Annex I
(normative)

Undertank Leak Detection and Subgrade Protection

This annex provides a number of design options requiring decisions by the Purchaser; standard requirements; recommendations; and information that supplements the basic standard. This annex becomes a requirement only when the Purchaser specifies an option covered by this annex or specifies the entire annex.

I.1 Scope and Background

I.1.1 This Annex provides acceptable construction details for the detection of product leaks through the bottoms of aboveground storage tanks, and provides guidelines for tanks supported by grillage.

NOTE API supports a general position of installation of a Release Prevention Barrier (RPB) under new tanks during initial construction. An RPB includes steel bottoms, synthetic materials, clay liners, and all other barriers or combination of barriers placed in the bottom of or under an aboveground storage tank, which have the following functions: (a) preventing the escape of contaminated material, and (b) containing or channeling released material for leak detection.

- **I.1.2** Several acceptable construction details are provided for detection of leaks through the tank bottom and details for tanks supported by grillage (see Figures I.1 through I.11). Alternative details or methods may be used if agreed upon by the tank owner and Manufacturer, provided the details or methods satisfy the requirements of I.2.

- **I.1.3** The tank owner shall determine whether the undertank area is to be constructed for leak detection. If leak detection is required, the owner shall specify the method or methods to be employed.

I.1.4 The bottoms of aboveground storage tanks may leak as a result of product side corrosion, soil side corrosion, or a combination of both. The extent of product side corrosion can be detected using standard inspection techniques during an internal inspection, but determining the nature and extent of soil side corrosion is more difficult. Therefore, in certain services and tank locations, it may be desirable to provide for undertank monitoring of leakage through the tank bottom plates.

I.1.5 For additional information on the use of internal linings to prevent internal bottom corrosion, see API 652. Similarly, see API 651 for guidelines and requirements relating to preventing corrosion from the soil side of the bottom plate.

I.1.6 When the appropriate tank foundation design is being selected, it is important to consider the environmental and safety regulatory implications of leakage of tank contents into the containment space below the tank bottom. Specifically, the contamination of permeable material such as sand used as a floor support may constitute the generation of a hazardous waste. The treatment or disposal costs of such contaminated material must be determined.

I.1.7 The requirements for secondary containment as it relates to diked areas and impoundments are not within the scope of this Annex.

I.2 Performance Requirements

The following general requirements shall be satisfied for all leak detection systems:

a) Leaks through the tank bottom shall be detectable by observation at the tank perimeter. If a leak is detected, it shall be collected.

b) The use of electronic sensors for the detection of vapors and liquids is acceptable; however, the requirements of Item a above shall be satisfied. Any such sensor shall be fail-safe or have provision for calibration.

c) The materials of construction shall be chemically resistant to the range of products to be stored at the temperature range expected in service. Other physical properties shall be specified by the tank owner.

d) The permeability of the leak detection barrier shall not exceed 1×10^{-7} cm (4×10^{-5} mils) per second.

e) The material in contact with the subgrade shall be suitable for below-grade service or be protected against degradation.

f) The leak barrier shall be of one-piece construction, or the joints shall satisfy the leak tightness, permeability, and chemical resistance requirements for the base leak-barrier material. The Manufacturer and a complete description of the leak barrier material shall be identified to the tank owner.

g) The installation of sumps and pipes below the tank bottom is acceptable; however, the required leak detection and leak tightness shall be maintained. See Figure I.8 and Figure I.9 for typical details.

I.3 Cathodic Protection

Cathodic protection systems may be installed in conjunction with undertank leak detection systems. See API Recommended Practice 651 for guidelines on the use of cathodic protection methods.

