MANUAL

# FIELD INSPECTION, MAINTENANCE AND REPAIR OF VERTICAL STEEL STORAGE TANKS

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**DESIGN AND ENGINEERING PRACTICE**

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**APPENDICES**

# 1. INTRODUCTION

## 1.1 SCOPE

This DEP 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 DEP.

This DEP is a revision of the DEP with the same number dated August 1984. A summary of the main changes since the previous edition is given in (1.5).

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This DEP 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 DEP, 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 DEP 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 DEP 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 DEP are made, the referenced section is shown in brackets. Other documents referenced by this DEP are listed in (10).

## 1.5 MAIN CHANGES SINCE PREVIOUS EDITION

The main changes in this edition of the DEP are:

a). References to EEMUA 159 and API 653 have been included

b). Appendix 1 (Inspection frequencies) has been revised. This Appendix now specifies different inspection frequencies for different climates.

c). Previous Appendices 2, 3, 4 and 5 were no longer applicable and have been deleted. Some of the text and photographs has been incorporated in other parts of this DEP.

They have been replace by the following new Appendices, as follows:

- Appendix 2 - Reference Point System. This Appendix specifies the numbering and location of permanent reference points. New tanks should have the reference points marked upon completion, existing tanks should have the reference points marked before the first external detailed inspection.
- Appendix 3 - Tank Jacking. This Appendix covers all aspects of tank jacking including pre-jacking and post-jacking requirements for testing and inspection.
- Appendix 4 - Tank Venting. This Appendix underlines the importance of checking the vents, vent settings and venting requirements as part of the inspection and maintenance programme.
- Appendix 5 - Shell Stability. This Appendix explains loading cases and calculation procedure. Sample calculations illustrates how the stability of a corroded tank shell can be checked.

d). Appendix 6 - Bottom repair methods have been updated.

e). Appendix 7 - Hydrostatic Testing. This new Appendix incorporates hydrostatic testing requirements and precautions. Included are guidelines for when a hydrostatic test is not mandatory after a repair or modification.

## 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 13) 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 DEP 34.11.00.11-Gen. 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, 2.2.1 through 2.2.7.

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, 2.2.6) 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, 2.5.2b 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, para 2.8

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 EEMUA 159, 2.7.9 |
| Roof seals: | See EEMUA 159, 2.7.6, Table 1, Figures 34 and 35. |
| 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

a. 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.

b. 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.

c. 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:

a. 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.

b. At the intersection of vertical and horizontal grid lines.

c. 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:

1. 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.

2. 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, 2.5.1 and CA is the maximum estimated corrosion until the next inspection date. Often, $t_{ref}$ is taken as the average of $t_{min}$ and $t_{as\text{-}built}$. The effective shell thickness shall be determined in accordance with EEMUA 159, 2.10.3.

### 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, 2.3.2 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, 2.4.2.

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, para 2.4.3.

### 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, 2.3.4 a), 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, 2.3.4 a), 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 DEP 64.51.01.31-Gen.

*Roof drains:*

See EEMUA 159, 2.7.4, 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, 2.7.6, 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 2.2, 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 2.5, for a description and maximum limits of different types of bottom settlement.

See EEMUA 159, section 2.10.4, 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 2.5.1 a) and b).

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 2.10.3.

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:

a) 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.

b) Internal vacuum inside fixed roof tanks.

c) 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 21).

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:

a) 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, section 2.6.2.

### 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 are 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 DEP 30.46.00.31-Gen.

For cathodic protection systems, see DEP 30.10.73.10-Gen 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

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 sheet 1 of 2 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 DEP 34.11.00.11-Gen. See also EEMUA 159, Figure 13.

### 6.2.4 Major edge settlement

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 sheet 1 of 2.

### 6.2.5 Differential settlement along periphery

When differential settlement or tilting of the shell has reached the limit specified in EEMUA 159, 2.2.6, 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, 2.4, 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.

## 6.3 BOTTOM REPAIR AND REPLACEMENT

### 6.3.1 Bottom repair

Before a bottom repair is undertaken, it shall be ascertained that the foundation is not contaminated with hydrocarbons. If it is not contaminated, local corrosion can be repaired by patching or replacing parts of the tank bottom. If it is contaminated, the tank should be jacked 2 to 2.5 m above the foundation for safety reasons.

Blend welding can be used to repair isolated pits with a remaining thickness of at least 3 mm. Blend welding of pits with less remaining thickness entails the risk of burn-through.

Patch plates may be square or rectangular. They shall be 6 mm thick and have a minimum width of 300 mm with corners rounded to a radius of 50 mm. Patch plates shall extend at least 75 mm beyond the hole or defect that they are to cover. Fillet welds shall be spaced at least 300 mm away from each other and from the bottom-to-shell fillet weld. If the fillet weld around a patch plate comes closer than 150 mm to a bottom lap joint, the size of the patch plate shall be increased so that it will overlap the joint by at least 150 mm. Patch plates should cross the lap joint at approximately 90 degrees with a “breakdown” at the lap joint. Any repair closer than 300 mm to the shell should be avoided. Holes in the bottom should be sealed with epoxy or tar before being covered with a patch plate. All patch plate welds shall be tested by vacuum box.

Repairs to annular plates shall not be made unless approved by a tank design engineer. As a general rule, if annular plates are severely corroded or have other defects, the annular plates shall be removed and replaced.

If a full tank bottom is to be replaced, it should be done using butt-welding with backing strips. The bottom plate thickness shall be as follows:

- 8 mm for tanks with 8 mm annular plates (thereby eliminating the need for new annular plates and extensive welding);
- minimum 6 mm for other tanks.

### 6.3.2 Replacement of annular plates using sequential jacking method

If all or some of the bottom annular plates have to be replaced, the following method may be used:

(i) remove internal and external bottom-to-shell fillet welds over a length of approximately 5 m;

(ii) jack shell over this length so that a gap of approximately 50 mm is present;

(iii) cut existing annular plate at location of gap and remove it via the gap;

(iv) position a new annular plate, with back-up bar attached to one end;

(v) jack up next 5 m of tank shell;

(vi) repeat actions a, c and d for the second annular plate;

(vii) weld outer 200 mm of radial joint between the 1$^{st}$ and 2$^{nd}$ annular plates;

(viii) radiograph 200 mm of radial butt joint;

(ix) lower the shell over the first 5 m down to 1 mm from the annular plate to avoid the weight of the shell resting on the annular plate during welding of fillet welds (x) and (xi). This will reduce upward distortion of annular plate;

(x) fillet weld to shell, outside;

(xi) fillet weld to shell, inside;

(xii) lower the welded part down onto the foundation;

(xiii) repeat all these actions until the old annular plates have been removed and new ones installed;

(xiv) weld remaining part of the annular butt joints and annular to sketch plate fillet;

(xv) vacuum box test internal shell-to-bottom fillet weld, radial butt joints and annular to sketch plate fillet weld;

(xvi) hydrostatically test tank, see Appendix 7.

### 6.3.3 Replacement of entire bottom using sequential jacking method

Replacement of the entire bottom can be accomplished as follows:

(i) replace annular plates as described in 6.3.2, steps (i) through (xiii);

(ii) cut opening in shell for the removal of old bottom plates and insertion of new bottom plates. The opening shall be rectangular with corners rounded to R = 150 mm. The distance between the lower edge of the opening and the annular plate shall be 100 mm;

(iii) remove old bottom plates, lay and weld new bottom (see Standard Drawing S 51.041);

(iv) vacuum box test complete bottom including internal shell-to-bottom fillet weld;

(v) hydrostatically test tank, see Appendix 7.

### 6.3.4 Replacement of entire bottom using letterbox method

The “double bottom” or “letterbox” method as outlined in API 653, 7.9.2, may only be used in exceptional circumstances. Since tanks with a double bottom cannot be jacked, a pre-condition for the double bottom method is that the foundations must be in good condition.

### 6.3.5 Replacement of entire bottom on contaminated foundation

This method requires the tank to be jacked up to a level of 2 to 2.5 m above the foundation.

(i) jack tank complete with bottom;

(ii) remove contaminated foundation material and replace with new;

(iii) layout and weld new bottom (see Standard Drawing S 51.041). Weld and radiograph outer 200 mm of annular plate radial butt joints;

(iv) spread about 25 mm sand on top of new bottom for protection during cutting of old bottom;

(v) lower tank to about 100 mm above new bottom;

(vi) start cutting old bottom working from the centre out leaving about 300 mm of annular plate attached to shell. Remove old bottom plates;

(vii) lower tank to 50 mm above new bottom. Cut and remove sections of annular plate and let shell come down sequentially to 1 mm above new annular plates to avoid the weight of the shell resting on the annular plate during welding of fillet weld (viii) and (ix). This will reduce upward distortion of annular plate;

(viii) fillet weld to shell, outside;

(ix) fillet weld to shell, inside;

(x) lower the welded part down on the foundation;

(xi) repeat all these actions until the old annular plates have been removed;

(xii) weld remaining part of annular butt joints and annular to sketch plate fillet;

(xiii) vacuum box test complete bottom including internal shell-to-bottom fillet weld;

(xiv) hydrostatically test tank, see Appendix 7.

## 6.4 COATING AND PROTECTION OF TANK BOTTOMS

### 6.4.1 Measures against internal corrosion

Non-metallic coatings and paint may be applied to prevent corrosion.

**a) Coatings**

If internal corrosion is observed to the extent that the corrosion allowance is almost completely used up, the need for expensive repairs in the future can be reduced considerably by coating the bottom internally with an Epikote resin-based paint system in accordance with DEP 30.48.00.31-Gen.

**b) Laminates**

If serious internal corrosion is observed but not yet to the extent that the tank's structural integrity is compromised, the application of Epikote resin/glass fibre laminates may be considered if the costs involved are economically justifiable when compared with those of bottom renewal.

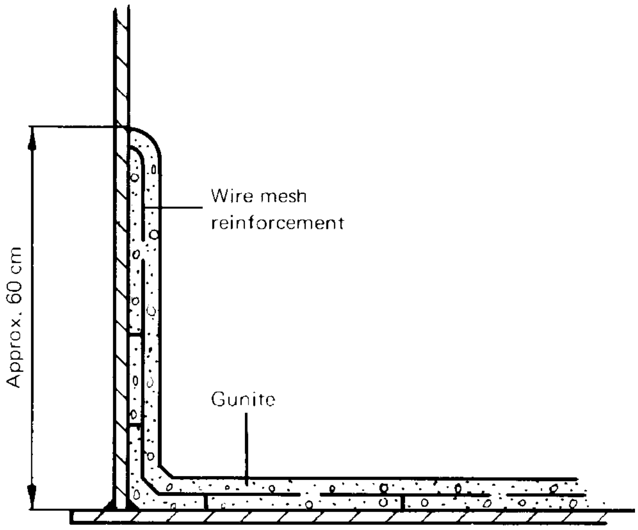
For a detailed description, see Appendix 6.

Before deciding on bottom repair by means of laminated plastic it shall be checked whether the annular plates are seriously corroded on the underside too. In that case replacement will be necessary, since these plates are highly stressed when the tank is full.

**c) Reinforced concrete liner**

The application of concrete liners shall be confined to water storage tanks only. For the best results, the bottom course of the shell shall also be lined to a height of 600 mm. See Figure 6.4.

**Figure 6.4 Reinforced concrete liner**




The surfaces of the plates should be free of scale before the concrete liner is applied. The thickness of the concrete liner (Gunite) and the type of reinforcing mesh to be applied depend on the diameter of the tank and the local soil conditions.

### 6.4.2 Measures against external corrosion

**Painting:** As described in (4.5.1) there may be grounds for lifting the entire tank to allow proper inspection and foundation repair. If the condition of the bottom allows, it is a good opportunity to shot blast and apply a paint coating in accordance with DEP 30.48.00.31-Gen.

**Cathodic Protection:** If immediate replacement of bottom plates is not required, the use of cathodic protection may be considered. See DEP 30.70.73.10-Gen.

**Laminates:** Only when the cause of the external corrosion is eliminated shall restoration of the tank bottom integrity by internal lamination be considered (6.4.1).

## 6.5 SHELL REPAIRS

### 6.5.1 General

The criteria for repair and alterations shall be equivalent to those for new tank construction as described in DEP 34.51.01.31-Gen and DEP 64.51.01.31-Gen.

### 6.5.2 Replacement of shell plates

6.5.2.1 Minimum thickness of replacement shell plate

The minimum thickness of the replacement shell plate material shall be calculated in accordance with the applicable tank design code. The thickness of the replacement shell plate shall not be less than the greatest nominal thickness of any plate in the same course adjoining the replacement plate except where the adjoining plate is a thickened insert plate. Any changes from the original design conditions, such as product specific gravity, design pressure, liquid level and shell height shall be taken into account.

6.5.2.2 Minimum dimensions of replacement shell plate

The minimum dimension of a replacement shell plate shall be 300 mm or 12 times the thickness of the replacement plate, whichever is the greater. The replacement plate may be circular, rectangular or square with rounded corners except if an entire shell plate is replaced. Refer to API 653, Figure 7-1 for typical details of acceptable replacement shell plates.

Entire shell plates or full height segments of shell plates may be removed and replaced by cutting and rewelding along the existing horizontal weld joints. Prior to welding the new vertical joints, the existing horizontal welds shall be cut for a minimum distance of 300 mm beyond the new vertical joints. The vertical joints shall be welded before the horizontal joints.

Before an entire shell plate or a large segment of a shell plate is removed, vertical support beams shall be installed and attached to the plates above and below the plate to be removed. The vertical support beams shall be installed not more than 3 m apart.

The purpose of the support beams is to prevent sagging of the shell above the opening. Sagging will cause additional stresses in the shell and makes fitting the new plate more difficult. The support beams shall be removed before the horizontal seams are welded.

6.5.2.3 Replacement of bottom shell course

If the entire bottom course has to be renewed the shell plates shall be cut free from the annular plates and the entire tank shell lifted bodily, using the jacking-up method, after which the corroded plates can be cut out and replaced.

On tanks with the shell insulation extending to the tank bottom, severe shell corrosion is often found around the lower edge of the outside shell plate. In such a case a tank design engineer shall be consulted to see if the loss of metal around the lower edges can be accepted without replacing the bottom shell course.

If corrosion is concentrated around the lower edge of the inside shell plate, the option shall be considered of cutting the shell course all around just above the corroded area and removing the corroded part. This will reduce the tank capacity and will require modification to fittings such as nozzles and stairways.

Acceptable details for replacement of shell plate material are given in API 653, Figure 7-1.

### 6.5.3 Weld joint design

Shell replacement plates shall be welded with butt joints.

To reduce the potential distortion of a tank due to welding a replacement plate into an existing tank shell, fit-up, heat input and welding sequence shall be considered.

Minimum spacing between butt welds and between those welds and the shell-to-bottom weld shall be as indicated in API 653, Figure 7-1.

### 6.5.4 Repair of defects in shell plate material

The need to repair flaws such as cracks, gouges or tears (such as those often remaining after the removal of temporary attachments) discovered during an inspection of the tank shell shall be determined from case to case. In areas of the shell where the plate thickness exceeds that required by design conditions, scars may be ground out to a smooth contour as long as the remaining thickness is adequate for the design conditions. Where grinding to a smoothly contoured surface would result in an unacceptable metal thickness, weld metal shall be added to repair the scar using a qualified weld procedure.

### 6.5.5 Repair of defective welds

Weld imperfections outside the acceptance criteria of the design code shall be removed completely by gouging and/or grinding and the resulting cavity properly prepared for welding.

Generally, it is not necessary to remove weld reinforcement in excess of that allowed by DEP 64.51.01.31-Gen if discovered on a tank with a satisfactory service history. However, if operational conditions are such that the excessive weld reinforcement may be deleterious (such as for a floating roof with flexible seals), it may have to be ground away.

Weld undercut deemed unacceptable for service shall be repaired by additional weld metal, or grinding, as appropriate.

Welded joints that have suffered loss of metal due to corrosion may be repaired by welding.

### 6.5.6 Non destructive examination

Repair welding shall be inspected in accordance with DEP 64.51.01.31-Gen with the following additional requirements:

1) Butt welds around shell insert plates shall be 100% radiographed.
2) Butt welds around one or more entirely new shell plates shall have all Tee-junctions (old and new) radiographed as well as one radiograph at the centre of each vertical joint.

### 6.5.7 Intermediate shell stiffeners

It may be that the remaining thickness of the upper part of a corroded shell is adequate for liquid loading but not for wind loading or vacuum. In that case, the shell can often be repaired by installing an intermediate wind girder rather than by replacing shell plates.

See Appendix 5 for details and calculation method.

