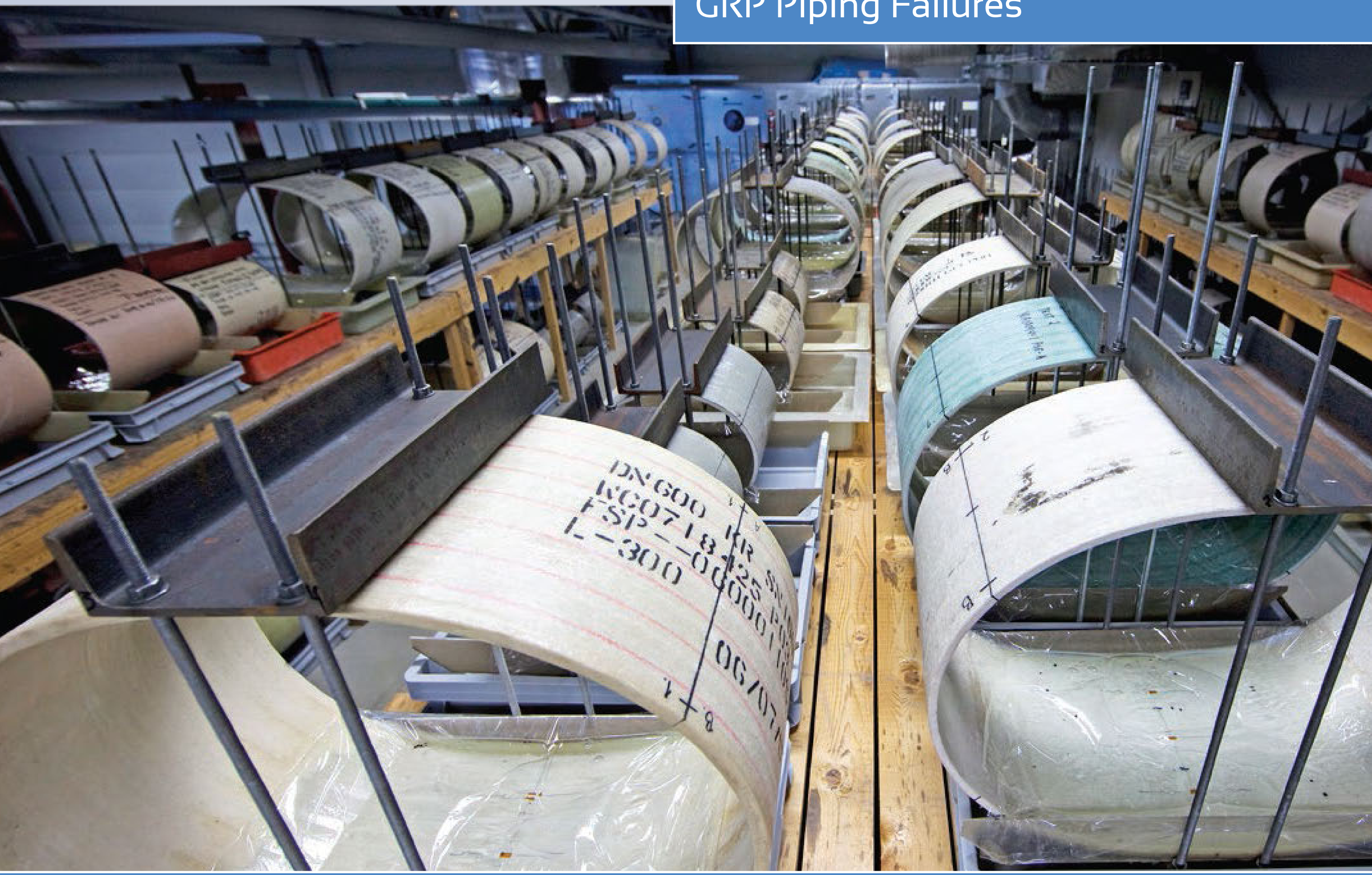
GRP Piping Failures



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Abstract

Glass-fibre Reinforced Plastic pipe (GRP) systems, also known as FRP pipe systems, have been successful in the world's markets for more than 50 years. During this time, they have developed into a modern pipe material that is predominantly convincing thanks to its lightweight, corrosion resistance, a smooth inner surface, and easy installation.

Continuously wound GRP pipes are also popular in AP and the Middle East where they have provided well-accepted concepts to many industries and in many applications for many years. GRP pipes also had a proven design life known in some case histories for a design life of more than 33 years.

All piping, in general, has a certain requirement related to design and installation. GRP piping as a semi-rigid material shares over 80% of these requirements, in this paper we will highlight the remaining specific requirements related to system design, materials qualification, and site installation.

Although we will try to present several modes of failure of GRP piping as real cases in terms of catastrophic failure, weeping De-lamination, cracking. we will share several root causes reports identifying what went wrong in terms of installation, design, operation, and testing. The analysis will not consider visual criteria only, but also some engineering tools and NDT methods/techniques to identify the defect, type, size, location trying to propose the best solution to avoid reoccurrence.

