A.4.2 The nominal thickness of shell plates (including shell extensions for floating roofs) shall not be less than that listed in 3.6.1.1. The nominal thickness of shell plates refers to the tank shell as constructed. The nominal thicknesses given in 3.6.1.1 are based on erection requirements.

A.5 Tank Joints

A.5.1 Vertical and horizontal joints in the shell, bottom joints, shell-to-bottom joints, wind-girder joints, and roof and top-angle joints shall conform to 3.1.5.

A.5.2 The requirements of 3.7.3 for the spacing of welds do not apply except for the requirement that the spacing between the toes of welds around a connection shall not be less than $2^1/_2$ times the shell thickness at the connection.

A.5.3 When radiographic inspection is required (joint efficiency = 0.85), the spot radiographs of vertical joints shall conform to 6.1.2.2, Item a, excluding the 10 mm ($^3/_8$-in.) shell-thickness limitation in Item a and excluding the additional random spot radiograph required by Item a. The spot radiographs of horizontal joints shall conform to 6.1.2.3.

● A.6 Intermediate Wind Girders

Calculations for and installation of intermediate wind girders are not required unless specified by the purchaser.

A.7 Shell Manholes and Nozzles

A.7.1 Except for other designs and shapes permitted by 3.7.1.2, shell manholes shall conform to 3.7.5, Figures 3-4A and 3-4B, and Tables 3-3 through 3-7.

A.7.2 Shell nozzles and flanges shall conform to 3.7.6; Figures 3-4B, 3-5, and 3-7; and Tables 3-8 through 3-10.

A.7.3 The radiographic requirements of 3.7.3.4 do not apply.

A.8 Flush-Type Cleanout Fittings

A.8.1 The details and dimensions of flush-type cleanout fittings shall conform to 3.7.7, Figures 3-9 and 3-10, and Tables 3-11 through 3-13; however, the increased shell-plate thickness given in 3.7.7.5 is not required unless needed to satisfy the minimum requirements of 3.7.7.4.

● **A.8.2** The provisions for stress relief specified in 3.7.4 and 3.7.7.3 are not required unless they are specified by the purchaser or unless any plate in the unit has a thickness greater than 16 mm ($^5/_8$ in.).

A.9 Flush-Type Shell Connections

The details and dimensions of flush-type shell connections shall conform to 3.7.8, Figure 3-11, and Table 3-14.

A.10 Flush-Type Bolted Door Sheets

A.10.1 Flush-type bolted door sheets shall conform to Figure A-1 and Table A-5.

A.10.2 Bolted door sheets shall be based on the specific design requirements in A.10.2.1 through A.10.2.7.

A.10.2.1 The minimum net cross-sectional area of the door plate, excluding the tapered ends, shall not be less than the product of the shell-plate thickness and the vertical height of the cutout in the shell plus twice the diameter of the bolt hole:

$$t_D\,(h_D - N_1 d) = t_s\,(h_c + 2d)$$

where

t_D = thickness of the door plate, in mm (in.),

h_D = height of the door plate, mm (in.),

N_1 = number of bolts in the first row of bolts next to the shell cutout,

d = diameter of bolts and bolt holes, in mm (in.),

t_s = thickness of the shell plate, in mm (in.),

h_c = height of the shell cutout, in mm (in.).

A.10.2.2 The shear stress in the cross-section of the bolts shall not exceed 110 MPa (16,000 lbf/in.^{2}).

A.10.2.3 The bearing stress on the bolts and bolt holes shall not exceed 220 MPa (32,000 lbf/in.^{2}), and the fit of the turned bolt in the reamed hole shall conform to the standards of AISC.

A.10.2.4 The shear strength of the bolted door sheet connection shall be at least 90% of the design tensile strength of the undisturbed shell plate as illustrated in the equations below. For shear loading on a flush-type door sheet:

In SI units:

$$(N)(a)(110) = t_s(h_c + 2.5d + f)(145)(0.9)$$

For shear loading on a raised-type door sheet:

