

Concrete Structures for Containment of Hazardous Materials

Reported by ACI Committee 350

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This report presents recommendations for structural design, materials, and construction of structures commonly used for hazardous materials containment, including reinforced concrete tanks, sumps, and other structures that require dense, impermeable concrete with high resistance to chemical attack. The report discusses and describes design and spacing of joints, proportioning of concrete, placement, curing, and protection against chemicals. Information on liners, secondary containment systems, and leak-detection systems is also included.

Keywords: construction joint; joint; joint sealant; precast concrete; prestress; water-cementitious material ratio; waterstop.

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ACI 350.2R-04 supersedes ACI 350.2R-97 and became effective June 28, 2004.
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CHAPTER 1—GENERAL

1.1—Scope

This report is intended for use in the structural design and construction of hazardous material containment systems. Hazardous material containment structures require secondary containment and, sometimes, leak-detection systems. Because of the economic and environmental impact of even small amounts of leakage of hazardous materials, both primary and secondary containment systems should be virtually leak free. Therefore, when primary or secondary containment systems involve concrete, special design and construction techniques are required. This report supplements and enhances the requirements of ACI 350, which is intended for structures commonly used in water containment, industrial and domestic water, and wastewater treatment works. ACI 350, however, does not give specific guidance on the design of the double containment systems, leak-detection systems, or the additional recommendations for enhancing liquid-tightness covered in this report. This report does not apply to

primary or secondary containment of cryogenic liquids, nonliquid materials, or to systems containing radioactive materials.

The use of 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based on the best technical knowledge available at the time they were written; however, they may be supplemented or superseded by applicable local, state, and national regulations. Therefore, it is important to research such regulations (see Section 8.1) 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.

Proper and thorough inspection of construction is essential to ensure a quality final product. The written program for inspection should be detailed and comprehensive, and should be clearly understood by all parties involved. See Section 4.3 for an inspection checklist. (See ACI 311.4R for guidance in inspection programs.) A preconstruction conference to discuss the program in detail is recommended. Personnel should be qualified, experienced, and certified as applicable to their specialty.

1.2—Definitions

The definitions in Sections 1.2.1 through 1.2.11 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.

NOTE: 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 degreasing 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 with self-supporting, watertight walls constructed of nonearthen material.

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 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 liquid from accidental spillage of hazardous material. It 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 Primary containment system—A primary containment system is the first containment system in contact with the hazardous material.

1.2.8 Secondary containment system—A secondary containment system is a backup system for containment of hazardous materials in case the primary system leaks or fails for any reason.

1.2.9 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.

1.2.10 Spill- or leak-detection system—A spill- or leak-detection system detects, monitors, and signals a spill or leakage from the primary containment system.

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

1.3—Types of materials

This report provides guidance for the design and construction of environmental tanks and sumps of reinforced concrete construction. Tanks may be constructed of prestressed or nonprestressed reinforced concrete, or steel or other materials with concrete foundations, 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 are made of stainless or coated steel, fiber-reinforced plastics (FRP), various combinations of esters, epoxy resins, or thermoplastics.

This report outlines and discusses options for construction materials and provides recommendations for use, where applicable.

CHAPTER 2—CONCRETE DESIGN AND PROPORTIONING

2.1—General

Concrete is particularly suitable for above- and below-grade environmental primary and secondary containment systems. When properly designed and constructed, concrete containment systems are impermeable and highly resistant to failure during fires. See ACI 216R, CRSI (1980), and Zwiers and Morgan (1989) for information on exposure of concrete to elevated temperatures.

Concrete is a general-purpose material that is easy to work with and is resistant to a wide range of chemicals. It is used in construction of both primary and secondary containment systems. The addition of pozzolans, latex, and polymer modifiers can increase concrete's resistance to chemical attack.

Measures that should be considered to help prevent cracking or to control the number and width of cracks include: prestressing, details that reduce or prevent restraint of movements due to shrinkage and temperature changes, higher than normal amounts of nonprestressed reinforcement, closer spacing of reinforcement, shrinkage-compensating

Table 2.1—Wall thickness and reinforcement locations based on concrete placement consideration

Description	Wall height	Minimum thickness	Reinforcement location
Cast-in-place concrete	Over 10 ft (3000 mm)	12 in. (300 mm)	Both faces
	4 to 10 ft (1200 to 3000 mm)	10 in. (250 mm)	Both faces
	Less than 4 ft (1200 mm)	6 in. (150 mm)	Center of wall
Precast concrete	4 ft (1200 mm) or more	8 in. (200 mm)	Center of wall
	Less than 4 ft (1200 mm)	4 in. (100 mm)	Center of wall
Description		Minimum wall thickness	
Tendon prestressed concrete tanks		See ACI 350	
Wrapped prestressed concrete tanks		See ACI 350	

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.

concrete, concrete mixtures proportioned to reduce shrinkage, and fiber reinforcement. Additionally, some construction techniques, such as casting floors and walls monolithically (Chapter 4), help prevent or reduce cracking by eliminating the restraint of shrinkage and temperature movements of the subsequently placed concrete along the joint with the previously placed concrete. See ACI 224R and ACI 224.3R for additional information on mitigation of cracking in concrete structures.