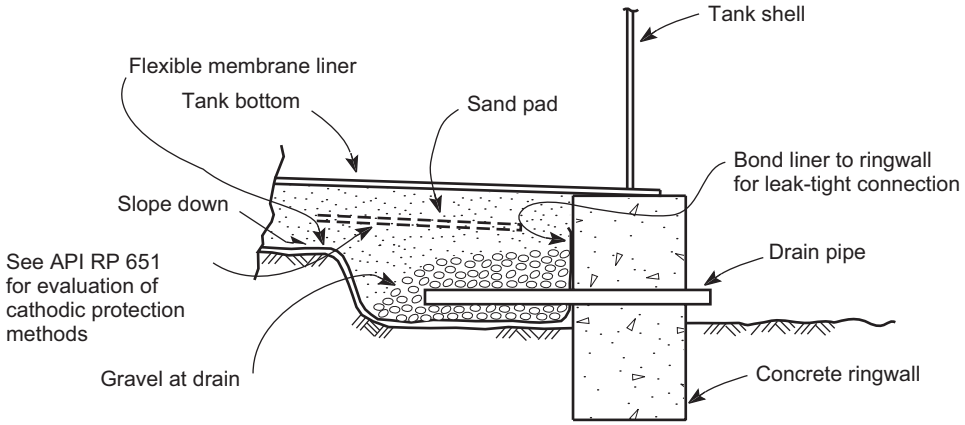


Figure I.1—Concrete Ringwall with Undertank Leak Detection at the Tank Perimeter (Typical Arrangement)

I.4 Double Steel Bottom Construction

I.4.1 If a double steel bottom is used, the details of construction shall provide for the proper support of the primary bottom and shell for all operating conditions. The design shall be evaluated to verify that the primary bottom and shell are not overstressed. The evaluation shall consider all anticipated operating conditions such as design metal temperature, maximum design temperature, fill height, hydrostatic testing, seismic conditions, and tank settlement. The evaluation is not required if the primary bottom is uniformly supported on both sides of the shell and is not structurally attached to the secondary bottom or primary bottom support.

I.4.2 For double steel bottom systems that use steel members (such as grating, structural shapes, or wire mesh) to separate the bottoms, ingress of water between the bottoms will result in local accelerated corrosion rates. If the perimeter of the bottoms is not sealed, corrosion protection of the tank bottoms shall be provided. See Figure I.4.

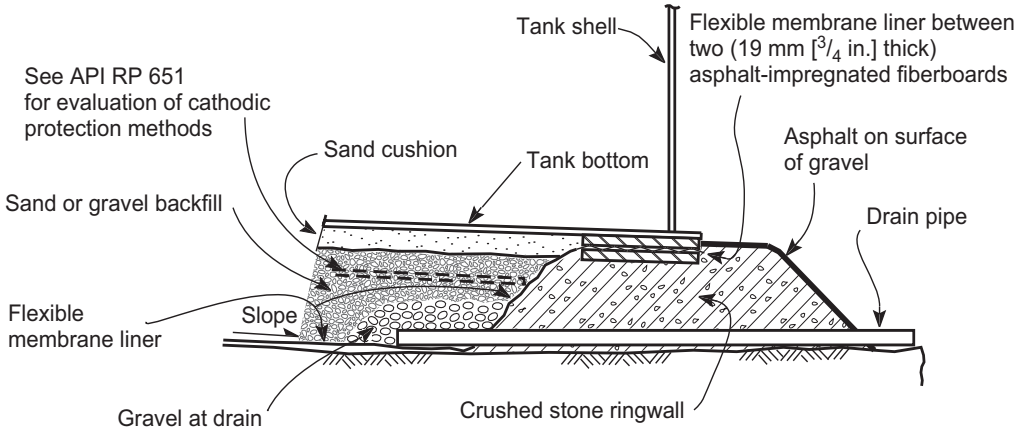


Figure I.2—Crushed Stone Ringwall with Undertank Leak Detection at the Tank Perimeter (Typical Arrangement)

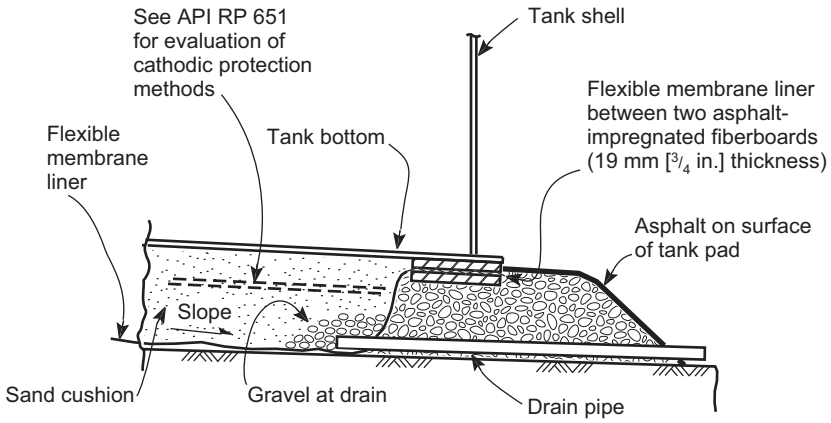


Figure I.3—Earthen Foundation with Undertank Leak Detection at the Tank Perimeter (Typical Arrangement)

