Design Considerations for Environmental Engineering Concrete Structures

Reported by ACI Committee 350

Charles S. Hanskat, Chair

Lawrence M. Tabat, Secretary

James P. Archibald*	William Irwin§	Jerry Parnes
Jon B. Ardahl†	Keith W. Jacobson	Andrew R. Philip§
John W. Baker	Dov Kaminetzky	Narayan M. Prachand
Walter N. Bennett‡	M. Reza Kianoush	Satish K. Sachdev‡
Steven R. Close	David G. Kittridge	William C. Schnobrich
Anthony L. Felder	Dennis C. Kohl	John F. Seidensticker
Carl A. Gentry§	Nicholas A. Legatos	William C. Sherman§
Clifford Gordon‖	Larry G. Mrazek	Lawrence J. Valentine
Paul Hedli	Javeed A. Munshi	Miroslav Vejvoda
Jerry A. Holland		Paul Zoltanetzky, Jr.

*Committee Secretary while this document was being prepared.
†Committee Chair while this document was being prepared.
‡Co-chair of subcommittee that prepared this document.
§Members of subcommittee that prepared this document.
‖Deceased.

Environmental engineering concrete structures provide conveyance, storage, and treatment of water, wastewater, and other materials. This report outlines special design considerations such as loads, stability, joint details, and special design conditions that are unique to these types of structures as well as ancillary structures.

Keywords: buoyancy; clarifier; contraction; design; expansion; filler; flood; flotation; forces; hazardous; ice; impact; joint; load; overturning; reservoir; safety; sealant; sliding; stability; tank; tension; torque; vibration; waterstop; weights.

TABLE OF CONTENTS

ACI 350.4R-04 became effective February 27, 2004.

CHAPTER 1—GENERAL

1.1—Scope

This report outlines design considerations that are unique to environmental engineering concrete structures and associated buildings. Environmental engineering concrete structures are defined in ACI 350 as concrete structures intended for conveying, storing, or treating water, wastewater, or other nonhazardous liquids, and for the secondary containment of hazardous liquids. Applicable building codes and other industry standards should be consulted for load and design considerations not included herein. The engineer should check with the local building department to confirm the applicable building code for the project location and determine if there are any local amendments.

The structural design recommendations given herein should be regarded as common industry practice and are recommended for general use. Any special structural features, unusual loading conditions, or unusual exposure conditions may require special design considerations to achieve a higher level of performance than implied by these minimum recommendations.

1.2—Related documents

Environmental engineering concrete structures should be designed and constructed in conformance with ACI 350/350R, 350.1, 350.2R, and 350.3. References 1 through 3 may also be useful in the design of liquid-containing structures.

CHAPTER 2—DESIGN LOADS

2.1—Floor live loads

Floor live loads in equipment and process areas generally take into account fixed equipment weights, stored material loads, and normal live loads due to personnel and transient loads. Floor live loads should account for installation, operation, and maintenance of equipment, and possible modifications or changes in use.

During installation or maintenance, portions of equipment may be laid down at various locations on the floor. For example, heavy electrical equipment may be temporarily placed near the center span of a floor during installation or maintenance, even though its final location may be near support locations. Weights of concrete bases for equipment may also be included in floor live loads, and consideration should be given to weights of piping, valves, and other equipment accessories that may be supported by the floor slab. Consequently, conservative uniform live loads are recommended.

Information on estimated equipment weights and footprints should be obtained so that design floor live loads can be verified. The engineer may consider distribution of the equipment loads over an area greater than the footprint dimensions using engineering judgment. Because actual equipment weights from various equipment suppliers may vary, conservative estimates of equipment weights should be used. A minimum floor live load of 150 lb/ft^2 (7.2 kPa) is commonly used for slabs that support equipment. Heavier live loads are common in electrical equipment rooms. Generally, stairways and walkways should be designed for a minimum live load of 100 lb/ft^2 (4.8 kPa). Where loads on catwalks are expected to be limited, a minimum live load of 40 lb/ft^2 (1.9 kPa) may be used in accordance with ASCE 7.

