



SAFETY ASSESSMENT
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Guidelines

Pressure Systems

The Integrity Management of Glass Reinforced Plastic Storage Tanks

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1. Introduction

SAFed Guide IMG01 provides specific information on the regulations applicable to storage tanks containing hazardous substances. IMG02 gives an overview of the inspection of storage tanks and this document contains specific guidance for Glass Reinforced Plastic (GRP) tanks. Thermoplastic and metallic tanks are covered in separate guidance.

Glass Reinforced Plastic storage tanks are used in chemical plants, factories and depots for the storage of substances. They can form the primary barrier against loss of containment for the substances stored or provide strength to a plastic lining. It is therefore essential to maintain their mechanical integrity. This can be achieved through an appropriate management system for the operation and maintenance of tanks, in conjunction with a scheme of examination for the periodic examination and testing. An examination and testing regime will need to take into consideration the lifecycle, from original specification and design, through its operation to decommissioning.

This guidance is published in the UK and therefore refers to its regulatory framework. However, much of the description of good practice it contains may be relevant elsewhere.

Storage tanks may form a confined space and reference should be made to the Confined Spaces Regulations and SAFed guideline PSG 10.

2. Scope

This document provides guidance on managing the mechanical integrity of Glass Reinforced Plastic storage tanks through periodic examination and testing. For further information on integrity management PM75 should be referenced.

This document does not cover the inspection of pipework, or protective systems associated with storage tanks.

This document does not cover the inspection of the secondary containment (bund) which is addressed in IMG07 of this series.

The maintenance or operation of the storage tanks necessary to ensure their continued safe operation is not covered in this document.

If the tank contains or is likely to contain a relevant fluid it is a pressure system and is excluded from the scope of this document. It will need to be included within a written scheme of examination as required by the Pressure System Safety Regulations.

3. Types of Storage Tanks – Common Materials/Types

There are many different designs of Glass Reinforced Plastic storage tanks which can be flat bottomed, possibly with conical or inclined bases fitted within the shell. Tanks can be rectangular or cylindrical in shape and may be constructed on site from “bolt together panels”.

They are manufactured from a number of material types and material combinations all of which have an impact on tank capabilities and will have been considered at the design stage.

Note: further information on the design of GRP tanks can be found in EN 13121 and BS 4994.

Thermosetting Resin – These can include but are not limited to: unsaturated polyester, vinylester, vinylester urethane, epoxy, furane & phenolic

Curing Agents – to start the free radical polymerisation process to move the resin from liquid to solid an initiator may be added to the resin. To increase the breakdown of the initiator an accelerator or promoter can also be added. Likewise to slow the hardening process down inhibitors may be added.

Reinforcing material – these are generally made from textile glass and come in different formats such as:

- Surface nonwovens
- Chopped strand mats
- Continuous strand mats
- Woven fabric/Woven roven fabrics
- Rovings for winding and for chopping applications

Additives – these can be viscosity controllers, conductive fillers to meet the needs of laminate conductivity for spark testing, fire retardants, paraffin wax for surface cure, pigments & Ultra violet absorbers.

Lining -To resist attack from the contents the inside surface of the tank will be lined. The lining can range from:

- Resin Layer (RL) - a simple layer of resin coating
- Veil layer (VL) - a layer of resin with one or two surface nonwovens
- Single Protective Layer (SPL) - a protective layer of resin with or without nonwovens
- Thermoplastic Lining (TPL) – a homogenous layer of the selected plastic

They can also be manufactured as an assembly within a bund or as a standalone item.

Each installation will require a specific inspection strategy based upon the design of the tank (shape, bunding arrangement etc.), material of construction, method of construction, nature of the content, operating conditions (including cycling), installation, design life, location, and the operating environment.

These all require to be taken into account in identifying the relevant damage & failure mechanisms and inspection strategies that are appropriate for each storage tank. The scheme of examination will apply appropriate inspection techniques and will take account of the initial integrity assessment.

4. Initial Integrity Management of Glass Reinforced Plastic Tanks

All Glass Reinforced Plastic tanks will require an assessment of initial integrity as described in section 4 of SAFed IMG02.

Where tank records are insufficient to establish its integrity the process flow chart indicated below will help to establish fitness for service.