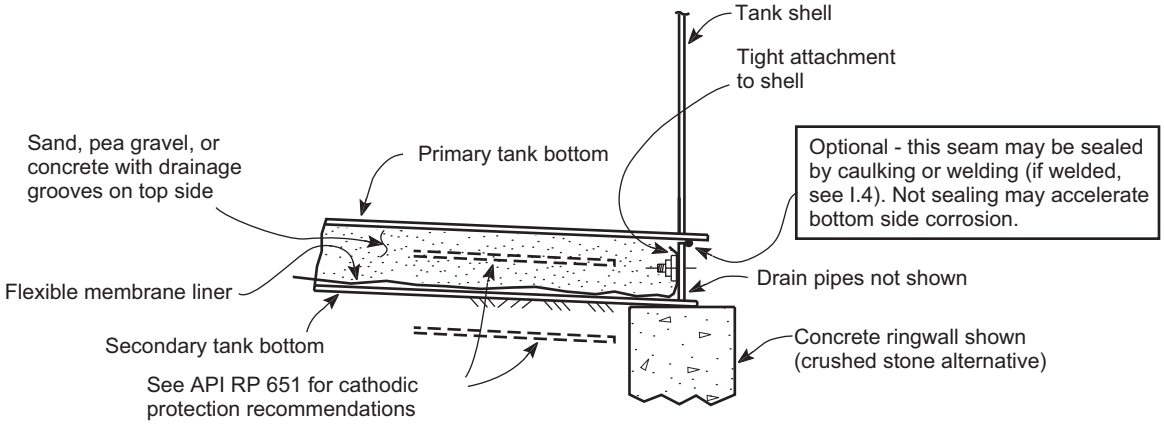


Figure I.4—Double Steel Bottom with Leak Detection at the Tank Perimeter (Typical Arrangement)

I.5 Material Requirements and Construction Details

I.5.1 The minimum thickness of flexible-membrane leak barriers shall be 800 micrometers (30 mils) for fiber-reinforced membranes and 1000 micrometers (40 mils) for unreinforced membranes. If clay liners are used, they shall be thick enough to meet the permeability requirements of I.2, Item d.

I.5.2 The leak barrier shall be protected as required to prevent damage during construction. If the foundation fill or tank pad material is likely to cause a puncture in the leak barrier, a layer of sand or fine gravel or a geotextile material shall be used as a protective cushion.

I.5.3 For a flexible-membrane liner installed over a steel bottom, all nicks, burrs, and sharp edges shall be removed or a layer of fine sand, gravel, or geotextile material shall be used to protect the liner.

I.5.4 The flexible leak barrier shall be covered by at least 100 mm (4 in.) of sand, except as otherwise shown in Figures I.1 through I.10. This dimension may have to be increased if cathodic protection is to be provided in the space between the tank bottom and the leak barrier.

- **I.5.5** If drain pipes are used around the tank perimeter, they shall be at least NPS 1 in diameter and have a minimum wall thickness of Schedule 40. The pipes may be perforated in the undertank area to improve their leak detection function. The inner ends and perforations of the drain pipes shall be protected from clogging by the use of gravel, screening, geotextiles, or another method approved by the tank owner. The drain pipes shall exit through the foundation and shall be visible to indicate any leakage. If specified by the owner, the undertank drains shall be fitted with a valve or piped to a leak detection well as shown in Figure I.10. The maximum spacing of drain pipes shall be 15 m (50 ft), with a minimum of four drain pipes per tank; however, two drain pipes may be used for tanks 6 m (20 ft) or less in diameter.

I.5.6 The need for pipe sleeves, expansion joints, or both in conjunction with drain pipes shall be evaluated.

I.5.7 The outlet of the drain pipes and collection sumps, if used, shall be protected from the ingress of water from external sources.

I.5.8 Leak detection systems that use sumps in the liner below the tank bottom shall have a drain line that extends from the sump to the tank perimeter. Consideration shall be given to installation of supplemental perimeter drains.

I.6 Testing and Inspection

I.6.1 The leak barrier, all leak-barrier penetrations, attachments of the leak barrier to the foundation ringwall, and other appurtenances shall be visually inspected for proper construction in accordance with applicable specifications.

