Concrete Structures for Containment of Hazardous Materials

Reported by ACI Committee 350

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Keywords: coating systems; construction joints; crack control; environmental structure; fiber reinforced plastic (FRP) sheets; flexible membrane liners; geotextile; hazardous material containment; joints; joint sealants; leak detection system; liners; liquid tightness; monolithic placement; pipe penetrations; precast concrete; prestressing; primary containment; secondary containment; starter wall; sump; tank; water-cementitious materials ratio; waterstops.

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CHAPTER 1—GENERAL

1.1—Scope
This report is primarily intended for use in the design and construction of hazardous material containment structures. Hazardous material containment structures require secondary containment and, sometimes, leak detection systems (see Section 1.2 for definitions). Because of the economic and environmental impact of even small amounts of leakage of hazardous materials, both primary and secondary containment systems must be virtually leak free. Therefore, when primary or secondary containment structures involve concrete, special design and construction techniques are required. This report is intended to supplement and enhance the recommendations of ACI 350R, “Environmental Engineering Concrete Structures.” As it says, that report is intended for “structures commonly used in water containment, industrial and domestic water, and wastewater treatment works.” The ACI 350 report does not give guidelines for double containment systems or leak detection systems. This report is not for structures containing radioactive materials.

Using the information in this report does not ensure compliance with applicable regulations. The recommendations in this report were based on the best technical knowledge available at the time they were written. However, they may be supplemented or superseded by applicable local, state and national regulations. It is, therefore, important to research such regulations thoroughly.

Guidelines for containment and leakage detection systems given in this report involve combinations of materials that may not be readily available in all areas. Therefore, local distributors and contractors should be contacted during the design process to ensure that materials are available.

The proper and thorough inspection of the construction is essential to assure a quality final product. The recommendations for inspection should be clearly understood by all parties involved.

1.2—Definitions
For purposes of this report, the following definitions have been correlated with the U.S. Environmental Protection Agency (EPA) Resource Conservation and Recovery Act (RCRA) regulations:

1.2.1 Hazardous material—A hazardous material is defined as having one or more of the following characteristics: ignitable (NFPA 49), corrosive, reactive, or toxic.

EPA listed wastes are organized into three categories under RCRA: source-specific wastes, generic wastes and commercial chemical products. Source specific wastes include sludges and wastewaters from treatment and production processes in specific industries, such as petroleum refining and wood preserving. The list of generic wastes includes wastes from common manufacturing and industrial processes, such as solvents used in de-greasing operations. The third list contains specific chemical products, such as benzene, creosote, mercury, and various pesticides.

1.2.2 Tank—A tank is a stationary containment structure whose walls are self-supporting, constructed of non-earthen material and designed to be watertight.

1.2.3 Environmental tank—An environmental tank is a tank used to collect, store or treat hazardous material. An environmental tank usually provides either primary or secondary containment of a hazardous material.

1.2.4 Tank system—A tank system includes the tank, its primary and secondary containment systems, leak detection system and the ancillary equipment.

1.2.5 Ancillary equipment—Ancillary equipment includes piping, fittings, valves, and pumps.

1.2.6 Sump—A sump can be any structural reservoir, usually below grade, designed for collection of runoff or accidental spillage. It also often includes troughs, trenches and piping connected to the sump to help collect and transport runoff liquids. Regulations may not distinguish between a sump and an underground tank.

1.2.7 Environmental sump—An environmental sump is a sump used to collect or store hazardous material.

1.2.8 Primary containment system—A primary containment system is the first containment system in contact with the hazardous material.

1.2.9 Secondary containment system—A secondary containment system is a backup system for containment of hazardous materials in case the primary system leaks or otherwise fails for any reason.
1.2.10 Spill or system failure—A spill or system failure is any uncontrolled release of hazardous material from the primary containment system into the environment or into the secondary containment system. It may also be from the secondary containment system into the environment.

1.2.11 Spill or leak detection system—A spill or leak detection system is a system to detect, monitor and signal a spill or leakage from the primary containment system.

1.2.12 Membrane slab—A membrane slab is a slab-on-grade designed to be liquid-tight and transmit loads directly to the subgrade.

1.3—Types of materials

This report is concerned with environmental tanks and sumps of reinforced concrete construction. Tanks may be constructed of prestressed or nonprestressed reinforced concrete. They may also be constructed of steel or other materials with concrete foundations and concrete secondary containment systems, or both. Reinforced concrete is the most widely used material for sumps, particularly below grade.

Liners for environmental tanks and sumps may be made of stainless or coated steel, fiber-reinforced plastics (FRP), various combinations of esters, epoxy resins or thermoplastics.

This report outlines and discusses each option for materials of construction, with recommendations for use where applicable. Information on availability, applications, and chemical resistance is given in other references on these subjects, see Chapter 8.

CHAPTER 2—CONCRETE DESIGN AND PROPORTIONING

2.1—General

Concrete is particularly suitable for above and below grade environmental tanks and sumps. When properly designed and constructed, concrete containment structures are impermeable, for all intents and purposes. Some reinforced concrete compression members, such as the walls of tanks, are also highly resistant to buckling during seismic events, unlike the walls of steel tanks. Reinforced concrete’s thermal conductivity and protective qualities make it highly resistant to failure during fires. See ACI 216R and the CRSI\(^1\) and PCI\(^2\) references in Section 8.1 for information on exposure of concrete to elevated temperatures.

Concrete is a good, general-purpose material that is easy to work with and has good resistance to a wide range of chemicals. It can be used as the primary and secondary containment system, or both. The addition of pozzolans, latex, and polymer modifiers generally increases resistance to chemical attack.

Measures that should be considered to help prevent cracking or to control the number and width of cracks include the following: prestressing; details that reduce or prevent restraint of shrinkage; higher than normal amounts of nonprestressed reinforcement; shrinkage-compensating concrete; concrete mixtures designed to reduce shrinkage; and fiber reinforcement. Also, some construction techniques, such as casting floors and walls monolithically (see Chapter 4), help prevent or control cracking by minimizing differential shrinkage and temperature stresses. See ACI 224R and ACI 224.3R for additional information on control of cracking in concrete structures.

2.2—Design

2.2.1 Design considerations—The walls, base slab, and other elements of containment structures should be designed for lateral pressure due to contained material, lateral earth pressure, wind, seismic, and other superimposed loads. ACI 350R provides guidance for the design of nonprestressed tanks and sumps. See ASTM C 913 for additional design provisions relating to factory precast sumps.

ACI 372 and AWWA D110 and ACI 373 and AWWA D115 provide guidance for the design of wrapped and tendon circular prestressed concrete structures, respectively.

Roofs should be designed for dead loads, including any superimposed dead loads (insulation, membranes, mechanical equipment, etc.) and live loads (earth load if buried, snow, pedestrians, wheel loads if applicable, etc.).