The Competent Person may request additional information to enable him to determine any bespoke special requirements to be included in a Scheme of Examination. Once the Scheme of Examination is completed a full examination of the Storage Tank in accordance with this document can be made. The inspection process should include reviewing any previous inspection records that are available.

To assist the Competent Person in preparing a suitable Scheme of Examination they will require, where available, the following information:

- Manufacturer and manufacturer's identification number.
- Date of fabrication.
- Design contents, specific gravity or pressure.
- Design temperature.
- Design specification
- A drawing of the tank showing principal dimensions / thickness and materials.
- Design and construction standard / code, date of first use and safe allowable operating limits.
- The nature and maximum volume of fluid(s) contained, including any historical change of use, in addition to fluid(s) that may be used for other purposes such as cleaning.
- Details of any significant modifications or repairs that could affect fluid containment.
- Overview of operation (cycling / temperatures etc.) and maintenance performed.

In addition the Competent Person may request a review of alarm/instrumentation testing.

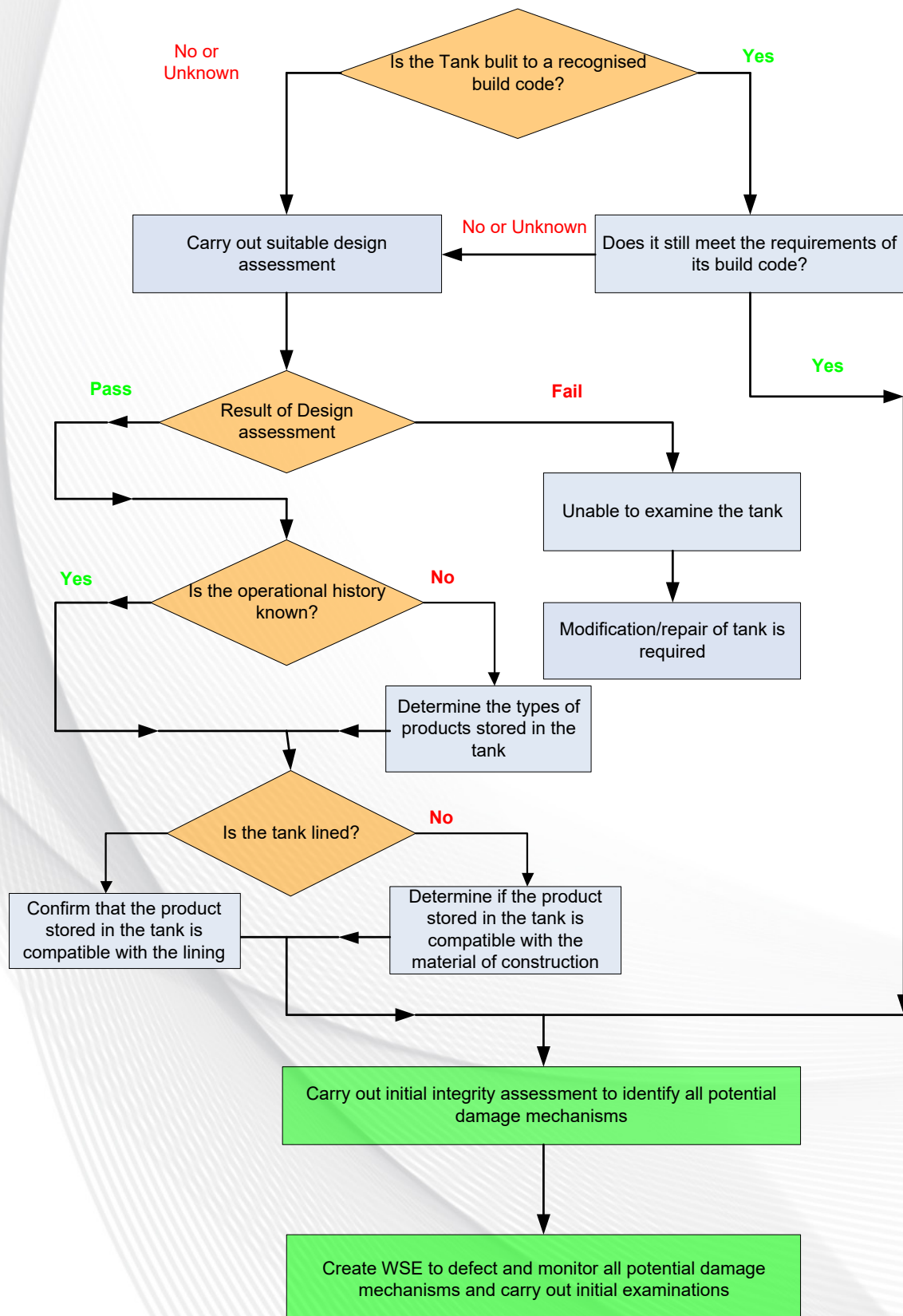
Where this information is not available further tests/assessment may be necessary. The process flow chart/decision tree indicated below will help to establish fitness for service.

