

PETRONAS TECHNICAL STANDARDS

DESIGN AND ENGINEERING PRACTICE

MANUAL

FIELD INSPECTION, MAINTENANCE AND REPAIR OF VERTICAL STEEL STORAGE TANKS

PTS 70.51.10.11

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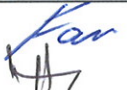
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All updates in the document are highlighted in *Italic* font

Document Approval

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1. INTRODUCTION

1.1 SCOPE

This PTS specifies requirements and gives recommendations for field inspection, maintenance and repair of vertical steel storage tanks.

The inspection and testing of fire-fighting facilities is excluded from the scope of this PTS.

This PTS is a revision of the PTS with the same number dated July 1998. A summary of the main changes since the previous edition is given in (1.5).

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by PETRONAS, the distribution of this document is confined to companies forming part of PETRONAS or managed by a Group company, and to Contractors nominated by them.

This PTS is intended for use in oil refineries, chemical plants, gas plants and, where applicable, in exploration and production installations and supply/marketing facilities.

If national and/or local regulations exist in which some of the requirements may be more stringent than in this PTS, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable as regards safety, environmental, economic and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this PTS which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned with the object of obtaining agreement to follow this PTS as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, installation, and commissioning or management of a project or operation of a facility. The Principal may sometimes undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party which manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant, authorised to act for the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.4 CROSS-REFERENCES

Where cross-references to other parts of this PTS are made, the referenced section is shown in brackets. Other documents referenced by this PTS are listed in (10).

1.5 SUMMARY OF MAIN CHANGES

The main changes in this edition of the PTS are:

- a). *References to EEMUA 159 have been updated to reflect the current edition of EEMUA 159 (3rd Edition, 2003)*

2. GENERAL

Although failure or leakage of storage tanks may not disturb normal operations as much as failure of process equipment does, it may have serious economic consequences and cause severe pollution.

Therefore, the philosophy applied to the inspection of process equipment shall also be applied to the inspection of storage tanks, although intervals between inspection of tanks are normally much longer.

To take a tank out of service for inspection involves great expenditure and inconvenience. For this reason it may be tempting to postpone such an activity until there are clear indications that repair is needed. It shall be realised, however, that if this approach is followed several tanks in identical duties may need urgent repair simultaneously, which may create greater inconvenience.

An important aspect of the tank inspection programme is "trending". Trending means determining the rate of corrosion, or some other parameter, and projecting this data say 5 or 10 years into the future. After each subsequent inspection, the trend is adjusted as necessary. A change in product stored or operating conditions may require the trend to be adjusted. In addition to corrosion rates, trending can also be used for tank settlement, coating systems and floating roof seals.

By establishing a long-term inspection and repair programme based on well-defined inspection procedures and trending, the following advantages will be obtained:

- corrosion rates can be predicted more accurately;
- tank settlement can be predicted more accurately;
- tank materials and spares required for repairs can be ordered in time;
- tank inspection intervals can be scheduled more accurately.

The full benefit of such an inspection and repair programme can only be obtained when proper records of inspection data and tank history are maintained.

Authorities in many countries now require tank owners to operate an effective tank inspection programme and to maintain inspection records in accordance with either EEMUA 159 or API 653.

Where the use of either EEMUA 159 or API 653 is required by the Authorities, the requirements of that document become the minimum requirements. If the Authorities require the use of another specification which is different from the requirements of this Manual, the more stringent of the two shall apply. This applies to each individual requirement.

Whether a tank is fit-for-purpose overall and the duration of its next service period shall be decided by a competent Tank Integrity Assessor (TIA). The TIA shall be a qualified API 653 inspector or holder of a Certificate of Competence issued by EEMUA/TWI.

3. INSPECTION FREQUENCY

3.1 GENERAL

The severity of external and/or internal corrosion of storage tanks depends on the the type of product, local atmospheric conditions, details of tank and foundation, soil conditions and anti-corrosion measures provided. Because of the many variables involved, no firm frequency for inspection can be given. Appendix 1 indicates inspection frequencies based on type of product and climatic conditions. These frequencies are for guidance, but they should be used unless information is available about actual corrosion rates.

Internal inspection of a tank in between two scheduled inspections should always be considered if an unexpected, dangerous situation such as tank settlement or abnormal condition of the roof occurs. Immediate action shall be taken at the first sign of bottom leakage.

To avoid an unforeseen reduction in storage capacity because of the unavailability of tanks, an inspection programme shall be prepared and followed. This programme should cover many years in advance because of the normally long intervals between internal inspections.

Scheduling of tanks for inspection shall be done in co-operation with the operating department to determine tank availability, and with the maintenance department which will plan the work.

If the inspection results of a tank indicate a more rapid deterioration due to corrosion or settlement, other similar tanks may need to be inspected earlier. Conversely, if the inspection results are more favourable an extension of the inspection interval may be considered if approved by the Principal. In no case shall the internal inspection interval for any tank exceed 20 years.