### 6.5.8 Repair of shell damaged by fire, wind and/or vacuum

Each case of damage to the shell caused by fire, wind and/or vacuum shall be evaluated by an experienced tank design engineer.

1) Damage due to fire

   All plates with visible deformations shall be replaced. Plates which have had direct exposure to the fire but without deforming do not need to be replaced subject to satisfactory material test results. Material samples shall be removed from different parts of the shell affected by the fire. The samples shall be analysed by a material testing laboratory for mechanical strength. If the results are in line with the original steel specification, the plates in question do not need to be replaced.

2) Damage due to wind and/or vacuum

   Shell plate areas with major deformations including creases shall be replaced. Deformations with no creases can sometimes be repaired by the installation of a stiffener around the entire circumference.

## 6.6 FIXED ROOF REPAIRS

If the reduction in thickness of the roof sheets endangers the safety of personnel working on the roof, or if there are leaks through which vapour can escape, the roof sheets should be partly or completely renewed. Severely corroded roof plates can be cut out and replaced by new plates using normal erection techniques. Isolated holes may be repaired by means of patch plates. Internal corrosion of the roof sheets can be reduced by coating the sheets with an ‘Epikote’ resin-based paint system, see DEP 30.48.00.31-Gen.

Corrosion of the roof-supporting structure may endanger the safety of the structure. If corrosion has reached or exceeded the 25% metal loss limit per 5.4.2, a tank design engineer shall be consulted for an evaluation of the corroded structure.

Members should be reinforced or renewed when necessary. Before any main members are renewed the roof and its structure should be well supported, e.g. by temporary columns from the bottom of the tank. This renewal can be accomplished by normal construction methods.

Corrosion of the roof structure can be reduced by coating the members with an ‘Epikote’ resin-based paint system, see DEP 30.48.00.31-Gen.

Repairs to the roof of small diameter tanks (≤ 12.5 m) shall be checked for compliance with EEMUA if the tank may contain explosive mixtures.

## 6.7 FLOATING ROOF REPAIRS

### 6.7.1 Corrosion repairs

Corrosion of the centre deck of a pontoon type roof may cause product backflow onto the deck. This creates a serious fire hazard as well as the risk of structural damage to the roof.

Corrosion of the pontoon bottom or the bottom deck of a double deck roof may cause flooding of pontoon compartments, resulting in tilting or sinking of the roof.

Repairs can be made by patching areas of local corrosion. For larger corroded areas, the corroded plates should be cut out and replaced.

Repairs shall be tested by spraying with penetrating oil or by vacuum box. A partial hydrostatic test shall be performed to confirm leak tightness (see Appendix 7).

Corrosion can be reduced by coating the roof plates with an ‘Epikote’ resin-based paint system, see DEP 30.48.00.31-Gen.

### 6.7.2 Sunken roof

A sunken internal or external floating roof is a serious safety problem. The problem is more complicated if the roof has jammed. Actions to be taken include:

1. consultation with fire/safety officers and tank design engineer;
2. take measures to avoid or combat a full surface fire;
3. determine cause of sinking or jamming;
4. check the possibility of withdrawing product while pumping water into tank to continue supporting the roof. Thereafter, water can be removed to bring the roof down to the bottom;
5. consult floating roof Manufacturer about repair or replacement of roof.

### 6.7.3 Drain replacement

The floating roof drain is a critical component of the tank. If the drain leaks the tank contents may drain into the bund area. If the drain is closed the roof may be overloaded by accumulated rainfall.

During internal inspection, the roof drain shall be hydrostatically tested, and carefully inspected for leakage (4.5.4). Drain repairs are not recommended. If necessary, the swivel joints for a pipe drain or the hose for a hose drain shall be replaced with new ones.

### 6.7.4 Seal replacement

Many seal Manufacturers offer a seal inspection and repair service. For external floating roof tanks such repairs can often be performed with the tank in operation.

Depending on the type of seal, a complete seal replacement can also be carried out with the tank in operation.

### 6.7.5 Rolling ladder repair/replacement

Simple repairs, such as bearing replacement, can be made while the tank is in operation with the roof floating near the top of the tank.

Structural repairs will usually require the tank to be out-of-service so that the ladder can be lowered onto the roof.

If the rolling ladder has been damaged, for example due to derailment or any other reason, the cause of the damage should be determined and steps taken to correct the cause and prevent recurrence.

### 6.7.6 Floating roof design check

If repairs have caused a substantial increase in the weight of the floating roof, the design of the roof shall be checked by a tank design engineer. Such an increase in weight could have been caused by replacing 5 mm thick centre deck plates by 6 mm thick plates. Especially in cases where the roof is floating on product with a very low density such an increase in weight could affect the design of the roof.

## 6.8 REPAIR TO FITTINGS

Repair to fittings, e.g. breather valves, should be carried out by the Supplier.

Replacement fittings should be the latest model and design.

## 6.9 HOT TAPS

Hot taps are sometimes used to install new shell nozzles while the tank is in-service. Hot tapping shall be performed in accordance with DEP 31.38.60.10-Gen., API 653 or other standards approved by the Principal. Hot taps shall be cosidered to be temporary measures; as soon as convenient the tank shall be taken out of operation and the nozzle re-welded using standard nozzle weld details.

## 6.10 EXTERNAL TANK COATING

All repairs should be painted on completion for protection against corrosion in accordance with DEP 70.48.10.10 Gen.

# 7. ADDITION OF COURSES TO EXISTING TANKS

## 7.1 DETAILS OF THE SYSTEM FOR ADDING COURSES

An economical method of increasing the storage capacity of existing tanks is to raise their height by adding courses.

The addition of a course will increase the load on the soil under the tank and therefore it shall be verified that the soil is capable of supporting the higher load. The soil underneath tanks which have been in use may permit higher tanks to be supported without exceeding the safe bearing capacity of the soil, but a proper soil investigation shall always be carried out before such a decision is taken, see DEP 34.11.00.11-Gen.

If the existing tank is of riveted construction, a sample of the old steel shall be analysed for weldability to ensure that the new shell plates can be welded to the existing riveted plates.

The method of lifting tanks to allow the addition of courses is as follows:

a. The tank shell is freed by removing the fillet weld between shell plates and annular plates, or for riveted tanks by flame cutting above the bottom curb angle. Lifting jacks are positioned internally along the tank shell at intervals of approximately 6 m and temporary lifting brackets are welded to the shell plates to transmit the tank weight to the jacks.

b. The tank shell is lifted high enough for the plates of the new course to be inserted and the vertical seams of the new plates are then welded. After lowering the existing tank onto the new plates, the horizontal seam joining the new plates to the existing shell is also welded. By repositioning the lifting brackets onto the new course of plates and repeating the operation, further courses can be added.

c. After the addition of the courses has been completed the lowest course shall be welded to the annular plates. For riveted tanks the curb angle shall have first been removed.

d. Welding and weld inspection shall be in accordance with DEP 64.51.01.31-Gen.

Lifting jacks should be positioned so that the vertical seams of new shell plates are readily accessible for welding.

## 7.2 TESTING

After adding courses to an existing tank the tank shall be tested by filling it with water to the maximum operating level (see Appendix 7).

## 7.3 VENTILATION

It shall be checked whether the open vents or pressure/vacuum valves have sufficient ventilation capacity for the new tank capacity (see Appendix 4).

# 8. DISMANTLING AND RE-ERECTION OF VERTICAL TANKS

## 8.1 GENERAL

The operation of dismantling a tank, its transportation to a new site and its re-erection is very expensive and may exceed the cost of a completely new tank. This method should only be used if demonstrated to be economic.

# 9. RESITING OF VERTICAL TANKS

## 9.1 GENERAL

Tanks may be lifted and moved to new positions without dismantling. This can be done using a crane with spreader beams, on rail tracks, by the ‘air-cushion’ method or by self-propelled trailers. Where the terrain is suitable and a sufficient supply of fresh water is available the tank may be moved by floating. Generally, the methods described in 9.2, 9.3, 9.4,and 9.6 are preferred.

Before carrying out any moving operation, the tanks should be thoroughly cleaned, gas-freed, inspected for leaks and repaired where necessary.

## 9.2 MOVING USING A CRANE PLUS SPREADER BEAM

This method is normally used for smaller diameter tanks.

## 9.3 MOVING ON RAIL TRACKS

To move a tank on rail tracks it first has to be lifted clear of its foundation by means of jacks placed around the circumference at maximum intervals of 6 m. A system of steel rails supported on timber sleepers to spread the load is then laid under the tank. The rails should be well greased, be adequately supported along their entire length, and have a slight slope towards the foundation prepared at the new site. Steel buggies are placed on the rails to support the tank during moving.

The tank is lowered by means of the jacks until it rests on the buggies and is hauled by winch and pulley or by tractor. At the new site the tank is again jacked up, the rails are removed and the tank is lowered on to the new foundation. Tank movement should be closely controlled. In windy weather, operations of this nature should be suspended and the tank adequately restrained by steel guy wires.

## 9.4 MOVING BY ‘AIR-CUSHION’ METHOD

An air-cushion under the tank bottom is provided by means of mobile compressors. A special skirt is placed around the shell at the bottom to contain the air which will support the tank during movement. The tank is then towed to its new location. It shall be checked that the area over which the tank has to be moved is free from unacceptable irregularities, as these may cause air leakage and consequently loss of support during the move.

## 9.5 MOVING BY FLOATING

An alternative method of moving tanks is to build earth dikes around the route between sites and flood the area with water to a depth suitable for floating the tank off its foundation. The floating tank can then be hauled to the foundation prepared at the new site and allowed to settle by releasing the water contained within the dikes.

Experience has shown that this method of moving may result in a run-off of water to other areas in plants and refineries and should therefore be carefully evaluated.

The depth of water required to float a tank is small. For instance, a tank of 36 m diameter and 12 m high will float in approximately 600 mm of water. Once a tank is floating it can be hauled by winch or tractor, using a separate system of cables to steady and control it.

Fixed roof tanks should be pressurised to their maximum pressure rating, with a maximum of 200 mm water gauge, before launching. The pressure should be maintained during the moving operation, as this will reduce the flotation stresses on the bottom plates, as well as draught of the tank.

In order to keep the floating tank perpendicular to the water surface the weight of stairways etc. should be counterbalanced by placing sandbags on the tank bottom.

Tanks have been moved over distances of several miles by floating, when tank sites are adjacent to a river, lake or open sea, and banks are suitable for moving the tank to the water's edge for launching. A small tug or motor launch can be used for towing a tank in open water. Rails are laid at the new site and the tank is hauled out of the water and moved on rail tracks to the position above the new tank foundation.

This method of moving tanks should not be applied during windy weather.

## 9.6 MOVING BY SELF-PROPELLED TRAILERS

Self-propelled modular trailers (SPMTs) may be used for the relocation of storage tanks. After the tank has been jacked up, SPMTs are located under the annular plates of the tanks shell and at the centre of the tank directly under the temporary steel structure which supports the tank bottom and the floating roof structure (see Appendix 3).

This method of relocation is also suitable when there is a difference in elevation between the existing and new tank foundation. The maximum gradient of the roadway between the two locations shall be checked by the specialist transport consultant/contractor but in general should not exceed about 0.7%.

The special designed temporary steel structure inside the tank is required to:

1. Jack up the tank to about 2.5 m above its foundation level; and
2. allow the load to be transferred from the jacking points onto the SMPTs.

For large floating roof tanks it is essential that the temporary steel structure is designed to accommodate any uneven load distribution resulting from level differences/deformations within the roof structure. Moreover, the difference in stiffness between the roof structure itself and the supporting structure must be considered to ensure an equal load distribution onto the jacks and trailers.

Only experienced contractors shall be engaged for the jacking and relocation and they shall decide at an early stage of the project the design principles and execution method.

The temporary roadway shall be designed and constructed to allow for the high concentrated wheel loads of the SPMTs. Adequate sub-soil drainage shall be provided for the roadway in areas with high rainfall.

The temporary heavy duty road structure is also required on top of the existing tank foundation after the tank is jacked up to about 2.5 m above the tank pad.

For the new tank foundation heavy duty road structures shall be extended to a minimum of 3 m all around the tank pad shoulder to avoid any damage to the original tank foundation.

This temporary road structure can be removed after the load has been transferred from the SPMTs onto the jacking points and before lowering the tank onto its new foundation.

Finally, the leak management/detection system and final sand/bitumen layer and levels shall be checked and accepted by the Principal before the tank is placed on its new foundation.

## 9.7 TESTING REQUIREMENTS

After a tank has been moved to a new location, the following tests shall be carried out:

a. vacuum box test of all bottom welds;

b. magnetic particle examination of the inside shell-to-annular fillet weld;

c. full hydrostatic test including settlement survey (Appendix 7).

## 10. REFERENCES

In this DEP reference is made to the following publications:

NOTE: Unless specifically designated by date, the latest edition of each publication shall be used, together with any amendments/supplements/revisions thereto.

**SHELL STANDARDS**

| | |
|---|---|
| Index to DEP publications and standard specifications | DEP 00.00.05.05-Gen |
| Cathodic protection | DEP 30.10.73.10.-Gen. |
| Thermal insulation for hot services | DEP 30.46.00.31-Gen. |
| Painting and coating of new equipment | DEP 30.48.00.31-Gen. |
| Hot-tapping on pipelines, piping and equipment | DEP 31.38.60.10-Gen. |
| Site preparation and earthworks | DEP 34.11.00.11-Gen. |
| Standard vertical tanks - Selection, design and fabrication | DEP 34.51.01.31-Gen. |
| Standard vertical tanks - Field erection and testing | DEP 64.51.01.31-Gen. |
| Maintenance painting | DEP 70.48.10.10-Gen. |
| MF Report “Criticality/benchmarking study of conventional storage facilities” | MF 95-1188 |

**STANDARD DRAWINGS:**

| | |
|---|---|
| Tank foundation - Sheet 1 - general tank foundation without leak detection | S 12.001 sheet 1 of 2 |
| Conceptual tank foundation with tank leak and management system | S 12.003 |
| Welding sequences | S 51.041 |
| Reference points for survey of vertical storage tanks | S 51.280 |

**AMERICAN STANDARDS**

| | |
|---|---|
| Inspection of atmospheric and low-pressure storage tanks | API 575 |
| Welded steel tanks for oil storage | API 650 |
| Cathodic protection of above ground petroleum storage tanks | API RP 651 |
| Tank inspection, repair, alteration and reconstruction | API 653 |
| Venting atmospheric and low-pressure storage tanks | API 2000 |

*Issued by:*
*American Petroleum Institute*
*1220 L Street, Northwest*
*Washington, D.C. 20005*
*USA*

| | |
|---|---|
| Flammable and Combustible Liquids Code | NFPA 30 |

*Issued by:*
*National Fire Protection Association*
*470 Atlantic Avenue*
*Boston, MA 02210*
*USA*

**BRITISH STANDARDS**

| | |
|---|---|
| Vertical steel welded storage tanks with butt-welded shells for the petroleum industry | BS 2654 |

*Issued by:*
*British Standards InstituteStandards*
*389 Chiswick High Road*
*London W4 4AL*

| | |
|---|---|
| Users guide to the maintenance and inspection of above-ground vertical cylindrical steel storage tanks | EEMUA 159 |
| Guide for designers and users on frangible roof joints for fixed roof storage tanks | EEMUA 180 |

*Issued by:*
*Engineering Equipment and Materials Users Association*
*45 Beech Street*
*London SW1X 8PS*
*U.K.*

| | |
|---|---|
| 'Octel' Handbook | 'Octel' Handbook |

*Issued by:*
*The Associated Octel Company Ltd.*
*20 Berkeley Square*
*London W1X 6DT*
*UK*

## APPENDIX 1 INSPECTION FREQUENCIES

| GROUP | SERVICE CONDITIONS | INSPECTION FREQUENCY: EXTERNAL ROUTINE VISUAL (months) | EXTERNAL detailed visual including ultrasonic thickness measurements of shell and roof (years) | | | INTERNAL detailed visual including ultrasonic thickness measurements of bottom and shell (years) | | |
|---|---|---|---|---|---|---|---|---|
| | | | CLIMATE CODE (*see below) | | | | | |
| | | | A | B | C | A | B | C |
| 1 | Slops, corrosive or aggressive chemicals, raw water, brine (not internally protected) | 3 | 1 | 1 | 1 | 3 | 3 | 3 |
| 1A | Same as Group 1 except internally protected by Epikote coal tar | 3 | 5 | 5 | 7 | 7 | 7 | 7 |
| 2 | Refrigerated Storage | see EEMUA 159 | | | | | | |
| 3 | Crude Oil | 3 | 5 | 5 | 7 | 8 | 8 | 10 |
| 4 | Fuel oil, gas oil, luboil, diesel oil, caustic soda, inert or non-aggressive chemicals, air foam liquid | 3 | 5 | 8 | 10 | 12 | 16 | 20 |
| 5 | Jet A1 (fully internally protected) | 3 | 10 | 10 | 15 | 15 | 15 | 20 |
| 6 | Light products, kerosine, gasoline, cracked distillates, treated water (not internally protected) | 3 | 3 | 5 | 7 | 8 | 10 | 12 |
| 7 | Heated and insulated tanks.<br>Note: External UT measurements only around bottom of shell and at selected locations around roof periphery | 3 | 3 | 3 | 5 | 6 | 6 | 6 |

*** CLIMATE CODES:**

**A** = Warm and humid, e.g. tropical and subtropical areas

**B** = Temperate climate with frequent rain and wind

**C** = Warm and dry, e.g. desert locations

**COMMENTS:**

The inspection frequencies indicated above are for guidance only. After each detailed external or internal inspection, the Tank Integrity Assessor (TIA) shall determine the date for the next inspection. This date shall ensure that the rejection limits as stated in EEMUA 159 are not exceeded.