In the event that fitness for purpose cannot be demonstrated a report might contain wording such as:

“This report does not represent a condition assessment of the physical structure nor the integrity of the storage tank, its fittings nor any fitted Protective Devices in accordance with inspection procedures. No assessment of the bunding arrangement has been carried out.

Other guidance is provided by such documents as SAFed – IMG01, DEFRA - Guidance note for the Control of Pollution (Oil Storage) (England) 2001 and HSE RR760 - Mechanical Integrity Management of Bulk Storage Tanks.”

TANK CONSTRUCTION



5. Possible Damage Mechanisms

Below are some of the damage mechanisms which may be identified using certain techniques:

| Damage mechanism | Location | Detection method-ology | Comments |
|------------------------------|--|---------------------------------|--|
| Fatigue cracking | External & internal and attachments | Visual & spark or holiday test | <p>Cyclic loading of tanks with repeated filling/emptying. Externally will show as cracking around nozzles and hold down supports. Internally will show as cracking in the base to shell junction, around nozzles, laminate behind the hold down supports.</p> <p>Vessels with liner, cracking in and adjacent to nozzle and base to shell welds. Ensure ladder and other attachments, piping connections, supports and agitator mountings are included in the inspection.</p> |
| Manufacturing defects | External & Internal surfaces and attachments | Visual & measure-ment | <p>Externally, mainly areas of exposed glass fibre where the laminate surface has insufficient resin applied, often around fittings and webs. Wrinkles and low areas in the shell circumference profile where insufficient laminate has been applied. Poor application of pigment or other surface coating. Internally, blisters in the corrosion barrier - closed or open. Scores or foreign matter in the corrosion barrier. Vessels with liner, missed liner welds. Misalignment of liner welds (usually circumferential welds). Undersize liner welds.</p> |
| Changes in surface condition | External | Visual, Barcol hardness testing | <p>Softening of the surface, star cracking, delimitation, discolouration, bulges/local swelling, tell-tale signs of leakage such as the appearance of liquid droplets permeating the surface, which often indicates imminent failure.</p> |

| Damage mechanism | Location | Detection method-ology | Comments |
|--|---------------------|--------------------------------|--|
| Changes in surface condition internally – without thermoplastic lining | Internal | Visual | Break down of the corrosion barrier including softening of the surface, star cracking, delamination, exposed fibres, erosion in the vicinity of dip pipes. |
| Changes in surface condition internally – with thermoplastic lining, | Internal | Visual | Discolouration, blistering or breakdown of the liner surface. Bulges in the lining (care should be taken as bulges are likely to contain product). |
| UV light degradation | External | Visual | For vessels outdoors, UV can slowly degrade/age the laminate. This can be caused by breakdown of the protective pigment or other surface coating (often non-slip surface). |
| Temperature properties | External | Visual | High temperature of delivered product resulting in pin holes or bulging. |
| Environmental cracking | External | Visual | Rapid temperature changes can lead to cracking. |
| Wind damage | External | Visual | Buckling of shell due to excessive winds. |
| Over pressure or vacuum | External | Visual | Deformation normally caused by incorrectly sized or blocked vent or overflow. |
| Mechanical damage | External & internal | Visual & spark or holiday test | Dropping loads onto vessel or walking on vessels that are not designed for such loads. Heavy scoring externally caused by handling or internally caused by scaffolding or mishandling when fitting metallic items in the vessel. |