Large pieces of equipment may be assembled in their final fixed location. While temporary laydown of individual pieces of equipment should still be considered, it may be permissible to consider the total weight of the equipment only in its fixed location on the floor. Additionally, operational loads should be considered with the equipment in its fixed location. Operational loads may include thrusts, torques, contained fluids or sludge, or impact. For example, supports for vertical turbine pumps should include the weight of the vertical column of water in the riser, and sludge press loads should include the weight of the sludge being processed in the press.

In areas where chemicals or other materials are stored, the maximum weight of stored material should be determined based on the height and density or specific gravity of the material and its container(s). The material densities listed in Table 2.1(a) and (b) may be used for estimating applicable loads. ASCE 7 may be referenced for other common material densities and floor live loads. Chemicals can be delivered and stored by a variety of methods and mediums, including bags, barrels, bottles, cylinders, drums, kegs, pails, rail cars, sacks, totes, or trucks. The engineer should confirm the delivery method and storage method for design.

Caution should be used in applying floor live load reductions as permitted by building codes, due to the greater likelihood of simultaneous distributed loading in some equipment and chemical storage areas. Consider the potential change of use of adjacent areas when setting the floor live load. It is preferable to use the same design live load in adjacent areas where practical. Floor live loads should be posted as indicated in the applicable building code and should be identified on the design drawings.

2.2—Contained fluid and sludge loads

The principal applied loads on liquid-containment structures are due to the fluid pressures on the walls and slabs caused by the contained fluids. The following densities are conservative values for calculating equivalent fluid pressures of common environmental materials encountered that may be used in structural design:

- Raw sewage 63 lb/ft^3 (1000 kg/m^3)

- Grit excavated from grit chamber 110 lb/ft^3 (1800 kg/m^3)
- Digested sludge, aerobic 65 lb/ft^3 (1000 kg/m^3)
- Digested sludge, anaerobic 70 lb/ft^3 (1100 kg/m^3)
- Thickened or dewatered sludge 63 to 85 lb/ft^3 (1000 to 1400 kg/m^3) (depending on moisture content)

Fluid loads should be considered for both the normal fluid levels and for the worst-case fluid level. One such worst-case design condition is where the fluid is at the top of the containment structure or at the level at which overflow would occur elsewhere in the hydraulic system, such that high fluid levels could not occur at the location being evaluated. Many liquid-containment structures have encountered such overflow conditions in the past. The code-required load factors and environmental durability factors apply to normal maximum fluid levels. Code-required

Table 2.1(a)—Densities in inch-pound units of chemical for structural design (refer to Reference 4 for listing of selected chemicals)

