in mm	8.9	17.1	+92%
Deflection in %	2.46	2.12	-14%
Shape factor in $D_{f,}$	8.0	4.5	
Strain in the pipe wall in %	0.17	0.16	-6%

In this example, the two pipes with a similar laminate structure (the pure filament winding) have been considered. Since the high stiffness pipes are generally produced with the sand added to the pipe wall, the reduction of the flexural E modulus leads to the increase of the wall thickness and, thus, of the strain, which will probably be higher than in the pipe with the lower stiffness, despite the lower shape factor.

9.3. Pressure-Defection Combined Loading

The strains (or stress), caused by the internal pressure section 9.5.1 – Longitudinal Tensile Strain Due to the Internal Pressure, combine with the strain caused by the deflection (section 9.2 - Strain in the Pipe Wall Due to the Deflection). But due to the re-rounding effect of the internal pressure on the deflection, the combined strain value will be lower than the simple arithmetical sum.

The two following safety conditions must prove positive:

$$\frac{HDB_{strain}}{FS_{pr}} \geq \frac{\varepsilon_{pr}}{1-\frac{\varepsilon_b r_c}{S_b}} \quad , \quad \frac{S_b}{FS_b} \geq \frac{\varepsilon_b r_c}{1-\frac{\varepsilon_{pr}}{HDB_{strain}}} .$$

The Analogues equation can be obtained for the analysis on the stress basis.

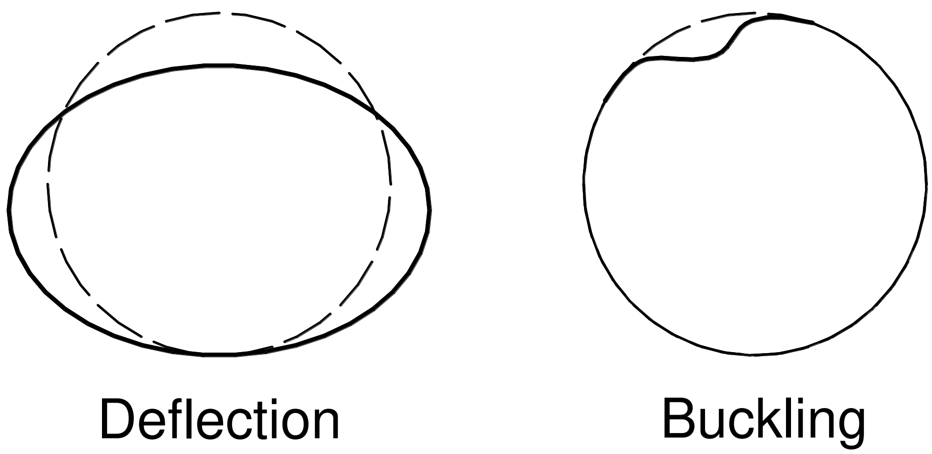
The re-rounding coefficient r_c is calculated as follows:

$$r_c = 1 - P_w/30 \text{ for } P_w \leq 30 \text{ or } r_c = 0 \text{ for } P_w > 30$$

with the internal working pressure P_w in bar.

9.4. The Buckling Analysis

The pipe can implode (buckle) due to the instability phenomenon if the external loads combined with the the internal vacuum exceed the critical load of the pipe-soil system.



The allowable load, according to the AWWA M45 manual, is calculated with the following equation, which is derived from the Luscher & Hoeg buckling equation:

$$q_a = \frac{1}{FS} \cdot 1.2 \cdot C_n \cdot (8 \cdot S)^{1/3} \left(\varphi_s \cdot M_s \cdot 10^6 \cdot k_v\right)^{2/3} R_h$$

R_h is the correction factor for the depth of fill and the others ($C_n, \varphi_{s,}\ k_v$) are the empirical coefficients.

It is important to point out that the stiffness of the pipe (*S*) and the stiffness of the soil (M_s) are closer in weight in this equation, contrary to the deflection equation. In fact, the two terms are also multiplied if the soil stiffness term is squared.

The loads, that can become critical, are the same type of loads considered in the deflection, treated in this case as the radial loads causing the compression in the pipe wall, plus (eventually) the hydrostatic load due to the water table and the internal vacuum. The water table will reduce the soil weight. The contemporary action of the live loads and the internal vacuum is generally not considered.

In this case, the minimum safety factor is 2.5, according to AWWA M45.

For the same example given earlier (section 9.2 - Strain in the Pipe Wall Due to the Deflection), the critical load is calculated at the 4 m depth:

Pipe Stiffness in Pa	1,250	10,000	8x
Wall thickness in mm	8.9	17.1	+92%
Allowable load in Pa	198,862	395,175	+199%

It demonstrates that an increase in the pipe stiffness has a noticeable impact on the buckling load.

9.5. The Longitudinal Combined Strain Analysis

Before the final wall structure can be determined, based on the results of the deflection and the buckling analysis, the effects of the various longitudinal loads on the pipe must be evaluated.

This is connected to the fact that the longitudinal strength of the fiberglass pipe, intended for the underground installation, is generally not as great as its strength in the hoop direction. Since there is no need for a great strength in the axial direction and it is possible to reduce the amount of the reinforcement applied axial wise, a more accurate analysis is required to verify the minimum straight wall structural strength and to ensure that the anticipated strain or stress does not exceed the allowable longitudinal strain or stress.

This analysis must consider the conditions given on the next pages.

9.5.1. Longitudinal Tensile Strain Due to the Internal Pressure

TOPFIBRA takes into the account the longitudinal strain imposed on the pipe by the Poisson Effect.

This condition occurs when the open-ended cylinder is subjected to the internal pressure.

As the cylinder expands diametrically, it simultaneously shortens longitudinally. Without the end loads or other constrains, the contraction in the longitudinal direction (the Poisson's effect) is calculated as:

$$\varepsilon_l(pressure) = -v_{lh}\frac{P \cdot r}{t_s E_h} = -v_{lh}\varepsilon_h$$

Where:

ε_l = the longitudinal strain (contraction, negative);

ε_h = the hoop strain, due to the internal pressure (extension, positive);

E_h = hoop tensile modulus;

v_{lh} = the Poisson's ratio (the longitudinal strain to hoop stress);

P = the internal pressure;

t_s = the pipe structural wall thickness;

r = the pipe radius in cm.

NOTE: Since fiberglass is not an isotropic material, there are at least two different Poisson's ratios referred to the main (the hoop and longitudinal) directions. The value of the two coefficients is variable and dependent on the fiber content and orientation. The longitudinal to hoop ratio is ranging from 0.2 to 0.3, while the hoop to longitudinal ratio is equal to the longitudinal to hoop ratio, multiplied the hoop to axial E-modulus ratio.

When the pipe is buried, the friction with the soil will prevent the free Poisson contraction, resulting in the longitudinal extension strain and tensile stress in the pipe wall, which is $\sigma_l = -\varepsilon_l E_l$. When the pipe has unrestrained joints, the length of a section bar is normally enough to develop the longitudinal stress, which is generally quite low, but should be considered if it is combined with the other longitudinal stresses.

9.5.2. Longitudinal Tensile Strain Generated by the Temperature Gradient

TOPFIBRA takes into the account the longitudinal strain as well, which may be generated by a decrease in the fluid temperature contained by the fiberglass pipe system. The contraction, produced by such a decrease in the temperature, produces a condition in which an open-ended cylinder attempts to shorten longitudinally. This movement is resisted by the surrounding soil and the tensile strain is generated in the pipe structure.

An analysis must be conducted to determine which of the two possible conditions will generate the most severe strain in the pipe. On this basis, the suitable wall structure shall be determined. One condition concerns the temperature differential, which is the half of the differential between the maximum and the minimum anticipated operating temperatures.

The second condition to be evaluated is the result of the difference between the maximum pipe-line temperature at installation and the minimum design temperature.

The following equation is used to determine the longitudinal tensile strain developed by the temperature gradient:

$$\varepsilon_l(temp) = \alpha \cdot \Delta T$$

where ΔT is the greater of:

$$\Delta T_a = \frac{T_{\max} - T_{\min}}{2}$$

$$\Delta T_i = T_{install} - T_{\min}$$

α = the linear coefficient of the thermal expansion.

9.5.3. Longitudinal Tensile Strain Generated by Bridging

TOPFIBRA recommends determining the generated longitudinal tensile strain when:

- the pipe comes off from a "hard point", i.e. a wall structure, a manhole, pipe support, etc;
- the bearing strength of the trench bedding is not uniform;
- the pipe is placed in a sub-aqueous environment instead of a dry, dewatered trench.

In the fiberglass piping system, where any of the conditions listed earlier are expected to exist, it is a good engineering practice to design the pipe to be strong enough to support the weight of its contents by itself as well as the overload, while spanning a void equivalent to the distance of two pipe diameters, or the length of the shortest gasket-pipe length in or near the affected area. The equation used to analyse these conditions considers the pipe to be a simple supported beam:

$$\varepsilon_l(bridging) = \frac{W_t(2d)^2 r_m}{8E_l J}$$

Where:

W_t = the contents + the pipe weight + the overload;

J = the transversal section momentum of the inertia;

$$= \frac{\pi}{2} d_m^3 t_s$$

d_m = an average diameter in cm;

t_s = the structural wall thickness in cm.

The design analysis must make use of all these equations simultaneously and determine the minimum wall thickness, which has strains equal to or less than the allowable design strain.

$$\varepsilon_{l-allowable} \leq \varepsilon_{l-pressure} + \varepsilon_{l-temperature} + \varepsilon_{l-bridging}$$

10. BASIS OF THE DESIGN FOR THE ABOVEGROUND (A/G) PIPE

The following methods of restraint for the A/G GRP-BRP pipe can be distinguished:

- the free-end pipe – with the axially restrained joints, and not anchored at the bends and singular points;
- the fixed-end pipe – with the sliding joints, anchored wherever the direction changes;
- a combination or a hybrid system.

The GRP-BRP piping system for the A/G is designed on the basis of the most severe loading forces, which the installation and the service conditions can impose.

The design considerations include: the end-loads exerted by the equipment; the hydrodynamic effects generated by the internal pressure; the effects of the thermal gradients; the pressure expansion; the bending loads; and the handling considerations. Heavy valves and other ancillary equipment should be self-supporting.

10.1. The Free-End A/G Pipe

The free-end piping systems require a basic flexibility analysis to ensure that the locations of the guides and the anchors, if required, will provide the necessary length and traversal space. This allows the pressure and the thermal expansion forces to be absorbed by the pipe bending. The ASME Code Case 1792, Sections ND 3641.1, ND 3652.1 and ND 3652.2 are the guiding lines to be followed in the design of the GRP piping.

The design of the hangers, supports, guides and anchors must ensure that:

- the mid-span deflection does not exceed 20 mm;
- the effect of the combined longitudinal loads and the weight does not over-stress the piping at the mid-span or at the support locations;
- the pipe is properly protected against the wear at the locations where the sliding takes place;
- the shape and the area of the contact surfaces of all supports are designed in a way to minimize the stresses caused by the interaction with the pipe structure;
- the support design criteria, as described in the ASME Code Case 1792, Section 3676.9, are followed;

- the 4 to 1 (or 3 to 1 for the transient conditions) buckling safety factor is incorporated in the design.

10.2. The Fixed-End A/G Pipes

This installation method uses the anchors and the thrust blocks at the points where the pipeline direction changes, in order to absorb the longitudinal loads. It is most suitable for the small diameter rack-mounted piping or for the large diameter piping systems installed close to the ground. Therefore, this method of installation should be restricted to the locations where the longitudinal thrusts can be economically or practically absorbed.

Although anchors absorb the end-thrusts, nevertheless, a design analysis is performed to ensure that the allowable strain will not be exceeded under the following conditions:

- the pipe span deflects to the maximum of 20 mm;
- when the maximum longitudinal mid-span flexural strains are generated by the combination of the pipe and the content weight, ice loading, wind loading, etc.
- when the local flexural stresses and the strain are present at the horns of the supports;
- when the supports are under the effect of the shear stress;
- when the combined strains in a straight pipe, which are generated by thermal gradients and the Poisson Effect, are superimposed on the mid-span flexural bending strains (unless the pipe is placed on the frictionless restraints and is free to expand and contract);
- the effect that the weight of the valves has on a pipe;
- the load transmitted to the pipe by the equipment;
- the built-in 4 to 1 bucking safety factor (or 3 to 1 for the transient conditions).

11. RESIN/FIBREGLASS OVERLAY (WELDED) JOINT DESIGN

It is also called the “BUTT AND STRAP JOINT”.

TOPFIBRA designs welded joints in the system so that they are equal in strength to the axial strength of the pipe which they are jointing. The shear length of the welded joint depends on the thickness of the overlay.

The equations used in the design of the butt and strap joint, the hardness bell and the spigot are the following:

$$t_1 = \frac{P \cdot d \cdot K}{2\sigma}$$

$$t_2 = \frac{1.25K}{\sigma}\frac{P \cdot d}{4} + E_l \cdot \alpha \cdot \Delta T \cdot t_p$$

Where:

t_1 = thickness, calculated for the hoop stresses;

t_2 = thickness, calculated for the sum total of the longitudinal loads. The governing factor is the one that is greater;

P = the inside design pressure in kg/cm2;

d = the pipe inside diameter in cm;

K = the safety factor;

σ = the longitudinal-axial ultimate tensile strength in kg/cm2;

El = the longitudinal modulus of elasticity in kg/cm2;

α = the thermal expansion coefficient in cm/cm °C;

ΔT = the temperature differential in °C;

tp = the pipe wall thickness in cm;

The length of the overlay is calculated by the following relation:

$$l = 2t\frac{\sigma}{\tau}$$

Where:

t	=	joint thickness in cm;
σ	=	joint tensile strength in kg/cm2;
τ	=	the interlaminar shear strength in kg/cm2.

For all standard joints: $\frac{\sigma}{\tau} = 20$.

12. FLANGED CONNECTIONS

Flanges are used to mate the GRP-BRP pipe and fittings with the ancillary equipment such as the pumps, valves, etc. Such flanges are constructed by hand lay-up or compression moulding methods where the drilling orientation matches the ANSI B.16.5 and the B. 16.1 or other applicable standard such as the ISO, EN, DIN and BS.

The standard fiberglass reinforced flanges are only used for mating with the full-faced flat-surface flanges.

Where the internal pressure multiplied by the pipe diameter exceeds the value of 450 (bar per cm - for example, 10 bar for the ND450 pipe = 10 bar per 45 cm), the GRP-BRP flange should have a groove, to insert an O-Ring and ensure a leak-tight seal.

13. SLEEVE COUPLING

The pipes manufactured by the Continuous Filament Winding machine are jointed with the sleeve couplings made of a lip-type elastomeric profile. The pipes are fitted into the FRP sleeve and sealing is made by the elastomeric profile compressed between the pipe spigot and the sleeve.

The hydraulic sealing is achieved through:

- the pressure of the conveyed fluid against the profile lips;
- the compression of the elastomeric profile between the external surface of the pipe and the surface of the internal sleeve.

- Different types of sleeves and gaskets are available.

14. THE BELL AND SPIGOT GASKET JOINTS

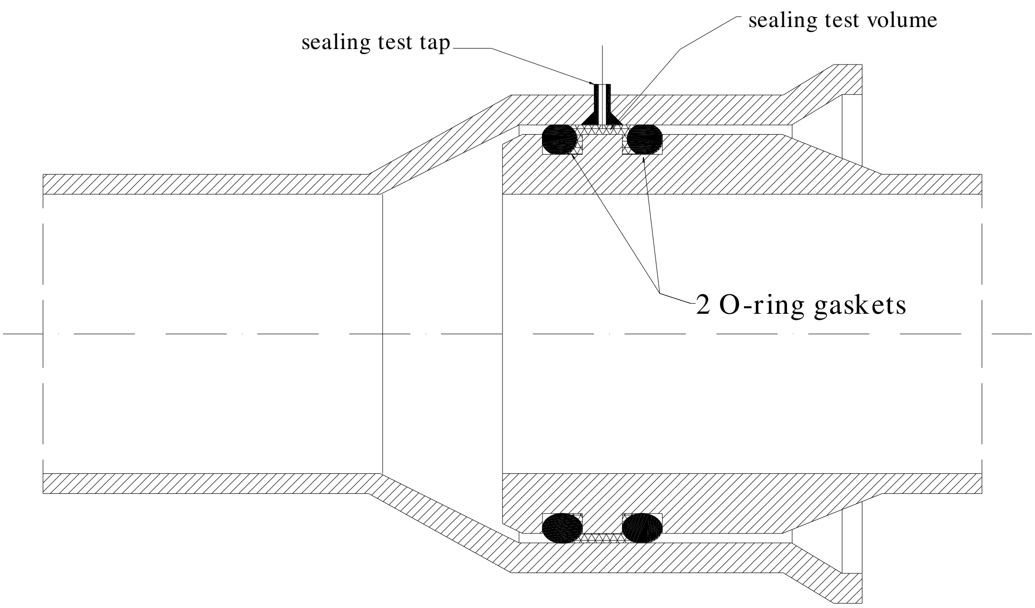
The Bell & Spigot Gasket Joints are available for the discontinuous filament wound pipes.

The bell and spigot gasket joint permits a very rapid assembly of the pipe sections, which can result in the substantial cost savings in the installation. This is true for the sub-aqueous and dry land installation conditions. A gasket joint is especially useful at the wall penetrations, since it permits a greater vertical and lateral freedom for movements, due to the differential settlements in the soil and concrete structures, without jeopardizing the joint integrity.

To ensure the optimum joint integrity of the pipes larger than 1,500 mm in diameter, they should have a matching bell and spigot stiffness. The bell should be an integral part of the pipe.

The following picture shows the double gasket joints with a sealing test tap.

Bell & Spigot Joint with 2 O-rings
and sealing test tap



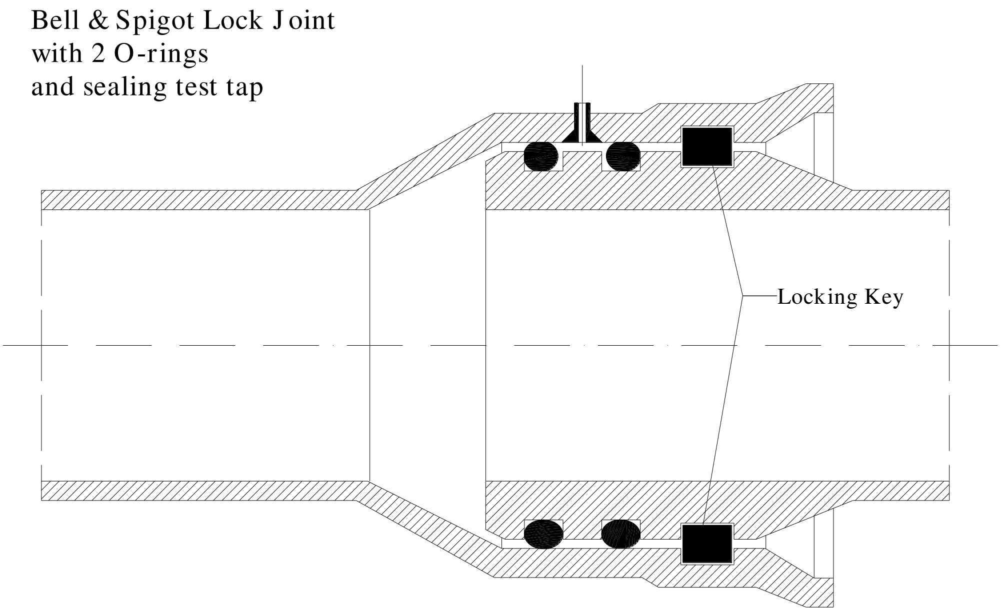
The double gasket joint enables the hydrotesting of the individual joints, without having to fill and pressurize the whole system.

If the pipeline is assembled, using the bell and spigot joints without a locking key, the axial load is not transmitted from one pipe to the other. In this case, the main load for the pipe is the hoop load, and the design winding angle can be 65° (measured from the longitudinal axis).

Gasket joints are also available with a locking key, which allows the axial load to transmit, due to the internal pressure, to the next adjacent section bar.

This permits the elimination of the thrust blocks or the reduction of their dimensions in most of the underground installations.

When the locking key bell & spigot gasket joint is used, the pipe is designed with a lower winding angle (55°) in order to give the required axial strength to the pipe wall.



15. THRUST BLOCKS

The design of the GRP-BRP pipe system tries to avoid the use of the thrust blocks whenever possible by two means:

- by using the welded joints for the pipeline run, which is greater than the self-anchoring run length on each side, where the direction changes;
- by using the joint with the locking keys instead.

However, if the thrust blocks cannot be eliminated due to the specific lay-out of the system, or due to the strength of the pipe, TOPFIBRA shall inform the Project Engineer about the anticipated loads that will develop, so the thrust blocks can be designed appropriately.

THE LIST OF THE STANDARD SPECIFICATIONS AND THE STANDARD TEST METHODS

THE LIST OF THE STANDARD SPECIFICATIONS AND THE STANDARD TEST METHODS

TABLE OF CONTENTS

All the following lists in this chapter are sorted in the alphabetical order.

We try to keep this list updated and show the revision date for your information, but that might not be the last revision.

Where applicable, we added a link to the web site of the organisation that published the document.

1 THE GENERAL RTRP/RPMP PIPE SPECIFICATIONS

API Spec 15LR-01
API Specification for Low Pressure Fiberglass Line Pipe.
This spec. aims to provide standards for Low Pressure Fiberglass Line Pipe for use in conveying produced fluids including oil, gas, non-potable water and mixtures thereof in the oil and gas producing industries
API SPEC 15LR

API Spec 15HR-04
Specification for High Pressure Fiberglass Line Pipe.
This spec. was formulated to provide for the availability of safe, dimensionally and functionally interchangeable high pressure fiberglass line pipe with an API Standard Pressure Rating greater than 1000 psi.
API Spec 15HR

ANSI/AWWA C950-07
Fiberglass Pressure Pipe
http://www.awwa.org/Publications/MainStreamArticle.cfm?ItemNumber=2798

ASTM D2310-06
Standard Classification for Machine-Made "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe
http://www.astm.org/Standards/D2310.htm

ASTM D2996 - 01(2007)e1
Standard Specification for Filament-Wound "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe
http://www.astm.org/Standards/D2996.htm

ASTM D 2517 – 06
Standard Specification for Reinforced Epoxy Resin Gas Pressure Pipe and Fittings
http://www.astm.org/Standards/D2517.htm

ASTM D3262-06
Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer Pipe
http://www.astm.org/Standards/D3262.htm

ASTM D3517-06
Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pressure Pipe
http://www.astm.org/Standards/D3517.htm

ASTM D3754-06
Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer and Industrial Pressure Pipe
http://www.astm.org/Standards/D3754.htm

ASTM D3840 - 01(2005)
Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe Fittings for Non-Pressure Applications
http://www.astm.org/Standards/D3840.htm

ASTM D4024-05
Standard Specification for Machine Made "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Flanges
http://www.astm.org/Standards/D4024.htm

ASTM D4161 - 01(2005)
Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe Joints Using Flexible Elastomeric Seals
http://www.astm.org/Standards/D4161.htm

ASTM D5421-05
Standard Specification for Contact Molded "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Flanges
http://www.astm.org/Standards/D5421.htm

ASTM D5685 -05
Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pressure Pipe Fittings
http://www.astm.org/Standards/D5685.htm

ASTM D6041 - 97(2002)
Standard Specification for Contact-Molded "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Corrosion Resistant Pipe and Fittings
http://www.astm.org/Standards/D6041.htm

ASME - B31.1 - 2004
Power Piping
http://catalog.asme.org/Codes/PrintBook/B311_2004_Power_Piping.cfm

ASME - B31.3 - 2004
Process Piping
http://catalog.asme.org/Education/ShortCourse/B313_Process_Piping.cfm

ASME BPVC – Section III – Division 1 – Subsection NC – Class 3
Fiberglass Reinforced Thermosetting Resin Pipe
http://catalog.asme.org/Codes/PrintBook/BPVCIII_NC_2007_BPVC_Section.cfm

ASME Code Case N-155-2 – Section III-1
Fiberglass Reinforced Thermosetting Resin Pipe

BS 5480 *SUPERSEDED* - 1990
Specification for Glass Reinforced Plastics (GRP) pipes, joints and fittings for use for water supply or sewerage
Currently Replaced by the following BS EN1796 and BS EN 14364

BS EN 1796:2006
Plastics piping systems for water supply with or without pressure. Glass-reinforced thermosetting plastics (GRP) based on unsaturated polyester resin (UP)
British-Adopted European Standard / 31-Aug-2006 / 64 pages
http://products.ihs.com/BS-SEO/30095759.htm

BS EN 14364:2006
Plastic 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
British-Adopted European Standard / 31-Aug-2006 / 74 pages
http://www.techstreet.com/cgi-bin/detail?product_id=1281679

ISO 7370:1983 Withdrawn
ISO/DIS 7370-96
Glass Fibre Reinforced Thermosetting Plastics (GRP) Pipes and Fittings
Nominal diameters, specified diameters and standard lengths

ISO 10467-2004
Plastics Piping Systems for Pressure and Non-Pressure Drainage and Sewerage
Glass-Reinforced Thermosetting Plastics (GRP) based on unsaturated polyester (UP) resin.
http://www.iso.org/iso/catalogue_detail.htm?csnumber=33530#

ISO 10639-2004
Plastics Piping Systems for Water Supply with or without Pressure
Glass-Reinforced Thermosetting Plastics (GRP) based on unsaturated polyester (UP) resin.
http://www.iso.org/iso/catalogue_detail.htm?csnumber=33531

ISO 14692-1-2002
Petroleum and Natural Gas Industries -- Glass-Reinforced Plastics (GRP) Piping
Part 1: Applications and materials
http://www.iso.org/iso/catalogue_detail.htm?csnumber=33433

ISO 14692-2-2002
Petroleum and Natural Gas Industries -- Glass-Reinforced Plastics (GRP) Piping
Part 2: Qualification and manufacture
http://www.iso.org/iso/catalogue_detail.htm?csnumber=33434

ISO 14692-3-2002
Petroleum and Natural Gas Industries -- Glass-Reinforced Plastics (GRP) Piping
Part 3: System design
http://www.iso.org/iso/catalogue_detail.htm?csnumber=33435

ISO 14692-4 -2002
Petroleum and Natural Gas Industries -- Glass-Reinforced Plastics (GRP) Piping
Part 4: Fabrication, installation and operation
http://www.iso.org/iso/catalogue_detail.htm?csnumber=33436

2 PIPE DESIGN, APPLICATIONS AND INSTALLATION

ANSI B16.1(1996) & B16.5 (1998-2009?)
Standard Dimensions for Cast Iron Flanges
http://catalog.asme.org/Codes/PrintBook/B161_1998_Cast_Iron_Pipe.cfm
http://webstore.ansi.org/FindStandards.aspx?SearchString=B16.5&SearchOption=0&PageNum=0&SearchTermsArray=null%7cB16.5%7cnull

ASTM D3839 -08
Standard Practice for Underground Installation of "Fiberglass" (Glass-Fiber- Reinforced Thermosetting-Resin) Pipe
http://www.astm.org/Standards/D3839.htm

ASTM F1675 -09
Standard Practice for Life-Cycle Cost Analysis of Plastic Pipe Used for Culverts, Storm Sewers, and Other Buried Conduits
http://www.astm.org/Standards/F1675.htm

AWWA Manual M 45 -2005
Fiberglass Pipe Design
http://apps.awwa.org/ebusmain/OnlineStore/ProductDetail/tabid/55/Default.aspx?ProductID=6733

BS 6464 -1984?
Specification for Reinforced Plastic Pipe, Fittings and Joints for Process Plants
Specifies materials, properties, design calculations, manufacture, inspection, testing and installation of reinforced plastics pipelines.
http://shop.bsigroup.com/en/ProductDetail/?pid=000000000000131634

BS 7159 -1989
Code of Practice for Design and construction of glass reinforced plastics (GRP) piping system for individual plants or sites
Complements recommendations given in BS 6464 and BS 4994 and provides a basis for design with reference to strain limits and flexibility analysis analogous to those applied for design of ferrous piping systems in accordance with BS 806.

http://shop.bsigroup.com/en/ProductDetail/?pid=000000000000203578

BS 8010 1989- confirm 2007
Code of Practice for Pipelines
Part 1. Pipelines on land: general
Covers aspects which affect land and are common to all applications and pipeline materials.
Currently Replaced by BS EN 14161:2003
http://shop.bsigroup.com/en/ProductDetail/?pid=000000000000200030

BS EN 14161:2003
Petroleum and natural gas industries. Pipeline transportation systems
British-Adopted European Standard / 23-Dec-2003 / 98 pages
http://shop.bsigroup.com/en/ProductDetail/?pid=000000000030057259

BS 8010-2.5
Code of Practice for Pipelines
Part 2. Pipelines on land: design, construction and installation
Section 2.5 Glass reinforced thermosetting plastics
Design considerations and construction and installation recommendations for pipelines incorporating pipes and fittings complying with BS 5480. To be read in conjunction with BS 8010-1
Currently Replaced by BS EN 14161:2003

CRD-C 655-95
"Standard Test Method for Determining the Modulus of Soil Reaction," replaces MIL-STD-621 (method 104)
http://www.wes.army.mil/SL/MTC/handbook/crd_c655.pdf

ISO/DTR 7512 -1990
Recommended practice for design and construction of fabricated butt joints in pipelines of glass fibre reinforced thermosetting plastics (GRP)

ISO/TR 10465-1:2007
Underground installation of flexible glass-reinforced thermosetting resin (GRP) pipes
Part 1: Installation procedures
http://www.iso.org/iso/iso_catalogue/catalogue_ics/catalogue_detail_ics.htm?csnumber=33353

ISO/TR 10465-2:2007
Underground installation of flexible glass-reinforced thermosetting resin (GRP) pipes
Part 2: Comparison of static calculation methods
http://www.iso.org/iso/catalogue_detail.htm?csnumber=38778

ISO/TR 10465-3:2007
Underground installation of flexible glass-reinforced thermosetting resin (GRP) pipes
Part 3: Installation parameters and application limits
http://www.iso.org/iso/catalogue_detail.htm?csnumber=38779

3 RAW MATERIALS STANDARD SPECIFICATIONS AND TEST METHODS

ASTM C33 -08
Standard Specification for Concrete Aggregates
http://www.astm.org/Standards/C33.htm

ASTM C581 - 08
Standard Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass-Fiber-Reinforced Structures Intended for Liquid Service

http://www.astm.org/Standards/C581.htm

ASTM D256 - 06
Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics
http://www.astm.org/Standards/D256.htm

ASTM D445 -09
Standard Test Method for Kinematical Viscosity of Transparent and Opaque Liquids (the Calculation of Dynamic Viscosity)
http://www.astm.org/Standards/D445.htm

ASTM D543 -06
Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents
http://www.astm.org/Standards/D543.htm

ASTM D570 -05
Standard Test Method for Water Absorption of Plastics
http://www.astm.org/Standards/D570.htm

ASTM D618 -08
Standard Practice for Conditioning Plastics for Testing
http://www.astm.org/Standards/D618.htm

ASTM D638- 08
Standard Test Method for Tensile Properties of Plastics
http://www.astm.org/Standards/D638.htm

ASTM D648 - 07
Standard Test Method for Deflection Temperature of Plastics Under Flexural Load in the Edgewise Position
http://www.astm.org/Standards/D648.htm

ASTM D695 - 08
Standard Test Method for Compressive Properties of Rigid Plastics
http://www.astm.org/Standards/D695.htm

ASTM D747-08
Standard Test Method for Apparent Bending Modulus of Plastics by Means of a Cantilever Beam
http://www.astm.org/Standards/D747.htm

ASTM D790-07e1
Standard Test Methods for Flexural Properties of Un-reinforced and Reinforced Plastics and Electrical Insulating Materials
http://www.astm.org/Standards/D790.htm

ASTM D792-08
Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
http://www.astm.org/Standards/D792.htm

ASTM D883 -08
Standard Terminology Relating to Plastics
http://www.astm.org/Standards/D883.htm

ASTM D1242 -95 Withdrawn no replacement
Standard Test Methods for Resistance of Plastic Materials to Abrasion
http://www.astm.org/Standards/D1242.htm

ASTM D 1544 -04
Standard Test Method for Color of Transparent Liquids (Gardner Color Scale)
http://www.astm.org/Standards/D1544.htm

ASTM D1600 -08
Standard Terminology for Abbreviated Terms Relating to Plastics
http://www.astm.org/Standards/D1600.htm

ASTM D 1639-96 Withdrawn, no replacement
Standard Test Method for Acid Value of Organic Coating Materials
http://www.astm.org/DATABASE.CART/WITHDRAWN/D1639.htm

ASTM D 1763 – 00 (Reapproved 2005)
Standard Specification for Epoxy Resins
http://www.astm.org/Standards/D1763.htm

ASTM D2291-09
Standard Practice for Fabrication of Ring Test Specimens for Glass-Resin Composites
http://www.astm.org/Standards/D2291.htm

ASTM D2343 -09
Standard Test Method for Tensile Properties of Glass Fibre Strands, Yarns, and Roving Used in Reinforced Plastics
http://www.astm.org/Standards/D2343.htm

ASTM D2471 -99 Withdrawn, no replacement
Standard Test Method for Gel Time and Peak Exothermic Temperature of Reacting Thermosetting Resins
http://www.astm.org/Standards/D2471.htm?A

ASTM D2562-08
Standard Practice for Classifying Visual Defects in Parts Molded from Reinforced Thermosetting Plastics
http://www.astm.org/Standards/D2562.htm

ASTM D2563-08
Standard Practice for Classifying Visual Defects in Glass-Reinforced Plastic Laminate Parts
http://www.astm.org/Standards/D2563.htm

ASTM D2583 -07
Standard Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor
http://www.astm.org/Standards/D2583.htm

ASTM D2734-09
Standard Test Methods for Void Content of Reinforced Plastics
http://www.astm.org/Standards/D2734.htm

ASTM D2990-09
Standard Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics
http://www.astm.org/Standards/D2990.htm

ASTM D3418-08
Standard Test Method for Transition Temperatures of Polymers By Differential Scanning Calorimetry
http://www.astm.org/Standards/D3418.htm

ASTM D6110-08
Standard Test Methods for Determining the Charpy Impact Resistance of Notched Specimens of Plastics
http://www.astm.org/Standards/D6110.htm

ASTM D6272 -08
Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulting Materials by Four-Point Bending
http://www.astm.org/Standards/D6272.htm

ASTM F477 -08
Standard Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe
http://www.astm.org/Standards/F477.htm