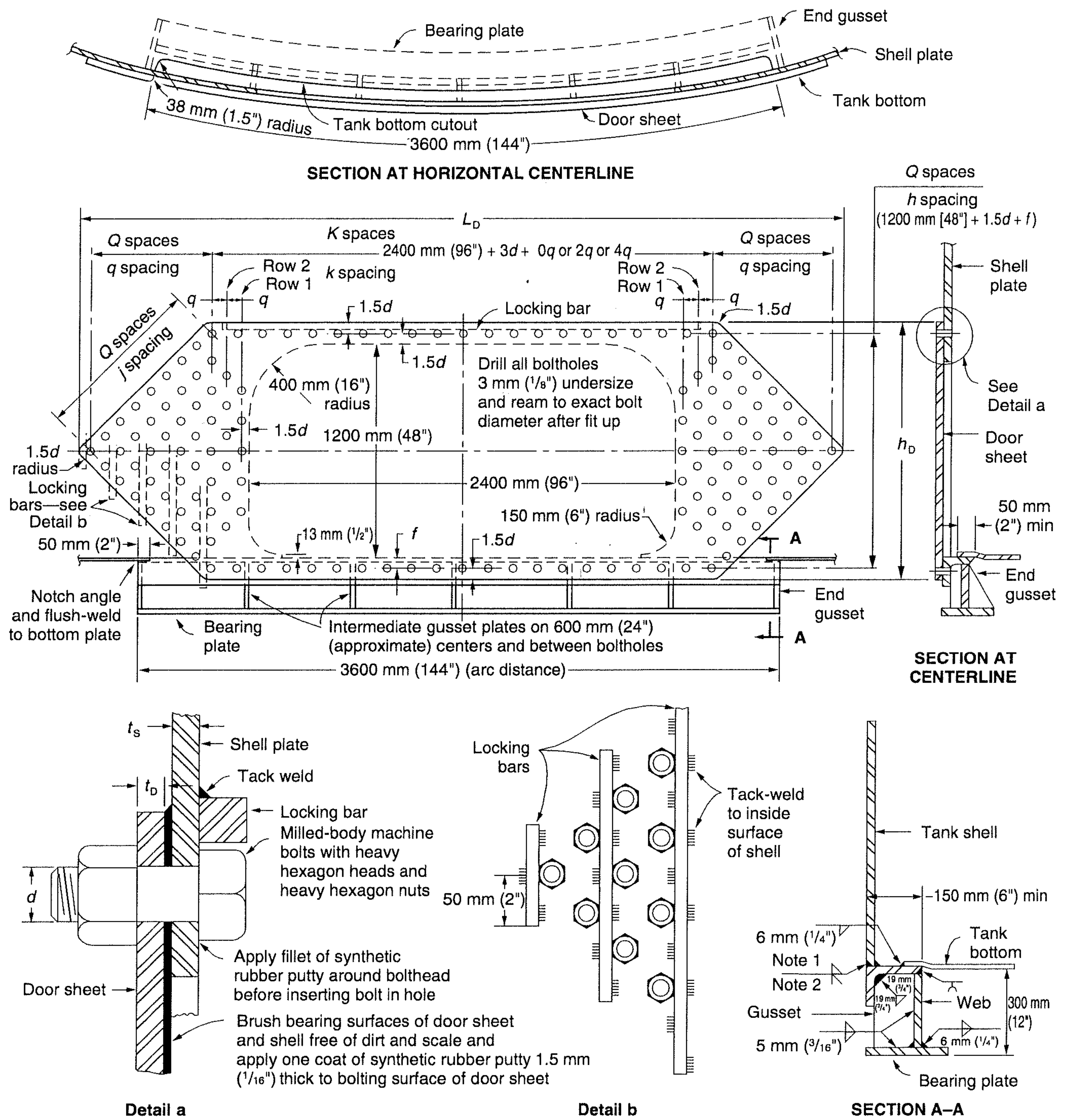
$$(N)(a)(110) = t_s(h_c + 4d)(145)(0.9)$$

where

N = number of bolts required in each end section of door plate,

a = cross-sectional area of the bolts, in mm^2,

f = distance from the bottom of the shell cutout to the centerline of the bottom row of bolts, in mm.



Notes:

1. This weld shall be the same size as the size specified for the fillet weld attaching the shell to the tank bottom.
2. This weld should be the same size as the size specified for the fillet weld attaching the shell to the tank bottom. After welding, the weld shall be ground smooth to clear the door plate.

Figure A-1—Flush-Type Bolted Door Sheet (See Table A-5)

Table A-5—Flush-Type Bolted Door Sheets (See Figure A-1)

(All dimensions in mm)

Column 1	Column 2	Column 3	Column 4	Column 5
Shell Thickness t_s	Q	q	h	j
6	7	51	185.0	105.6
8	8	51	161.9	95.7
10	8	51	161.9	95.7
11	8	62	162.6	102.3
13	8	62	162.6	102.3

Column 6	Column 7	Column 8	Column 9	Column 10
K	k	t_D	h_D	f
36	71.2	11	1355	65
30	82.0	11	1355	65
30	88.8	11	1355	65
24	107.9	13	1364	65
22	123.4	14	1364	65

Column 11	Column 12	Column 13	Column 14	Column 15
	Number of Bolts			Bolt Diameter
L_D	Row 1	Row 2	Total	d
3336	0	7	156	20
3336	0	0	146	20
3540	3	6	164	20
3648	0	2	138	22
3772	3	6	148	22

Column 16	Column 17	Column 18	Column 19	Column 20
Bolt Length	Length of Bolt Thread	Square Locking Bar	Angle	Web
50	35	16	152 × 102 × 9.5	6 × 290
50	35	16	152 × 102 × 9.5	6 × 290
50	35	16	152 × 102 × 9.5	6 × 290
55	35	20	152 × 102 × 12.7	10 × 285
65	40	20	152 × 102 × 12.7	10 × 285

Column 21	Column 22	Column 23
Intermediate Gusset	End Gusset	Bearing Plate
6 × 125 × 290	6 × 200 × 290	6 × 225
6 × 125 × 290	6 × 200 × 290	6 × 225
6 × 125 × 290	6 × 200 × 290	6 × 225
10 × 125 × 285	10 × 200 × 285	10 × 225
10 × 125 × 285	10 × 200 × 285	10 × 225

(All dimensions in inches)

Column 1	Column 2	Column 3	Column 4	Column 5
Shell Thickness t_s	Q	q	h	j
1/4	7	1 15/16	7.375	4.165
5/16	8	1 15/16	6.453	3.766
3/8	8	1 15/16	6.453	3.766
7/16	8	2 1/4	6.477	3.945
1/2	8	2 1/4	6.477	3.945

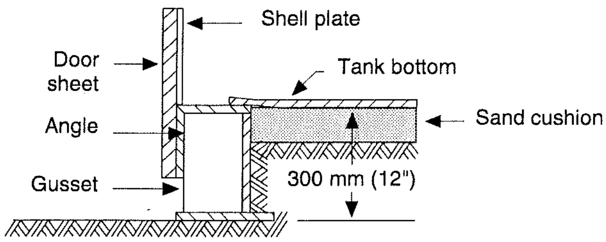
Column 6	Column 7	Column 8	Column 9	Column 10
K	k	t_D	h_D	f
36	2.837	7/16	53 7/8	2 1/2
30	3.275	7/16	53 7/8	2 1/2
30	3.533	7/16	53 7/8	2 1/2
24	4.297	1/2	54 7/16	2 1/2
22	4.892	9/16	54 7/16	2 1/2