1. INTRODUCTION

Piping is the most common component in a construction site which is used to transport fluids. Since several decades the importance of this component became crucial and for that several standards from ASME, ASTM, ISO, API, BS, DIN, and others, have been published to cover the requirement of piping including raw materials, design conditions, system design, grades, rating, fittings, joints, flanges, accessories, testing, inspection, installation, commissioning, operation, maintenance, and rehabilitation. Standards could be a design code which is having several categories (design conditions, pressure design, flexibility and stress intensification, material, standards, fabrication and assembly, inspection and testing) like ASME B 31.1, B31.2, B31.3, ISO 14692, or it could be a piping specification document like ASTM D 3517, BS 5911. Other standards could be an auxiliary document related to testing, inspection, installation or other. [1]

GRP Glass Fiber Reinforced Polyester material as one of piping materials and due to its versatility it is used in several applications and services like gravity, high pressure, low pressure, seawater, potable water, irrigation, industrial waste, cooling water, wastewater, circulating water, sewer, firewater, above ground, underground, on ground, subsea, ducting and more applications.

In this paper, we will highlight the shared requirement of GRP piping with other materials, and then we will demonstrate the special requirements of GRP piping which make it unique from other materials. We will explain several failure modes for GRP piping some case histories including root cause analysis of several failures.

2 PIPING REQUIREMENT (GRP VS OTHER):

2.1 GRAVITY SEWER/ DRAINAGE UG (SEWER, CHEMICAL WASTE, WASTEWATER):

In gravity application, the client needs to construct pipe which can handle at least the below requirement:

- Availability of piping material with all components and accessories.
- Long design life, (50 – 100 years) with lower maintenance cost
- Minimum leakage and infiltration incidents which are and environmental impact also.
- Good corrosion resistance internal and external including biological and gaseous medium.
- Smooth vs rough surface, which will have an impact on pipe sizing for gravity flow.
- High abrasion resistance to water jet cleaning
- External load resistance at short term and long term
- Adapting to special design conditions like road crossing, shallow depths, high wheel load, water table, settlement. [2]

GRP pipes dominate the best choice material for above service and here is the proof:

1. Design proof: GRP pipes design has been done considering long term behavior as per ASTM D 3681 where pipes are over deflected along with Sulfuric acid solution which is a case simulating a gravity sewer, Amiblu R & D facility has performed a type test results up to 30 years as stated by Mr. Hogni in his interview. Refer to figures 1 and 2.

Figure 1: Strain Corrosion Test Amiblu Center [3]

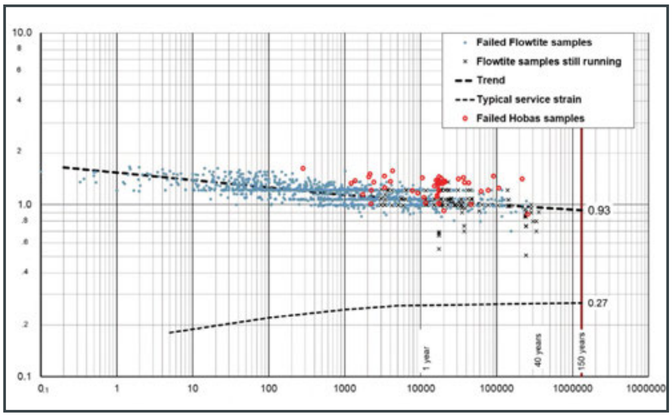

Figure 2: Test data for Hobas and Flowtite Pipes for 40 years, results extrapolated to 150 years. [3]

2. Flexibility vs Rigidity: GRP considered unique material between flexible (PVC, PE) and Rigid (RC, VC). Rigid pipes fail by cracking mode under ring bending loading, unlike flexible pipes that are deforming in a deflected mode. Dieter Scharwächter consulting explained the difference between flexible pipe and rigid pipe in buried condition, rigid pipe is more rigid than the soil and it bears the burden of external loading due to soil movement, water table fluctuation, settlement

along with dead and live loads and cracks developed with time, while the flexible pipe react in a heavy deformation mode but with a minimum number of cracking. in GRP take advantage of failure mode and it has somehow higher stiffness and strength than traditional plastics (PVC, PE) refer to figure 3. [4]

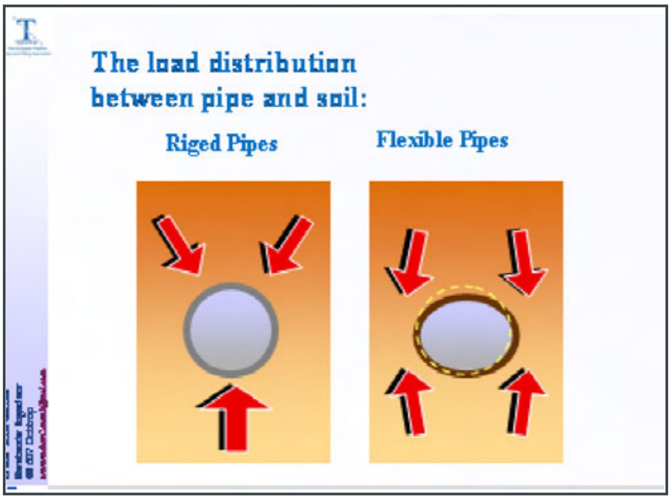

Figure 3: Rigid and Flexible Pipe Loading with the surrounding soil

3. Abrasion resistance: GRP pipes with special liner consideration has been improved to meet high-pressure water jet cleaning standard up to 120 bar nozzle pressure and at an angle less than 30 Degrees refer to figure 4.