ASTM F913 -08
Standard Specification for Thermoplastic Elastomeric Seals (Gaskets) for Joining Plastic Pipe
http://www.astm.org/Standards/F913.htm

ISO 62 - 2008
Determination of water absorption
ISO 62:2008

ISO 75 -04
Plastics and Ebonite
Determination of deflection under load
ISO 75-1:2004 General test method
ISO 75-2:2004 Plastics and ebonite
ISO 75-3:2004 High-strength thermosetting laminates and long-fibre-reinforced plastics

ISO 175-99
Plastics
Methods of test for the determination of the effects of immersion in liquid chemicals.
ISO 175:1999

ISO 178-75
Plastics
Determination of flexural properties of rigid plastics
ISO 178:2001
ISO 178:2001/Amd 1:2004

ISO 179-82
Plastics
Determination of Charpy impact properties
ISO 179-1:2000 Non-instrumented impact test
ISO 179-1:2000/Amd 1:2005
ISO 179-2:1997 Instrumented impact test
ISO 179-2:1997/Cor 1:1998

ISO 291-77
Plastics
Standard atmosphere for conditioning and testing
ISO 291:2008

ISO 472-88
Plastics
Vocabulary
ISO 472:1999 (under revision)

ISO/DIS 527-1 and 4
Plastics
Determination of tensile properties
ISO 527-1:1993 General principles
ISO 527-1:1993/Cor 1:1994
ISO 527-1:1993/Amd 1:2005
ISO 527-4:1997 Test conditions for isotropic and orthotropic fibre-reinforced plastic composites
ISO 527-5:1997 Test conditions for unidirectional fibre-reinforced plastic composites

ISO 537-80
Plastics
Testing with the torsion pendulum
WITHDRAWN

ISO 1172-75
Textile Glass Reinforced Plastics
Prepregs, moulding compounds and laminates -- Determination of the textile-glass and mineral-filler content -- Calcination methods
ISO 1172:1996

ISO 1210-99
Plastics
Determination of flammability characteristics of plastics in the form of small specimens in contact with a small flame
http://www.iso.org/iso/catalogue_detail.htm?csnumber=5808

ISO 1268-05
Plastics
Preparation of glass fiber reinforced, resin bonded, low-pressure laminated plates or panels for test purposes
http://www.iso.org/iso/catalogue_detail.htm?csnumber=5869

ISO 1887-95
Textile glass
Determination of combustible matter content
http://www.iso.org/iso/catalogue_detail.htm?csnumber=6561

ISO 2114-2000
Plastics
Unsaturated polyester resins
Determination of acid value
http://www.iso.org/iso/catalogue_detail.htm?csnumber=29827

ISO 2535-01
Plastics
Unsaturated polyester resins
Measurement of gel time at 25
http://www.iso.org/iso/catalogue_detail.htm?csnumber=30340

ISO 2554-97
Plastics
Unsaturated polyester resins
Determination of hydroxyl value
http://www.iso.org/iso/catalogue_detail.htm?csnumber=27071

ISO 2555-89
Plastics
Resins in the liquid state or as emulsions or dispersions
Determination of apparent viscosity by the Brookfield test method
http://www.iso.org/iso/catalogue_detail.htm?csnumber=7504

ISO 2558-74
Textile Glass Chopped-Strand Mats for Reinforcement of Plastics
Determination of time of dissolution of the binder in styrene
http://www.iso.org/iso/catalogue_detail.htm?csnumber=7512

ISO 2859-02
Sampling Procedures for Inspection by Attributes
http://www.iso.org/iso/catalogue_detail.htm?csnumber=36164

ISO 3205-76
Preferred Test Temperatures
http://www.iso.org/iso/catalogue_detail.htm?csnumber=8404

ISO 3268-78 Withdrawn
Plastics
Glass-reinforced materials
Determination of tensile properties

ISO 3342-95
Textile Glass
Mats
Determination of fracture strength by traction
http://www.iso.org/iso/catalogue_detail.htm?csnumber=23273

ISO 3521-97
Plastics
Polyester and epoxy casting resins
Determination of total volume shrinkage
http://www.iso.org/iso/catalogue_detail.htm?csnumber=8895

ISO 3597-2003
Textile Glass Reinforced Plastics
Composites in the form of rods made from textile glass roving
Determination of flexural (cross-breaking) strength
http://www.iso.org/iso/catalogue_detail.htm?csnumber=9015

ISO 3672/1-2000
Plastics
Unsaturated polyester resins
Part 1: Designation
http://www.iso.org/iso/iso_catalogue/catalogue_ics/catalogue_detail_ics.htm?ics1=83&ics2=080&ics3=10&csnumber=25206

ISO 3673/1-96
Plastics
Epoxide resins
Part 1: Designation
http://www.iso.org/iso/catalogue_detail.htm?csnumber=27072

ISO 3951-05
Sampling procedures and charts for inspection by variables for percent non-conforming
http://www.iso.org/iso/catalogue_detail.htm?csnumber=34640

ISO 4573-78 Withdrawn
Plastics
Epoxide resins and glycidyl esters
Determination of inorganic chlorine

ISO 4583-98
Plastics
Epoxide resins and related materials
Determination of easily saponifiable chlorine
http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=10508

ISO 4585-97
Textile Glass Reinforced Plastics
Determination of apparent interlaminar shear properties by short-beam test
http://www.iso.org/iso/catalogue_detail.htm?csnumber=10509

ISO 4589-3-96
Plastics
Determination of flammability by oxygen index
http://www.iso.org/iso/catalogue_detail.htm?csnumber=16963

ISO 4615-79
Plastics
Unsaturated polyesters and epoxide resins
Determination of total chlorine content
http://www.iso.org/iso/catalogue_detail.htm?csnumber=10553

ISO 4899-93
Textile Glass Reinforced Thermosetting Plastics
Properties and test methods
http://www.iso.org/iso/catalogue_detail.htm?csnumber=10917

ISO 6355-88
Textile Glass
Vocabulary
http://www.iso.org/iso/catalogue_detail.htm?csnumber=12661

ISO 7822 -90
Plastics
Textile glass reinforced plastics
Determination of void content
http://www.iso.org/iso/catalogue_detail.htm?csnumber=14740

ISO 8515 -91
Textile Glass Reinforced Plastics
Determination of compression properties parallel to the laminate.
http://www.iso.org/iso/catalogue_detail.htm?csnumber=15741

4 TESTS FOR THE MATERIAL PROPERTIES OF THE FINISHED PRODUCTS

ASTM C581 -08
Standard Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass-Fiber-Reinforced Structures Intended for Liquid Service
http://www.astm.org/Standards/C581.htm

ASTM D1598 – 2008
Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure
http://www.astm.org/Standards/D1598.htm

ASTM D1599 - 05
Standard Test Method for Resistance to Short-Time Hydraulic Failure Pressure of Plastic Pipe, Tubing and Fittings
http://www.astm.org/Standards/D1599.htm

ASTM D2105 - 07
Standard Test Method for Longitudinal Tensile Properties of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Tube
http://www.astm.org/Standards/D2105.htm

ASTM D2290 - 08
Standard Test Method for Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe by Split Disk Method
http://www.astm.org/Standards/D2290.htm

ASTM D2344/D2344M - 06
Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates
Formerly "Standard Test Method for Apparent Interlaminar Shear Strength of Parallel Fiber Composites by Short-Beam Method."
http://www.astm.org/Standards/D2344.htm

ASTM D2412 - 08
Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading
http://www.astm.org/Standards/D2412.htm

ASTM D2584 -08
Standard Test Method for Ignition Loss of Cured Reinforced Resins
http://www.astm.org/Standards/D2584.htm

ASTM D2924 -06
Standard Test Method for External Pressure Resistance of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe
http://www.astm.org/Standards/D2924.htm

ASTM D2925 -07
Standard Test Method for Beam Deflection of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe Under Full Bore Flow
http://www.astm.org/Standards/D2925.htm

ASTM D2992-06
Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Fittings
http://www.astm.org/Standards/D2992.htm

ASTM D 3567 -06
Standard Practice for Determining Dimensions of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe and Fittings
http://www.astm.org/Standards/D3567.htm

ASTM D3681 -06
Standard Test Method for Chemical Resistance of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe in a Deflected Condition
http://www.astm.org/Standards/D3681.htm

ASTM D3846-08
Standard Test Method for In-Plane Shear Strength of Reinforced Plastics
http://www.astm.org/Standards/D3846.htm

ASTM D5365 -06
Standard Test Method for Long-Term Ring-Bending Strain of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe
http://www.astm.org/Standards/D5365.htm

BS 6920 – Sections 1÷4 (2000-08)
Suitability of Non-Metallic Products for Use in Contact with Water Intended for Human Consumption with Regard to their Effect on the Quality of the Water.
http://shop.bsigroup.com/en/ProductDetail/?pid=000000000030178052

ISO 7432:2002
Glass-reinforced thermosetting plastics (GRP) pipes and fittings -- Test methods to prove the design of locked socket-and-spigot joints, including double-socket joints, with elastomeric seals
http://www.iso.org/iso/catalogue_detail.htm?csnumber=33014

ISO 7509:2000
Plastics Piping Systems
Glass-reinforced thermosetting plastics (GRP) pipes
Determination of time to failure under sustained internal pressure
http://www.iso.org/iso/catalogue_detail.htm?csnumber=14276

ISO 7510:1997
Plastics Piping Systems
Glass-reinforced plastics (GRP) components
Determination of the amounts of constituents using the gravimetric method
http://www.iso.org/iso/catalogue_detail.htm?csnumber=14277

ISO 7511:1999
Plastics Piping Systems
Glass-reinforced thermosetting plastics (GRP) pipes and fittings
Test methods to prove the leak-tightness of the wall under short-term internal pressure
http://www.iso.org/iso/catalogue_detail.htm?csnumber=14278

ISO 7684:1997
Plastics Piping Systems
Glass-reinforced thermosetting plastics (GRP) pipes
Determination of the creep factor under dry conditions
http://www.iso.org/iso/catalogue_detail.htm?csnumber=14503

ISO 7685:1998
Plastics Piping Systems
Glass-Reinforced Thermosetting Plastics (GRP) Pipes
Determination of initial specific ring stiffness
http://www.iso.org/iso/catalogue_detail.htm?csnumber=14504

ISO 8483:2003
Glass-Reinforced Thermosetting Plastics (GRP) Pipes and Fittings
Test method to prove the design of bolted flange joint.
http://www.iso.org/iso/catalogue_detail.htm?csnumber=33015

ISO 8513:2000
Plastics Piping Systems
Glass-reinforced thermosetting plastics (GRP) pipes
Determination of longitudinal tensile properties
http://www.iso.org/iso/catalogue_detail.htm?csnumber=15738

ISO 8521:2009
Plastics Piping Systems
Glass-reinforced thermosetting plastics (GRP) pipes
Determination of the apparent initial circumferential tensile strength
http://www.iso.org/iso/catalogue_detail.htm?csnumber=15747

ISO 8533:2003
Glass-Reinforced Thermosetting Plastics(GRP) Pipes and Fittings
Test methods to prove the design of cemented or wrapped rigid joints.
http://www.iso.org/iso/catalogue_detail.htm?csnumber=33016

ISO 8572:1991 Withdrawn
Pipes and Fittings Made of Glass-Reinforced Thermosetting Plastics (GRP)
Definitions of terms relating to pressure, including relationships between them, and terms for installation and jointing

ISO 8639:2000
Glass-Reinforced Thermosetting Plastics (GRP) Pipes and Fittings
Test methods for leak-tightness of flexible joints
http://www.iso.org/iso/catalogue_detail.htm?csnumber=16001

ISO 10466:1997
Glass-reinforced thermosetting plastics (GRP) pipes
Test method to prove the resistance to initial ring deflection
http://www.iso.org/iso/catalogue_detail.htm?csnumber=18529

ISO 10468:2003
Glass-reinforced thermosetting plastics (GRP) pipes
Determination of the long-term specific ring creep stiffness under wet conditions and calculation of the wet creep factor
http://www.iso.org/iso/catalogue_detail.htm?csnumber=32230

ISO 10471:2003
Glass-reinforced thermosetting plastics (GRP) pipes
Determination of the long-term ultimate bending strain and the long-term ultimate relative ring deflection under wet conditions.
http://www.iso.org/iso/catalogue_detail.htm?csnumber=32234

ISO 10928:2009
Plastics Piping Systems
Glass-reinforced thermosetting plastics (GRP) pipes and fittings
Methods for regression analysis and their use
http://www.iso.org/iso/catalogue_detail.htm?csnumber=38777

ISO 10952:2008
Plastics Piping Systems
Glass-reinforced thermosetting plastics (GRP) pipes and fittings
Determination of the resistance to chemical attack from the inside of a section in a deflected condition
http://www.iso.org/iso/catalogue_detail.htm?csnumber=26653

ISO/DIS 14828.2-03
Glass-reinforced thermosetting plastics (GRP) pipes
Determination of the long-term specific ring relaxation stiffness under wet conditions and calculation of the wet relaxation factor
http://www.iso.org/iso/iso_catalogue/catalogue_ics/catalogue_detail_ics.htm?ics1=23&ics2=040&ics3=20&csnumber=32235

ISO/WD 15090
Glass-Reinforced Thermosetting Plastics(GRP) Pipes and Fittings
Determination of the shear properties of GRP laminates

ISO 15306:2003
Glass-reinforced thermosetting plastics (GRP) pipes
Determination of the resistance to cyclic internal pressure
http://www.iso.org/iso/catalogue_detail.htm?csnumber=27204

4.1 Soil Properties

ASTM D2166-06
Standard Test Method for Unconfined Compressive Strength of Cohesive Soil
http://www.astm.org/Standards/D2166.htm

ASTM D2487-06
Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System)
http://www.astm.org/Standards/D2487.htm

ASTM D422-07
Standard Test Method for Particle-Size Analysis of Soils
http://www.astm.org/Standards/D422.htm

ASTM D1586 -08
Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils
http://www.astm.org/Standards/D1586.htm

CRD-C 655-95
Standard Test Method for Determining the Modulus of Soil Reaction
Formerly MIL-STD-621A, Method 104, 22 December 1964.
http://www.wes.army.mil/SL/MTC/handbook/crd_c655.pdf

THE BURIED PIPE DESIGN SPECIFICATION FOR: THE GLASS-FIBER-REINFORCED THERMOSETTING-RESIN PIPE (RTRP) AND THE GLASS-FIBER-REINFORCED PLASTIC MORTAR PIPE (RPMP)

THE BURIED PIPE DESIGN SPECIFICATION FOR: THE GLASS-FIBER-REINFORCED THERMOSETTING-RESIN PIPE (RTRP) AND THE GLASS-FIBER-REINFORCED PLASTIC MORTAR PIPE (RPMP)

TABLE OF CONTENTS

1. DESIGN DATA

The calculations presented on the next pages, comply with the recommendations of the AWWA Manual M45 – "Fiberglass Pipe Design" Ed.2-2005, mainly with the Chapter 5 of the Manual.

From here on, the AWWA Manual will be referred to simply as the "M45".

The minimum necessary design data for the mechanical check of the buried GRP-BRP pipeline is the following:

- the maximum operating pressure;
- surge pressure;
- flow;
- service;
- vacuum;
- the minimum covering;
- the maximum covering;
- the traffic load;
- the traffic load scheme;
- the installation type;
- native soil type;
- backfilling type and compaction;
- trench width.

The following formulae are adopted in the calculations and in the supplied Buried Pipe Design (BPD) computer program. Foot notes are added in the following test as a guide or comment to the use of the BPD program.

2. PRESSURE CLASS DESIGN

The hoop stress in the pipe wall, due to the internal pressure p, is calculated by using the classic Mariotte's equation:

$$\sigma_{pr_H} = \frac{pD}{2t}$$

D is the internal diameter and t is the reinforced wall thickness.

At the pressure calculation the stress is generally referred to the reinforced wall thickness disregarding the internal liner or the outer liner. Their contribution to the pressure resistance is indeed very small, compared to the strength of the mechanical wall of the pipe.

If the pipe has restrained joints, the axial stress caused by the internal pressure is:

$$\sigma_{pr_A} = \frac{pD}{4t}.$$

The pressure class is defined with reference to the long term (50 years) failure pressure (or stress; or strain) applying the Safety Factor of 1.8 (according to AWWA or the ASTM standards) and to the short-term failure pressure (or stress) with the Safety Factor of 4. Other International Standards may recommend slightly different Safety Factors.[2]

Hence, the Pressure Class P_c, will be the smallest value among:

$$\frac{1}{1.8} PF_{lt} \quad \text{or} \quad \frac{1}{1.8}\frac{2t \cdot HDB_{stress}}{D} \quad \text{or} \quad \frac{1}{1.8}\frac{2t \cdot HDB_{strain} \cdot E_h}{D}$$

and

$$\frac{1}{4} PF_{st} \quad \text{or} \quad \frac{1}{4}\frac{2t \cdot \sigma_h}{D}$$

Where:

PF = the failure pressure (long or short term);

t = the structural wall thickness;

D = the pipe diameter;

HDB = the long term hydrostatic design basis (stress or strain basis);

E_h = the hoop tensile elastic modulus of the pipe wall material;

σ_h = the hoop ultimate tensile strength.

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[2] In the BPD program, the Pressure Class is an input data, while the program calculates if the Pc is lower than the pressure calculated from the HDB. The HDB is also an input data.

A check of the short-term strain is not practical due to the non-linear stress/strain relation at the high stress levels (close to failure).

The minimal required pressure class P_c is determined according to the Equation 5-3 and 5-4 of the M45:

$$P_c \geq P_w \quad \text{and} \quad P_c \geq \frac{P_w + P_s}{1.4}$$

Where:

P_w = the working pressure;

P_s = the surge pressure.

The surge pressure in the pipeline is caused by the valve closing/opening and pumps shutting down. The allowable pressure is higher than the pressure class in the case of water hammer, as stated in the M45, Section 5.7.1.3:

> *"The surge pressure allowance is intended to provide for rapid transient pressure increases normally encountered in transmission systems. The surge pressure allowance of 0.4 Pc is based on the increased strength of fiberglass pipe for rapid strain rates. Special consideration should be given to the design of systems subject to rapid and frequent cyclic service."*

To minimize the effect of the surge pressure, it is necessary to perform a slow closure of the valves and pumps.

However, for the GRP-BRP pipes, the water hammer effect is substantially weaker than for the steel pipes, due to the lower elastic modulus of the material.

The velocity of the wave travel through the liquid in an elastic pipe is:

$$c = \frac{C}{\sqrt{1 + \frac{\varepsilon}{E} \cdot \frac{D}{t}}} \left[m / s \right]$$

Where:

C = the sound velocity in liquid = 1420 m/s for water;

ε = the bulk modulus of elasticity of liquid = 2028 N/mm2;

E = the pipe E modulus;

D = pipe diameter;

t = pipe thickness;

For a sudden change of velocity, the maximum excess pressure due to the water hammer is:

$$\Delta h = \frac{cV_0}{g} \text{ [meters of liquid column]}$$

Where:

V_0 = the sudden change of water velocity;

g = the gravitational constant = 9.81 m/s2.

The surge pressure in bar is:

$$Ps = \frac{\Delta h \times \rho \times 9.81}{10{,}000}$$

if ρ is the density of the fluid in kg/m^3.

3. SOIL PARAMETERS

In 2000, the AASHTO changed the principle of evaluation of the soil stiffness for the plastic (flexible) pipe, using the constrained soil modulus M_S, instead of the modulus of soil reaction *E'*, and also took into the account the depth of the pipe embedment.

The passive soil resistance is defined mainly through the composite constrained soil modulus M_s that depends on:

- the embedment material of the pipe zone and compaction measured with the M_{sb} constrained modulus of soil reaction;[3]
- the width B_d of the trench at spring-line;[4]
- the native soil type on site and the degree of compaction, measured with the M_{sn} constrained modulus of native soil reaction.[5]

3.1 Embedment Material

When installing the pipeline underground, it is crucial to specify the material of the pipeline bed and the degree of its compaction in order to guarantee a side soil support of the installed pipe, which will maintain the deflection of the pipe in the desired limits.

The first classification of the soils (and the only one that is interesting for this analysis) is based on the fine content. The fines are the particle passing the ASTM No. 200 sieve (75 μm mesh).

The fines content can be determined using the ASTM D422 "Standard Test Method for Particle-Size Analysis of Soils".

This test method covers the quantitative determination of the distribution of the particle sizes in soils. The distribution of the particle sizes larger than 75 μm (retained on the No. 200 sieve) is determined by sieving, while the distribution of the particle sizes smaller than 75 μm is determined by a sedimentation process, using a hydrometer to secure the necessary data.

The fine-grained soils contain 50% or more of the particles passing the ASTM No. 200 sieve, and are defined as cohesive soils and are mainly constituted by silts and clays.

The coarse-grained soils contain 50% or more of the particles retained on the ASTM No. 200 sieve and are constituted by sands and gravels.

The soil Stiffness Categories are the following:

[3] In the BPD program, the user chooses the soil Stiffness Category (SC) and the Soil Proctor Density (SPD). The program will calculate the modulus.

[4] In the BPD program, the trench width is suggested as 2x the pipe diameter, but no less than the pipe diameter + 1 m. The user can modify the trench width. The trench width should in any case be wide enough to allow for the proper placement and compaction of the material surrounding the pipe.

[5] In the BPD program the constrained modulus of the native soil is, by default, equal to the modulus of the embedment material, however the user is allowed to vary the modulus.

Soil Stiffness Category	Content of Fines Retained on the No. 200 sieve	Description
SC1	<5%	Crushed rock.
SC2	5÷12%	Clean, coarse-grained soils: sand or gravel, or mixed sand and gravel.
SC3 a	12÷50%	Coarse-grained soils with fines.
SC3 b	50÷70%	Sandy or gravelly fine-grained soils.
SC4	>70%	Fine-grained soils.
SC5		Highly plastic and organic soils.

Materials belonging to the SC1 and SC2 categories are the best, but they generally come from a mine or a crushing plant and are more expensive (this is not true for the desert areas or the like). The sea sand or the sea beach sand can be conveniently used with fiberglass pipes since they are absolutely inert to seawater.

Cohesive fine-grained soils with less than 30% of the coarse-grained particles (SC4) are generally unsuitable or require a great compaction effort to provide a proper modulus of the soil reaction. Do not use them in such conditions where the water in the trench prevents proper placement and compaction.

SC5 materials are not suitable to be used as a backfill for the flexible pipes and must be excluded from the pipe zone embedment.

Soils in the SC3 category are generally an optimal compromise, since they are most easily found locally, or can be made by mixing the coarse-grained soil with the fine grained native soil.

The M_{sb} for different embedment materials is given in the following tables as a function of the vertical stress level in the soil at the springline elevation (at the pipe’s horizontal diameter) and of the SPD (Standard Proctor Density). The depth refers to the Soil Density of 18.8 kN/m3.

M_{sb} for the Soil Stiffness, Categories SC1 & SC2					
Vert. Stress kPa	Depth m	SPD100	SPD95	SPD90	SPD85
6.9	0.4	16.2	13.8	8.8	3.2
13.8	0.7	18.1	14.8	9.2	3.3
20.7	1.1	20.0	15.9	9.6	3.4
27.6	1.5	21.9	16.9	9.9	3.5
34.5	1.8	23.8	17.9	10.3	3.6
43.1	2.3	25.1	18.6	10.5	3.7
51.8	2.8	26.4	19.3	10.8	3.8
60.4	3.2	27.7	20.0	11.0	3.8
69.0	3.7	29.0	20.7	11.2	3.9
86.3	4.6	31.2	21.5	11.5	4.1
103.5	5.5	33.5	22.3	11.8	4.2
120.8	6.4	35.7	23.0	12.1	4.4
138.0	7.3	37.9	23.8	12.4	4.5
172.5	9.2	41.4	25.2	12.9	4.8
207.0	11.0	44.8	26.6	13.5	5.1

M_{sb} for the Soil Stiffness, Categories SC1 & SC2					
Vert. Stress kPa	Depth m	SPD100	SPD95	SPD90	SPD85
241.5	12.8	48.3	27.9	14.0	5.4
276.0	14.6	51.7	29.3	14.5	5.7
310.5	16.5	54.8	30.6	15.2	6.0
345.0	18.4	57.9	31.9	15.9	6.3
379.5	20.2	61.0	33.2	16.5	6.6
414.0	22.0	64.1	34.5	17.2	6.9

M_{sb} for the Soil Stiffness, Category SC3					
Vert. Stress kPa	Depth m	SPD100	SPD95	SPD90	SPD85
6.9	0.4	not app.	9.8	4.6	2.5
13.8	0.7	not app.	10.2	4.7	2.6
20.7	1.1	not app.	10.7	4.9	2.6
27.6	1.5	not app.	11.1	5.0	2.7

M_{sb} for the Soil Stiffness, Category SC3					
Vert. Stress kPa	Depth m	SPD100	SPD95	SPD90	SPD85
34.5	1.8	not app.	11.5	5.1	2.7
43.1	2.3	not app.	11.7	5.1	2.7
51.8	2.8	not app.	11.9	5.2	2.8
60.4	3.2	not app.	12.0	5.2	2.8
69.0	3.7	not app.	12.2	5.2	2.8
86.3	4.6	not app.	12.4	5.3	2.9
103.5	5.5	not app.	12.6	5.3	2.9
120.8	6.4	not app.	12.8	5.4	3.0
138.0	7.3	not app.	13.0	5.4	3.0
172.5	9.2	not app.	13.4	5.6	3.1
207.0	11.0	not app.	13.7	5.8	3.3
241.5	12.8	not app.	14.1	6.0	3.4
276.0	14.6	not app.	14.4	6.2	3.5
310.5	16.5	not app.	14.8	6.4	3.7
345.0	18.4	not app.	15.2	6.7	3.8

M_{sb} for the Soil Stiffness, Category SC3					
Vert. Stress kPa	Depth m	SPD100	SPD95	SPD90	SPD85
379.5	20.2	not app.	15.5	6.9	4.0
414.0	22.0	not app.	15.9	7.1	4.1

M_{sb} for the Soil Stiffness, Category SC4					
Vert. Stress kPa	**Depth m**	**SPD100**	**SPD95**	**SPD90**	**SPD85**
6.9	0.4	not app.	3.7	1.8	0.9
13.8	0.7	not app.	3.9	1.9	1.0
20.7	1.1	not app.	4.0	2.0	1.1
27.6	1.5	not app.	4.2	2.1	1.1
34.5	1.8	not app.	4.3	2.2	1.2
43.1	2.3	not app.	4.4	2.3	1.3
51.8	2.8	not app.	4.6	2.4	1.3
60.4	3.2	not app.	4.7	2.4	1.4
69.0	3.7	not app.	4.8	2.5	1.4
86.3	4.6	not app.	4.9	2.6	1.5
103.5	5.5	not app.	5.0	2.6	1.5
120.8	6.4	not app.	5.0	2.7	1.6
138.0	7.3	not app.	5.1	2.7	1.6
172.5	9.2	not app.	5.2	2.8	1.7
207.0	11.0	not app.	5.4	3.0	1.8
241.5	12.8	not app.	5.5	3.1	1.9
276.0	14.6	not app.	5.6	3.2	2.0
310.5	16.5	not app.	5.8	3.3	2.1
345.0	18.4	not app.	5.9	3.4	2.2
379.5	20.2	not app.	6.1	3.5	2.3
414.0	22.0	not app.	6.2	3.6	2.4

The degree of compaction is measured through the percent Proctor density (ASTM D698) or the relative density (ASTM D4253-4254).

3.2 Native Soil

Constrained modulus of the soil reaction for the native soil M_{sn} depends on the type of the soil (granular or cohesive) and on the compaction. It is shown in the following table and is equal to the previous *E′* modulus of the soil reaction.

Granular Soils		Cohesive Soils			
Blows/ft(1)	**Description**	**q_u(2)**		**Description**	**M_{sn}**
		(Tons/sqf)	**kN/m²**		**(MPa)**
0-1	very, very loose	0-0.125	0-13	very, very soft	0.34
1-2	very loose	0.125-0.25	13-27	very soft	1.38
2-4		0.25-0.50	27-54	soft	4.83
4-8	loose	0.50-1.0	54-107	medium	10.3
8-15	slightly compact	1.0-2.0	107-215	stiff	20.7
15-30	compact	2.0-4.0	215-429	very stiff	34.5
30-50	dense	4.0-6.0	429-644	hard	69.0
>50	very dense	>6.0	>644	very hard	138

(1) – Standard penetration test SPT (ASTM D 1586);

(2) – Unconfined Compressive Strength (ASTM D2166).

In case of the installation in rock, use $M_{sn} = 345$ MPa.

The native soil modulus can also be measured with the CRD-C 655-95 "Standard Test Method for Determining the Modulus of Soil Reaction", formerly the MIL-STD-621A, Method 104, 22 December 1964.

3.3 Combined Soil Modulus

A good embedment (a good material and a good compaction) is weakened by a poor native soil. The soil support combining factor (S_c) should be applied depending on the ratios between the native and embedment moduli, and between the trench width (***B***) and the pipe diameter.

The following table (derived from the M45 Table 5-5) gives the soil support combining factor:

	B/D												
M_{sn}/M_{sb}	1.25	1.38	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.50	4.00	4.50	5.00
0.005	0.02	0.04	0.05	0.08	0.12	0.18	0.23	0.33	0.43	0.58	0.72	0.86	1.00
0.01	0.03	0.05	0.07	0.11	0.15	0.21	0.27	0.37	0.47	0.61	0.74	0.87	1.00
0.02	0.05	0.08	0.10	0.15	0.20	0.26	0.32	0.42	0.52	0.65	0.77	0.89	1.00
0.05	0.10	0.13	0.15	0.20	0.27	0.33	0.38	0.48	0.58	0.69	0.80	0.90	1.00
0.10	0.15	0.18	0.20	0.27	0.35	0.41	0.46	0.56	0.65	0.75	0.84	0.92	1.00
0.20	0.25	0.28	0.30	0.38	0.47	0.53	0.58	0.67	0.75	0.82	0.88	0.94	1.00
0.30	0.35	0.38	0.40	0.47	0.56	0.61	0.67	0.73	0.80	0.85	0.91	0.95	1.00
0.40	0.45	0.48	0.50	0.56	0.64	0.70	0.75	0.80	0.85	0.89	0.93	0.97	1.00
0.50	0.55	0.58	0.60	0.66	0.73	0.77	0.81	0.85	0.90	0.93	0.96	0.98	1.00
0.60	0.65	0.68	0.70	0.75	0.81	0.84	0.87	0.91	0.94	0.96	0.98	0.99	1.00
0.70	0.75	0.77	0.79	0.83	0.87	0.89	0.92	0.94	0.96	0.98	0.99	1.00	1.00
0.80	0.84	0.86	0.87	0.90	0.93	0.95	0.96	0.97	0.98	0.99	1.00	1.00	1.00
0.90	0.92	0.93	0.94	0.95	0.97	0.97	0.98	0.99	0.99	1.00	1.00	1.00	1.00
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.25	1.20	1.18	1.15	1.10	1.06	1.05	1.03	1.02	1.02	1.01	1.00	1.00	1.00
1.50	1.40	1.35	1.30	1.20	1.12	1.09	1.06	1.05	1.03	1.02	1.00	1.00	1.00
1.75	1.55	1.48	1.40	1.30	1.21	1.17	1.13	1.10	1.07	1.05	1.03	1.01	1.00
2.00	1.70	1.60	1.50	1.40	1.30	1.25	1.20	1.15	1.10	1.08	1.05	1.03	1.00
2.50	1.95	1.80	1.65	1.53	1.40	1.34	1.28	1.21	1.15	1.11	1.08	1.04	1.00
3.00	2.20	2.00	1.80	1.65	1.50	1.43	1.35	1.28	1.20	1.15	1.10	1.05	1.00
4.00	2.60	2.30	2.00	1.78	1.60	1.51	1.43	1.34	1.25	1.19	1.13	1.06	1.00
5.00	3.00	2.60	2.20	1.90	1.70	1.60	1.50	1.40	1.30	1.23	1.15	1.08	1.00

The composite modulus of the soil reaction M_s is:

$$M_s = S_c \cdot M_{sb}$$

3.4 The Special Cases of Embedment:

- In case of the very poor native soils, it is advisable to apply a geotextile wrap to the bottom of the trench and to the sides of the trench. The native soil modulus for the earlier calculation may be increased by 1.5;
- if permanent solid sheeting S_c = 1 is used for any native soil;
- when cement stabilized sand (1 sack per ton) is used in the pipe zone bedding and side-filling, the modulus of the reaction for the hardened embedment must be M_{sb} = 170 MPa (simple compacted sand before hardening);
- for the embankment installation use M_{sb} for M_{sn}.

4. DETERMINATION OF THE EXTERNAL LOADS

4.1 Soil Load

The soil load is the weight of the entire column of ground above the top of the pipe:

$$W_c = \gamma_s H$$

Where:

W_c	= the vertical soil load on top of the pipe (weight per unit of surface);
γ_s	= the unit weight of the soil (dry);
H	= the height of covering on the top of the pipe.

For conservative reasons, no reduction in the vertical soil load due to the trench effect is considered. However, for the very deep trenches, special considerations can be made. [6]

[6] In BPD program is possible to add external additional dead and live loads per unit of surface, that will be added to the soil and traffic load for the deflection, strain and buckling checks. The option is useful to analyse special load cases that require specific calculation.

4.2 Traffic Load

The vertical pressure on the pipes due to the live & traffic loads is calculated according to the M45 Manual, considering the propagation of the load with an angle of 27° (30° for *LLDF* =1 .15) from the vertical direction, with a few variation as shown on the next pages.

In the traveling direction, the width L_1 of the load distribution area is:

$$L_1 = t_l + LLDF \cdot h$$

Where:

tl	=	the length of the tyre footprint (generally 0.25 m);
LLDF factor	=	1.15 for the SC1 and SC2 backfill and 1 for the SC3 and SC4;
H	=	the burial depth to the top of the pipe (in meters).