An external routine visual inspection, with the tank in service, shall be carried out at least once every 3 months. An external detailed inspection, with the tank in service, shall be performed at intervals in accordance with Appendix 1, or as determined by the Tank Integrity Assessor (TIA) after each detailed internal or external inspection.

Certain soil may cause severe corrosion to the underside of tank bottoms, which could result in serious accidents. Such conditions can be:

- soil containing corrosive elements, e.g. salts or chlorides;
- soil capable of capillary action;
- moisture content;
- temperature.

Note: Corrosion is an electrochemical process which usually accelerates with an increase in temperature, e.g. tank heating

- level of foundation not sufficiently elevated above level of bund floor;
- mill scale not removed from underside of bottom plates.

Furthermore, the type of foundation is important with regard to the consequences of a leak in the tank bottom. Sand pad foundations without an adequate shoulder can be subject to a 'wash-out' or 'slip-circle' type failure, the consequences of which can be very serious. A foundation with a reinforced concrete ring wall or a crushed stone ring wall is unlikely to suffer such a failure. Available information about any of the above conditions shall be taken into account when scheduling tanks for inspection.

A separate schedule shall be made for the regular inspection of safety relief valves (see Appendix 4).

3.2 CONDITION-BASED INSPECTION

In considering condition-based inspection, report MF 95-1188 shall apply.

4. TANK INSPECTION

4.1 GENERAL

The Tank Integrity Assessor (TIA) shall be thoroughly familiar with the design requirements and construction details for storage tanks. Moreover, the TIA shall be fully qualified to judge the tank integrity based on the information supplied by the various specialist contractors or consultants, for example settlement data and ultrasonic thickness measurements. Upon evaluation of the data, the TIA shall declare the tank fit for purpose or not. If the tank is found not to be fit for purpose, the TIA will be responsible for the specifying and acceptance of the repair work. Upon completion of the repair, the TIA shall issue the fit for purpose statement.

The fit for purpose statement shall clearly specify the next inspection date, which may be different from the recommendation in Appendix 1.

The TIA is responsible for maintaining a detailed record for each individual tank. The record shall include tank drawings, design conditions, pumping rates used for vent sizing, maximum fill height, settlement readings and the results of all inspections, repairs and modifications. Any change in product stored or operating conditions shall be noted in the records. The records shall also include calculations made for evaluation purposes and the trending plots.

For internal inspection, the inspection procedure shall, if possible, be established before the inspection starts.

For detailed external inspection, including ultrasonic thickness measurements of shell and roof, a fixed programme shall be followed. Permission shall be obtained from the operating department for each individual tank. Ultrasonic instruments are not always intrinsically safe and are allowed for thickness measurements on the shell subject to having a safety permit. For ultrasonic thickness measurements on the roof with the tank in service, additional precautions and a special safety permit will be required. Permission to perform the roof thickness measurements may depend on product volatility and ambient temperature. Special conditions such as gas monitoring on the roof and halting product movement will probably be required. Severe corrosion of the roofs plates may require additional safety precautions before personnel are allowed on the roof.

4.2 EXTERNAL ROUTINE VISUAL INSPECTION

The external routine visual inspection may be carried out by an inspector or an operator experienced in tank operation and maintenance. The main purpose of the external routine visual inspection is to check the foundation, shell, accessories and roof.

In the first place, the observations shall concentrate on leakage from under the bottom, shell settlement, shell deformations (flat spots, buckles or bulges), corrosion spots, condition of insulation and anything else out of the ordinary or different from previous inspections. Attention shall also be paid to bottom edge settlement (see *EEMUA 159, Figure 7.3.5-1*) and the ability of piping attached to shell fittings to follow tank settlement. For tanks provided with a leak detection management system, the detection sump shall be inspected for traces of product.

Secondly, the observations shall concentrate on the condition of paint work, safety of stairs, platforms and handrails and proper functioning of equipment.

Operational personnel should pay frequent attention to the proper functioning of rainwater drains on floating roof tanks, e.g. product leakage from or clogging of the roof drains.

A check list such as included in EEMUA 159, API 653 and API 575 shall be used. The completed check list with any additional comments shall be submitted to the TIA for his review and record keeping.

4.3 EXTERNAL DETAILED INSPECTION

The external detailed inspection consists of a visual inspection combined with ultrasonic thickness measurements of shell and roof and a shell settlement survey. These inspections shall be carried out using the standard system of reference points as specified in (Appendix 2). If reference points are not yet marked on the tank shell, they shall be marked before the external inspection starts.

External corrosion may occur on all external parts of a tank and may become quite severe under certain conditions. The external inspection shall consist of an examination for signs of corrosion, leakage and settlement. It shall also include the connected pipelines and, if applicable, bellows. The proper functioning of external equipment such as vents, pressure/vacuum valves, gauging devices and water-draining equipment shall be established.

In the following subsections a more detailed description of the external inspection is given.