2.2.2 Wall thickness and reinforcement—The minimum wall thickness and reinforcing steel location in walls should be as follows:

<table>
<thead>
<tr>
<th>Description</th>
<th>Wall Height</th>
<th>Minimum Thickness</th>
<th>Reinf. Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast-in-place concrete</td>
<td>Over 10 ft (3 m)</td>
<td>12 in. (300 mm)</td>
<td>Both faces</td>
</tr>
<tr>
<td></td>
<td>4 ft (1200 mm) to 10 ft (3 m)</td>
<td>10 in. (250 mm)</td>
<td>Both faces</td>
</tr>
<tr>
<td></td>
<td>Less than 4 ft (1200 mm)</td>
<td>6 in. (150 mm)</td>
<td>Center of wall</td>
</tr>
<tr>
<td>Note: Placement windows (temporary openings in the forms), or tremies are recommended to facilitate concrete placement in cast-in-place walls greater than 6 ft (1800 mm) in height</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precast concrete</td>
<td>4 ft (1200 mm) or more</td>
<td>8 in. (200 mm)</td>
<td>Center of wall</td>
</tr>
<tr>
<td></td>
<td>Less than 4 ft (1200 mm)</td>
<td>4 in. (100 mm)</td>
<td>Center of wall</td>
</tr>
<tr>
<td>Description</td>
<td>Minimum wall thickness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tendon prestressed concrete tanks</td>
<td>See ACI 373</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wrapped prestressed concrete tanks</td>
<td>See ACI 372</td>
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</tr>
</tbody>
</table>

2.2.3 Footings—Footings should have a minimum thickness of 12 in. (300 mm).

2.2.4 Slabs-on-grade

2.2.4.1 Membrane slabs—ACI 372 and ACI 373 provide guidance on the design of membrane floor slabs for circular prestressed concrete structures. In general, these guidelines apply to noncircular structures as well. To enhance liquid tightness, membrane slabs should be placed without construction joints. A membrane slab may be reinforced with prestressed and nonprestressed reinforcement in the same layer in each direction, or with nonprestressed reinforcement only, at or near the center of the slab. The high percentages of reinforcement or residual prestressing recommended in these reports are effective in providing liquid-tightness without...
excessive cracking due to local differential settlements, shrinkage and temperature effects.

2.2.4.2 Pavement slabs—The term “pavement slabs” as used in this report denotes the particular case of slabs-on-grade designed for drainage capture and primary or secondary containment of hazardous materials when vehicle or other concentrated loads are anticipated. Pavement slabs may be either prestressed or nonprestressed and designed as plates on elastic foundations. The properties of the subgrade should be determined by a qualified geotechnical engineer. Acceptable analytical techniques include finite element, finite difference and other techniques that give comparable results. Use the flexural and punching shear stresses to design the reinforcement and post-tensioning.

Nonprestressed pavement slabs designed for vehicle loads of AASHTO H-10 or heavier should be at least 8 in. (200 mm) thick and should contain two layers of reinforcement in each direction. The slab thickness for lighter wheel loads may be according to Section 2.2.4.3. The reinforcement percentage should total at least 0.5 percent of the cross sectional area in each orthogonal direction. Place at least one half, and not more than two-thirds, of this amount in the upper layer. ACI 350R provides guidance on the design of flexural reinforcement, including the additional “durability coefficient” where applicable. A durability coefficient is an extra load factor intended to increase the reinforcing calculated using the strength design method to amounts equivalent to those calculated using the working stress method and found to be needed in environmental structures.

Prestressed pavement slabs designed for vehicle loads of AASHTO H-10, or heavier, should be at least 6 in. (150 mm) thick. Slab thicknesses for lighter wheel loads may be designed according to Section 2.2.4.3. When unbonded post-tensioning tendons are used, the nonprestressed reinforcement percentage should total at least 0.30 percent for primary containment, and 0.15 percent for secondary containment, in each orthogonal direction. The reinforcement is usually placed at the middepth of the slab when the prestressed pavement slab is less than 8 in. (200 mm) thick. When the prestressed pavement slab is 8 in. (200 mm) thick, or more, the nonprestressed reinforcement is usually divided into two mats, one near each face. The prestressed reinforcement, however, should remain near the center of the slab. The compressive stress in the slab should be at least 200 psi (1.5 MPa) after strand friction and long-term losses and after deducting for friction between the slab and the subgrade. Flexural tensile stresses should not exceed 2 \( \sqrt{f_c} \) psi (0.167 \( \sqrt{f_c} \) MPa) unless bonded reinforcement is provided in the precompressed tensile zone. Design this reinforcement according to ACI 318, except that the allowable stresses should be limited to the values given in Table 2.6.7(b) of ACI 350R for the various bar sizes, exposure conditions, and grades of reinforcement.

As with membrane slabs, pavement slabs intended to be liquid-tight should be placed without construction joints whenever possible. When joints are unavoidable, they should be designed and detailed according to the other recommendations of this report.

2.2.4.3 Other slabs-on-grade—ACI 360R and 350R provide guidance on the design of slabs-on-grade, other than membrane slabs or pavement slabs. Additional guidance is given in this section. These slabs-on-grade should have a minimum thickness of 6 in. (150 mm) if nonprestressed and 5 in. (125 mm) if prestressed. If prestressed, they should have a minimum of 200 psi (1.5 MPa) average compression, after deducting for all losses, including the friction between the slab and the subgrade.

2.2.5 Mat foundations—Mat foundations should be at least 12 in. (300 mm) thick with two layers of nonprestressed reinforcement or 10 in. (250 mm) thick with prestressed reinforcement. Provide additional concrete thickness to help resist buoyancy if required.

2.2.6 Shrinkage and temperature reinforcement for nonprestressed secondary containment—The minimum reinforcement for concrete used as secondary containment structures should be provided according to Fig. 2.5 of ACI 350R except when shrinkage-compensating concrete is used. Contraction and construction joint spacings of up to 75 ft (23 m) have been used successfully with shrinkage-compensating concrete and 0.3 percent reinforcement. Develop construction details for shrinkage-compensating concrete according to the recommendations of ACI 223.

2.2.7 Shrinkage and temperature reinforcement for nonprestressed primary containment—The minimum reinforcement for concrete used as primary containment should be 0.5 percent of the cross-sectional area, each way. In order to control shrinkage cracks caused by restraint of free shrinkage, the reinforcement should be increased to 1.0 percent for about the first 4 ft (1200 mm) when floor or wall concrete is placed against and bonded to previously placed concrete, such as at construction joints (see Fig. 2.1). For crack control, it is preferable to use several small diameter bars rather than an equal area of large bars. The maximum bar spacing should not exceed 12 in. (300 mm). When shrinkage-compensating concrete is used according to ACI 223, the likelihood of cracking at the bottom of the wall from shrinkage is reduced. Consideration can, therefore, be given to reducing or eliminating the extra 0.5 percent shrinkage and temperature reinforcement placed parallel to the joint in the lower 4 ft (1200 mm) of the wall.

2.2.8 Minimum nonprestressed reinforcement for prestressed concrete—The minimum nonprestressed reinforcement in prestressed concrete containment structures should be 0.15 percent for secondary containment and 0.30 percent for primary containment when shrinkage is partially restrained (such as for slabs-on-grade) and as recommended for nonprestressed concrete wherever shrinkage is fully restrained (such as when concrete is placed against and bonded to hardened concrete). See ACI 372 and ACI 373 for additional recommendations for circular prestressed concrete tanks.