Perpendicular to the traveling direction, the width L_2 of the load distribution area is:

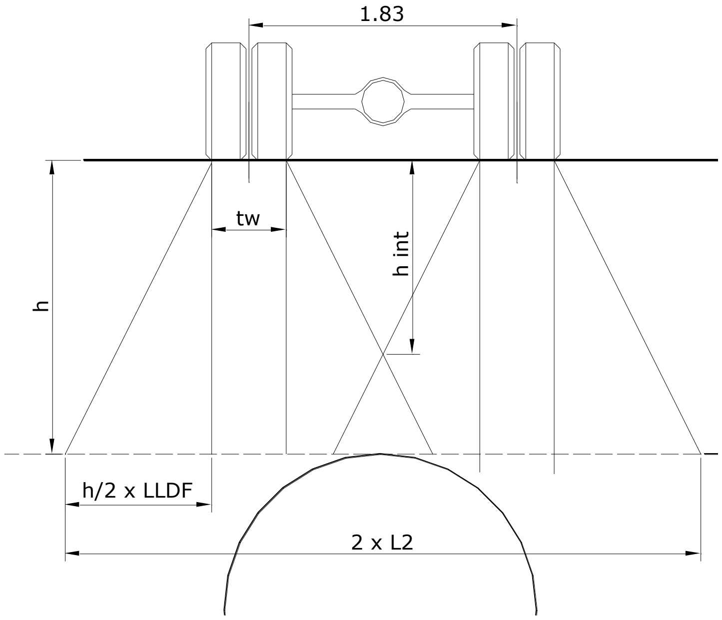
$$L_2 = t_w + LLDF \cdot h$$

where t_w is the width of the tyre footprint (0.5 m).

If $h > h_{int} = (1.83 - t_w) / LLDF$ (i.e. 1.33 or 1.16 m) the width L_2 becomes:

$$L_2 = \left(t_w + 1.83 + LLDF \cdot h\right) / 2$$

in order to consider the mutual influence of different wheels at deeper burial.



The live load W_L on the top of the pipe is:

$$W_L = \frac{M_p \cdot P \cdot I_f}{L_1 \cdot L_2}$$

Where:

M_P = the multiple presence factor = 1.2;

P = load for one single or twin wheel[7];

I_f = the impact factor = $1 + 0.33[(2.44 - h)/2.44] \geq 1$

This approach may be conservative for the large diameter pipes in a shallow trench, since the pressure will propagate only on a part of the pipe diameter. In this case the load may be reduced by the factor:

L_1 / OD if the trucks moves across the pipe and $L_1 < OD$

L_2 / OD if the trucks moves parallel to the pipe and $L_2 < OD$

On the contrary, at a very shallow trench (<0.6m) and with a heavy live load, the risk of local damages (buckling) at the pipe crown should be considered.

[7] *In the BPD program, the user can select several types of trucks. Other types can be added on request.*

For the tandem-axle trucks the equation for L_1 is:

$$L_1 = \left(a_s + t_l + LLDF \cdot h\right)/2$$

where a_s is the axle spacing (in meters).

Other theories to calculate the pressure on the top of the pipe due to the traffic load can be used for special cases and upon request from the Engineers. [8]

4.3 Hydrostatic Load Due to the Ground Water

The load on the pipe due to the ground load is a hydrostatic load, i.e. a radial pressure directed toward the pipe axis.

Since this is a radial load, it does not cause any deflection of the pipe and will not be considered in the calculation of the vertical deflection of the pipe. On the other hand, it has a considerable effect on the elastic stability check.

It is generally calculated (according to the M45) as $\gamma_w \cdot h_w$, where γ_w is the water density [1000 kg/m^3] and h_w is the height of the water surface above the top of the pipe. For pipes of a large diameter, compared to the burial depth, it is safer to calculate the hydrostatic pressure at the pipe axis or at the bottom of the pipe.

The ground water reduces the weight of the part of the soil that is submerged, and thus gives positive buoyancy. According to the M45, this reduction is equal to 1/3 for the part that is submerged.

In the presence of ground water, the buoyancy of the pipe itself has to be checked on condition of the pipe not filled with water. See section 5.4 – Buoyancy.

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[8] *The user can select 0 = "none" as a traffic load and externally calculate the specific pressure on the pipe due to a special case and add an input in the BPD program as "Other live load".*

5. SAFETY CONDITION FOR A FIBERGLASS PIPE

5.1 Deflection

The reduction of the vertical diameter of a pipe is caused by the external loads on the pipe. It is expressed in percentage of the diameter itself.

The deflection is generally limited to 5% or 3%, for the hydraulic calculation reasons, since the section and the hydraulic radius are reduced, as well as the expected flow volume of the pipe.

Furthermore, it is often not acceptable to have the settlements and the movement of the ground surface over a certain value. In this case, the Engineer will give different (and variable) limitations to the vertical deflection.

Because of the safety, the deflection must be confined to the value that does not cause a stress or strain in the pipe wall greater than the allowable one.

The allowable values are referred to as the long-term values, with the application of an appropriate Safety Factor.

Since, generally, the long-term ring bending **strain,** rather than the long-term ring bending **stress,** is defined for the fiberglass pipes, we will refer only to the strain in the pipe wall. The International Standard (for example ASTM D5365 or ASTM D3681, which are used to investigate a long term resistance to the ring bending), make reference to a long term strain, while the stress can be calculated with the common elasticity equation $\sigma = \varepsilon \cdot E$.

Considering this premise, the bending strain in pipe wall is calculated by the equation:

$$\varepsilon_b = D_f \frac{\Delta y}{D} \frac{t_t}{D}$$

Where:

ε_b = the ring bending strain;

D_f = the shape factor;

$\frac{\Delta y}{D}$ = the vertical deflection / the mean pipe diameter;

$\frac{t_t}{D}$ = the total wall thickness / the mean pipe diameter.

The shape factor D_f, initially taken as 6 in the technical literature, is now tabled by the M45 in the function of the pipe-zone embedment material and the compaction, and in the function of the pipe stiffness. The Table 5.1 of the M45 reads:[9]

SHAPE FACTOR				
Pipe Stiffness Pa	**Pipe-Zone Embedment Material and Compaction**			
	Gravel		**Sand**	
	<85% Proctor	**≥85% Proctor**	**<85% Proctor**	**≥85% Proctor**
1250	5.5	7.0	6.0	8.0
2500	4.5	5.5	5.0	6.5
5000	3.8	4.5	4.0	5.5
10000	3.3	3.8	3.5	4.5

The maximum strain in the pipe wall due to the vertical deflection is:

$$\varepsilon_b \le \frac{S_b}{SF}$$

and thus, the maximum allowable long-term deflection will be:

$$\frac{\Delta y_{all}}{D} \le \frac{1}{D_f}\frac{D}{t_t}\frac{S_b}{SF}$$

The Strain Basis S_b is defined as a "long-term ring-bending strain" and determined by ASTM D5365 or ASTM D3681 or the other International Standards. The minimum required Safety Factor is 1.5, according to the M45.

For the TOPFIBRA pipe, the allowable deflection is always higher than 5%, apart from the low-pressure mortar pipes installed in soil with a higher degree of compaction.

As an example and in order to give some numerical references for the TOPFIBRA pipes, we have calculated the allowable deflection for a few common pipe classes (FW stand for the reciprocal filament wound pipe with a 60° winding angle; CH stands for the continuous filament wound, high pressure; and CL stands for the continuous filament wound, low pressure, mortar):

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[9] *The BPD program always takes D_f for the sand at more than 85% Proctor.*

ALLOWABLE DEFLECTION FOR TOPFIBRA PIPES												
Pipe Stiffness Pa	**Pipe-Zone Embedment Material and Compaction**											
	Gravel						**Sand**					
	<85% Proctor			**≥85% Proctor**			**<85% Proctor**			**≥85% Proctor**		
	FW	**CH**	**CL**	**FW**	**CH**	**CL**	**FW**	**CH**	**CL**	**FW**	**CH**	**CL**
1250	8.1%	7.7%	5.7%	6.3%	6.1%	4.5%	7.4%	7.1%	5.2%	5.6%	5.3%	3.9%
2500	7.9%	7.7%	5.6%	6.5%	6.3%	4.6%	7.1%	7.0%	5.1%	5.5%	5.4%	3.9%
5000	7.5%	7.5%	5.4%	6.3%	6.3%	4.5%	7.1%	7.1%	5.1%	5.2%	5.2%	3.7%
10000	7.0%	6.9%	5.0%	6.0%	6.0%	4.3%	6.6%	6.5%	4.7%	5.1%	5.1%	3.6%

These values are indicative, presented in order to get an idea of the concept. The actual allowable deflection must be calculated for each pipe separately.

The predicted deflection is calculated by the following Equation (M45: 5-8), derived from the Spangler formula:

$$\frac{\Delta y}{D} = \frac{(D_L W_c + W_L) K_x}{0.149 PS + 0.061 M_s} = \frac{(D_L W_c + W_L) K_x}{8S + 0.061 M_s}$$

Where:

D_L = the deflection lag factor;

K_x = bedding coefficient;

PS = pipe stiffness according to the US standards;

S = pipe stiffness according to European standards.

If the load is measured in N/m^2, the stiffness S in N/m^2 and the soil modulus in N/mm^2, the previous equation changes to the following one with the deflection in percentages:

$$\frac{\Delta y}{D}\% = \frac{(D_L W_c + W_L) K_x}{8S + 0.061 M_s \times 10^6} 100$$

The relation between the US and the European pipe stiffness is as follows:

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

$$EI = 0.149 \cdot r^3 \cdot PS = D^3 \cdot S$$

$$0.149 \cdot r^3 \cdot PS = (2 \cdot r)^3 \cdot S$$

$$0.149 \cdot r^3 \cdot PS = 8 \cdot r^3 \cdot S$$

$$0.149 \cdot PS = 8 \cdot S$$

E is the flexural elastic modulus of the pipe wall, I is the moment of inertia of a unit length of a pipe, and $r = D/2$ is the mean radius.

For a plain solid pipe wall the moment of inertia is $I = t_t^3 / 12$.

The deflection lag factor D_L converts the immediate deflection to the long-term deflection, due to the reduction of the arching effect in the backfilling, and due to the creep and the consolidation of the pipe zone embedment material. For the slightly compacted materials, a value of 1.05 is used, while for a highly compacted material 1.5 can be used, since the initial deflection will be low.

The bedding coefficient K_x is normally taken as 0.1 and can be reduced to 0.083 for the uniform well shaped bedding only.

The long-term deflection should be lower than 5% of the original vertical diameter or of the value indicated by the Engineer, or of the allowable value depending on the ring-strain analysis given earlier.

A note on the deflection control:

In the deflection equation given earlier, the part at the denominator is the *sum* of 2 terms, the first representing the stiffness of the pipe and the second representing the stiffness of the soil. The first term, for a stiff pipe (S=5000 N/m^2) is 40,000 N/m^2, the second term, for the soils with a low-medium stiffness (Ms = 5 N/mm^2) is 366,000 N/m^2, more than 9x the pipe stiffness. It means that the stiffness of the soil is much more important for the control of the deflection. It is useless to increase the pipe stiffness in order to reduce the deflection.

5.2 Combined Loading

Except for determining the minimum required pressure class as per section 2 – Pressure Class Design, a check is required whether the combined load of the internal pressure and the ring bending does not lead to the excess strain in the pipe wall, as per section 5.7.4 of the M45.

The stress or strain due to the pressure and deflection cannot be simply added, since the internal pressure tends to re-round the pipe, reducing the pipe ovalization.

The M45 Equations can also be written in a more immediate manner, where the actual tensile or bending strains, modified for the load combination, are compared to the allowable ones:

$$\varepsilon_{pr} \le \frac{HDB_{strain}}{FS_{pr}}\left(1-\frac{\varepsilon_b r_c}{S_b}\right)$$

and

$$\varepsilon_b \cdot r_c \le \frac{S_b}{FS_b}\left(1-\frac{\varepsilon_{pr}}{HDB_{strain}}\right)$$

where:

ε_{pr} = the strain, due to the internal working pressure = $\frac{P_w D}{2tE_h}$;

ε_b = the ring bending strain, due to the max allowed deflection (see section 5.1 – Deflection);

FS_{pr} = the safety factor for pressure (min 1.8);

FS_b = the safety factor for bending strain (min 1.5).

The re-rounding coefficient r_c is calculated as:

$r_c = 1 - P_w/30$ for $P_w \le 30$ bar or $r_c = 0$ for $P_w > 30$ bar with the internal working pressure P_w in bar.

A note on the combined loading control:

The pressure class of the pipe should always be higher than the pressure class, otherwise the first condition mentioned earlier, will not be satisfied.

Sometimes, it is difficult to satisfy the safety conditions of the previous equations, since the bending strain, according to the M45 Manual, is due to the *maximum permitted* deflection and not due to the *actual calculated* deflection. Please note that the tensile strain must be calculated due to the actual working pressure.

The maximum permitted deflection can be reduced from 5% to 3% or even lower, in order to satisfy the previous equations, if the actual predicted deflection is lower than 3%. It seems like a trick, but does not contradict the standard, especially because the maximum permitted deflection is assigned by the Designer.

5.3 Buckling

A buried pipe is subjected:

- to the radial component of the live and soil loads;
- to the hydrostatic pressure of the groundwater;
- and to the internal vacuum, which can buckle the pipe because of the instability phenomenon.

On the other hand, the surrounding soil renders a restraining influence, reducing the critical buckling load of the pipe.

The allowable buckling pressure q_a [Pa] is (as per the 5-24b equation of the M45):

$$q_a = \frac{1}{FS} \cdot 1.2 \cdot C_n \cdot (0.149 \cdot PS)^{1/3} (\varphi_s \cdot M_s \cdot 10^6 \cdot k_v)^{2/3} R_h$$

that can be written in term of Stiffness *S*:

$$q_a = \frac{1}{FS} \cdot 1.2 \cdot C_n \cdot (8 \cdot S)^{1/3} (\varphi_s \cdot M_s \cdot 10^6 \cdot k_v)^{2/3} R_h$$

being $0.149 \cdot PS = 8 \cdot S$, as defined in section 5.1 –Deflection, where:

FS = the design factor, 2.5;

Cn = the scalar calibration factor, 0.55;

φ_s = the factor for variability of the soil stiffness, 0.9;

k_v = the factor for Poisson's effect on the soil, 0.74;

M_s = the constrained modulus for the composite soil, as already defined [MPa];

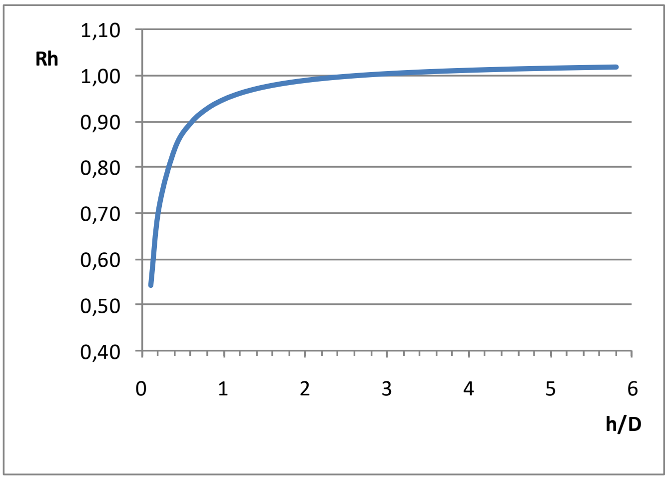
S = the pipe specific stiffness [Pa];

R_h = the correction factor for the depth of fill = $11.4/(11 + D/h))$.

This formula becomes (when we replace the numerical factors):

$$q_a = \frac{1}{FS} \cdot 0.50 \cdot (8 \cdot S)^{1/3} \left(M_s \cdot 10^6\right)^{2/3} R_h$$

The correction factor R_h is 1 for $h = 2.5 \times D$ and reduces rapidly for the shorter height of the cover ($h < 1 \times D$), whilst it does not increase for the deeper burial depth. The shallow burial depth could sometime lead to difficulties in positively checking for the buckling.



Plot of the R_h correction factor

The actual load to be compared with the allowable load is:

$$q_L = \gamma_w h_w + R_w W_c + W_L \qquad \text{with live loads}$$

and

$$q_V = \gamma_w h_w + R_w W_c + P_V \quad \text{with internal vacuum.}$$

The permanent soil load W_c and the live load W_L were defined earlier (chapter ▪ – "DETERMINATION OF THE EXTERNAL LOADS").

P_V = the internal vacuum pressure, 1 bar (100,000 Pa) for a full vacuum;

R_w = the water buoyancy factor $= 1 - 0.33(h_w / H) \quad for \quad 0 \le h_w \le H$;

h_w = the height of the ground water surface above the top of the pipe;

H = the burial depth (the height of the ground from the top of the pipe to the surface).

If the internal vacuum is not a transient condition but a permanent working condition, the traffic load, if any, should be added to the load q_V given earlier.

In order to satisfy the safety requirements under the conditions of a vacuum and a shallow burial depth, the Designer may consider the stiffening due to the rigid joint, flanges, wall crossing, etc. However, this effect is feasible only for the distance between the stiffeners lower than 4x the pipe diameter.

The critical buckling load for the above ground pipe is given by the von Mises formula which doesn't take into the account the Poisson's effect for *n*=2 and can be reduced for an infinite pipe length to the following, simpler equation:

$$q_{crAG} = 24 \cdot S$$

where *S* is the pipe stiffness, as defined earlier.

For the burial depths lower than 0.6 m, the von Mises critical load can be used as the ultimate load, without applying a safety factor.

A note on the buckling control:

In the buckling equation, unlike in the deflection equation, the contributions of the pipe stiffness and of the soil stiffness are multiplied, and the variation of each element gains a considerable influence. The soil stiffness is squared compared to the pipe stiffness.

5.4 Buoyancy

If the pipe is submerged in the ground water and is not filled with water, it receives buoyancy equal to:

$$P_B = \pi\left(\frac{ID}{2}\right)^2 \cdot 9810 \quad \text{[N/m]}$$

where *ID* is the inside diameter in mm.

The buoyancy must be balanced by the weight of the soil above the pipe, plus the weight of the pipe itself and the other permanent loads.

The weight of the soil above the pipe (W_c) must be reduced for the submerged part (below the water table), using the water buoyancy factor (R_w) as according to the section 5.3 -Buckling.

A safety factor of 2 is recommended:

$$P_B \leq \frac{1}{FS}\left(w_p + R_w \cdot W_c \cdot D + w_{c2}\right).$$

The pipe weight w_p [N/m], if not available directly, can be calculated on the basis of the relative density of 1.85.

The other extra permanent load w_{c2} [N/m] should be taken into account only in case it is really present. If the permanent load w_{c2} is not applied immediately after the filling of the trench, a reduced safety factor may be allowed for the period of transition. The Engineer will analyse the risk.

GRP-BRP FITTING DESIGN

GRP-BRP FITTING DESIGN

TABLE OF CONTENTS

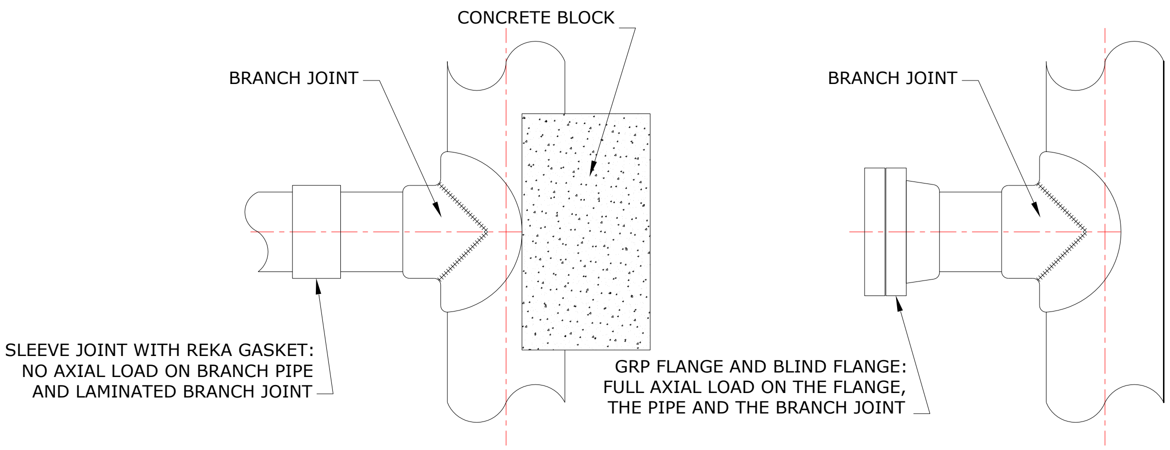
1. GENERAL STATEMENT

This Handbook refers to the piping systems, manufactured with the TOPFIBRA Continuous Filament Winding (CFW) machine, which are joined with the Gasket Sleeve Joints that do not transfer the axial loads from one joined element to the other. Hence, the axial thrust of the internal pressure on the elbows, reducers, flanged pieces, etc. must be balanced by the concrete thrust blocks or other external structures.

The fittings must have the same minimum strength as the strength required for the parent pipe and eventually increased by an intensification factor as shown on the next pages.

Special design attention should be paid to the fittings, which are not completely encased in the concrete blocks or in other supporting structures, since the high local stresses could affect the pieces. Sometimes it is advisable to increase the thickness of the pipe, which is used to make the mitered fittings or the laminations. The full axial load, because of the pressure or an even higher load, could stress the wall of the fittings or the laminated joints, depending on the conditions of constraints of the system.

When the fitting is supposed to hold the full axial load, due to the internal pressure, special design considerations should be made. For example, a TEE branch connected to another pipe by the standard sleeve joints and backed by a concrete thrust block, does not have an axial stress. On the other hand, a TEE branch with a flange and a blind flange (or a valve or other equipment) directly on the branch end (flanged TEE), can be subjected to the full axial load, due to the internal pressure.



Therefore, in this chapter, a dualistic design approach will be shown, which supposes the usage of one of the two following methods:

- **DESIGN "A"** - for the minimum axial strength for the parent pipe (this is the basic design, covered by this specification), and
- **DESIGN "B"** - for the full hydrostatic axial pressure (this will be given for a reference, and it always requires the availability of the pipe with the extra axial strength).

GRP-BRP Fittings can be made by using several processes:

- hand lay-up over a male mould;
- hand lay-up in a female mould;
- joining the mitered pipe elements;
- filament winding;
- injection moulding;
- vacuum moulding.

GRP-BRP fittings can be designed to different specifications and strength requirements, according to the Client's requirements and the design conditions.

AN IMPORTANT REMARK 1:

In case of the "B" design, the standard CFW pipe is not suitable for making the elbow mitres and flange hubs, nor to be connected to these fittings using an axial resistant joint. <u>Instead, a special GRP-BRP pipe is required, which is produced with the helical winding on a Discontinuous Filament Winding (DFW) TOPFIBRA machine, or a CFW pipe that contains extra chopped glass, has a higher pressure class or an axial tape reinforcement, or has a higher hoop pressure class in order to get the required axial strength.</u>

AN IMPORTANT REMARK 2:

Please note that the ultimate axial strength (U_{ATS}) is given by the AWWA or the ASTM standards (AWWA C950-01 - Table 11) for a pipe without the axial pressure load, and ranges from 1/3 to 1/8 of the required ultimate hoop strength (U_{HTS}) for the same pressure class (Table 10).

The ultimate hoop strength is strictly related to the pressure class since it is exactly 4 times the stress in the pipe wall at pressure class.

That means that 4 is the short time safety factor and the same factor will be applied to the axial load in case of the fitting subjected to the axial load.

When the axial stress, due to the internal pressure, develops in a pipe (i.e. when the pipe is joined with the rigid joints such as the laminated butt & strap, adhesive tapered sleeve, or sleeve or bell & spigot with a locking key) it equals half the hoop stress, due to the same pressure.

Since the GRP-BRP laminate, which is used to make the fittings and butt & strap laminated joints, is generally orthotropic, the thickness of the laminate, calculated for the hoop stress, is twice the thickness required for the axial stress. In this case, a check for the axial stress in the laminate is not required.

In case of the butt & strap laminated joints and fitting, made with the pieces of the pipe joined with the butt & strap laminated joints, the lamination/pipe bonding length should also be verified, for "A" and "B" design approaches.

AN IMPORTANT REMARK 3:

There are several standards and recommendation that the designer can refer to for the design of the GRP-BRP fittings, each covering several aspects, but none all-embracing.

Moreover, in some singular points and intersection points (for instance in the tee sections and flanges), stresses and their directions become complex and cannot be easily related to the applied pressure and the tensile loads. There are no analytical expressions for the anisotropy that can be used to calculate the stresses within tees or flanges. As a consequence, the expressions relationships for the pressure stress multipliers; the stress intensification factors; and the flexibility factors available in piping codes (and in this document), are often empirical.

2. BASIC EQUATIONS

The basic equations to calculate the thickness and the bonding length are:

Thickness of the Laminate:

$$t = k_1 \frac{p_d \times D}{2 \times \sigma_d}$$

Bonding Length:

Design “A”	**Design “B”**
(for the parent pipe strength)	(for the full axial load)
$l_A = k_2 \frac{U_{ATS}}{4 \times \tau_d}$	$l_B = k_3 \frac{p_d \times D}{4 \times \tau_d}$

where:

p_d = the design pressure (> 6 bar, also for the gravity pipe);

D = the internal diameter;

σ_d = the design tensile stress for the HLU laminate (20-25 MPa depending on the laminate type);

U_{ATS} = the ultimate axial tensile strength of the pipe in N/mm;

τ_d = the design bonding shear stress (1 MPa);

k_n = the product of all the stress intensification factors or pressure multipliers.

☞ The divider factor “4”, in the equations for l_A and l_B, has a completely different meaning in each equation. For the design “A”, it is a divider for U_{ATS}, which is an ultimate stress, while τ_d is the allowable shear stress at a working condition, then 4 is the safety factor (short term). For the design “B”, it is a factor in the formula for the axial stress in a cylinder which is subjected to the internal pressure.

3. HAND LAY-UP LAMINATE

The hand lay-up (HLU) laminate is obtained by the lamination of layers of the fiberglass fabrics (mat, woven roving, combined fabrics), impregnated with the resin, over a male mould or into a female mould.

Please see the Installation Handbook, chapter: "REINFORCED-OVERLAY JOINTS AND REPAIRS" for more details on how to build up the HLU laminate.

Generally, the lamination sequence starts with a mat tissue. The alternate layers of woven roving fabrics and mat tissues are added on top of it, always ending with a mat tissue.

For this process, TOPFIBRA recommends using the following materials:

- mat tissues, 450 g/m^2 weight (M450);
- woven roving, 500 g/m^2 weight (WR500).

When each layer made of the 1 M450 + 1 WR500 is cured, it provides a GRP laminate with the following characteristics:

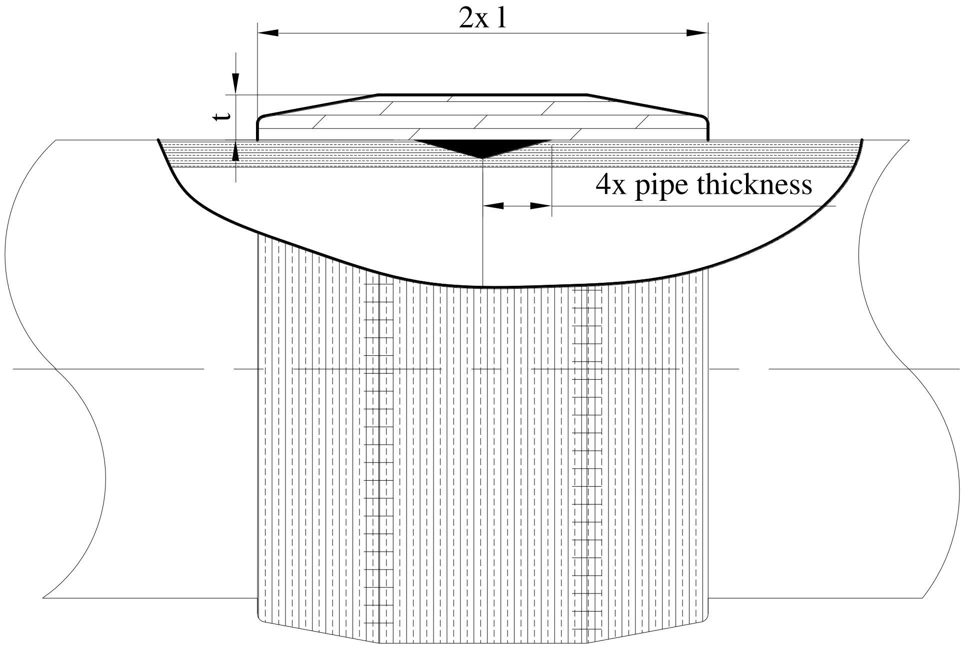
Thickness	1.5	mm
Weight	2300	g/m^2
Resin content	1320	g/m^2
Resin content	0.59	% by weight
Young modulus	10	GPa
Tensile design strain	0.25	%
Tensile design stress	25	MPa
Bonding design shear stress	0.675	MPa

Laminates with different glassfibre tissues can be used, as chosen by the manufacturer. The characteristics for the various composition of the laminates can be calculated with the CFW Fitting Design Program.

4. BUTT & STRAP JOINT

The joints between the lengths of the pipe and between the pipes and specials, are made by butt welds with the HLU lamination of the fiberglass mat and the resin impregnated fiberglass tissues.

From here onwards and in the Fitting Design Program, this type of joint will be referred to as the B&SJ or ROJ (Reinforced Overlay Joint).



Thickness of the laminate

The thickness of the Hand Lay-Up laminate for the overlay of the B&SJ is calculated according to the basic formula, where $k_1 = 1$:

$$t = \frac{p_d \times D}{2 \times \sigma_d}$$

Length of the laminate

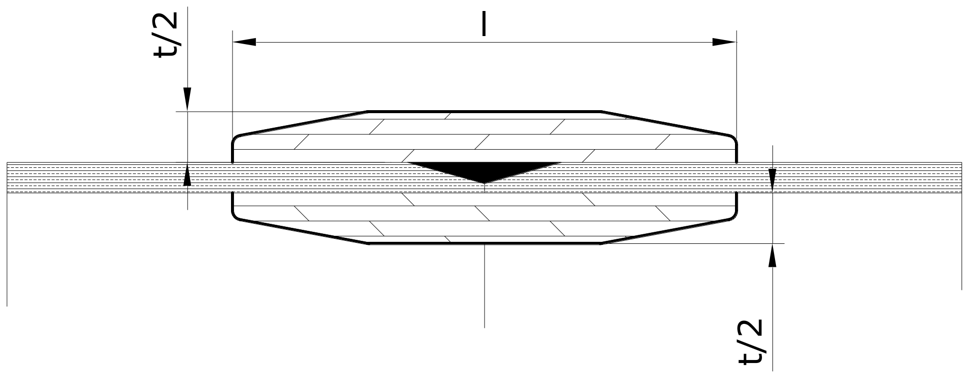
For the **design "A"**, the bonding length is calculated using the basic equation, where $k_2 = 1$:

$$l_A = \frac{U_{ATS}}{4 \times \tau_d}$$

For the **design "B"** (the full axial load), the length is (where $k_3 = 1$):

$$l_B = \frac{p_d \times D}{4 \times \tau_d}$$

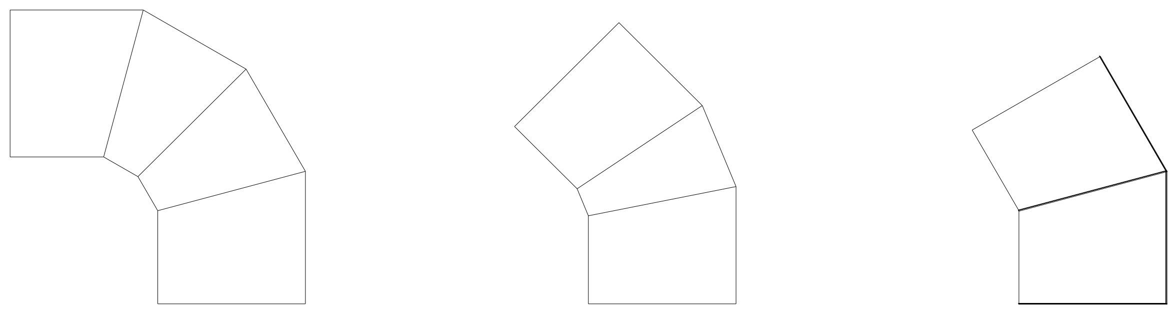
The overlay laminate can be applied only on outside of the pipe, or if possible (for 600 mm and larger diameters) outside and inside of the pipe, halving its thickness and length and therefore the cost.



An interior lay-up of 2 plies of mat of 120 mm width and one surface mat, must always be applied for the ND>500 mm and every time when it is possible to reach the inside of the pipe.

5. ELBOWS

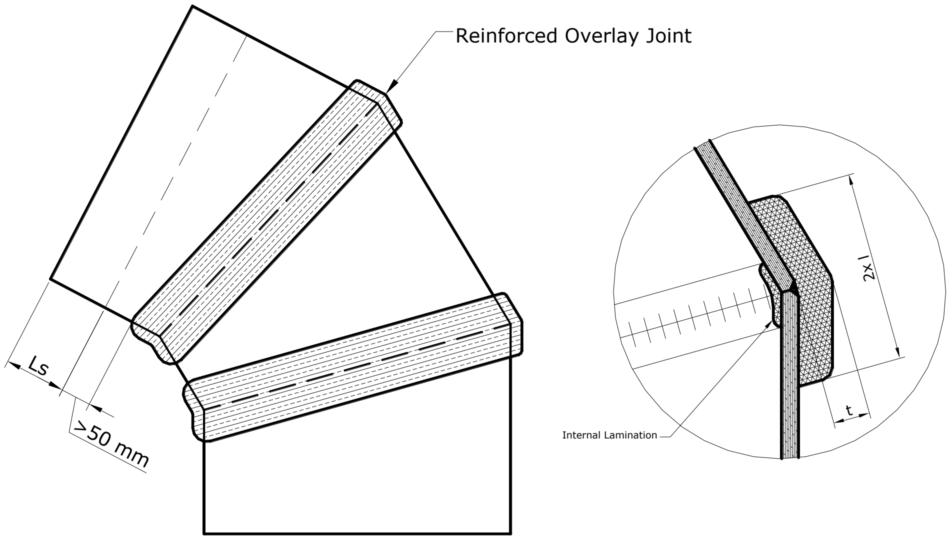
The elbows are produced by but joining of the mitered pieces of pipes, according to the following design schemes:



90°-60° 60° -30° <30°

The pressure class of the pipe, used to make a mitered section, should not be lower than the class of the pipeline where the elbow has to be installed. The stiffness class is not important, since the elbow will be stiffened by the lamination and by the shape itself, but it is advisable to have a pipe with the same internal diameter in the adjoining sleeve joints in order to avoid the turbulence in the water flow.

Mitres are joined with the ROJ. For more detail, see the Manufacturing Handbook and the Installation Handbook.



Ls in this drawing, is the length of the machined spigot end for joining to the straight pipe, through the Gasket Sleeve Joint. It must be spaced from the lamination of the ROJ for at least 50 mm. The machined spigot should be prepared before making the joint. Care should be taken to protect it during the lamination.