2.2—Design

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

ACI 372R, AWWA D110, ACI 373R, and AWWA D115 provide additional guidance for the design of prestressed concrete liquid-containment structures. See ACI 223 for information and guidance on shrinkage-compensating concrete.

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

A minimum slope of 2% should be included in the design of floors and trench bottoms to prevent ponding and help drainage. Secondary containment systems for flammable and combustible liquids should have a slope that is in accordance with NFPA 30, "Flammable and Combustible Liquids Code," or an applicable fire code.

2.2.2 Wall thickness and reinforcement—The minimum wall thickness and reinforcing steel location in walls should comply with Table 2.1.

2.2.3 Footings—Footings should be cast monolithically with the floor slab to enhance liquid tightness.

Uprturned footings help reduce restraint of shrinkage and its associated cracking.

2.2.4 Slabs-on-ground

2.2.4.1 Membrane slabs—ACI 350 provides requirements for the minimum shrinkage and temperature reinforcement and, if post-tensioned, the residual prestressing requirements for membrane floor slabs. Prestressed membrane slabs should have a minimum thickness of 5 in. (125 mm). Nonprestressed membrane slabs should have a minimum thickness of 6 in. (150 mm). To enhance liquid-tightness, membrane slabs should be placed without construction joints. A membrane slab can 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. If prestressed, they should have a minimum of 200 psi (1.4 MPa) residual compression after deducting for all losses, including the effects of friction between the slab and the subgrade and after allowing for any tension tie forces. This amount of prestressing has been found to provide liquid-tightness without excessive cracking due to gradual differential subgrade settlements, shrinkage and temperature effects, or both, in slabs on properly prepared subgrade.

2.2.4.2 Pavement slabs—The term “pavement slabs,” as used in this report, denotes the particular case of slabs-on-ground designed for drainage capture and primary or secondary containment of hazardous materials when vehicle or other concentrated loads are anticipated. Pavement slabs can be either prestressed or nonprestressed and designed as plates on elastic foundations. A qualified geotechnical engineer should determine the properties of the subgrade, including soil classification and modulus of subgrade reaction. Acceptable analytical techniques include finite element, finite difference, and other techniques that give comparable results. Flexural and punching shear stresses should be used to design the conventional and prestressed reinforcement.

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 (AASHTO Standard Specification). The slab thickness for lighter wheel loads may be according to Section 2.2.4.1. The reinforcement percentage should total at least 0.5% of the cross-sectional area in each orthogonal direction, with at least one-half, but not more than two-thirds, of this amount in the upper layer. ACI 350 provides requirements for the design of flexural reinforcement, including the additional “durability factor,” where applicable.

Prestressed pavement slabs designed for vehicle loads of AASHTO H-10 or heavier should be at least 6 in. (150 mm) thick. Slab thickness 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% for primary containment and 0.15% for secondary containment in each orthogonal direction. The reinforcement is usually placed at the mid-depth 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 residual compressive stress in the slab should be at least 200 psi (1.4 MPa) after deducting strand friction, long-term losses, and losses due to friction between the slab and the subgrade. Flexural tensile stresses should not exceed $2\sqrt{f'_c}$ psi ($0.167\sqrt{f'_c}$ MPa) under service loads, unless bonded reinforcement is provided in the precompressed tensile zone. Flexure and shear requirements are given in ACI 350, Section A.3.2(b) 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.

2.2.5 Mat foundations—Mat foundations are usually 12 in. (300 mm) thick with two layers of nonprestressed reinforcement or 10 in. (250 mm) thick with prestressed reinforcement. Additional concrete thickness can be provided to help resist buoyancy, if required.

2.2.6 Minimum reinforcement for nonprestressed secondary containment—The minimum reinforcement to counter the effects of shrinkage and temperature changes for concrete used as secondary containment structures should comply with ACI 350.

