11.1.2 Pontoon type floating roofs

For these roofs, buoyancy is provided by an annular pontoon of approximately 20 to 30% of the total roof area. Roofs are designed to enable the centre deck to carry approximately 250mm depth of rainfall over the total roof area that accumulates on the centre deck. Finally, it has sufficient buoyancy for the roof to remain afloat when two adjacent pontoon compartments and the centre deck are punctured and flooded (See Figures 11-1 and 11-2).

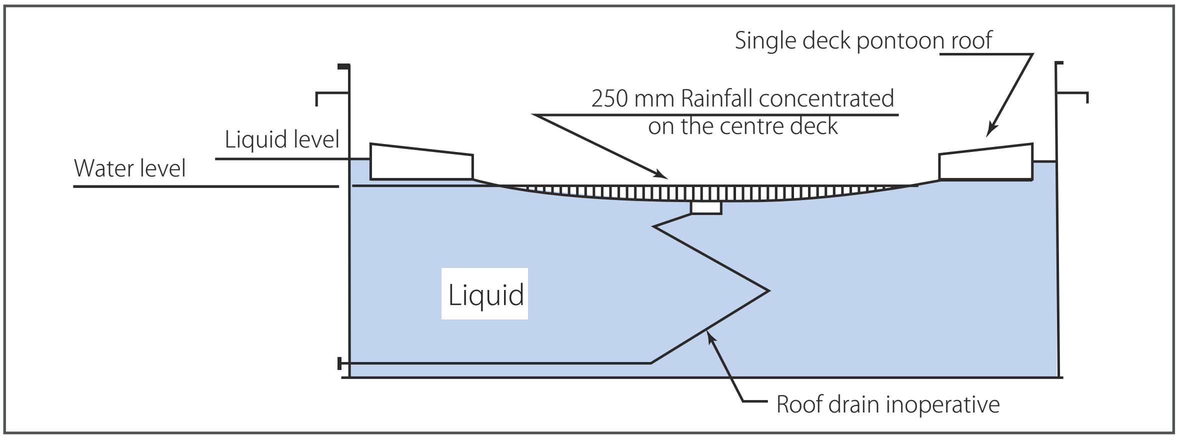

Figure 11-1 Rainwater load on the centre deck of a pontoon with drain inoperative

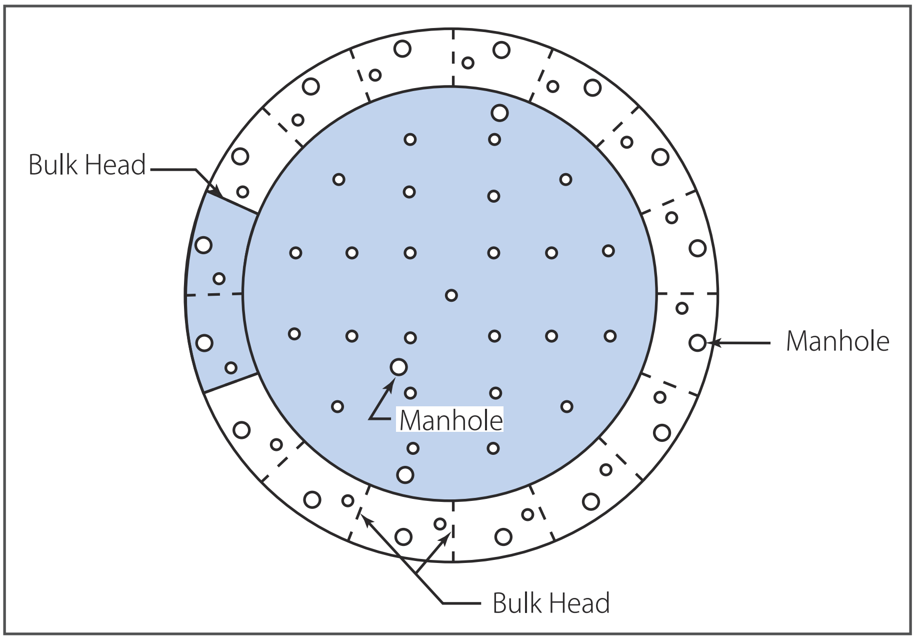

Figure 11-2 Design of a pontoon roof *(Capable of floating with centre deck and two bulkheads punctured)*

Emergency roof drains cannot be installed as the level of the centre deck is below the level of the oil in the tank. Rainwater drains, such as syphon type (emergency) drains may still be found on older existing singledeck roofs but they should be flanged off or removed in view of operational problems and the high risk that such a drain could create, e.g. a centre deck leak.