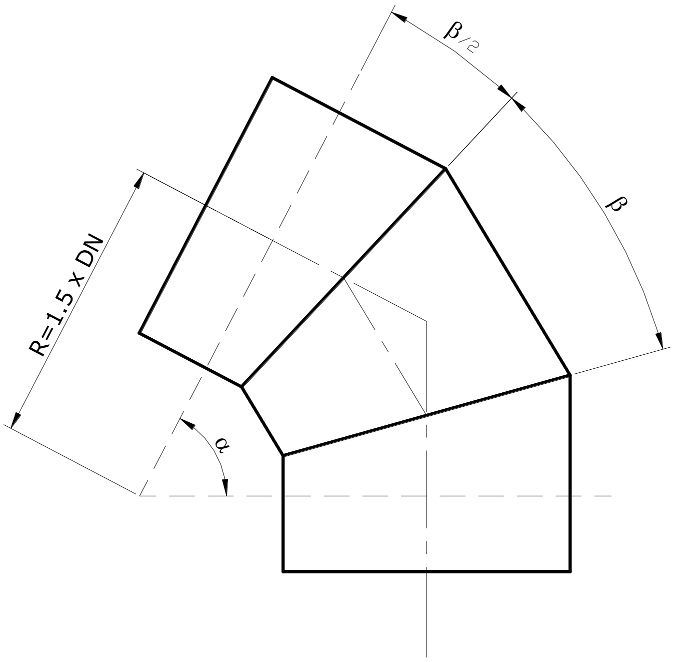
Thickness and bonding length is as per section 4 - Butt & Strap Joint section 4. An intensification factor (1.2 to 1.5) can be applied according to the designer option.

5.1 Internal Lamination

It is always advisable to perform a light internal lamination with 1 or 2 layers of the mat tissues. TOPFIBRA also recommends finishing the hand lay-up with a layer of the "C" surfacing glass, or coating it with the resin mixed with the "C" glass flakes (10 % by weight).

5.2 The Mitring Criterion

The criterion for the mitring angles is shown here:



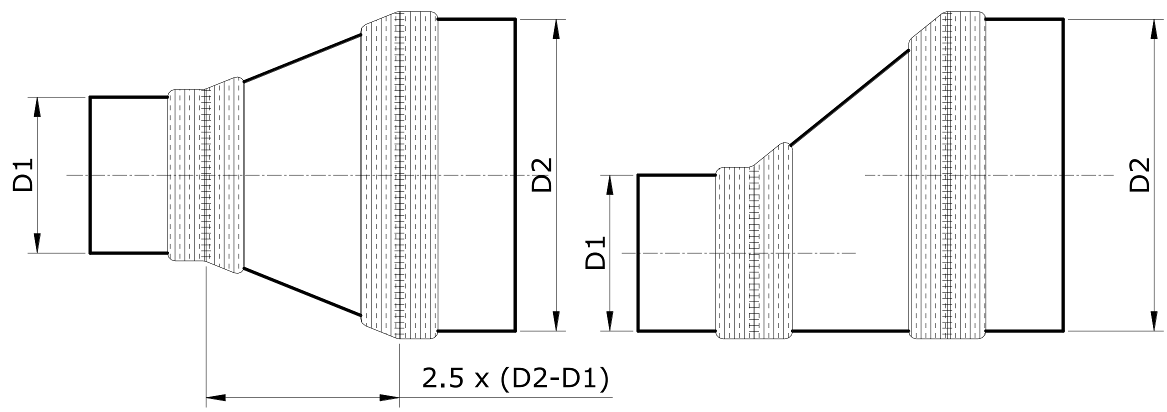
α = the required bending angle;

β = the maximum allowed mitre angle, generally 30°.

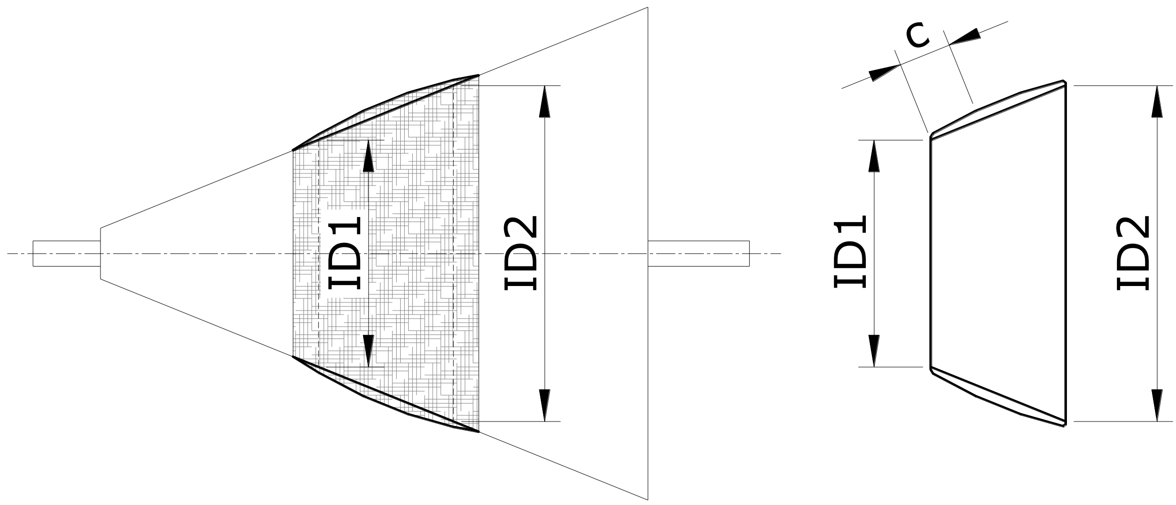
For the $\alpha \leq 30$, there is no intermediate mitre; there is 1 intermediate mitre for up to 60° bending angle ($\beta = \alpha / 2$); and 2 mitres for a larger bending angle ($\beta = \alpha / 3$).

6. REDUCERS

The special pieces for eccentric or concentric reducing are produced by joining the Reinforced Overlay Joints of one conical piece with two short cylindrical stubs, cut in advance from a pipe with the spigot machine.



The conical piece is produced by the hand lay-up lamination on a male mould. A unique, long conical mould can be used for several diameters, since the angle is equal for any size. The GRP-BRP cone element is laminated on one part of the conical mould, trimmed to the exact size and then joined to the cylindrical studs.



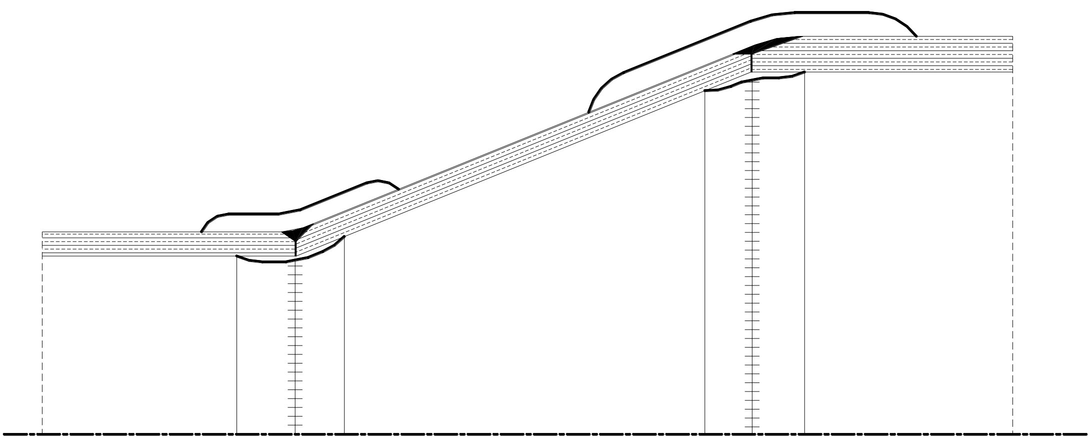
The cone should be laminated and cut to the exact internal diameters of the cylindrical stub pipes, which vary, depending on the pipe class.

The thickness of the cone in the middle is calculated according to the following equation:

$$t = \frac{p_d \times ID2}{2 \times \sigma_d}$$

The design pressure and the design stresses for the reducers are defined in chapter 2 – "BASIC EQUATIONS".

The cone thickness is generally lower than the thickness of the stub pipes, which can be filled with mortar. The connections between the surfaces that will be overlaid, should be smoothly filleted, as shown in this drawing:



The thickness and the length of the ROJ are calculated using the equations in section 2 – "BASIC EQUATIONS", with $k = 1.2 \div 1.5$.

Any reducer will be subjected to a considerable axial thrust, from the side of the larger ND, to the other side (from D2 to D1).

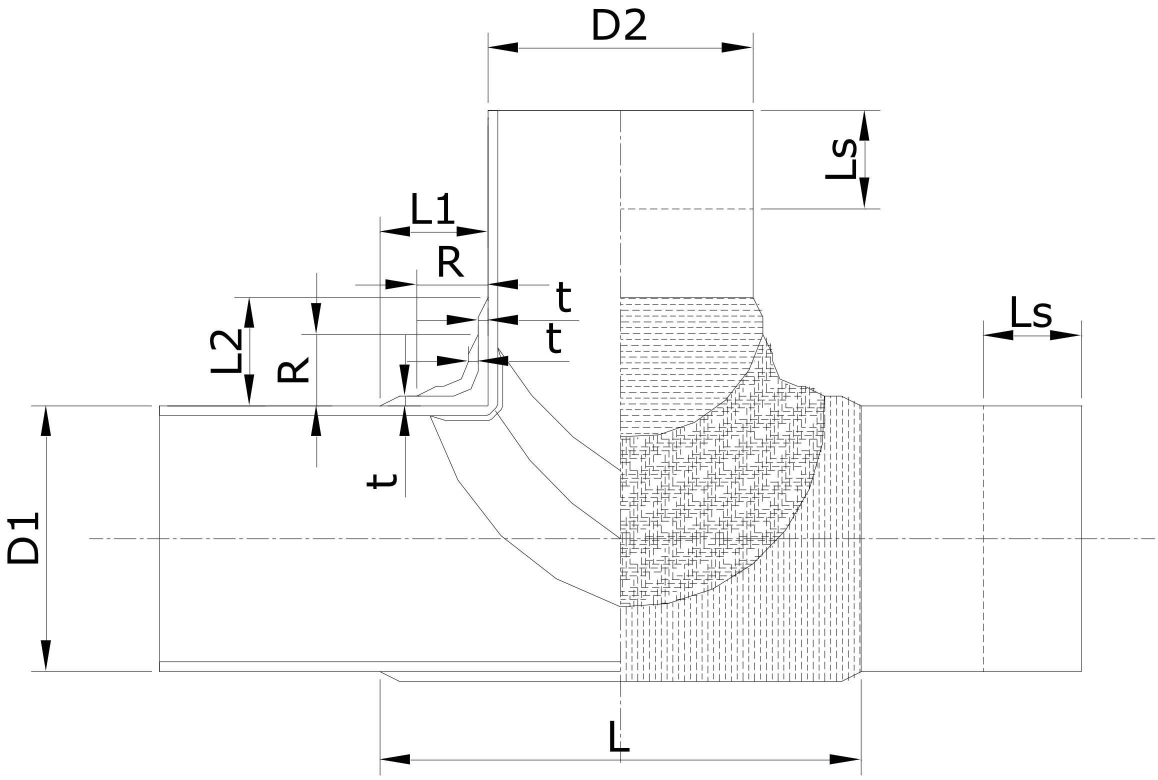
If the reducing piece is connected to the adjoining pipes by sleeve joints, the reducer should be blocked with a concrete block or a steel collar, which is linked to a stiff and strong structure. Otherwise, the reducing piece will move and it can slip off the sleeve joint.

If the reducing piece is connected to the adjoining pipes by the B&SJ, the axial thrust will be transferred to the next fixed point, and the pipe will be designed and selected to carry this axial load.

7. TEES

Tee pieces and the branch joints are made by connecting the shaped pieces of the pipe by the hand lay-up lamination.

This drawing shows the reinforcements for $D1 < 2 \times D2$.



The reinforcement is made of two parts. The first part completely wraps the main header ($D1$) for a length equal to $L = D2 + 2 \times L1$, and has a thickness that is calculated with the basic formula with $k_1 = 1$[10]:

$$t = k_1 \frac{p_d \times D2}{2\sigma_d}$$

[10] *The intensification factor is 1, but the thickness is doubled, since the reinforcement is applied in two layers.*

while the length $L2 = L1$ is calculated as:

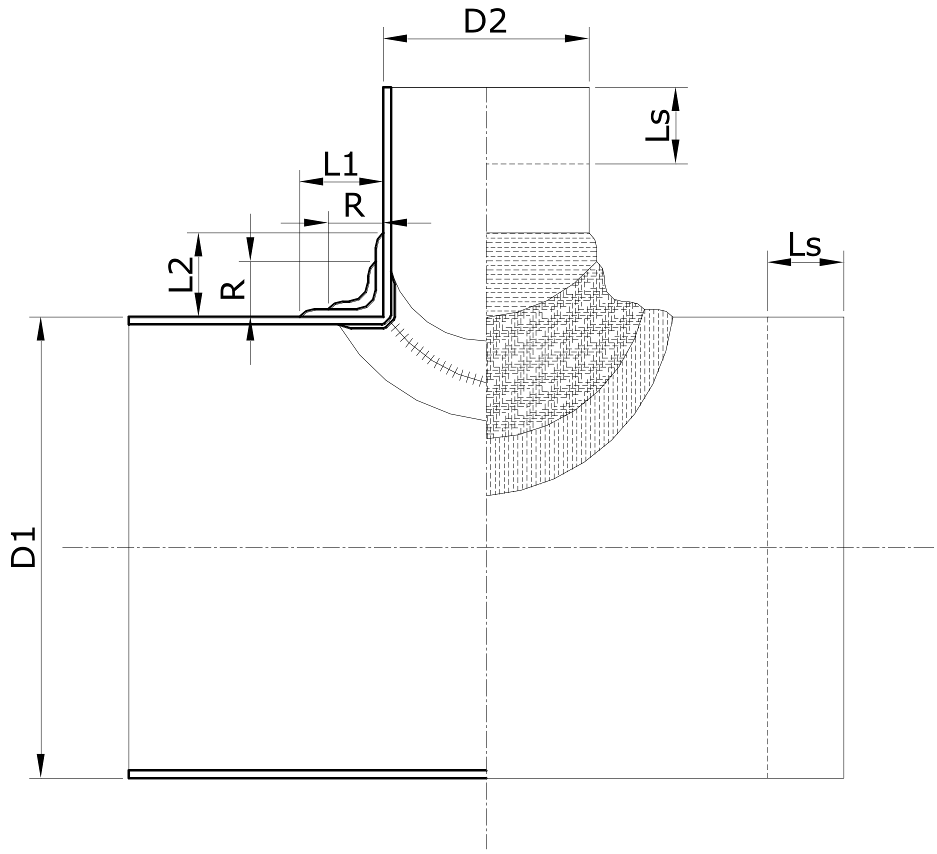
$$L2_A = k_2 \frac{U_{ATS}}{\tau_d}$$

where U_{ATS} is referred to the branch pipe ($D2$).

The thickness of this first reinforcement over the branch pipe $D2$ is the same.

The second reinforcement is applied over the seam with the pipe and has the same thickness t and an extension $2 \cdot R = (L1 + L2)/2$.

For $D2 < D1/2$ the reinforcement is applied as seen on this picture:



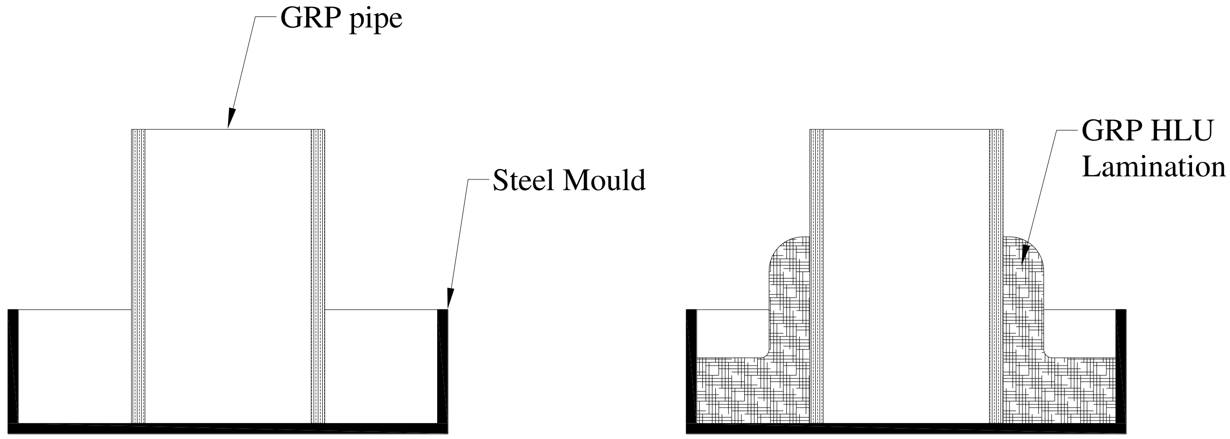
In both cases Ls is the length of the machined spigot end. It is advisable to machine the spigot before making the lamination and to protect the surfaces during the lamination of the ROJ.

If the TEE piece or the TEE joint is intended for sustaining the full axial load in the branch, as shown in the drawing in chapter 1 – "GENERAL STATEMENT", a special design is required, as per relevant standards (for instance the ISO 14692 - Section 3).

8. FLANGES

Flanges are used to connect the GRP-BRP pipes to valves, pumps and other equipment or to the pipes made of other materials.

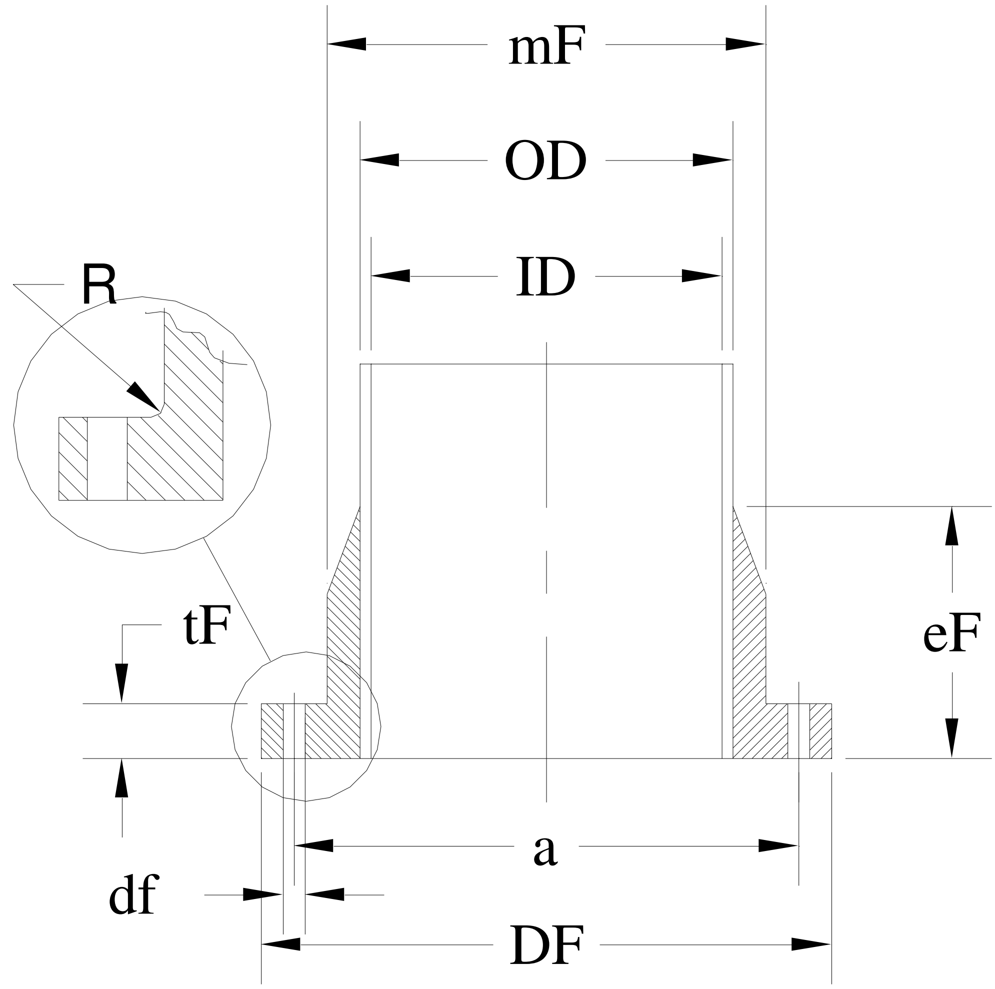
Flanged pieces can be made in the GRP-BRP, by laminating the layers (HLU) of the fiberglass tissues (mat and woven roving) over a GRP-BRP pipe stub and in an open ring mould. Two alternative manufacturing methods for the GRP-BRP flanges are: the injection moulding or the centrifugal cast or filament winding.



The topic of this chapter is limited to the HLU manufacturing.

Flanges can be either fixed or have a steel backing ring. The ring type flange is not required for the GRP-BRP pipe and sleeve coupling that have limited axial loads and resistance requirements. The sleeve coupling also allows for the rotation of the pipe and flange on its axis, making the flange installation and bolting easier.

The shape of the flange and the meaning of the symbols are shown in the following drawing:



The bolt circle diameter (a), the number of bolts, and the diameter of the bolt hole (d_F) are defined by the Flange Standards (ISO, AWWA, ANSI, DIN, UNI, etc.).

The thickness (t_F) of the GRP-BRP flange and of the hub reinforcement, as well as the extension of the hub reinforcement (e_F), should be calculated according to the design conditions. The extension of the hub reinforcement is related to the bonding length.

The gasket between the GRP-BRP flange and the mating flange or the equipment (the pump, strainer, etc.) can be a flat soft rubber gasket or an O-ring gasket. Generally, the O-ring gasket is used for the $ND \times PN \geq 6000$ (*ND mm* and *PN bar*). The O-ring gaskets have the groove inside the GRP-BRP flange.

The flat gasket should be a full face, in the 75 Shore A rubber, not fabric reinforced, with:

- 4 mm thickness up to ND=400 mm;
- 5 mm up to ND=800 mm;
- 6 mm up to ND=1600 mm;
- 7 mm for the larger pipe diameters.

The diameter of the O-ring gasket section is:

- 12 mm for ND<1200 mm;
- 17 mm for the larger pipe diameters.

The width of the groove is 18 mm and 25 mm respectively, and the depth is 7 and 10 mm respectively. The diameter of the O-ring depends on the bolting circle, as well as on the diameter of the groove.

Since the flat gaskets are in the soft rubber and the O-ring gasket are self-energizing, no high pre-stressing of the gasket is required.

8.1 Design "A" for the Parent Pipe Axial Strength

The hub of the flange is always connected through a sleeve joint.

The axial load on the flange itself (i.e. the load that stretches the bolts) is generally low, since the axial load, transferred from the sleeve coupling and from the pipe, is virtually zero. It is limited to the pressure on the ring surface between the pipe diameter and the diameter of the area of the reaction of the gasket load. This load acts only on the flange and is not transferred to the hub and to the pipe wall, since the pipe has no axial constrain.

A <u>simple practical design method</u> is outlined on the next pages.

TOPFIBRA suggests designing the flange in such a way, that it has the same strength as the parent pipe (U_{tAS}), defined by the Standards for the pipe wall (for an example, see the Table 11 of AWWA C950-01 or similar tables of the ASTM Standards or the National Standards), plus the strength due to the pressure on the flange face, between the pipe ID and the pipe OD.

The additional axial load due to the pressure is calculated as:

$$A_P = \pi \times \left(\frac{OD^2 - ID^2}{4} \right) \times P_d$$

where:

OD = the outer pipe diameter;

ID = the internal pipe diameter;

P_d = design pressure.

With this criteria, the length of the hub reinforcement (e_F) must be:

$$e_F = \left(\frac{1}{4} U_{t\,AS} + \frac{A_p}{\pi \times OD} \right) \frac{1}{\tau_d}$$

A safety factor (4) is included in the $U_{t\,AS}$ and for this reason, it is reduced 4x to make it congruous to the axial load due to the design (working) pressure.

For this calculation of the flange, the design shear strength (τ_d) of the pipe/hub overlapping can be taken (as 1 MPa), but it should be additionally verified by tests.

The flange itself is subjected to a complex flexural load, due to the load in the bolts, to compress the gasket and to keep it compressed with the water pressure on the mating faces of the flanges. A practical rule is to make the thickness of the flange ¼ of the hub reinforcement length:

$$t_F = \frac{1}{4} e_F \, .$$

The thickness of the hub reinforcement should be ½ of the thickness of the flange and therefore:

$$m_F = OD + t_F \, .$$

If the gasket is an O-ring gasket, the thickness of the flange calculated earlier, must be increased by the depth of the O-ring gasket seat.

8.2 Design for the Full Axial Load

If, due to the internal pressure, the full axial load is applied to the flange, the design load is much higher, since it reveals the pressure on the full disk of the blind flange, valve or other equipment connected to the flange.

$$A_{pB} = \pi \times \left(\frac{OD^2}{4} \right) \times P_d$$

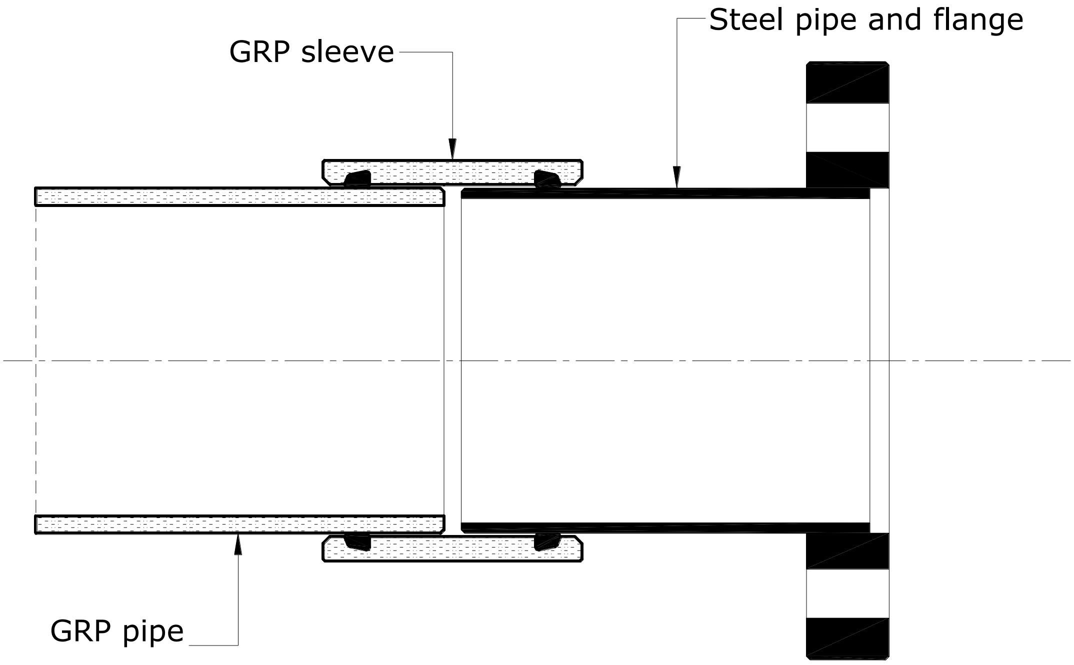
For example, for a ND 1000 pipe NP 10 bar, the design axial load for the **design "A",** is equal to the 300 kN, while for the **design "B",** it is equal to the 826 kN, which is more than twice as much. The real load in the **design "A"** (i.e. A_p) is actually very low (less than 50 kN).

The flange can be designed according to:

- ASME BPV: Section VIII, Division 1, Appendix 2 "Rules for bolted flange connection"
- ASME B 31.1: Appendix III "Rules for non-metallic piping";
- ASTM D 5421 "Standard Specification for Contact Moulded Fiberglass Flanges".

8.3 Connection with Different Materials

Pipes of different materials can be directly connected to the GRP-BRP pipe if their outer diameters are equal. Hence, the steel flanges can be used instead of the GRP-BRP flanges.



SEISMIC DESIGN FOR THE BURIED GRP-BRP PIPE

SEISMIC DESIGN FOR THE BURIED GRP-BRP PIPE

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1. EARTHQUAKE ACTION

During the design of the fiberglass pipes and pipelines, it is important to consider the seismic factor, which may negatively affect the product and its service. The seismic design and the need for it, are connected with the natural phenomenon the earthquake. The earthquake displays its action along the three space directions, but only two of them (vertical and parallel directions to the pipeline) have a practical effect.

1.1 Vertical Action

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

1.2 Parallel Action

The soil movement along the pipeline creates friction between the soil and the pipeline, which results in the sliding of the pipeline joints if they are Sleeve or Bell-and-Spigot Joints without a Locking Key. It can also result in the axial stress accumulation if the joints are Bell-and-Spigot Joints with a Locking Key or Reinforced Overlay Joints.

The earthquake action along the direction normal to pipeline and parallel to ground, is negligible.

2. SEISMIC ACCELERATION CALCULATION

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

$$a_v = \frac{F_v}{M} = m \cdot C \cdot I \cdot g$$

$$a_h = \frac{F_h}{M} = R \cdot C \cdot I \cdot g$$

Where:

av = the vertical acceleration in m/s2;

ah = the horizontal acceleration in m/s2;

m = the dimensionless coefficient, usually = 2;

C = the seismic intensity coefficient = (S-2)/100;

I = the seismic protection coefficient, usually = 1.2;

R = the response coefficient of the structure;

g = the gravity acceleration, which is 9.81 m/s2;

S = seismic grade (S>=2), usually = 9.

R (response coefficient) is assumed as a function of the fundamental period T_0 of the structure for oscillations along the considered direction:

When $T_0 > 0,8$ s $R = 0.862 / T_0^{0.667}$

When $T_0 < = 0.8$ s R = 1

In case of the indetermination of $T_{0,}$ a value of R equal to 1 (maximum value) should be assumed.

The vertical and horizontal accelerations due to the earthquake are:

$$a_v = 2 * (9 – 2) / 100 * 1.2 * g = 0.17 \text{ g} = 1.65 \text{ m/s}^2$$

$$a_h = 1 * (9 – 2) / 100 * 1.2 * g = 0.084 \text{ g} = 0.82 \text{ m/s}^2$$

The acceleration during the earthquake must be:

2.1 Vertical Action

$$av + g = 1.17g = 11.5m/s^2$$

2.2 Horizontal Action

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

3. CHECK OF PIPE BUCKLING DURING EARTHQUAKE

The vertical action increases the weights of the ground and live load affecting the pipeline. This condition determines a reduction of the safety factor to buckling.

The buckling is checked at the depth foreseen by the design, by using the following formula:

$$q_{ER} = q_R \cdot \frac{a_v + g}{g} \leq q_a$$

Where:

q_a = the allowable radial pressure, as, for example, calculated in the AWWA M45 Manual;

q_R = the radial external loads;

q_{ER} = the radial load increased for the earthquake effects.

4. SEISMIC GROUND STRAIN

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

$$\varepsilon_g^{'} = (T_g \cdot a_h)/(2 \cdot \pi \cdot v_s)$$

Where:

T_g = the seismic wave period in s;

a_h = the horizontal acceleration in m/s^2;

v_s = the propagation speed of the seismic wave in m/s.

5. AXIAL PIPE STRAIN

5.1 Restrained Joint (Bell and Spigot Double O-ring Lock Joint or Laminated Joint)

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

It is important to determine the pipe axial strain due to the earthquake, then add the strain due to the working pressure, and verify that the total strain is less than the axial allowable strain.

5.2 Unrestrained Joint (Sleeve or Bell and Spigot Double O-ring)

The Sleeve Joint and Bell and Spigot Double O-ring Joint do not transmit the axial stresses and allow for the rotation between a pipe length and its adjacent.

The pipe axial strain due to the earthquake must be determined. It is also important to check that the joint sliding does not allow the spigot to slip of out of the bell.

THRUST BLOCK DESIGN FOR THE BURIED GRP-BRP PIPE

THRUST BLOCK DESIGN FOR THE BURIED GRP-BRP PIPE

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1. ANCHOR BLOCKS

When buried pipes are installed with flexible joints (Bell-and-Spigot or Sleeve), it is necessary to arrange the suitable concrete anchor blocks for the elbows, tees, reducers, blind flanges, etc. Such anchor blocks can also be used when working with rigid joints (Locking Key joints or Butt-and-Strap laminated joints). They are designed to withstand the force exerted by the internal hydraulic pressure on those buried fittings.

2. ELBOWS

The force acts in the direction of the bi-setting line of the elbow:

$$F = 2 \cdot p \cdot A \cdot \sin\left(\frac{\beta}{2}\right)$$

Where:

P	= the test pressure in N/mm^2;
A	= the flow area in mm^2;
β	= the deviation angle.

3. SINGULAR POINTS (TEES - FLANGES - REDUCERS)

The force acts along the flow axis (entering at the particular point):

$$F = p \cdot (A - A_1)$$

Where:

A	= a section of a larger diameter;
A_1	= a section of a lower diameter (reduction);
A_1	= 0 in case of tees or blind flange.

4. EXECUTION

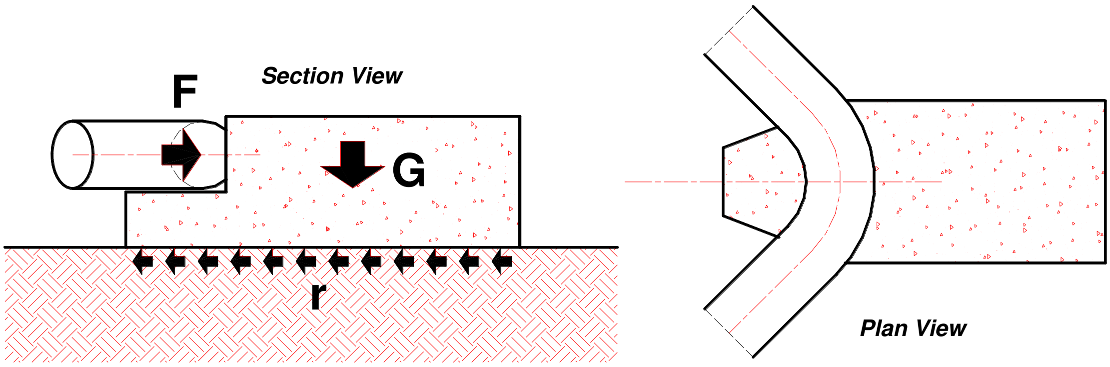
Anchor blocks can be performed in three ways:

- gravity;
- reaction;
- mixed.