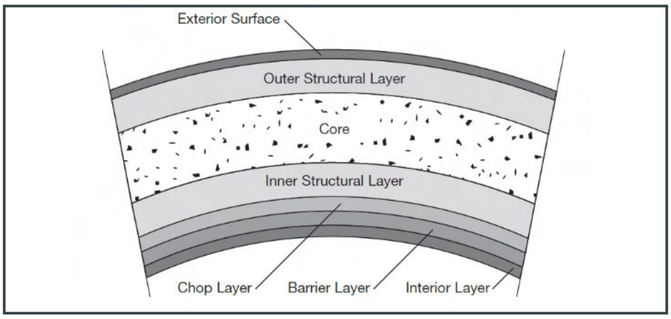

Figure 4: GRP layers with a special barrier liner for high water jet resistance, Fowtite product guide sewer pipes.

2.2 LOW-PRESSURE PIPES UG UNRESTRAINED SYSTEM (SEWER, IRRIGATION, WATER, SEAWATER)

In pressure application underground pipes, the client will need to demonstrate the below requirement:

- Availability of piping material rated pressure
- Long term design life (50 – 60 years) at lower maintenance cost.
- Low friction and lower pumping cost.
- Eliminate failures or leakage to avoid major shutdowns.
- Good corrosion resistance especially for external (soil, groundwater).
- Resistance to soil traffic combined with internal pressure.
- Resistance to soil traffic combined with a vacuum.
- Adapting to special design conditions, road crossing, connection to chambers.
- Thrust blocks for fittings.

In addition to the advantages in paragraph 3.1 (1 and 2), GRP pipes are considered as a well-accepted choice for above service especially for seawater, irrigation, treated sewer due to:

1. 1. GRP Pipes as semi-rigid materials are designed based on long term hydrostatic design basis as per ASTM D 2992 where minimum 18 samples are pressurized to high pressure to induce a failure under creep loading, the period for this test will reach to 14 months, and data will be used to pressure class demonstration. Unlike metallic piping which is designed based on corrosion rate, where metallic piping will experience pipe wall thinning risk of piping system failure is increasing with time.
Pressure class of GRP pipes is selected to meet minimum working pressure and temperature and with a factor of safety between 1.5 to 2 depends on different standards, and the value is calculated from the extrapolated value (50 years or more). HDB / Stress t Pressure Class >= 1.8 (As per AWWA M45) refer to figure 5.

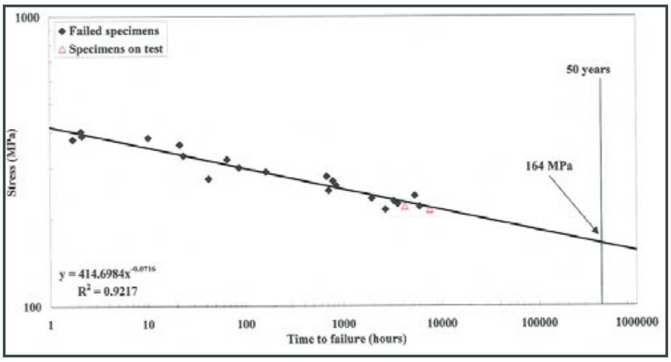

Figure 5: Typical regression line (HDB Test results as per ASTM D 2992).[5]

Unlike steel piping where pipe wall design will be relying on corrosion rate MPY (millimeter per year) to determine the design life. Steel pipe as a conductive medium along with high conductive soil (resistivity less than 5000 Ohm-cm) will not survive without cathodic protection. Refer to table 1 where typical aging rates vs soil resistivity.
The risk of catastrophic failure is increasing with time for metallic piping due to wall thinning and weakening which could occur at the sudden change in pressure, or surge incident during pump start-up or valve open-

Environmental Factors	General Corrosion Rates, mpy			Pitting Corrosion Rates, mpy		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Soil Resistivity Ohm-cm						
Less Than 1,000	2.5	0.7	1.3	12.2	4.3	7.9
1,000 to 5,000	2.3	0.2	0.7	17.7	2.0	5.5
5,000 to 12,000	1.3	0.2	0.7	9.1	2.4	5.5
Greater Than 12,000	1.4	0.1	0.6	10.2	1.2	4.3

Table 1: Typical soil resistivity vs corrosion rates for steel pipes.

Figure 6: External corrosion in DI Pipes, High

ing/closing refer to table 2.
The risk of catastrophic failure is increasing with time for metallic piping due to wall thinning and weakening which could occur at the sudden change in pressure, or surge incident during pump start-up or valve opening/closing refer to table 2.

2. Flowtite Norway has a case study proofing the design life of the GRP pipe is more than 30 years refer to figure 7. In the power plant north of Lillehammer and due to planned shutdown, Flowtite has taken out the sample from pipeline 30 years in operation, the sample looks brand new pipe with a smooth surface and no signs of aging or visible cracks.[6]

Figure 7: Flowtite pipe sample taken out from service after 30 years of operation.

2.3 LOW-PRESSURE PIPES FOR AG OR UG, RESTRAINED SYSTEM (WATER, SEAWATER, CHEMICALS, PROCESS).

For this application for pressure below 50 bar, the client will request to ensure:

- Piping availability at required pressure and temperature.
- Design life (20 – 50 years)
- UV resistance
- Eliminate failures to avoid major shutdowns.
- Good corrosion resistance and additional corrosion protection may be required
- Good vacuum resistance
- Resistance to water hammering and dynamic load
- Vibration if any
- Minimum sagging at desired spans
- Resistance to fatigue
- System design is required to combine several loading conditions by using computer software like Caesar II.
- Chemical resistance chart if any
- High-temperature resistance chart if any
- Resistance to soil load, traffic, settlement in case of underground installation.