Chemical	Density, lb/ft^3	Chemical	Density, lb/ft^3
Acetic acid	65 (liquid)	Fluosillicic acid	79 (liquid at 30%)
Activated carbon	Powder 8 to 28; average 12	Hydrochloric acid	73 (liquid at 35%)
Activated silica	Approximately 90 (liquid)	Hydrofluoric acid	73 (liquid at 55%)
Alum, liquid	83 (liquid at 60 °F)	Hydrogen peroxide	75 (liquid at 50%)
Aluminum ammonia sulfate	70 (granular or powder)	Methanol	98 (liquid)
Aluminum chloride solution	72 (liquid)	Oxygen	71 (liquid)
Aluminum potassium sulfate	70 (granular or powder)	Phosphoric acid	98 (liquid at 75%)
Aluminum sulfate	60 to 75 (granular, powder); 84 (liquid at 50%)	Polyaluminum chloride	91 (liquid at 5%)
Ammonia, anhydrous	43 (liquid at –28 °F)	Polyelectrolyte or polymer	Dry 88; liquid 62 to 92
Ammonia, aqua (ammonium hydroxide)	56 (liquid at 60 °F)	Polyphosphate (zinc orthophosphate)	80 to 100 (liquid)
Ammonia silicoflouride	80 (crystals)	Potassium aluminum sulfate	67 (crystals)
Ammonium aluminum sulfate (ammonium alum)	75 (crystals)	Potassium permanganate	102 (powder); 64 (3% solution)
Ammonium sulfate	60 (damp); 49 to 64 (dry) (crystals)	Sodium aluminate	High-purity 50; standard 60 (powder, crystals); 98 (45% solution)
Barium carbonate	52 to 78 (powder)	Sodium bicarbonate	62 (granular, powder)
Bentonite	Powder 45 to 60; granules 75	Sodium bisulfate	70 to 85 (powder, crystals)
Bromine	194 (liquid)	Sodium carbonate (soda ash)	Dense 65; medium 40; light 30 (granular, powder)
Calcium carbonate	Powder 35 to 60; granules 115	Sodium chloride	Rock 60; crystal 78; powder 66
Calcium hydroxide (hydrated lime)	20 to 50 (powder)	Sodium chlorite	80 (25% solution)
Calcium hypochlorite	Granules 80; powder 32 to 52	Sodium fluoride	Powder 65 to 100; granules crystal 106
Calcium oxide (quick lime, pebble lime)	55 to 70; 60 typical hopper load (pebbles)	Sodium fluorosilicate	72 (powder)
Carbonic acid (carbon dioxide solution)	62 (liquid)	Sodium hexametaphosphate (sodium polysulfate)	Glass 64 to 100; powder and granular 44 to 60
Chlorinated lime	50 (powder)	Sodium hydroxide	Pellets 70; flakes 46 to 62; 95 (50% solution)
Chlorine	92 (liquid)	Sodium hypochlorite	76 (liquid at 15%)
Citric acid	77 (liquid at 50%)	Sodium silicate	88 (liquid)
Copper sulfate	Crystal 90; powder 68	Sodium silicoflouride	Granular 85 to 105; powder-granular 60 to 96
Diatomaceous earth	Natural 5 to 18; calcined 6 to 13; flux-calcined 10 to 25 (fibrous material)	Sodium sulfate	70 to 100 (crystals, powder)
Disodium phosphate	Crystal hydrate 90; anhydrous 64	Sodium sulfite	Powder 80; granular 107; liquid 82 (at 12.5%)
Dolomitic hydrated lime	30 to 50 (powder)	Sodium thiosulfate	60 (granules, crystals)
Dolomitic lime	Pebble 65; ground or lump 50 to 65; powder 37 to 65; average 60	Sulfur dioxide	89.6 at 32 °F (liquid)
Ferric chloride	93 (liquid); crystal 64; anhydrous 45 to 60	Sulfuric acid	115 (liquid)
Ferric sulfate	72 (granular)	Tetrasodium pyrophosphate	Crystal 50 to 70; powder 46 to 68
Ferrous chloride	86 (liquid at 35%)	Trisodium phosphate	Crystal 60; monohydrate 65; anhydrous 70
Ferrous sulfate	66 (granular, powder)		

factors intended to improve durability may not be applicable to worst-case load conditions.

For enclosed liquid-containment structures, consideration should also be given to internal positive or negative air pressures caused by rapid filling or emptying of the containment structure. Positive and negative air pressures can also be caused by induced ventilation, such as for odor control. The worst-case design for negative pressure may be due to pipe rupture and rapid drawdown of the tank contents, and the maximum positive pressure is related to the maximum fill rate of the equipment. Generally, suitably sized gooseneck vents should be provided at top slabs to alleviate significant variations in

Table 2.1(b)—Densities in metric units of chemicals for structural design (refer to Reference 4 for listing of selected chemicals)