NOTE: A rubber stripe (which is 10-30 mm thick and 150-200 mm long), must be placed between the pipe and concrete at the exit of the pipe from the anchor blocks.

5. GRAVITY ANCHOR BLOCKS

The gravity anchor blocks react only by friction with the soil plane. They are usually placed when the soil conditions ensure only friction forces. The anchor blocks are made in such a way that their own weight can oppose the force due to the pressure.

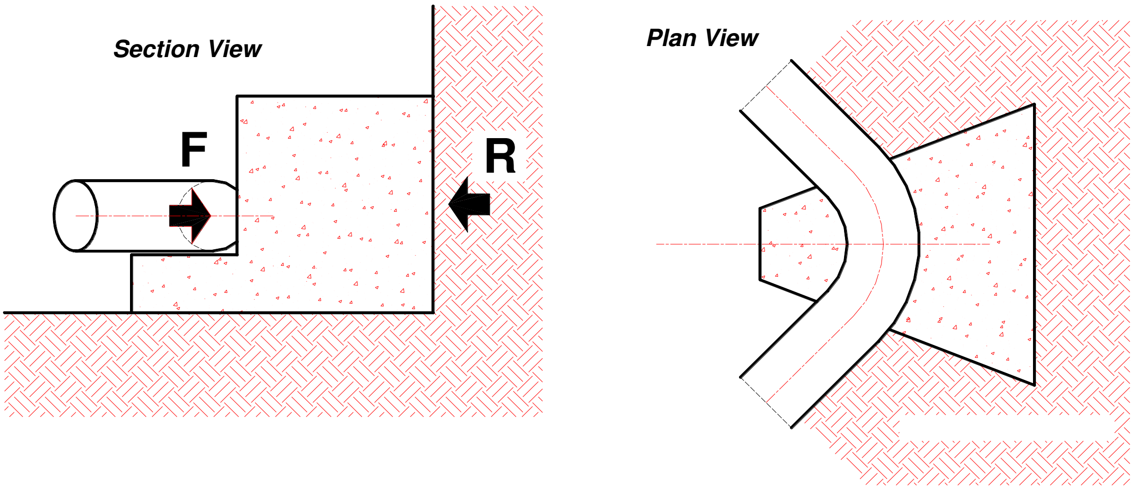


The water table must be taken into consideration, since it reduces the weight of the concrete block.

A proper friction coefficient concrete/soil should be selected in accordance with the soil type and conditions.

6. REACTION ANCHOR BLOCKS

The reaction anchor blocks are made when the soil possesses the stability characteristics (rocky ground, compact and firm soil). In particular, an adequate depth of cover not lower than 1 m is required.



Such anchor blocks work through the passive reaction of the soil. For this purpose, the blocks must be cast against a vertical wall of undisturbed soil.

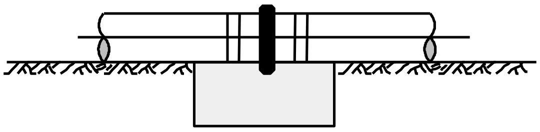
7. REACTION-GRAVITY ANCHOR BLOCKS

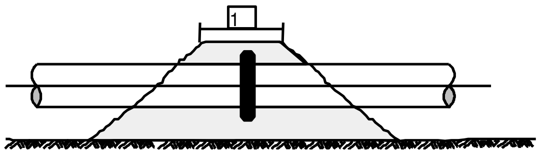
The reaction-gravity anchor blocks are placed when dealing with the mixed type soil (partially stable soil) and when it is possible to exploit the characteristics of the gravity and of the reaction anchor blocks.

NOTE: For each kind of the anchor block, care should be taken when compacting the surrounding ground and when stabilizing the ground below, if necessary.

8. LINE ANCHOR BLOCKS

The line anchor blocks are used to control the axial movements of the buried pipelines with flexible joints (bell-and-spigot or sleeve). Such movements might be caused by the pressure variations or by the thermal gradients. The anchor blocks can be placed under the pipe and connected to the pipe by using nylon strips.

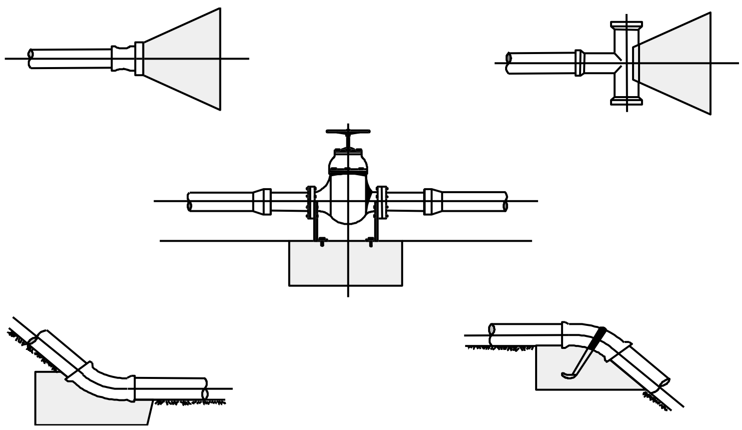




As an alternative, the anchor blocks can be made with the lean concrete (50-70 kg/m^3), for a suitable length, leaving the lean concrete flow according to its natural friction angle. In both cases, the pipe must have a rib in the GRP-BRP (which is 25 mm thick and 150 mm long).

9. TYPICAL ANCHOR BLOCKS

Some of the typical anchor blocks are shown on this picture. They can be used during the erection of the buried pipeline (altimetrical elbows, tees, blind flanges, etc.).



Valves should always be blocked in order to discharge stress to the soil, which happens due to the operation movements and thrusts when the valves are closed.

10. ANCHOR BLOCKS CALCULATION

In order to calculate the properties of the concrete thrust blocks, the following soil parameters must be taken into consideration:

- the internal friction angle;
- cohesion;
- specific weight;
- the friction coefficient of the concrete/soil;
- the passive soil reaction.

Types of soil	Internal friction angle (∅)	Cohesion [Pa]	Specific weight [N/m3]	Friction coefficient concrete /soil
Wet soils: silty clays and organic soils.	20° 25°	10000	18000	0.30
Sandy soils: clayey sands and sand.	30° 35°	5000 0	17000	0.50
Dry soils: gravel and crushed stone.	40°	0	16000	0.70

11. PASSIVE SOIL REACTION

The passive soil reaction against the concrete block is:

$$T_S = 0.5 \cdot \gamma_S \left(H_1^2 - H_2^2\right) \cdot B \cdot tg^2\left(45 + \phi / 2\right)$$

Where:

T_S = the soil reaction in N;

Υ_S = soil specific weight in N/m^3;

H_1 = the distance from the ground level to the concrete block base in m;

H_2 = the distance from the ground level to the concrete block top in m;

B = the width of the concrete block in contact with the undisturbed or well compacted soil in m.

ABOVEGROUND PIPELINE DESIGN

ABOVEGROUND PIPELINE DESIGN

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1. PRELIMINARY REMARKS

The GRP-BRP pipes produced with the TOPFIBRA Continuous Filament Winding (CFW) Machines are generally intended for the underground/buried applications.

These pipes have a Sleeve Joining System with rubber gaskets that does not allow the transfer of the axial load between one element and the subsequent element.

The axial strength of the pipes is proportionate to the stress in the Sleeve Joining System and to the axial loads arising from the manufacturing; from the handling; and from the below ground installation, including uneven soil support.

The axial strength of this type of the CFW GRP pipes is no less than the prescribed one by the International Standard (AWWA C-950 and ASTM) for this type of pipes.

TOPFIBRA Company also supplies the Discontinuous Filament Winding Machines for the production of the GRP pipes with an unlimited axial strength and with joining systems that allow the transfer of axial loads.

In case the CFW GRP-BRP pipes are used for the aboveground installation, special design considerations and the previously mentioned actual axial strength must be used in the calculation.

The Finite Elements Method (FEM) systems and programs are suggested for the stress analysis of the complex, above ground pipelines, subjected to the pressure and thermal stresses.

Aboveground pipelines are usually hung or supported at regular intervals.

The piping and its supports have to be designed to accomplish the pressure and the thermal length variation, as well as the bending loads, imposed by supports and spans.

2. INTERNAL PRESSURE CLASS

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

This method involves exposing a minimum of 18 pipe specimens to the constant internal hydrostatic pressures at different pressure levels in a controlled environment and measuring the time to failure for each of the pressure levels.

The test results are analysed by using the least square method.

The long-term hydrostatic strength is calculated at 50 years.

On the strain basis HDB:

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

Where:

P_C = the pressure class in MPa;

HDB = the hydrostatic design basis in mm/mm;

FS = the minimum design factor, which is 1.8;

t = mechanical thickness in mm;

D = the mean pipe diameter in mm;

E_h = the hoop tensile modulus of elasticity in MPa.

3. THE EXTERNAL PRESSURE OR VACUUM

The critical (buckling) pressure is calculated as:

$$P_C = \frac{E_h t^3}{4(1-\upsilon_{hl}\upsilon_{lh})R^3}$$

$$P_{ca} = \frac{P_c}{SF}$$

Where:

P_c = the critical buckling pressure in MPa;

P_{ca} = the allowable buckling pressure in MPa;

SF = the safety factor 2.5 for the transient condition (3.0 for the permanent condition);

E_h = the hoop tensile modulus of elasticity in MPa;

t = mechanical thickness in mm;

ν_{hl} , ν_{lh} = the Poisson's coefficients;

R = mean radius in mm.

4. THERMAL EXPANSION IN UNRESTRAINED PIPELINE

The variation of the pipeline length is determined by the following formula:

$$\Delta l = \pm \alpha l \Delta t$$

Where:

Δl = the length change in mm;

α = the thermal expansion coefficient 1.8×10^{-5} 1/°C (for the 54°winding angle);

l = the initial pipeline length in mm;

Δt = $T_d - T_i$ in °C;

T_d = the design temperature in °C;

Ti = the installation temperature in °C.

5. THERMAL END LOADS IN THE RESTRAINED PIPELINE

The end forces generated by the GRP-BRP pipes are lower when compared to those generated by the metal piping, because the GRP-BRP pipes have a lower longitudinal elasticity modulus.

The equation for calculating the thermal end load is:

$$F = \alpha \Delta t E A$$

Where:

F = the thermal end load in N;

A = the cross section area in mm^2;

E = the longitudinal modulus of elasticity in MPa.

6. SPAN LENGTH

The pipe span is defined as the distance between two pipe supports or anchoring devices.

The span length is limited by the following considerations:

- the maximum axial strain must not exceed the allowable value;
- the mid span deflection is < 1/500 of the span length.

The following table shows the maximum span length for the various diameters and pressure classes, for the discontinuous filament wound pipe with a 55° winding angle and at a temperature of 40°C.

ND	NP 6	NP 10	NP 16
25	-	-	2.0
50	-	-	2.5
75	-	-	3.0
100	-	-	3.0
125	-	-	3.5
150	-	-	3.5
200	-	-	3.5
250	-	4.0	4.5
300	-	4.0	4.5
350	4.0	4.5	5.0
400	4.0	4.5	5.0
450	4.0	4.5	5.5
500	4.0	4.5	5.5
600	5.0	5.5	6.0
700	5.0	5.5	6.0
800	6.0	6.0	6.0
900	6.0	6.0	6.0
1000	6.0	6.0	6.0
1200	6.0	6.0	6.0

When the specific gravity of the fluid is higher than the water specific gravity, the support span length must be reduced as:

$$L = L_0 J$$

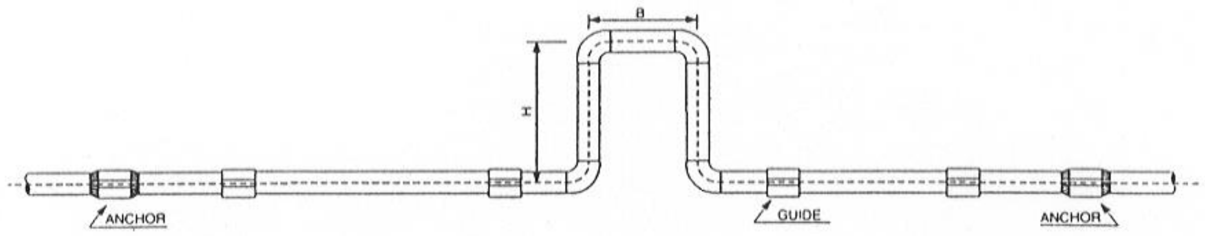
Where:

- L = the span length;
- L_0 = the standard span support;
- J = the specific gravity correction factor.

Specific gravity of fluid Kg/m^3	Correction Factor J
1000	1,00
1250	0,90
1500	0,85
1800	0,80

7. EXPANSION LOOPS

The expansion loops are designed by analysing the stress developed in a cantilevered beam with a concentrated load at the free end.



This analysis ignores the flexibility of the bends and the leg parallel to the line:

$$H = \sqrt{\frac{k \cdot \Delta L \cdot E_t \cdot D_e}{\sigma_1}}$$

Where:

H	= the leg length in mm;
K	= the coefficient 3 (for a guided cantilevered beam);
ΔL	= the length change in mm;
E_1	= the longitudinal modulus of elasticity in MPa;
D_e	= the external diameter in mm;
σ_l	= σ_{allow} - σ_p;

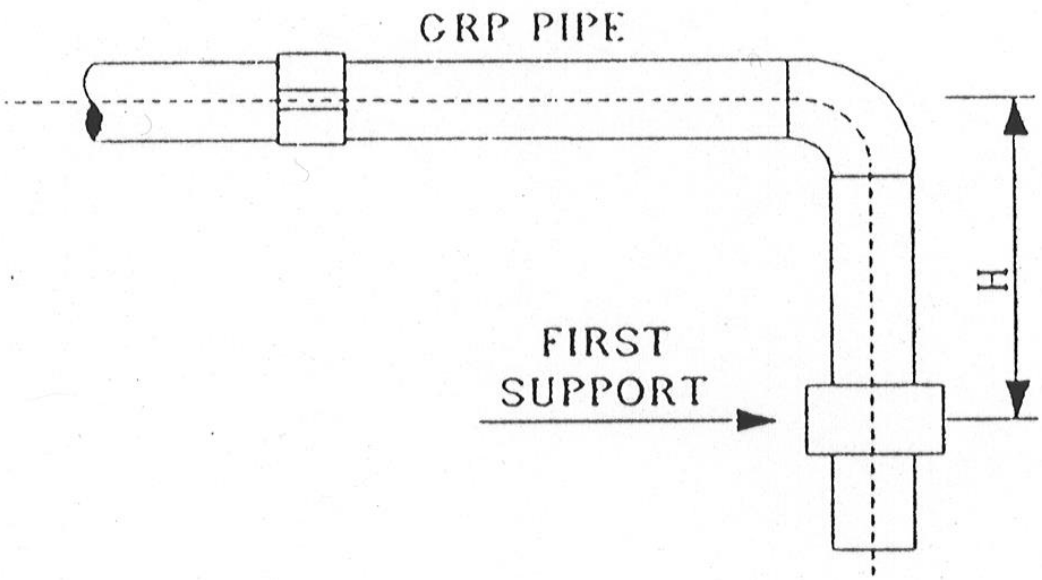
σ_l = the residual axial stress in MPa;

σ_{allow} = the allowable axial stress in MPa;

σ_p = stress due to the pressure in MPa.

The B length is usually assumed to equal 2 times the H length.

8. DIRECTIONAL CHANGES



Directional changes of the pipeline provide the same flexibility as the expansion loops.

The calculation of the length required to compensate a given expansion is equal to the one used for the loops using a *k* value equal to 1.5:

$$H = \sqrt{\frac{1.5 \cdot \Delta L \cdot E_l \cdot D_e}{\sigma l}}$$

Where:

H = the length from the direction change to the first support in mm;

ΔL = the length change in mm;

E_l = the longitudinal modulus of elasticity in MPa;

D_e = the external diameter in mm.

9. TYPICAL SUPPORTS AND ANCHORS

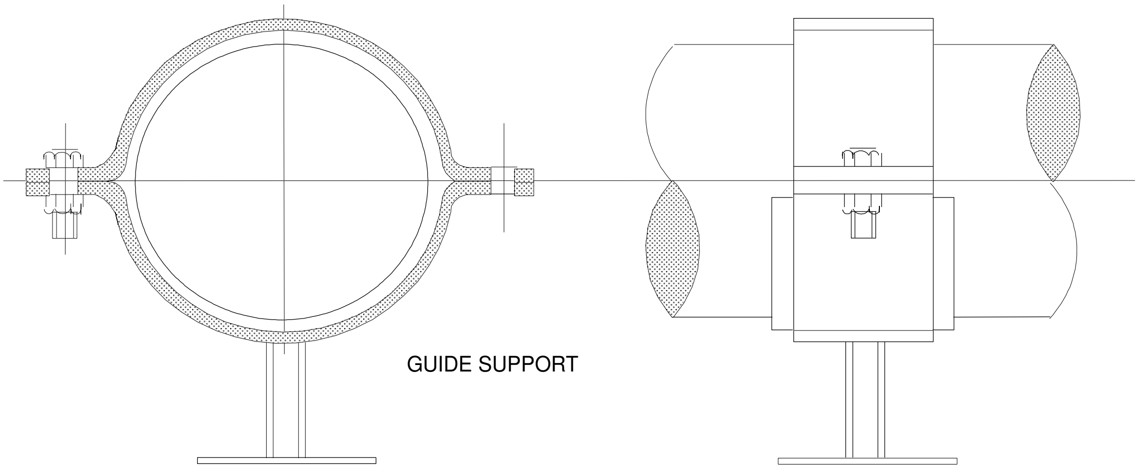
When the fiberglass pipes are supported, it is necessary to avoid the line contacts and point loads.

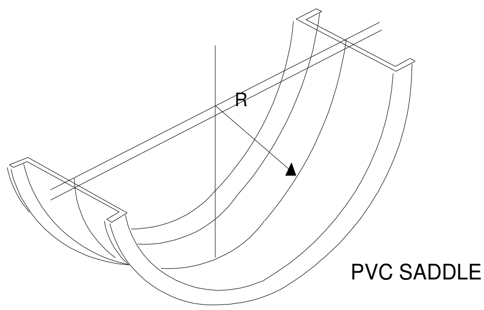
Thus, a PVC saddle is inserted between the pipe and the steel collar to allow free axial sliding of the pipe due to the thermal elongation.

Heavy equipment (valves, vents, etc.) must be supported independently in the horizontal and vertical direction.

Excessive loading in the vertical runs must be avoided.

Anchors prevent the pipe axial movement against the applied forces and can be installed in the horizontal and vertical directions.





LONG TERM PROPERTIES OF THE TOPFIBRA FIBERGLASS PIPE

LONG TERM PROPERTIES OF THE TOPFIBRA FIBERGLASS PIPE

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1. PRELIMINARY REMARKS

As already defined in the chapter: "GENERAL DESIGN SPECIFICATION", the mechanical properties of the fiberglass (stiffness and strength) are time dependant, which is the characteristic most plastic materials have.

The TOPFIBRA fibreglass pipe shows both creep and relaxation as all GRP-BRP pipes. That is why, several tests were made in order to ascertain and measure these phenomena, according to the relevant international standards.

The HDB (Hydrostatic Design Basis) and the Sb (Strain Basis) are both measures of the long term resistance of the GRP-BRP pipes.

"Long-term" generally means 50 years for the civil applications (the aqueducts and sewers) and 100,000 hours (11.5 years) for the industrial applications. However, there can be specific requirements for each project.

The HDB measures the long term resistance under a constant uniform stress, which is typical for the pipe subjected to the internal pressure of a fluid. It is generally expressed in terms of stress (hoop hydrostatic stress in the pipe wall), strain or also as pressure (the Pressure Design Basis – PDB).

The Sb measures the long term resistance under a constant flexural strain or stress, as in case of a buried gravity sewer pipe, which is deflected due to the soil load.

The HDB and the Sb are highly dependent on the characteristics of the internal liner of the pipe. Once the liner is damaged and flawed, the impermeability of the pipe is jeopardized, because the structural wall of the pipe is not completely impermeable due to the presence of a high quantity of the fibre reinforcement. For this reason the "failure" of a GRP-BRP pipe generally means the failure of the internal liner[11], shown as weeping, as a more visible spurt, or very rarely, as a sudden burst.

On the other hand, the strain in the liner is dependent on the stiffness of the mechanical wall (not considered as the Specific Transversal Stiffness of the pipe, but as the elastic modulus against the stress, induced by the internal pressure) and its viscoelastic/plastic degradation in time. An excess strain yields to damages and flaws in the liner.

[11] A part the case of failure due to the sudden elastic instability or excess of deflection, or, for above-ground pipe, due to the beam overload.

For a pipe with a monolithic wall structure, for example the classical discontinuous filament winding (DFW) pipe with 54° winding angle, the HDB is rather constant and predictable, and the results of the proof test for a certain diameter and pressure class can be deduced for a different pipe.

For a pipe with a sandwich wall structure, with an internal mortar core faced by two pure fibreglass skins, predicting the HDB is more complex. It depends on the thickness ratio between the skins and the core in addition to taking into the account the characteristics of each layer. It is also widely variable with the Pressure Class and the Stiffness Class of the pipe, since the pipe wall composition is different for each Pressure/Stiffness pair.

This is the case for the TOPFIBRA Continuous Filament Wound (CFW) pipe, but also for the DFW pipe with a similar sandwich structure.

It is practically impossible to have the HDB proof tests for every pipe that can be produced with the CFW machines, due to variety of different Pressure/Stiffness pairs and to the composition and the raw materials variants that can be implemented due to the flexibility of the machines and of the process. The resin system also has a strong influence.

The stress basis HDB can vary from 40 MPa for a stiff low pressure pipe with a high content of sand, to more than 200 MPa for a high pressure pipe without a sand core. If measured as *strain* rather than *stress*, the HDB spread is considerably reduced.

On the basis of many tests and years of experience with the Clients, TOPFIBRA developed a method to predict the HDB for each single pipe. The CFW Pipe Design Program supplied by TOPFIBRA, gives the predicted HDB for each designed pipe, and the regression line parameters. The Manufacturer can decide to make its own long term test campaign starting from that data.

The Sb value is more constant and mainly dependent on the characteristics of the internal liner, since the deformation is almost fixed, at least for the test according to ASTM D3681. If the reference standard is ASTM D5365, the characteristics of the structural wall have a bigger influence on the results of the test, but the used fluid is water instead of a strong acid. See chapter 3 – “INTERNATIONAL STANDARDS”.

2. USE OF THE HDB AND SB

HDB is used to determine the Pressure Class of the pipe, according to the used standard applying a Safety Factor (generally 1.8 to 2.5). The Pressure Class is calculated as (see the chapter: "GENERAL DESIGN SPECIFICATION"; Section 6.1 – Pressure Class):

$$P_c = \left(\frac{HDB_\sigma}{SF}\right)\left(\frac{2t}{d}\right),$$

for the stress basis HDB, or:

$$P_c = \left(\frac{HDB_\varepsilon E_h}{SF}\right)\left(\frac{2t}{d}\right)$$

For the strain basis HDB, where:

E_h = the hoop elastic modulus;

t = pipe thickness;

d = mean pipe diameter.

The *SF* safety factor is defined by the International Standards or by the Project Specification. The AWWA M45 "Fiberglass Pipe Design Manual" requires, for instance, the minimum Safety Factor of 1.8. Other Standards or Project Specifications can require different values of the safety factor.

Sb is used to verify the safety of the buried pipe subjected to the external soil load, as well as when combined with the internal pressure (see chapter: "GENERAL DESIGN SPECIFICATIONS" sections 9.2 – Strain in the Pipe Wall due to the Deflection, and section 9.3 – Pressure-Deflection Combined Loading). With reference to AWWA M45, it is common practice to calculate the allowable deflection (AWWA M45, section 5.7.2) applying the 1.5 Safety Factor and to verify the combined load due to the pressure stress and deflection (AWWA M45, section 5.7.4).

The allowable deflection is linked to S_b by the formula:

$$\varepsilon_b = D_f \frac{\Delta y}{D} \frac{t_t}{D} \leq \frac{S_b}{SF}$$

where the bending strain ε_b, due to the pipe deflection in buried condition $\frac{\Delta y}{D}$, should be lower than S_b divided by the Safety Factor (1.5 according to the AWWA M45). D_f is the shape factor depending on the pipe stiffness and the installation condition.

3. INTERNATIONAL STANDARDS

All international standards provide definitions and test methods for the HDB and SB.

Please see the chapter: “THE LIST OF THE STANDARD SPECIFICATIONS AND THE STANDARD TEST METHODS”, for an extended list of the applicable standards. The main source of those standards, and probably the source for all others, are:

ASTM D1598
Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure.

ASTM D2992
Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Fittings.

ASTM D3681
Standard Test Method for Chemical Resistance of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe in a Deflected Condition.

ASTM D5365
Standard Test Method for Long-Term Ring-Bending Strain of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe.

The ASTM Standard D1598 is the only method to measure the time-to-failure and is referenced by D2992.

Both ASTM D3681 and ASTM D5365 give as a result the strain basis S_b.

The main differences between the D3681 and D5365 are:

- in D3681, the specimens are subjected to a **constant deflection** and only the bottom inside part of the specimens (300 mm long pipe rings) is in contact with the test solution (like in the culvert of a sewer). The test solution is a quite strong acid;

- in D5365 the specimens are subject to a **constant load** and the whole specimen is immersed in the test solution, which is water.

The AWWA C950-01 Standard Specification requires the use of D5365, but also allows D3681 (since the test condition is more severe) or even the usage of the HDB instead of Sb, since HDB is generally lower than Sb.

4. FACTORS AFFECTING THE HDB AND SB

Several factors affect getting good HDB and Sb values in the manufactured GRP-BRP pipe. The main are:

- the characteristic of the resin selected for the product;
- a suitable curing system and mixing equipment for the resin;
- the curing temperature and time;
- quality of the liner reinforcement and its sizing (of the surfacing veil and the anti-diffusion glass mat barrier);
- cleanliness, the temperature and moisture of the working environment;
- quality and suitability of the winding machine and other equipment;
- professionalism and skills of the workers;
- quality control.

5. PREDICTION OF THE HDB AND SB

Due to the variety of the mentioned factors it is not easy to immediately predict, without any tests, the long term resistance of the GRP-BRP pipes produced in a specific manufacturing plant, with specific raw materials, curing system and environmental conditions.

Because of our experiences, gained in a number of the GRP-BRP pipe manufacturing plants all over the world, TOPFIBRA Company can provide the testing specification, suggestions and the starting point for determining the regression line for the HDB and Sb. Please see the chapters: “OBTAINING THE HYDROSTATIC DESIGN” and “OBTAINING THE STRAIN BASIS”.

If the raw materials are not the ones tested and recommended by TOPFIBRA, the raw materials manufacturers can also be considered as a source of information and useful data.

The suggested starting regression line and values for the HDB and S_b, according to TOPFIBRA experiences, are given in the CFW Pipe Design Program.

The figures should be confirmed by a test campaign, which has to be planned as soon as the plant is working.

OBTAINING THE HYDROSTATIC DESIGN BASIS FOR THE TOPFIBRA FIBERGLASS PIPE ACCORDING TO ASTM D2992, Proc. B

INTRODUCTION

As already defined in the chapter: "GENERAL DESIGN SPECIFICATION", the mechanical properties of the fiberglass (stiffness and strength) are time dependant, which is a characteristic most plastic materials have.

All the GRP-BRP pipes show both creep and relaxation. That is why, several tests were made in order to ascertain and measure these phenomena according to the relevant international standards.

Creep was investigated through the long term pressure tests according to ASTM D2992. Several specimens were loaded with a constant internal pressure (i.e. a constant stress) of different levels. For the creep phenomenon, the strain in the pipe wall increases continuously over time, leading to the pipe failure (leaking) after several hours. Failure points are recorded and analysed according to the standard.

The result of the test is approximately 35% decay in the failure stress after 10,000 hours, which is extrapolated to 45% after 50 years.

The design stress for the internal pressure is generally taken as **½** of the failure stress for 50 years, and thus, **¼** of the short term failure stress. This is also reflected by most standards that require a short time strength of the pipe wall in hoop direction, which is exactly 4 times the hoop stress for the pressure class. See, for example, the Table 8 of the ASTM D3517 Standard Specification, or the equivalent Table 10 of the AWWA C950 Standard.

The long-term failure stress due to the internal pressure is called the "Hydrostatic Design Basis" (HDB) and is often expressed as strain rather than stress. The long or short time failure stress varies considerably in the fiberglass pipes, since the structural pipe wall can be made with various structures, materials and reinforcements content. On the contrary, the failure strain is more constant. After all, an excess strain is the cause for most pipe failures, resulting as micro-cracks in the resin, debonding of the reinforcement, and weeping of the pipe without a catastrophic rupture of the reinforcement.

Reports and analysis of these tests can be found in separate documents included in the Engineering Handbook:

- chapter: "OBTAINING THE HYDROSTATIC DESIGN BASIS FOR THE DISCONTINUOUS FILAMENT WOUND PIPE ACCORDING TO ASTM D2992, Proc. B"
- chapter: "OBTAINING THE HYDROSTATIC DESIGN BASIS FOR THE CONTINUOUS FILAMENT WOUND PIPE ACCORDING TO ASTM D2992, Proc. B"

Both documents are relevant to the tests which were made a few years ago. The results were analysed according to the code revision that was in use during those years.

The test results have been newly analysed by TOPFIBRA, according to the revision of ASTM D2992 in use by 1996[12], in order to make the test results and the regression line comparable with the new tests. This allows the manufacturers of the fiberglass pipes, who is operating the TOPFIBRA machines, to immediately use the data of the TOPFIBRA tests for the validation of the medium term test results, while waiting for the availability of a complete set of the long term test results. This allows them to calculate their own regression line.

As a guidance for the validation of the earlier test results and for the completion of the long term test according to ASTM D2992, TOPFIBRA has edited the document (also included in this Engineering Handbook):

chapter: "TESTING PROGRAM FOR THE RECONFIRMATION OF THE HYDROSTATIC DESIGN BASIS ACCORDING TO THE ASTM D2992 STANDARD PRACTICE".

[12] The D2992 revision issued in 2006 does not change the principles and the method for determination of the HDB.

OBTAINING THE HYDROSTATIC DESIGN BASIS FOR THE DISCONTINUOUS FILAMENT WOUND FIBERGLASS PIPE ACCORDING TO ASTM D2992, Proc. B

OBTAINING THE HYDROSTATIC DESIGN BASIS FOR THE DISCONTINUOUS FILAMENT WOUND FIBERGLASS PIPE ACCORDING TO ASTM D2992, Proc. B

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1. SCOPE

Long term tests have been made with the scope of obtaining the long term mechanical characteristics of the "Plastiwind" FRP Pipe (the fiberglass reinforced polyester pipe) and their time-to-failure, compared to the short term values.

1.1. Applicable Documents

The tests have been made according to the ASTM – D 2992 STANDARDS "Standard Method for Obtaining Hydrostatic Design Basis for Reinforced Thermosetting Resin Pipe and Fittings", Procedure B (the static test), and the ASTM D 1598 "Standard Test Method for Time-to Failure of Plastic Pipe Under Constant Internal Pressure".

1.2. Summary of the Method

The procedure consists of exposing the pipe specimens to constant internal hydrostatic pressures of different levels in a controlled environment and measuring the time-to-failure for each pressure level. When the test specimen develops a leak or rupture, it is considered failed.

Average dimensions of the pipe samples are given in Table 1:

TABLE 1:

Nominal diameter	mm	150
Resistant internal diameter	mm	150.48
Mechanical resistant average diameter	mm	155.00
Nominal wall thickness	mm	4.50
Measured average thickness	mm	4.70
Liner thickness	mm	1.30
Mechanical resistant thickness	mm	3.00
Outer layer thickness	mm	0.20

2. PIPE CHARACTERISTICS

The pipes are produced by the filament winding process, according to ASTM D – 2996 (type 1 = filament wound, grade 2 = the polyester resin, class E = the reinforced polyester resin liner). Their nominal characteristics are:

- the inner liner reinforced with the "C" glass veil (33 g./ m^2) and the "E" type glass mat (450 g/ m^2);
- the mechanical resistant layer consisting of 3 crossed windings with 2400 Tex roving, with a 54° angle vs. the pipe axis and a 70% glass content by weight;
- the outer layer of the non-reinforced polyester resin.

3. TEST EQUIPMENT

3.1. Endcaps

To close the specimens, 6 pairs of the steel end-caps with a rubber toroidal O-rings were manufactured. The end-caps adhered to the internal wall of the pipes, due to their knurled surfaces, and transmitted the axial strength, which ensued from the internal pressure, to the specimens.

3.2. Constant Temperature System

The pipe specimens were tested in the air environment where the temperature was controlled.

3.3. Pressurizing System

Each specimen was connected with a thermally insulated steel cylinder, where an electric resistance was dipped. Once filled with water and vented, this system (composed of the specimen and the cylinder) was hand-pumped to reach the desired test pressure. Pressure should have been maintained for the duration of the test by a pressure switch, which controlled the electric resistance dipped in the cylinder.

4. TEST RESULTS

The obtained results are reported in following Table 2, where the following symbols have been used:

N = the specimen number;

P = the failure pressure in bar;

O = hours number;

s = hoop stress in Mpa;

h = log (o),

f = log (s).

TABLE 2

N	P	o	S	h	f
9	125	0.1	322.92	-1.3010	2.5091
21	115	0.1	297.08	-1.0969	2.4729
14	105	4.7	271.25	0.6721	2.4334
6	100	0.5	258.33	-0.3010	2.4122
13	95	0.1	245.42	-1.3010	2.3899
19	95	2.0	245.42	0.3010	2.3899
12	92	22.0	237.67	1.3424	2.3760
17	90	520.0	232.50	2.7160	2.3664
5	90	115.0	232.50	2.0607	2.3664
16	90	2580.0	232.50	3.4116	2.3664
11	90	2556.0	232.50	3.4076	2.3664
20	85	1422.0	219.58	3.1529	2.3416
4	80	816.0	206.67	2.9117	2.3153
3	80	230.0	206.67	2.3617	2.3153
2	80	7000.0	206.67	3.8451	2.3153
18	80	10000.0	206.67	4.0000	2.3153
7	75	13500.0	193.75	4.1303	2.2872

5. TEST RESULTS ANALYSIS

The straight line geometrical equation is calculated as:

$$h = a + b \cdot f$$

Where:

h = logarithm of the failure time;

f = logarithm of the failure stress.