Piping for this category is widely used in oil and gas, power plants, desalination plants, sewage treatment plants, and other industrial sectors. Major clients recommend the use of GRP in this service considering the below criteria:

1. Stability in UV: GRP which is manufactured using thermosetting is more stable in hot weather and UV radiation, old samples exposed to UV have shown a change in color only and minor degradation. In all cases for an aboveground application, it is required to use an additional UV inhibitor to ensure the maximum stability of the piping. Also, it is well known that GRP surface radiation temperature in hot weather in the GCC region will be within 10 °C than ambient temperature due to low thermal conductivity in glass fibers, unlike metallic piping where external radiation temperature could reach to 80 °C in the mid-day summer season. C. Pechyen1, D. Atong2, and D. Aht-Ong have investigated the effect of UV accelerated exposure of GRE materials with different additives the results shows an increase in mechanical properties after short term exposure to UV and then the results are slightly degreased after 10 years exposure which is considered as minor degradation compared to thermoplastic materials. [7].
2. 2. Smooth interior surface: GRP pipes have a smooth interior surface and remain smooth with time as we have seen in the Flowtite case study [6] and Mr. Hogni's interview [3]. This will have an impact on pumping costs if we compare GRP with steel piping.

Material	C	Dia	Loss 100m	Pump (HP)	Energy Cost/Year
GRP	150	800	0.2956	466	0.14
Steel	120	800	0.4466	704	0.21
Difference %				33.8%	33.3%

12345678jhbgfcdxsyrdtfghj

2.4 HIGH-PRESSURE PIPES AG OR UG (GAS, HOT WATER INJECTOR)

Pipe at a pressure higher than 50 bar, is very critical and clients require to meet some special criteria as per API 15 HR.

- The availability of piping with high-pressure joint configuration (threaded joint).
- Design life (20 – 50 years)
- UV resistance
- Fire retardancy may be required
- Conductive pipe most likely is required.
- High-temperature resistance in some applications.
- High gas permeability.
- Resistance to combined loading, thermal, pressure, bending, vacuum, torque.
- Resistance to fatigue.
- Resistance to surge loads and dynamic loads.
- System design required to combine several loading conditions.
- Detailed support design and support loads.

Pipes under this category require more research and development, and few manufacturers around the globe have developed this tubing technology and qualified them to cover certain sector in oil and gas, the most advantage of composite pipes is its inherited corrosion resistance, however, some clients still prefer to go with metallic tubes provided with additional corrosion barriers. Most likely the composite pipes have limitations in temperature, fatigue behavior.

3 SPECIAL REQUIREMENT OF GRP PIPING:

3.1 PIPE ADJACENT TO RIGID STRUCTURE:

Connection of buried pipes or exposed pipes into a rigid structure is very common in a construction site, the rigid structure could be manhole, chamber, pump house, thrust block. GRP pipes require certain measures to avoid damage due to structural settlement. As the structured settlement is an unavoidable issue. Engineers should deal with the problem by providing some means of protection.
GRP pipes in an unrestrained system using double bell coupling have an advantage of angular deflection allowance in the coupling, and by using a short pipe length adjacent to the concrete structure.

Concrete shrinks during curing which will create point loads on GRP pipe and risk of damage under shear, and concrete structure settlement will expose the pipe into concentrated bending load and the rocker pipe will be deflected to accommodate this slight movement. It is worth to know the zone near the structure shall have special backfill procedure (backfill material with cement stabilizer) to ensure a sufficient compaction level is achieved where mechanical compaction probably is not feasible in this zone, this special compacted zone should be installed along the rocker pipe length and should have an angle less than 45 ° to provide enough internal friction to avoid slippery of layers, refer to figure 8.

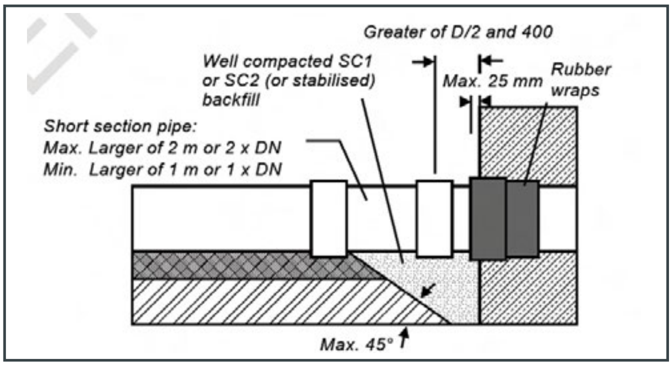

Figure 8: GRP Pipe connection to a rigid structure, Flowtite Installation Guide.

On the other hand, if the pipe system is self-restrained using the laminated joint, the means of protection are different. Sometimes construction can be done with hollo pipe inside concrete this will provide no direct interaction between pipe and concrete structure.

Other ways are to wrap the pipe with highly flexible wrapping material like sponge rubber, several layers of thin rubber layers at a certain length outside the concrete wall to provide room for pipe flexibility during settlement refer to figure 9.

3.2 JOINT PREPARATION AND INSPECTION:

GRP Pipes with coupler or spigot/ bell joint configuration should have rubber gaskets installed for water tightness, pipefitter may have the rubber ring slipped away from groove during pushing. There are few methods to confirm a correct rubber installation as shown below:

1. Insertion of blade piece from coupler edge to ensure that rubber placement is even along the coupler perimeter refer to figure 10.

2. Internal joint tester: this is applicable for large diameter pipes, and it could a good tool to ensure pipes joints are tested, in some cases the final site hydro test could be avoided refer to figure 11.