2.2.9 Slope—A minimum slope of 2 percent should be included in the design of floors and trench bottoms to prevent ponding and to help drainage.
2.2.10 Roofs

2.2.10.1 Joints in roofs—Cast-in-place roofs intended to be liquid-tight should be placed without construction joints whenever possible to enhance liquid tightness. When joints in cast-in-place roofs are unavoidable, they should be designed and detailed according to the recommendations of Section 2.2.7 of this report. Joints between precast roof members should be designed and detailed for liquid-tightness with guidance provided by ACI 350R and Section 3.2 of this report.

2.2.10.2 Roof design—ACI 372 and ACI 373 provide guidance on the design of domes and post-tensioned roof slabs for circular prestressed concrete liquid-containing structures. Roof slabs may be either prestressed or nonprestressed. Acceptable analytical techniques include finite element, finite difference, equivalent frame and other techniques that give comparable results. Use the flexural and punching shear stresses to design the section thickness, reinforcement and post-tensioning when applicable.

Flat nonprestressed roof slabs should be at least 6 in. (150 mm) thick with two layers of reinforcement in each direction. The reinforcement percentage should total at least 0.5 percent of the cross sectional area in each orthogonal direction. ACI 350R provides guidance on the design of flexural reinforcement, including the additional durability coefficient where applicable.

Flat prestressed roof slabs should be at least 6 in. (150 mm) thick. When unbonded post-tensioning tendons are used, the nonprestressed reinforcement percentage should be in accordance with the requirements of ACI 318. The compressive stress in the slab should be at least 150 psi (1.0 MPa) after tendon friction and long term losses and after deducting for any interaction with the wall. This is less than the minimum compressive stress recommended for floors and walls because the roof does not actually “contain” the hazardous material.

Flexural tension should be limited to 2$\sqrt{f_{c}'}$ psi (0.167 $\sqrt{f_{c}'}$ MPa) unless bonded reinforcement is provided in the precompressed tensile zone. Design this reinforcement according to ACI 318, except that the allowable stresses should be limited to the values given in Table 2.6.7(a) of ACI 350R for the various bar sizes, exposure conditions, and grades of reinforcement.

2.3—Concrete cover

Reinforcement should have at least the minimum concrete cover recommended by ACI 350R. Use additional concrete cover or coatings on the concrete as needed for supplemental corrosion protection.

Concrete cover on plant precast reinforcing steel may be reduced up to 25 percent from the amounts recommended in ACI 350R, but should always be at least $\frac{3}{4}$ in. (20 mm).

2.4—Exposure

2.4.1 Freezing and thawing—Concrete in a critically saturated condition is susceptible to damage due to cycles of freezing and thawing. Air entrainment improves freeze-thaw resistance and should be specified for concrete exposed to freezing and thawing. Resistance to freeze-thaw damage is also improved by measures that increase the density or reduce the permeability of the concrete, such as lowering the water-cementitious material ratio.

In severe freezing and thawing environments, concrete should be protected from multiple freeze-thaw cycles or protected from reaching near saturated conditions. External insulation or burial helps limit the number of cycles and severity of the freezing. Also, internal liners or coatings can be used to reduce the moisture saturation of the concrete.

2.4.2. Other Durability Considerations—For very harsh environmental conditions (more acidic than a pH of 5 or exposure to sulfate solutions greater than 1500 ppm), reinforcement cover should be increased to reduce corrosion of the reinforcing steel. Coated reinforcement or coated prestressing should be considered in very corrosive chemical applications. When using coated reinforcement, consider the reduction in bond strength, particularly as it may affect cracking. Using a greater number of smaller bars or a higher percentage of reinforcing will reduce these effects. See ACI 201.2R for other durability considerations.

2.4.3 Chemical resistance—Some chemicals, such as strong acids, are so aggressive to concrete that all of the above will have little or no effect on chemical attack resistance. In these cases chemically resistant coatings or liners are recommended.
2.5—Concrete mixture proportions

2.5.1 Water and cementitious material—The maximum water-cementitious materials (cement plus pozzolan) ratio should be 0.40 for primary containment and 0.45 for secondary containment. The 0.45 w/c is consistent with ACI 350R and 0.40 is consistent with the Committee’s experience in primary containment structures.

In order to reduce permeability, the minimum cementitious materials content should be 700 lb/yd\(^3\) (420 kg/m\(^3\)) for primary containment and 600 lb/yd\(^3\) (360 kg/m\(^3\)) for secondary containment. Unless needed for specific chemical resistance properties, fly ash or other pozzolans should generally not exceed about 25 percent of the total cementitious material content.

2.5.2 Admixtures—Workability may be increased by the addition of normal or high-range water-reducing admixtures and air-entraining admixtures. Calcium chloride or admixtures containing chloride from other than incidental impurities should not be used in concrete for either primary or secondary hazardous material containment structures.

2.5.3 Compressive strength—The minimum cementitious material contents and maximum water-cementitious materials ratios given above should result in compressive strengths of the concrete that exceed most structural requirements.

2.5.4 Air entrainment—ACI 350R provides guidance on the air entrainment of concrete.

2.6—Fiber reinforced concrete

2.6.1 General—Fiber reinforced concrete uses fibers that are available in lengths ranging from \(\frac{3}{4}\) in. (20 mm) to 2 in. (50 mm) long. Mixing these fibers with concrete may reduce plastic shrinkage cracking.

When selecting fibers for use in reinforced concrete, consideration should be given to the fact that some fibers (for example, rayon, acrylic, fiberglass and polyesters) are subject to alkali attack by the cement. If fibers are used, they should be chemically compatible with the contained materials.

Fiber reinforced concrete can be of any thickness. Fibers do not replace structural or shrinkage and temperature reinforcement.

Fibers, together with an epoxy bonding agent, should allow the application of a thinner (2 in. [50 mm] minimum) overlay on existing concrete.

2.6.2 Proportioning—The fiber ratio should follow the manufacturer’s recommendations. The fibers can be added at the batch site or the construction site. In either case, the fibers need a mixing time of at least seven minutes (at the mixing speed recommended by the manufacturer) to ensure dispersion of the fibers throughout the concrete.

The addition of fibers normally reduces the slump by 1 to 2 in. (25 to 50 mm). This should be considered in the mix design. The use of high-range water-reducing admixtures should regain the lost workability without the addition of water.

2.6.3 Finishing—The addition of polypropylene fibers to concrete makes it more difficult to achieve a smooth steel-troweled finish. The fibers will usually protrude from the concrete. The exposed portions of the fibers should degrade quickly due to traffic abrasion or UV exposure.

CHAPTER 3—WATERSTOPS, SEALANTS AND JOINTS

3.1—Waterstops

3.1.1 General—Provide waterstops at expansion/contraction joints and where construction joints cannot be avoided. Waterstops are positioned in concrete to prevent the passage of liquids. Mechanical joints may be considered for repairing an existing joint (see Fig. 3.1). Provide joints with chemically resistant sealants. See ACI 504R for additional information on sealing joints.

3.1.2 Materials—The chemical resistance of the waterstop material, exposure, temperature, and chemical concentration should be considered. Evaluate each situation individually when selecting a waterstop material.