Note that all logarithms are the common logarithms.

TABLE 3

N = number of the valid points	17
F = the average value of all "f"	2.3729
H = the average value of all "h"	1.7829
$W = \Sigma f \cdot h - N \cdot F \cdot H$	-1.5538
$V = \Sigma h^2 - N \cdot H^2$	59.6860
$U = \Sigma f^2 - N \cdot F^2$	0.0561
$b = W/U$	-27.6774
$a = H - b \cdot F$	67.5058

With these values, the tensile stresses at 1, 10, 100, 1000, 10.000, 100.000 hours and at 438.000 hours (50 years) can be calculated as per Table 4.

The Hydrostatic Design Basis is determined against the value at 100.000 hours, because the value at 50 years is not lower than 80% of the one relevant to the 100.000 hours.

Otherwise, HDB is determined against the value at 50 years.

The category of the specimen pipes is relevant to 25.000 psi (172.0 Mpa).

TABLE 4

HOURS	**STRESS**	**%1**	**%2**
1	274	100.00	151.54
10	252	92.02	139.45
1000	213	77.93	118.09
10000	196	71.71	108.67
100000	181	65.99	100.00
438000	171	62.56	94.81

6. ATTACHMENT – TNO Test report no 247/'87

Netherlands
organization for
applied scientific
research

KRI

TNO Plastics and Rubber
Research Institute

P.O.Box 71,
2600 AB Delft
Schoemakerstraat 97
Delft, The Netherlands

Telex 38071 zptno nl
Fax +31 15 56 63 08
Phone + 15 56 93 30

June 26, 1987

Report no 247/'87

GRP PIPE TESTING

Sponsor	Tubi Sarplast SPA Via Melchiorre Gioia 181 20125 MILAAN-Italie
References	letter dated april 16th 1982
Carried out by	Ir T.A. der Kinderen Department of Physics Section Mechanical Properties
Order Number KRI	200361024
File Number	FY 7318
Contents	1. INTRODUCTION 2. TEST AND RESULTS

plastics and rubber research institute tno

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1. INTRODUCTION

On the request of Tubi Sarplast S.A. Milan, Italia, a series of tests is carried out to obtain the hydrostatic designstress according to ASTM D2992, procedure B.(static) at ambient temperature (23°C). See letter april 16 1982. According to this letter, the pipe to de tested had the following characteristics:

The nominal size was 149.8+0.3 mm
The external diameter was 160.0±1 mm
Liner thickness: 1.2 mm

The tests were to be continued to a maximum of 10.000 hours. The pipes were received May 1982.

2. TESTS AND RESULTS

2.1 Dimensions

The dimensions of the pipe were determined, the results are given in Table 1.

The measurments were difficult to make accurately due to the irregular surface of the outside pipewall. Also the thickness of the nonreinforced outerlayer was irregular and difficult to determine. The exact dimensions are therefore somewhat uncertain.

For purposes of extrapolation in our opinion the nominal dimensions should be used, disregarding the possible presence of an outerlayer.

2.2 Endcaps.

Endcaps according to TNO, unsupported, were used for the internal pressuretest.

2.3 Testresults.

The testresults are summarised in Table 2.

Owing to the uncertainty in the dimensions the results are given as bar and hoopstresses, calculated on the measured dimensions, against time of failure.

TNO

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Table 1. Pipedimensions.

Pipe Nr.	wallthickness (mm) side A max.	side A min.	side B max.	side B min.	internal diameter (mm)	external diameter (mm)
1	5,40	4,20	5,05	4,20	150,5	159,9
2	5,00	4,30	5,40	4,10	150,5	159,9
3	5,00	3,95	4,90	3,90	150,5	159,3
4	5,80	4,30	5,10	4,20	150,2	160,0
5	5,00	3,85	4,80	3,90	150,4	159,1
6	4,80	3,95	5,20	3,90	150,6	159,5
7	5,10	4,30	5,00	4,20	150,0	159,3
8	6,90	5,10	5,40	4,30	150,0	160,8
9	5,50	4,35	5,10	4,30	150,4	160,0
10	5,40	4,18	5,40	4,10	150,4	159,9
11	5,40	4,30	5,40	4,35	151,1	160,8
12	5,50	4,70	5,50	4,40	150,9	160,9
13	5,30	4,00	5,00	4,10	150,4	159,6
14	5,00	3,80	4,90	3,95	150,6	159,4
15	6,20	5,10	5,50	4,40	149,4	160,0
16	5,05	4,05	5,00	4,10	150,6	159,7
17	5,50	4,30	5,20	4,25	150,5	160,1
18	5,05	3,95	5,00	4,20	151,3	160,5
19	4,60	3,85	4,95	3,85	151,2	159,8
20	5,50	4,35	5,30	4,10	150,4	160,0
21	4,80	4,10	5,30	4,00	150,2	159,3

TNO

plastics and rubber research institute tno

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Table 2 Summary of testresults

pipe nr.	test pressure (bar)	hoop stress (N/mm2)	time to failure hour	type of failure
9	125	316.3	0.05	weeping
21	115	322.0	0.08	weeping
14	105	316.6	4.7	pinhole
6	100	290.4	0.5	pinholes
13	95	266.0	0.05	pinholes
19	95	282.0	2	weeping
12	92	226.7	22	weeping
17	90	231.7	40/520	pinhole/weeping
5	90	265.7	115	weeping
16	90	252.1	2580	fracture in endcap X
11	90	228.9	2556	cracks
1	85	222.3	0,01	pinholes
20	85	230.2	1422	fracture
4	80	209.3	816	small cracks
3	80	232.0	230	fracture in endcap X
2	80	216.6	>10000 +)	-
18	80	229.5	>10000 +)	-
7	75	195.4	>13500 +)	-

+) Test discontinued.

TNO

OBTAINING THE HYDROSTATIC DESIGN BASIS FOR THE CONTINUOUS FILAMENT WOUND FIBERGLASS PIPE ACCORDING TO ASTM D2992, Proc. B

OBTAINING THE HYDROSTATIC DESIGN BASIS FOR THE CONTINUOUS FILAMENT WOUND FIBERGLASS PIPE ACCORDING TO ASTM D2992, Proc. B

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1. INTRODUCTION

This chapter contains the report of the long term test for the evaluation of the Hydrostatic Design Basis according to ASTM D2992, commissioned by ANYANG FLYING EAGLE GROUP Co. Ltd. for the Horizon Engineering Group Co. Ltd. in 1997.

The calculation scheme, supplied by TOPFIBRA, was used to analyse the test data.

2. REPORT OF THE LONG TERM TEST FOR THE EVALUATION OF THE HYDROSTATIC DESIGN BASIS ACCORDING TO ASTM D2992

GRP pipe

HDB (Hydrostatic Design Basis) Calculation

according to ASTM D 2992 (Proc. B) Standard Specification

Generality

Scope

The scope of long term test, commissioned by ANYANG FLYING EAGLE GROUP CO. LTD. to the testing laboratories is to ascertain the long term mechanical characteristics of GRP (Glass Reinforced Plastic) pipe produced by continuous filament winding machine, and the variation against short term values due to creep phenomena.

Standards

Tests were carried out according to ASTM D2992 "Standard Method for Obtaining Hydrostatic or Pressure Design Basis for Reinforced Thermosetting Resin Pipe and Fitting", procedure B (static), e ASTM D1598 "Standard Test Method for Time-To-Failure of Plastic Pipe Under Constant Internal Pressure".

Description

A set of specimens of the same of the same type of pipe are tested at different level of pressure and the time to failure is recorded for each specimen.

The failure happens when the pipe leaks.

The actual pipe dimensions, as measured by the testing laboratory, are shown in Table 1 attached to the present document. Mean and nominal values are the following:

Table 1		
nominal diameter	mm	500
outside AWWA diameter	mm	514
average measured outside diameter	mm	514.12
nominal wall thickness	mm	8.90
average measured wall thickness	mm	8.96
Internal liner thickness	mm	1.2
average mechanical resistant thickness	mm	7.56
outer coat thickness	mm	0.2
average mean mechanical resistant diameter	mm	506.17

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Pipe Characteristics

GRP pipes to be tested were manufactured in ANYANG FLYING EAGLE GROUP plant, in October 1997, and delivered to testing laboratories on 4th November 1997.

The pipe is produced by continuous filament winding according to ASTM D3517-96 and accordingly the designation is:

Type	1	glass-fiber-reinforced thermosetting polyesther resin mortar,
Liner	1	reinforced thermoset internal liner
Grade	2	polyester resin surface liner – non reinforced,
Class	C150	pressure class (150 psi - 10 bar)
Pipe Stiffness	D	72 psi / 5000 Pa

The nominal characteristics of pipe are the following:

- The innermost part of the liner is reinforced with 1 "C" glass surfacing veil (33 g/m^2) with a glass to resin ratio 10/90 by weight and a thickness of 0.27 mm.
- The second layer of the liner is reinforced with chopped "E" glass roving mat (400 g/m^2) with a glass to resin ratio of 30/70 and a thickness of 0.93 mm for a total thickness of the internal liner of 1.2 mm.
- The mechanical resistant wall is made of approximately:

  40% polyesther resin

  10% chopped glass fibre roving

  32% continuous glass fibre roving, hoop wound

  18% siliceous sand

  the above percentages are by weight.
- The outer coat is made by not reinforced resin with a thickness of 0.2 mm.

The resin used are standard isophtalic resins, normally used by ANYANG FLYING EAGLE GROUP.

Testing Equipment

- End cap
  The testing laboratories designed and realised 8 couples of restrained - end closures, with O-ring gaskets. The caps join to external part of the pipe and are connected by steel rods that sustain the full axial load. The pipe shall not be loaded axially .

4

- Thermostate environment.
  The specimens are put vertical in insulated box, conditioned by air.
- Pressurization
  Each specimen is connected to a steel cylinder, thermally insulated, containing a heating resistor.

The system is filled with water, deareated and pressurised to the testing pressure by means of a hand pump. The testing pressure is then governed by a manostat that acts on the heating resistor, using the water expansion to compensate pressure drops.

Test Results

Test results are in the attached Table 1.

Test Analysis

Please see the attached Tables 2, 3 and graph.

In Table 2 are summarised the test results and the log calculations according to ASTM Standard.

In Table 3 is evaluated the data suitability and the predicted failure stress at 100,000 hours and 50 years. Since that the value at 100,000 hours is less than 125% of the the value at 50 years, the value at 100,000 hours can be used as Hydrostatic Design Basis (HDB=146 MPa).

In Table 4 is calculated the lower confidence limit (L+F) that does not differ more than 15% from $f_{100,000}$. The data are suitable.

In the graph is plotted the regression line stress/time and the failure points. Since the y-axis scale is not logarithmic the line is not a straight line.

The relation stress strain is the well know:

$$\sigma = \varepsilon \cdot E$$

where:

σ stress;
ε strain or elongation;
E E-modulus.

From the equation we calculate the long term hydrostatic design strain, using the measured E-modulus and the long term hydrostatic stress above calculated

Being the E- modulus of tested pipe 18,000 MPa, and the HDB 146 MPa the long term hydrostatic design strain (also called HDB strain basis)is :

$$\varepsilon = \frac{\sigma}{E} = \frac{146}{18000} = 0.0081\,.$$

For pipe with different E-modulus, i.e. with different composition, but with same (or better) resin and liner, the long term hydrostatic stress is calculated with the above formula putting the actual measured E-modulus.

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The design strain or stress (strain or stress at the pressure class, used to design the pipe thickness for the internal pressure), is obtained dividing this value for the Factor of Safety generally taken between 1.8 and 2.5, depending on the International Standard or Client Specification used.

An allowable strain value of 0.0035 is used to verify the pipe in working conditions, where other loads are applied to the pipe together with the internal pressure, while a strain of 0.0025 is used to design the thickness for the internal pressure alone. This allows to use the pressure class as working pressure in most of the installation. A pressure class higher of the actual working pressure shall not be specified.

6

HDB Calculation according to ASTM D2992-B

Table 1 - Pipe Dimensions and Test Results

	Nominal	Average	
Nominal Diameter	500		mm
Outer Diameter (AWWA)	514	514,12	mm
Nominal Wall Thickness	8,90	8,96	mm
Resistant Wall Thickness	7,50	7,56	mm
Internal liner tickness	1,20	=	mm
Outer liner thickness	0,20	=	mm
Mean resitant diameter	506,10	506,17	mm
Hoop Tensile Modulus	18000 MPa		

Pipe Number	(1) Outer Diameter mm	(2) Wall Thickness mm	Test Pressure bar	Time to Failure h	(3) Hoop Stress MPa	
1	514,48	9,12	65,00	5	208,91	
2	514,94	9,33	65,00	8	203,57	
3	514,95	9,33	65,00	12	203,57	
4	514,03	8,91	65,00	4	214,56	
5	514,79	9,26	60,00	90	189,52	
6	513,25	8,56	60,00	201	207,41	
7	514,61	9,18	60,00	150	191,40	
8	513,77	8,79	60,00	120	201,16	
9	513,51	8,68	55,00	312	187,09	
10	514,16	8,97	55,00	345	180,16	
11	513,35	8,61	55,00	404	188,84	
12	513,53	8,69	55,00	307	186,84	
13	514,41	9,08	50,00	5600	161,51	
14	513,80	8,81	50,00	1580	167,19	
15	514,53	9,14	50,00	12000	160,30	(*)
16	513,90	8,85	50,00	9890	166,33	
17	512,93	8,41	45,00	12000	158,78	(*)
18	513,29	8,58	45,00	12000	155,13	(*)
19	515,09	9,40	60,00	2680	186,32	
20	514,54	9,15	60,00	3250	192,12	
21	514,96	9,34	60,00	5840	187,68	
22	514,14	8,97	60,00	3500	196,53	
23	514,41	9,09	58,00	7220	187,11	
24	513,88	8,85	58,00	8200	192,93	
25	513,85	8,83	82,00	0,01	273,49	

(*) Discontinued
(1) Measured according to ASTM D3567
Average of 5 readings
(2) Measured according to ASTM D3567
Average of 4+ readings at each end of the pipe
(3) Calculated on mechanical thickness

HDB Calculation according to ASTM D2992-B

Table 2 - Logs Calculation according to ASTM D2992-B, based on test results

Pipe nr.	Stress MPa	Time h	Used (*)	Log(stress) f	f^2	Log(time) h	h^2	fh
1	208,9	5	1	2,3200	5,3822	0,6990	0,4886	1,6216
2	203,6	8	1	2,3087	5,3301	0,9031	0,8156	2,0850
3	203,6	12	1	2,3087	5,3302	1,0792	1,1646	2,4915
4	214,6	4	1	2,3315	5,4361	0,6021	0,3625	1,4037
5	189,5	90	1	2,2777	5,1877	1,9542	3,8191	4,4511
6	207,4	201	1	2,3168	5,3677	2,3032	5,3047	5,3361
7	191,4	150	1	2,2819	5,2073	2,1761	4,7354	4,9657
8	201,2	120	1	2,3035	5,3063	2,0792	4,3230	4,7895
9	187,1	312	1	2,2720	5,1622	2,4942	6,2208	5,6668
10	180,2	345	1	2,2556	5,0879	2,5378	6,4405	5,7244
11	188,8	404	1	2,2761	5,1806	2,6064	6,7932	5,9324
12	186,8	307	1	2,2715	5,1596	2,4871	6,1859	5,6494
13	161,5	5600	1	2,2082	4,8762	3,7482	14,0489	8,2768
14	167,2	1580	1	2,2232	4,9427	3,1987	10,2314	7,1113
15	160,3	12000	1	2,2049	4,8617	4,0792	16,6397	8,9943
16	166,3	9890	1	2,2210	4,9327	3,9952	15,9616	8,8732
17	158,8	12000	1	2,2008	4,8435	4,0792	16,6397	8,9775
18	155,1	12000	1	2,1907	4,7992	4,0792	16,6397	8,9363
19	186,3	2680	1	2,2703	5,1541	3,4281	11,7521	7,7827
20	192,1	3250	1	2,2836	5,2147	3,5119	12,3333	8,0196
21	187,7	5840	1	2,2734	5,1684	3,7664	14,1859	8,5626
22	196,5	3500	1	2,2934	5,2598	3,5441	12,5604	8,1280
23	187,1	7220	1	2,2721	5,1624	3,8585	14,8883	8,7670
24	192,9	8200	1	2,2854	5,2231	3,9138	15,3179	8,9447
25	273,5	0,01	0	0,0000	0,0000	0,0000	0,0000	0,0000

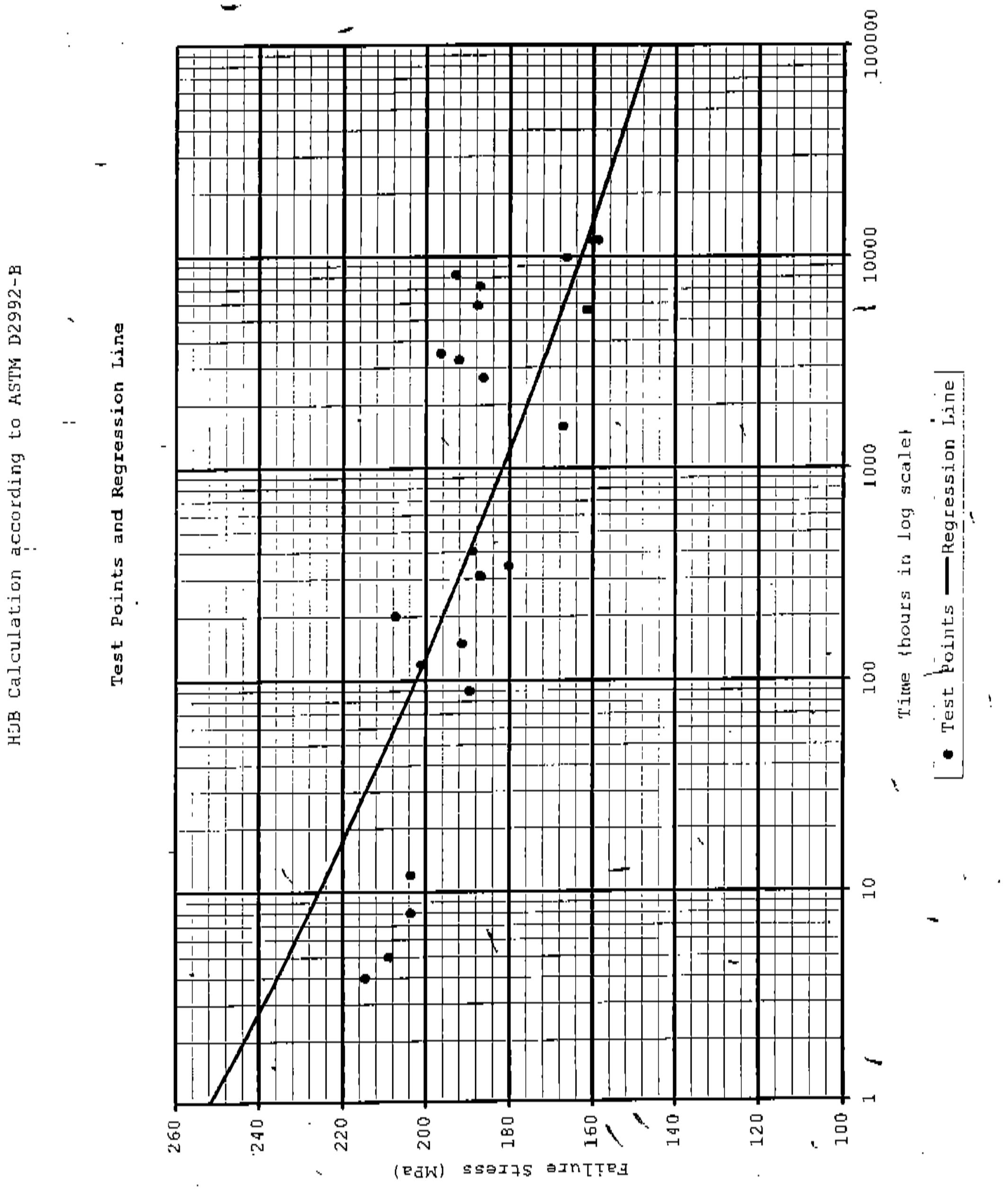
HDB Calculation according to ASTM D2992-B

Table 3 - LEAST SQUARES CALCULATIONS FOR LONG-TERM HYDROSTATIC STRENGHT (according to ASTM D2992 - Annex A1)

f	see Table 1	logarithm(10) of failure stress
h	see Table 1	logarithm(10) of hours-to-failure
N	24	number of failure point included in the analysis
S f	54,45115	
S f^2	123,57636	
S h	67,12394	
S h^2	217,85283	
S fh	151,49132	
F	2,26880	arithmetic average of f values
H	2,79683	arithmetic average of h values
U	0,03772	
V	30,11852	
W	-0,79933	
b	-21,19093	"b" is negative: the data are suitable for evaluating the material
a	50,87477	
f 100,000 h	2,16483	logarithm(10) of failure stress at 100,000 hours
LTHS	146,16 MPa	failure stress at 100,000 hours
f 50 years	2,13456	logarithm(10) of failure stress (MPa) at 50
S50	136,32 MPa	failure stress at 50 years
125% S50	170,40 MPa	LTHS < 125% S50 - HDB=LTHS
HDB	146,16 MPa	

Table 4 - CALCULATION OF 95% LOWER CONFIDENCE LIMIT (according to ASTM D2992 - Annex A3)

D	2,20317	
s^2	0,59909	variance
s	0,77401	standard deviation
t	2,07390	Sudent's t Statistic
M	380,74465	"M" is positive: the lower confidence limit can be calculated
L	-0,17331	
L+F	2,09549	
	124,59 MPa	95% lower confidence limit at 100,000 h
	14,8%	difference from LTHS


HDB Calculation according to ASTM D2992-B
Test Points and Regression Line
Time (hours in log scale)
Failure Stress (MPa)
Test Points
Regression Line
1
10
100
1000
10000
100000
260
240
220
200
180
160
140
120
100

TESTING PROGRAM FOR THE RECONFIRMATION OF THE HYDROSTATIC DESIGN BASIS ACCORDING TO THE ASTM D2992 STANDARD PRACTICE

TESTING PROGRAM FOR THE RECONFIRMATION OF THE HYDROSTATIC DESIGN BASIS ACCORDING TO THE ASTM D2992 STANDARD PRACTICE

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1. SCOPE

The ASTM D2992 "Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Fittings" states in Section 4.6 (edition 1996) – "Reconfirmation of HDB or PDB":

4.6 *Reconfirmation of HDB or PDB for Altered Constructions*—When a product already has an HDB or PDB determined in accordance with this practice and a change of process or material is made, a reconfirmation of the original HDB or PDB may be attempted in accordance with Section 12. At least six specimens must be tested and meet the specified criteria.

Already available test results (regression line and the confidence limits) are used to verify and validate the newly obtained test results.

TOPFIBRA puts at their Client's disposal the results of the tests executed in the past on the products manufactured with the TOPFIBRA machines and according to the TOPFIBRA technology and know-how.

This enables the Manufacturer to quickly verify whether the test results (the failure points) fall in the range allowed by the ASTM Standard. This is done with the reference to the TOPFIBRA regression line and curves. The reconfirmation test lasts 1 ½ month and maximum 3 months, when the groundwork, the data analysis and contingencies are included.

Afterwards, the Manufacturer should perform the tests for obtaining their own regression line, while using the TOPFIBRA HDB for the design of their pipes.

When major changes in materials, a manufacturing process, or liner reinforcement and/or thickness occur, the Manufacturer that has already obtained their own regression line, should plan a new testing campaign for the reconfirmation and eventually for the amelioration of the Hydrostatic Design Basis.

The testing campaign can be first made internally and eventually with the supervision and witnessing of an external authority, or it can be commissioned from an external certified testing laboratory.

On the basis of the test results it is possible:

- to plot a new regression line and calculate a new value for the HDB if the newly obtained test results satisfy the requirements of the standard;
- using an interim HDB (when planning a complete testing program).

To perform the test, it is necessary to obtain at least three valid failure points for both sets of the specimen which is subject to the testing pressure (±1.4 bar), leading to a failure in 10 to 200 hours for the first set and to a failure after more than 1000 hours for the second set.

Please note, that the calculation method for the regression line was revised in ASTM D2992, 1996 edition (with a few editorial corrections in 1999, 2001 and 2006). These modifications are mainly formal and relative to the statistical method. However, they lead to slightly different results and the regression lines equations are different, now giving the stress in function of the time-to-failure. In the previous release of the Code the regression line was expressed as time-to-failure in the function of the stress.

For this document and recommendation, TOPFIBRA has recalculated the regression line and updated the old analysis in compliance with the last edition of the Code, using the previous test data.

2. TERMS AND SHORTS

RL	Regression Line;	It is the statistical line, showing the anticipated failure stress (or pressure) in the function of the time-to-failure, calculated using the least squares method.
TF	Time-To-Failure;	
CL	The 95% Confidence Limit (Upper And Lower);	*It is an area, bound by two statistical lines around the regression line. There is a 95% probability that the mean value of the failure stress for a certain time will fall in this area.*
LCL	The Lower Confidence Limit;	*It is the lower curve for the confidence limit. The probability that the failure stress for a given time-to-failure is over this curve is 97.5%.*
PL	The 95% Prediction Limit (Upper And Lower);	*Same as CL, but for a single failure point.*
LPL	The Lower Prediction Limit.	*Like LCL for the prediction limit.*

3. REFERENCE STANDARDS

ASTM D1598
Standard Test Method for Time-to-Failure of Plastic Pipe under Constant Internal Pressure

ASTM D1599
Standard Test Method for Resistance to Short-Time Hydraulic Failure Pressure of Plastic Pipe, Tubing and Fittings

ASTM D2992
Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Fittings

4. END CLOSURES

Depending on the type of the pipe the end closures can be:

- free-end closures;
- restrained-end closures.

4.1. Free-End Closures

Free-end closures (either the mechanically fixed fittings, the fibreglass end-caps laminated on the specimen, or a flanged-end with a blind flange) can be only used for the pipes with an axial strength equalling at least ½ of the hoop strength. Since the specimens with free-end closures are stressed by the internal pressure in axial and hoop directions. The hoop stress being 2 times the axial stress.

Typically, free-end closures are used for the double helix reciprocal filament wound pipe with the winding angle as low as 55°, measured from the pipe axis.

4.1. Restrained-End Closures

Restrained-end closures are used for the pipes with a low axial strength, such as the pipes manufactured with the continuous filament winding or on the reciprocal filament winding machine but with higher winding angles. Due to a low friction in the sealing gaskets, the specimens are subjected only to stress in the hoop direction.

The obtained long term strength is referred only to the hoop direction, but this kind of pipes are intended to sustain only a limited axial load.

These closures generally have one or more tie-rods, linking the two closures together and carrying all the thrust on the end closures.

5. SPECIMENS

The reconfirmation test requires at least 6 valid failure points. 3 of them must fail in the laps from 10 to 200 hours and other 3 in more than 1000 hours (42 days).

It is advisable to provide a higher number of specimens to assure that the required number of valid failure points is reached. The failure points can be used in the analysis of the results. Generally, the more testing points are available the better the results of the test, since the dispersion of the points around the average line is lower (and thus, the coefficient of correlation is better).

The net length between the end closures of the specimens is:

- for ND ≤ 150 mm 5xND ≥ 300 mm;
- for ND > 150 mm 3xND ≥ 760 mm.

It is recommended to use a tapered zone outside the minimum required net length, thickened and reinforced with the wrapped mats which are impregnated with resin, in order to avoid local cracks near the end closures. The Code allows to discard (or to repair) the failure point if the leakage is within one diameter distance from an end-closure. But this foresight reduces the risks of premature and undesirable failures.

6. FAILURE DEFINITION

A specimen fails only if there is leakage or weeping of the tested medium.

If there is a visible external crack or delamination without leakage or weeping, the test can continue.

A specimen with a failure within one diameter from the end closures can be discarded or repaired and the test can continue, but the internal surface of the specimen should be carefully examined to find the crack that caused the leakage. Sometimes, the outer leakage can appear a certain distance away from the internal liner crack. A crack in the end-zone can lead to a leak in the middle of the specimen, and vice versa. Only if the failure is due to an end-effect, the specimen can be rejected from the analysis.

7. TESTING PRESSURE

It is possible to calculate the failure pressure in a function of the time-to-failure using the available regression line and the characteristics of the tested pipe.

The main dimensional and mechanical (short time) characteristics of the pipe have to be known:

Internal diameter	D	mm;
Total thickness	t_t	mm;
Reinforced wall thickness	t_r	mm;
Hoop E-modulus	E_H	mm;

Specific values should be used for each specimen, but the average values obtained from many specimens can also be used without appreciable errors.

The hoop E-modulus (at the pipe pressure rating) can be theoretically calculated with the computer programs supplied by TOPFIBRA. It should be confirmed by tests (see the relevant testing specification in Quality Control and Testing Handbook).

The hoop failure stress at any time-to-failure is obtained by the following equation:

$$V(t) = \left(\frac{E_H}{E_{H_0}} \right) \times 10 \hat{} \left(\frac{\log(t) - a}{b} \right)$$

where (using the symbols of ASTM D2992):

$V(t)$ = failure stress at time *t* in Mpa;

t = time-to-failure in hours;

a = the regression line parameter, intercept on the Y axis;

b = the regression line parameter, slope;

E_{H_0} = the hoop E-modulus for which the regression line parameters are given.

The correction factor $\left(E_H / E_{Ho} \right)$, which is the ratio between the hoop modulus of the pipe under test and the hoop modulus relevant to the available regression line, is necessary to make the data comparable.

The predicted failure pressure for time *t* can be calculated as:

$$p_f(t) = \frac{2t_r \cdot V(t)}{D}.$$

The lower and upper prediction limits can also be calculated in order to better estimate the pressure levels for the test, as shown in the Excel worksheet supplied by TOPFIBRA. An example of the calculation for the TOPFIBRA FW pipe is given in the following Tables, taken from the worksheet:

Reconfirmation of HDB for FW - VEM pipes

Pipe to be tested (restrained ends closures)		
Nominal Diameter	300	mm
Internal Diameter	300	mm
Nominal Wall Thickness	5.07	mm
Resistant Wall Thickness	4.04	mm
Liner tickness	0.83	mm
Mean Diameter	305.7	mm
Winding Angle	65	°
Hoop E-Modulus	27550	MPa

Predicted pressure level vs. time to failure

Time to Failure	*10*	*100*	*200*	*1000*	*2000*	*10000*	*hrs*
Failure stress 55°	267.0	246.7	240.9	228.0	222.7	210.7	MPa
Failure stress 65°	319.8	295.5	288.6	273.1	266.7	252.4	MPa
Failure pressure	86.1	79.6	77.7	73.6	71.8	68.0	bar

95% Prediction Limit

Time to Failure	*10*	*100*	*200*	*1000*	*2000*	*10000*	*hrs*
lower PL stress 55°	230.8	213.6	208.5	196.7	191.7	180.3	MPa
lower PL pressure	74.5	68.9	67.3	63.5	61.8	58.2	bar
upper PL stress 55°	308.8	284.9	278.4	264.3	258.6	246.3	MPa
upper PL pressure	99.6	91.9	89.8	85.3	83.4		bar

95% Confidence Limit

Time to Failure	*10*	*100*	*200*	*1000*	*2000*	*10000*	*hrs*
lower CL stress 55°	260.6	241.3	235.5	222.0	216.3	203.3	MPa
lower CL pressure	84.1	77.9	76.0	71.6	69.8	65.6	bar
upper CL stress 55°	273.5	252.2	246.5	234.2	229.2	218.4	MPa
upper CL pressure	88.2	81.4	79.5	75.6	74.0	70.4	bar

From these tables it is clear that the failure stress for a given time period is quite scattered. So it could be difficult to obtain the desired failure point. For example, the 95% prediction interval at 1000 hours is 63.5 to 85.3 bar: which is ±15% of the mean value. On the contrary, for the time-to-failure passing from 1000 to 2000 hrs (a 100% increase) the mean anticipated failure pressure should decrease from 73.6 to 71.8 bar: which is only -2.5%! This fact is due to the flattening of the regression line as time increases.

For this reason, we suggest using more specimens than the required minimum, starting with a higher pressure and shorter time. On the basis of the first results, the pressure for the 1000 hrs specimens should be adjusted.

If, for example, the mean time-to-failure of the 10-200 hrs test is considerably longer that predicted and the failure points are less scattered, the failure stress for the 1000 hrs specimens can be increased in order to avoid excessively extending the test. Otherwise, some non-failure points can be forcefully used as the failure points, thus giving a computed regression line. This line is worse than the actual one. The best solution is to use two or more sets of three specimens, which are tested at different pressure levels around the mean anticipated pressure level at 1000 hrs.

If only three couples of end closures are available, the first test is performed for the 100 hr mean pressure.

This is the case for the tests carried out outside or when it is necessary to free the equipment for other tests. If the tests can be prolonged without restrictions, any non-failed point can be used for the reconfirmation of the LTHS and HDB and for the calculation of a new provisional regression line, which will be updated as soon as new failure points become available.

Any failure point, satisfying certain requirements, can be added to the set of data used to calculate the regression line.

Once a complete set of new data for the new product is available (satisfying the Standard requirements), the old data can be cancelled and the new LTHS, HDB and regression line can be calculated for the product.

8. PRELIMINARY TESTS

Before giving the specimens to an authorized testing laboratory or before officially starting the test, it is advisable to make some internal tests in order to check the failure stresses at the short time periods and the condition, whether the requirements of the ASTM Standard for the applicability of the procedure are fulfilled.

9. APPLICABILITY

The reconfirmation procedure is applicable, according to ASTM D2992, if the following conditions are fulfilled:

- the average failure point for each stress or pressure level falls on or above the 95 % lower confidence limit of the given regression line;
- the first individual failure point of each stress or pressure level falls on or above the 95% lower prediction limit of the given regression line;
- no more than two thirds of the individual failure points fall below the given regression line.

Or alternatively:

- all failure points fall above the 95% lower confidence limit of the given regression line;
- at least two points exceed 3000-hour time-to-failure.

The applicability of the reconfirmation procedure should always be confirmed, since the improvements and refinements in the TOPFIBRA manufacturing technologies and in the raw materials properties in recent years, have led to ever better performances of our products.

If, unfortunately, this should not happen, the reasons of the event shall be investigated.

If, on the contrary, major changes in the manufacturing process or in the raw materials have taken place due to the special design requirements, this leads to a justified lower strength of the laminate. Thus, a new regression line shall be determined according to the ASTM code.