11.1.3 Double-deck floating roofs

For this roof type, the entire roof area is designed/constructed with a double deck, making the roof more rigid than the pontoon roof. The double deck consists generally of an annular pontoon with concentric rings in the centre part of the roof; see Figure 11-3.

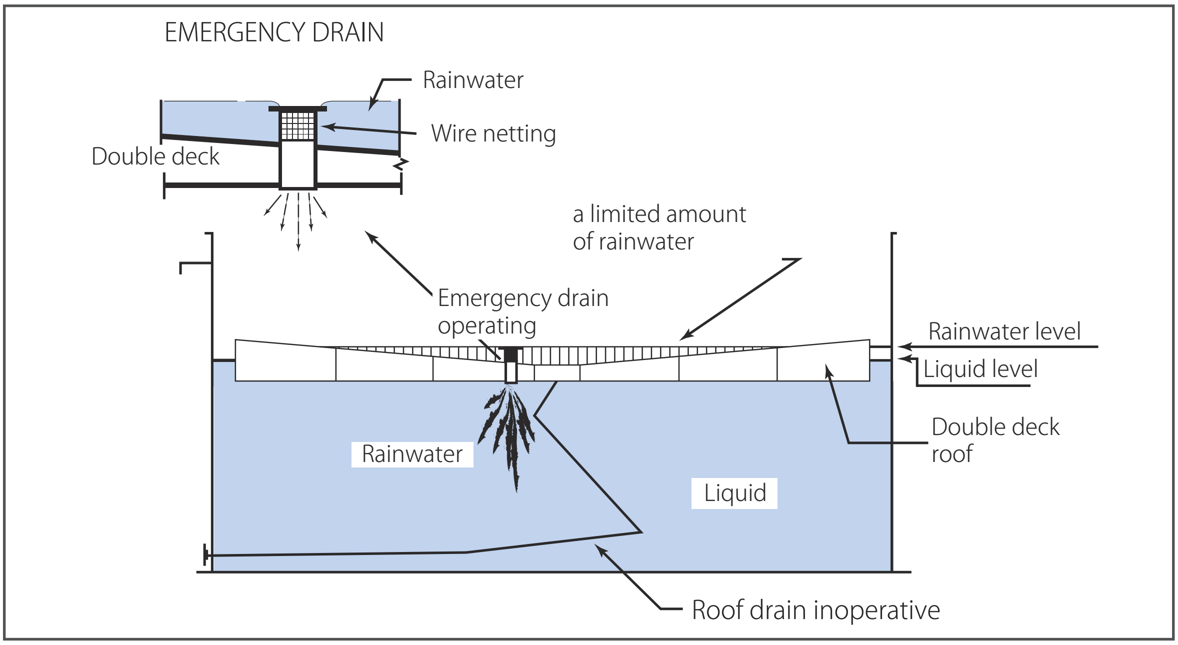

Figure 11-3 Rainwater load on the upper deck of a double-deck with drain inoperative

The design specification of double deck floating roofs requires that the roof remains afloat with any two adjacent pontoon compartments punctured and flooded: see Figure 11-4.

Note: Two adjacent compartments could well be two peripheral compartments but, depending on the type of roof design, this could be two adjacent compartments somewhere else existing in the total surface of the roof. Figure 11-4 provides two examples of what the compartment design might be: the most critical situation should be determined to assess the buoyancy capabilities of the roof. The structural integrity of the roof under the loads induced by punctured and flooded compartments in adjacent structures of the roof should also be investigated.

Double-deck roofs are generally installed in large diameter tanks (over 50m diameter). They avoid the wind problems of pontoon roof centre decks. They are also used in small diameter tanks (e.g. up to 15m diameter), since for such diameters the centre deck of a pontoon roof would be too small.