4.3.1 Tank foundation

The part of the foundation which projects beyond the base of the tank (the shoulder) shall be inspected to verify that the sealing coat is in good condition and that the slope of the shoulder will ensure good drainage, see PTS 34.11.00.11. It is possible that minor, even settlement of a tank will form a channel around the periphery of the tank bottom in which rainwater will collect and cause serious corrosion of the bottom-to-shell connection. Minor, uneven settlement will cause pockets with the same result. Special attention shall therefore be paid to such settlements and to the proper drainage of the tank foundation, because rainwater penetrating underneath a tank bottom will cause corrosion, particularly of tanks storing hot products.

4.3.2 Settlement survey

A shell settlement survey shall be conducted by taking level readings at the reference points marked on the shell (see Appendix 2) by placing the rod on the bottom edge next to the shell-to-bottom fillet weld. Level readings shall be evaluated against the criteria set out in *EEMUA 159, section 7.3.1 through 7.3.7*.

For tanks with an internal or external floating roof, the out-of-plumbness of the shell shall be measured at each horizontal seam. Measurements shall be taken along a vertical line from the reference points used for the level survey.

Preparations for internal inspection and repair shall be made in cases of severe or uneven settlement (*EEMUA 159, section 7.3.4*) which may cause high stresses at the bottom-to-shell connection.

4.3.3 Bottom leakage

If there are signs of product leakage all around the periphery of the tank, this may be an indication of a leak near the centre of the tank or a number of leaks spread over the bottom. If the leakage appears to be at one location of the tank pad only, the leak may be in the bottom close to the periphery. This situation is considered dangerous since the leaking liquid may cause cavities in the tank pad close to the tank shell and the bottom will not be completely supported. A hole or crack may cause an unstable condition due to liquefaction of the soil. With an increase in load (filling of tank), a wash-out or slip failure may occur resulting in rupture of the tank bottom and total release of contents. If leakage near the shoulder is discovered immediate action is required. The use of acoustic emission may be considered to establish the possible location of a bottom leak.

4.3.4 Tank shell

The tank shell shall be inspected for signs of deformation (flat spot, buckle or bulge), leakage or corrosion of bottom edge and shell plates.

On insulated tank shells the waterproof sealing/cladding of the insulation shall be examined every year, in particular the shell just above a stiffener ring and above the annular plate shall be inspected since the entry of moisture will greatly reduce the insulating properties

and may also result in serious undetected corrosion of the tank plates underneath the insulation. If it is suspected that moisture has penetrated into the insulation material, a small area of the tank shall be uncovered and examined for signs of corrosion. Stiffening rings, to prevent buckling of the shell by wind loads, are insulated to prevent high thermal stresses at low ambient (winter) temperatures and should also be checked.

See *EEMUA 159, section 15* for comments on insulated shells.

4.3.5 Shell nozzles and manholes in bottom shell course

If excessive soil settlement has occurred, all pipe connections to the tank shall be visually inspected for external corrosion and possible distortion. Excessive settlement may require readjustment of the piping or re-levelling of the tank.

If nozzles have been subjected to significant piping forces due to settlement or due to vibration such as may be induced by side entry mixers or jet mixers, the nozzle or manhole attachment welds shall be magnetic particle inspected.

Bellows in pipe connections shall be inspected to see whether they have reached the ultimate movements as indicated in the design specification.

Tell-tale holes in reinforcing plates (if fitted) shall be checked that they are not plugged and not leaking product. Tell-tale holes shall be filled with grease to prevent moisture entering.

4.3.6 Ladders, stairways, platforms and railings

See *EEMUA 159, section 13.1*

In addition to a general inspection of the steelwork particular attention shall be paid to:

- supports to tank shell;
- intermediate platforms and handrailing;
- concrete pedestal supports for stairways.

4.3.7 Fixed roof

Before stepping onto the roof of a cone-roof tank a visual check shall be made for external corrosion or holes. If there are indications that corrosion has penetrated the roof, access to the roof shall be prohibited and internal inspection of the tank and roof structure shall be carried out as soon as possible.

Roof plates of cone-roof tanks built before 1945 were riveted with overlaps. These roof plates had a thickness of only 3 mm. Since 1945 roof plates have been welded on the top side only, with overlaps of 25 mm, and the thickness has been increased to 5 mm.

See Appendix 4 for venting requirements

4.3.8 Floating roof

Access to a floating roof shall be allowed only when the roof is in a high position and with the permission of the operating department. See also 4.4.7 and 4.5.5.

Rolling ladders:	See <i>EEMUA 159, section 12.6</i>
Roof seals:	See <i>EEMUA 159, section 12.3, Table 12.3.1-1, Figures 12.3.1-1 through 12.3.1-4.</i>
Roof drain:	Check that the drain sump is clear and the non-return valve (pontoon type roofs only) is not blocked open.
Foam dam:	Check that rain water will drain away from behind the foam dam. Visually inspect top pontoon for corrosion behind foam dam and at outer rim. Perforations in pontoon top deck can cause flooding of pontoon compartments.
Automatic bleeder vents:	Check that automatic bleeder vents are pinned in the same position as the adjustable roof supports.