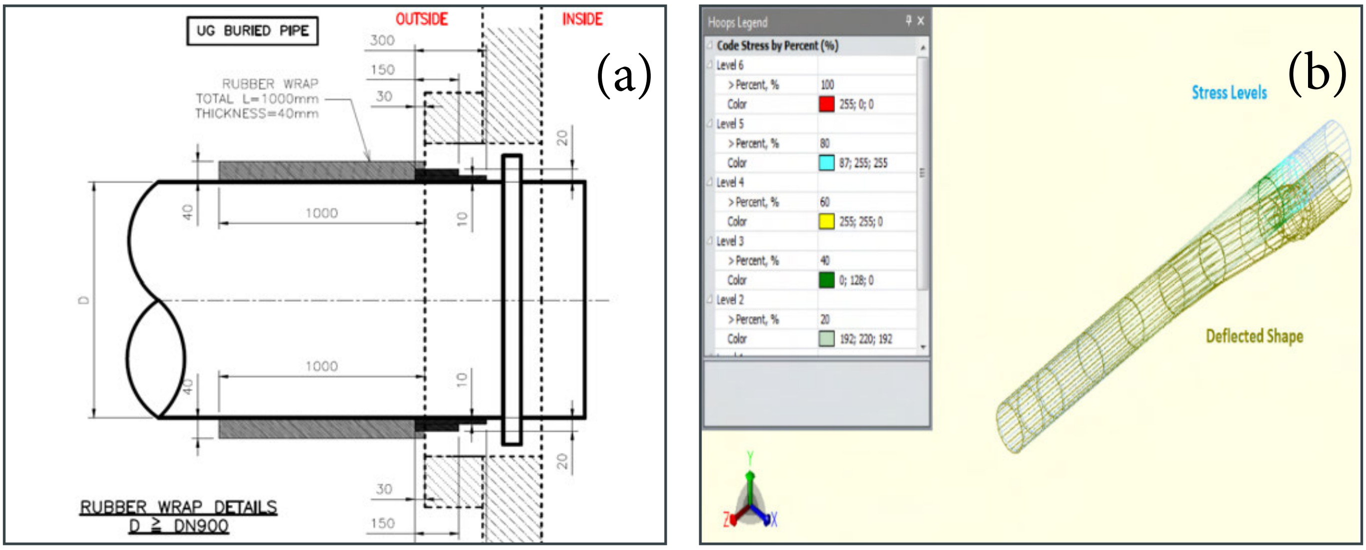

Figure 9: a – flexible wrapping adjacent to concrete. b – simulation of settlement with rubber wrapping

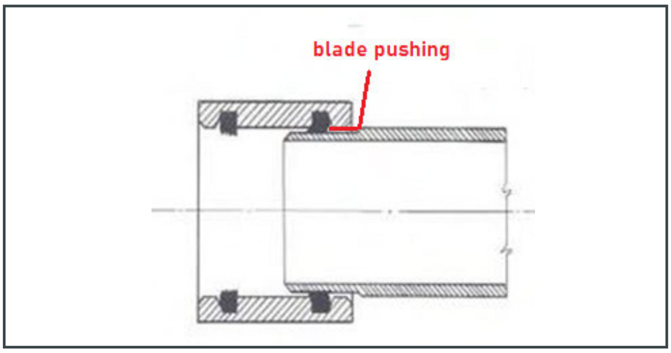

Figure 10: Blade pushing inspection in GRP coupler

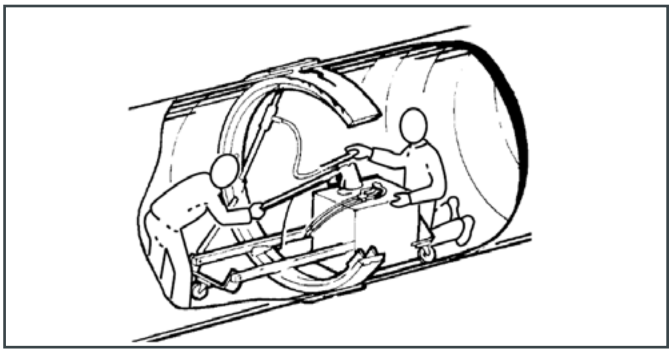

Figure 11: Internal Joint Tester (Amiantit Installation Guide)

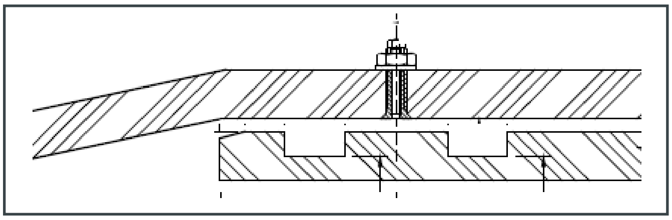

Figure 12: Spigot / Bell with nipple tester.

Figure 13: Layers dripping in laminate:

3. Spigot/ Bell joint test method is done when there are two rubber rings, where the nozzle can be installed in between the groove and water test can be done at joint prior final hydro test. Also testing rubber rings is from outside only, but it should be a good indication for the installer about proper rubber placement refer figure 12.