According to ASTM D2992, while the new test program is under way, an interim HDB for the material or the process change may be taken as the lowest of the following:

- a 95 % lower confidence limit of the value obtained by extrapolating the failure points to 438 000 h (50 years) by the ASTM D2992 Annex A1 procedure;
- a 95 % lower confidence limit of the given regression line at 50 years.

To estimate the long term strength of the material, for the preliminary design purposes, the reduction characteristic of the short/medium term strength can be applied to the long term strength conditions. It is only feasible, provided that the data is lower than the data mentioned earlier. However, this is not in line with the Code requirements.

10. EQUIPMENT

Equipment and instrumentation may vary depending on the availability of the items at the Manufacturer's factory or the testing laboratory.

The minimum required equipment is:

- the end closures, free ends or restrained ends. For the small diameter pipes, tested at a full axial load, the fiberglass end cap, laminated on the specimen, can be a convenient solution, provided that the built end caps and the lamination are much stronger than the pipe;
- the pressurization system;
- the temperature control system.

11. DATA ANALYSIS

The test data can be analysed by the TOPFIBRA computer program, following the instructions of the Appendix A of ASTM D2992.

12. STARTING THE REGRESSION LINE AND THE CONFIDENCE/PREDICTION LIMITS

The starting parameters for the reconfirmation of the HDB according to the ASTM D2992 Standard Annex A.1 are given for two sample cases.

The actual parameters are given for each pipe in the Pipe Design Programs.

All symbols are in compliance with the ASTM Code.

The regression line equation is:

$$y = a - bx$$

Where:

$x = \log_{10} t$ (*t* being the time to failure in hours),

$y = \log_{10} V$ (*V* being the failure stress in Mpa).

12.1. For the Discontinuous Filament Winding Process

- Functional Relationships:

y		Logarithm (10) of failure stress
x		Logarithm (10) of hours-to-failure
n	17	number of failure points included in the analysis
Sum(y)	40.7883	
Sum(y^2)	97.9347	
Sum(x)	30.4681	
Sum(x^2)	114.9535	
Sum(xy)	71.3728	
Y	2.3993	arithmetic average of y values (stress)
X	1.7922	arithmetic average of x values (time)
Sxy	-0.1017	the sum is < 0: the data are suitable
Syy	0.0042	
Sxx	3.5498	
r_{min}	0.6055	
r	0.8369	$r > r_{min}$: the data are suitable
λ	0.0012	
b	-0.0342	slope of the regression line
a	2.4607	intercept of the regression line

- Calculation of the Variances:

σ_δ^2	0.6562	error variance
τ	0.0011	
D	3.05E-05	
B	-5.47E-05	
C	3.05E-05	variance of b
A	1.89E-04	variance of a
σ_ε^2	0.00077	error variance
t_v	2.1315	student t_v

- Long Term Hydrostatic Strength at 100,000 hours:
  - LTHS 195 Mpa
  - HDB 172 Mpa

- Long Term Hydrostatic Strength at 50 years:
  - LTHS 185 Mpa
  - HDB 172 Mpa
  - HDB_{strain} 0.75%

- The Confidence Limits:

Time Hours	Mean Mpa	LCL Mpa	LPL Mpa
1	289	280	248
10	267	261	231
100	247	241	214
1,000	228	222	197
10,000	211	203	180
100,000	195	186	165
438,000	185	175	155

12.2. For the Continuous Filament Winding Process

- Functional Relationships:

y		Logarithm (10) of failure stress
x		Logarithm (10) of hours-to-failure
n	24	number of failure point included in the analysis
Sum(y)	54.4510	
Sum(y^2)	123.5757	
Sum(x)	67.1239	
Sum(x^2)	217.8528	
Sum(xy)	151.4901	
Y	2.2688	arithmetic average of y values (stress)
X	2.7968	arithmetic average of x values (time)
Sxy	-0.0333	the sum is < 0: the data are suitable
Syy	0.0016	
Sxx	1.2549	
r_{min}	0.5145	
r	0.7503	$r > r_{min}$: the data are suitable
λ	0.0013	
b	-0.0354	slope of the regression line
a	2.3678	intercept of the regression line

- Calculation of the Variances:

σ_δ^2	0.3418	error variance
τ	0.0002	
D	3.79E-05	
B	-1.06E-04	
C	3.79E-05	variance of b
A	3.32E-04	variance of a
σ_ε^2	0.00043	error variance
t_v	2.0739	student tv

- Long Term Hydrostatic Strength at 100,000 hours:

  LTHS 155 Mpa

  HDB 138 Mpa

- Long Term Hydrostatic Strength at 50 years:

  LTHS 147 Mpa

  HDB 138 Mpa

HDB_{strain} 0.77%

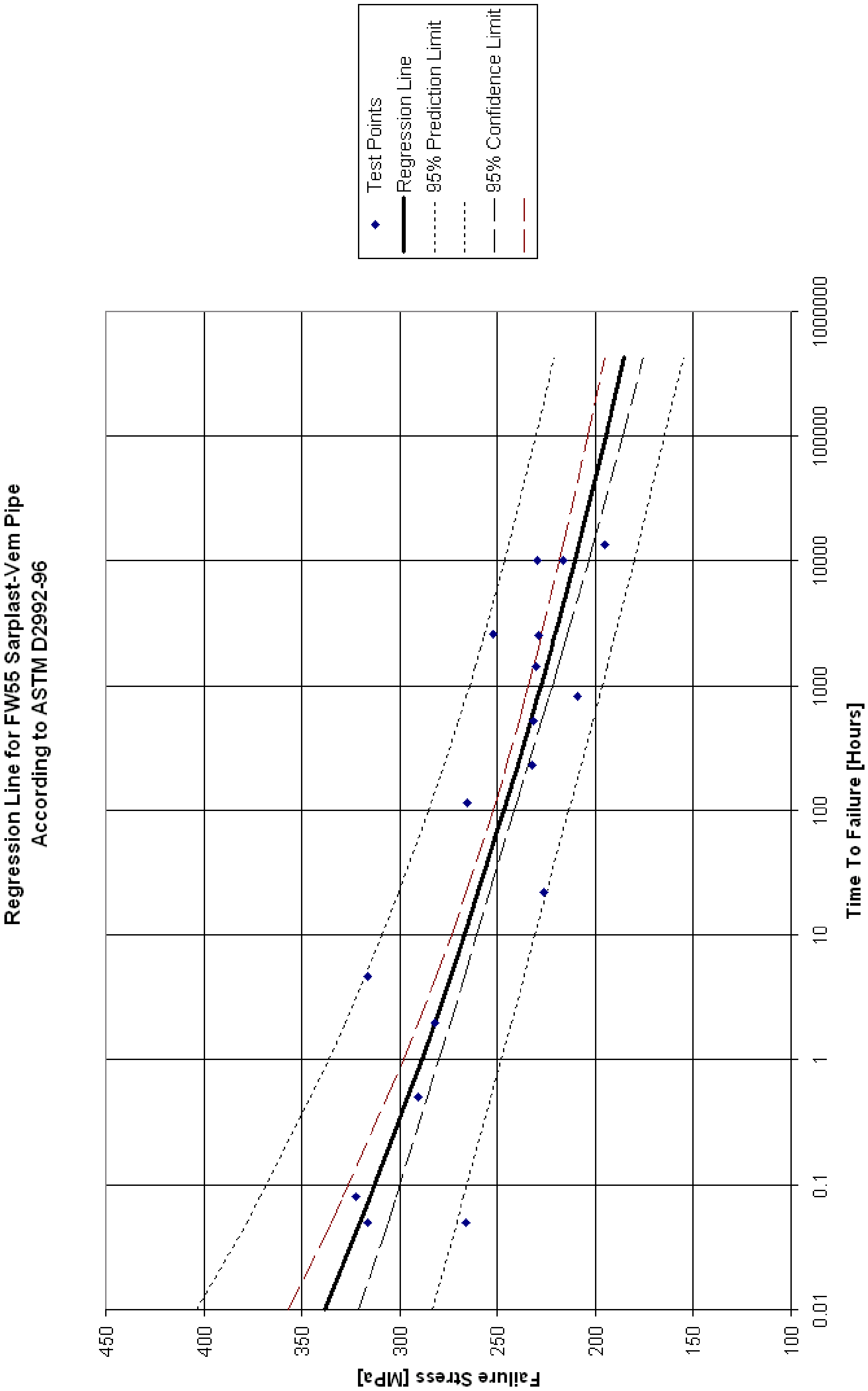
- Confidence Limits:

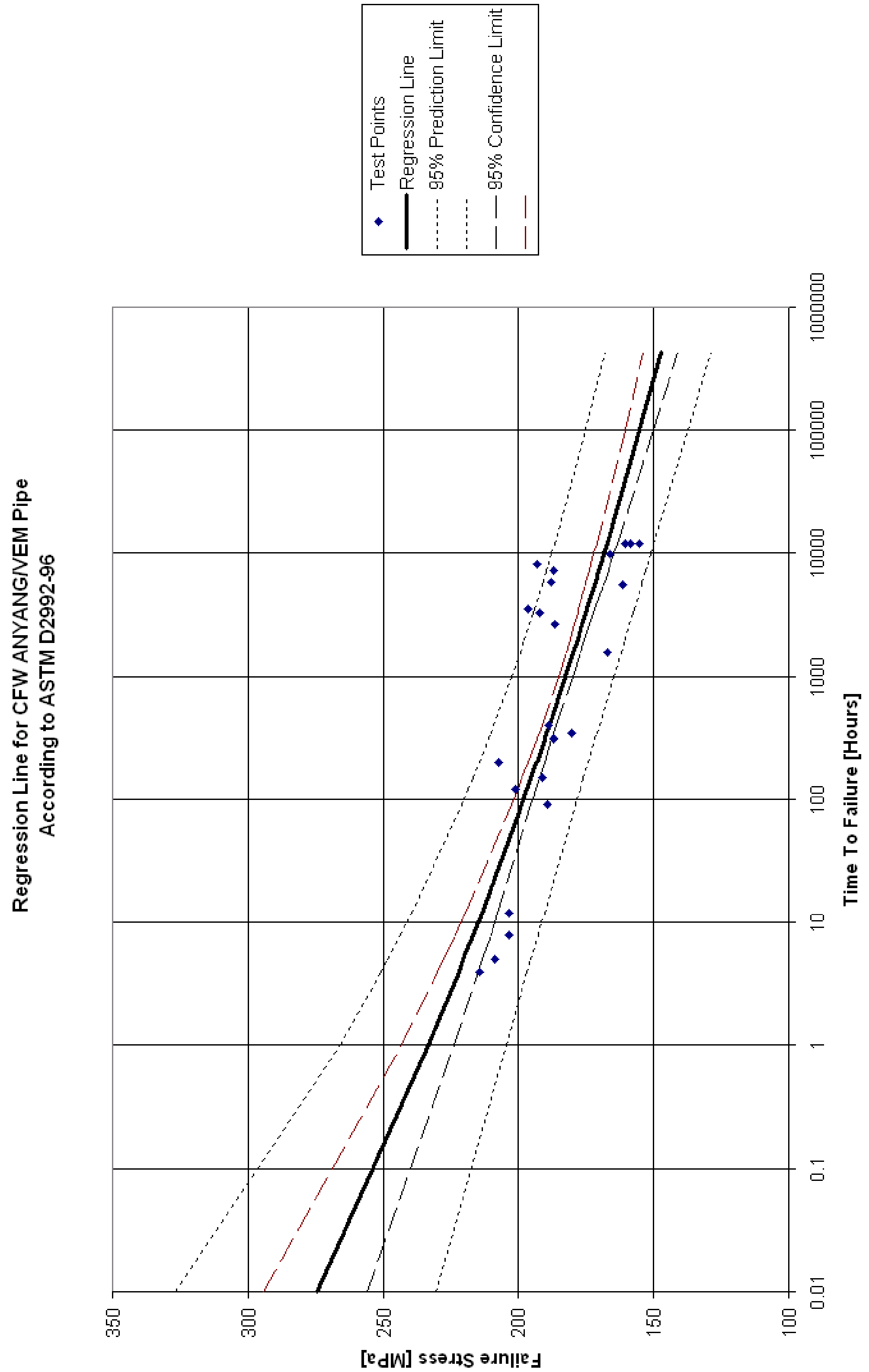
Time Hours	Mean Mpa	LCL Mpa	LPL Mpa
1	233	224	204
10	215	209	192
100	198	195	178
1000	183	180	165
10000	168	165	151
100000	155	150	137
438000	147	141	129

12.3. Plot Charts

On the next pages, the plot charts for both regression lines are attached.

The stress scale (*Y* coordinate) is linear instead of logarithmic to improve the readability of the charts.


Regression Line for FW55 Sarplast-Vem Pipe
According to ASTM D2992-96
Test Points
Regression Line
95% Prediction Limit
95% Confidence Limit
Failure Stress [MPa]
450
400
350
300
250
200
150
100
Time To Failure [Hours]
0.01
0.1
1
10
100
1000
10000
100000
1000000


Regression Line for CFW ANYANG/VEM Pipe
According to ASTM D2992-96
Test Points
Regression Line
95% Prediction Limit
95% Confidence Limit
Failure Stress [MPa]
350
300
250
200
150
100
Time To Failure [Hours]
0.01
0.1
1
10
100
1000
10000
100000
1000000

OBTAINING THE STRAIN BASIS FOR THE TOPFIBRA FIBERGLASS PIPE ACCORDING TO ASTM D3681 OR D5365

OBTAINING THE STRAIN BASIS FOR THE TOPFIBRA FIBERGLASS PIPE ACCORDING TO ASTM D3681 OR D5365

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1. PRELIMINARY REMARKS

As already defined in the previous chapters of this Handbook, chapter: "GENERAL DESIGN SPECIFICATION" and "LONG TERM PROPERTIES OF THE TOPFIBRA FIBREGLASS PIPE", the mechanical properties of the fiberglass (stiffness and strength) are time dependant, which is the characteristic most plastic materials have.

TOPFIBRA fibreglass pipe shows both creep and relaxation as all the GRP-BRP pipes. That is why several tests were made in order to ascertain and measure these phenomena, according to the relevant international standards.

The "Strain Basis" (the long-term, ring-bending strain, generally written as S_b) measures the long term resistance under a constant flexural strain or stress. For example, for a buried gravity sewer pipe that is deflected due to the soil load.

The reference standards for the determination of the "Strain Basis" are:

ASTM D3681
Standard Test Method for Chemical Resistance of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe in a Deflected Condition

ASTM D5365
Standard Test Method for Long-Term Ring-Bending Strain of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe

In the ASTM D3681 Test, the specimens (300 mm long pipe rings) are subjected to a **constant deflection**. Only the bottom inside part of the specimens is in contact with the test solution (like in the culvert of a sewer) and the test solution is a quite strong acid. In the D5365, the specimens are subjected to a **constant load** and the whole specimen is immersed in the test solution, which is plain water.

The AWWA C950 Standard Specification requires the use of the D5365 but also allows the D3681, since the test conditions are more severe due to the presence of the acid test solution. It is also possible to use the HDB instead of Sb, since in technical literature and in practice, the HDB is always lower than Sb.

From AWWA C950:

Sec. 4.8 Long-Term Ring-Bending Strain

4.8.1 *Long-term ring-bending strain, Sb*. Long-term ring-bending strain can be determined with creep-failure tests instrumented to detect an abrupt, significant reduction in mechanical properties. The test data should be statistically extrapolated to establish strength at 50 years. The value for Sb may be determined by testing per ASTM D5365, using a water test solution with any pH between 5 and 9. If these test results are not available, the value for Sb may be taken as the results of either of the following testing methods:

1. In accordance with ASTM D3681, using 1N H_2S0_4.

2. Using results of ASTM D2992, method B, extrapolated to 50 years.

Sample calculations and test results are shown in the attached documents in the chapters: "OBTAINING THE STRAIN BASIS FOR THE DISCOUNTINOUS FILAMENT WOUND FIBERGLASS PIPE ACCORTING TO ASTM D3681" and "OBTAINING THE STRAIN BASIS FOR THE COUNTINOUS FILAMENT WOUND FIBERGLASS PIPE ACCORTING TO ASTM D3681". The tests, relevant to the example, were conducted on the pipes produced on the GRP Pipe-Manufacturing Machines made by TOPFIBRA in the past years.

As a guidance for the validation of the earlier test results and for the completion of the long term test according to ASTM D3681 and D5365, TOPFIBRA edited the document (included in the Engineering Handbook):

- chapter: "TESTING PROGRAM FOR THE RECONFIRMATION OF THE STRAIN BASIS ACCORDING TO ASTM D3681 OR ASTM D5365 STANDARD PRACTICE".

1.1 Ad interim suggested design strain

From the results of the long term tests, as per chapters: "OBTAINING THE STRAIN BASIS FOR THE DISCOUNTINOUS FILAMENT WOUND FIBERGLASS PIPE ACCORTING TO ASTM D3681" and "OBTAINING THE STRAIN BASIS FOR THE COUNTINOUS FILAMENT WOUND FIBERGLASS PIPE ACCORTING TO ASTM D3681", the long-term ring-bending strain is calculated as follows, from the regression line:

$$y = a + bx$$

Where:

y = a common logarithm of the time to failure;

x = a common logarithm of the failure strain;

a = an intercept of the regression line;

b = the slope of the regression line.

Test Report	DFW Strain basis	CFW Strain basis
Filament winding type	discontinuous	continuous
Regression line parameter "a".	0.244295	0.187848
Regression line parameter "b".	-0.051098	-0.061604
Long-term ring-bending strain at 50 years.	0.90370 %	0.69291 %

For both types of pipes, TOPFIBRA suggests the "ad interim" long-term ring-bending 0.9% strain (S_b) for the allowable deflection calculation and combined loading calculation according to the M45 AWWA Manual.

OBTAINING THE STRAIN BASIS FOR THE DISCONTINUOUS FILAMENT WOUND FIBERGLASS PIPE ACCORDING TO ASTM D3681

OBTAINING THE STRAIN BASIS FOR THE DISCONTINUOUS FILAMENT WOUND FIBERGLASS PIPE ACCORDING TO ASTM D3681

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1. INTRODUCTION

This document shows the results of a test conducted at the TNO Laboratory in 2001, as well as the TOPFIBRA style revision and data analysis that characterizes all the supplied computer programs.

The test has been conducted according to the EN 705 Standard, which is practically equivalent to the ASTM D3681 Standard.

2. ORIGINAL TEST RESULTS

Sb Determination according to EN 705 **Page 1/3**

KIWA project n. 28028/1

1) **TNO report BU4.00/036929-5/PL dated September 12, 2001**
2) **KIWA reference KLS/502769/MAB dated September 25,2001**

Nominal Diameter	**600**	**mm**
Stiffness	**5000**	**N/m²**
Average thickness	**10.44**	**mm**
Liner thickness	**2**	**mm**
Average Diameter	**609.7**	**mm**

TEST RESULTS

	1	2	3	4	5	6	7	8	9	10		
	Strain %											**Valid**
Specimen	**REK %**	**Dy/Dm%**	**Dy**	**thk**	**Dint**	**Dm**	Strain	STISS		**Time**		**test**
	NEN_EN 1120	**[%]**					ISO/FDIS 10471:2003			h		1=yes
1	1.250	20.55	125.2	10.53	598.6	609.1	1.25	5150	5150	1416		1
2	1.385	22.87	139.2	10.69	597.9	608.6	1.38	5630	5630	144		1
3	1.050	15.68	95.5	11.08	597.7	608.8	1.05	6020	6020	6480		1
4	1.125	18.07	110.0	10.52	598.0	608.5	1.12	5630	5630	5712		1
5	1.200	19.40	118.2	10.59	598.5	609.1	1.20	5460	5460	2880		1
6	1.100	18.17	110.9	10.27	600.1	610.4	1.10	5110	5110	6696		1
7	1.300	22.55	137.5	10.17	599.7	609.9	1.30	5080	5080	314		1
8	1.350	22.47	137.0	10.59	599.2	609.8	1.35	5200	5200	360		1
9	1.150	19.11	116.6	10.29	599.7	610.0	1.15	5180	5180	888		1
10	1.400	24.14	147.1	10.37	598.9	609.3	1.40	5020	5020	36		1
11	1.150	18.26	111.2	10.67	598.2	608.9	1.15	5300	5300	10128		1
12	1.275	21.23	129.7	10.49	600.6	611.1	1.27	5120	5120	204		1
13	1.150	19.05	116.2	10.32	599.5	609.8	1.15	5140	5140	1507		1
14	1.200	19.36	118.3	10.64	600.2	610.8	1.20	5440	5440	4704		1
15	1.175	19.41	118.4	10.38	599.6	610.0	1.17	5040	5040	9264		1
16	1.299	22.05	134.5	10.35	599.6	610.0	1.30	5130	5130	135		1
17	1.125	18.19	110.8	10.47	598.5	609.0	1.12	5360	5360	9912		1
18	1.125	18.18	110.8	10.49	599.2	609.7	1.12	5030	5030	2568		1
19	1.250	21.20	129.3	10.28	599.7	610.0	1.25	5100	5100	1172		1
20				10.3	599.4	609.7		5070	0			0
21				10.34	600.5	610.8		5030	0			0
22	1.100	17.70	107.8	10.48	598.8	609.3	1.10	5070	5070	9504		1
23	1.400	24.98	152.4	10.11	600.1	610.2	1.40	4850	4850	232		1
24				10.38	599.5	609.9		5180	0			0
25	1.350	23.53	143.6	10.22	599.9	610.1	1.35	4850	4850	264		1
								So	So			
Average				***10.44***		***609.70***		***5208***	***5223***			22

Min L. T. relative ring deflection in a corrosive environment for 5000 N/m²	Min value,standard	12.00	%
Min L. T. relative ring deflection in a corrosive environment for 5223 N/m²	Min value,actual	11.83	%

Sb Determination according to EN 705

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INTERMEDIATE CALCULATIONS

FOR TIME-TO-FAILURE =		10	COLUMN	h	
FOR STRAIN =		1	COLUMN	strain%	
FOR DEFLECTION =		2	COLUMN	**DY/D %**	
COLUMN CHOSEN		**1**		strain%	

Valid only for determining average of points

		strain%	Time	Samples		Log(strain)	Log(time)
Pipe nr.		**strain%**	**h**	**number**		***y***	***x***
1		1.250	1416	1		0.0970	3.1511
2		1.385	144	1		0.1413	2.1584
3		1.050	6480	1		0.0213	3.8116
4		1.125	5712	1		0.0510	3.7568
5		1.200	2880	1		0.0790	3.4594
6		1.100	6696	1		0.0412	3.8258
7		1.300	314	1		0.1139	2.4969
8		1.350	360	1		0.1303	2.5563
9		1.150	888	1		0.0605	2.9484
10		1.400	36	1		0.1462	1.5563
11		1.150	10128	1		0.0607	4.0055
12		1.275	204	1		0.1054	2.3096
13		1.150	1507	1		0.0608	3.1781
14		1.200	4704	1		0.0791	3.6725
15		1.175	9264	1		0.0699	3.9668
16		1.299	135	1		0.1137	2.1303
17		1.125	9912	1		0.0510	3.9962
18		1.125	2568	1		0.0511	3.4096
19		1.250	1172	1		0.0969	3.0689
20		0.000	0	0		0.0000	0.0000
21		0.000	0	0		0.0000	0.0000
22		1.100	9504	1		0.0413	3.9779
23		1.400	232	1		0.1461	2.3655
24		0.000	0	0		0.0000	0.0000
25		1.350	264	1		0.1305	2.4216
26						0.0000	0.0000
27						0.0000	0.0000
28						0.0000	0.0000
29						0.0000	0.0000
30						0.0000	0.0000
31						0.0000	0.0000
32						0.0000	0.0000
				22		0.0858	3.1011
				n		***Y***	***X***

Sb Determination according to EN 705						Page 3/3
LINE PARAMETERS						
a=	**0.24429**					
b=	**-0.05110**					
Strain % 6 min =		**1.97**				
Strain % 50 years =		**0.90**				

REGRESSION LINE CALCULATION

h	yL	xL	Flexural Creep factor %	mean value LTHStrain %	VL0.95 confidence interval	VL0.95 prediction interval
0.1	0.29539	-1.00000	100%	**1.97**	1.75	1.72
1	0.24429	0.00000	89%	**1.76**	1.60	1.57
10	0.19320	1.00000	79%	**1.56**	1.46	1.42
100	0.14210	2.00000	70%	**1.39**	1.34	1.29
1000	0.09100	3.00000	62%	**1.23**	1.21	1.15
10000	0.03990	4.00000	56%	**1.10**	1.06	1.02
100000	-0.01120	5.00000	49%	**0.97**	0.92	0.89
438000	-0.04398	5.64147	46%	**0.90**	0.84	0.82
438000	*= 50 years*					

3. TOPFIBRA DATA ANALYSIS

Sb Calculation according to ASTM D3681-96

Table 1 - TABLE OF TEST RESULTS

Nominal Diameter	600	mm
Nominal Wall Thicknes	10.44	mm
Resistant Wall Thickn	9.44	mm
Liner tickness	1.00	mm
Average diameter	609.70	mm

						Regression Line									
	Strain	Time	OK	Log(strain)	Log(time)	Log	Strain %	95% Prediction Interval				95% Confidence Interval			
Pipe nr.	%	h		y	x	yL	VL	y lower	V lower	y upper	V upper	y lower	V lower	y upper	V upper
10	1.40014	36	1	0.14617	1.55630	0.16459	1.461	0.12987	1.349	0.19930	1.582	0.15467	1.428	0.17451	1.495
16	1.29914	135	1	0.11366	2.13033	0.13525	1.365	0.10381	1.270	0.16669	1.468	0.12828	1.344	0.14222	1.387
2	1.38458	144	1	0.14132	2.15836	0.13382	1.361	0.10251	1.266	0.16513	1.463	0.12698	1.340	0.14066	1.382
12	1.27478	204	1	0.10544	2.30963	0.12609	1.337	0.09541	1.246	0.15676	1.435	0.11995	1.318	0.13223	1.356
23	1.39985	232	1	0.14608	2.36549	0.12323	1.328	0.09277	1.238	0.15370	1.425	0.11734	1.310	0.12913	1.346
25	1.35048	264	1	0.13049	2.42160	0.12037	1.319	0.09010	1.231	0.15064	1.415	0.11471	1.302	0.12603	1.337
7	1.29981	314	1	0.11388	2.49693	0.11652	1.308	0.08649	1.220	0.14655	1.401	0.11116	1.292	0.12188	1.324
8	1.34983	360	1	0.13028	2.55630	0.11348	1.299	0.08362	1.212	0.14334	1.391	0.10835	1.283	0.11862	1.314
9	1.14956	888	1	0.06053	2.94841	0.09345	1.240	0.06428	1.160	0.12262	1.326	0.08932	1.228	0.09757	1.252
19	1.25011	1172	1	0.09695	3.06893	0.08729	1.223	0.05817	1.143	0.11640	1.307	0.08325	1.211	0.09132	1.234
1	1.25032	1172	1	0.09702	3.06893	0.08729	1.223	0.05817	1.143	0.11640	1.307	0.08325	1.211	0.09132	1.234
13	1.15024	1507	1	0.06079	3.17811	0.08171	1.207	0.05258	1.129	0.11084	1.291	0.07765	1.196	0.08576	1.218
18	1.12495	2568	1	0.05113	3.40960	0.06988	1.175	0.04051	1.098	0.09924	1.257	0.06545	1.163	0.07431	1.187
5	1.19963	2880	1	0.07905	3.45939	0.06733	1.168	0.03788	1.091	0.09678	1.250	0.06278	1.156	0.07189	1.180
14	1.19980	4704	1	0.07911	3.67247	0.05644	1.139	0.02649	1.063	0.08640	1.220	0.05118	1.125	0.06171	1.153
4	1.12463	5712	1	0.05101	3.75679	0.05214	1.128	0.02192	1.052	0.08235	1.209	0.04654	1.113	0.05773	1.142
3	1.05029	6480	1	0.02131	3.81158	0.04934	1.120	0.01893	1.045	0.07974	1.202	0.04351	1.105	0.05516	1.135
6	1.09963	6696	1	0.04125	3.82582	0.04861	1.118	0.01815	1.043	0.07906	1.200	0.04273	1.103	0.05449	1.134
15	1.17462	9264	1	0.06990	3.96680	0.04140	1.100	0.01040	1.024	0.07241	1.181	0.03489	1.084	0.04791	1.117
22	1.09978	9504	1	0.04130	3.97791	0.04084	1.099	0.00978	1.023	0.07189	1.180	0.03427	1.082	0.04740	1.115
17	1.12465	9912	1	0.05102	3.99616	0.03990	1.096	0.00877	1.020	0.07104	1.178	0.03326	1.080	0.04655	1.113
11	1.15000	10128	1	0.06070	4.00552	0.03942	1.095	0.00825	1.019	0.07060	1.177	0.03273	1.078	0.04612	1.112
	0.974547	100000				-0.01140	0.974	-0.04871	0.894	0.02592	1.062	-0.02329	0.948	0.00050	1.001
	0.904337	432000				-0.04387	0.904	-0.08650	0.819	-0.00124	0.997	-0.05933	0.872	-0.02841	0.937

Intermediate data is hidden. All the columns and calculations are shown in the computer program.

Sb Calculation according to ASTM D3681-96

Table 2 - LEAST SQUARES CALCULATIONS FOR LONG-TERM STRAIN BASIS (according to ASTM D3681 - Annex A1)

Functional Relationships

y	see Table 1	logarithm(10) of failure stress
x	see Table 1	logaritm(10) of hours-to-failure
n	22	number of failure point included in the analysis
Sum(y)	1.8884	
Sum(y^2)	0.1926	
Sum(x)	68.1414	
Sum(x^2)	222.7435	
Sum(xy)	5.3216	
Y	0.0858	arithmetic average of y values (stress)
X	3.0973	arithmetic average of x values (time)
Sxy	-0.023970	the sum is < 0: the data are suitable
Syy	0.001387	
Sxx	0.531222	
r min	0.538600	
r	0.882997	r > r min : the data are suitable
λ	0.002611	
b	-0.051102	slope of the regression line
a	0.244116	intercept of the regression line

Calculation of Variances

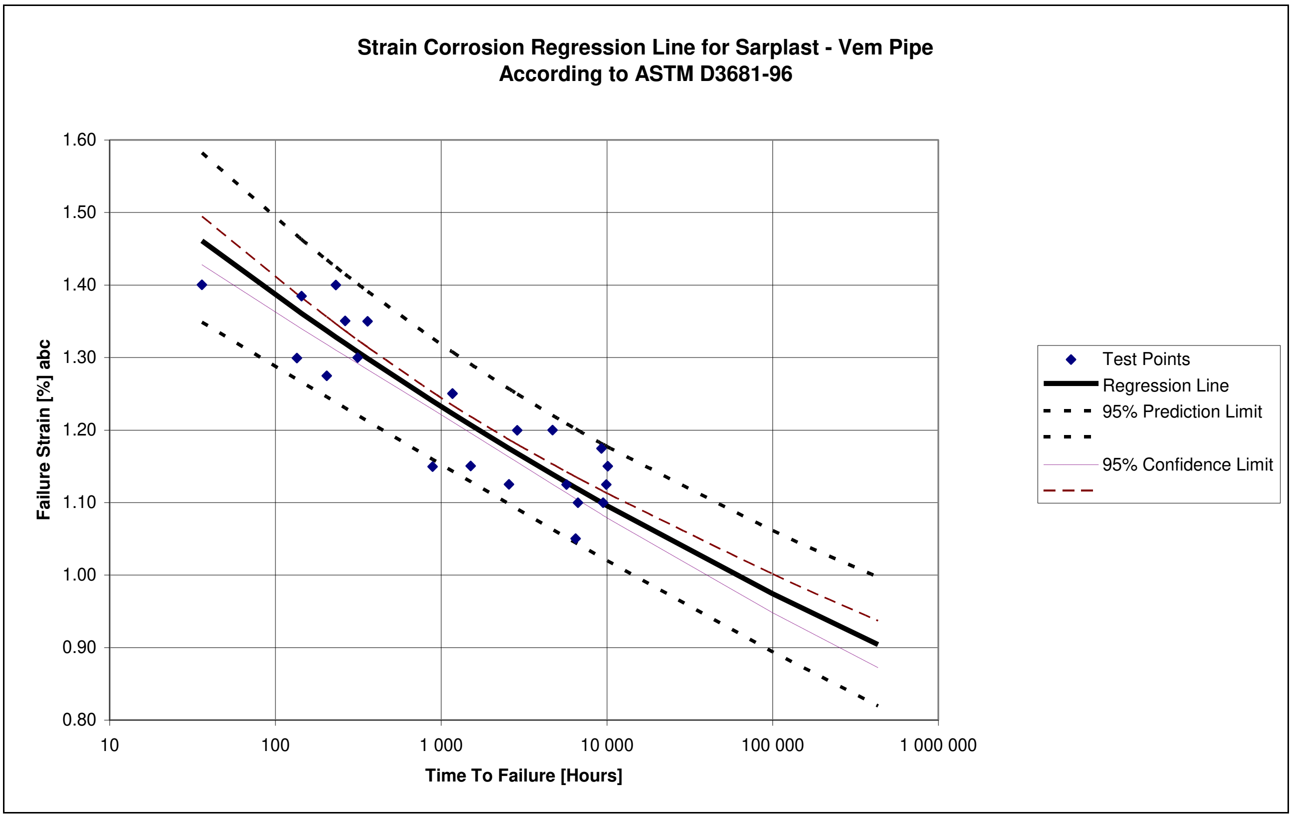
σ_δ^2	6.83702E-02	error variance
τ	4.18748E-05	
A	3.48213E-04	variance of a
B	-1.07183E-04	
C	3.46049E-05	variance of b
D	3.46035E-05	
σ_ε^2	1.78545E-04	error variance
tv	2.086	student tv

Strain basis at 100,000 hours

Sb 0.9741 %

Strain basis at 50 years

Sb 0.9039 %


Strain Corrosion Regression Line for Sarplast - Vem Pipe
According to ASTM D3681-96
Failure Strain [%] abc
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
10
100
1 000
10 000
100 000
1 000 000
Time To Failure [Hours]
Test Points
Regression Line
95% Prediction Limit
95% Confidence Limit

OBTAINING THE STRAIN BASIS FOR THE CONTINUOUS FILAMENT WOUND FIBERGLASS PIPE ACCORDING TO ASTM D3681

OBTAINING THE STRAIN BASIS FOR THE CONTINUOUS FILAMENT WOUND FIBERGLASS PIPE ACCORDING TO ASTM D3681

TABLE OF CONTENTS

1. INTRODUCTION

This document shows the results of the test conducted by the Al Watani Factory or Fiber Glass Co. in 2005, as well as the TOPFIBRA style revision and data analysis that characterizes all the supplied computer programs.