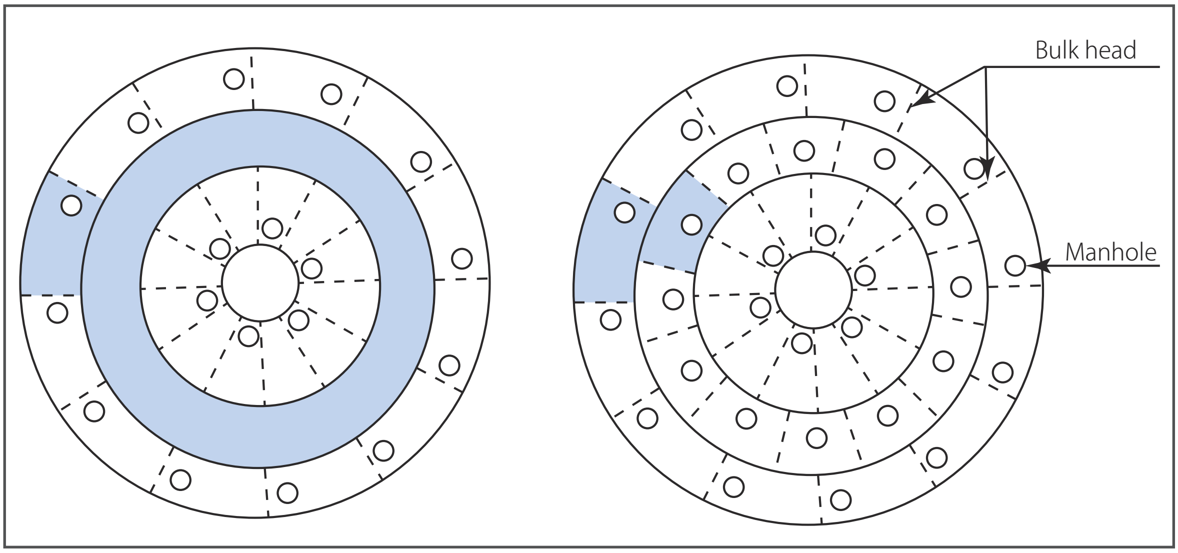

Figure 11-4 Design of a double deck roof
(capable of floating with two peripheral pontoons punctured and flooded)

Excess rainwater on the roof due to a non-functioning roof drain will be automatically discharged via the emergency drain into the tank product. The setting of the emergency drain overflow level should be checked against the draught of the deck in the product. The top level of the centre deck should always be above the level of the product in the tank.

11.1.4 Special roofs such as buoy type and radially reinforced roofs

The buoy type roof is a pontoon roof with a relatively small annular pontoon, but with a number of buoys spread over the centre deck to give additional buoyancy as shown in Figure 11-5. It is mainly used for large diameter roofs.

Figure 11-5 Example of buoy type radially reinforced roof

The radially reinforced roof is a pontoon roof with heavy stiffening beams installed radially on the centre deck. It is a stiff roof designed for larger diameter tanks only (over 50m diameter) to prevent centre deck wind problems. Some owners' specifications restrict stiffening to circumferential concentric stiffening beams. Such stiffening does not affect the normal dishing profile of the deflected deck with a centre drain.

11.2 Degradation limits

Note: The following sections have been written as a guideline to assess degradation allowances on single deck floating roofs that are exposed to the normative loads as described in Section 11.1. ***Roofs should not be operated beyond the stated degradation limits subject to these loads without further integrity assessment.***

11.2.1 General corrosion

As an example, the degradation limits as described in sub-sections a) and b) below are valid for single deck roofs satisfying the so called "30% rule" subject to the normative loads. In this case the surface of the pontoons shall be equal to or higher than 30% of the total surface of the floating roof:

$$\frac{D^2 - d^2}{D^2} \geqslant 30\%$$

Where:
d Inner rim diameter of the pontoons/centre deck diameter (m)
D Outer rim diameter of the pontoons (m)

For roofs that do not satisfy this requirement (the 30% rule) degradation limits of the floating roof components should be evaluated.

The degradation limits shown in these examples are valid for the material located near welds where joint efficiency factors (see Table 11-1) have been taken into account. These joint efficiency factors are applicable in areas of 16 × nominal thickness on both sides of the weld.