GRP Pipes with self-restrained joint (laminated or adhesive) required skilled pipefitters to prepare the joint. Normally laminated joint higher-skilled requirement than the adhesive joint, on the other hand, the adhesive joint is more challenging to inspect the joint after finishing the adhesive, we highlight here few points could be helpful during site installation:

1. The laminated joint which required skilled laminators to perform it should have inspection points related to visual, barcol hardness, and dimensions, however, it is essential to have proper layers dripping (laminate tapper) to avoid stress concentration laminate ends which could be peel off during operation especially due to thermal and vibration loads refer to figure 13.
2. Pipe ends with misalignment, ovality or different OD are very common at the site, the pipe ends will not be in a perfect position to start the lamination, in this case, special pipe ends preparation should be done, pipe edge grinding, or laminate layers for leveling refer to figure 14.

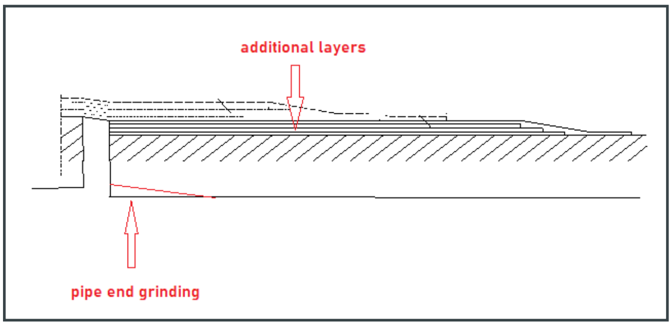

Figure 14: Pipe end grinding and additional layers due to misalignment

3. Adhesive joint after finish can have some NDT method to verify if any lack of adhesive occurred or improper adhesion on the pipe/ coupler surface. By using an ultrasound device that should be capable to have signal energy penetrated through the coupler thickness, in general sensor with 0.5 Mhrz should be capable to penetrate and defect a reflection in GRP depth up to 40 – 50 mm. which could be enough for the adhesive coupler. Refer to figure 15.

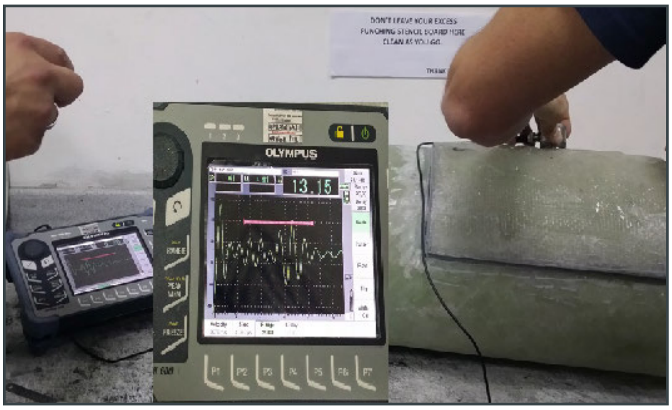

Figure 15: Ultrasound NDT on adhesive joint

3.3 PIPELINE STABILITY BEFORE THE HYDRO TEST:

Pipeline ready for site hydro test should have the following points checked up:

1. Ventilation at highest points, or vertical loops, sometimes these piping areas did not have the nozzles accommodated in design drawing or Isometric drawing, site team should be aware of it and install it in all necessary places to ensure air is removed during pipe filling. Refer to figure 16.
2. In case of any supports, restraints or thrust blocks are added to the system, this is necessary to be installed as per design conditions before starting the hydro test.
3. Common problems during the hydro test are pressure drop, in GRP piping as it has more flexibility than metallic piping could be exposed to pressure variation or drop during 4 hours or 24 hours of site hydro test, only a few standards and specification highlighted this issue. In Qatar Construction Specification, it is required to run 24 hours site hydro test, during this time the amount of water to be refilled to the system to accommodate the drop is measured and confirmed to meet certain criteria which is a maximum of 0.02 liter per mm diameter per km length per 24 hours per 1 bar. Shell DEP and some oil gas specification, required to have a pressure chart recorded during the test during, which can explain piping behavior during the test, obviously leakage in piping should be a visible leak or continuous drop of pressure. A pressure chart can be investigated along with temperature variation. Refer to figure 17.

Figure 16: Vertical loop with nozzle

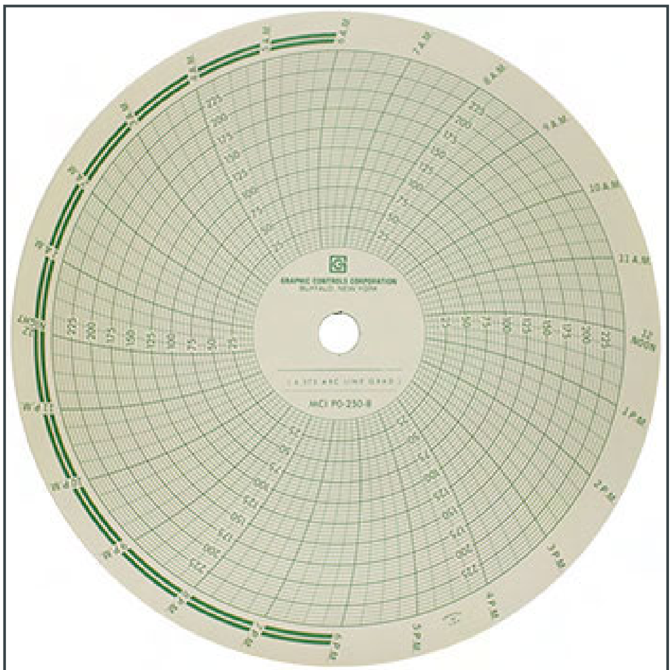

Figure 17: Pressure chart

4 GRP PIPING FAILURES:

In this paragraph, we are presenting several real failures that occurred in GRP piping, during which the root cause was conducted to investigate the possible cause and avoid.