4.4 THICKNESS MEASUREMENTS (EXTERNAL)

4.4.1 Grid system

- Mark vertical grid lines from reference points at the bottom of the shell to the top of shell. Number the vertical grid lines the same as the reference numbers.
- Mark two horizontal grid lines on each shell course, the first one at 30 mm above the lower edge of each course, the second one at mid-height of each course. Number horizontal grid lines 01, 02, 03, etc. starting with 01 at 30 mm above tank bottom.
- For fixed roof tanks, extend vertical grid lines to roof centre.

Grid line intersections are identified as 11:04, meaning vertical grid line number 11 and horizontal grid line 04 (mid-height second course).

4.4.2 Coating thickness

Coating thickness shall be deducted from the thicknesses measured.

4.4.3 Pit depth measurements

In areas of significant external pitting, the depth shall be measured with a pit gauge and subtracted from the shell thickness adjacent to the pit. This provides the remaining thickness at the bottom of the pit.

4.4.4 Ultrasonic thickness measurements of tank shell and bottom edge

The use of a painter's scaffold for taking shell thickness measurements is preferred because it offers the opportunity to look at the plate surface. A digital ultrasonic thickness gauge shall be used to take thickness measurements along the vertical grid lines, as specified under a) and b) below. Alternatively, if an A-scan cathodic ray tube display unit is available, it shall be used to scan the horizontal and vertical grid lines over 100% of their length to identify areas with a thickness less than the pre-set reference thickness or areas with material defects such as laminations.

Ultrasonic thickness measurements shall be taken at the following locations:

- On the bottom course as close as possible to the toe of the shell-to-annular fillet weld. This measurement shall be taken at each vertical grid line.
- At the intersection of vertical and horizontal grid lines.
- At locations where the A-scan has indicated areas of thickness less than the reference thickness or areas with material defects such as laminations.

- Note:
- The scope of the inspection can be reduced to say 50% by using alternative grid lines if definite evidence is available that other tanks of the same age and storing the same type of product have suffered only minor corrosion.
 - If the inspection indicates severe corrosion necessitating shell repairs, the scope of inspection shall be extended to establish the boundaries of areas to be repaired.

Reference thickness t_{ref} for scanning should be equal to $[t_{min} + CA]$, where t_{min} is the minimum acceptable shell thickness (mm) as calculated in *EEMUA 159, section 9.3* and CA is the maximum estimated corrosion until the next inspection date. Often, t_{ref} is taken as the average of t_{min} and $t_{as-built}$. The effective shell thickness shall be determined in accordance with *EEMUA 159, section 9.2*.

4.4.5 Ultrasonic thickness measurements of nozzle and manhole neck plates

Take ultrasonic thickness measurements of nozzle/manhole neck as close as possible to reinforcing or shell plate. Take measurements at 12, 3, 6 and 9 o'clock positions.

4.4.6 Ultrasonic thickness measurements of fixed roof

Take ultrasonic thickness measurements of roof plates along the radial grid lines (extension of vertical grid lines) at 200 mm from shell, at 2/3 radius and at 1/3 radius. In addition, take thickness measurements at locations where significant external corrosion is observed. No

ultrasonic thickness measurements of the roof shall be performed if the roof plates have been perforated by corrosion (4.3.7).

4.4.7 Ultrasonic thickness measurements of floating roof (pontoon type)

Thickness measurements of floating roof shall be carried out when the tank is empty and gas free. The requirements are stated under internal inspection (4.5.4).

4.5 INTERNAL INSPECTION

Whenever a tank has been made available for internal inspection, a more critical external inspection shall be carried out in advance, since any repairs required can be made more conveniently while the tank is out of service.

The tank should be thoroughly cleaned, after which an initial visual inspection can give a first impression of the condition of the tank and provide information on the extent to which further activities are required, e.g. shot-blasting for scale removal etc. The application of shot-blasting for scale removal will also facilitate the detection of pitting corrosion.

4.5.1 Tank bottom

A detailed visual check shall be made for cracks and any sign of bottom leakage. Attention shall be paid to the connection between shell and bottom, particularly if uneven local settlement along the periphery has occurred. If there is evidence of cracks, further examination by magnetic particle inspection shall be considered.

Lap-welded joints shall be inspected for leaks by means of a vacuum box. This test shall be repeated after the completion of repairs.

4.5.1.1 Tank bottom corrosion and thickness measurements

Corrosion on tank bottoms can occur from inside of a tank, particularly if water separates from the product. Corrosive deposits or rainwater can also enter floating roof tanks via improperly closing roof seals. This corrosion will generally be concentrated at low spots of the bottom.

Severe corrosion may also have occurred underneath the bottom plates. See *EEMUA 159, section 4.3* for underside and topside corrosion of bottom plates.

For large diameter bottoms with anticipated external corrosion, the floor scanner (magnetic flux leakage) provides the highest coverage and assurance. Indications by the floor scanner and areas which cannot be reached with the floor scanner e.g. annular plates, should be checked with an ultrasonic thickness gauge.

For smaller diameter bottoms, if previous experience indicates little or no external corrosion, thickness measurements can be taken with an ultrasonic thickness gauge at the same location as the bottom level survey points (4.5.1.3). In addition, thickness measurements should be taken at any point where the visual inspection has indicated significant corrosion.