Table 11-1 Weld efficiency factors

Weld type	Efficiency factor	Remark
Butt welded	0.85 1.00	tanks built ⩽ 1968 tanks built ⩾ 1968
Single lap welded	0.35	
Double lap welded	0.50	

a) ***Centre deck***

The degradation limit with respect to general corrosion of the centre deck of a floating roof is the larger of 50% of the nominal thickness or 2.5mm:

$$t_{\text{min acc. fl. roof gen}} = 0.5t_{nom}, \text{ 2.5mm (whichever is larger)}$$

Where:

$t_{\text{min acc. fl roof gen.}}$	Minimum acceptable plate thickness of the centre deck of a floating roof (mm)
t_{nom}	Nominal as built plate thickness excluding an initial applied corrosion allowance (mm)

b) *Floating roof pontoons*

b.1 Bottom plates

The degradation limit of the bottom plates of the pontoons is the larger of 80% of the nominal thickness or 2.5mm:

$$t_{\text{min acc. pont. bottom}} = 0.8t_{nom}, \text{ or } 2.5\text{mm (whichever is larger)}$$

Where:

$t_{\text{min acc. pont. bottom}}$ Minimal acceptable thickness for the bottom plates of the pontoons (mm)

b.2 Top plates

The minimal acceptable thickness of the top plates of the pontoons is the larger of 50% of the nominal thickness or 2.5mm:

In formula:

$$t_{\text{min acc. pont. top}} = 0.5t_{nom}, 2.5\text{mm (whichever is larger)}$$

Where:

$t_{\text{min acc. pont. top}}$ Minimal acceptable thickness of the top plates of the pontoons (mm)

Note: For a, b.1 and b.2 above 2.5mm is the absolute minimum that can be allowed including any compensation for joint efficiency factors.

b.3 Rim plates

Inner and outer rim plate thicknesses are governed largely by considerations of buckling stability or the combination of membrane and bending stresses. Some calculations show that even a 9% decrease in design thickness may lead to stresses above the allowable ones, under normative loads. However, this percentage is greatly depending on the type of roof, the design thicknesses used etc. For this reason, this document cannot state a single degradation limit for the rim plates.

Note: History shows that corrosion of the rim plates is usually not the governing failure mode of floating roofs.

11.2.2 Pit corrosion

The minimal acceptable thickness of the roof plates with respect to pit corrosion is 50% of the degradation limit with respect to general corrosion of the roof plates, provided that the pits are widely scattered and that the sum of the pit diameters over a straight line of 200mm does not exceed the value of 50mm:

$$t_{\text{min acc. fxt./fl/ roof pit.}} = 50\% t_{\text{min acc. fxt./fl. roof gen.}}$$

Where:

$t_{min\ acc.\ fxt./fl.\ roof\ pit.}$ Minimal acceptable thickness of roof plates for pitting corrosion (mm)

$t_{min\ acc.\ fxt./fl.\ roof\ gen.}$ Minimal acceptable thickness of roof plates for general corrosion or localized general corrosion (mm)

11.3 Equipment on External floating roofs

Safe and reliable operation of steel external floating roofs requires that the equipment on the roof performs reliably over a significant number of years. It is therefore important that design, construction and material selection are done with reliability in mind. Malfunctioning EFR equipment will result in costly repairs as the tank will have to be taken out of service. It is recommended to perform an RCM analysis on this equipment whenever it is replaced during out of service maintenance.

11.3.1 Roof drains

There are three main types of primary roof drains:

- Steel articulated pipe drains;
- Flexible hose drains; and
- Steel pipes with flexible hose type joints.