Column 11	Column 12	Column 13	Column 14	Column 15
	Number of Bolts			Bolt Diameter
L_D	Row 1	Row 2	Total	d
131 1/2	—	7	156	3/4
131 1/2	—	—	146	3/4
139 1/4	3	6	164	3/4
141 3/4	—	2	138	7/8
146 1/4	3	6	148	7/8

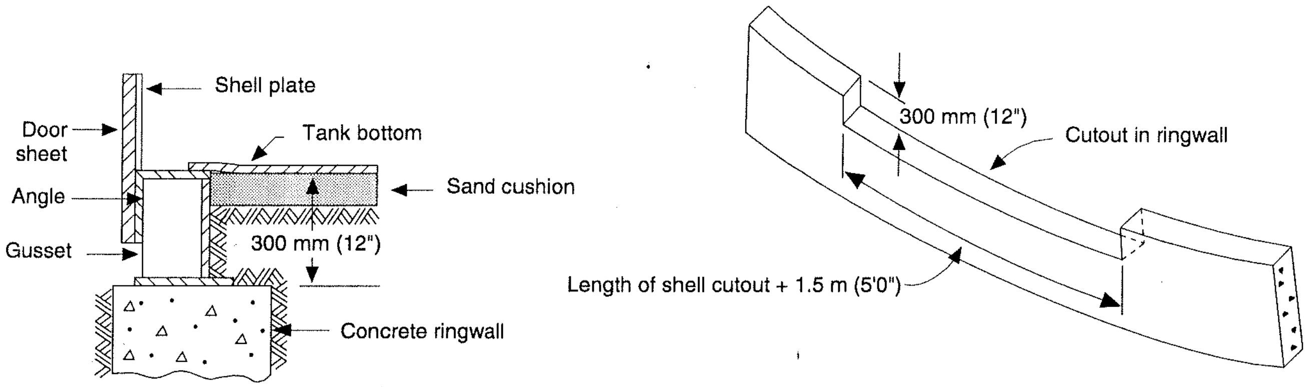
Column 16	Column 17	Column 18	Column 19	Column 20
Bolt Length	Length of Bolt Thread	Square Locking Bar	Angle	Web
2	1 1/8	5/8	6 × 4 × 3/8	1/4 × 11 5/8
2	1 1/16	5/8	6 × 4 × 3/8	1/4 × 11 5/8
2	1	5/8	6 × 4 × 3/8	1/4 × 11 5/8
2 1/4	1 1/8	3/4	6 × 4 × 1/2	3/8 × 11 3/8
2 1/2	1 1/4	3/4	6 × 4 × 1/2	3/8 × 11 3/8

Column 21	Column 22	Column 23
Intermediate Gusset	End Gusset	Bearing Plate
1/4 × 5 × 11 5/8	1/4 × 8 × 11 5/8	1/4 × 9
1/4 × 5 × 11 5/8	1/4 × 8 × 11 5/8	1/4 × 9
1/4 × 5 × 11 5/8	1/4 × 8 × 11 5/8	1/4 × 9
3/8 × 5 × 11 3/8	3/8 × 8 × 11 3/8	3/8 × 9
3/8 × 5 × 11 3/8	3/8 × 8 × 11 3/8	3/8 × 9

Note: Washers shall be used on both sides of the plate for shell thicknesses of 16 mm (5/8 in.) or less.



METHOD A—TANK RESTING ON EARTH GRADE, WITH OR WITHOUT RETAINING WALL



METHOD B—TANK RESTING ON CONCRETE RINGWALL

Note: Before the bottom plate is attached to the angle, (a) a sand cushion shall be placed flush with the top of the angle, and (b) the earth fill and sand cushion shall be thoroughly compacted.

Figure A-2—Supports for Flush-Type Bolted Door Sheet

In US Customary units:

$$(N)(a)(16{,}000) = t_s(h_c + 2.5d + f)(21{,}000)(0.90)$$

For shear loading on a raised-type door sheet:

$$(N)(a)(16{,}000) = t_s(h_c + 4d)(21{,}000)(0.90)$$

where

N = number of bolts required in each end section of door plate,

a = cross-sectional area of the bolts (in.^{2}),

f = distance from the bottom of the shell cutout to the centerline of the bottom row of bolts (in.).

A.10.2.5 The distance between centers of bolt holes shall not be less than three times the bolt diameter, and the spacing of bolt holes at the sealing edge of the plate shall not exceed seven times the sum of the minimum door-sheet thickness plus the nominal bolt diameter plus the washer thickness (if washers are used).

A.10.2.6 The tensile stress in the net section of the door plate at the first row of bolt holes next to the shell-plate cutout shall not exceed 145 MPa (21,000 lbf/in.^{2}), and at the subsequent rows, the tensile stress shall not exceed 145 MPa (21,000 lbf/in.^{2}), after allowance is made for the total shearing value or bearing value (whichever is less) of the bolts in the preceding row or rows.

A.10.2.7 The following provisions apply to flush-type bolted door sheets:

a. The girder shall be designed to withstand the bending moment that would result if the ends of the girder were on hard ground and the center was unsupported.

b. The load on the girder shall be equal to the weight of a column of water with the following dimensions: 1) 0.03 times the tank radius, in m (ft); 2) the width of the shell cutout, in m (ft), plus 2; and 3) the tank height, in m (ft).

c. The design length of the girder shall be equal to the width of the shell cutout, in ft, plus 2.