Chemical	Density, kg/m^3	Chemical	Density, kg/m^3
Acetic acid	1000 (liquid)	Fluosillicic acid	1300 (liquid at 30%)
Activated carbon	Powder 100 to 450; average 190	Hydrochloric acid	1200 (liquid at 35%)
Activated silica	Approximately 1400 (liquid)	Hydrofluoric acid	1200 (liquid at 55%)
Alum, liquid	1300 (liquid at 16 °C)	Hydrogen peroxide	1200 (liquid at 50%)
Aluminum ammonia sulfate	1100 (granular or powder)	Methanol	1600 (liquid)
Aluminum chloride solution	1200 (liquid)	Oxygen	1100 (liquid)
Aluminum potassium sulfate	1100 (granular or powder)	Phosphoric acid	1600 (liquid at 75%)
Aluminum sulfate	960 to 1200 (granular, powder); 1300 (liquid at 50%)	Polyaluminum chloride	1500 (liquid at 51%)
Ammonia, anhydrous	690 (liquid at –33 °C)	Polyelectrolyte or polymer	Dry 1400; liquid 990 to 1500
Ammonia, aqua (ammonium hydroxide)	900 (liquid at 16 °C)	Polyphosphate (zinc orthophosphate)	1300 to 1600 (liquid)
Ammonia silicoflouride	1300 (crystals)	Potassium aluminum sulfate	1100 (crystals)
Ammonium aluminum sulfate (ammonium alum)	1200 (crystals)	Potassium permanganate	1600 (powder); 1000 (3% solution)
Ammonium sulfate	960 (damp); 780 to 1000 (dry) (crystals)	Sodium aluminate	High-purity 800; standard 960 (powder, crystals); 1570 (45% solution)
Barium carbonate	830 to 1200 (powder)	Sodium bicarbonate	990 (granular, powder)
Bentonite	Powder 720 to 960; granules 1200	Sodium bisulfate	1100 to 1400 (powder, crystals)
Bromine	3100 (liquid)	Sodium carbonate (soda ash)	Dense 1000; medium 640; light 480 (granular, powder)
Calcium carbonate	Powder 560 to 960; granules 1800	Sodium chloride	Rock 960; crystal 1200; powder 1100
Calcium hydroxide (hydrated lime)	320 to 800 (powder)	Sodium chlorite	1280 (25% solution)
Calcium hypochlorite	Granules 1300; powder 510 to 830 (pebbles)	Sodium fluoride	Powder 1100 to 1600; granules crystal 1700
Calcium oxide (quick lime, pebble lime)	880 to 1100; 960 typical hopper load (pebbles)	Sodium fluorosilicate	1200 (powder)
Carbonic acid (carbon dioxide solution)	990 (liquid)	Sodium hexametaphosphate (sodium polysulfate)	Glass 1000 to 1600; powder and granular 700 to 960
Chlorinated lime	800 (powder)	Sodium hydroxide	Pellets 1100; flakes 740 to 990; 1520 (50% solution)
Chlorine	1500 (liquid)	Sodium hypochlorite	1200 (liquid at 15%)
Citric acid	1200 (liquid at 50%)	Sodium silicate	1400 (liquid)
Copper sulfate	Crystal 1400; powder 1100	Sodium silicoflouride	Granular 1400 to 1700; powder-granular 960 to 1500
Diatomaceous earth	Natural 80 to 290; calcined 100 to 210; flux-calcined 160 to 400 (fibrous material)	Sodium sulfate	1100 to 1600 (crystals, powder)
Disodium phosphate	Crystal hydrate 1400; anhydrous 1000	Sodium sulfite	Powder 1300; granular 1700; liquid 1300 (at 12.5%)
Dolomitic hydrated lime	480 to 800 (powder)	Sodium thiosulfate	960 (granules, crystals)
Dolomitic lime	Pebble 1000; ground or lump 800 to 1000; powder 590 to 1000; average 960	Sulfur dioxide	1400 at 0 °C (liquid)
Ferric chloride	1500 (liquid); crystal 1000; anhydrous 720 to 960	Sulfuric acid	1800 (liquid)
Ferric sulfate	1200 (granular)	Tetrasodium pyrophosphate	Crystal 480 to 1100; powder 740 to 1100
Ferrous chloride	1400 (liquid at 35%)	Trisodium phosphate	Crystal 960; monohydrate 1000; anhydrous 1100
Ferrous sulfate	1100 (granular, powder)		