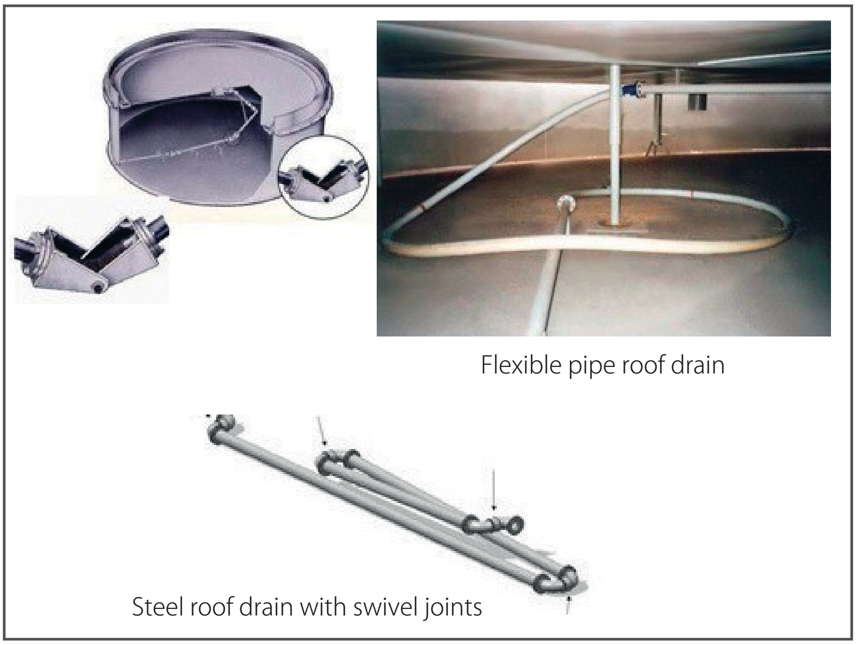

Figure 11-6 Types of primary roof drains

The types of primary roof drains are shown in Figure 11-6. Their specific features, problems etc. are discussed in Sections 11.3.1.1 to 11.3.1.5.

Roof drains should be fitted with an isolation valve at the discharge end, just outside of the tank shell. The valve is normally kept open to avoid rainwater accumulation on the roof but can be closed in the event of a leaking drain (inside the tank) to prevent loss of product. In such circumstances, it is nevertheless important that the valve be reopened if water starts to accumulate on the roof (e.g. during a heavy downpour), with special precautions taken to handle the product–water mixture. This situation should not be allowed to exist for a long period on too many tanks at the same time. Repair of the roof drain should be carried out as soon as possible. In climates where stored product temperatures can drop below 0°C, the drain should be designed to allow complete drainage to prevent bursting of the pipe by frozen stagnant water in the drain.

As illustrated in Figure 11-1, the centre deck of a singledeck pontoon roof lies below the level of the stored product at the periphery. It is therefore necessary that the drain collecting sump at the centre deck be fitted with a non-return valve (NRV) to prevent back flow of product onto the roof in the case of a leaking drain when the isolation valve would be closed. This back flow could even cause the roof to sink if loads on the deck exceed the design parameters. Furthermore, in thunderstorms, product floating on the rainwater on the roof could be ignited by lightning.

It is also recommended that drainage sumps in double-deck roofs be fitted with NRVs, particularly in climates with heavy rainfall and frequent thunderstorms. Although no part of the top deck of this type of roof lies below the level of the stored product - as is the case with single-deck floating roofs - a leaking drain (with a closed isolation valve and no sump NRV) would result in product built up in the sump. Heavy rainfall could cause this to overflow onto the roof, with an elevated fire risk as described above.

This may also be valid under a (rim) fire-fighting attempt where foam and foam/water solution may be sprayed on the roof surface at such a great extent and volume that the water flow through the drain opening may rotate at such a speed, that product from within the leaking drain pipe may be pushed upwards and flow onto the roof level. This could cause the product level to be ignited by the fire; the action the foam spraying aimed to prevent.

Occasionally, roof drains malfunction and cause an accumulation of rainwater on the roof. This can result in the floating roof to sink with severe damage to the roof as consequence. The need for correct operation, maintenance and inspection of external floating roofs cannot be over-emphasised.

The number, size and location(s) of the roof drains are determined by the diameter of the roof, the location of the tank, and the type of roof. The normal sizes of roof drains are DN 80, 100 or 150 (3, 4 or 6 inch). In all cases, water is collected in sumps in the roof. It is most important that the sumps, their drain holes or strainers, if installed, are not allowed to become blocked by debris. Accidents have been caused by blockage by scale, leaves, rags, sample bottle bungs, birds, etc. In areas with heavy rainfall, it may be necessary to install more than one roof drain for large diameter roofs.