If the inspection results indicate a more rapid deterioration due to corrosion or settlement, other similar tanks may need to be inspected earlier. On the other hand, if the inspection results are favourable an extension of the inspection interval may be considered subject to the Principal's approval.

## APPENDIX 2 REFERENCE POINT SYSTEM

Reference points shall be as specified on Standard Drawing S 51.280.

Measurements as required for the external or internal detailed inspection shall be taken at locations related to a set of standard reference points. This applies in particular to ultrasonic thickness measurements, level and out-of-plumbness measurements and floating roof rim space measurements. The same standard reference points should be used during construction to check tolerances and to carry out the level and plumbness survey during the hydrostatic test.

This Appendix specifies the requirements for locating the reference points.

Reference points shall be marked on the outside shell at about 200 mm above the bottom. The marking shall consist of a short vertical arrow with the reference point number. Markings shall be made by paint.

The number of reference points shall be as indicated in Standard Drawing S 51.280.

The first reference point shall be located at ‘Plant North’, and from there the other reference points shall be equally spaced around the tank circumference. Reference points shall be numbered consecutively, starting with number 1 at Plant North and moving around in a clockwise direction. It is important that the layout and numbering system are applied consistently. When reference points fall on a vertical joint, move the reference point 50 mm clockwise from the vertical joint.

Using the reference points, vertical grid lines can be marked on the shell and continued onto the roof as radial grid lines to tank centre. Reference point locations can be transferred to the inside of the shell to give the starting point for radial grid lines on the bottom or vertical grid lines on the inside of the shell.

NOTE: Grid lines are not permanent. They are marked as required when measurements are carried out. The reference point locations are permanent.

## APPENDIX 3 TANK JACKING

### A3.1 GENERAL

Jacking is a very important tool for making repairs or modifications to the foundation and tank bottom. Tanks are jacked up by using hydraulic jacks or air bags, which lift the tank 2.0 to 2.5 m above the foundation where the tank is supported on timber stacks. The 2.0 to 2.5 m free height allows small earth moving equipment to operate under the tank.

More specifically, jacking is often used for the following purposes:

1. to correct unacceptable foundation settlement;
2. to remove contaminated soil caused by bottom leakages and restore the foundation;
3. to install a high density polyethylene (HDPE) membrane under the entire tank together with a leak detection system or leak detection and management system;
4. to ensure safe replacement of the tank bottom if the foundation is contaminated;
5. to inspect tank bottom for under-bottom corrosion. If necessary, the underside of the tank bottom can be blasted and coated after the inspection;
6. to install a cathodic protection system under the tank bottom.

### A3.2 TYPES OF JACKS

There are two types of jacks commonly being used. These are:

a. Hydraulic jacks
b. Inflatable air bags

**Hydraulic jacks**: High capacity (up to 60 tons per jack) but heavy to move around. Lifting lugs need to be welded to the outside of the shell or large excavations are required to position the jacks directly under the shell. Such large excavations are undesirable.

**Air bags:** Lower capacity (up to 30 tons per air bag) but easy to handle and move around. Air bags require a small excavation under the shell, about 60 mm high, to insert an empty air bag. Usually, two excavations are required to lift part of the shell when additional air bags can be inserted at adjacent locations.

### A3.3 JACKING METHODS

**a. One-stage method using hydraulic jacks**

This method requires an excavation into the tank pad shoulder to place hydraulic jacks directly under the shell on a temporary foundation of hardwood blocks laid on a well compacted gravel base.

When the jacks have been positioned, the tank will be jacked in lifts of 100 mm each time, this being the effective “stroke length” of the hydraulic jacks. The 100 mm gap will then be filled with hardwood blocks laid in a special configuration to ensure adequate load transfer and stability and allow the hydraulic cylinder to be retracted and the jack repositioned for the next lift. This way the tank is jacked to about 2.0 to 2.5 m above its foundation.

After the repairs/modifications have been completed, the tank is jacked down onto its foundation in the reverse sequence. When the tank is resting on its foundation, the jacks and temporary foundation are removed and the excavation back-filled and well compacted.

The back-filling and compaction of the foundation directly under the shell and annular plate are critical operations. In addition, this method creates a major complication when an HDPE liner with leak detection system needs to be installed.

It should be noted that the one-stage method using hydraulic jacks cannot be used on tanks supported on a concrete ring wall or concrete raft.

In view of the above constraints, a “two-stage jacking method” as described below shall be used.

**b. Two-stage method using hydraulic jacks**

For this method, special steel brackets are installed equally spaced around the circumference and welded to the bottom shell course. Hydraulic jacks are located directly below the special brackets. The jacks are placed on temporary hardwood foundations on top of the existing tank pad shoulder. Initial jacking is carried out in 100 mm lifts to an elevation adequate to place other jacks on hardwood foundations directly underneath the shell/annular plate and on top of the exposed tank foundation.

After the load transfer from the initial “external” jacks to the jacks underneath the tank, the second stage jacking can commence and the tank is jacked in 100 mm lifts to approximately 2.0 to 2.5 m above the tank foundation.

After the repairs/modifications have been completed, the tank is jacked down in two stages onto its foundation in the reverse sequence. Once the tank is resting on its foundation, the special brackets, jacks and temporary foundation are removed.

**c. Combined air bag / hydraulic jack method**

This jacking method uses both air-bags and hydraulic jacks. Two shallow excavations (about 60 mm deep) are made under the shell to insert an empty air bag. A small section of the shell is lifted with these two air bags so that additional air bags can be inserted between the top of the foundation and the underside of the tank next to the first air bags. This sequential lifting continuous all around the tank. Thereafter, the tank is jacked uniformly up to a level of 300 to 400 mm above the foundation, at which point hydraulic jacks are installed directly underneath the shell to complete the jacking operation.

The combined method has the advantage that no large excavations or special brackets welded to the shell are required. If a concrete ring wall is present, one or two external lifting points are needed to lift the shell just enough above the foundation to insert the first air bag.

**d. Sequential jacking**

Sequential jacking is the method described under c) whereby the tank is lifted a short distance off its foundation, starting at one point and moving around from there. Timbers are placed between the tank and the foundation, and the jack is released and moved to the next location (leapfrogging). The method is frequently used for the replacement of annular plates for which the shell needs to be about 100 mm above the foundation. Special attention shall be given to how much the tank can be jacked at a single point without causing shell distortions. Considerable experience is already available with this method and it works well provided small lifts are made at any time. Air bags are particularly suitable for this method because of their flatness and light weight.

**e. Tank re-levelling**

Tank re-levelling consists of local jacking at tilted or depressed sections of the shell. At these locations the tank is jacked up, in an empty and clean condition, by means of hydraulic jacks or air bags such that the shell/bottom perimeter is back in a horizontal plane. The space then formed between the tank bottom and tank pad shall be packed with clean sand and adequately sealed with sand bitumen mix. The tank pad shoulder shall be finished with a slope as in Standard Drawing S 12.001, sheet 1 of 2.

## A3.4 NUMBER OF JACKS REQUIRED

The number of jacks required shall be adequate to lift the weight of the entire tank while allowing for adhesion between tank bottom and foundation. The jacks shall have adequate reserve capacity to perform this task.

The maximum spacing between jacks is determined by the stiffness of the shell. If the spacing is too great, the bending stresses in the shell can cause deformations in the upper shell courses. The maximum spacing between two support points (jacks or timbers) shall be 6 m. For tanks with a severely corroded shell, a closer spacing may be required.

## A3.5 JACKING OF FIXED ROOF TANKS

Jacking of a fixed roof tank with self-supporting roof structure up to a diameter of approximately 34 m can be done with jacks equally spaced around the circumference.

Jacking of a fixed roof tank with self-supporting roof structure greater than 34 m diameter requires guy wires installed from the roof/shell connection to the tank bottom to control the sag of the latter. With the guy wires installed, the tank can be lifted with jacks equally spaced around the circumference.

Jacking of a fixed roof tank with column-supported roof structure requires a cutout to be made in the tank bottom and jacks placed under the column. These column jacks shall be operated in concert with the shell jacks. Methods exist whereby the columns are supported with guy wires, but great care shall be exercised with such a system as the framing can easily become unstable with the possibility of “corkscrewing” down.

## A3.6 JACKING OF FLOATING ROOF TANKS

**Pontoon floating roof:** Jacking of pontoon type floating roof tanks with a diameter up to around 34 m diameter can be done with jacks equally spaced around the circumference.

The limited sag of the bottom of the lifted tank ensures sufficient support for the roof legs and keeps the roof deflection within allowable limits.

Jacking of pontoon type floating roof tanks over 34 m diameter requires special measures to support the roof structure. Triangular support brackets are attached to the inner surface of the first shell course to form a horizontal sliding support for the roof edge. The support brackets should be placed under the pontoon bulkhead plates.

Besides the triangular support brackets at the shell, the deflection of the roof and bottom plates shall be controlled by temporary lattice girders connecting the roof and bottom plates. These temporary support structures are located in between extra jacking supports which are equally spaced in a ring around the roof centre. In this way the tank shell, bottom and roof are jacked simultaneously. It should be noted that the centre jacking supports require a temporary opening through the tank bottom plate.

**Double deck floating roof:** For double deck floating roofs, the jacking procedure is in principle identical to the jacking of a pontoon roof. For tanks larger than approximately 34 m diameter, additional supports are also required around the roof centre. The space between top deck and bottom deck shall be packed with wood directly above the jacking positions.

**SIPM floating roof:** Jacking of these tanks, normally tanks with a diameter over 50 m, is similar to that for tanks with a pontoon type floating roof. However, special attention shall be given to maintaining the downward slope of the roof and radial beams during the jacking of the tank and when placing the tank on its new foundation.

## A3.7 GENERAL REQUIREMENTS

a. Select an experienced jacking contractor.

b. Jacking contractor to perform site survey including level measurements.

c. Jacking contractor to submit detailed method and calculation for overturning stability under wind. In addition, the jacking contractor shall demonstrate by means of calculations that the tank integrity (shell and roof structure) is maintained during jacking. Special attention shall be given to tanks with corroded shell plates, i.e. more jacking points may be required to reduce vertical bending stresses.

d After jacking, a vacuum box test of the tank bottom and internal shell-to-bottom fillet weld shall be performed, followed by a full hydrostatic test.

## A3.8 ACCEPTANCE CRITERIA AFTER JACKING

a Levelness, verticality and roundness shall be in accordance with DEP 64.51.01.31-Gen.

# APPENDIX 4 VENTING

## A4.1 INTRODUCTION

This appendix specifies the requirements for the sizing, selection, inspection and maintenance of venting systems for oil storage tanks.

Each fixed roof shall be provided with one or more vents to permit product vapour to be expelled from the tank as liquid is being pumped in and air to flow into the tank as liquid is being pumped out. In addition, changes in temperature cause contraction or expansion of the vapour resulting in flow into or out of the tank. Clogged vents, or vents too small for the pumping rates being used and/or temperature changes, may result in the tank being ruptured by internal pressure or collapsing due to internal vacuum (see EEMUA 159, Figures 27 through 30).

Many tank failures are caused by inadequate or poorly maintained venting. It is essential that vents are regularly inspected and maintained. See A4.8 for details of vent inspection and maintenance.

## A4.2 TYPES OF VENTS

### A4.2.1 Open vents or free vents

Open vents may only be used on non-pressure tanks (BNC and BND). They should be provided with a mesh screen and prevent rain water entering the tank. See Table A4.1 for the venting capacity through free circular openings.

### A4.2.2 Pressure/vacuum relief valves or breather valves

PV valves are used for low-pressure (BLC and BLD) and high-pressure fixed roof tanks (BHC and BHD) designed to operate at an internal pressure and vacuum. The valves are weight loaded and should be set to be fully open at design pressure.

### A4.2.3 Pilot-operated pressure relief valves

Consist of a main valve and an integrated pilot valve. Expensive but high degree of accuracy and reliability. Normally used on refrigerated storage tanks operating at low pressures.

### A4.2.4 Emergency pressure relief manhole covers

These are an economical solution for tanks without a frangible roof-to-shell connection to provide protection against overpressure due to fire. Usually large diameter (20 or 24 inches) valves designed to be bolted onto a roof manhole. Valves are not self-closing and must be closed manually. Alternatively, several large diameter breather valves (with vacuum side blanked off) can be used to meet emergency relief requirements.

### A4.2.5 Automatic bleeder vents

These are used on internal or external floating roofs. Automatic bleeder vents allow air to escape from under the roof when the tank is being filled while the roof is resting on its supports. The automatic bleeder vents close automatically soon after the roof starts floating. When the tank is being emptied, the bleeder vents open automatically just before the roof comes to rest on its supports, admitting air under the roof to avoid a vacuum. The bleeder vents have a low position and a high position the same as the roof support legs. The bleeder vents shall be pinned in the same position as the roof supports (see Figure A4.1).

### A4.2.6 Rim vents

These are used on floating roofs equipped with a mechanical shoe type seal. The rim vent is a simple pressure relief valve connected to the rim space to prevent overpressure in the rim space which could damage the sealing ring.

## A4.3 INFORMATION REQUIRED FOR VENTING CALCULATIONS

Units are those required for using the tables and equations in API 2000.

- tank diameter;
- tank height;
- tank capacity;
- pumping rates;
- flash point of product stored;
- normal boiling point of product stored;
- maximum temperature of product stored;
- does tank have a frangible roof-to-shell attachment?
- is tank externally insulated?

  If yes: What is thickness of insulation?
  Will insulation resist dislodgement by fire hose streams?
  Is insulation non-combustible?

## A4.4 VENTING REQUIREMENTS

### A4.4.1 Normal venting requirements

a. Vacuum relief (in-breathing) for products of any flash point:
   - Maximum liquid movement out of tank (API 2000, 2.4.2.1.1), plus thermal in-breathing (API 2000, 2.4.2.1.2 and Table 2, Column 2)

b1 Pressure relief (out-breathing) for products with flash point of 100 °F (37.8 °C) or above or normal boiling point of 300 °F (149 °C) or above:
   - Maximum liquid movement into a tank (API 2000, 2.4.2.2.1), plus thermal out-breathing (API 2000, 2.4.2.2.2 and Table 2, Column 3)

b2 Pressure relief (out-breathing) for products with flash point below 100 °F (37.8 °C) or normal boiling point below 300 °F (149 °C):
   - Maximum liquid movement into a tank (API 2000, 2.4.2.3.1), plus thermal out-breathing (API 2000, 2.4.2.3.2 and Table 2, Column 4)

### A4.4.2 Emergency venting requirements

Emergency venting is required to relieve excessive internal pressure caused by exposure to fire. The main objective is to prevent tank rupture below the maximum liquid level which could cause product to spill into the bund area. Failure of the roof-to-shell connection with the top-angle buckling and roof plates tearing away from the top-angle is considered acceptable for the emergency case.

For fixed roof tanks with a frangible roof-to-shell connection complying with the requirements of API 650, 3.10.2.5.1 or BS 2654, F.4, additional venting for emergency purposes is not required.

For fixed roof tanks without a frangible roof-to-shell connection, the emergency venting capacity shall be determined as follows:

a) determine total rate of emergency venting required from API 2000, Table 3;
b) determine Environmental Factor ‘F’ from API 2000, Table 4;
c) multiply total rate of emergency venting under a) with Factor ‘F’ under b);
d) determine capacity of vents for normal venting at full-open pressure equal to design pressure + 20%;
e) additional venting capacity required is c) minus d).