- The shop and field seams of flexible-membrane liners shall pass a vacuum-box test. All leaks shall be repaired and retested. Alternative testing methods may be used with the tank owner's approval.
- **I.6.2** Proof testing of samples of the flexible-membrane liner seam shall be performed to verify the seam strength and flexibility and the adequacy of the bonding. The procedure (including testing methods) used to bond or weld the liner seams shall be submitted to the owner for review and shall specify all critical parameters, such as temperature, speed, surface preparation, and curing time, required to achieve liquid-tight seams. The required strength and flexibility of the liner seams shall be agreed upon by the tank owner and Manufacturer. The seam samples shall be produced at the beginning of each shift for each operator and welding machine.

- **I.6.3** All liner penetrations, attachments of the liner to the foundation ringwall, and other appurtenances shall be demonstrated to be leak tight. This may be demonstrated by a mock-up test, prior experience, or other methods acceptable to the owner.

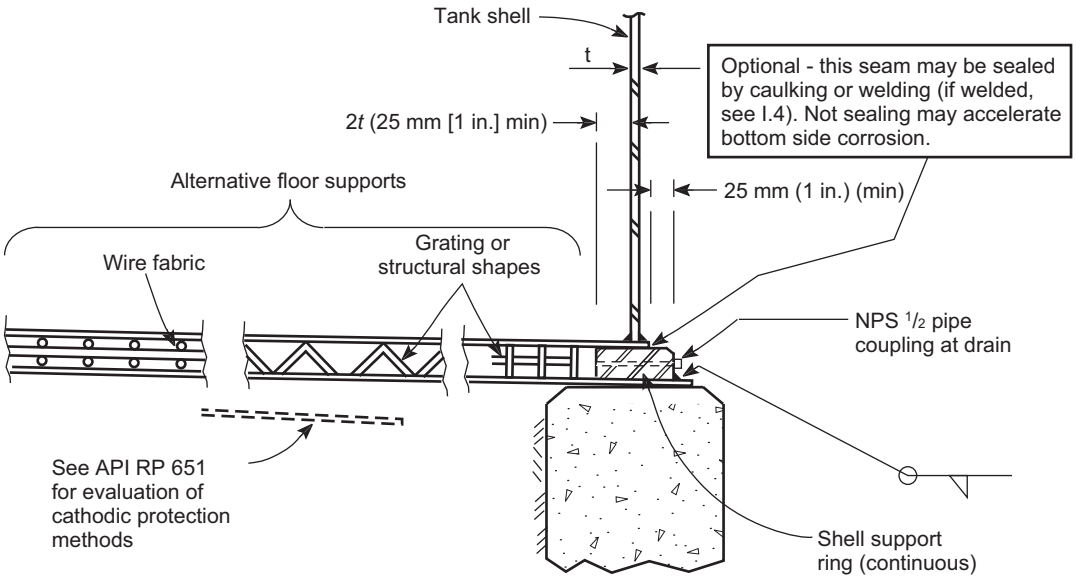


Figure I.5—Double Steel Bottom with Leak Detection at the Tank Perimeter (Typical Arrangement)

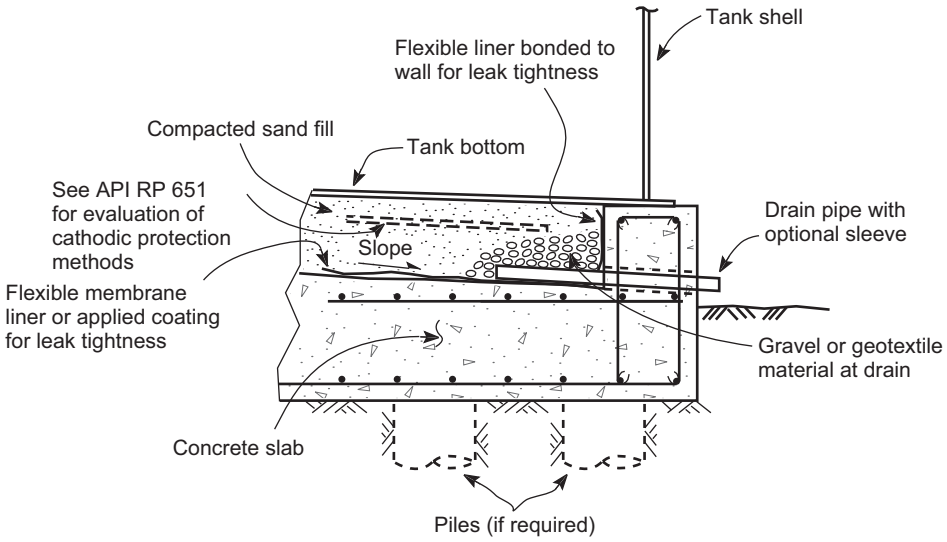


Figure I.6—Reinforced Concrete Slab with Leak Detection at the Perimeter (Typical Arrangement)