Water sometimes forms pools and fails to drain from the area where the rolling ladder is supported on the centre deck. Drainage may be arranged from that area through an additional drainpipe to the sump under the roof.

The efficiency of a primary roof drain is at its minimum when the floating roof has landed on its supporting legs, as the static head is very low.

Failures have occurred when roofs were landed during maintenance and the roof drains were inoperative, either intentionally or by accident, or when the drainage capacity of the roof drain was inadequate in the landed position.

It should be noted that an extra drain opening is required in the floating roof when it is to be landed for a prolonged period. Normally, a plugged additional drain is installed in the centre deck, and the plug removed after landing. Experience has shown, however, that it is often impossible to remove this drain plug after several years of service. In such cases, a temporary drain opening should be made in the centre deck to prevent the possibility of overload due to rainwater accumulation.

11.3.1.1 Steel articulated primary roof drains

This is the most common type of primary roof drain. Straight lengths of steel pipe are connected together with packed swing joints, which allow movement of the drainpipe sections within fixed limits: see Figure 11-6.

Experience has shown that over long periods of service, the swing joints sometimes fail and allow stored product to leak into the drainpipe and to contaminate drain water. When this occurs, tank operation has to be modified to prevent product leakage into the sewer system or the ground around the tank. Eventually, the tank has to be taken out of service and prepared for entry to enable the roof drain joints to be repacked or replaced, and tested.

The integrity of the roof drains is an important factor in deciding the inspection interval of a tank. Careful testing of swing joints prior to service is essential to prevent premature leakage. It is important that the packing of the swing joint is suitable for the stored product. The following conditions may make the roof drain more prone to leakage:

- Single off-centre joints, since they are subject to torsional forces;
- Strong lateral movement of the liquid being stored, particularly when the roof is in a low position;
- Tank inlet at right angles to the roof drain; and/or
- The action of side entry mixers, when operating with the roof in a low position.

Evidence from evaluated roof failures showed that in some cases a swivel joint (or swing joint) had deteriorated to such an extent by wear and tear that excessive friction occurred in the swivel itself. This led to extreme horizontal forces and stresses in the sump attachment of the drain system, causing fracture in the sump and consequent failure of the roof.

Note: This failure mode cannot be inspected nor observed during normal operations of the floating roof.

11.3.1.2 Flexible hose primary roof drains

To overcome leakage problems encountered with articulated pipe drains, reinforced flexible hose drains are sometimes used (see Figure 11-6).

The top and bottom sections of flexible hose drains need to be rigid (reinforced hose or rigid pipe) in order to prevent a possible airlock at the top or water-lock at the bottom which may prevent gravity flow.

Hoses should be manufactured from materials that withstand long-term exposure to the liquids to be stored. They are generally strengthened with helical steel reinforcement to prevent kinking and collapse, which reduces the risk of mechanical damage. The hose is weighted to prevent the hose from floating, as this would form air locks and hinder drainage. The hose drain should not be used in a tank with water on the bottom that could freeze in winter, as part of the drain could be trapped in the ice. Also, rainwater freezing inside the hose may be a problem as the hose would lose its flexibility.

Figure 11-7 Examples of hose guards

Hose drains are flexible and will therefore rest on the tank bottom in an arbitrary pattern. Hose movement can be restricted to certain areas of the bottom, and guards as shown in Figure 11-7 should be installed around the location of some roof supports to prevent mechanical damage. Fatigue failures of flexible hose drains have been known to occur at highly stressed locations, e.g. the connection to the shell nozzle and when tank operation causes frequent significant movement of the drain. Such a failure may occur very suddenly and will result in serious leakage and may even cause release of the complete contents of the tank.

To prevent such a serious accident, it is sometimes recommended that the drain outlet valve is kept closed and only opened when rainwater begins to collect on the roof. This is not recommended in areas of high rainfall.

11.3.1.3 Hinged hose drains

Proprietary drain designs are sometimes proposed to overcome one or more of the problems stated in Sections 11.3.2 and 11.3.3 above. They should be less prone to leakage than the swing joints of the articulated pipe drains, and to fatigue failure of the flexible hose drains. Such designs should be checked very thoroughly to ensure that they do not introduce new problems.