| Damage mechanism | Location | Detection method-ology | Comments |
|--|----------|--------------------------------|---|
| External loading | External | Visual & spark or holiday test | Snow & ice build-up or unauthorised modifications with load bearing consequences e.g. additional platforms, heavy dip pipes/temp probes in nozzles, heating coils, baffles, addition of agitators into nozzles not designed for this loading. |
| Localised overloading on flat or sloping roofs | External | Visual & spark or holiday test | Overload from personnel, tools and equipment. Or drainage restrictions from vegetation and other debris. |
| Settlement of base or support structure | External | Visual | Subsidence – To avoid subsidence it is recognised good practice for Glass Reinforced Plastic tanks to be installed on continuous, horizontal, flat, smooth surfaces e.g. a load bearing concrete plinth. This should be inspected prior to installation. Bitumen, sand etc must not be used between the tank & the flat surface as loss of the layer will result in uneven stresses possibly resulting in mechanical failure. |
| Hold down anchorages, corroded, over tightened, loose or missing | External | Visual | Anchor bolts – Corrosion may occur below the base plate of the anchorage bolt. |
| Earthing connections | External | Visual & resistance test | Ground Connections to earth (if employed) - Ensure that a visual examination for corrosion is carried out; if any doubt a resistance test, by suitably qualified personnel, should be called for. |

Note: Appendix 1 contains photographs of typical defects

6. Scheme of examination for the periodic examination and testing

Section 6.2 of SAFed Guidance IMG01 sets out the general contents for a written scheme of examination.

IMG02b sets out inspection methodologies which can be applied to Glass Reinforced Plastic storage tanks. Where these methodologies are applied depends on the specific type and mode of operation of each storage tank.

- Although bunding will not form part of the tank examination itself, it is good practice to consider the adequacy of the bunding arrangements at the initial examination. This may be carried out by:
- Visual examination of the bund arrangement to ensure adequacy of capacity, current condition, general integrity and suitability.
- If the bund is manufactured from masonry or concrete the structure should be built to suitable standards such as CIRIA guidelines (Oil Storage). All penetrations e.g. fill or drain lines, must be fully sealed to prevent leakage. The bund must be impervious to leakage & a membrane may be fitted to ensure this.
- It is recognized good practice for the bunding to be constructed to ensure that “jetting” beyond the bund in the event of puncture is avoided. Examples of control mechanisms;
 - Keeping the container as low as possible
 - Increasing the height of the bund wall
 - Leaving sufficient space between the tank & bund walls
 - Not sitting one tank above another
 - Providing screening.

7. Flat bottomed tanks.

Tanks built after 2008 are generally built to EN 13121; prior to this BS 4994 may have been applicable. They can be either self-supporting or supported by beams. In addition to the general requirements the following types of inspection may be included in the scheme of examination.

- Circumferential tank measurements to check for deformation
- High voltage spark testing of welded joints
- Acoustic emission
- Thermography
- Barcol hardness tests.

Examples of other test methodologies can be found at National Composites Network.

Foundation

Visually assess foundation flatness and bottom elevation to look for signs of excessive tank settlement & check all anchor points including any fitted earthing connections etc.

Check for broken or cracked concrete, particularly around any annular ring. Examine for any cavities under the foundation and evidence of moisture ingress or growth of vegetation.

Check that run off rainwater from the tank shell flows away from the tank base.

However it should be noted that there are many variations in design so each case is individual.

8. Underground Tanks

Storage tanks may be sited underground or be mounded. Such tanks must be designed to take the soil loading & may be externally & internally ribbed for additional strength

Due to the nature of such tanks they obviously form a challenging environment to determine mechanical integrity. The inspection regime for these types of tanks may take the form of the following inspections,

- Internal visual inspection
- Dimensional survey
- For mounded tanks these should be de-mounded at determined intervals to check the external condition.
- Underground tanks are normally anchored down to prevent movement & may float if the water table rises and the contents are either of a lower specific gravity than water or the tanks is near empty. The integrity of anchors should be considered. If a mounded or buried tank settles after installation, this can have serious repercussions for the fixed pipework.

Where excavation of the tank is necessary care should be taken to avoid damage to the tank.

9. Lined Tanks

To provide chemical resistance some storage tanks have a protective liner. Dependent upon tank contents a variety of plastics may be used or occasionally a metallic liner. This is usually bonded to the load bearing structure of the tank. In cases such as this it is normal for the integrity of the liner to be checked by visual means to ensure its integrity. In high integrity cases this may need to be supplemented by spark testing (holiday testing). Due care should be taken in order to avoid damage to the liner. Liners may have a finite life and this should be factored into the scheme of examination periodicity and type of examination.