I.7 Tanks Supported by Grillage

- **I.7.1** Tanks designed and constructed in accordance with API Standard 650 that have a maximum nominal shell thickness of 13 mm (1/2 in.), including any customer specified corrosion allowance, and maximum design temperature not exceeding 93 °C (200 °F) may be supported by steel or concrete grillage. By agreement between the Purchaser and the Manufacturer, these rules may be applied to tanks with shell thickness greater than 13 mm (1/2 in.). These rules apply to single steel butt-welded bottoms supported by grillage members.

I.7.2 The thickness and design metal temperature of the bottom plate shall be in accordance with Figure 4.1.

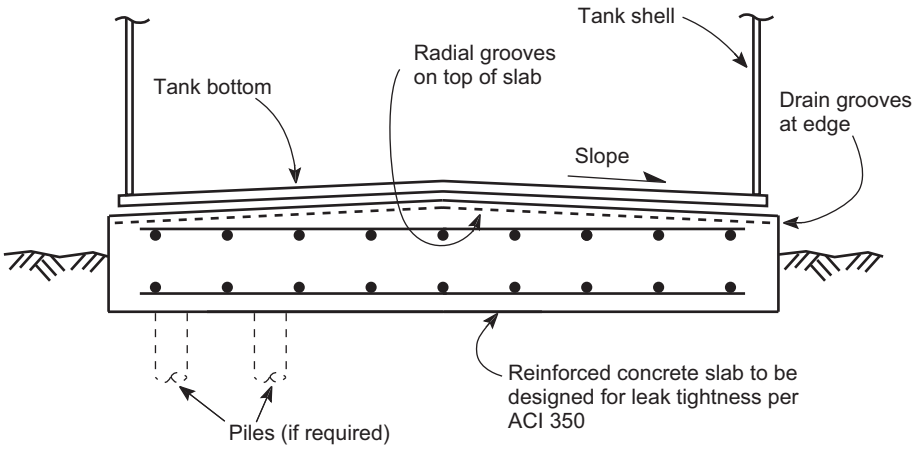


Figure I.7—Reinforced Concrete Slab

I.7.3 The maximum spacing between adjacent or radial grillage members and the bottom plate thickness shall satisfy the requirements of I.7.3.1 and I.7.3.2.

I.7.3.1 The maximum spacing between adjacent or radial grillage members shall not exceed:

$$b = \left[\frac{1.5F_y(t_g - CA)^2}{p}\right]^{0.5} \quad \text{(I.7.3.1-1)}$$

I.7.3.2 The required nominal thickness of the bottom plate supported on grillage shall not be less than that determined by the following equation:

$$t_g = \left[\frac{b^2(p)}{1.5F_y}\right]^{0.5} + CA \quad \text{(I.7.3.2-1)}$$

where

b is the maximum allowable spacing (center-to-center) between adjacent or radial grillage members, in mm (in.);

F_y is the specified minimum yield strength of bottom plate material, in MPa (psi);

t_g is the nominal thickness (including any corrosion allowance) of the bottom plate supported on grillage, in mm (in.);

CA is the corrosion allowance to be added to the bottom plate, in mm (in.). The Purchaser shall specify the corrosion allowance;

p is the uniform pressure (including the weight of the bottom plate) acting on the bottom resulting from the greater of the weight of the product plus any internal pressure, or the weight of the hydrostatic test water, in MPa (psi).

I.7.3.3 The maximum calculated deflection of the bottom plate at mid-span shall not exceed $(t_g - CA) / 2$:

$$d = \frac{0.0284pb^4}{E_s(t_g - CA)^3} \leq (t_g - CA) / 2 \qquad \text{(I.7.3.3-1)}$$

where

d is the maximum calculated deflection of the bottom plate at mid-span, in mm (in.);

E_S is the modulus of elasticity of the bottom plate material, in MPa (psi).

