SAFETY ASSESSMENT FEDERATION

Guidelines

Pressure Systems

The Integrity Management of Metallic Storage Tanks-Guidelines for Users and Competent persons

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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. IMG02a contains specific guidance for metallic tanks. GRP and plastic tanks are covered in separate guidance.

Metallic storage tanks are used in chemical plants, factories and depots for the storage of substances. They form the primary barrier against loss of containment for the substances stored and therefore it is essential to maintain the tank's 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 metallic storage tanks through periodic examination and testing. The maintenance or operation of storage tanks necessary to ensure their continued safe operation is not covered in this document.

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.

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 may need to be included within a 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 metallic storage tanks and each installation will require a specific inspection strategy. They are manufactured from various materials, the most common being carbon steel and austenitic stainless steel.

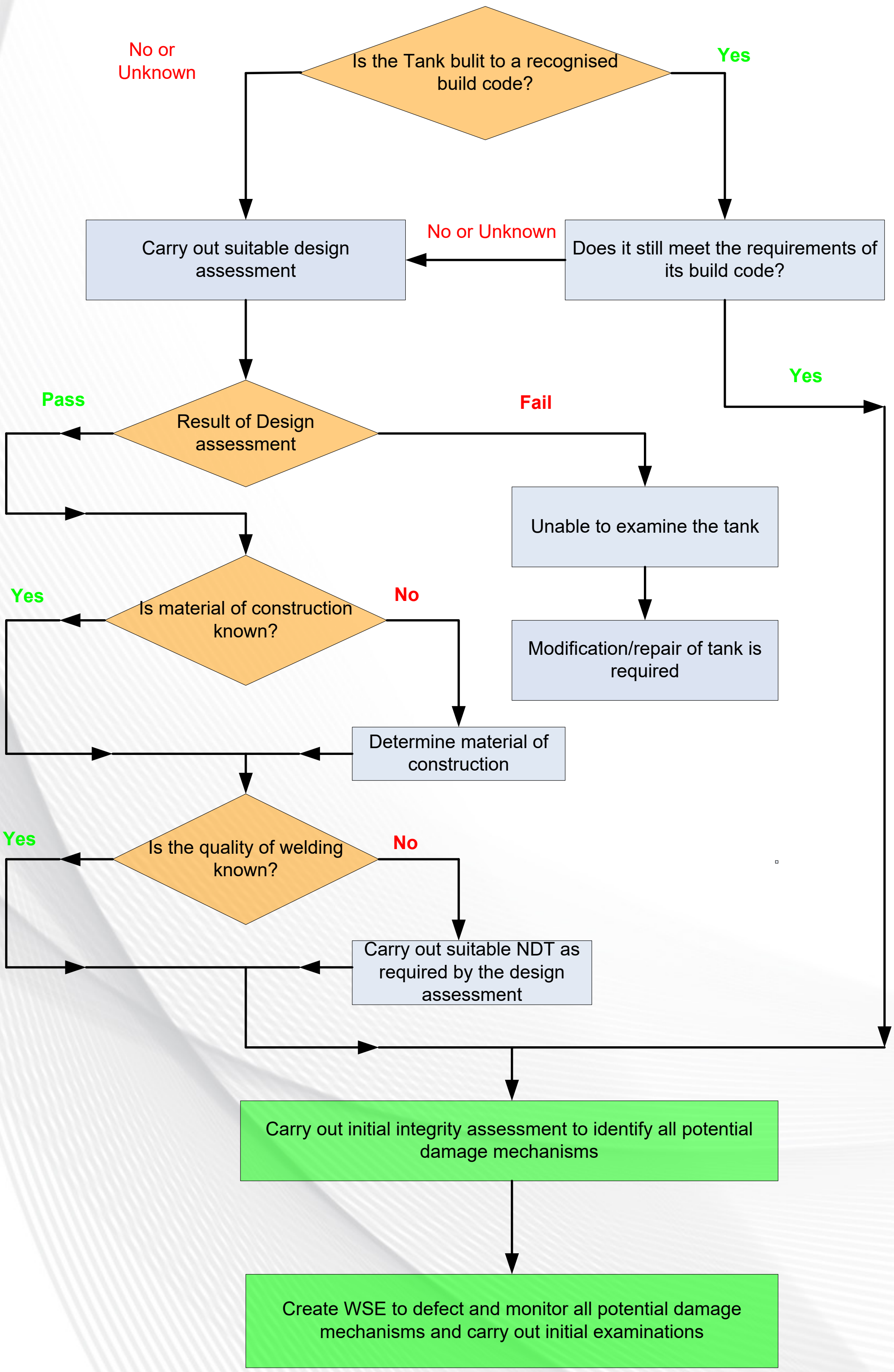
The design of the tank, material of construction, nature of the content, operating conditions, location, and environment requires to be taken into account in identifying the relevant damage mechanisms and inspection strategies that are appropriate for each storage tank and material of construction. The scheme of examination will apply appropriate inspection techniques and will take account of the initial integrity assessment.