4.1 FLOODED PIPES:

Flooding of pipes is a very common problem especially in GCC where sudden rain heavy rain could occur at any moment during winter or groundwater return to the trench zone during installation. refer to figure 18.

The contractor always advised applying a min backfilling layer as soon as the pipe is laid on trench which will help to maintain the pipe in position during the flood. Refer to table 4.

4.2 FLANGE CRACKS:

GRP flanges are critical parts of the system, they are necessary to connect piping into equipment, valves or other. normally GRP flanges are more delicate than other metallic flanges and require special attention during design and installation especially in thickness, type of gasket and tightening. It is very common for the installer to have flange connection cases with misalignment and site personnel attend to align the flanges by tightening creating cracks on the neck, these cracks could be major lead to immediate failure during hydro testing or it could be minor causing a failure on long term operation refer to figure 19.

GRP Flanges are not designed to carry other equipment loads like valves, it is most common to have all valves supported to avoid transfer loads to flange neck unless detailed analysis is performed to ensure flange is capable to carry the loads, in some cases automated valves are equipped with motors which will create additional moment on the flange during operation. Refer to figure 20.

DN	h min [m] für Sicherheit S = 1,1
100	0.07
300	0.20
600	0.37
1000	0.62
2000	1.25
2400	1.50

Table 4: Min depth against floatation (AQAP Installation guide)

Figure 18: Flooded pipes cases

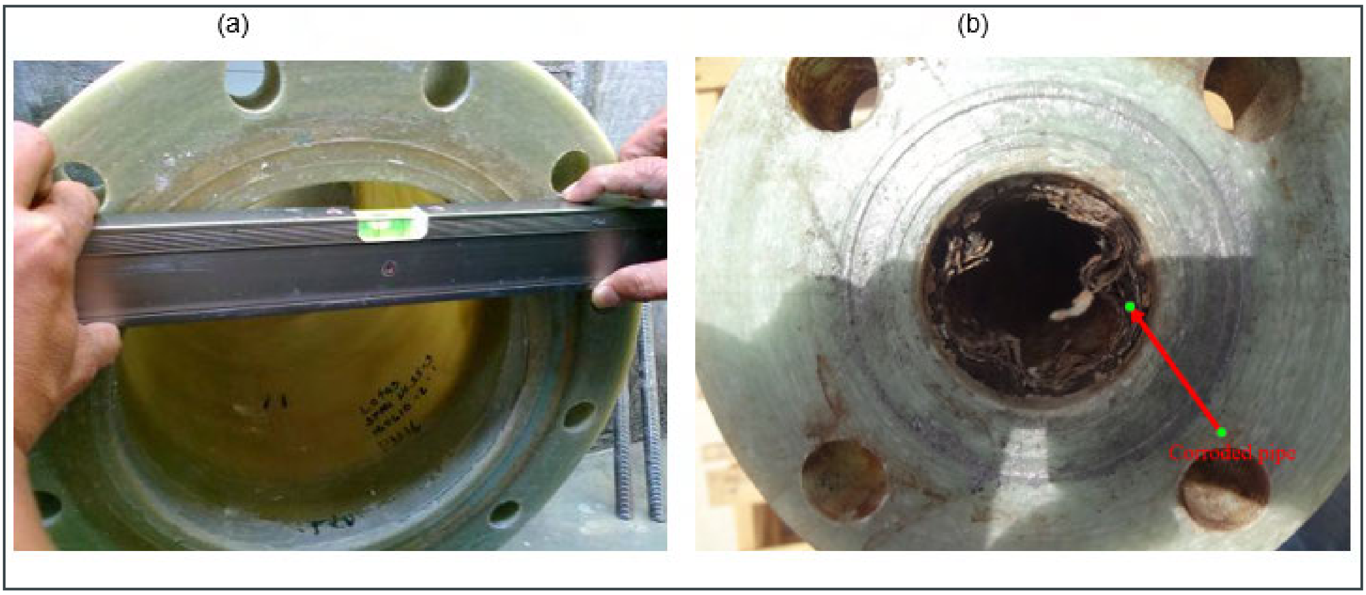

Figure 19: Flange Cracks due to misalignment (a- leak during the hydro test, b- flange leak after operation sour line

Figure 20: Flange crack, the valve is not supported

Figure 21: Flange cracks due to rerouting

Stress analysis for all piping is an essential activity, and the purpose for running this works is to ensure piping system is provided with adequate support, control the piping movement, ensure no major loads are transferred to equipment, comply with stress allowable with different load cases including occasional loads like hydro test, snow, thermal, wind and seismic. It is very common for that installer due to some site obstacles he has to reroute the GRP piping, in some cases, this rerouting will have different behavior in the piping and will require to ensure stress analysis is satisfied or not. Below is one example of flange cracks where the installer did some rerouting without consulting the stress engineer. Refer to figure 20,21 and 22.

4.3 PIPING DAMAGE DUE TO SETTLEMENT:

GRP piping going into the rigid structure should be treated carefully as explained in paragraph 4.1, below an example of GRE piping for fire water entering a building, failure occurred within 1 m from the wall due to settlement. As this piping system is self-restrained with a rigid joint, it is recommended to wrap the pipe with rubber or flexible material to protect the pipe from damage. Refer to figure 23.