### A4.4.3 Other venting requirements

A4.4.3.1 Unusual climatic conditions:

Tanks located in subtropical or tropical climates can sometimes be cooled rapidly when a sudden rain storm occurs on a hot sunny day. Such a drop in temperature causes rapid contraction of the air-vapour mixture in the vapour space requiring a large inflow of air through the vacuum vents. Often the vacuum vents for normal vacuum relief have insufficient capacity for such an event. A similar situation can occur with tanks containing warm product. DEP 34.51.01.31-Gen, recognises this condition and specifies an increase of at least 20% of the thermal venting requirements for locations or situations where such an event may occur.

A4.4.3.2 Special operational conditions:

The following special conditions, which may be due to failure of the equipment, failure of the controls, power failures and operating errors, can seriously affect the venting requirements.

- internal tank heating;
- external product heating;
- external cooling jackets or coils;
- inert gas blanketing system;
- vapour balancing system;
- vapour recovery system;
- liquid transfer into the tank by pressurisation;
- pipeline surges.

The venting design shall consider the consequences of any such system. For example, failure of the supply regulator for an inert gas blanketing system can result in unrestricted gas flow into the tank. In the case of a vapour balancing system, the failure of one tank in a group could create a vacuum in each of the other tanks in the group.

## A4.5 VENT SETTING AND CAPACITY

The set pressure of a pressure or vacuum relief valve is the pressure at which the valve will start to open. It takes a certain overpressure (overvacuum) for the valve to reach full flow conditions. The full flow pressure is the sum of set pressure and overpressure (overvacuum). For normal venting the full flow pressure shall not exceed the design pressure (vacuum) for the tank.

During emergency venting, the full flow pressure may rise to 20% above the tank design pressure.

Example for Low Pressure Tank (BLC or BLD):

| | | | | |
|---|---|---|---|---|
| a) | Design pressure: | Pd = | 20 | mbar (ga) |
| | Set pressure normal pressure relief valve: | Ps = | 15 | mbar (ga) |
| | Maximum overpressure for normal pressure relief: | | | |
| | (Pd-Ps)/Ps * 100% | = | 33 | % |
| | Max overpressure for emergency pressure relief: | | | |
| | (1.2*Pd-Ps)/Ps * 100% | = | 60 | % |
| b) | Design vacuum: | Vd = | 6 | mbar (ga) |
| | Set pressure vacuum valve | Vs = | 4 | mbar (ga) |
| | maximum overvacuum: (Vd-Vs)/Vs * 100% | = | 50 | % |
| c) | Max pressure during emergency pressure relief: | 1.2*Pd = | 24 | mbar (ga) |
| | Set pressure emergency pressure relief valve: | Es = | 20 | mbar (ga) |
| | Max overpressure for emergency pressure relief: | | | |
| | (1.2*Pd-Es)/Es * 100% | = | 20 | % |

Set pressures do not apply to open vents. The capacity of an open vent shall be based on a pressure differential of 7.5 mbar pressure and 2.5 mbar vacuum.

See Table A4.1 for the venting capacity of free orifice vents.

Capacities for pressure/vacuum valves shall be determined from flow curves or tabulated data published by the valve Manufacturer. See sample calculation 2 for the flow curves for Whessoe Varec Figure 4020 Breather Valve.

Emergency vents shall be set at design pressure or lower. Full flow pressure (set pressure + overpressure) shall not exceed design pressure + 20%. Capacity shall be determined from the flow curves, flow equation or tabulated data published by the vent Manufacturer.

Automatic bleeder vents, as used on floating roofs, do not have a set pressure because they are activated by the movement of the roof. Automatic bleeder vents are normally supplied by the tank Manufacturer. The Purchaser should specify the maximum pumping rates for the tank Manufacturer to determine the number and size of automatic bleeder vents. Pontoon type floating roofs should have at least two 10-inch diameter bleeder vents. The vents should be located close to the pontoon inner rim and evenly spaced around. Double deck floating roofs should have at least one 12-inch diameter bleeder vent, located close to the centre. For guidance, the capacity of one 10-inch diameter automatic bleeder vent as shown in Figure A4.2 is 1 500 $m^3$/hour, the capacity of one 12-inch diameter automatic bleeder vent as shown in Figure A4.3 is 3 000 $m^3$/hour.

Rim vents, as used on floating roofs with a mechanical shoe type seal, have a standard size of 6 inch dia. and a standard setting of 0.5 oz/inch$^2$ (22 mm water gauge).Whessoe Varec Figure 4126 is often used for the rim vent on floating roofs. Usually one 6-inch diameter vent is adequate. For very large floating roofs two or three rim vents are sometimes used.

## A4.6 INSTALLATION OF VENTS

Vents should be connected to the vapour space in such a way that they cannot be sealed off by the liquid level. The vents should be located reasonably close to the roof centre. Vent nozzles should be trimmed flush with the underside of roof plates to avoid a flow obstruction. Oil storage tanks usually vent direct to atmosphere without a vent stack. Tanks for special products may require a vent stack, relieving pressure at about 3 m above the roof for personnel protection. If a vent stack is needed, the pressure relief valve requires a flanged side outlet port. The capacity of a relief valve with vent stack will be reduced due to the pressure drop through the vent stack. Relief valves for oil storage tanks are mounted direct on the roof nozzle without shut-off valve.

Open vents and pressure/vacuum relief valves should be provided with a mesh screen to prevent the ingress of dirt. The openings of the mesh screen should be large enough to prevent clogging and provide minimum flow resistance. See Table A4.2 and Figure A4.2 for mesh details.

## A4.7 FLAME ARRESTERS

Flame arresters should not be used under relief valves for oil storage tanks. Flame arresters seriously restrict the venting capacity making it necessary to use larger vent sizes. Flame arresters do not provide protection against back-flash into the tank, because the relief valve itself provides this protection. Any time the relief valve is open, the exit velocity of the gas is greater than the velocity of flame propagation. With viscous products clogging of the flame arrester can present a real danger.

## A4.8 VENT INSPECTION AND MAINTENANCE

All vents, including open vents with screens, shall be inspected and cleaned at intervals not exceeding one year. An annual service contract with a reputable valve Manufacturer or service company is highly recommended.

The inspection/maintenance shall include as a minimum:

a. open valve and remove any dirt;

b. thoroughly clean screen with a brush;
c. verify screen is 4 x 4 mesh (6.35 mm spacing of wires) or a mesh with larger openings (see Figure A4.4);
d. remove and clean pallets and pallet seats;
e. verify loose weights conform to set pressure;
f. report on corrosion of metal parts and/or deterioration of rubber seals and membranes. If corrosion or deterioration is apparent, recommend valve or part replacement using a different material;
g. complete inspection/maintenance record.

For open vents, the inspection/maintenance is limited to items a, b, c and g.

The Tank Integrity Assessor shall periodically verify that there has been no change in the operation of the tank, e.g. increased pumping rates, which could affect the design of the venting system.

A4.9 SAMPLE CALCULATION NO. 1

This sample calculation demonstrates the valve sizing and selection procedure for normal and emergency venting in accordance with API 2000.

**Tank data:**

| | SI Units | US Customary Units |
|---|---|---|
| Diameter D | 30 m | 98.425 ft |
| Height H | 15 m | 49.213 ft |
| Type roof | Cone with 1:5 slope | Cone with 1:5 slope |
| Code | Low pressure (BLC) | Low pressure (BLC) |
| Design pressure | 20 mbar (ga) | 8.03 inch water gauge |
| Design vacuum | 6 mbar (ga) | 2.41 inch water gauge |
| Product | Class II | Class II |
| Flash point | Below 37.8 °C | Below 100 °F |
| Max pump-in rate | 600 $m^3$/hour | 3773 barrels/hour |
| Max pump-out rate | 300 $m^3$/hour | 1887 barrels/hour |
| Tank insulated | No | No |

**Calculate venting requirements:**

**(1) Calculate tank capacity (volume of cylindrical shell):**

$V = \pi D^2 H/4 = 10\,603\ m^3$

V = 10 603 x 6.289 = 66 683 barrels

**(2) Normal outbreathing (pressure relief) requirements**:

a) Required venting capacity for normal pressure relief due to pumping-in (API 2000, 2.4.2.3.1 for products with flash point below 100 °F)
Required pressure relief capacity = 12 x 3 773 = 45 276 SCFH

b) Required venting capacity for normal pressure relief due to thermal outbreathing (API 2000, 2.4.2.3.2 for products with flash point below 100 °F)
From Table 2, Column 4: Interpolate for tank capacity of 66 683 barrels

Required normal pressure relief capacity = 46 673 SCFH air

c) Total required normal pressure relief capacity = a) + b) = 91 949 SCFH air

**(3) Normal in breathing (vacuum relief) requirements:**

a) Required venting capacity for normal vacuum relief due to pumping-out (API 2000, 2.4.2.1.1 for products of any flash point)
Required vacuum relief capacity = 5.6 x 1 887 = 10 567 SCFH

b) Required venting capacity for normal vacuum relief due to thermal, inbreathing (API 2000, 2.4.2.1.2 for products of any flash point)
From Table 2, Column 2: Interpolate for tank capacity of 66 683 barrels

Required normal vacuum relief capacity = 46 673 SCFH air

c) Total required normal vacuum relief capacity = a) + b) = 57 240 SCFH air

**(4) Emergency pressure relief requirements for fire exposure**

a) Determine emergency pressure relief requirements for fire exposure (API 2000, 2.4.3, Tables 3 and Table 4)

b) Calculate wetted area to a maximum height of 30 feet above grade

Wetted area = $\pi$ (98.425)(30) = 9 276 ft²

c) Emergency venting capacity required (from Table 3) Q = 742 000 SCFH air

d) Environmental factor (from Table 4) F = 1.0

e) Total required emergency pressure relief capacity = (F)(Q) = 742 000 SCFH

**(5) Valve selection for normal pressure and vacuum relief**

a) Select Whessoe Varec Figure 4020 pressure/vacuum breather valve
For 8.03 inch water gauge design pressure use 6.0 inch water gauge set pressure

For 2.41 inch water gauge design vacuum use 1.0 inch water gauge set vacuum

b) Pressure relief capacity one 6-inch valve: 105 000 SCFH > 91 956 SCFH air
Vacuum relief capacity one 6-inchvalve: 45 000 SCFH < 57 239 SCFH air

One 6-inch valve is insufficient to meet vacuum requirement, try one 8-inch valve:

Pressure relief capacity one 8-inch valve: 170 000 SCFH > 91 956 SCFH air

Vacuum relief capacity one 8-inch valve: 74 000 SCFH > 57 239 SCFH air

One 8-inch valve is adequate for both pressure and vacuum conditions.

**(6) Valve selection for emergency pressure relief**

a) Permissible pressure during emergency = 8.03 inch water gauge + 20% = 9636 inch water gauge

Pressure relief capacity one 8-inch valve = 200 000 SCFH air, 9.636 inch water gauge

Emergency relief capacity required = 742 000 SCFH air

Additional capacity required = 542 000 SCFH air

b) Select Whessoe Varec Figure 4210 Emergency Vent and Manhole Cover

Use 8.0 inch water gauge set pressure and permit 20% overpressure

Pressure relief capacity one 20-inch valve: 588 693 SCFH air > 542 000 SCFH

**(7) Summary of requirements:**

One 8-inch Whessoe Varec Breather Valve, set at 6 inch water gauge pressure and 1 inch water gauge vacuum.

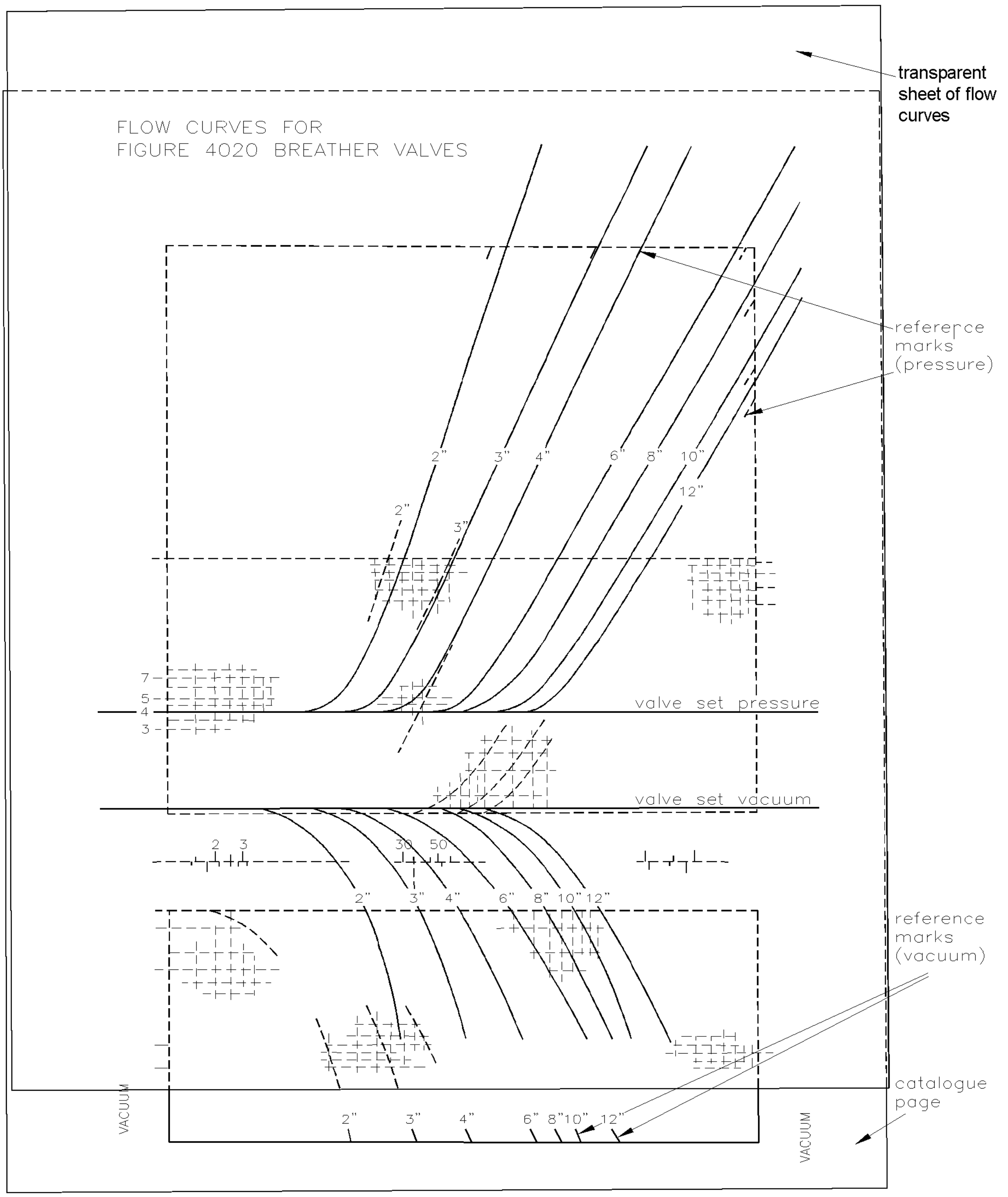
One 20-inch Whessoe Varec Emergency Vent, set at 8 inch water gauge pressure.