4. Initial Integrity Management of Metallic Tanks

All metallic 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/decision tree indicated below will help to establish fitness for service.

TANK CONSTRUCTION



5. Possible Damage Mechanisms

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

Damage Mechanism	Location	Detection Methodology	Comments
Atmospheric corrosion	External parts and attachments	Visual, ultrasonic thickness survey	More sophisticated corrosion mapping techniques may be used
Corrosion under insulation (CUI)	External	Visual, thermal imaging, sample removal of insulation	Aggressive at temperatures of 30°C to 120°C, (carbon steels)
Coating breakdown	External	Visual	
Impact damage	External	Visual	E.g. scaffolding impact during erection and dismantling, access equipment
Settlement of base or support structure	External	Visual	Use of plumb bob or spirit level
Environmental assisted cracking	External	Visual, NDT surface flaw techniques	E.g. chloride cracking of stainless steel in coastal areas
Hold down anchorages, corroded, over tightened, loose or missing	External	Visual	Necking due to crevice corrosion, overtightening preventing expansion e.g. floating saddle
Localised overloading on flat or sloping roofs	External	Visual	Overload from personnel, tools and equipment. Or drainage restrictions from vegetation and other debris.
Fatigued induced cracking at tank attachments. (Filling, emptying and or temperature cycling)	External/internal	Visual, NDT surface flaw techniques or volumetric technique	Ladder and other attachments, piping connections, supports and agitator mountings
Corrosion/erosion	Internal	Visual, tactile, ultrasonic thickness survey	Corrosion from content and/or contamination, condensation on upper surfaces or water layer on lower surfaces

Damage Mechanism	Location	Detection Methodology	Comments
Coating breakdown	Internal	Visual and holiday test, conductivity test	Rubber, plastic or glass linings
Impact damage	Internal	Visual and holiday test, conductivity test (if tank is lined)	E.g. scaffolding impact during erection and dismantling, agitator paddles,
Environmental assisted cracking	Internal	Visual, NDT surface flaw techniques	E.g. chloride cracking of stainless steel due to content, content contamination e.g. cleaning solutions.

6. Scheme of examination for the periodic examination and testing

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

IMG02a sets out inspection methodologies which can be applied to metallic 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. Reference should be made to IMG07.

7. Circular Vertical Flat bottomed tanks

- These tanks are generally built to BS 2654 or similar specification such as BS EN 14015. Although some tanks are large diameter oil storage facility type storage tanks, the majority of tanks outside this type of usage generally pose less onerous engineering problems. Examples of inspection techniques are as follows;
- Thickness survey of base, annular rings and shells (Grid dimensions should be appropriate to the size of the tank and the consequence associated with the loss of content).
- Check of the annular ring to shell welds for cracking and corrosion using suitable NDT method.
- Check of the lower section of the shell for corrosion, the lower 100mm of the shell is often most vulnerable to corrosion. The upper section of the shell and the curb ring is also vulnerable to corrosion.

- Insulated tanks – the lower 100mm is better free from insulation (where possible) to prevent moisture being absorbed into the insulation and to allow examination.

- Foundation - Visually assess foundation flatness and bottom elevation to look for signs of excessive tank settlement.
- Check for broken or cracked concrete, particularly around any annular ring.
- Examine for any cavities under the foundation (at annular ring) and evidence of moisture ingress or growth of vegetation.
- Check that run off rainwater from the tank shell flows away from the tank base.