Note: When, because of wear, the difference in the diameters of the bolts and bolt holes is approximately 0.5 mm (0.020 in.), it is recommended that the holes be rereamed and fitted with oversize milled-body bolts; however, the holes shall not be reamed so much that the efficiency of the bolted connection becomes less than 0.85. This point is reached when the bolt-hole diameters become 6 mm ($^1/_4$ in.) larger than the bolt diameters specified in Tables A-5 and A-6.

A.10.3 When a flush-type bolted door sheet is installed on a tank that is resting on an earth grade with or without a concrete retaining wall and without a concrete or masonry wall under the tank shell, provision shall be made to support the fitting and retain the grade as shown in Figure A-2, Method A.

A.10.4 When a flush-type bolted door sheet is installed on a tank resting on a ringwall, a cutout with the dimensions shown in Figure A-2, Method B, shall be provided.

A.10.5 Openings larger than NPS 2 nominal pipe size in flush-type bolted door sheets shall be reinforced in accordance with 3.7.2, and the reinforcement shall replace the cutout area of the door plate.

A.11 Raised-Type Bolted Door Sheets

Raised-type bolted door sheets shall conform to Figure A-3 and Table A-6.

Table A-6—Raised-Type Bolted Door Sheets (See Figure A-3)

(All dimensions in mm)

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Shell Thickness t_s	Q	q	h	j	K
6	7	51	180	103.4	36
8	7	51	180	103.4	30
10	8	51	157.5	93.8	30
11	8	62	159	100.8	24
13	8	62	159	100.8	22

Column 7	Column 8	Column 9	Column 10	Column 11	Column 12
				Number of Bolts	
k	t_D	h_D	L_D	Row 1	Row 2
71.2	11	1320	3336	0	5
85.4	11	1320	3336	0	7
85.4	11	1320	3438	0	8
103	13	1332	3524	0	0
118	14	1332	3524	0	6

Column 13	Column 14	Column 15	Column 16	Column 17
Number of Bolts Total	Bolt Diameter[d]	Bolt Length	Length of Bolt Thread	Square Locking Bar
152	20	50	29	16
144	20	50	27	16
164	20	50	25	16
136	22	55	30	20
144	22	65	32	20

(All dimensions in inches)

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Shell Thickness t_s	Q	q	h	j	K
$\frac{1}{4}$	7	$1\frac{15}{16}$	7.179	4.080	36
$\frac{5}{16}$	7	$1\frac{15}{16}$	7.179	4.080	30
$\frac{3}{8}$	8	$1\frac{15}{16}$	6.281	3.691	30
$\frac{7}{16}$	8	$2\frac{1}{4}$	6.328	3.883	24
$\frac{1}{2}$	8	$2\frac{1}{4}$	6.328	3.883	22

Column 7	Column 8	Column 9	Column 10	Column 11	Column 12
				Number of Bolts	
k	t_D	h_D	L_D	Row 1	Row 2
2.837	$\frac{7}{16}$	$52\frac{1}{2}$	$131\frac{1}{2}$	—	5
3.404	$\frac{7}{16}$	$52\frac{1}{2}$	$131\frac{1}{2}$	—	7
3.404	$\frac{7}{16}$	$52\frac{1}{2}$	$135\frac{3}{8}$	—	8
4.109	$\frac{1}{2}$	$53\frac{1}{4}$	$137\frac{1}{4}$	—	—
4.688	$\frac{9}{16}$	$53\frac{1}{4}$	$141\frac{3}{4}$	—	6

Column 13	Column 14	Column 15	Column 16	Column 17
Number of Bolts Total	Bolt Diameter[d]	Bolt Length	Length of Bolt Thread	Square Locking Bar
152	$\frac{3}{4}$	2	$1\frac{1}{8}$	$\frac{5}{8}$
144	$\frac{3}{4}$	2	$1\frac{1}{16}$	$\frac{5}{8}$
164	$\frac{3}{4}$	2	1	$\frac{5}{8}$
136	$\frac{7}{8}$	$2\frac{1}{4}$	$1\frac{1}{8}$	$\frac{3}{4}$
144	$\frac{7}{8}$	$2\frac{1}{2}$	$1\frac{1}{4}$	$\frac{3}{4}$

Note: Washers shall be used on both sides of the plate for shell thicknesses of 16 mm ($\frac{5}{8}$ in.) or less.