**(8) Instructions for the use of flow curves (from Whessoe Varec catalogue)**

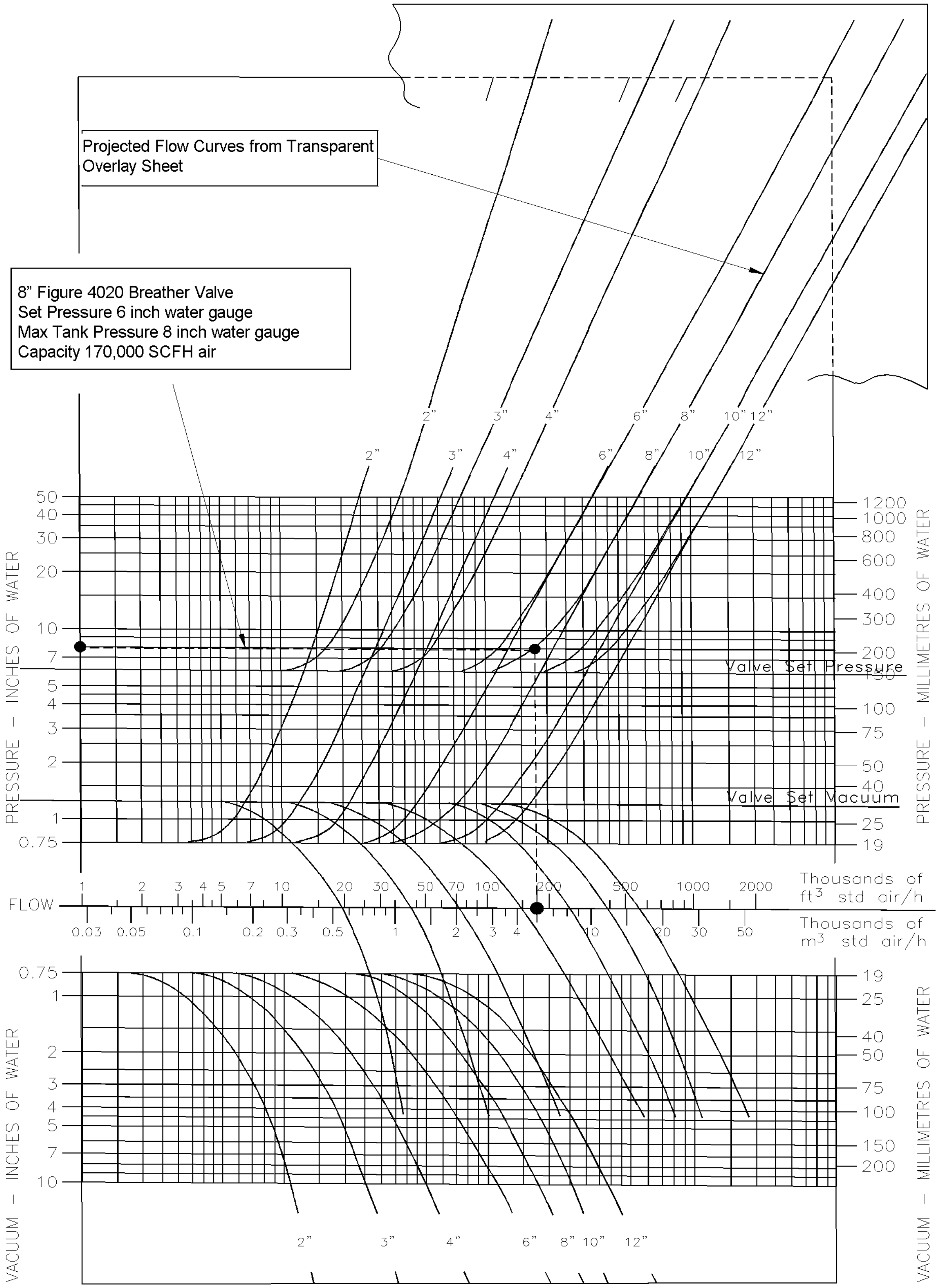
Place the transparent sheet of flow curves over the grid on the catalogue page. Move the transparent sheet upwards until the base line of the pressure flow curves reaches the elevated set pressure on the grid. Move the transparent sheet to the right until the flow curve for the valve concerned is aligned with the corresponding reference mark for the valve size at the boundary of the grid. Read the flow rates from the co-ordinates of the grid using the total tank pressure (valve set pressure plus overpressure).

The example below shows the catalogue page and transparent sheet positioned to obtain flow rates for a 4-inch valve set at 4 inch water gauge.

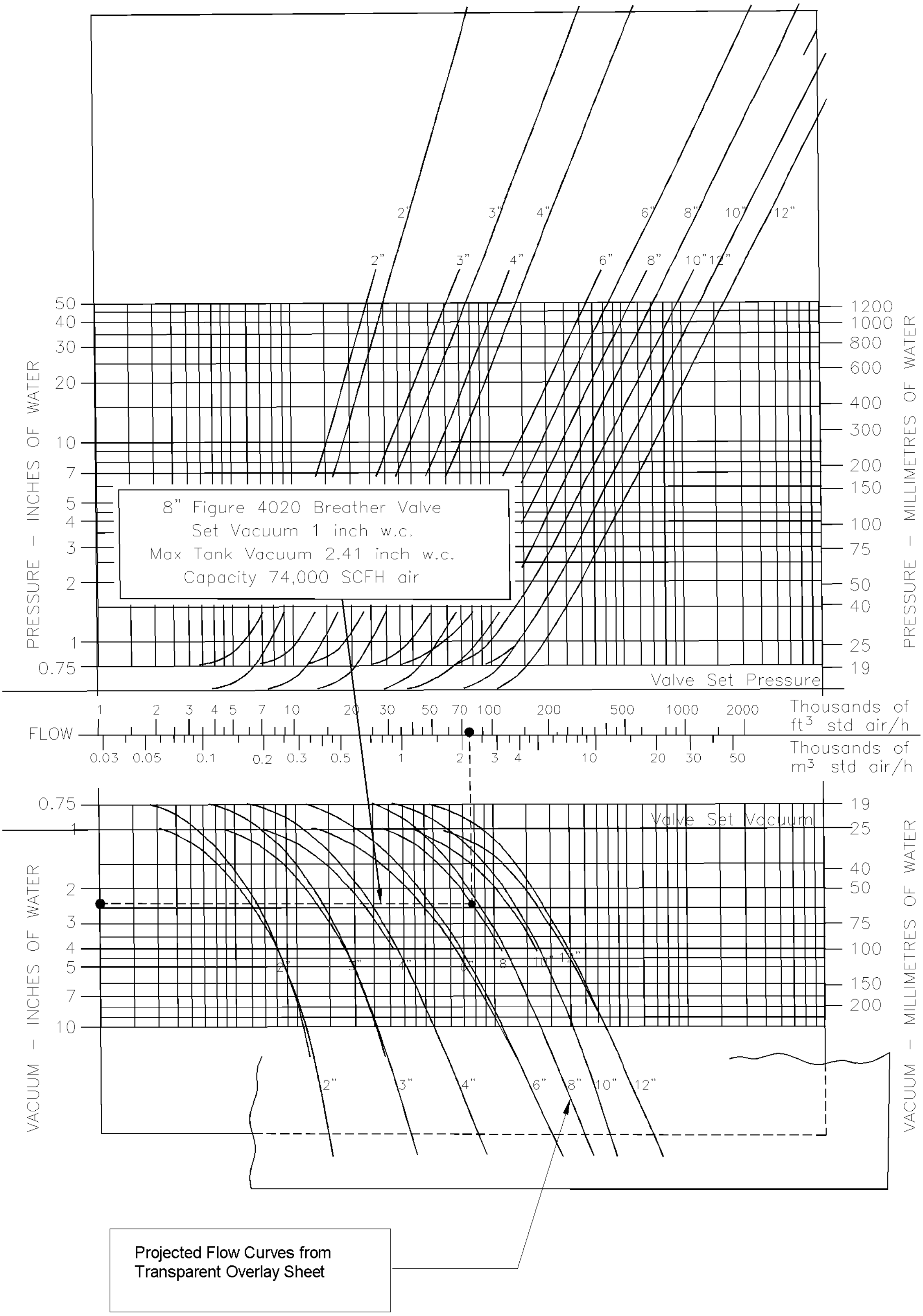
**Flow Curves for Figure 4020 Breather valves**



**(9) Example pressure relief capacity determination for 8" figure 4020 valve**



**(10) Example vacuum relief determination for 8" figure 4020 valve**



## A4.10 SAMPLE CALCUALATION NO. 2

This sample calculation (simplified) demonstrates, for each tank category, the drop in ambient temperature that can be accommodated before the vacuum relief valve opens.

Within the Shell Group, cone roof and dome roof tanks are divided into standard categories as shown in the table below. The larger the span between maximum pressure and maximum vacuum, the more ambient pressure and/or temperature variations the tank can accommodate without either the pressure relief or vacuum relief valve opening. As long as the pressure and vacuum relief valves remain closed there are no breathing losses. In other words, the larger the pressure span, the higher the vapour-saving efficiency.

| | Code | Design Pressure mbar (gauge) | Design Vacuum mbar (gauge) |
|---|---|---|---|
| Non-Pressure | BNC or BND | 7.5 | 2.5 |
| Low-Pressure | BLC or BLD | 20 | 6.0 |
| High-Pressure | BHC or BHD | 56 | 6.0 |

The calculation is based on the fundamental law of gases:

P1 V1/T1 = P2 V2/T2

where:

P1 = initial pressure in vapour space, mbar (abs)

P2 = final pressure in vapour space, mbar (abs)

V1 = initial volume of vapour space, $m^3$

V2 = final volume of vapour space, $m^3$

T1 = initial temperature in vapour space, K

T2 = final temperature in vapour space, K

In this case, the volume of the vapour space remains constant, thus P1/T1 = P2/T2

Assume T1 = average vapour space temperature = 20 °C = 293 K
Assume P1 = pressure relief set pressure, mbar (abs)
Assume P2 = vacuum relief set pressure, mbar (abs)
Assume atmospheric pressure Pa = 1013 mbar (abs)

| | Units | Code BNC or BND | Code BLC or BLD | Code BHC or BHD |
|---|---|---|---|---|
| Design pressure | mbar (ga) | 7.5 | 20 | 56 |
| Design vacuum | mbar (ga) | -2.5 | -6.0 | -6.0 |
| Pressure relief set pressure | mbar (ga) | 6.0 | 15 | 45 |
| Vacuum relief set pressure | mbar (ga) | -1.5 | -4.0 | -4.0 |
| Pressure relief set pressure | mbar(abs) | 1019 | 1028 | 1058 |
| Vacuum relief set pressure | mbar (abs) | 1011.5 | 1009 | 1009 |
| Average vapour space temp | K | 293 | 293 | 293 |
| Calculate T2 = P2/P1*T1 | K | 290.8 | 287.6 | 279.4 |
| Drop in temp = T1-T2 | °C or K | 2.2 | 5.4 | 13.6 |

The calculation indicates that a high pressure tank can accommodate a temperature drop of 13.6 °C whereas the non-pressure tank can only accommodate a drop of 2.2 °C.

## A4.11 SAMPLE CALCULATION NO. 3

This sample calculation demonstrates that the API 2000 required venting capacity for thermal inbreathing (vacuum relief) may be inadequate for certain unusual climatic conditions.

API 2000 venting requirements for vacuum relief are based on the inflow of air due to product movement plus thermal inbreathing. Thermal inbreathing is caused by changes in atmospheric conditions. API 2000 requirements for thermal inbreathing are based on a mean rate of change of 100 °F (56 °C) per hour in the vapour-space temperature (see API 2000, Appendix A for further details).

The sample calculation will check the required vacuum relief capacity of a 80 ft dia. x 30 ft high tank in Colombo. A temperature record is available for this tank which indicates a temperature drop of not less than 30 °F (from 87 °F to 57 °F) in 15 minutes. This sharp temperature drop occurred during a downpour after a hot and sunny day.

| | | | | | | |
|---|---|---|---|---|---|---|
| Tank diameter | D = | 24.38 | m | = | 80.0 | feet |
| Tank height | H = | 9.14 | m | = | 30.0 | feet |
| Roof tangent | TAN = | 0.20 | | | | |
| Tank capacity | | 26855 | Barrels | | | |
| Tank volume incl. roof space | | 4650 | $m^3$ | = | 164200 | $ft^3$ |
| <u>Assume tank empty:</u> | | | | | | |
| Volume of vapour space | V1 = | 4650 | $m^3$ | | | |
| Molecular weight of gas | m= | 29 | | | | |
| Atmospheric pressure | | 1.033 | $kg/cm^2$ | | | |
| Gas Constant | R = | 0.08478 | litre-atmos/mole | | | |
| Normal vapour density | | 1.294 | $kg/cm^3$ at 0 °C | | | |
| Vapour temperature | T1 = | 87 | °F | = | 304 | K |
| Vapour density at T1 | | 1.164 | $kg/cm^3$ | | | |
| Total weight of vapour at T1 | | 5412 | kg | | | |
| Vapour temperature | T2 = | 57 | °F | = | 287 | K |
| Vapour density at T2 | | 1.232 | $kg/cm^3$ | | | |
| Vapour volume at T2 | | 4394 | $m^3$ | | | |
| Volume contraction | $\delta V$ = | 256 | $m^3$ in 1 hour | | | |
| Inbreathing due to temperature drop | = | 36162 | $ft^3$/hr | = | 36162 | SCFH air |
| API 2000 inbreathing requirement | | | | = | 25484 | SCFH air |
| Percentage increase over API 2000 | | | | = | 42 | percent |

It should be noted that this calculation is not exact. It is presented to illustrate the effect of a rapid cool down of the vapour space.

**Table A4.1 Capacity of free orifice type vents**

The capacity of a vent which consists of a free circular opening or which is of such simple construction that it is practically a free circular opening, may be determined from the table below for openings of 200 mm diameter or smaller. For openings greater than 200 mm dia., use the following formula:

Venting capacity ($m^3$/hour) = 0.01818 $d^2 \sqrt{(\delta p)}$

where:

d = diameter of orifice (mm)

$\delta p$ = pressure differential between inside and outside of tank (mbar (ga))

| Venting capacity ($m^3$/hour) | Orifice diameter* (mm) | | | | | |
|---|---|---|---|---|---|---|
| | 2.5 | 5.0 | 7.5 | 70 | 175 | 350 |
| | Differential pressure (mbar (ga)) | | | | | |
| 50 | 42 | 35 | 32 | 32 | 32 | 32 |
| 100 | 60 | 50 | 45 | 32 | 32 | 32 |
| 250 | 93 | 78 | 71 | 41 | 32 | 32 |
| 500 | 132 | 111 | 100 | 57 | 46 | 38 |
| 750 | 162 | 136 | 123 | 70 | 56 | 47 |
| 1000 | 187 | 157 | 142 | 81 | 65 | 54 |
| 1250 | - | 175 | 158 | 91 | 72 | 61 |
| 1500 | - | 192 | 174 | 99 | 79 | 66 |
| 2000 | - | - | 200 | 115 | 91 | 77 |
| 4000 | - | - | - | 162 | 129 | 108 |
| 6000 | - | - | - | 200 | 158 | 133 |
| 8000 | - | - | - | - | 182 | 153 |
| 10000 | - | - | - | - | 200 | 172 |
| 12000 | - | - | - | - | - | 188 |
| 14000 | - | - | - | - | - | 200 |

* Interpolate diameter for intermediate values of venting capacity and differential pressure

Example:

For a given venting capacity of 500 $m^3$/hour and a differential pressure of 7.5 mbar (ga), the minimum orifice diameter is 100 mm.

**Figure A4.1 Operation of automatic bleeder vent**

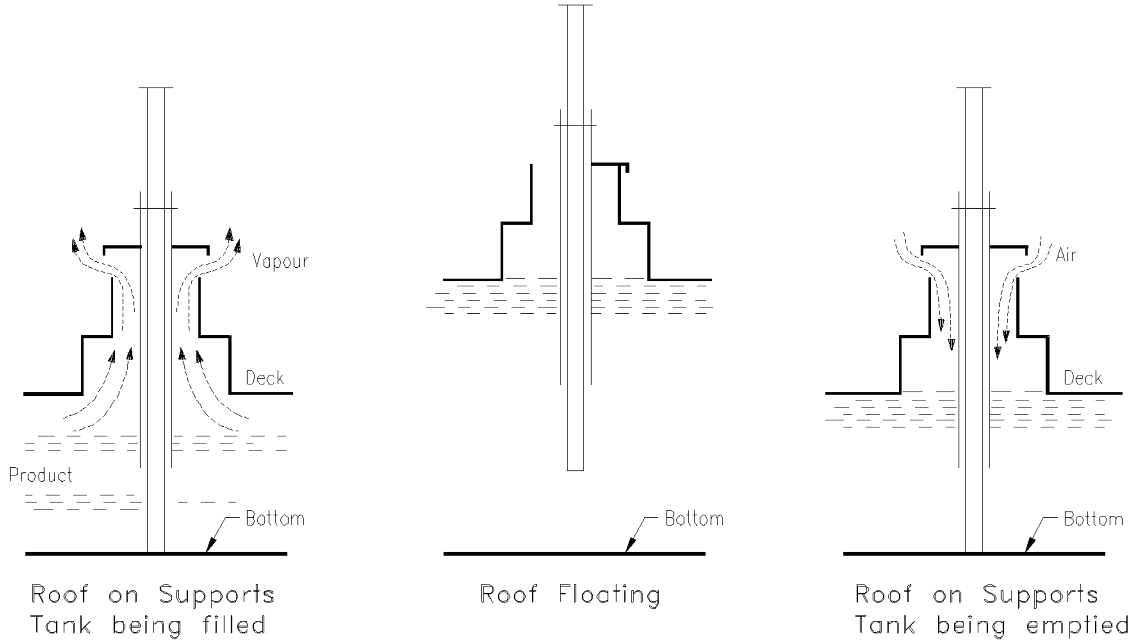



**Figure A4.2 10-inch auto bleeder vent pontoon type floating roof**

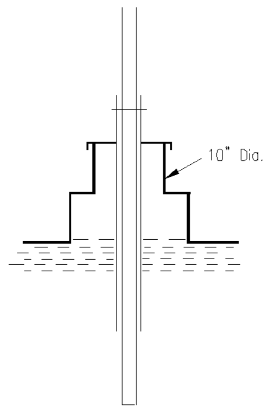



**Figure A4.3 12-inch auto bleeder vent pontoon type floating roof double deck floating roof**

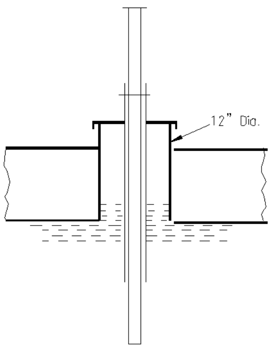
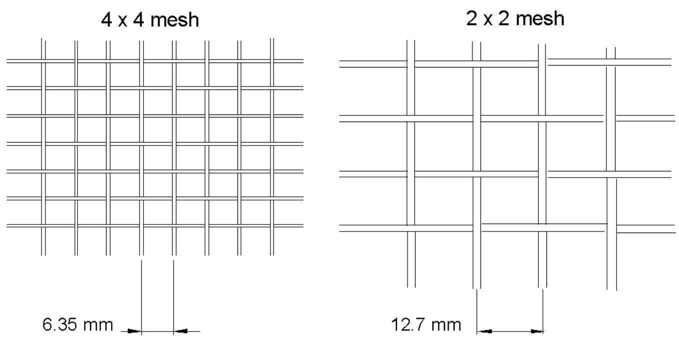


**Table A4.2 Details of screen mesh**

| | | Minimum | | Maximum | |
|---|---|---|---|---|---|
| Designation (gaps per inch) | | 4 x 4 | | 2 x 2 | |
| Distance between centres of adjacent wires | | 0.25 inch (6.35 mm) | | 0.50 inch (12.7 mm) | |
| Wire diameter | | UK SWG | US SWG | UK SWG | US SWG |
| | gauge | 23 | 24 | 18 | 18 |
| | inch | 0.024 | 0.023 | 0.048 | 0.0475 |
| | mm | 0.610 | 0.584 | 1.219 | 1.207 |
| Wire material | | Stainless or galvanised steel | | | |

**Figure A4.4 Examples of mesh**



## APPENDIX 5 SHELL STABILITY

### A5.1 GENERAL

Tanks built before 1960 were normally fabricated from mild steel using an allowable stress of 21 000 psi (145 N/mm$^2$) under water test and a joint efficiency factor of 0.85. This design basis resulted in relatively thick shell plates for which a stability check was not required.