Example of external floor plate lifting from the foundation

- Other External features to consider depending on tank design:

    - Wind girders - Should be examined for corrosion and secure attachment to the shell. Drain holes should be clear.
    - Anchor bolts – Should be secure, although allowance for expansion is required.
    - Frangible roofs – Should be checked to confirm the roof joint has not been compromised

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

8. Horizontal Tanks

If the tanks are built to contain a relevant fluid, as defined in the Pressure System Safety Regulations (PSSR), they will be a pressure system and not covered in the scope of this document.

Horizontal vessels will have some common degradation mechanisms including – but not limited to:-

- Corrosion (See section 12 for information on supports)
    - Internal depending upon the contents.
    - This will need to be checked for by carrying out visual and thickness surveys from the inside of the vessel where external access is unavailable due to insulation/fire protection.
    - External, may be caused by spilt product or the atmospheric conditions. Where the tank is insulated or coated in fire protection then corrosion under the insulation must be considered. Where there is evidence of damp area's or damage to the coverings then they should be removed to the extent that any underlying damage is exposed.

- Tank Movement.
    - If the tank settles after installation, this can have serious repercussions for the fixed pipework, therefore the movement should be checked during commissioning for a new tank, and re-assessed during service.
    - Tanks may float if the bund floods and the contents are either of a lower specific gravity than water or the tanks is near empty. For this reason tanks may require anchoring during installation with examination of the anchors in service.

- Inspections for tanks as appropriate but not limited to the following:-
    - External/Internal visual inspection.
    - Thickness survey.
    - Check the earth bonding (where fitted).
    - NDT of "T "intersection joints and branch connection welds.
    - The integrity of anchors should be considered.
    - Tanks where internal access is not available, access to the external shell should be made available at a predetermined frequency to check the external condition of the tank.

9. Underground Tanks

These tanks are generally buried or mounded to reduce the risk of fire engulfment or reduce the heating effects of sun's rays on the contents. Eg. Solvents. By mounding or burying tanks, they reduce the environmental impact by not requiring a large volume of water to be held on site for the fire suppressant systems, also the ground works can be more aesthetically pleasing than normal above ground tanks.

Mounded and Buried vessels will have some common degradation mechanisms including – but not limited to:-

- Corrosion:-
    - Internal depending upon the contents.
    - This will need to be checked for by carrying out thickness surveys from the inside of the vessel.
    - External.
      Buried and mounded vessels are normally fitted with cathodic protection as well as the external surfaces having protective coatings. The cathodic protection needs to be included within a scheme of examination and the records checked at regular intervals.
    - Corrosion of pipework to and from buried and mounded vessels
    - Pipework should be included within the cathodic protection circuit, where pipework falls within the ground covering layer.
- Tank Movement:-
    - If a mounded or buried tank settles after installation, this can have serious repercussions for the fixed pipework, the cathodic protection wiring and the protective covering.
    - Buried tanks 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. For this reason some buried tanks may require anchoring during installation.
- Inspections for buried and mounded tanks as appropriate but not limited to the following:-
    - Internal visual inspection.
    - Thickness survey.
    - Check the cathodic protection (if fitted).
    - NDT of "T "intersection joints and branch connection welds from inside the vessel.

- Mounded tanks should be de-mounded at determined intervals to check the external condition. Care should be given not to cause damage to the tank coating during this work.
- The integrity of anchors on buried tanks, should be considered and access given if ground water table has been recorded at above contents level.
- Mounded tanks where internal access is not available, the tank should be de-mounded.
- Buried tanks where internal access is not available, access to the external shell should be made available at a predetermined frequency to check the external condition of the tank.

10. Lined Tanks

To provide chemical resistance some storage tanks have a protective liner, usually rubber, PTFE and occasionally a metallic liner, which 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.

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. A blister could be a tell-tale sign that the content has breached the lining and is causing corrosion to the steel structure underneath and any blister will require investigation.

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.