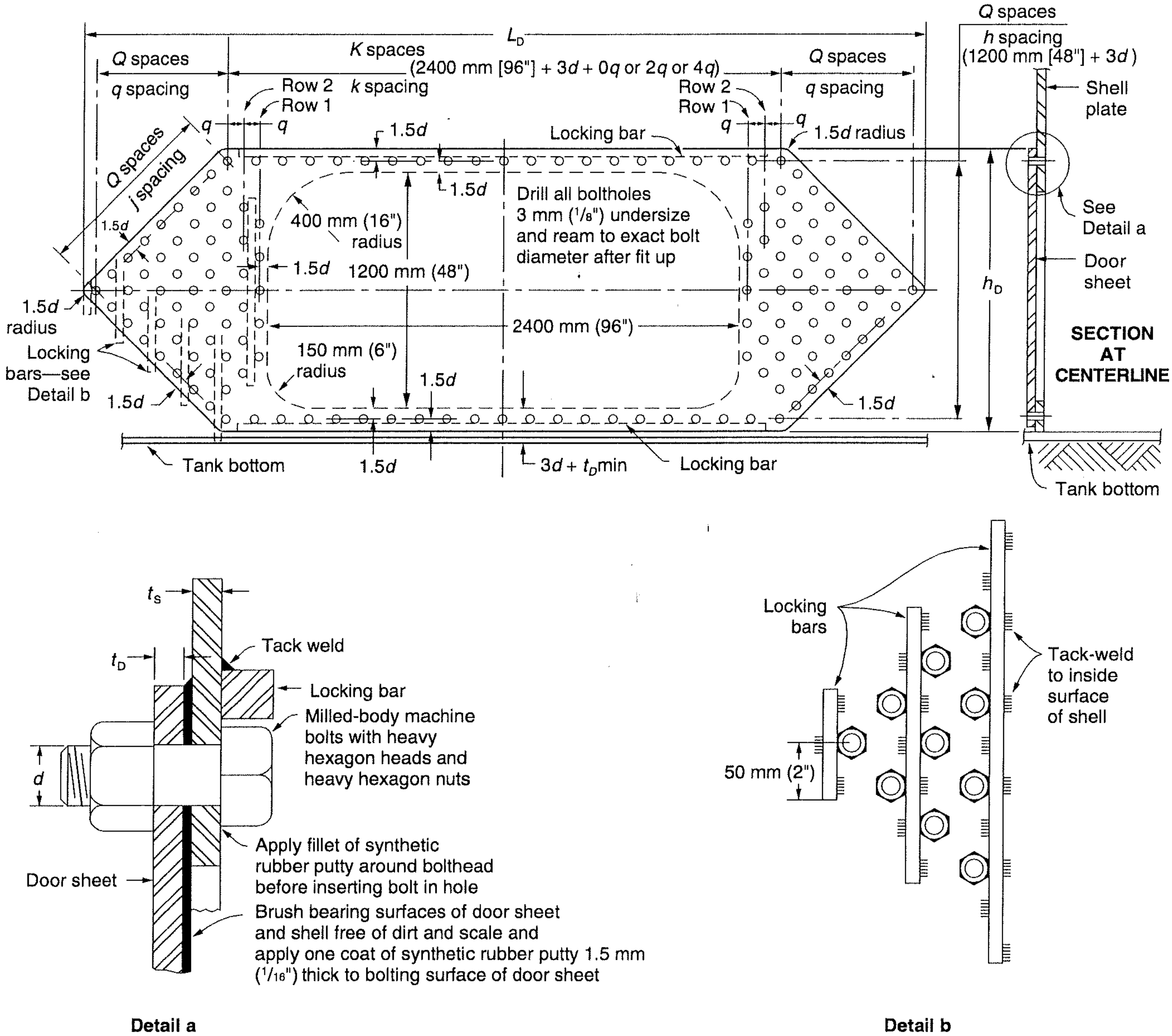


Figure A-3—Raised-Type Bolted Door Sheet (See Table A-6)

APPENDIX B—RECOMMENDATIONS FOR DESIGN AND CONSTRUCTION OF FOUNDATIONS FOR ABOVEGROUND OIL STORAGE TANKS

B.1 Scope

B.1.1 This appendix provides important considerations for the design and construction of foundations for aboveground steel oil storage tanks with flat bottoms. Recommendations are offered to outline good practice and to point out some precautions that should be considered in the design and construction of storage tank foundations.

B.1.2 Since there is a wide variety of surface, subsurface, and climatic conditions, it is not practical to establish design data to cover all situations. The allowable soil loading and the exact type of subsurface construction to be used must be decided for each individual case after careful consideration. The same rules and precautions shall be used in selecting foundation sites as would be applicable in designing and constructing foundations for other structures of comparable magnitude.

B.2 Subsurface Investigation and Construction

B.2.1 At any tank site, the subsurface conditions must be known to estimate the soil bearing capacity and settlement that will be experienced. This information is generally obtained from soil borings, load tests, sampling, laboratory testing, and analysis by an experienced geotechnical engineer familiar with the history of similar structures in the vicinity. The subgrade must be capable of supporting the load of the tank and its contents. The total settlement must not strain connecting piping or produce gauging inaccuracies, and the settlement should not continue to a point at which the tank bottom is below the surrounding ground surface. The estimated settlement shall be within the acceptable tolerances for the tank shell and bottom.

● **B.2.2** When actual experience with similar tanks and foundations at a particular site is not available, the following ranges for factors of safety should be considered for use in the foundation design criteria for determining the allowable soil bearing pressures. (The owner or geotechnical engineer responsible for the project may use factors of safety outside these ranges.)

a. From 2.0 to 3.0 against ultimate bearing failure for normal operating conditions.

b. From 1.5 to 2.25 against ultimate bearing failure during hydrostatic testing.

c. From 1.5 to 2.25 against ultimate bearing failure for operating conditions plus the maximum effect of wind or seismic loads.

B.2.3 Some of the many conditions that require special engineering consideration are as follows:

a. Sites on hillsides, where part of a tank may be on undisturbed ground or rock and part may be on fill or another construction or where the depth of required fill is variable.

b. Sites on swampy or filled ground, where layers of muck or compressible vegetation are at or below the surface or where unstable or corrosive materials may have been deposited as fill.

c. Sites underlain by soils, such as layers of plastic clay or organic clays, that may support heavy loads temporarily but settle excessively over long periods of time.

d. Sites adjacent to water courses or deep excavations, where the lateral stability of the ground is questionable.

e. Sites immediately adjacent to heavy structures that distribute some of their load to the subsoil under the tank sites, thereby reducing the subsoil's capacity to carry additional loads without excessive settlement.

f. Sites where tanks may be exposed to flood waters, possibly resulting in uplift, displacement, or scour.

g. Sites in regions of high seismicity that may be susceptible to liquefaction.

h. Sites with thin layers of soft clay soils that are directly beneath the tank bottom and that can cause lateral ground stability problems.