External corrosion can be a pitting type of corrosion spread over the entire surface or it can be localised. It is very difficult to detect from the inside whether and where it has occurred, because ultrasonic measurements on plates which are irregularly corroded underneath may not give accurate results, and the area to be inspected is generally too large to be covered by a single probe. Therefore, repairing a single leak from the inside by patching may result in other potential leaks being overlooked and they may appear shortly after the tank has been taken back into service.

Alternative methods for inspection include magnetic flux leakage or, if the tank is still in service, acoustic emission.

If external corrosion is severe, the best way to inspect the underside of tank bottoms is to jack up the entire tank so that effective inspection and repairs can be carried out. At the same time the tank pad and external bottom protection can be improved and attention paid to the drain sump in the tank bottom.

Heating coils, if installed, shall be hammer-tested, particularly at the underside of the coils and the bends. In addition radiography can be applied to give an indication of any internal corrosion.

The appearance of a tank bottom after the tank has been in service for some time depends on its original condition after construction and on soil conditions. If the bottom had originally been constructed as a cone with its apex upwards at the centre of the tank, after settlement the bottom may be flat, and buckling or rippling along a longitudinal line of lap welds in the

centre may have occurred due to the bottom changing shape. This is acceptable as long as the buckling is not too severe (less than 75 mm in height), with no sharp corners, and if no further settlement is expected). If buckling is severe or further settlement is expected, ripples shall be removed. Otherwise cracking may occur in the welds adjacent to the ripples. See *EEMUA 159, section 7.3.3*

4.5.1.2 Riveted bottoms

The rivet heads should be checked with a caliper and should be rejected if they have decreased to about 50% of the original dimensions. If the tank bottom has been thinned by internal corrosion, checking with this caliper can be misleading.

The rivet heads should be inspected visually to ascertain whether the bearing pressure on the plates is still sufficient. When in doubt, leakage tests should be carried out with a vacuum box. If unacceptable corrosion of the rivet heads has occurred, they may be successfully welded as an alternative to re-riveting, provided that the bottom plates are still in good condition. Both rivets and rivet joint shall be shot-blasted before being welded with two passes.

4.5.1.3 Bottom level survey

Transfer the reference points marked on the outside shell to the inside shell (see Appendix 8) using the same numbering system. Level readings shall be taken along radial lines from each reference point to tank centre at the following positions:

- a. next to internal bottom-to-shell fillet weld;
- b. at 300 mm from inside shell;
- c. at 750 mm from inside shell;
- d. thereafter at 3 m intervals to centre;
- e. at centre or on flange of centre sump.

In addition, level readings and contour measurements shall be taken of major bulges, depressions or ripples in the bottom.

Level measurements at positions a. and c. should be used to evaluate the edge settlement condition as specified in *EEMUA 159, section 7.5.2*.

4.5.2 Tank shell

Internal corrosion of storage tanks depends on the contents of the tank. Corrosion can occur in the vapour space and in the area covered by the liquid.

The decision to erect scaffolding inside a tank or to use scaffolding mounted on wheels solely for inspection should be delayed until visual inspection has indicated that the scaffolding will be required.

If external ultrasonic thickness measurements of the shell have been taken in accordance with 4.4.4, then no further thickness measurement inside the shell are necessary. If few or no external thickness measurements have been taken, then the inside shell shall be examined to the same degree as specified for the external inspection (4.4.4).

Insulated shells shall also be inspected internally to the same degree as specified for the external inspection. In addition, insulated shells may need further thickness measurements e.g. just above an intermediate stiffener where moisture may have accumulated inside the insulation.

A close visual examination shall be carried out of the bottom-to-shell fillet weld, the plate surface of the first shell course, the vertical butt welds of the bottom shell course, the girth joint between the first and second shell course and the nozzle or manhole attachment welds. Additional ultrasonic thickness measurements and/or pit depth measurements may be required if corroded plate areas are found which were not detected by the external investigation. If corrosion is found along the welded joints, magnetic particle inspection shall be performed to check for cracks in the weld or base metal.

From thickness measurements taken on the shell during the external detailed inspection (4.4.4), information should already be available whether any general corrosion has occurred. From external inspection of the roof and from plate thickness measurements taken on the roof, it can be determined whether any corrosion has taken place in the vapour space.

Attention shall also be given to any sign of shell buckling which may have been caused if the empty tank was exposed to abnormally strong winds. Corrosion may have weakened the resistance to wind load.

With the information obtained and using searchlights for further visual inspection, it should be decided whether scaffolding needs to be erected for a more detailed examination. This will definitely be required if there are signs of leakage in the tank shell.

4.5.3 Fixed roof plates and framing

See *EEMUA 159, section 4.4.1* for a general discussion about corrosion of roof plates and supporting structural members.

The roof framing shall be inspected from the tank bottom using a strong searchlight. The inspection shall concentrate on the arrangement of members and ensure that no members are buckled or bent and that trusses and rafters are on a straight line through centre. If trusses and rafters are not on a straight line through centre, it could mean that the framing has rotated (corkscrew movement). This situation is potentially dangerous and should first be investigated by a tank design expert (structural engineer) before any further work is done inside the tank.