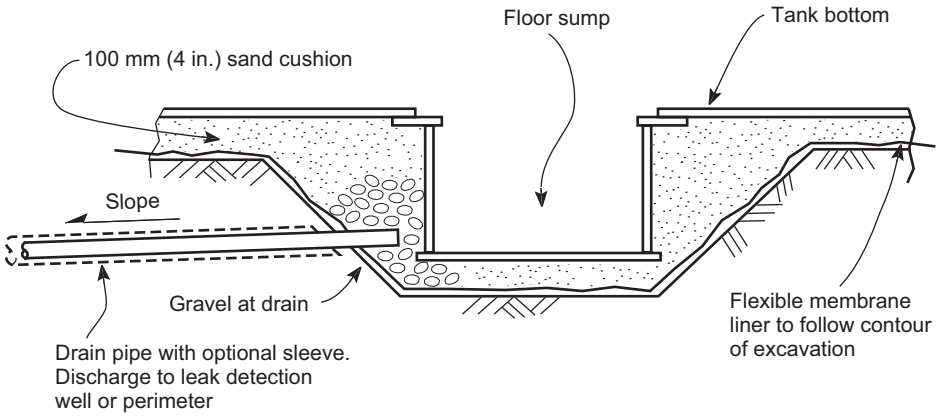


Figure I.8—Typical Drawoff Sump

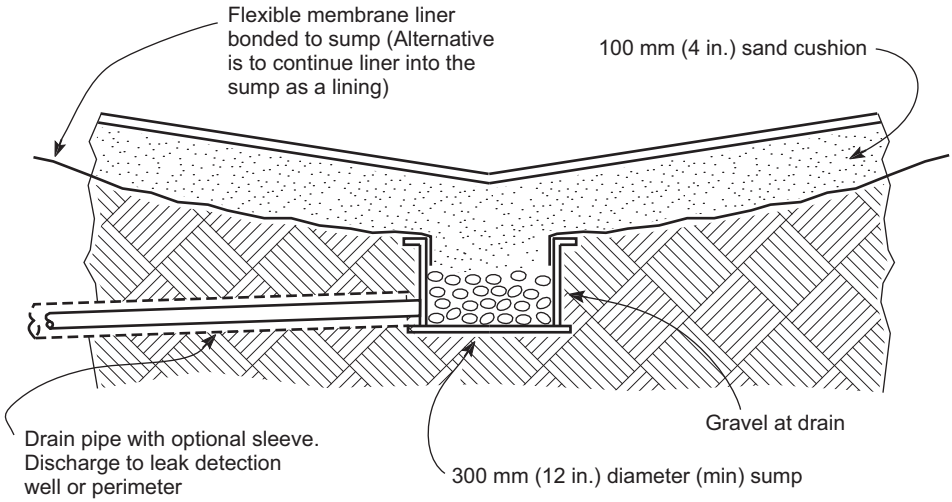
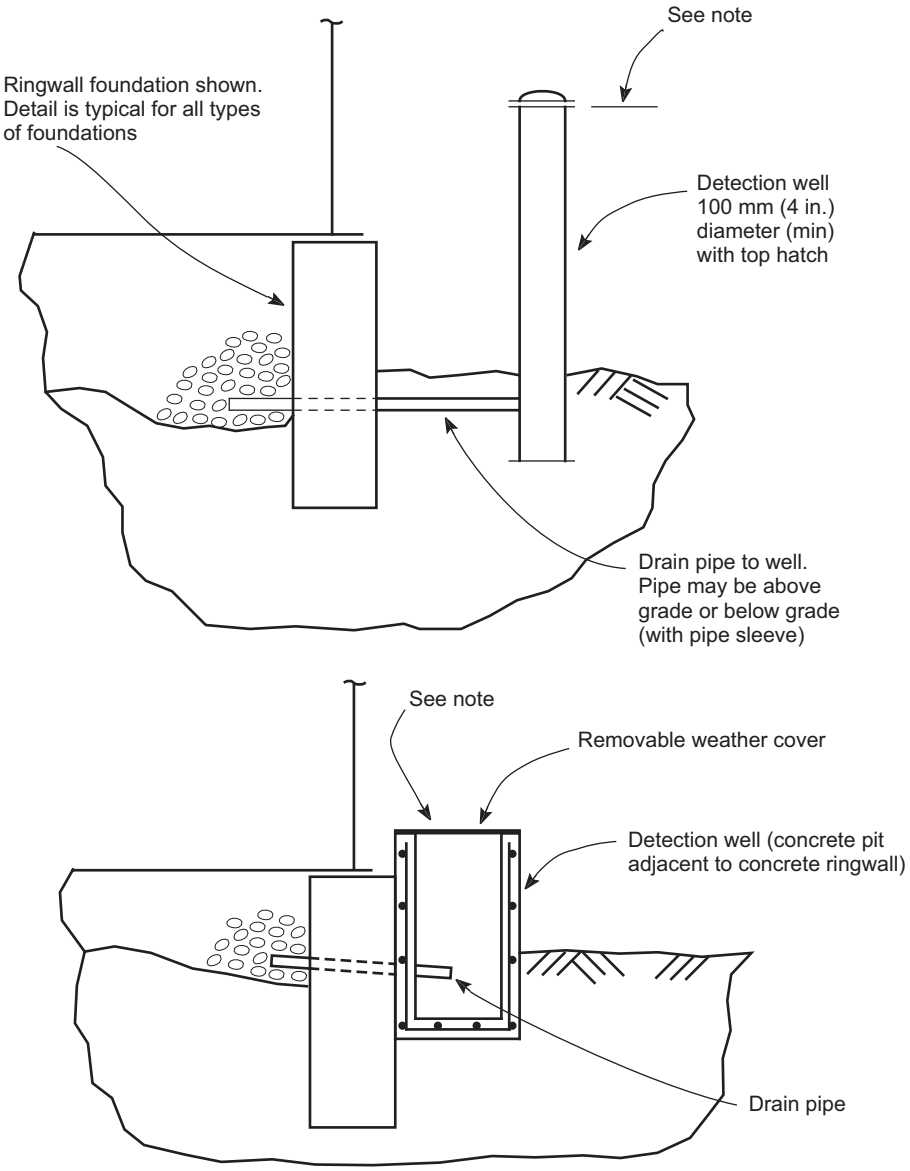