Since the early 1960's, tanks have been designed using higher tensile steels, higher design stresses and a joint efficiency factor of 1.0. This has resulted in thinner shells which are more vulnerable to damage as a result of wind and/or vacuum loading. A shell stability check for such tanks is essential.

For new tanks designed to BS 2654, the tank is checked for stability under combined wind and vacuum loading. If the transformed shell height 'HE' (see A5.3) exceeds the maximum unstiffened shell height 'Hp', one or more secondary wind girders will be required. Alternatively, the thickness of one or more shell courses may be increased as necessary to avoid the need for secondary wind girders. If a corrosion allowance is specified for a new tank, BS 2654 requires the stability calculations to be made using the plate thickness less corrosion allowance. It is important that the correct wind design speed and design vacuum are used (see A5.3).

For existing corroded tanks, the average measured thickness less paint allowance of each shell course shall be used to check the stability. The average measured thickness is the average of thickness measurements taken along a vertical line over the height of the shell course. The paint allowance should be determined by measuring the shell thickness with and without paint at a representative number of locations.

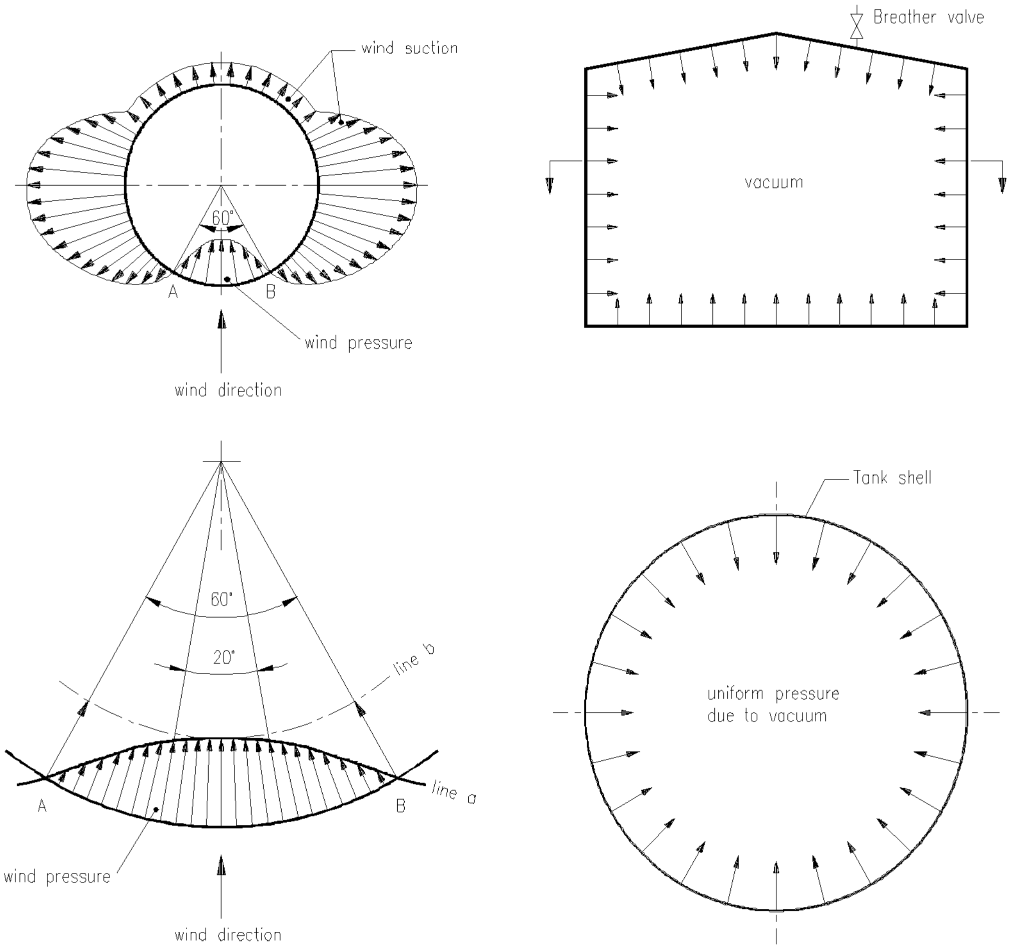
It is recommended that the same wind condition is applied to corroded tanks as was used for the original design. In special circumstances, the maximum allowable wind speed the corroded shell can withstand can be calculated. This will allow the risk of a higher wind speed to be evaluated. The vacuum condition cannot be changed except by reducing the vacuum set pressure.

For open-top floating roof tanks, a design vacuum of 5.0 mbar (ga) should be used. This vacuum is caused by wind suction. If the design wind speed is less than 45 m/s, the design vacuum may be reduced in direct proportion to the design wind speed. If the design wind speed is equal to or greater than 45 m/s, the design vacuum remains constant at 5.0 mbar (ga).

Sample calculation A5.5, item D, covers the case of a tank with one secondary wind girder. Checking the stability of the corroded shell with a secondary wind girder already present requires the transformed shell height to be determined above and below the secondary wind girder. In each case the transformed height shall be checked against the maximum unstiffened height 'Hp'.

Figure A5.1 illustrates how wind and vacuum loading act on the tank.

## Figure A5.1 Wind and vacuum loading




External wind loading on tank shell

Fixed roof tank with internal vacuum

## A5.2 LOADING CASES

**a. Wind loading**

The design wind speed 'Vw' used in the shell stability calculations is based on a basic wind speed 'V' for the area where the tank is located. The basic wind speed is equal to the maximum 3-second gust speed, estimated to be exceeded on average only once in 50 years. The design wind speed is calculated from:

Vw = V * S1 * S2 * S3 where:

S1 = Topography factor. Use S1 = 1.0 for normal locations, and use S1 = 1.10 if tank is located on an exposed hill side or in a valley where funnelling of wind occurs

S2 = Ground roughness and height above ground factor

Use: S2 = 1.00 for height up to and including 10 m

S2 = 1.03 for height up to and including 20 m

S2 = 1.07 for height up to and including 30 m

S3 = Statistical factor. Use S3 = 1.0

For locations where 3-second gust wind data is not available, a correction factor should be used. For example, a 1-minute gust wind speed should be multiplied by a factor of 1.2 to obtain the corresponding 3-second gust value.

**b. Vacuum loading**

For the design vacuum for the shell stability calculations use:

Va = 2.5 mbar (ga) for non-pressure fixed roof tanks

Va = 5.0 mbar (ga) for open top floating roof tanks

Va = 6.0 mbar (ga) for low and high pressure fixed roof tanks

**c. Roof load**

To calculate axial compression in the tank shell, use the dead weight of the roof plates, roof framing and roof insulation (if any) plus a superimposed load of 1.2 kN/m$^2$ over the projected roof area. The superimposed load shall be deemed to include any internal vacuum.

## A5.3 CALCULATION PROCEDURE FOR WIND AND VACUUM LOADING

The calculation procedure for checking the stability of the shell subject to wind load plus internal vacuum is as outlined in BS 2654, 7.3.2. The procedure is repeated in more detail below:

Step 1: Information required to perform the stability calculation is:

| | | |
|---|---|---|
| D | = | tank diameter (m) |
| t | = | corroded thickness of each shell course (mm) |
| h | = | height of each shell course (m) |
| Vw | = | design wind speed (3-second gust, m/sec) |
| Va | = | design vacuum (mbar (ga)). See A5.2 for values to use |

Step 2: Transpose the actual height 'h' of each shell course to an equivalent height 'He' of thickness '$t_{min}$' using the following equation:

$$He = h \sqrt{\left(\frac{t_{min}}{t}\right)^5}$$

Where:

| | | |
|---|---|---|
| $t_{min}$ | = | corroded thickness of the top course (mm) |
| t | = | corroded thickness of each shell course (mm) |
| h | = | actual height of each shell course (m) |
| He | = | transposed height of each shell course (m) |

Step 3: Calculate transformed shell height: $HE = \sum He$

Note: The transformed shell has a uniform thickness '$t_{min}$' and a height 'HE' which provides equivalent stability as the actual shell with variable thickness and a top course thickness equal to '$t_{min}$'. See Figure A5.3.1

Step 4: Calculate factor 'K' using following equation:

$$K = 95\ 000 / (3.563\ Vw^2 + 580\ Va)$$

Step 5: Calculate maximum permitted spacing 'Hp' of stiffener rings on transformed shell (m):

$$Hp = K \sqrt{\left(\frac{t^5_{min}}{D^3}\right)}$$

Step 6: Calculate required number of stiffening rings 'N' from:

$$N = (HE / Hp) - 1$$

and round up to next higher number

Step 7: If one stiffening ring is required, it shall be located on the transformed shell as high as permitted by the calculation results. That will be at (HE-Hp) below the top-angle for a fixed roof tank, or below the primary wind girder for an open-top floating roof tank.

If more than one stiffening rings is required, the stiffeners shall be located on the transformed shell at an equal spacing of:

$$L = HE / (N+1)$$

where

L = spacing between stiffener rings on transformed shell (m)

Step 8: Transpose stiffener position on transformed shell to actual shell.

Step 9: Check stiffener position on actual shell is at least 150 mm away from a horizontal shell seam. If not, move stiffener to obtain the required distance from the horizontal shell seam. If the stiffener has been moved, check that the new spacing transposed to the transformed shell is less than Hp.

Step 10: Select the required stiffener size from Table A5.3.

**Table A5.3 Secondary wind girders**

| Tank diameter (m) | Stiffener size (angle section, mm) |
|---|---|
| $D \leq 20$ | 100 x 65 x 8 |
| $20 < D \leq 36$ | 125 x 75 x 8 |
| $36 < D \leq 48$ | 150 x 90 x 10 |
| $48 < D$ | 200 x 100 x 12 |
| Other shapes with equivalent section modulus may be used. The section modulus may include a portion of the shell for a distance of 16 times shell plate thickness above and below the stiffener. | |

Step 11: For stiffener installation details, see Figure A5.3.2

## A5.4 CALCULATION PROCEDURE FOR ROOF LOADING

Severe shell corrosion can cause the shell to buckle under the dead weight of the roof plus superimposed load. In addition, the weight of the shell above the corroded area should be taken into account. BS 2654 specifies a superimposed load of 1.2 kN/m$^2$. For areas with extra heavy snow fall, the use of a higher superimposed load may be needed.

The calculation procedure given below assumes that the total weight is uniformly distributed around the shell. On tanks with a truss supported cone roof, the trusses exert a point load on the shell. This point load will spread quickly but if severe corrosion in the top course just below the truss connection has occurred, there is a risk of local buckling in that area.

Step 1: Review results of visual inspection and ultrasonic thickness measurements of the upper shell courses. When checking for the hoop stress condition (see 5.3.1), corrosion in a vertical plane is the most important. When checking for buckling under roof load, corrosion in the horizontal plane is the most important. For buckling, small areas of corrosion are insignificant. However, a horizontal band of corrosion, for example at the liquid/vapour interphase, could be critical. If such corrosion is present, determine the minimum average thickness over a horizontal length of 2000 mm. Use this thickness for the buckling calculation under roof load.

Step 2: Calculate the total load due to a superimposed load of 1.2 kN/m$^2$ plus total dead weight of the roof plates, roof framing and shell above the corroded area under consideration. Load to be expressed per unit of circumference, e.g. N/mm. Divide load by the minimum average corroded thickness to obtain the vertical (axial) compression ‘fa’ in the shell. See sample calculation A5.5, item E.

Step 3: Compare calculated axial compression against an allowable compression of Fa = (12411)(t/R), where:

| | | |
|---|---|---|
| Fa | = | allowable axial compression (N/mm²) |
| t | = | minimum average corroded thickness (mm) |
| R | = | tank radius (mm) |

The allowable axial compression is the same as the API 620, 3.5.4.2, allowable compression of Scs = 1 800 000 (t/R), psi.

Step 4: If the calculated axial compression fa > Fa, the corroded parts of the shell shall be replaced.

## A5.5 SAMPLE CALCULATION FOR TANK STABILITY

### A. Calculate shell thickness for new tank

| | | | | |
|---|---|---|---|---|
| Design code | = | BS 2654 : 1989 + DEP 34.51.01.31-Gen | | |
| Type of tank | = | Low-Pressure Cone Roof Tank (BLC) | | |
| Climate | = | Temperate (LODMAT = °C) | | |
| Shell material | = | BS 4360 Grade 430 A | | |
| Shell material yield | = | 275.00 | $N/mm^2$ for t <= 16 mm | |
| Design stress | S = | 183.33 | $N/mm^2$ | |
| Joint efficiency | E = | 1.00 | | |
| Tank diameter | D = | 33.00 | m | |
| Tank height | H = | 14.60 | m | |
| Maximum fill height | h = | 14.60 | m | |
| Design pressure | p = | 20.00 | mbar (ga) | |
| Corrosion allowance | CA = | 0.00 | mm | |
| Minimum thickness | = | 8.00 | mm | |
| SG product | w = | 1.00 | (minimum required for shell design) | |
| SG steel | = | 7.85 | | |
| Number of shell courses | = | 6 | | |

Top-angle is 200 mm angle, lap welded to shell and extending 30 mm above shell

Formula used for shell thickness calculation:

t = (D/20 S*E) [(98*w*(hu-0.3) + p)] + CA

Note: hu = distance from max fill height to bottom of course under consideration

| Course Number | Course Height (mm) | hu (mm) | $t_{calculated}$ excluding CA (mm) | $t_{selected}$ (mm) |
|---|---|---|---|---|
| 1 | 2430 | 14600 | 12.79 | 12.80 |
| 2 | 2430 | 12170 | 10.65 | 10.70 |
| 3 | 2430 | 9740 | 8.51 | 8.60 |
| 4 | 2430 | 7310 | 6.36 | 8.00 |
| 5 | 2430 | 4880 | 4.22 | 8.00 |
| 6 | 2430 | 2450 | 2.08 | 8.00 |
| Top-angle | 20 | | | |

**B. Calculate shell stability for new tank**

| | | | |
|---|---|---|---|
| Design wind speed | Vw = | 54.00 | m/s (3-second gust) |
| Design vacuum | Va = | 6.00 | mbar (ga) |
| Factor | K = | 6.85 | |
| Thickness top course (excluding CA) | | 8.00 | mm |

| Course Number | Course Height (mm) | t req'd incl CA (mm) | t req'd excl CA (mm) | He corroded (m) |
|---|---|---|---|---|
| 1 | 2430 | 12.80 | 12.80 | 0.750 |
| 2 | 2430 | 10.70 | 10.70 | 1.175 |
| 3 | 2430 | 8.60 | 8.60 | 2.028 |
| 4 | 2430 | 8.00 | 8.00 | 2.430 |
| 5 | 2430 | 8.00 | 8.00 | 2.430 |
| 6 | 2250 | 8.00 | 8.00 | 2.250 |
| Top-angle | 0 | | | |
| Transformed shell height | | | HE =Σ He | 11.063 |
| Maximum permitted spacing (see step 5) | | | Hp = | 6.540 |
| No. of secondary wind girder required | | | = | 1 |

Note: Transformed shell taken to underside top-angle. Course 6 reduced accordingly.