3.1.2.1 PVC waterstops—PVC waterstops are manufactured in various sizes and many special shapes, such as dumbbell, serrated, with or without center bulb, split, and tear web. When movement is expected, use serrated or ribbed profiles with center bulbs. The ribs increase the effective mechanical seal area of the waterstop, while the bulbs accommodate the movement.

3.1.2.2 Expansive rubber—Expansive rubber waterstops may be used in joints cast against previously placed concrete and in new construction. Only use adhesive type expansive rubber waterstops where movement is prevented.

3.1.2.3 Metal waterstops—Metal waterstops should be stainless steel or other metals compatible with the hazardous material. Metal waterstops should not be used in joints subject to movement.

3.1.2.4 Other materials—Other materials may be used provided they are compatible with the hazardous material.

3.1.3 Splicing

3.1.3.1 PVC waterstops—Proper splicing of waterstops is extremely important. Avoid splices if possible. Splices for corner, tee, and cross junctions made in the factory are also available for certain types of materials and shapes. The procedures for splicing vary with the type of material, and the manufacturer’s recommendations for proper splicing.

3.1.3.2 Metal waterstops—Metal waterstops should be spliced as recommended by the engineer or manufacturer.

Fig. 3.1—Mechanical joint repair at an existing joint
3.1.4 Installation

3.1.4.1 General—Improperly installed waterstops can create leaky joints. The waterstop should be clean and free of dirt and splattered concrete. Intimate contact with the concrete is essential over the entire surface of the waterstop. Entrapped air and honeycombing near the joint will nullify the value of the waterstop. The waterstop should be located accurately. The center bulb should be placed directly at the centerline of expansion and contraction joints. Otherwise, the value of the center bulb is lost.

3.1.4.2 Horizontal PVC waterstops—Care should be taken to place concrete without voids or honeycombing under horizontal PVC waterstops. Horizontal PVC waterstops should be supported in such a way as to be able to be lifted as the concrete is placed underneath (see Fig. 2.1 and 3.2). Any dowels through the joints should not interfere with the edges of the waterstops when they are lifted. Vibrate the concrete under the lifted waterstop. Lay the PVC waterstop into the concrete. Finally, place the concrete on top of the waterstop and vibrate the entire joint again.

Continuous inspection of concrete placement around horizontal PVC waterstops in floor slabs is recommended. Joints in floor slabs are the most critical to the liquid tightness of the structure and are not otherwise observable for liquid tightness.

3.1.4.3 Vertical PVC waterstops—Vertical PVC waterstops should be braced or lashed firmly to the reinforcement at no more than 12 in. (300 mm) centers to prevent movement during placing of the concrete (see Fig. 3.2 and 4.4).

3.1.4.4 Metal waterstops—Metal waterstops should be installed in accordance with the manufacturer’s recommendations and the construction documents. Take care to properly place and consolidate the concrete under horizontal metal waterstops.

3.2 Joint sealants

3.2.1 General—Sealants may be classified into two main groups: field-molded and preformed. Field-molded sealants are applied in liquid or semi-liquid form, and are thus formed into the required shape within the mold provided at the joint opening.

The manufacturer’s recommendations and applications for use should be thoroughly explored for each specific application of a sealant. Refer to ACI 504R for additional information on joint sealants.

For satisfactory performance, a sealant should:
A. Be impermeable.
B. Be deformable to adapt to the expected joint movement. The sealant should only be bonded to the sides of expansion and contraction joints to spread the movement over the full width of the sealant.
C. Recover its original properties and shape after cyclical deformations.
D. Remain bonded to joint faces.
E. Remain pliable and not become brittle at lower service temperatures.
F. Be resistant to weather, sunlight, aging, continuous immersion (when applicable), and other service factors.

G. Be resistant to chemical breakdown when exposed to the contained material.

Generally, the “elastomeric” sealants, according to ASTM C 920, are preferable to oil-based mastic or bituminous compounds.

Although initially more expensive, thermosetting, chemical-curing sealants have a generally longer service life and should withstand greater movements. The sealants in this class are either one-component systems or two-component systems that cure by chemical reaction. Sealants in this category include polysulfides, silicones, and urethanes.

Some sealants require primers to be applied to joint faces before sealant installation. If the manufacturer specifies the use of a primer as optional, use it for hazardous material containment structures.

Backup materials limit the depth of sealants, support them against sagging and fluid pressure, and help tooling. They may also serve as a bond breaker to prevent the sealant from bonding to the back of the joint.

Backup materials typically are made of expanded polyethylene, polyurethane, polyvinyl chloride, and flexible polypropylene foams. Follow the sealant manufacturer’s recommendations to ensure compatibility with backup materials.

Use polyethylene tape, urethane backer rods, coated papers, metal foils or other suitable materials if a separate bond breaker is necessary.

3.2.2 Joint preparation—Joint faces should be clean and free from defects that would impair bond with field-molded
sealants. Sandblasting joints is the best method to clean joint faces on existing structures. Use sandblasting also if the membrane curing compound used does not dissipate before the installation of the sealant, particularly with chemically cured thermostetting sealants. Solvents should not be used to clean joint faces. Final cleanup to dry and remove dust from the joint may be accomplished by oil-free compressed air or vacuum cleaner.

Inspection of each joint is essential to ensure that it is clean and dry before placing backup materials, primers, or sealant. Give primers the required time to dry before sealant installation. Failure to allow this may lead to adhesion failure. Primers can be brushed or sprayed on. Follow the manufacturer’s specifications and recommendations.

3.2.3 Sealant installation—Backup materials require proper positioning before sealant is installed. Backup materials should be set at the correct depths. Avoid contamination of the cleaned joint faces. Take care to select the correct size and shape of backup material so that, after installation, it is approximately 50 percent compressed. Avoid stretching, braiding, or twisting rod stock.

Backup materials containing bitumen should only be used in combination with compatible oil-based or bituminous sealants. Oils absorbed into joint surfaces may impair adhesion of other sealants.

Sealants with two or more components require full and intimate mixing if the material is to cure with uniform properties.

Hold the gun nozzle at a 45-degree angle to install the sealant. Move the gun steadily along a joint to apply a uniform bead by pushing the sealant in front of the nozzle without dragging, tearing, or leaving unfilled spaces. In large joints, build up the sealant in several passes, applying a triangular wedge on each pass.

Tooling may be required to ensure contact with joint faces, to remove trapped air, to consolidate material, and to provide a neat appearance. Follow the manufacturer’s recommendations concerning tooling.

3.2.4 Sealant inspection and maintenance—Conduct joint inspections during construction and at scheduled periods following construction to ensure sealant integrity.

Immediately repair defective joints and sealants in hazardous material containment structures and sumps.

Repairs of small gaps and soft or hard spots in sealants can usually be made with the same material. When the repair is extensive, it is usually necessary to remove the sealant, properly prepare the surfaces, and replace the sealant.

3.3—Joints

Avoid joints in primary and secondary containment applications wherever possible. Provide joints only where shown and detailed on the drawings or allowed by the engineer.

Construction joints should only be used when absolutely necessary for construction. Since liquid tightness is of primary concern in environmental structures, the design drawings and specifications should show the location of acceptable construction joints and specify waterstops and sealants.

