

THE ENGINEERING EQUIPMENT AND MATERIALS USERS' ASSOCIATION

Frangible Roof Joints for Fixed Roof Storage Tanks: Guide for designers and users

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Comments will be considered by the relevant EEMUA Technical Committees and may be incorporated in future editions of this Publication. New editions will be publicised on the EEMUA website.

Foreword

This Publication has been developed by the EEMUA Storage Tanks Technical Committee to give guidance to designers and users of fixed roof vertical cylindrical storage tanks on methods of ensuring that, in the event of vapour over-pressure, tank failure occurs preferentially at the roof-to-shell joint. This Publication covers the essential features both for new structures and for the modification of existing structures and includes illustrated examples of good design practice and photographs of tank failures.

The reader's attention is also drawn to the companion EEMUA publications: *Users' Guide to the Maintenance and Inspection of Above-ground Vertical Cylindrical Steel Storage Tanks*, EEMUA Publication 159 and *Guide for the Prevention of Bottom Leakage from Vertical Cylindrical Steel Storage Tanks*, EEMUA Publication 183.

Acknowledgements

EEMUA gratefully thanks the American Petroleum Institute and the British Standards Institution for granting permission to reproduce selected diagrams from their respective publications.

API 650 Welded steel tanks for oil storage.

BS 2654 Specification for manufacture of vertical steel welded non-refrigerated storage tanks with butt-welded shells for the petroleum industry.

Note on the Use of Units

This Publication uses SI units throughout, except for the use of bar and mbar signifying gauge pressure, and in extracts from American API documents (US customary units).

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1. Introduction and Scope

1.1 Introduction

Vertical, cylindrical storage tanks with fixed roofs have a vapour space between the roof and the stored liquid. This vapour space contains a mixture of product vapour and air; for certain products this mixture may be in the flammable range. Fixed roofs are provided with open vents or pressure-vacuum valves for venting (see Figure 1).

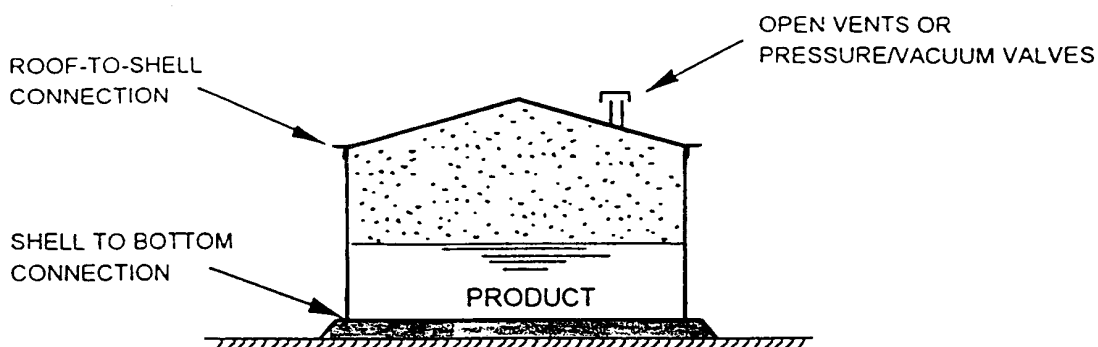


Figure 1 Fixed roof storage tank

Under normal operating conditions these vents ensure that the pressure in the vapour space remains close to atmospheric pressure by relieving when over-pressure or vacuum exceeds certain specified values. Over-pressure can occur when a tank is being filled, or when the temperature and hence pressure in the vapour space is increased by the sun's heat on the roof (see Figure 2). The reverse occurs when a tank is being emptied or when the ambient temperature falls.

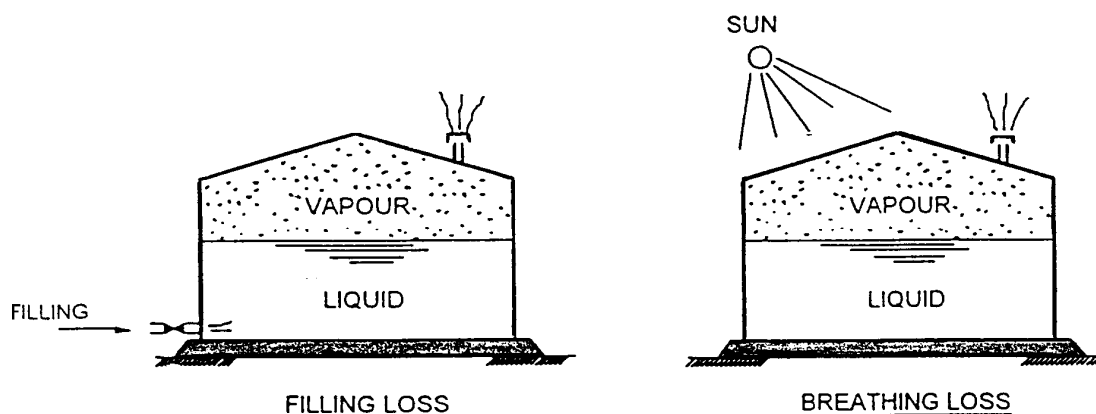


Figure 2 Evaporative losses from a fixed roof tank

Under conditions of differing degrees of abnormality, caused for example by mal-operation, external fire or internal explosion, the resulting increase in vapour pressure may be so rapid that the venting devices are unable to handle the demand. This may be so even when additional 'emergency' venting capacity is