According to DEP 34.51.01.31-Gen., 6.5.2.2, the secondary wind girder shall be located as high as permitted by the calculation results, which is at (HE-Hp) below top-angle.

| | | | |
|---|---|---|---|
| Location of secondary wind girder (transformed shell) | = | 4.523 | m (below top-angle) |
| Transposed location on actual shell | = | 4.523 | m (below top-angle) |
| Check clearance to nearest girth seam | = | 0.157 | m above 4-5 girth, so OK |
| Size of secondary wind girder | = | angle | 125 x 75 x 8 mm |

**C. Check hoop stress condition for corroded shell (see 5.3.1)**

The calculation uses the same tank as used for sample calculation A).

Assume tank has been in operation for 5 years storing light products. The first detailed external inspection (including ultrasonic thickness measurements) has been completed and the corroded shell now needs to be evaluated in accordance with (5.3).

| | | | |
|---|---|---|---|
| Minimum thickness | = | 4.00 | mm |
| Allowable stress | = | 220.00 | $N/mm^2$ |
| SG product | = | 1.00 | (use 1.00 to accommodate future hydrostatic test) |
| Paint thickness | = | 0.50 | mm |

| Course Number | Course Height (mm) | hu (mm) | t as-built (mm) | t measured less paint (mm) | t calc'd rejection (mm) | Acceptable for hoop stress condition? |
|---|---|---|---|---|---|---|
| 1 | 2430 | 14600 | 12.80 | 12.5 | 10.66 | Yes |
| 2 | 2430 | 12170 | 10.70 | 10.5 | 8.87 | Yes |
| 3 | 2430 | 9740 | 8.60 | 8.3 | 7.09 | Yes |
| 4 | 2430 | 7310 | 8.00 | 7.4 | 5.30 | Yes |
| 5 | 2430 | 4880 | 8.00 | 7.0 | 4.00 | Yes |
| 6 | 2250 | 2450 | 8.00 | 6.8 | 4.00 | Yes |
| Top-angle | 0 | | | | | |

**D. Check buckling condition for corroded shell (see 5.3.2)**

| | | | |
|---|---|---|---|
| Design wind speed | Vw = | 54.00 | m/s (3-second gust) |
| Design vacuum | Va = | 6.00 | mbar (ga) |
| Factor | K = | 6.85 | |
| Thickness top course (excluding CA) | $t_{min}$ = | 6.80 | mm |

| Course Number | Course Height | $t_{measured}$ (less paint) (mm) | He corroded (m) |
|---|---|---|---|
| 1 | 2430 | 12.5 | 0.530 |
| 2 | 2430 | 10.5 | 0.820 |
| 3 | 2430 | 8.3 | 1.476 |
| 4 | 2430 | 7.4 | 1.967 |
| 5a | 157 | 7.0 | 0.146 |
| 5b | 2273 | 7.0 | 2.114 |
| 6 | 2250 | 6.8 | 2.250 |
| Top-angle | 0 | | |
| Transformed shell 1-5a | | Hea = | 4.940 |
| Transformed shell 5b-6 | | Heb = | 4.364 |
| Transformed shell 1-6 | | HE = | 9.304 |
| Max permitted spacing | | HP = | 4.357 |

**Conclusion:**

1. Heb (above stiffener) is just less than Hp. Any further corrosion will make shell above stiffener unstable.
2. HEa (below stiffener) is greater than Hp. However, lower part of shell is less at risk because of liquid level and less corrosion

**Recommendation:**

Reduce design vacuum to 2.5 mbar (ga) or add two stiffeners, one above and one below the existing stiffener
Comment: Reducing design vacuum to 2.5 mbar (ga) will increase K to 8.02 and increase Hp to 5.104 which is greater than Hea and Heb.

**E. Check corroded shell for uniform roof load condition (see 5.3.2)**

| | | | | | | |
|---|---|---|---|---|---|---|
| Superimposed load | = | 1200 | N/m² | = | 9.90 | N/mm |
| Wt roof plates (5 mm) | = | 400 | N/m² | = | 3.30 | N/mm |
| Wt roof framing | = | 300 | N/m² | = | 2.48 | N/mm |
| Wt topangle | = | 82 | kg/m | = | 0.80 | N/mm |
| Wt course 6 | = | 120 | kg/m | = | 1.18 | N/mm |

| | | | |
|---|---|---|---|
| Total weight at lower edge of course 6 | q = | 17.65 | N/mm |
| Axial compression at lower edge of course | fa = | 2.60 | N/mm² |

Allowable compression

| | | | | |
|---|---|---|---|---|
| Fa = 12411*(t/R) | Fa = | 5.11 | N/mm² | > fa<br>so OK |

**Figure A5.3.1 Tank shell transformation**

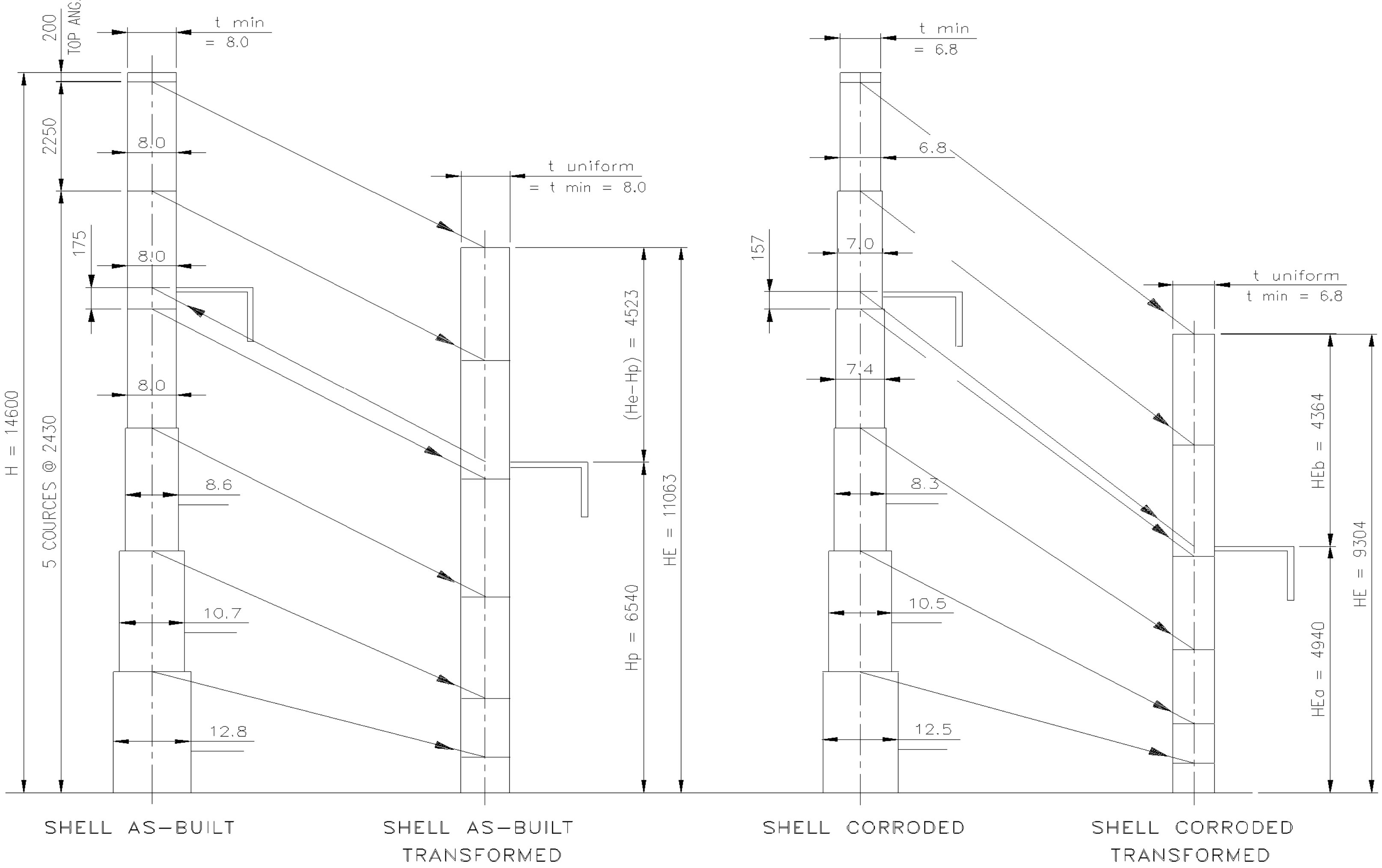
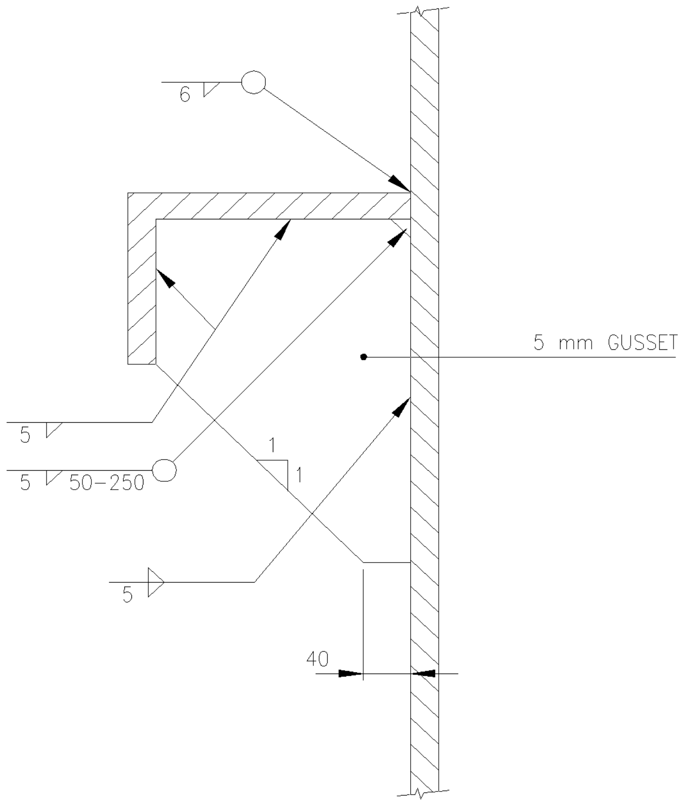
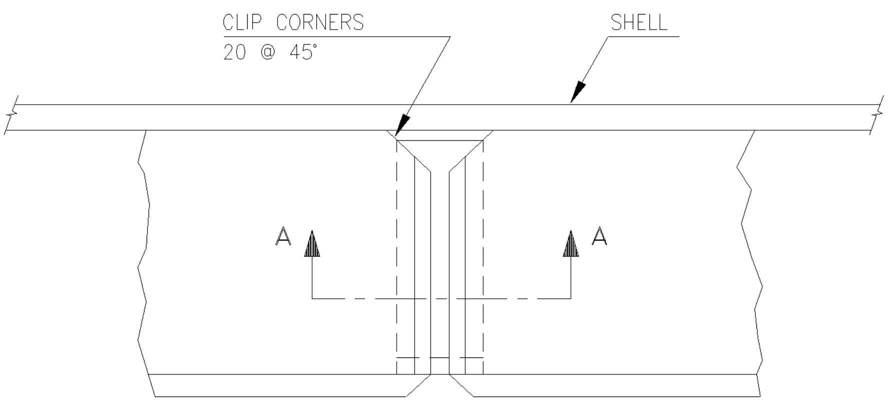
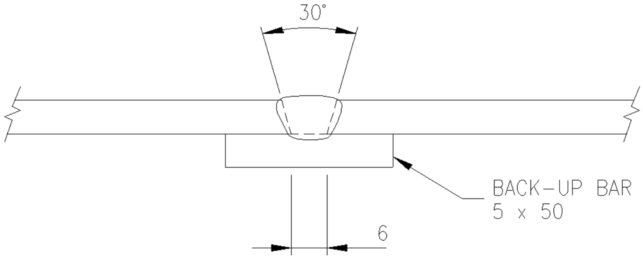


**Figure A5.3.2 Stiffener installation details**




SECTION A–A

## APPENDIX 6 INTERNAL COATING AND LINING SYSTEM FOR STORAGE TANKS

### A6.1 INTRODUCTION

Glass fibre reinforced linings can be used successfully to protect the tank bottom and first course of the tank shell against internal corrosion but an internal lining does not stop external corrosion. Once external corrosion has perforated through the steel plate, the internal lining will only be able to prevent product leakage for a limited period of time. As the external corrosion continuous to eat away at the tank bottom, the unsupported area will increase in size until the liner fails. There is also a risk that moisture will start to separate the lining from the steel bottom around the perforation.

Consequently, if corrosion is mainly external do not use an internal lining. If corrosion is mainly internal, then an internal lining is a suitable means of protecting the bottom. However, since a high quality internal lining is expensive, the cost of complete bottom replacement shall be evaluated before a decision is taken (see Figure A6.2). Such decision shall also be evaluated against the rejection criteria for the tank bottom and annular plates.

### A6.2 APPLICATION

The application of a coating and/or lining system shall be strictly in accordance with the Supplier's instructions including the priming, filling and laminate built-up. A typical example is shown in Fig. A6.1.

The steel surface preparation required for such application shall be according to DEP 70.48.00.31-Gen.

### A6.3 TESTING AND REPAIR

Testing, inspection and repair shall be in accordance with DEP 30.48.00.31 for new coatings/linings and according to DEP 70.48.10.10 for maintenance and repair of coatings/linings.

### A6.4 SAFETY PRECAUTIONS

Although no hot work is required the normal safety precautions should be observed as regards gas-freeing the tank, flame/explosion proofing of blasting equipment and compressors, etc. If the tank has contained leaded gasoline, special precautions as given in the 'Octel' handbook shall be observed.