Figure 23: GRE pipe damage due to settlement

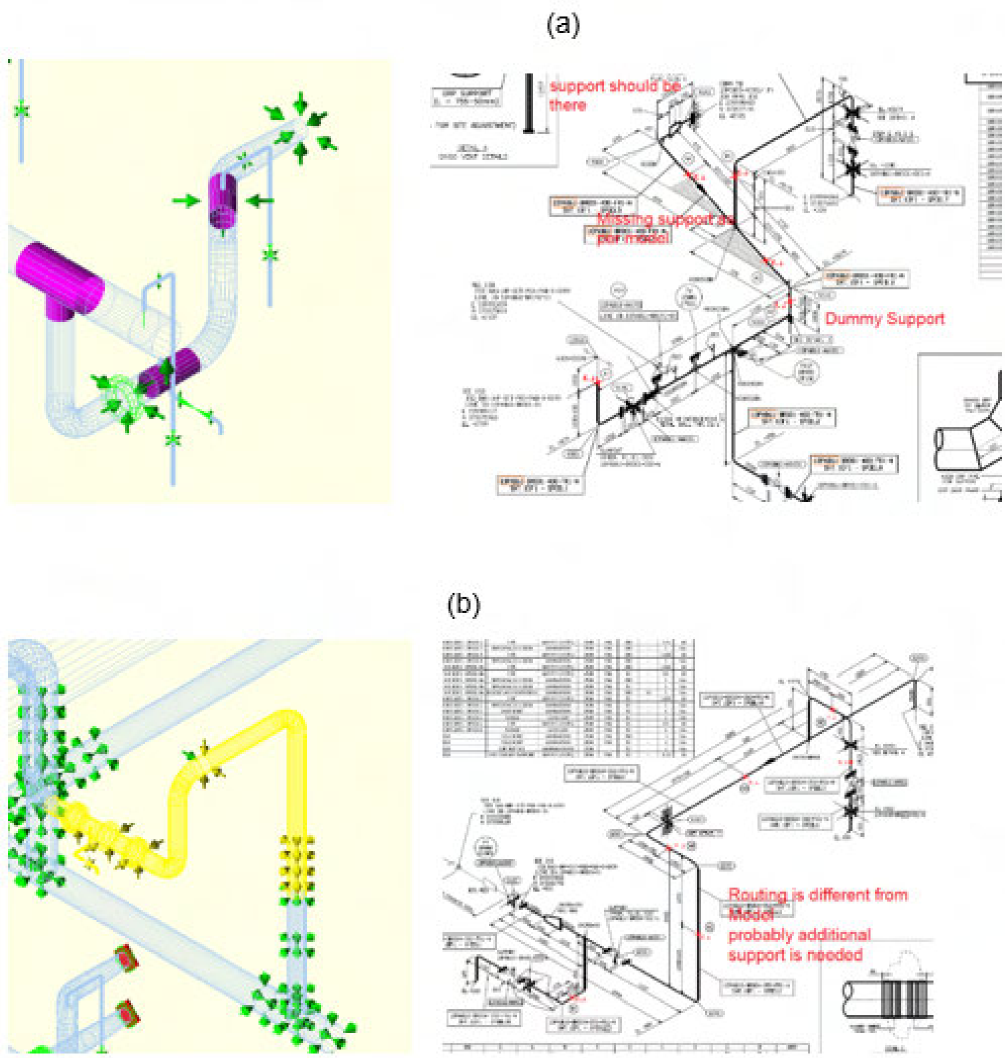

Figure 22: Rerouting is done without updating the stress model (a- case 1, b- case 2)

4.4 FAILURE IN CONNECTIONS:

GRP pipe coupling or mechanical coupling connection could be a source of leakage due to wrong gasket placement or high angular deflection, water will spray at high velocity along with abrasive soil will cause abrasion on external pipe surface which will lead to pipe wall thinning and then catastrophic failure at any pressure change, below photos for GRP coupling used to connect two different GRP pipes (restrained and unrestrained), it is well noted that this short piece is pipeline closure which could have different levels and high angular deflection has occurred during installation. refer to figure 24.

Mechanical coupling most probably used to connect two different pipes together with same or different outer diameter, failure on this coupling is possible if it is not suitable to one of both material, in Figure 30, we investigated several co failures in mechanical coupling (step coupling) connecting GRP to DI Piping, all of them has a sign of abrasion on pipe spigot nearby the edge of the coupling this is an indication of gasket leakage occurred during pipe operation which was caused by wrong rubber profile along with soil settlement. Refer to figure 31 it shows flat rubber profile used which is not acceptable in GRP piping, the best one used shall be sealing lips (REKA Type). Refer to figure 25 and 26.

Figure 24: GRP Coupling failure (abrasion on pipe surface)

Figure 25: Failure near mechanical coupling

Figure 26: Rubber profile of leaked mechanical coupling

5 FUTURE OF GRP PIPING:

It is well known that GRP piping requires additional specific requirement that is sometimes more critical than the standard piping requirement. There is poor literature related to GRP piping failures, however, after many decades of using GRP piping, it is necessary to learn from mistakes and improve the quality integrity if piping system during design, fabrication, and installation. NDT technique especially the Ultrasound is a method that is well understood in traditional homogeneous materials, but for composite pipes, the technique is still in an immature phase and a lot of research is required to standardize the method and categorize the defects. UTcomp has developed UltraAnalysis method on GRP material to evaluate aging by using an ultrasound device to study the stiffness reflection of polymer in the laminate and give digital data about the material status of aging and quality. [9]

6 ACKNOWLEDGEMENT:

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