provided. As a consequence the tank may be damaged. In such cases the design should ensure, as far as possible, that the failure occurs at the roof-to-shell connection and not at the shell-to-bottom connection. Failure of the roof-to-shell connection will normally create sufficient extra venting capacity so that no further damage to the tank shell occurs and the stored liquid is safely retained inside the shell of the tank (see Photo 1).

To increase the likelihood of a preferential roof-to-shell failure, fixed roof tanks are generally provided with a weak roof-to-shell connection known as a 'frangible roof joint'. A sectional view of a typical frangible roof joint is shown in Figure 3.

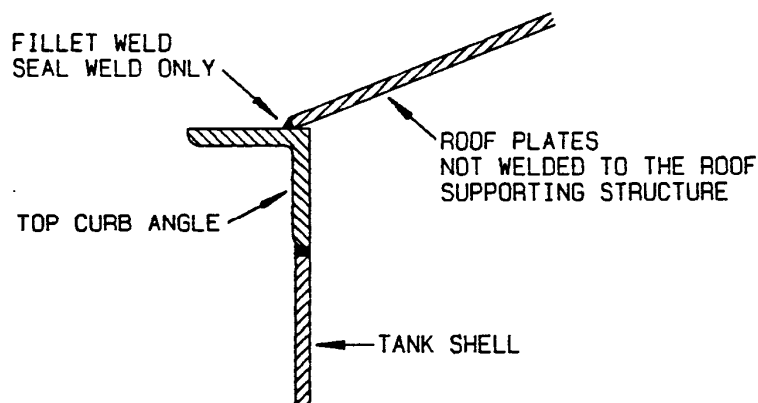


Figure 3 Typical frangible roof joint

1.2 Scope

This Guide covers the factors and conditions that influence, favourably or unfavourably, the effectiveness of a frangible roof joint. These factors and conditions and their effects on roof frangibility are considered from both theoretical and practical standpoints. The Guide is intended to assist designers and users of such tanks to carry out detailed evaluation, of both new designs and existing tanks, as to whether there is:

- a reasonable chance that the tank will fail preferentially at the roof-to-shell connection;
- a significant risk that the tank will fail at the shell-to-bottom connection;

and in the event of the latter, to assist in identifying the design, constructional or operational parameters which may need to be changed in order to increase the probability of a roof-to-shell failure occurring before a shell-to-bottom failure.

2. Types of Fixed Roof Storage Tanks

In Europe, fixed roof storage tanks are now generally designed and constructed in accordance with EN 14015.

EN 14015 classifies tanks as follows:

- non pressure tanks, rating from -5 to +10 mbar;
- low pressure tanks, rating from -8.5 to +25 mbar;
- high pressure tanks, rating from -8.5 to +60 mbar;
- very high pressure tanks, rating from -20 to +500 mbar.

Older tanks, constructed before 2004, were mostly designed and constructed in accordance with other codes. Note that these existing tank classifications do not change over time and tanks should be checked against the design codes used in their construction.

These codes were:

- BS 2654 for tanks with internal pressures up to and including 56 mbar. In this code, tanks are subdivided in three classes:
 - non pressure tanks, rating from -2.5* to +7.5 mbar;
 - low pressure tanks, rating from -6* to +20 mbar;
 - high pressure tanks, rating from -6* to +56 mbar;
- API 650 for tanks with internal pressures up to and including 180 mbar;
- API 620 for tanks with internal pressures exceeding 180 mbar up to and including 1025 mbar.

Tanks designed and constructed for design conditions equal to or exceeding 20 mbar will have roof-to-shell joints designed for service conditions and these may not be frangible. In such cases the designer should check whether the frangibility characteristics could be met.

* For stability calculations these negative pressures have to be amended, from -2.5 mbar to -5 mbar and from -6 mbar to -8.5 mbar, to allow accumulation for the vacuum valves to develop full design throughput.

3. Venting Capacities

EN 14105 Appendix L, BS 2654 Appendix F, API 650 Appendix F and API 2000 specify the venting capacities required for both operational (normal) and emergency (external fire) conditions.

3.1 Normal Venting

Normal venting requirements are dependent upon maximum filling and emptying rates (mainly), thermal effects and vapour pressure of the stored product.