If external visual inspection and thickness measurements of roof plates have proved satisfactory, no further internal inspection of roof plates or framing is necessary.

If external inspection indicated internal corrosion of the roof plates, the same type of attack can be expected for the roof structure. If so, preparations shall be made for a more detailed inspection from inside the tank. For the inspection of the framing, a mobile scaffold tower will probably be the most convenient way of access.

As guidance, the supporting structure should be rejected when the loss of metal exceeds 25%. Roof plates corroded to an average thickness of less than 2 mm in 500 mm x 500 mm area shall be repaired or replaced. The expected corrosion rate until next shutdown shall be taken into account.

The roof should still be sufficiently strong and reliable if the average thickness of the supporting structure and the plates is greater than the minimum values given above. Only if isolated holes are observed may the roof be patched.

See *EEMUA 159, section 4.4.1*, for corrosion of roof plates and supporting structural members.

4.5.4 External floating roof (open top)

Pontoon compartments:

Each pontoon compartment should be visually inspected internally for corrosion and leakage, supplemented by thickness measurements. Ultrasonic thickness measurements shall be taken in areas where the visual inspection has observed corrosion. Pontoon compartments shall be tested for tightness with air in accordance with PTS 64.51.01.31

Roof drains:

See *EEMUA 159, section 12.2* for a detailed description of the various types of roof drain. The steel pipe drains and flexible hose drains shall be hydrostatically tested at 3.5 bar (ga) and carefully checked for leakage as part of the internal inspection.

The following items, although subject to external routine visual inspection (4.2), shall be included:

Roof seals:

See *EEMUA 159, section 12.3* for a detailed description of the various types of roof seals. Roof seals shall be checked for damage, distortion, dirt or improper functioning. Malfunctioning of seals may be caused by uneven settlement of the tank. Deformation of the shell as a result of uneven settlement may cause jamming of the roof or gaps between roof seal and tank shell.

Shunts:

The electrical connections (shunts) between the floating roof and the tank shell shall be inspected. Improperly installed, broken or corroded connections may result in a rim fire due to a discharge of static electricity and/or lightning. If a secondary seal is installed above an existing primary seal, the original shunts should be removed and new shunts should be installed outside the secondary seal. With a secondary seal, the foam dam may need to be extended to project at least 50 mm above the secondary seal in its steepest position.

Rolling ladder:

Check hinge bolt at top of rolling ladder, wheel and axle at the foot of rolling ladder, alignment of ladder and runway and any other indication which may cause the ladder to jump the track or get stuck on the track.

4.5.5 Internal floating roof (in tank with geodesic dome)

These are usually open top floating roofs with a geodesic (aluminium) dome added to reduce emissions and maintenance. Covered floating roofs are protected from the elements and will require less maintenance than an open-top floating roof. A roof drain is not normally required, but an existing roof drain may be left in place. Access to the roof is not permitted during service, consequently the roof inspection shall become part of the internal inspection.

4.5.6 Internal floating cover (in fixed roof tank)

- a. Access to roof.** It is not permitted to enter a fixed-roof tank with floating cover during operation to inspect the cover.

Because internal floating covers cannot be observed during operation there is a greater risk that something may go unnoticed. Every opportunity should be used to internally inspect the roof to reduce the risk. The best opportunity to check the operation of the roof is during a hydrostatic test when it is possible to go onto the roof while it is floating.

- b. Inspection of cover.** As a first inspection, the floating cover shall be observed through a roof manhole using an intrinsically-safe search light.

The requirements for inspection and maintenance of the floating cover depend on the type of cover, e.g. whether made from steel, aluminium or fabric. A separate procedure should be prepared for the inspection and maintenance of the cover, if necessary in conjunction with the Manufacturer of the cover, or based on Manufacturer's inspection and maintenance data.

- c. Foam-filled rim seals.** When the tank has been gas-freed and cleaned, and is then entered for inspection, foam-filled rim seals, which may be saturated with oil due to a leak in the rubber envelope around the foam, shall be examined. If the foam is saturated the seal shall be removed from the tank and be replaced by a new one.

The rim seals of floating covers are of a simple construction. Their maximum inward and outward movement is generally at least 25% less than that of seals used with floating roofs. Therefore it is essential that the tank shell is as round as possible for the floating cover to function properly.

4.6 FLOATING SUCTION

A distinction should be made between the following types:

- a. floating suction in fixed roof tank;
- b. floating suction in open-top floating roof tank;
- c. floating suction in fixed roof tank with internal floating cover.

In a fixed roof tank, the floating suction is free floating and will project a short distance above the liquid level.

In open-top floating roof tanks and fixed roof tanks with internal cover, the floating suction will be completely submerged and will travel along guide rails mounted against the underside of the floating roof or internal cover.

Inspection of floating suctions shall include:

- check alignment, bearings and seal of swivel joint;
- pressure test floats for leak tightness;
- check track angles on underside floating roof for deformations;
- check chain is free to move without getting caught behind some part;
- if aluminium piping is used, check electrical isolation of piping and shell against galvanic corrosion.