Figure I.9—Center Sump for Downward-Sloped Bottom

I.7.4 The bottom plates shall be jointed together by butt-welds having complete penetration and complete fusion. Joints shall be visually examined prior to welding to ensure the weld gap and fit-up will allow complete penetration. Each weld pass shall be visually examined. The alignment and spacing of grillage members shall be such that the joints between bottom plates are located approximately above the center of the grillage members to the greatest



Note: Top of well shall be above maximum high water level within dike.

Figure I.10—Typical Leak Detection Wells

extent practical. Grillage members shall be arranged to minimize the length of unsupported tank shell spanning between grillage members.

I.7.5 Grillage members shall be symmetrical about their vertical centerline. Steel grillage members shall be designed to prevent web crippling and web buckling as specified in Chapter K of the AISC, *Manual of Steel Construction*. Concrete grillage members may also be used.

• **I.7.6** The Purchaser shall specify the corrosion allowance to be added to steel grillage members. If a corrosion allowance is required, the manner of application (added to webs only, added to webs and flanges, added to one surface, added to all surfaces, and so forth) shall also be specified.

I.7.7 For tanks designed to withstand wind or seismic loads, provisions shall be made to prevent sliding, distortion, and overturning of the grillage members. Lateral bracing between the top and bottom flanges of adjacent steel