3.2 Emergency Venting

Additional, emergency venting capacity is required only for tanks without frangible roof joints. The requirement in each particular case is based on a rate of heat input from an external fire which is assumed to depend on the wetted area of the tank. The correlation between heat input rate and wetted area given in API 2000 is based on actual fire tests.

Experience suggests that the emergency venting capacity will usually cater only for a gradual rate of increase in vapour pressure such as may result from a moderate, and gradual increase in, heat input from a distant fire. The venting requirements specified in the standards assume steady state conditions and do not consider rate of increase in vapour pressure.

It is emphasised that emergency vents may not be able to handle the sudden relief demand under the conditions of severity described in Section 4.

3.3 Roof Joints and Frangibility

3.3.1 According to BS 2654 and API 650

The latest editions of BS 2654 Appendix F and API 650 Appendix F specify a tank to have a frangible roof joint when the cross-sectional area of a complete roof-to-shell section is less than a specific calculated maximum. (See applicable codes for detailed information about formulae to assess this maximum cross-sectional area.)

However, the operational internal pressure will induce membrane stresses in the roof plates which, in turn, will try to pull the top curb section inwards (see Figure 4).

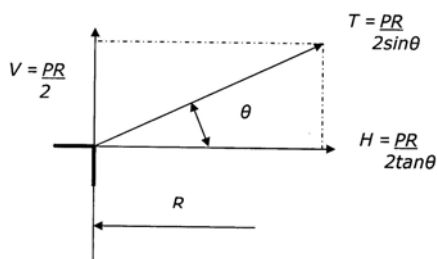


Figure 4 Force distribution in roof-to-shell joint induced by an internal pressure in a storage tank

where:

- T = tensile membrane force in roof plates induced by an internal pressure in a tank (N)
- V = vertical force derived from force T (N)
- H = horizontal force derived from force T (N)
- P = pressure in vapour space of storage tank above liquid level diminished by the own weight of the roof plates (N/m^2)
- R = nominal radius of tank shell (m)
- θ = angle of roof plates with horizontal surface (degrees).

The available design codes, therefore, prescribe a method to assess the minimum required cross-sectional area of the roof-to-shell section of a tank that is capable to take up the loads induced by the design internal pressure of a storage tank.

Only when the maximum cross-sectional area, as determined from the formulae of BS 2654 Appendix F and API 650 Appendix F, is in excess of the minimum required cross-sectional area to accommodate the loads induced by the design internal pressure in a tank, may a roof joint considered to be frangible.

3.3.2 According to EN 14015

EN 14015 Appendix K gives formulae which can be used to determine whether the failure pressure (the pressure at which the joint fails) of the shell-to-bottom connection is higher than the failure pressure of the roof-to-shell joint. For new tanks, it is specified that the difference between the failure pressure of the shell-to-bottom connection and the failure pressure of the roof-to-shell joint should be assessed according to the following formula:

$$p_b = 2 * \gamma * p_r \text{ (in mbar)}$$

where:

- p_b = failure pressure of shell-to-bottom connection (mbar)
- γ = safety factor, within the range $1 < \gamma < 1.5$
- p_r = failure pressure of roof-to-shell joint (mbar).

3.4 Older Tanks

The requirement for emergency venting was introduced around 1980. It should therefore be assumed that fixed roof tanks built before that year are operating without emergency venting. This means that these older tanks are dependent on the effectiveness of their frangible roof joints for relieving excessive internal pressure caused by fire in the vicinity of the tank.

Where a roof joint is known not to be frangible, or where there is doubt about its effectiveness, consideration should be given to the retrofitting of emergency venting capacity and to weakening the roof-to-shell joint as described in Section 7.3.

Appendix 1 of this Publication, assessment of presence of frangible roof-to-shell joint in a tank structure, provides a quick scan data sheet for assessing the need on an urgent basis for a frangible roof-to-shell joint.

4. Explosions inside Tanks

Explosion in the vapour space of a tank resulting in a sudden increase in vapour pressure may be caused by:

- welding or grinding operations on or near the tank;
- a lightning strike on the tank;
- a discharge of static electricity;
- a major fire in the vicinity of the tank;
- water entering a tank in which product with a temperature over 100°C is stored (explosion due to flashing steam);
- pyrophoric iron sulphide deposits inside the tank causing ignition;
- glowing carbonaceous (coke) deposits in bitumen tanks;
- possible other reasons, e.g. overfilling.

EN 14015, BS 2654, API 650 and API 2000 do not take internal explosion into account when considering the design and venting requirements of tanks. The open vents and pressure relief valves are not able to handle the sudden, very high rates of relief required by these conditions. The only practical safety measure is to provide a frangible roof joint to give the required additional venting capacity and ensure that the contents of the tank are safely retained within the shell.