Expansion and contraction joints should only be used at logical separations between segments of the structure. When expansion and contraction joints are used, the spacing of such joints should be coordinated with the amount of the reinforcement (refer to Fig. 2.5 in ACI 350R). See Fig. 3.2 for typical expansion and contraction joints.

Shrinkage-compensating concrete (ASTM C 845), may be used to further reduce shrinkage stresses (see ACI 223). However, the recommended reinforcement percentages should be according to ACI 350R.

CHAPTER 4—CONSTRUCTION CONSIDERATIONS

4.1—Sump construction techniques

4.1.1 Precasting sumps in a single unit—There are three major advantages of precasting concrete sumps in a single unit. First, this eliminates construction joints, which can be a major source of leakage and cracking. Second, this gives better control of the concrete placement when the sump is precast in the upside-down position. Third, this results in lower construction cost and more efficient job scheduling. Precast sumps may be fabricated at the contractor’s convenience. Also, with proper scheduling, the precast units can cure as long as required before installation. The unit can be set and backfilled the same day the secondary containment system is completed. In contrast, when sumps are cast-in-place, the excavation for the sump will be open for several days or weeks to build the forms and cast the concrete. To prevent damage to the sump walls, it takes additional time to cure the concrete and strip the forms before backfilling.

The size of a precast concrete sump is limited by the size of lifting and hauling equipment.

Secondary containment slabs, sloped as required, below the precast sumps reduce the dispersion of potential leakage. See Fig. 4.1 for setting techniques.

4.1.2 Monolithic placement of cast-in-place sumps—Like the precast sumps, monolithic placement of concrete in walls and slabs eliminates joints and associated shrinkage cracks. One of two conditions is needed to place concrete in walls monolithically with slabs: (1) walls less than 4 ft (1200 mm) high or, (2) a base width less than 4 ft (1200 mm). The following paragraphs discuss each of these conditions. Monolithic placement is limited by the shape and size of the sump.

4.1.2.1 Walls less than 4 ft (1200 mm) high—Form walls less than 4 ft (1200 mm) high as shown in Fig. 4.2. This includes placing an approximately 6 in. (150 mm) high lift of the wall concrete shortly after placing the base slab concrete. This “starter wall segment” should be placed after the slab concrete starts to stiffen but before a cold joint forms between the starter wall segment and the base slab. Place the remaining portion of the wall before a cold joint forms at the top of starter wall segment, but after the slab concrete has set sufficiently to prevent a blowout. If high-range water-reducing admixtures are used in the slab concrete, wait until their plasticizing effects have dissipated before placing the starter wall segment. To help prevent a possible blowout of the slab concrete, use hand rodding, initially, (not a vibrator) to ensure a bond between the first wall lift and the starter wall segment. Then use vibrators to consolidate the wall concrete.
including the first lifts; however, do not allow the vibrators to penetrate into the slab concrete.

4.1.2.2 Base widths less than 4 ft (1200 mm)—In sumps that have deep walls but bottom slabs less than 4 ft (1200 mm) wide, use a plywood form with \( \frac{3}{8} \) in. (15 mm) holes spaced at 12 in. (300 mm) on center each way to form the top surface of the base slab (see Fig. 4.3). The holes in the plywood should help ensure the slab concrete is placed without honeycombing. High-range water-reducing admixtures may be beneficial in this mixture. Visual inspections of the concrete protruding through these holes during placement will help ensure that the concrete in the floor is being properly placed.

4.1.3 Traditional construction—When joints cannot be avoided, a starter section (see Fig. 4.4) is recommended for walls. This facilitates wall forming, leak detection and repair if needed.

Trench bottoms and tank floor slabs should be cast over the top of a pit or sump wall instead of butting up against the wall (see Fig. 4.5).

Wall ties should have a welded cutoff collar. Also, they should be broken off 1 in. (25 mm) from the face of the wall in a cone shaped depression. Use epoxy or dry-packed shrinkage-compensating grouts with an epoxy bonding agent to fill the resulting holes.

Form materials should provide a smooth form finish, according to ACI 301. Base slabs should have a power-float finish.

4.1.4 Pipe penetrations—Pipe penetrations should be avoided when possible. If penetrations are necessary, they should be through walls (Fig. 4.6 and 4.7), or through the sides of bottom slabs (Fig. 4.8), to permit visual inspection. Protection of pipes coming out of bottom slabs should be considered. Dual containment pipes and flexible couplings are two means of providing this protection.

“Trim reinforcement” should be provided around pipe penetrations that interrupt other reinforcing bars. Generally, trim reinforcement should at least replace the area of reinforcing bars cut to accommodate the opening, in every applicable direction. Some designers also recommend additional trim bars placed at 45 degrees to the orthogonal reinforcement.

4.1.5 Backfilling—When a below-grade sump is part of or attached to a tank floor, the backfill around the sump walls should be thoroughly compacted, or be made of lean concrete. This should prevent excessive differential settlement of the floor slab around the sump.

4.2—Curing and protection

4.2.1 Curing—One of the most important operations in reinforced concrete construction is curing. Without proper curing, even the best-designed reinforced concrete develops surface cracks. Refer to ACI 308 for a complete description of curing procedures.
The primary purposes of curing are to maintain the moisture content of the fresh concrete at satisfactory levels and to protect the concrete against rapid temperature changes. Otherwise, these may cause excessive cracking or crazing. For concrete placed during cold weather, curing also provides protection against freezing.

Consider wetting the subgrade before placing cast-in-place concrete for sump bottoms and slabs-on-grade. This should help prevent loss of moisture from fresh concrete and provide reserve moisture for curing. Standing water, however, should not be allowed.

Curing procedures should start when placing and finishing operations allow. Do not allow the surface of the concrete placed early in the placing operation to dry while placing subsequent concrete. The materials and equipment needed for curing should be available and ready for use before the concrete arrives.

While there are many methods of curing concrete, there are two main approaches: (1) apply water, or cover with materials saturated with water and (2) prevent loss of water by impervious covers (membranes), or membrane-forming curing compounds. Use one or more of the methods described below.

4.2.1 Ponding—Ponding is one of the best methods of curing concrete slabs-on-grade, especially for slabs using shrinkage-compensating concrete. Cover the concrete with water and leave it there, adding to make up for evaporation, preferably until the structure is complete and ready to be cleaned up before being placed in service.

4.2.1.2 Running water—Use sprinklers or soaker hoses whenever running water is available, and the runoff does not...
cause any harm to the surrounding area. Fog spraying during finishing and curing is also good, especially in hot weather.

With any methods involving running water, keep the pressure and flow of water low enough to avoid washing away the surface of the newly placed concrete.

4.2.1.3 Absorptive coverings—Concrete may also be cured by covering it with wet burlap, blankets, or cotton mats. These coverings can be hung to cover vertical surfaces, as well as horizontal surfaces. These materials should be kept wet during the entire curing period. Burlap should be heavy-weight and should be thoroughly rinsed before use. Overlap the strips of burlap about half their width to provide a double layer. Burlap and other absorbent materials can be used on vertical surfaces as well.

4.2.1.4 Steam—Steam curing can be a suitable method of curing for precast concrete, especially in cold weather. Use atmospheric pressure procedures. Refer to ACI 517.2R for a complete description of steam curing procedures.