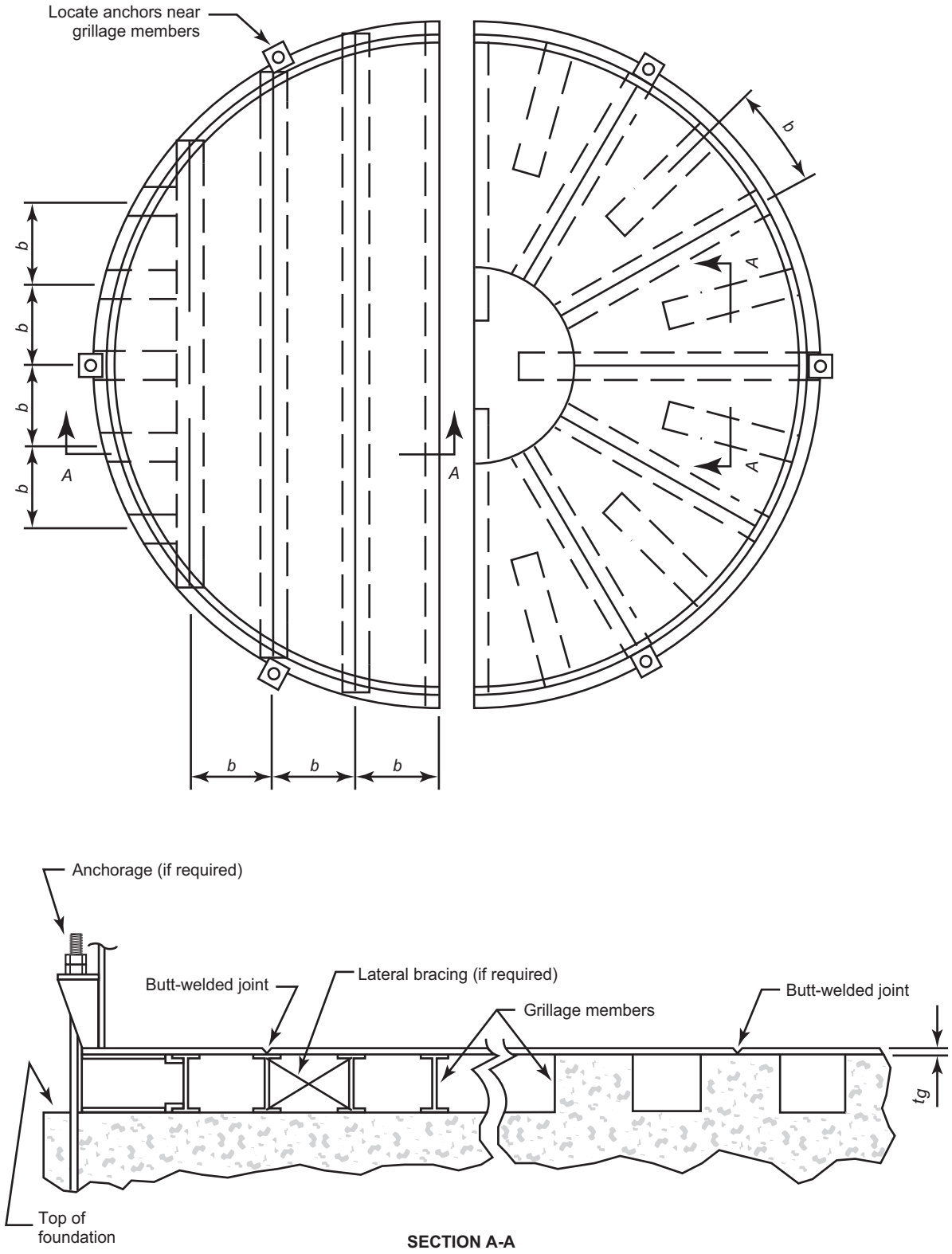


Figure I.11—Tanks Supported by Grillage Members (General Arrangement)

grillage members may be required to prevent distortion and overturning. The lateral bracing and connections shall be designed to transfer the specified lateral loads. If friction forces between the grillage members and the foundation are not adequate to transfer the specified later load, the grillage members shall be mechanically anchored to the foundation.

I.7.8 The tank shall be mechanically anchored to resist uplift forces (in excess of the corroded dead load) due to pressure and wind or seismic overturning. Anchors shall be located near the intersection of the tank shell and a grillage member, or near an additional stiffening member.

I.7.9 The tank shell shall be designed to prevent local buckling at the grillage members and consideration shall be given to shell distortion when the spacing of the grillage members is determined.

I.7.10 The bottom plate and grillage members directly beneath roof support columns and other items supported by the bottom shall be designed for the loads imposed. Additional support members are to be furnished if required to adequately support the bottom.

I.7.11 If flush-type cleanouts or flush-type shell connections are furnished, additional support members shall be provided to adequately support the bottom-reinforcing and bottom-transition plates. As a minimum, the additional support members shall consist of a circumferential member (minimum length and location according to Method A of Figure 5.12) and radial support members. The radial support members shall extend from the circumferential member to the inner edge of the bottom reinforcing (for flush-type cleanouts) or bottom-transition plate (for flush-type shell connections). The circumferential spacing of the radial support members shall not exceed 300 mm (12 in.).

I.7.12 For tanks located in a corrosive environment, and where atmospheric corrosion due to wet/dry cycles may occur, consideration shall be given to protecting the soil side of the bottom plates, grillage members, and in particular, the contact surface between the bottom plates and grillage members by utilizing protective coatings or by adding a corrosion allowance to these members.

I.8 Typical Installations

Although it is not the intent of this Annex to provide detailed designs for the construction of undertank leak detection systems and tanks supported by grillage, Figures I.1 through I.11 illustrate the general use and application of the recommendations presented in this Annex.