2.2.7 Minimum reinforcement for nonprestressed primary containment—To counter the effects of shrinkage and temperature changes, the minimum reinforcement content for concrete used as primary containment should be 0.5% of the cross-sectional concrete area. To further limit cracking caused by restraint of free movement due to shrinkage and temperature dropping, the reinforcement parallel to a construction joint should be increased to 1.0% within the first 4 ft (1200 mm) of a construction joint in the subsequent placement (Fig. 2.1). For crack mitigation, it is preferable to use several small-diameter bars rather than fewer bars of a larger diameter. The maximum bar spacing should not exceed 12 in. (300 mm).

2.2.8 Minimum nonprestressed reinforcement for prestressed concrete—The minimum nonprestressed reinforcement in prestressed concrete containment structures should be 0.15% for secondary containment and 0.30% for primary containment when movement due to shrinkage is partially restrained, such as slabs-on-ground. It should be the same as recommended for nonprestressed concrete wherever movement due to shrinkage is fully restrained, such as when concrete is placed against and bonded to hardened concrete at a construction joint.

2.2.9 Roofs

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

2.2.9.2 Roof design—ACI 350 provides requirements for the design of domes and post-tensioned roof slabs for prestressed concrete liquid-containing structures. Roof slabs can be either prestressed or nonprestressed. Acceptable analytical techniques include finite element, finite difference, equivalent frame, and other techniques that give comparable results. Flexural and punching shear stresses should be used to design the section thickness and conventional and prestressed reinforcement.

Flat nonprestressed roof slabs should be at least 6 in. (150 mm) thick. The reinforcement percentage should total at least 0.5% of the cross-sectional concrete area in each orthogonal direction. ACI 350 provides requirements for the design of flexural reinforcement, including the additional durability coefficients where applicable. Roof slabs should be checked for long-term deflection and the potential for ponding.

Flat prestressed roof slabs should be at least 6 in. (150 mm) thick. When unbonded post-tensioning tendons are used, the nonprestressed reinforcement ratio should be in accordance with the requirements of ACI 350. The compressive stress in the slab should be at least 150 psi (1.0 MPa) after tendon friction and long-term losses and after considering the restraining effects of walls. 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. This reinforcement's design requirements are given in ACI 350 for the various bar sizes, exposure conditions, and grades of reinforcement.

2.3—Concrete cover

Reinforcement should have at least the minimum concrete cover required by ACI 350. Additional concrete cover or coatings on the concrete can be used as needed for supplemental corrosion protection.

2.4—Exposure

2.4.1 Freezing and thawing—Concrete in a saturated or near saturated condition is susceptible to damage due to freezing-and-thawing cycles. Air entrainment improves freezing-and-thawing resistance and should be specified for concrete exposed to such conditions. Resistance to freezing-and-thawing damage is also improved by measures that increase the density or reduce the permeability of the concrete.

In severe freezing-and-thawing environments, concrete should be protected from multiple freezing-and-thawing cycles or 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 harsh service conditions, reinforcement cover should be increased and, if necessary, the concrete should be provided with a corrosion-protection system. Harsh service conditions include exposure of the concrete to chemicals and materials that will have a chemical reaction with the concrete. These service conditions include exposure to certain acids and bases and high sulfate

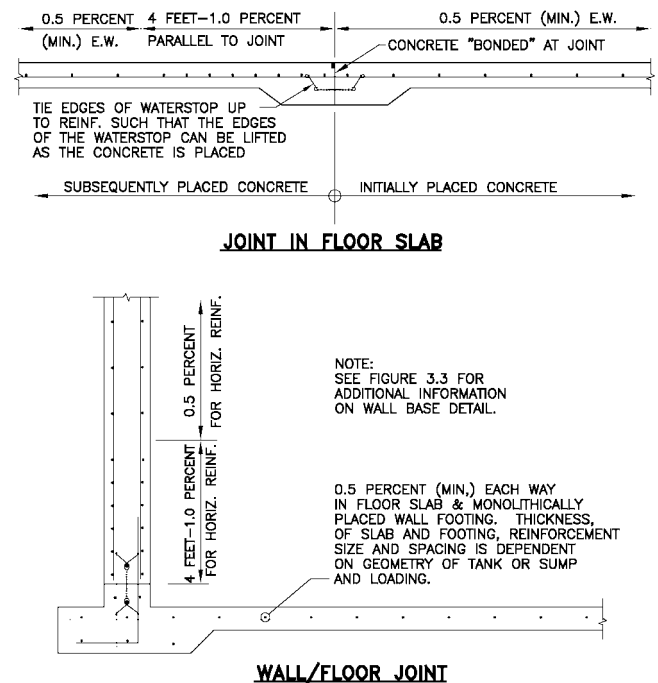


Fig. 2.1—Recommendations for increased reinforcement percentage parallel to bonded joints.

content solutions. Coated reinforcement or coated prestressing, stainless steel, or nonmetallic reinforcement should be considered in corrosive chemical applications. When using coated reinforcement, the reduction in bond strength, particularly as it may affect cracking, should be taken into account. Using a greater number of smaller diameter bars or a higher percentage of reinforcing (a higher reinforcing ratio) will reduce these effects. See ACI 201.2R for other durability considerations.