4.2.1.5 Plastic films—Concrete slabs-on-grade and walls may be cured by covering them with 6 mil (0.15 mm) plastic sheets securely anchored at the edges and overlaps.

4.2.1.6 Curing compounds—Use curing compounds only when the other methods described in this report are either impossible, or economically impractical. Curing compounds should be sprayable, with a high solids content (18 percent minimum), and should be placed at twice the manufacturer’s recommended rate. Do not apply curing compounds on surfaces expected to bond with subsequently placed concrete or with other materials such as coatings or sealants.

4.2.1.7 Duration—Concrete should be cured for at least seven days.

4.2.2 Cold-weather concrete—In cold weather, concrete should be cured and protected from freezing as recommended by ACI 306R. Use the ACI 306.1 standard specification for specifying cold weather curing and protection. That standard also provides guidance on minimum durations for maintaining the protection. As with other structures falling under ACI 350R guidelines, calcium chloride should not be used as a concrete admixture. Excessive chloride quantities promote corrosion of the reinforcing steel. See ACI 318 for chloride limits.

4.2.3 Hot weather concrete—In hot weather, concrete should be cured and protected from exposure to the sun. Use ACI 305R. Wood or metal forms remaining in place should not be considered a satisfactory means of curing. Forms should be covered and kept moist. Loosen the forms as soon as possible without damaging the concrete and run the curing water down the inside of the forms.

4.3 Inspection

Inspect the following items during construction. See ACI SP-2 (ACI 311.1R) for guidance on inspection procedures.

4.3.1 Subgrade preparation—Check compaction and verify proper grade.

4.3.2 Reinforcing steel—Inspect reinforcement size, grade, spacing, minimum concrete cover, proper location and height of supports, splices, cleanliness, and condition of any protective coatings.

4.3.3 Post-tensioning tendons—Check size, spacing, profile and condition of sheathing of unbonded tendons and location and condition of ducts and grouting of bonded tendons.

4.3.4 Waterstops—Look for proper placement of waterstops including alignment. Inspect the ties of PVC waterstops (when used) to supports for adequacy to maintain proper alignment of the waterstop during concrete placement. Also, check the welds of PVC waterstops, when used.

4.3.5 Joints—Verify that joint preparation is complete when placing new concrete against previously placed or existing concrete.

4.3.6 Formwork—Check line and grade.

4.3.7 Inserts—Verify condition and location of penetrations and inserts are proper, including their sealants and waterstops.

4.3.8 Concrete—Check mix proportions, including admixture dosages (at the batch plant) and time from plant to site.

4.3.9 Concrete Placement—Inspect placing techniques and consolidation, including placement around waterstops and embedded items.

4.3.10 Curing—Be sure curing requirements and conditions are being met.

4.3.11 Miscellaneous—Verify that any special requirements for placing are being met.

4.3.12 Concrete testing—Concrete testing should be according to the requirements of ACI 301.

5.1 Liners

Liners can function as either the primary or secondary containment, depending upon the type of installation and the location of the liner within the installation.

A liner should exhibit good chemical resistance to deterioration and compatibility with the hazardous material.

5.2 Liner materials

Many different types of liner materials can be used. In some cases, the material has been specifically developed for
an application. In others, the material has been adopted due to its specific properties.

In general, all liner materials that can be used for primary containment are also suitable for secondary containment. As with primary liners, each use is project specific.

Additional discussion of liners used as primary or secondary containment and as part of a leak detection system is given in Chapters 6 and 7, respectively.

Liner materials may be categorized as follows:

5.2.1 Metallic—Metal plate liners are suitable for many applications. The wide range of metals available makes this alternative attractive. For instance, carbon steel may be used to line caustic tanks, trenches and sumps. Since the liner is usually thin (for economic reasons), the liner usually cannot stand without structural support. Fastening the liner to the concrete walls of the structure (see Fig. 5.1) solves this problem. Consider the details of fastening carefully, to prevent leakage and to account for all stresses, including thermal. Corrosion protection of metallic liners should also be considered.

5.2.2 Geomembrane materials—This group of liner materials includes geomembranes consisting of flexible thermoplastic or thermoset polymeric materials or combinations thereof.

Many types of geomembranes are available. They range in thickness from 30 to 100 mil (0.75 to 2.5 mm). Some geomembranes have a reinforcing scrim (grid) made of woven polyester or polypropylene filaments. The materials are manufactured in large sheets or panels, and are joined or seamed together using heat or chemical welding techniques.

Other specialty products are made of polyethylene. These include sheets, ranging from 50 mil (1.5 mm) to 2 in. (50 mm) thick. Thick sheets are joined at the seams by extrusion welding. These materials work well for lining the interior of concrete sumps or pipes.

The most widely used types of geomembranes include polyethylene (PE), high-density polyethylene (HDPE), polyvinyl chloride (PVC), and chlorosulfonated polyethylene (CSPE).

Thermosets include polyester, vinylester, derakane, furan, and epoxy resins made into fiber-reinforced plastic (FRP) sheets, pre-formed sections, or applied in place. These materials are generally best in high-temperature, aggressive acid service. They may be relatively brittle and may have high thermal expansion coefficients compared to steel and concrete. Their use as liners for concrete installations can be difficult due to the problems of fastening. Therefore, they are often used as bonded coatings.

5.3—Coatings

When the material contained in the primary system is highly aggressive to concrete, a coating may be appropriate. Coating systems include materials such as paints, mortars, liquefied rubbers, and resins. Some coating systems incorporate reinforcing scrims applied in multiple layers. Other coating systems include vitrified clay tile and acid-proof and chemical-resistant mortar.

Application methods include brushing, spraying, rolling, troweling, and shotcreting. These depend on the material and the type of installation. In coating systems, the bond to the concrete (see ASTM C 811) and the curing conditions are critical. Take care to understand and follow the manufacturer’s recommendations.

See ACI 515.1R for additional information on coatings.

5.4—Design and installation considerations for liners and coatings

5.4.1 Testing for compatibility—Compatibility of the liner or coating material with the contents is the primary design consideration. Compatibility tests between the contents and liner or coating materials, including fabricated seams, should be performed. These tests should simulate the actual operational conditions, pH, temperature, pressure, and other service conditions as closely as possible. Vendor literature and past case history are good starting points for information, but actual testing should definitely be considered. Testing may take up to six months to complete; therefore, the testing should be initiated as early in the design process as possible. Accelerated testing procedures may be available, but exercise caution in use and interpretation of the results.

Perform liner or coating immersion and other tests, see ASTM C868, C870, D1474, D1973, D2197, D2370, D2485,
D3456, D4060, D5402, and D5322, with the hazardous material to be contained when using the liner or coating for primary containment.

When using a liner or coating for secondary containment, perform liner or coating immersion and other tests (see Chapter 8) with the sump contents, and perform liner burial testing in the substrate on which the liner will be placed.

5.4.2 Thermal effects—Liner or coating materials may have a much different coefficient of thermal expansion than the concrete support structure or substrate on which they are installed. Consider the amount of the potential expansion/contraction differential movement between the liner or coating and the support structure or substrate. This affects the design of the liner fastening or anchorage system, the liner joints or seams, and the integrity of the bond between the coating and the concrete.