Defects may present themselves as cracks in lining welds or as cracks adjacent to welds, radiating from lining and internal support attachment welds, especially around the base to shell knuckle and lower nozzle/manway welds. Also discoloration, blistering or breakdown of the liner surface & bulges in the lining should be looked for Note - care should be taken as bulges are likely to contain vessel/tank contents. Heavy scoring due to mechanical damage may be encountered.

The use of an oblique light source may assist in detecting minor blisters forming in the lining by casting a shadow from the raised surface.

It will also be necessary to confirm that the mechanical structure is not suffering thickness loss underneath the liner, usually by thickness checking in suspect areas from the outer surface.

10. Supports

10.1. Bracket / Leg Supported

Legs must not be directly attached to the bottom of a dished vessel. The use of direct leg supports is generally limited to tanks of up to 1.5m diameter & 2m high designed for contents with an S.G. of up to 1.2. Above this legs are required to be fitted to a ring or angle girder.

Leg and bracket attachments require visual crack detection of attachment bonding to the tank and any fitted doubling plate to confirm continued suitability for purpose.

10.2. Saddle Supported

Horizontal cylindrical tanks may be supported by two longitudinal beams running the full length of the vessel but are more usually supported on two or more saddles. If the saddles are rigid they require a minimum angle of 120 degrees if they are flexible they need to embrace the lower region for 180 degrees.

Where more than two saddles have been used this can result in very high stresses at one of the saddles if there is any misalignment of the shell or settlement/subsidence at one of the supports.

The highest stresses at saddle supports are normally at the horns of the saddle and there may be a reinforcement between the saddle and the shell to ensure that the stresses are acceptable. Visual examination for cracks externally at the saddle horns will be required to confirm tank integrity. If the saddle or reinforcing plate is not continuously bonded to the shell there is a risk of contamination between the shell & support structure from external spillage etc.

Saddle supported horizontal tanks generally have a lower support loading than bracket supported tanks but the examination still needs to focus on the support area, particularly the horns of the saddle.

11. Remote Visual Inspection (RVI) & Non Invasive Inspection (NII)

Many of the sections above discuss the need for a full internal examination, however developing technologies may allow for remote examination reducing the risks associated with gaining entry into a tank to carry out a full internal examination. For example new camera technologies may be able to provide sufficient visual proximity to provide an equivalent examination without the need for man access. This Remote Visual Inspection is carried out from the outside of the tank with only the camera entering the tank through a suitable nozzle. There are many benefits of these techniques.

Advantages

- Potential reduction in the costs associated with preparing a tank for man entry.
- Reduced exposure of personnel to confined spaces.
- Can be used where man access is not possible.
- Can be used where access has not been provided in the original design of the equipment.
- Can be used for pre entry screening, i.e. in order to determine the condition of the tank prior to a planned shutdown.
- Potential reduction in shut-down / start-up issues.
- Higher plant availability.
- Can provide video/still photographs as a permanent record of the examination.
- Some Non-Invasive Inspection techniques can be carried out whilst the tank is in service.

Disadvantages.

- Requires good access for the camera equipment.
- Equipment is expensive and rarely intrinsically safe.
- Requires special operator training.
- Examination takes longer
- Tank will require cleaning, in some cases higher cleanliness than for tank entry. (Man entry)
- Defect interpretation and sizing can be more challenging.
- May still require man entry to confirm defect type and size.

When considering RVI it is vital that all potential degradation mechanisms are correctly identified in order to apply suitable Non-Invasive Inspection techniques. Any RVI/NII techniques applied would need to be evaluated on a case by case basis as to the capabilities and limitations in detecting the anticipated degradation / defects which would normally have been detected by a full internal examination. For any RVI/NII technique the probability of defect detection should be considered. The RVI/NII techniques must be justifiable in terms of the techniques used and the periodicity of examination.

Where these techniques are to be used as part of an examination procedure under a Scheme of Examination then their use should be defined within the Scheme of Examination. The inclusion of the techniques within a Scheme of Examination should be considered as part of a formal technical review of the Scheme. The technical review of a Scheme of Examination should lead to an examination regime at least as effective as the previous scheme. Failure to carry out effective examinations may lead to an increased risk of degradation leading to an incident. Non-Invasive Inspection should not be seen as an option in lieu of any procedural requirements of existing Written Schemes.