A flexible hose joint in a typical, long proven design of pipe drain is shown in Figure 11-8.

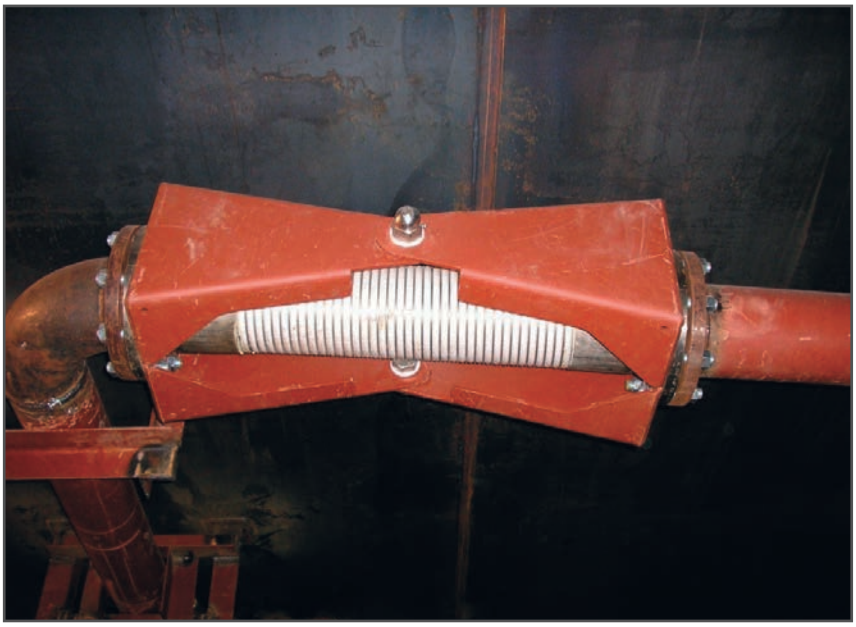

Figure 11-8 Flexible hose joint

The main advantage of this type of flexible joint in the drain piping system is the philosophy that functions are well split between elements of the joint. The side flanges, including the so called "pivot" or "pin", are designed to take up loads during operation of the floating roof (level changes of the roof and side movements of the drain piping in the tank due to high in-pumping rates of product – sometimes predicted to be more than 4m side movements), whereas the liquid lightness of the joint is ensured by the hose.

11.3.1.4 Siphon drains

Siphon drains may have been installed in some of the older tanks as the main drainage option, or as emergency drains on singledeck floating roofs. They are, however no longer used because of operational problems encountered. They do not function when insufficiently primed with water, and may not function if the specific gravity of the product is different from that of the original design specification.

11.3.1.5 Emergency roof drains

When a primary roof drain is inoperative and rainwater begins to accumulate on the floating roof, an emergency drain allows discharge directly into the tank, settling at the bottom. This water should be drawn off to prevent contamination of discharged product and to reduce the risk of internal bottom corrosion.

Figure 11-9 Typical emergency roof drain

Emergency drains should not be installed on single-deck pontoon roofs as the product level in the tank is always higher than the rainwater level on the centre deck. In this situation the product would discharge through the drain onto the roof rather than allow water to drain into the tank (see Figure 11-1).

Emergency drains are provided on the majority of double-deck roofs. The level of the product in the tank is always lower than the inlet of the emergency drain so the product stored cannot flow onto the roof (see Figure 11-9). The majority of emergency drains are simple open-ended pipes. They require little maintenance, and inspection is limited to a visual check to see that they are clear.

11.3.2 Floating roof seals

11.3.2.1 General

The opening between the outer rim of the floating roof and tank shell is often referred to as rim-space or rim-gap. All floating roofs have rim-gaps to permit smooth travel of the roof within the tank. The dimensions of the rim gap depend on the type of roof, expected settlement and design code used. Rim seals such as those shown in Figure 11-10 are used to seal this space. The functions of these seals are reducing the emission and evaporative loss from the stored product, maintaining the product purity by reducing the amount of (rain) water that can enter the tank and safety (reducing rim fires). The rim seal structure may also help to centre the roof in the tank.

It has to be noted that the design of the seal has a major impact of the fire safety of external floating roof tanks, especially in areas with a high thunderstorm risk.