B.2.4 If the subgrade is inadequate to carry the load of the filled tank without excessive settlement, shallow or superficial construction under the tank bottom will not improve the support conditions. One or more of the following general methods should be considered to improve the support conditions:

a. Removing the objectionable material and replacing it with suitable, compacted material.

b. Compacting the soft material with short piles.

c. Compacting the soft material by preloading the area with an overburden of soil. Strip or sand drains may be used in conjunction with this method.

d. Stabilizing the soft material by chemical methods or injection of cement grout.

e. Transferring the load to a more stable material underneath the subgrade by driving piles or constructing foundation piers. This involves constructing a reinforced concrete slab on the piles to distribute the load of the tank bottom.

f. Constructing a slab foundation that will distribute the load over a sufficiently large area of the soft material so that the load intensity will be within allowable limits and excessive settlement will not occur.

g. Improving soil properties by vibrocompaction, vibroreplacement, or deep dynamic compaction.

h. Slow and controlled filling of the tank during hydrostatic testing. When this method is used, the integrity of the tank may be compromised by excessive settlements of the shell or bottom. For this reason, the settlements of the tank shall be closely monitored. In the event of settlements beyond established ranges, the test may have to be stopped and the tank releveled.

B.2.5 The fill material used to replace muck or other objectionable material or to build up the grade to a suitable height shall be adequate for the support of the tank and product after the material has been compacted. The fill material shall be free of vegetation, organic matter, cinders, and any material that will cause corrosion of the tank bottom. The grade and type of fill material shall be capable of being compacted with standard industry compaction techniques to a density sufficient to provide appropriate bearing capacity and acceptable settlements. The placement of the fill material shall be in accordance with the project specifications prepared by a qualified geotechnical engineer.

B.3 Tank Grades

B.3.1 The grade or surface on which a tank bottom will rest should be constructed at least 0.3 m (1 ft) above the surrounding ground surface. This will provide suitable drainage, help keep the tank bottom dry, and compensate for some small settlement that is likely to occur. If a large settlement is expected, the tank bottom elevation shall be raised so that the final elevation above grade will be a minimum of 150 mm (6 in.) after settlement.

B.3.2 There are several different materials that can be used for the grade or surface on which the tank bottom will rest. To minimize future corrosion problems and maximize the effect of corrosion prevention systems such as cathodic protection, the material in contact with the tank bottom should be fine and uniform. Gravel or large particles shall be avoided. Clean washed sand 75 to 100 mm (3 to 4 in.) deep is recommended as a final layer because it can be readily shaped to the bottom contour of the tank to provide maximum contact area and will protect the tank bottom from coming into contact with large particles and debris. Large foreign objects or point contact by gravel or rocks could cause corrosion cells that will cause pitting and premature tank bottom failure.

During construction, the movement of equipment and materials across the grade will mar the graded surface. These irregularities should be corrected before bottom plates are placed for welding.

Adequate provisions, such as making size gradients in sublayers progressively smaller from bottom to top, should be made to prevent the fine material from leaching down into the larger material, thus negating the effect of using the fine material as a final layer. This is particularly important for the top of a crushed rock ringwall.

Note: For more information on tank bottom corrosion and corrosion prevention that relates to the foundation of a tank, see API Recommended Practice 651.

● **B.3.3** Unless otherwise specified by the owner, the finished tank grade shall be crowned from its outer periphery to its center at a slope of one inch in ten feet. The crown will partly compensate for slight settlement, which is likely to be greater at the center. It will also facilitate cleaning and the removal of water and sludge through openings in the shell or from sumps situated near the shell. Because crowning will affect the lengths of roof-supporting columns, it is essential that the tank manufacturer be fully informed of this feature sufficiently in advance. (For an alternative to this paragraph, see B.3.4.)

● **B.3.4** As an alternative to B.3.3, the tank bottom may be sloped toward a sump. The tank manufacturer must be advised as required in B.3.3.

B.4 Typical Foundation Types

B.4.1 EARTH FOUNDATIONS WITHOUT A RINGWALL

B.4.1.1 When an engineering evaluation of subsurface conditions that is based on experience and/or exploratory work has shown that the subgrade has adequate bearing capacity and that settlements will be acceptable, satisfactory foundations may be constructed from earth materials. The performance requirements for earth foundations are identical to those for more extensive foundations. Specifically, an earth foundation should accomplish the following:

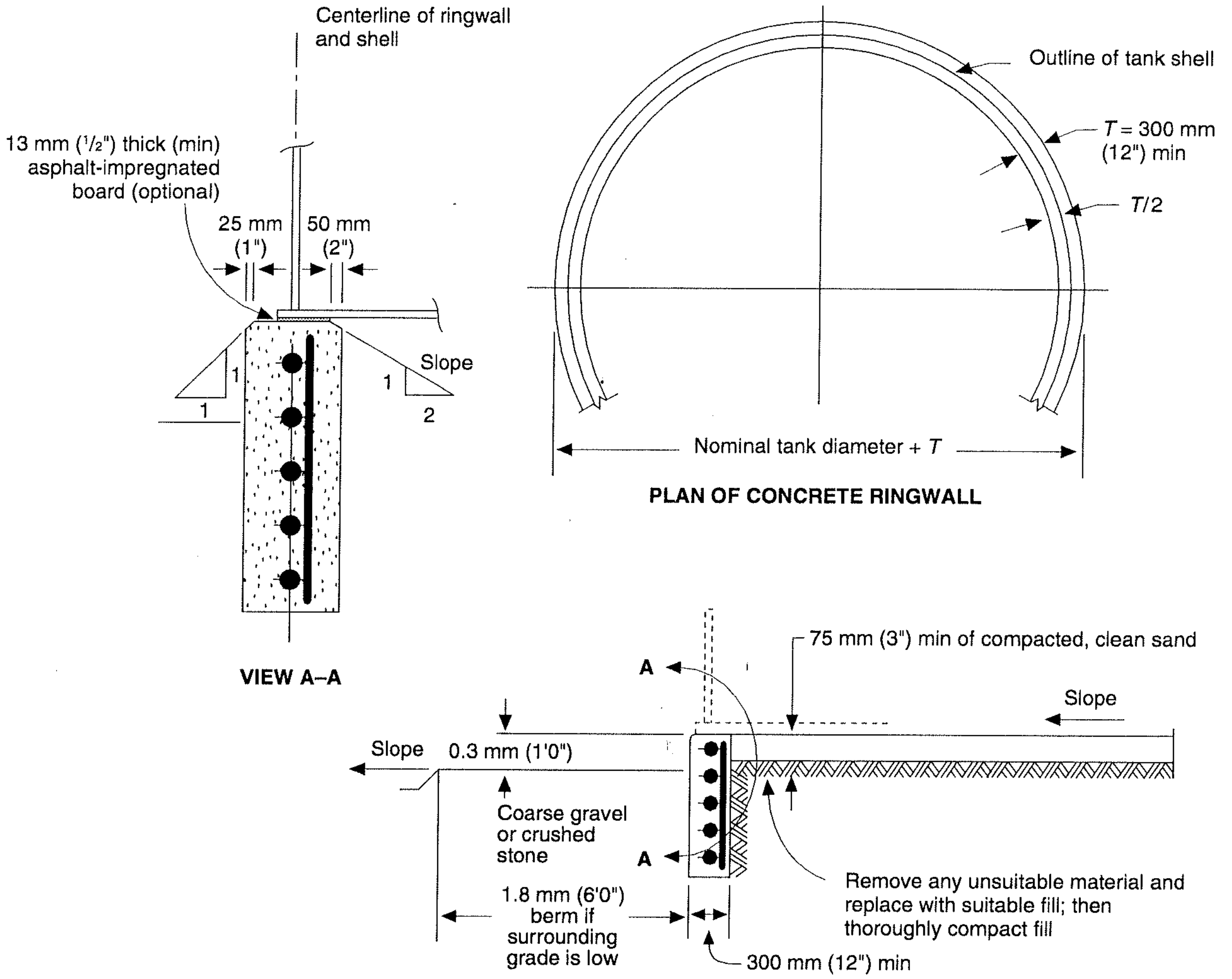
a. Provide a stable plane for the support of the tank.

b. Limit overall settlement of the tank grade to values compatible with the allowances used in the design of the connecting piping.

c. Provide adequate drainage.

d. Not settle excessively at the perimeter due to the weight of the shell wall.

B.4.1.2 Many satisfactory designs are possible when sound engineering judgment is used in their development. Three designs are referred to in this appendix on the basis of their satisfactory long-term performance. For smaller tanks, foundations can consist of compacted crushed stone, screenings, fine gravel, clean sand, or similar material placed directly on virgin soil. Any unstable material must be removed, and any replacement material must be thoroughly compacted. Two recommended designs that include ringwalls are illustrated in Figures B-1 and B-2 and described in B.4.2 and B.4.3.



Notes:

1. See B.4.2.3 for requirements for reinforcement.
2. The top of the concrete ringwall shall be smooth and level. The concrete strength shall be at least 20 MPa (3000 lbf/in.^{2}) after 28 days. Reinforcement splices must be staggered and shall be lapped to develop full strength in the bond. If staggering of laps is not possible, refer to ACI 318 for additional development requirements.
3. Ringwalls that exceed 300 mm (12 in.) in width shall have rebars distributed on both faces.
4. See B.4.2.2 for the position of the tank shell on the ringwall.

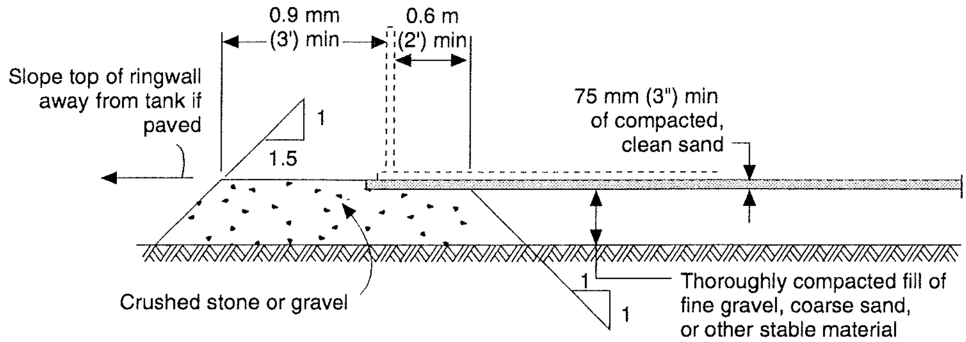
Figure B-1—Example of Foundation With Concrete Ringwall

B.4.2 EARTH FOUNDATIONS WITH A CONCRETE RINGWALL

B.4.2.1 Large tanks, tanks with heavy or tall shells and/or self-supported roofs impose a substantial load on the foundation under the shell. This is particularly important with regard to shell distortion in floating-roof tanks. When there is some doubt whether a foundation will be able to carry the shell load directly, a concrete ringwall foundation should be used. As an alternative to the concrete ringwall noted in this section, a crushed stone ringwall (see B.4.3) may be used. A foundation with a concrete ringwall has the following advantages:

a. It provides better distribution of the concentrated load of the shell to produce a more nearly uniform soil loading under the tank.
b. It provides a level, solid starting plane for construction of the shell.
c. It provides a better means of leveling the tank grade, and it is capable of preserving its contour during construction.
d. It retains the fill under the tank bottom and prevents loss of material as a result of erosion.
e. It minimizes moisture under the tank.