5.4.3 Fasteners and joints—Fastening points and joints are typically the weak links in the integrity of a lining system. Every fastening device that penetrates the liner and every joint is a potential leak point. This includes metal batten strips that mechanically anchor the liner to the support structure. Seal each of these potential leak points. For geomembranes, weld cap strips of the liner material over the penetrating fasteners or the non-welded joints. When possible, use concrete inserts made of liner material to fasten the liner to the concrete (see Fig. 5.1).

5.4.4 Ultraviolet light resistance—Ultraviolet (UV) light may attack or degrade the thermoplastic and thermoset liners unless UV light stabilizers have been added during the liner manufacture. If the liner is going to be covered after installation, UV light protection is not as critical; however, protection may be required during construction.

5.5—Inspection and testing of liners and coatings

5.5.1 General—Inspection and testing of the liner or coating material should start right after the selection of the manufacturer of the product and continue through its installation.

Written certification of the manufacturer’s inspection and testing should ensure that the liner or coating meets the project specifications. Similar certification should also be required from anyone who works on or adds to the product before shipping it to the end user. Inspections of the manufacturer or fabrication plant by the design engineer may also be warranted.

Inspection and testing during installation should include, but not be limited to, the following: substrate condition, the condition of the liner, joints or seams, and fastenings or anchorages.

Non-destructive and destructive testing methods are available where applicable, both at the factory and on-site, during and after installation is complete.

5.5.2 Non-destructive test methods—There were no ASTM standards for the following tests known to ACI Committee 350 at the time of publication of this report.

5.5.2.1 Hydrostatic test—This test is mainly used to test the integrity and liquid-tightness of the concrete structure. The structure should be hydrostatically tested before the application of liners or coatings. Use hydrostatic testing to test the liner material as well, when applicable. Fill the lined structure with water and measure the level drop over a specified period to detect if any leakage has occurred. Consider the effects of evaporation. See ACI 350.1R for additional guidance on hydrostatic testing, which can take several days.

5.5.2.2 Electric current tests—These tests use an electrical current to verify continuity of the liner. These types of test systems can also be used as leak-detection systems while the structure is in service. In spark testing, an electric current is passed through the liner. A spark should be seen wherever holes or “holidays” are present. Use this technique on thermosets, thermoplastics, and coating systems.

5.5.2.3 X-ray testing—X-ray testing is most effective on metals but may also be used with some success on thermosets and thermoplastics.

5.5.2.4 Ultrasonic testing—Ultrasonic testing may be used for metal, thermoset, and thermoplastic materials and joints.

5.5.2.5 Vacuum testing—Vacuum testing can be done on joints or seams to evaluate their integrity. Vacuum testing may be used on metals, thermosets, and thermoplastic liners.

5.5.2.6 Air pressure testing—Air pressure testing is done on structures intended to be air-tight by pressurizing the structure, or a portion of it, and checking for a loss in pressure over a specified period. Use low air pressure and perform the test with extreme caution. The structural design should consider the test pressure.

5.5.2.7 Air lance testing—The air lance testing method uses a high-pressure air stream directed at the seam in the liner to detect loose edges. This test is used on some types of geomembrane installations.

5.5.3 Destructive test methods—Destructive testing of liners involves cutting test coupons from the joints or seams and the liner material. These coupons may be subjected to a variety of tests as described below. There were no ASTM standards for the following tests known to ACI Committee 350 at the time of publication of this report.

5.5.3.1 Tensile test—Tensile tests are used to check tensile strength of the joints, seams and the material. This test is used on metals, thermosets, and thermoplastics.

5.5.3.2 Tear test—Tear tests are used to check the tear strength of the material, especially thermoplastics.

5.5.3.3 Peel test—The peel (or bond) test is used to check the peel strength of the joints or seams and bond strength of coating systems to the substrate. This test is used on thermosets, thermoplastics and coating systems.

CHAPTER 6—SECONDARY CONTAINMENT

6.1—General

A secondary containment system should prevent any primary-containment leak from escaping to the environment. The secondary containment system should either retain such a leak until it is removed or should direct the leaked material to a predetermined and controllable drainage channel or sump.

Secondary containment systems are normally dry in service. These systems include apron slabs and trenches.
Secondary containment, even if not required by regulation, is recommended for environmental tanks, sumps, and underground piping systems that store, treat, or transport hazardous materials.

The design recommendations for secondary containment structures constructed of reinforced concrete are usually less stringent than those for primary containment. However, if the secondary containment structure is required to have the same reliability and performance as the primary containment structure, use the design recommendations for primary containment structures for the design of the secondary containment structure.

6.2—Secondary containment system features

6.2.1 Chemical compatibility—Chemical compatibility is required to prevent failure of the secondary containment system due to physical contact with both the materials contained and with the substrate on which they are installed. The secondary containment system need not necessarily be suitable for prolonged contact with the hazardous material. This is because the hazardous material can be removed and the leak in the primary containment system located and repaired.

Secondary containment systems also should not fail due to climatic conditions, nor to settlement, or stress of daily activity such as cleaning, flushing, or pedestrian or vehicular traffic.

6.2.2 Leak-detection systems—See Chapter 7 for information on leak-detection systems.

6.3—Secondary containment materials

The secondary containment system may be constructed of the same material as the environmental tank or sump, such as concrete inside concrete. It may also be constructed of different materials, such as concrete inside polyethylene (see Fig. 6.1).

Secondary containment materials include concrete, metals, thermoplastics, thermosets, composites and native soils, compacted clays, bentonite, or other soil mixtures, with low permeability \(1 \times 10^{-7} \text{ cm/sec}\).

The secondary containment system should be designed to the structural criteria given in this report. However, it may not require long-term compatibility with the contents if a spill or leak will be cleaned up within a short time. This may allow the construction material for the secondary containment to be less expensive than that used for the primary containment.

When small sumps are required, commercially available prefabricated metal sumps or precast manholes may be applicable (see Fig. 6.2). These may be used for primary containment, secondary containment, or both. The prefabricated shapes may also be used to retrofit an existing sump or manhole.

Flexible membrane liners, also known as geomembranes, may be used on the outside of the tank or sump as the secondary containment (see Fig. 6.3). External liners may need protection from damage by backfilling or from UV rays.

CHAPTER 7—LEAK DETECTION SYSTEMS

7.1—General

Leak-detection systems are recommended for tanks and sumps that contain a hazardous material, or that may do so in the future. A leak-detection system should be far less expensive to install during the construction of a new facility, than during the retrofit of an existing facility. It may also help save the costs of cleanup and regulatory penalties.
Leak-detection systems should be able to detect leakage in the primary containment system as soon as feasible after the initiation of a leak. The detection should occur not later than 24 hr after initiation of the leakage but before a breach or overflow occurs in the secondary containment system.

Recommended leak-detection systems are those that rely on visual inspection of the system and gravity flow of the leakage. Other leak-detection systems use instruments to detect and sometimes to pinpoint the location of leaks. These instruments range from gas monitors to single probes or installed grid systems. The probes and grids measure thermal or electrical conductivity, or electrical resistivity.