**Figure A6.1 Typical example of a GRP lining**

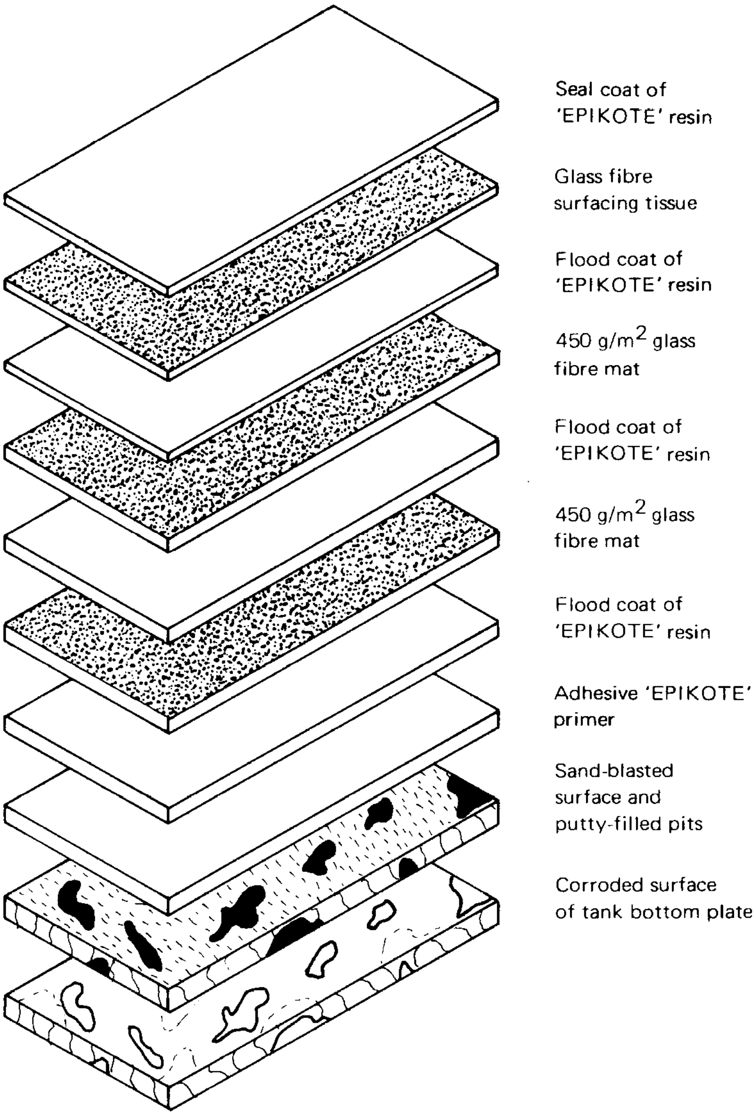
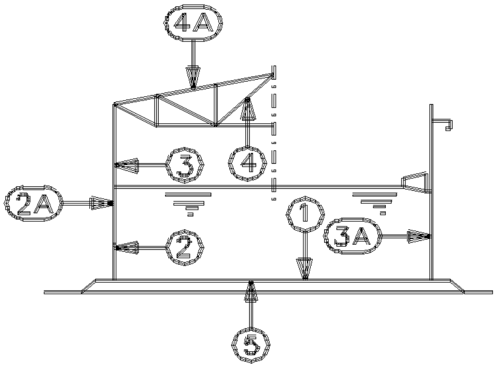



Fig.1

**Figure A6.2 Selection chart for internal coating/lining of vertical storage tanks**




| Location | Corrosion evaluation criteria | Products stored* | Coating/lining type (1) to be applied for: general corrosion | pitting |
|---|---|---|---|---|
| **1** Tank Bottom | A | Crude | 11 | 11 |
| | A | Slops | 11 | 11 |
| | A | Intermediates | 10 | 10 |
| | A | Gasolines | 10 | 10 |
| | A | Kerosines | 10 | 10 |
| | A | Gas Oils | 10 | 10 |
| | A | Fuel Oils | 10 | 10 |
| | N | | Repair / Replace | Replace |
| **2, 2A** **** Inside Tank Shell | A | Crude | 11 | 11 |
| | A | Slops | 11 | 11 |
| | A | Intermediates | 10 | 10 |
| | A | Gasolines | 10 | 10 |
| | A | Kerosines | 10 | 10 |
| | A | Gas Oils | 10 | 10 |
| | A | Fuel Oils | 10 | 10 |
| | N | | Repair / Replace | Replace |
| **3** Vapour Space | A | Crude | 10 | 10 |
| | A | Slops | 11 | 11 |
| | A | Intermediates | 10 | 10 |
| | A | Gasolines | 10 | 10 |
| **3A** Seal Rim Space | A | Kerosines | 10 | 10 |
| | A | Gas Oils | 10 | 10 |
| | A | Fuel Oils | 10 | 10 |
| | N | | Repair / Replace | Replace |
| **4, 4A** **** Roof Structure | A | Crude | 10 | 10 |
| | A | Slops | 11 | 11 |
| | A | Intermediates | 10, 11 *** | 10, 11 *** |
| | A | Gasolines | 10, 11 *** | 10, 11 *** |
| | A | Kerosines | 10, 11 *** | 10, 11 *** |
| | A | Gas Oils | 10, 11 *** | 10, 11 *** |
| | A | Fuel Oils | 10, 11 *** | 10, 11 *** |
| | N | | Repair / Replace | Replace |
| **5**** Underside Tank Bottom | A | | Jack-up, Apply Coating | |
| | N | | Replace | |

(1) For coating/lining types 10 and 11, see DEP 30.48.00.31-Gen.

A = Acceptable (or Limited Service)

N = Not Acceptable

* Product info for coating / lining selection

** Eliminate corrosion source first

Note: Coating/lining is not a replacement for the structural integrity of the tank bottom.

*** Choose between 10 and 11 depending on corrosiveness of tank contents. Select type 11 if in doubt.

**** Outside tank: See DEP 30.48.00.31-Gen.

## APPENDIX 7 HYDROSTATIC TESTING

### A7.1 GENERAL

The most important reasons for a hydrostatic test are as follows:

- to demonstrate that the tank is strong enough to satisfactorily withstand the liquid pressure during service. A hydrostatic test is also an overload as the specific gravity of water is higher than most of the products stored;
- to demonstrate that there are no leaks in the shell or bottom of the tank;
- to demonstrate that the foundation can satisfactorily carry the load of the tank and its liquid contents;

Note: Before testing, the external shoulder of the foundation shall be installed in accordance with the foundation design. Testing the tank without the foundation shoulder in place could cause a foundation slip failure during test.

- to allow most of the soil settlement to occur before the tank is put into service
- to allow plastic yielding at locations of stress peaks in the tank at a temperature above the brittle ductile transition temperature. This will increase the safety factor against brittle fracture during service;
- to demonstrate that floating roofs can move up and down with the liquid level without problems.

### A7.2 PIPE CONNECTIONS

No pipes shall be connected to the tank during the water test except for the pipe used to fill the tank with water. Product lines shall be connected to the tank after the water test. This has the advantage that these lines are not affected by settlement that occurs during the water test.

### A7.3 QUALITY OF TEST WATER

Fresh (potable) water shall be used for the hydrostatic test if possible. At locations where potable water is not available in sufficient quantity or where the cost of using potable water is prohibitive, river water, dock water or sea water may be used. In such a case, a water chemistry test shall be performed to determine the pH factor, chloride content and presence of other potentially corrosive elements. The analysis will provide an indication of the corrosiveness of the water. For example, a pH factor of between 6 and 8.3 is acceptable, while a lower or higher pH factor increases corrosiveness.

Whenever non-potable water is used for testing, the length of time that the water is kept in the tank shall be kept as short as possible. The corrosiveness of the water will assist in determining the maximum time that the water can remain in the tank. If the time limitation is unacceptable, corrosion inhibitors may need to be added to the water. Immediately after draining the test water, the tank interior shall be hosed down using fresh water.

Where an aluminium internal floating roof is fitted in the tank, there is no alternative but to use potable water.

### A7.4 TEMPERATURE OF TEST WATER

The hydrostatic test subjects the tank to its heaviest load. Locations with stress peaks can yield. The ability to accommodate yielding is influenced by the toughness of the material. The toughness is lowest at low temperatures. It is therefore essential that hydrostatic testing be carried out at a temperature of 4 °C or above. A higher temperature may be necessary due to plate thickness and material toughness. See BS 2654, Figure 1, for guidance on minimum test water temperature.

### A7.5 MAXIMUM FILLING HEIGHT

The tank shall be filled to the top of the shell or to the overflow designed to limit the liquid level. For tanks with an external floating roof, the maximum filling height may be limited to 300 mm below top of shell. For tanks with an internal floating roof, the hydrostatic test provides a unique opportunity to enter the tank while the roof is floating near the top. This will permit the exact maximum fill height to be established based on a minimum clearance of 150 mm between the highest point on the internal roof and the lowest point of the fixed roof framing or other internal member.

Do not overfill the tank! Overfilling of a fixed roof tank will cause an upward pressure against the underside of the roof plates which could result in the top-angle and roof supporting trusses being buckled. Overfilling of a tank with an internal floating roof can seriously damage and possibly sink the internal roof.

## A7.6 SETTLEMENT MONITORING

A settlement monitoring programme is an essential part of the hydrostatic test. Monitoring frequency depends on soil conditions and expected settlement.

For tanks with no predicted settlement, shell level measurements shall be taken with tank empty, 67% full, 100% full, and when empty again.

For tanks with predicted settlement, the following monitoring frequency should be employed:

| | | |
|---|---|---|
| a | Before filling starts | Take levels around shell circumference |
| b | With 0.25 m water in tank | Measure bottom profile |
| c | During filling to stage 1 | Take levels every 24 hours |
| d | While holding at stage 1 | Take levels every 12 hours until rate of settlement is diminishing |
| e | During filling to stage 2 | Take levels every 12 hours |
| f | While holding at stage 2 | Take levels every 12 hours until rate of settlement is diminishing |
| g | During filling to stage 3 | Take levels every 12 hours or more frequently depending on rate of settlement |
| h | While holding at stage 3 | Take levels every 12 hours until rate of settlement is diminishing |
| I | During filling to stage 4 (full) | Take levels every 12 hours or more frequently depending on rate of settlement |
| j | While holding at stage 4 (full) | Take levels every 12 hours until rate of settlement is diminishing |
| k | Empty with 0.25 m water left | Measure bottom profile to establish total bottom settlement |
| l | Completely empty | Take levels to establish total shell settlement |

Shell settlement readings shall be taken along the circumference at every other reference point (Appendix 2). Shell settlement readings shall be evaluated by calculating the total tilt and the deviation from the uniform tilted plane.

Measurement of the tank bottom profile shall be done before starting to fill the tank and again when the tank is nearly empty. When draining the test water, leave about 25 cm of water in the tank to ensure that the tank bottom is in contact with its foundation profile. The tank bottom profile shall then be measured.

## A7.7 FILLING RATE

Tanks built on a stable foundation with no predicted settlement, e.g. rock or concrete slab, can be filled at a rate of up to 1.5 m/hour.

Tanks built on foundations where significant settlement during filling is predicted should have filling rates limited such that the subsoil layers under the tank get sufficient time to absorb the settlements without problems. The filling rates, holding times and frequency of settlement monitoring shall be laid down in the hydrostatic test procedure. For guidance on filling rates and monitoring periods, see DEP 64.51.01.31-Gen.

NOTES: 1. When filling a fixed roof tank, ensure that sufficient venting capacity is available. It will usually be adequate if all the roof vents plus at least one 24” dia. roof manhole are fully open.

2. When filling a tank with external or internal floating roof, use a low filling rate of not more than 0.25 m/hour until the roof is afloat. Thereafter, the filling rate can be increased to the specified maximum filling rate.

## A7.8 HOLDING TIME

For tanks with no settlement, the minimum holding period shall be 24 hours. This time is required for small leaks to show up. If there is rainfall during the holding period, the period may need to be extended to observe the tank under dry conditions.

For tanks with predicted settlement, the holding time shall be 48 hours or longer until settlement monitoring gives a clear indication that the rate of settlement is diminishing.

## A7.8 EMPTYING RATE

When withdrawing water from a fixed roof tank, ensure that at least one 24” roof manhole is open.

When withdrawing water from an external floating roof tank, ensure that the automatic bleeder vents are pinned in the same position as the roof supports. Also, remember to slow down the withdrawal rate when the roof approaches its landing position. Floating roofs should be landed gently to avoid damage. The same applies to fixed roof tanks with internal floating roofs.

## A7.9 WHEN TO HYDROSTATIC TEST AFTER REPAIR OR MODIFICATION

Refer to Figure A7.1

### A7.9.1 Full hydrostatic test

A full hydrostatic test is always required after the following repairs or modifications have been made:

(a) - partial or complete replacement of bottom annular plates;
- any repair or replacement of the internal shell-to-bottom fillet weld;
- istallation of new shell plates or insert plates, except as exempted under (j);
- installation of shell nozzles or shell manholes, except as exempted under (j);
- installation of a flush type clean-out door, a flush type nozzle (API 650, 3.7.8) or a D-type sump (BS 2654, Figure 32);

(b) - partial or complete replacement of bottom plates;

(c) - complete jacking of tank shell;

(d) - new foundation or major foundation repairs including the installation of a membrane or clay mats under the tank;

(e) - installation of internal floating roof in existing fixed roof tank. Fill tank to maximum fill height to test operation of internal floating roof;

(f) - floating roof seal or drain replacement.

**A7.9.2 Partial hydrostatic test**

A partial hydrostatic test is required after the following repairs or modifications have been made:

(g) - weld repairs to floating roof. Fill tank to float roof and observe for leaks;

(h) - installation of external intermediate shell stiffener in upper part of shell to stiffen corroded shell against buckling due to wind and/or vacuum. Fill tank to 500 mm above stiffener location and observe leaks.

**A7.9.3 No hydrostatic test**

No hydrostatic test is required after the following repairs or modifications have been made:

(i) - local repairs to tank bottom by means of patch plates;

- partial or complete replacement of roof plates and roof framing (fixed roof tanks), provided steps are taken to protect the tank bottom from damage. A thorough visual inspection of the tank bottom is required after the work is finished;

- minor repair to foundation shoulder.

**A7.9.4 No hydrostatic test (API 653 exemptions)**

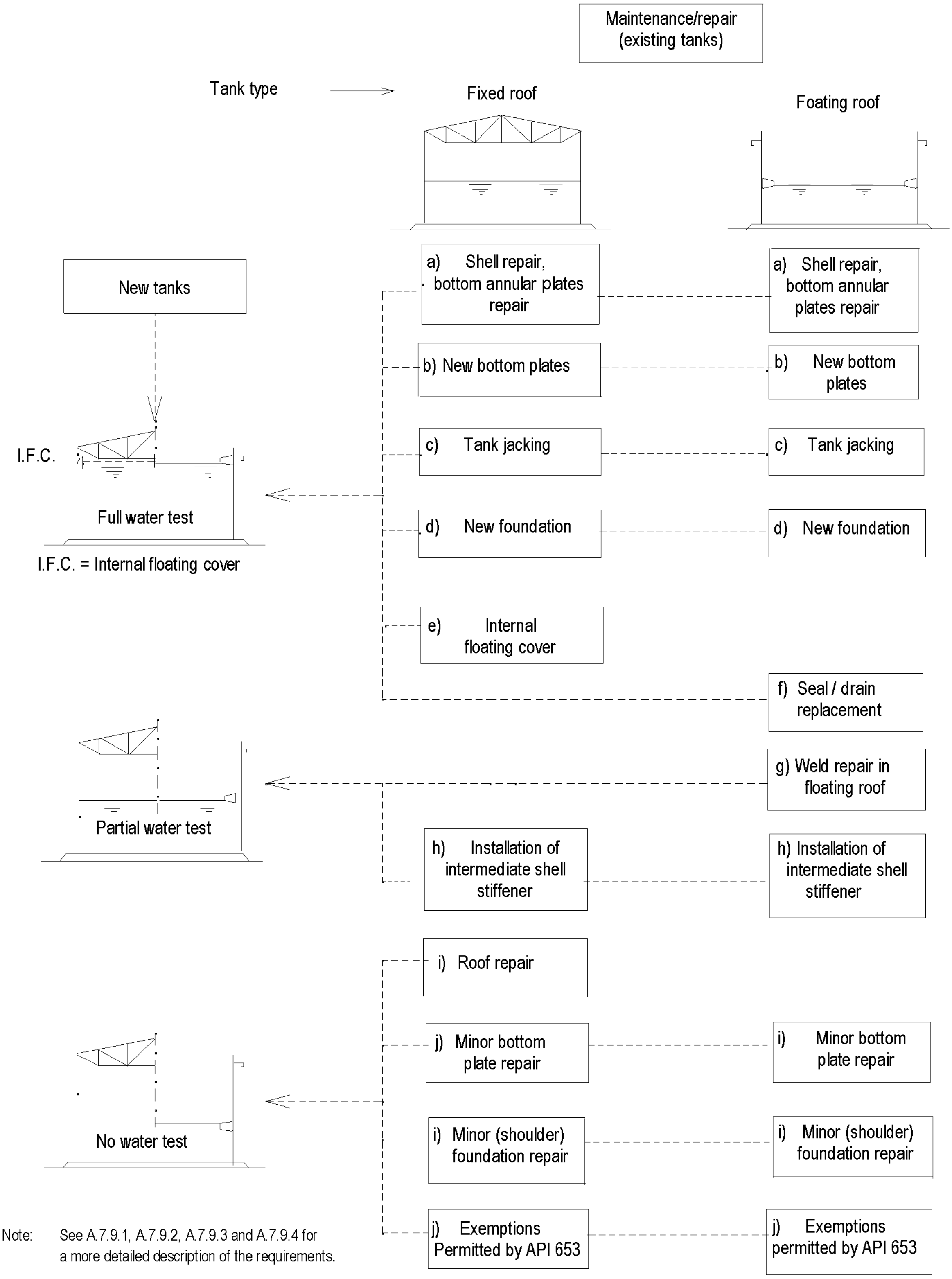
No hydrostatic test is required after the following repairs or modifications provided all the conditions of API 653, as stated below, have been fulfilled:

(j) - replacement of a door sheet, provided the conditions of API 653, 10.3.2.3 are fulfilled and the joint is welded and radiographed in accordance with API 653, 10.3.2.2.b;

- installation of shell nozzles ≤ 12” dia in shell plates with t ≤ 12.7 mm. Nozzle installation and examination shall be in accordance with API 653, 10.3.2.2.d;

- installation of new shell plates or insert plates in shell courses with t ≤ 12.7 mm, provided the total area of the replacement plate does not exceed 2.0 $m^2$ and provided the plate is installed in accordance with API 653, Figure 7-1, and welded and radiographed in accordance with API 653, 10.3.2.2.c.

**Figure A7.1 Selection diagram for hydrostatic testing of vertical tanks**




Note: See A.7.9.1, A.7.9.2, A.7.9.3 and A.7.9.4 for a more detailed description of the requirements.