2.4.3 Chemical resistance—Some chemicals are so aggressive to concrete that the only way to provide protection for the concrete is to provide a corrosion-protection system, such as a coating or covering. The corrosion-protection system should provide not only corrosion protection but, to the maximum extent possible, the flexibility to span cracks and accommodate the expansion and contraction the concrete will experience due to moisture and temperature changes.

2.5—Concrete mixture proportions

2.5.1 Water and cementitious material—The maximum water-cementitious material ratio (w/cm) (cement plus pozzolan) should be 0.40 for primary containment and in accordance with ACI 350 for secondary containment.

Water demand for shrinkage-compensating concrete is higher than for portland-cement concrete. Refer to ACI 223, Section 4.2, for guidance on shrinkage-compensating concrete proportions.

To reduce permeability, the minimum cementitious materials content should be 700 lb/yd³ (420 kg/m³) for primary containment and 600 lb/yd³ (360 kg/m³) for secondary containment. When fly ash or other pozzolans exceed 25%

of total cementitious materials content, the designer should consider their effects on durability and chemical resistance.

2.5.2 Admixtures—Workability can 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 systems. The admixture should undergo certification, tests, or both, to confirm this requirement.

2.5.3 Compressive strength—The minimum cementitious material contents and maximum w/cm given in Section 2.5.1 should result in compressive strengths of the concrete that exceed most structural requirements and the requirements of ACI 350.

2.5.4 Air entrainment—ACI 350 provides requirements for the air entrainment of concrete.

2.6—Fiber-reinforced concrete

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

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. Only fibers that are chemically compatible with the hazardous materials contained should be used.

Fibers do not replace reinforcement. The same member sizes and minimum reinforcement apply for concrete with or without fibers.

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

2.6.2 Proportioning—The fiber ratio should follow the manufacturer's recommendations. The fibers can be added at the batch plant or the construction site. In either case, the fibers need a mixing time of at least 7 min (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 mixture proportioning. 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—Waterstops should be provided at expansion/contraction joints and where construction joints cannot be avoided. Waterstops are positioned in concrete joints to

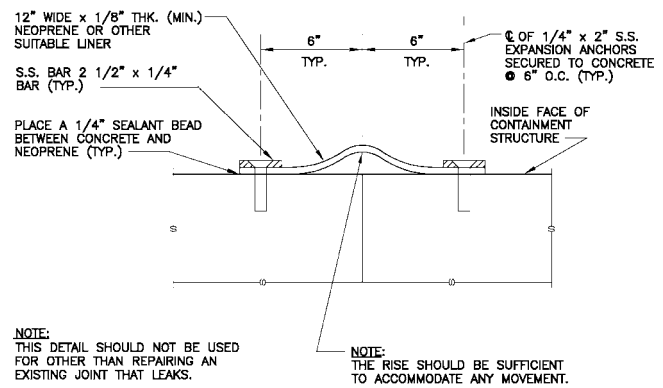


Fig. 3.1—Mechanical joint repair at an existing joint.

prevent the passage of liquid through the joint. Mechanical joints may be considered for repairing an existing joint. (See Fig. 3.1 as an example.)

3.1.2 Materials—The chemical resistance of the waterstop material, exposure, temperature, and chemical concentration of the contained material should be considered when selecting the waterstop material. Each situation should be evaluated individually, including concrete placement and concrete cover recommendations from the manufacturer.

3.1.2.1 PVC waterstops—PVC waterstops are manufactured in various sizes and many special shapes such as dumb-bell, serrated, with or without center bulb, split, and tear web. When movement across the joint is expected, serrated or ribbed profiles with center bulbs should be used. 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, which expand on contact with water, may be used in joints cast against previously placed concrete and in new construction. Adhesive type expansive rubber waterstops should only be used where joint movement is prevented. Expansive rubber waterstops expand on contact with water and may contract if permitted to dry out. Joints using such waterstops may leak until adequate moisture is present to re-expand the waterstop. Furthermore, the waterstop may not have the same expansive properties when exposed to chemicals instead of water.

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 Injectable tube systems—Injectable tube waterstopping systems can also be used in concrete environmental structures. The injected material should be compatible with the hazardous material to be contained.

3.1.2.5 Other materials—Other materials can 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 to ensure continuity and liquid-tightness. Splices should be avoided if possible. Splices for corner, tee, and cross junctions made in the factory are available for certain types of material and shapes. The