There have been failures of this type of tank after inspection due to un-managed removal of equipment from the interior of the vessel. A hydrochloric acid tank failed within six weeks of inspection. Though the lining had been proven intact during examination, the removal of the scaffolding was uncontrolled and a scaffold pole was dropped into the vessel. The company involved in the removal of the scaffold was not aware of the consequences of the lining failure and did not report the incident. The tank went back into service with a damaged lining.

11. Insulated Tanks.

Many tanks are insulated for either frost protection or for thermal efficiency where the tank is heated to reduce the viscosity of the fluid stored. This can make inspections of the outer surfaces problematic. A thickness survey from the inside of the tank can be used to identify areas of corrosion but it is more usual and more effective to remove areas of the insulation to examine the surfaces underneath. The extent and location of areas to be examined will be dependent on the condition of the insulation and in particular how well it is sealed to prevent ingress of moisture or ingress from spillage of product. The condition of the cladding should form part of the examination, with particular attention paid to the seal at the insulation termination points and at penetrations through the insulation. The lower point of the insulation should terminate approximately 100 mm above the annular plate on flat bottomed tanks to ensure that any water in the bund cannot ingress upwards through a wicking effect. This will also provide good access for examination of the junction of the lower shell with the annular ring. The areas of insulation to be removed should be specifically nominated in the Scheme of Examination but it may also be necessary to remove further areas dependant on the findings at the time of the examination.

Some tanks may suffer thermal fatigue from heating and cooling duties, and as such this should be considered in the integrity assessment as a possible damage mechanism and incorporated into the Scheme of Examination where necessary.

12. Supports

12.1. Skirt

One of the more robust methods of supporting a vertical, cylindrical storage tank is to fit a skirt support. When properly designed this provides a strong support to the shell and, when provided with suitable openings, allows easy access for inspection of the bottom dished end externally. Historically it provides few engineering problems during service. This type of support would normally have a full visual inspection at each examination, a thickness survey if evidence of corrosion is found and crack detection of the attachment weld. For the other parts of the tank the types of inspection outlined for flat bottomed tanks should be applied as appropriate.

12.2. Bracket / Leg Supported

Many vertical cylindrical storage tanks are supported on legs, either welded directly to the cylindrical portion of the shell, attached to the shell via brackets or welded to the bottom dished end. Often these will require doubling plates to reduce the stresses applied to the tank to acceptable levels. Where the design specification is not available it may be necessary to carry out a design assessment to ensure that applied stresses are acceptable.

In addition to the loads applied from the weight of the tank and contents, brackets on the shell and legs on the bottom dished end create bending stresses at the attachments.

All leg and bracket attachments would generally require surface crack detection of attachment welds to the tank and doubling plate to confirm continued suitability for purpose.

12.3. Saddle Supported

Horizontal cylindrical tanks are usually supported on two saddles. 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 is often a reinforcing plate between the saddle and the shell to ensure that the stresses are acceptable. Surface crack detection externally at the saddle horns and crack tests at the internal areas opposite the saddle horns are often required to confirm tank integrity.

If the saddle or reinforcing plate is not continuously welded to the shell there is a risk of corrosion or contamination between the plates. Loose saddles on carbon steel vessels may require the tank to be lifted from the saddles to check for corrosion of the shell in this area. Alternatively ultrasonic thickness testing of the saddle area can be carried out when there is internal access.

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. Older tanks tend to have loose saddles which are not integrally attached to the tank. If there is evidence to suggest that moisture or other corrosive substance has penetrated the interface between the saddle support and the tank shell then a tank thickness survey should be carried out from the inside the tank to check for corrosion.

13. 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 Schemes of Examination.

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.

14. 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.

15. 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 on Storage Tanks
- SAFed IMG07 – The Integrity Management of bunds associated with Storage Tanks
- EEMUA 159: Users' Guide to the Inspection, Maintenance and Repair of Above ground Vertical Cylindrical Steel Storage Tanks
- API 650: Welded Tanks for Oil Storage
- API 653: Tank Inspection, Repair, Alteration and Reconstruction.
- BS2564:1989 Design and Build of Storage Tanks.
- DNV RP G103, Non-Intrusive Inspection.

16. Useful References:

RR760 Mechanical Integrity of Bulk Storage Tanks.

Environment Agency Web Site:

https://www.gov.uk/government/organisations/environment-agency