2. ORIGINAL TEST RESULTS

AL-WATANI FACTORY FOR FIBER GLASS CO.
P. O. Box 26947 - Safat 13130 - Kuwait

STRAIN CORROSION TEST

Report Number
GRP- SC-05-01

Date: 30 September 2005

Test Conducted by:
Elias C. Quijano

Strain-corrosion test following the guidelines of ASTM D 3681-96 have been conducted on 20 Nos. of DN400 x 300mm L GRP pipes manufactured by ALWATANI'S continuous filament winding machine.

The object of the test is to establish the long-term (50-year) resistance to acid strain corrosion of ALWATANI pipe.

Test data was analyzed using linear regression. This technique is based on the equation of a straight line. In slope form, the line with the slope m and y-intercept b is the graph of the equation y = m(x) + b. Once y-intercept, b and slope, m are found, the relationship of x and y can be established, hence a graph can be plotted.

A computer program was used to analyze the test data and the 50-year predicted failure strain was found to be 0.52%

Setting-up the test apparatus

Test Procedure

Following Test Procedure A of ASTM D 3681-96 "Standard Test Method for Chemical Resistance of Fiberglass (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe in a Deflected Condition". 20 Nos. specimen was set-up in the test apparatus and deflected to differing levels to induce tensile bending strain on the invert of the specimen pipe. Pipe ends were provided with dams and sealed. 0.1N sulfuric acid was poured into the interior of the pipe specimen and time-to-failure was measured when the test solution leaked through the pipe wall. Time–to-failures spread over days to several months. Some specimen goes beyond 10.000 hours. Test temperature was maintained at 23 °C ± 2°C .

Test Specimen
20 Nos. specimen was cut from a production pipe of PN6, STIS=10.000 Pa, DN400. Length of the ring is 300mm. The pipe was produced by continuous filament winding using polyester resin, glass reinforcements, and silica sand.

Test Results

Test data was calculated following guidelines mandated in ASTM D 3681 Annexes:
A1 - LEAST SQUARES CALCULATIONS FOR LONG-TERM STRAIN
A2 – CALCULATIONS OF LOWER CONFIDENCE LIMIT
A3 – CALCULATION AND CURVE PLOT OF 95% CONFIDENCE LIMITS AND 95% PREDICTION LIMITS.

The test data is given in table 1. The slope, m = –0.036 and correlation coeffecient, r = –0.5937, y-intecept , b = –9.56.

Graph of the regression line, 95% upper and lower confidence limit, and 95% upper and lower prediction limit is shown in fig. 2 of this report.

AL-WATANI FACTORY FOR FIBER GLASS CO.

P. O. Box 26947 - Safat 13130 - Kuwait

Table 1 – test result data

Specimen No.	Length mm	Thickness mm	Time-to-failure hours	Initial Strain %
GRP-SC-05-01-1	300	10.2	1.228	1.20
GRP- SC -05-01-2	301	10.6	320	1.15
GRP- SC -05-01-3	302	10.1	50.2	1.19
GRP- SC -05-01-4	300	10.2	48.5	1.21
GRP- SC -05-01-5	301	10.4	52.1	1.23
GRP- SC -05-01-6	300	10.3	630	1.00
GRP- SC -05-01-7	301	10.6	9.520	1.05
GRP- SC -05-01-8	302	10.2	672	1.00
GRP- SC -05-01-9	301	10.2	10.120	0.89
GRP- SC -05-01-10	301	10.2	5.987	0.92
GRP- SC -05-01-11	300	10.6	985	0.98
GRP- SC -05-01-12	302	10.3	1.930.1	0.97
GRP- SC -05-01-13	301	10.6	30.9	1.28
GRP- SC -05-0-114	300	10.2	43.6	1.26
GRP- SC -05-01-15	301	10.4	1.381	0.98
GRP- SC -05-01-16	301	10.1	1.501	1.00
GRP- SC -05-01-17	300	10.2	1.938	1.02
GRP- SC -05-01-18	300	10.3	8.105	0.89
GRP- SC -05-01-19	301	10.2	3.628	0.86
GRP- SC -05-01-20	301	10.2	11	0.87

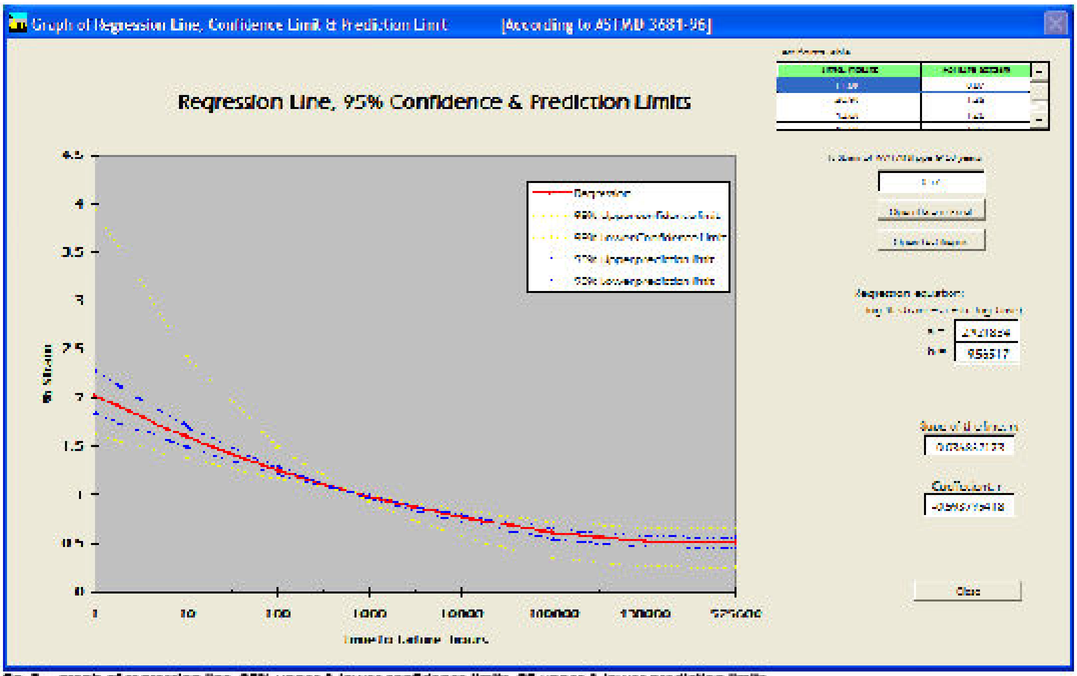


fig. 2 – graph of regression line. 95% upper & lower confidence limits. 95 upper & lower prediction limits

3. TOPFIBRA DATA ANALYSIS

Sb Calculation according to ASTM D3681-96

Table 1 - TABLE OF TEST RESULTS

Nominal Diameter	300	mm
Nominal Wall Thicknes	10.2	mm
Resistant Wall Thickn	9.2	mm
Liner tickness	1	mm

						Regression Line									
	Strain	***Time***	***OK***	***Log(strain)***	***Log(time)***	***Log(strain)***	***Strain %***	***95% Prediction Interval***				***95% Confidence Interval***			
Pipe nr.	***%***	***h***		***y***	***x***	***yL***	***VL***	***y lower***	***V lower***	***y upper***	***V upper***	***y lower***	***V lower***	***y upper***	***V upper***
1	0.87	11.0	1	-0.06048	1.04139	0.12369	1.330	0.02044	1.0	0.22695	1.7	0.09183	1.2	0.15556	1.4
2	1.28	30.9	1	0.10721	1.48996	0.09606	1.248	0.00159	1.0	0.19053	1.6	0.07112	1.2	0.12100	1.3
3	1.26	43.6	1	0.10037	1.63949	0.08685	1.221	-0.00513	1.0	0.17883	1.5	0.06411	1.2	0.10958	1.3
4	1.21	48.5	1	0.08279	1.68574	0.08400	1.213	-0.00726	1.0	0.17526	1.5	0.06193	1.2	0.10607	1.3
5	1.19	50.2	1	0.07555	1.70070	0.08308	1.211	-0.00796	1.0	0.17411	1.5	0.06123	1.2	0.10493	1.3
6	1.23	52.1	1	0.08991	1.71684	0.08208	1.208	-0.00871	1.0	0.17287	1.5	0.06046	1.1	0.10371	1.3
7	1.15	320.0	1	0.06070	2.50515	0.03352	1.080	-0.04951	0.9	0.11655	1.3	0.02079	1.0	0.04625	1.1
8	1.00	630.0	1	0.00000	2.79934	0.01540	1.036	-0.06705	0.9	0.09784	1.3	0.00356	1.0	0.02723	1.1
9	1.00	672.0	1	0.00000	2.82737	0.01367	1.032	-0.06879	0.9	0.09613	1.2	0.00181	1.0	0.02553	1.1
10	0.98	985.0	1	-0.00877	2.99344	0.00344	1.008	-0.07936	0.8	0.08624	1.2	-0.00894	1.0	0.01581	1.0
11	1.20	1228.0	1	0.07918	3.08920	-0.00246	0.994	-0.08564	0.8	0.08072	1.2	-0.01541	1.0	0.01049	1.0
12	0.98	1381.0	1	-0.00877	3.14019	-0.00560	0.987	-0.08904	0.8	0.07784	1.2	-0.01892	1.0	0.00772	1.0
13	1.00	1501.0	1	0.00000	3.17638	-0.00783	0.982	-0.09148	0.8	0.07582	1.2	-0.02145	1.0	0.00579	1.0
14	0.97	1930.1	1	-0.01323	3.28558	-0.01456	0.967	-0.09896	0.8	0.06984	1.2	-0.02918	0.9	0.00007	1.0
15	1.02	1938.0	1	0.00860	3.28735	-0.01467	0.967	-0.09908	0.8	0.06975	1.2	-0.02931	0.9	-0.00002	1.0
16	0.86	3628.0	1	-0.06550	3.55967	-0.03144	0.930	-0.11847	0.8	0.05558	1.1	-0.04921	0.9	-0.01367	1.0
17	0.92	5987.0	1	-0.03621	3.77721	-0.04484	0.902	-0.13466	0.7	0.04497	1.1	-0.06553	0.9	-0.02416	0.9
18	0.89	8105.0	1	-0.05061	3.90875	-0.05295	0.885	-0.14473	0.7	0.03884	1.1	-0.07550	0.8	-0.03039	0.9
19	1.05	9520.0	1	0.02119	3.97864	-0.05725	0.876	-0.15016	0.7	0.03566	1.1	-0.08083	0.8	-0.03368	0.9
20	0.89	10120.0	1	-0.05061	4.00518	-0.05889	0.873	-0.15224	0.7	0.03446	1.1	-0.08285	0.8	-0.03492	0.9
		100000.0				-0.12017	0.758	-0.23460	0.6	-0.00575	1.0	-0.15975	0.7	-0.08059	0.8
		438000.0				-0.15969	0.692	-0.29106	0.5	-0.02832	0.9	-0.20979	0.6	-0.10959	0.8

Intermediate data is hidden. All the columns and calculations are shown in the computer program.

Sb Calculation according to ASTM D3681-96

Table 2 - LEAST SQUARES CALCULATIONS FOR LONG-TERM STRAIN BASIS (according to ASTM D3681 - Annex A1)

Functional Relationships

y	see Table 1	logarithm(10) of failure stress
x	see Table 1	logaritm(10) of hours-to-failure
n	20	number of failure point included in the analysis
Sum(y)	0.3313	
Sum(y^2)	0.0674	
Sum(x)	55.6076	
Sum(x^2)	170.9238	
Sum(xy)	0.3252	
Y	0.0166	arithmetic average of y values (stress)
X	2.7804	arithmetic average of x values (time)
Sxy	-0.029797	the sum is < 0: the data are suitable
Syy	0.003096	
Sxx	0.815685	
r min	0.561400	
r	0.592972	r > r min : the data are suitable
λ	0.003795	
b	-0.061604	slope of the regression line
a	0.187848	intercept of the regression line

Calculation of Variances

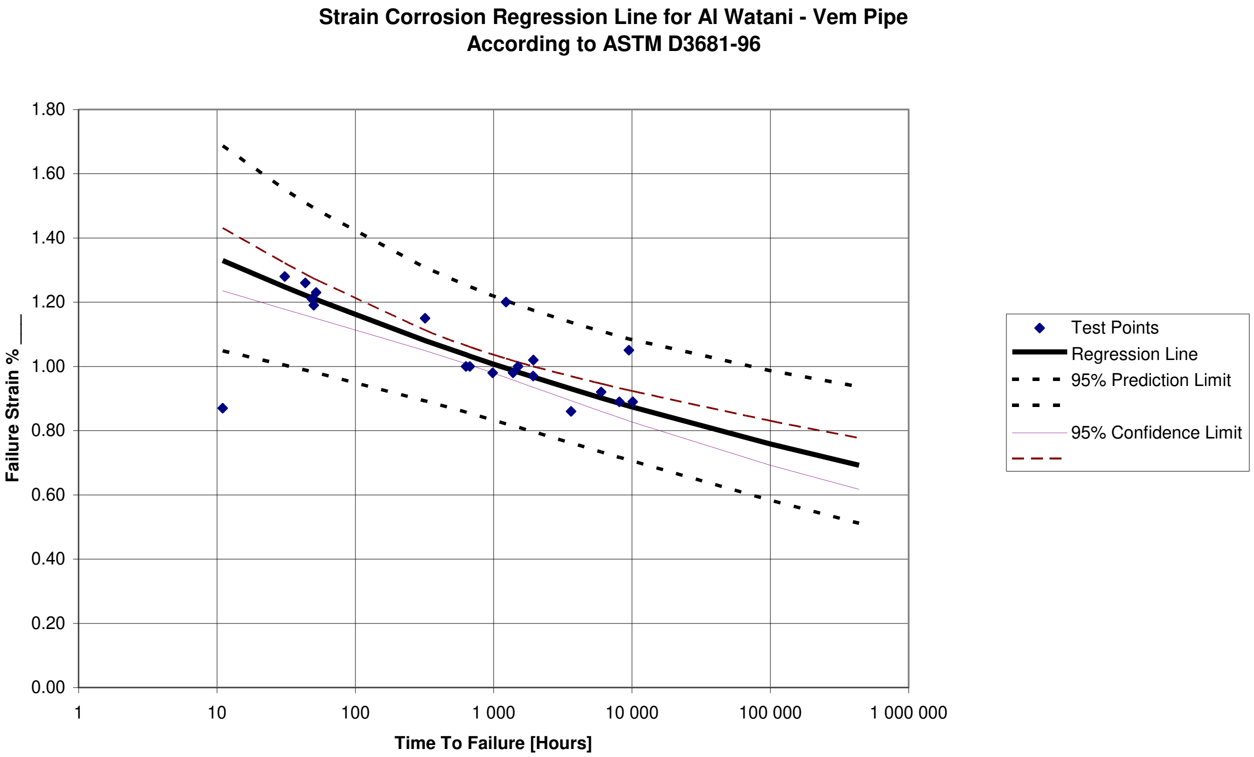
σ_δ^2	3.68897E-01	error variance
τ	3.38576E-04	
D	2.89449E-04	
B	-8.05051E-04	
C	2.89547E-04	variance of b
A	2.37835E-03	variance of a
σ_ε^2	1.40000E-03	error variance
tv	2.1009	student tv

Strain basis at 100,000 hours

Sb 0.76 %

Strain basis at 50 years

Sb 0.69 %


Strain Corrosion Regression Line for Al Watani - Vem Pipe
According to ASTM D3681-96
Failure Strain %
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
10
100
1 000
10 000
100 000
1 000 000
Time To Failure [Hours]
Test Points
Regression Line
95% Prediction Limit
95% Confidence Limit

TESTING PROGRAM FOR THE RECONFIRMATION OF THE STRAIN BASIS ACCORDING TO ASTM D3681 OR ASTM D5365 STANDARD PRACTICE

TESTING PROGRAM FOR THE RECONFIRMATION OF THE STRAIN BASIS ACCORDING TO ASTM D3681 OR ASTM D5365 STANDARD PRACTICE

TABLE OF CONTENTS

1. SCOPE

The available test results (the regression line and the confidence limits) are used as a basis for verification and validation of the newly obtained test results.

TOPFIBRA puts at its Client's disposal the results of the tests that were executed in the past, on the products which were manufactured with the TOPFIBRA machines and according to the TOPFIBRA technology and know-how.

This enables the Manufacturer to quickly verify whether the test results (the failure points) fall in the range which is allowed by the ASTM Standard. This is done with the reference to the TOPFIBRA regression line and curves. The reconfirmation test lasts 1 ½ month or maximum 3 months, including the groundwork; the data analysis; and contingencies.

Afterwards, the Manufacturer should continue the tests for obtaining their own full regression line, meanwhile, using TOPFIBRA Strain Basis (Sb) for the design of their pipes.

When a major change in the materials, the manufacturing process, the liner reinforcement, and/or the thickness occurs, the Manufacturer that has already obtained their own regression line, should plan a new testing campaign for the reconfirmation and, eventually, for the amelioration of the Strain Basis.

The testing campaign can be made internally. Eventually it can be made with the supervision and certification of an external authority, or it can be commissioned from an external certified testing laboratory.

On the basis of the test results it is possible:

- to plot a new regression line and calculate a new value for Sb if the newly obtained test results satisfy the requirements of the standard (explained on the next pages);
- to plan a complete testing program, using an interim Sb.

To perform the test, it is necessary to obtain at least three valid failure points for each two sets of specimens, which are subjected to the testing condition (deflection or load), leading to a failure in 10 to 200 hours for the first set and to a failure after a time longer than 1000 hours for the second set.

2. TERMS AND SHORTS

RL	Regression Line;	This is the statistical line showing the anticipated failure stress (or pressure) in the function of time-to-failure, calculated using the least squares method.
TTF	Time-To-Failure;	
CL	95% Confidence Limit (Upper And Lower);	This is an area bound by two statistical lines around the regression line where there is a 95% probability that the mean value of the failure stress for a certain time will fall in this area.
LCL	Lower Confidence Limit;	This is the lower curve for the confidence limit. The probability that the failure stress for a given time-to-failure is over this curve is 97.5%.
PL	95% Prediction Limit (Upper And Lower);	Like CL, but for a single failure point.
LPL	Lower Prediction Limit.	Like LCL but for the prediction limit.

You can find these terms in the graphs at the end of this chapter.

3. REFERENCE STANDARDS

ASTM D3681
Standard Test Method for Chemical Resistance of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe in a Deflected Condition;

ASTM D5365
Standard Test Method for Long-Term Ring-Bending Strain of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe.

In the ASTM D3681 Test, the specimens are subjected to a **constant deflection**. Only the bottom inside part of the specimen (300 mm long pipe rings) is in contact with the test solution (like in the sewer culvert), and the test solution is a quite strong acid. In D5365 Test, the specimens are subjected to a **constant load** and the whole specimen is immersed in the test solution, which is water with 5 to 9 PH, and then pure water.

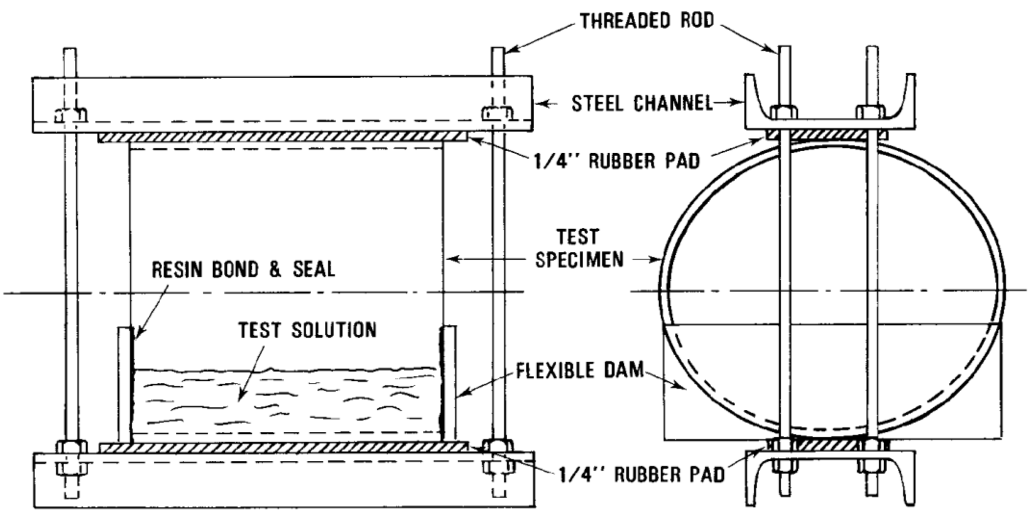
4. SPECIMENS AND TESTING EQUIPMENT

The reconfirmation test requires at least 6 valid failure points. 3 of them must fail in laps from 10 to 200 hours and other 3 in more than 1000 hours (42 days).

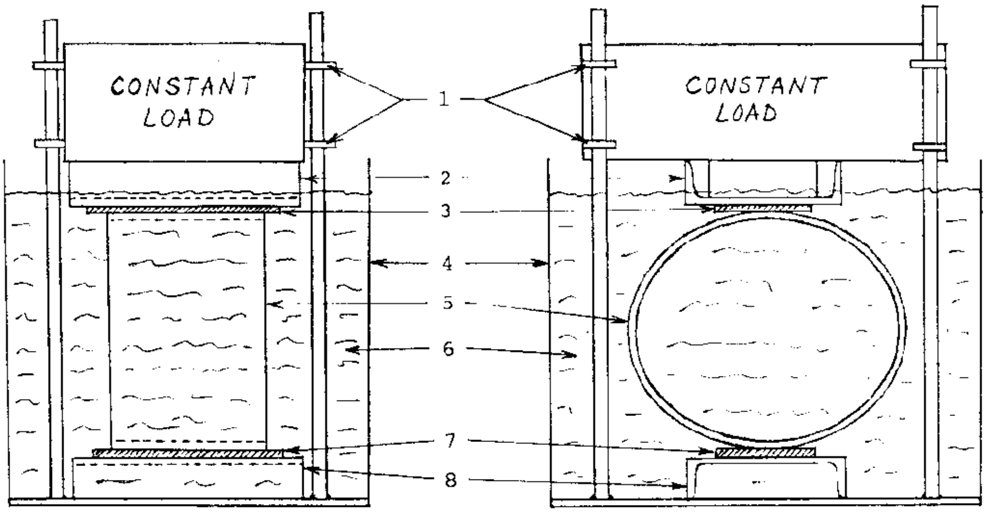
It is advisable to provide a higher number of specimens to assure that the required number of valid failure points is reached. The failure points acquired from this limit can be in any case used for the analysis of the results. Generally, the more testing points are available, the more precise the results of the test will be, since the dispersion of the points around the average line is lower (and thus, the correlation coefficient is better).

The specimens are ring sections of the pipe, with a length of one nominal pipe diameter, but not longer than 300 mm. I.e. the length shall be 300 mm for all pipes larger than 300 mm in diameter.

The testing equipment is the same simple apparatus for both procedures, made out of simple steelworks.



Apparatus as per ASTM D3681



Side View
1 Load-Application Guides
2 Load-Application Device
3 0.25 in (6 mm) Rubber Pad
4 Test Enclosure

Front View
5 Submerged Test Specimen
6 Test Solution
7 0.25 in. (6 mm) Rubber Pad
8 Load-Applicatiion Device

Apparatus as per ASTM D5365

5. FAILURE DEFINITION

For ASTM D3681, the failure definition is "the passage of the fluid through the pipe wall, unless otherwise stated".

For ASTM D5365, the failure definition is any fracture in the pipe wall.

6. TESTING STRAIN

Using the available regression line and the characteristics of the tested pipe, it is possible to predict the failure strain in function of the time-to-failure, and to calculate the required testing deflection for ASTM D3681, or the testing load for ASTM D5365.

Relation between the strain and deflection is:

$$\varepsilon = \frac{428(t)(\Delta)}{\left(D_m + \frac{\Delta}{2}\right)^2}$$

where:

ε = strain in %;

t = thickness of the pipe wall;

D_m = the pipe mean diameter;

Δ = the required deflection.

The worksheet supplied by TOPFIBRA (Reconfirmation of SB), provides the strain level, the deflection, and the load in function of the preliminarily suggested regression line and as well as the characteristics of the pipe which will be tested.

For the test, according to ASTM D5365, the load for the unit length (F), applied in order to calculate the desired strain, can be calculated for the deflection equation:

$$F = \Delta \cdot PS$$

where PS is the pipe stiffness according to the US standards (ASTM, AWWA) or:

$$F = \Delta \cdot S \cdot 53.69$$

where the pipe stiffness S is according the European Standards. All units must be consistent and identical.

Reconfirmation of Sb for GRP - VEM pipes

Pipe to be tested according to ASTM D3681 or ASTM D5365

Nominal Diameter	600	mm
Internal Diameter	600	mm
Nominal Wall Thickness	11.5	mm
Resistant Wall Thickness	10.47	mm
Liner tickness	0.83	mm
Mean Diameter	612.13	mm
Pipe Stiffness	11051	Pa

Predicted deflection (mm) vs. time to failure

Time to Failure	*hours*	*10*	*100*	*200*	*1 000*	*2 000*	*10 000*
Failure strain	%	1.560	1.386	1.338	1.233	1.190	1.096
Failure deflection	mm	149.5	129.0	123.5	111.7	107.1	97.2
Failure deflection/Dia	%	24%	21%	20%	18%	17%	16%
Predicted load	N/m	88 703	76 515	73 254	66 302	63 551	57 665

95% Prediction Limit

Time to Failure		*10*	*100*	*200*	*1 000*	*2 000*	*10 000*
Lower PL strain	%	1.426	1.288	1.247	1.153	1.112	1.020
Lower PL deflection	mm	133.5	117.8	113.3	103.2	98.9	89.4
Predicted load	N	79 238	69 902	67 228	61 205	58 687	53 043
Upper PL strain	%	1.706	1.493	1.436	1.318	1.272	1.177
Upper PL deflection	mm	167.9	141.4	134.7	121.2	116.1	105.8
Predicted load	N/m	99 621	83 904	79 942	71 910	68 897	62 760

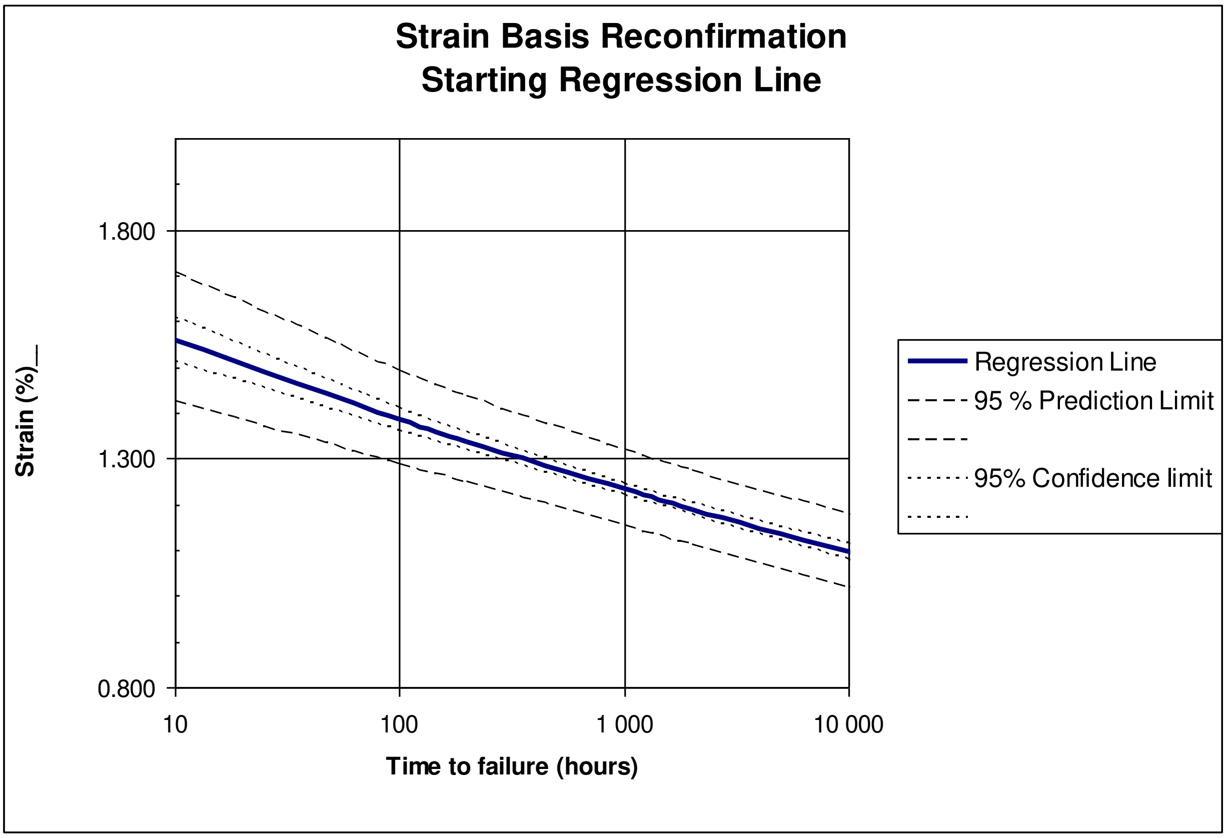
95% Confidence Limit

Time to Failure		*10*	*100*	*200*	*1 000*	*2 000*	*10 000*
Lower CL strain	%	1.514	1.362	1.319	1.221	1.178	1.079
Lower CL deflection	mm	143.9	126.2	121.3	110.5	105.9	95.5
Predicted load	N	85 393	74 881	71 991	65 561	62 823	56 638
Upper CL strain	%	1.607	1.411	1.357	1.244	1.201	1.113
Upper CL deflection	mm	155.3	131.8	125.6	113.0	108.4	99.0
Predicted load	N/m	92 174	78 194	74 543	67 053	64 289	58 713

Please see the chapter: "GENERAL DESIGN SPECIFICATIONS" for the information on the pipe stiffness and the relation between the US and the European definition of the pipe stiffness.

An alternative way to impose the desired strain is to measure the strain directly (in the invert) by a strain gauge equipment.

The lower and upper prediction limits are also calculated by the ASTM worksheet, in order to better estimate the strain levels for the test. An example of the calculation for the TOPFIBRA FW pipe is given in the following Tables and Graph, copied from the worksheet.



The predicted load is given for information only and for the test according to ASTM D5365.

The failure point should fall into the ±95% prediction interval, to continue to use the TOPFIBRA S_b suggested value, until a full set of the results and the calculation of the Manufacturer's own regression line is obtained.

It is clear from the tables that the failure deflection for a given time period is quite scattered, which means it could be difficult to obtain the desired failure point. For example, the 95% prediction interval at 1000 hours is, for this specific example, from 103.2 to 121.2 mm: which is ±8% of the mean value. On the contrary, for the time-to-failure, passing from 1000 to 2000 hrs (100% increase), the mean anticipated failure pressure should decrease from 111.7 mm to 107.1 mm: which is only 4 % less! This is due to the flattening of the regression line as the time increases.

For this reason, we suggest using more specimens than the required minimum, starting with a higher deflection and a shorter time, and on the basis of the first results, adjust the deflection (load) for the 1000 hrs specimens.

If, for example, the 10-200 hrs mean time-to-failure test is considerably longer than predicted and the failure points are less scattered, the failure strain for the 1000 hrs specimens can be increased in order to avoid excessively extending the test. Otherwise, some points that are non-failure, can be forcefully used as failure points, thus, giving a computed regression line. This line is worse than the possible, actual one. The best solution is to use two or more sets of three specimens tested at different strain levels around the mean anticipated strain level at 1000 hrs.

If only three sets of the testing equipment are available, the first test is performed for the 100 hr strain.

This is the case for the tests made outside, or when it is necessary to free the equipment for other tests. If the tests can be prolonged without restrictions, any non-failed point can be used for the reconfirmation of S_b and for the calculation of a new provisional regression line, which will be updated as soon as the new failure points become available.

Any failure point satisfying certain requirements can be added to the set of data that is used to calculate the regression line.

Once a complete set of new data for a new product is available and it satisfies the Standard requirements, the old data can be cancelled and a new S_b and regression line should be calculated for the product.

7. PRELIMINARY TESTS

Before giving the specimens to an authorized testing laboratory or officially starting the test, it is advisable to make some internal tests in order to check the failure strain at the short time periods, as well as check if the ASTM Standard requirements, for the applicability of the procedure, are fulfilled.

8. APPLICABILITY

The reconfirmation procedure is applicable, according to ASTM D3681 or ASTM D5365, if all following conditions are fulfilled:

- an average failure point for each stress or pressure level falls on or above the 95 % lower confidence limit of the given regression line;
- the first individual failure point of each stress or pressure level falls on or above the 95 % lower prediction limit of the given regression line;
- no more than two thirds of the individual failure points fall below the given regression line.

Or alternatively:

- all failure points fall above the 95 % lower confidence limit of the given regression line;
- at least two points exceed the 3000 hrs time-to-failure.

The reconfirmation procedure should always be applied, since the improvements and refinement in the raw material properties and manufacturing technologies have in recent years led to the ever better performances of our products.

If, unfortunately, this should not happen, the reasons for the event shall be investigated.

If, on the contrary, major changes in the manufacturing process or in the raw materials have taken place due to the special design requirements and this leads to a justified lower strength of the laminate, a new regression line shall be determined according to the ASTM code.

According to the ASTM, while a new test program is under way, an interim S_b for the material or process change, may be taken as the lowest of the following:

- the 95 % lower confidence limit of the value, obtained by extrapolating the failure points to 438 000 h (50 years);
- the 95 % lower confidence limit of the given regression line at 50 years.

To estimate the long-term strength of the material for the preliminary design purposes, the reduction characteristic of the short/medium term strength can be applied to the long term strength conditions. It is only feasible if the data is lower than the data mentioned earlier, however, this is not in line with the Code requirements.

9. DATA ANALYSIS

The test data can be analysed by TOPFIBRA computer program, following the instructions of the Appendix A of the ASTM.

10. STARTING REGRESSION LINE AND CONFIDENCE/PREDICTION LIMITS

The starting parameters for the reconfirmation of the S_b, according to the ASTM Standard Annex A.1, are continuously updated and are given as included in the supplied computer programs for the calculation and reconfirmation of the S_b, according to the ASTM. All symbols are in compliance with the ASTM Code.

For more information, contact us writing at

support@topfibra.eu

or

visit our page

www.topfibra.eu

To learn more of the EFW technology visit our blog

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