5. EVALUATION CRITERIA

The main tank components (foundation, bottom, shell and roof) shall be evaluated by the Tank Integrity Assessor (TIA) according to the inspection results. Guide lines and rejection limits to assist with the evaluation of these components are given in the following subsections.

5.1 FOUNDATION

See API 653, section 2.5, for evaluation of tank foundations.

See *EEMUA 159, section 7*, for a description of the different types of settlement and maximum limits of differential settlement and out-of-verticality of tank shell.

API 653, Appendix B, may also be used for the evaluation of differential shell settlement.

5.2 BOTTOM

See *EEMUA 159, section 7*, for a description and maximum limits of different types of bottom settlement.

See *EEMUA 159, section 8.4*, for minimum acceptable corroded thickness of bottom and annular plates.

5.3 TANK SHELL

For the evaluation of a welded tank shell, it is essential to know the joint efficiency factor, allowable stress and date of issue or edition of the design code on which the design of the tank shell has been based. Knowledge of the material properties, i.e. guaranteed minimum yield, tensile strength and material toughness are also important in evaluating the shell. Such information shall be stated in the tank inspection records.

Based on the inspection results, the tank shell shall be evaluated for the following two conditions:

a. Hoop Stress Condition:

Tank filled with product to maximum filling height internal pressure

b. Buckling Condition:

Tank empty but subject to wind, vacuum and concentrated vertical loads from roof structure.

The corroded shell shall also be checked for seismic stability if this was a requirement for the original tank design.

5.3.1 Hoop stress condition

The minimum acceptable shell plate thickness for the hoop stress condition shall be calculated as follows:

a. Butt-welded shells:

According to *EEMUA 159, section 9.3*.

Note: The minimum acceptable plate thickness should not be less than 2.5 mm or 50% of the original shell thickness, whichever is greater.

For evaluation purposes, the minimum acceptable thickness shall be equal to or greater than the effective corroded shell plate thickness as determined according to the procedure described in *EEMUA 159, section 5.5*.

For many tanks, especially of medium and large size, the top shell courses may buckle before the minimum acceptable thickness limit has been reached. The rejection limit for top shell courses should therefore not be determined before the buckling criteria of the shell have been checked according to the requirements described under (5.3.2).

b. Lap-welded shells:

Same as for butt-welded shells except that the joint efficiency factor shall be taken as $E = 0.75$.

c. Riveted shells:

Same as for butt-welded shells except that the joint efficiency factor shall be taken as listed below:

Configuration	Plate thickness (mm)	Joint type	Joint efficiency factor
single	15	lap	0.60
double	15	lap	0.73
3-fold	18	lap	0.73
4-fold	18	butt	0.87
5-fold	21	butt	0.91
5-fold	25	butt	0.91
5-fold	28	butt	0.90

5.3.2 Buckling condition

The minimum acceptable thickness limits for shell plates specified in 5.3.1 are based on the condition that the tank is completely filled with liquid. However, buckling of the shell could occur before the above-mentioned minimum acceptable thickness limits are reached.

Buckling of shell plates may occur when the stability of the tank shell is insufficient to withstand one or a more of the following loads:

- Wind on the outside of the tank shell. For open top tanks the wind suction on the inside of the tank shall also be considered.
- Internal vacuum inside fixed roof tanks.
- Vertical loads caused by the roof structure.

Buckling due to wind will exhibit a local buckle on the upper shell, over 60° maximum of the circumference on the windward side.

Buckling due to internal vacuum will exhibit buckles over the entire circumference of the shell course. This type of buckling is more likely to occur with low-pressure and high-pressure tanks than with non-pressure tanks, since low-pressure and high-pressure tanks are to withstand a vacuum of 6 mbar and non-pressure tanks a vacuum of 2.5 mbar in conjunction with the windload. Therefore, assuming similar tank shells, critical buckling values will be reached earlier for low and high pressure tanks (See *EEMUA 159, Figure 9.5.1.1-1 through 9.5.2-1*).

Sometimes tank shells are constructed in such a way that the surface of the upper courses shows slight flat spots. This mostly occurs with tanks of 30 and 33 m diameter where 6 mm thick plates are still used for the upper courses. These flat spots have an unfavourable influence on the stability of the shell and may cause buckling at an earlier stage than theoretically expected.

The stability of the corroded tank shell against buckling shall be checked in accordance with the calculation method given in Appendix 5.

It is also pointed out that:

- Maximum wind gusts mostly result in a wind load which is approximately 20% higher than the wind loads specified in building regulations. The 3-second gust value shall be taken in the stability calculation for the shell.

- b) Stability calculations should be based on the total vacuum, that is the vacuum set pressure + vacuum accumulation to achieve full opening of the vacuum relief valve. See Appendix 4 for information on venting and vent setting.

If the welding required to install the stiffening rings is not immediately feasible it is possible to reduce the tank shell loading conditions of tanks equipped with vacuum valves by reducing the setting of the vacuum valves, e.g. from 6 mbar to 2.5 mbar. Since this will increase breathing losses slightly, it should be considered a temporary solution.