It may be appropriate to use Non-Invasive Inspection techniques in order to extend the periodicity between full internal (person entry) examinations but should not be considered a replacement for a full internal examination. If, for example, it was found through evaluation that Remote Visual Inspection could detect all predicted degradation mechanisms for a vessel then the period between full internal examinations could justifiably be increased with the Remote Visual Inspection examinations falling between full internal examinations. Recommended Practice DNV RP G103, Non-Intrusive Inspection, provides structured guidance as to when RVI/NII may be appropriate in support for deferment of internal visual examination.

Where any RVI/NII regime is in place the opportunity for a full internal examination should be taken whenever the tank is opened. Opportunistic examinations such as this allow for the identification of any unexpected degradation and help in the justification that the selected Non-Invasive Inspection techniques remain suitable for the examination of the tank.

12. Summary

This document highlights the main types of storage tanks that are used in industry, and provides guidance on the type of inspection regime that may be called up within a Scheme of Examination to ensure their continuing integrity during operation.

Whilst these are general guidelines each individual storage tank is different and as such will need an individual assessment to confirm its pedigree, history, operating conditions, future loading etc to determine an inspection strategy that best fits the risks encountered.

13. References

SAFed IMG01 – The Mechanical Integrity of Plant Containing Hazardous Substances

SAFed IMG02 – The Integrity Management of Storage Tanks

SAFed IMG02d – The Integrity Management of Protective Devices

SAFed IMG07 – The Integrity Management of Bund Walls Associated with Storage Tanks

HSE PM75 – Glass Reinforced Plastic vessels & tanks - Advice to users

CBA / SAFed – Non-metallic Storage Tanks manufactured prior to 2007 – Guidance for Operators

EN 13121 – GRP tanks & vessels for use above ground

BS 4994 1987 - Design and construction of vessels and tanks in reinforced plastic

DNV RP G103 - Non-Intrusive Inspection

14. Useful References:

RR760 Mechanical Integrity of Bulk Storage Tanks

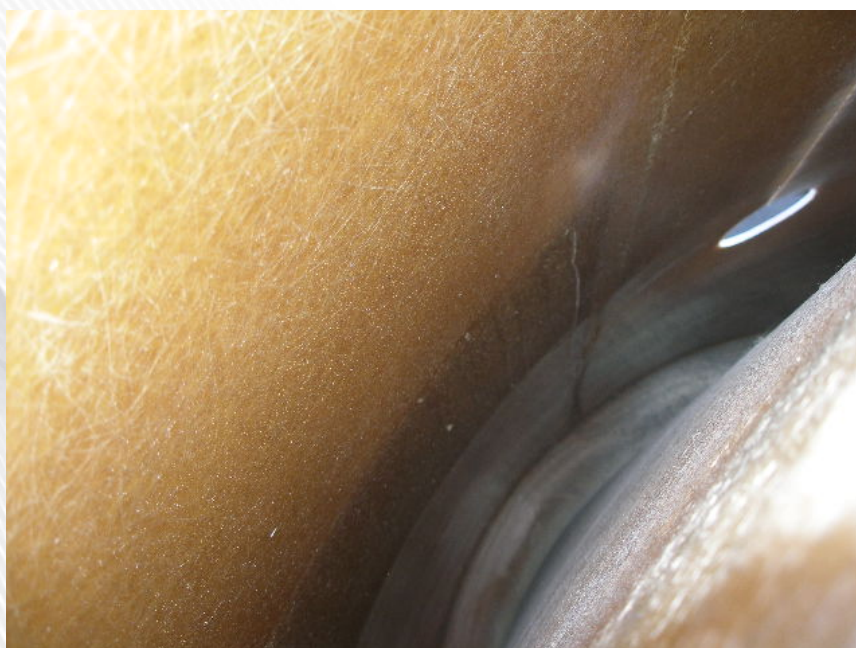
National Composites Network

Environment Agency

Appendix 1 – Examples of defects found in GRP tanks



Picture 1 - Chemical attack causing blisters



Picture 2 - Fatigue crack internal on surface of self bunded tank



Picture 3 - Delamination caused by poor bonding at manufacture



Picture 4 - Poor bonding at manufacture



Picture 5 - Crack propagating from base to shell attachment.



Picture 6 - Historical image of a catastrophic failure



Picture 7 - Insufficient landing on base causing excessive load leading to cracking



Picture 8 - Severe cracking on shell