A disadvantage of concrete ringwalls is that they may not smoothly conform to differential settlements. This



Note: Any unsuitable material shall be removed and replaced with suitable fill; the fill shall then be thoroughly compacted.

Figure B-2—Example of Foundation With Crushed Stone Ringwall

disadvantage may lead to high bending stresses in the bottom plates adjacent to the ringwall.

B.4.2.2 When a concrete ringwall is designed, it shall be proportioned so that the allowable soil bearing is not exceeded. The ringwall shall not be less than 300 mm (12 in.) thick. The centerline diameter of the ringwall should equal the nominal diameter of the tank; however, the ringwall centerline may vary if required to facilitate the placement of anchor bolts or to satisfy soil bearing limits for seismic loads or excessive uplift forces. The depth of the wall will depend on local conditions, but the depth must be sufficient to place the bottom of the ringwall below the anticipated frost penetration and within the specified bearing strata. As a minimum, the bottom of the ringwall, if founded on soil, shall be located 0.6 m (2 ft) below the lowest adjacent finish grade. Tank foundations must be constructed within the tolerances specified in 5.5.5. Recesses shall be provided in the wall for flush-type cleanouts, drawoff sumps, and any other appurtenances that require recesses.

B.4.2.3 A ringwall should be reinforced against temperature changes and shrinkage and reinforced to resist the lateral pressure of the confined fill with its surcharge from product loads. ACI 318 is recommended for design stress values, material specifications, and rebar development and cover. The following items concerning a ringwall shall be considered:

a. The ringwall shall be reinforced to resist the direct hoop tension resulting from the lateral earth pressure on the ringwall's inside face. Unless substantiated by proper geotechnical analysis, the lateral earth pressure shall be assumed to be at least 50% of the vertical pressure due to fluid and soil weight. If a granular backfill is used, a lateral earth pressure coefficient of 30% may be used.

b. The ringwall shall be reinforced to resist the bending moment resulting from the uniform moment load. The uniform moment load shall account for the eccentricities of the applied shell and pressure loads relative to the centroid of the resulting soil pressure. The pressure load is due to the fluid pressure on the horizontal projection of the ringwall inside the shell.

c. The ringwall shall be reinforced to resist the bending and torsion moments resulting from lateral, wind, or seismic loads applied eccentrically to it. A rational analysis, which includes the effect of the foundation stiffness, shall be used to determine these moments and soil pressure distributions.

d. The total hoop steel area required to resist the loads noted above shall not be less than the area required for temperature changes and shrinkage. The hoop steel area required for temperature changes and shrinkage is 0.0025 times the vertical cross-sectional area of the ringwall or the minimum reinforcement for walls called for in ACI 318, Chapter 14.

e. For ringwalls, the vertical steel area required for temperature changes and shrinkage is 0.0015 times the horizontal cross-sectional area of the ringwall or the minimum reinforcement for walls called for in ACI 318, Chapter 14. Additional vertical steel may be required for uplift or torsional resistance. If the ring foundation is wider than its depth, the design shall consider its behavior as an annular slab with flexure in the radial direction. Temperature and shrinkage reinforcement shall meet the ACI 318 provisions for slabs. (See ACI 318, Chapter 7.)

f. When the ringwall width exceeds 460 mm (18 in.), using a footing beneath the wall should be considered. Footings may also be useful for resistance to uplift forces.

g. Structural backfill within and adjacent to concrete ringwalls and around items such as vaults, undertank piping, and sumps requires close field control to maintain settlement tolerances. Backfill should be granular material compacted to the density and compacting as specified in the foundation construction specifications. For other backfill materials, sufficient tests shall be conducted to verify that the material has adequate strength and will undergo minimal settlement.

B.4.3 EARTH FOUNDATIONS WITH A CRUSHED STONE AND GRAVEL RINGWALL

B.4.3.1 A crushed stone or gravel ringwall will provide adequate support for high loads imposed by a shell. A foundation with a crushed stone or gravel ringwall has the following advantages:

a. It provides better distribution of the concentrated load of the shell to produce a more nearly uniform soil loading under the tank.
b. It provides a means of leveling the tank grade, and it is capable of preserving its contour during construction.
c. It retains the fill under the tank bottom and prevents loss of material as a result of erosion.
d. It can more smoothly accommodate differential settlement because of its flexibility.

A disadvantage of the crushed stone or gravel ringwall is that it is more difficult to construct it to close tolerances and achieve a flat, level plane for construction of the tank shell.

B.4.3.2 For crushed stone or gravel ringwalls, careful selection of design details is necessary to ensure satisfactory performance. The type of foundation suggested is shown in Figure B-2. Significant details include the following:

a. The 0.9 m (3 ft) shoulder and berm shall be protected from erosion by being constructed of crushed stone or covered with a permanent paving material.
b. Care shall be taken during construction to prepare and maintain a smooth, level surface for the tank bottom plates.
c. The tank grade shall be constructed to provide adequate drainage away from the tank foundation.
d. The tank foundation must be true to the specified plane within the tolerances specified in 5.5.5.

B.4.4 SLAB FOUNDATIONS

● **B.4.4.1** When the soil bearing loads must be distributed over an area larger than the tank area or when it is specified by the owner, a reinforced concrete slab shall be used. Piles beneath the slab may be required for proper tank support.

B.4.4.2 The structural design of the slab, whether on grade or on piles, shall properly account for all loads imposed upon the slab by the tank. The reinforcement requirements and the design details of construction shall be in accordance with ACI 318.

B.5 Tank Foundations for Leak Detection

Appendix I provides recommendations on the construction of tank and foundation systems for the detection of leaks through the bottoms of storage tanks.