Any leak-detection system using drainage media should be compatible with the hazardous material contained. Long-term compatibility of the drainage medium may not be required if the hazardous material can be removed from medium contact shortly after the leakage occurs. This may allow for the use of a less expensive drainage medium material. If leakage enters the drainage medium, the system should be thoroughly flushed and cleaned before returning the medium to service. If cleaning the system is very difficult or economically impractical, consider replacement of the drainage medium, or conversion to a leak-collection system.

Leak detection systems are only as good as their general design and the location of the actual leak detection points or devices. The designer should take great care in providing a path of travel through drainage media, or along slabs or trenches, for the contained material to travel to the point of detection. Finally, cathodic protection, if used, may affect the design of the leak detection system.

### 7.2—Drainage media materials

Drainage netting, or drainage cell (usually called geonet or geocell, respectively) is a highly permeable “net” or “cellular” material, typically made from polyethylene. Drainage netting may be installed in single or multiple layers.

Place a geotextile above the net or cells to act as a filter. This keeps out soil particles or other debris. Non-woven geotextiles (typically made from polypropylene or polyester) of either the heat bonded or needle punched variety are typically used. The heat-bonded materials are stiffer and impinge less on the geonet or geocell flow channels. The needle punched materials are typically more permeable and less susceptible to clogging. Some nets and cells come with the geotextile attached to one or both sides and are called a composite or double composite, respectively.

A granular material with high permeability, such as coarse-graded sand (size No. 1, ASTM C 404), pea gravel (size No. 8, ASTM C 33), or a mixture of both, can be an effective drainage medium. These materials are typically placed in layers 6 to 12 in. (150 to 300 mm) thick. A well-graded mixture is more stable underfoot and less affected by washout than sand or ungraded gravel alone. Not more than 5 percent should pass the No. 200 sieve.

Do not use geotextiles alone, due to the compressibility of these materials under sustained loads.

### 7.3—Design and installation of drainage media

#### 7.3.1 Under tanks and sumps

Slope geonet, geocell, or granular material under tanks and sumps to one or more low points for collection of any leakage. A minimum slope of 3 percent is recommended for earthen or flexible membrane surfaces, and 2 percent for concrete surfaces (see Fig. 7.1).

#### 7.3.2 Collection pipes

Where a granular material drainage medium is used for a tank, or large sump, perforated collection pipes are recommended if leaked material must travel more than 50 ft. (15 m). The pipes should be 4 to 6 in. (100 to 150 mm) in diameter and installed radiating from low points. Cover the pipes with a granular envelope. The gradation of the granular material should be such that the ratio \( D_{85}/D_p \geq 2 \), where \( D_{85} \) is the sieve opening dimension smaller than 85 percent of the sample and \( D_p \) is the diameter or least dimension of the pipe perforation. If the drainage medium includes sand or other fines, the pea gravel envelope can be wrapped with a geotextile filter to further protect the pipe from clogging. The geotextile should be the same as those described in Section 7.2.

Where geonets or geocells are used, collection pipes may not be needed. This is due to the good flow characteristics of the geonet or geocell.

On small sumps, where sand or pea gravel is used as the drainage medium, the collection pipes may be eliminated. This is due to the short flow distances involved.

#### 7.3.3 Risers

Manholes or perforated riser pipes should be installed at the low point(s) of the drainage medium or collection pipes (see Fig. 7.2). Using a manhole or riser allows for periodic sampling of any liquid or gas that may collect in the system. The riser should be large enough to allow for the monitoring and sampling device or recovery pumping.

### CHAPTER 8—REFERENCES

#### 8.1—Recommended references

Documents of various standards-producing organizations referred to in this document are listed below with their serial designation. Since some of these documents are revised frequently, generally in minor detail only, the user of this document...
Fig. 7.2—Double-walled sump with leak detection system

should check directly with the sponsoring group for the latest revision, if necessary.

American Concrete Institute (ACI)
201.2R Guide to Durable Concrete
216R Determining the Fire Endurance of Concrete Elements
223 Standard Practice for the Use of Shrinkage-Compensating Concrete
224R Control of Cracking in Concrete Structures
224.3R Joints in Concrete Construction
301 Specifications for Structural Concrete
305R Hot Weather Concreting
306.1 Standard Specification for Cold Weather Concreting
306R Cold Weather Concreting
308 Standard Practice for Curing Concrete
311.1R SP-2: ACI Manual of Concrete Inspection
318 Building Code Requirements for Reinforced Concrete and
318R Commentary on Building Code Requirements for Reinforced Concrete
372R Design and Construction of Circular Wire and Strand Wrapped Prestressed Concrete Structures
373R Design and Construction of Circular Prestressed Concrete Structures with Circumferential Tendons
350R Environmental Engineering Concrete Structures
350.1R Testing Reinforced Concrete Structures for Watertightness
360R Design of Slabs on Grade
504R Guide to Joint Sealants for Concrete Structures

515.1R Guide To The Use of Waterproofing, Damp-proofing, Protective and Decorative Barrier Systems For Concrete.
517.2R Accelerated Curing of Concrete at Atmospheric Pressure

American Society For Testing And Materials (ASTM)
C 33 Specification for Concrete Aggregates
C 404 Specification for Aggregates for Masonry Grout
C 811 Specification for Preparation of Concrete for Application of Chemical-Resistant Resin Monolithic Surfacings
C 845 Specification for Expansive Hydraulic Cement
C 868 Test Method for Chemical Resistance of Protective Linings
C 870 Practice for Testing Water Resistance of Coatings Using Water Immersion
C 878 Test for Restrained Expansion of Shrinkage-Compensating Concrete
C 913 Specification for Precast Concrete Water and Wastewater Structures
C 920 Specification for Elastomeric Joint Sealants
D 1474 Test Method for Indentation Hardness for Organic Coatings
D 2197 Test Method for Adhesion of Organic Coatings by Scrape Adhesion
D 2370 Test Method for Tensile Properties of Organic Coatings
D 2485 Test Method for Evaluating Coatings for High Temperature Service
D 3456 Practice for Determining by Exterior Exposure Tests the Susceptibility of Paint Films to Microbiological Attack
D 4060 Test Method for Abrasion Resistance of Organic Coatings by Taber Abraser
D 5402 Practice for Assessing the Solvent Resistance of Organic Coatings Using Solvent Rubs
D 5322 Practice for Immersion Procedures for Evaluating the Chemical Resistance of Geosynthetics to Liquids

American Water Works Association (AWWA)
D110 AWWA Standard for Wire and Strand Wrapped Circular Prestressed Concrete Water Tanks
D115 AWWA Standard for Circular Prestressed Concrete Water Tanks With Circumferential Tendons

National Fire Protection Association (NFPA)
NFPA 49 Hazardous Chemical Data
NFPA 325 Fire Hazard Properties of Flammable Liquids, Gases and Solids
The above publications may be obtained from the following organizations:

American Concrete Institute (ACI)
P.O. Box 9094
Farmington Hills, MI 48333-9094

American Society For Testing And Materials (ASTM)
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959

American Water Works Association (AWWA)
6666 West Quincy Ave.
Denver, CO 80235

National Fire Protection Association (NFPA)
Batterymarch Park
P.O. Box 9101
Quincy, MA 02269-9959

8.2—Cited References


This report was submitted to letter ballot of the committee and was approved in accordance with ACI balloting procedures.