5.4 FIXED ROOF

5.4.1 Roof plates

For rejection criteria for roof plates, see *EEMUA 159, 10.3*.

5.4.2 Roof structure

If corrosion of the roof structure has caused a loss of metal of 25% or more, a tank design engineer shall be consulted for an evaluation of the corroded structure.

5.5 FLOATING ROOF

5.5.1 External floating roof

Plates corroded to an average thickness of less than the limits listed below shall be repaired or replaced. Local corrosion not exceeding the following limits can be considered acceptable:

Double deck roof top deck	-	2 mm over an area of 500 x 500 mm
Double deck roof bottom deck	-	3 mm over an area of 500 x 500 mm
Pontoon top deck	-	2 mm over an area of 500 x 500 mm
Pontoon bottom deck	-	3 mm over an area of 500 x 500 mm
Centre deck	-	3 mm over an area of 500 x 500 mm
Vertical rim plates	-	3 mm over an area of 500 x 500 mm

5.5.2 Internal floating roof

For internal floating roofs made of steel, the same rejection criteria apply as for external floating roofs (5.5.1).

5.6 WIND GIRDERS

For primary wind girders used as walkways, the average corroded thickness over an area of 500 x 500 mm shall not be less than 3 mm.

For both primary and secondary wind girders the section modulus in the corroded condition shall not be less than 75% of the original wind girder section.

6. TANK REPAIR AND PROTECTION

6.1 GENERAL

For significant repairs, the TIA or a tank design engineer shall check whether the proposed repair method is acceptable.

It should be noted that the repair procedures are generally based on experience with fixed roof tanks. The procedures may also be applied to floating roof tanks; however, special requirements may be necessary in view of the type and diameter of the floating roof concerned. The TIA, tank design engineer or the Manufacturer of the floating roof should therefore be consulted.

Repairs to thermal insulation shall meet the requirements for new construction in accordance with PTS 30.46.00.31.

For cathodic protection systems, see PTS 30.10.73.10 and API RP 651.

6.2 FOUNDATION REPAIR

6.2.1 Erosion of shoulder

The shoulder of elevated tank pads should be well maintained to prevent damage or erosion by rain or wind, particularly rain flowing down the tank when it can penetrate into the foundation. Any damage to the surface of the sealing coat, or breakdown of the sand bitumen mix of that part of the foundation which projects beyond the base of the tank, should be repaired before the underlying foundation is damaged.

6.2.2 Minimum width of shoulder

Amended per
Circular 112/08

The shoulder should have sufficient width to provide lateral support for the foundation material under the tank. The width of the shoulder will depend on tank height, tank diameter and elevation of tank pad above grade. An insufficient shoulder width may cause the shoulder to slip away when the tank is fully loaded creating a very serious safety risk. See Standard Drawing S 12.001 for details and minimum shoulder width.

6.2.3 Minor edge settlement

Even with relatively minor settlement, the outer edge of the bottom plates of a vertical tank will settle at a level below the surface of the sealing layer of the foundation shoulder. This results in the formation of a channel around the periphery of the tank, in which rain water collects. In such cases the surface of the projecting part of the foundation should be trimmed and a new sealing layer of sand bitumen mix should be laid to provide proper drainage with a surface sloping away from the toe of the tank bottom. Refer to PTS 34.11.00.11. See also *EEMUA 159, Figure 7.3.5-1*.

6.2.4 Major edge settlement

Amended per
Circular 112/08

With major edge settlement, the level of the tank bottom may sink until access to connections in the bottom course of the shell becomes difficult and proper drainage of the foundation becomes impossible. If such a settlement occurs, it may be necessary to restore the level of the tank bottom by lifting the tank and building a new shoulder to a design which will prevent future major edge settlements. See standard drawing S 12.001.

6.2.5 Differential settlement along periphery

When differential settlement or tilting of the shell has reached the limit specified in *EEMUA 159, 7.5.1*, re-levelling of the foundation and the tank will be necessary. Re-levelling is done by jacking the tank and repairing the foundation. Re-levelling usually means raising the elevation of the foundation under the shell to the level of the highest point. It is recommended that the entire tank is jacked to a level of 2 to 2.5 m above the tank foundation to permit proper placement and compaction of the fill material.

6.2.6 Deformations of bottom due to settlement

Deformations of the tank bottom, as described and illustrated in *EEMUA 159, 7.5.4*, shall be eliminated when the acceptable limits have been exceeded. In some cases the foundation needs to be reshaped, in other cases both the foundation needs to be reshaped and parts of the bottom replaced. Repairs can be made from inside the tank by removing some of the bottom plates, or by jacking the tank to re-work the foundation.

6.2.7 Installation of impervious membrane

The installation of an impervious membrane requires the tank to be jacked to a level of 2 to 2.5 m above the foundation. See Standard Drawing S 12.003.

6.2.8 Tank jacking

See Appendix 3 for Information about tank jacking.

6.2.9 Testing requirements

A full hydrostatic test is always required after jacking the tank and/or major foundation repairs. See Appendix 7.