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SCOPE

This section covers special design and construction aspects of in-ground structures as found in refineries and chemicals plants. In-ground structures, as considered herein, includes facilities such as:

- Cooling tower basins
- Sewer manholes and catch basins
- Rain water and wastewater sumps
- Sulfur pits
- Separators

Not covered are facilities such as furnace ducts, sewer lines, and electrical duct banks, or basements for buildings.

REFERENCES

INTERNATIONAL PRACTICES

IP 4-1-1	Concrete Design and Construction
IP 19-1-1	Paint and Protective Coatings

OTHER LITERATURE

ACI 301	Specifications for Structural Concrete for Buildings
ACI 305R	Hot Weather Concreting
ACI 306R	Cold Weather Concreting
ACI 350R	Environmental Engineering Concrete Structures
AASHTO T 260	Sampling and Testing for Total Chloride Ion in Concrete and Concrete Raw Materials

Civil Works Maintenance Manual - TMEE 063, Section 2 - Equipment Support Structures, Section 4 - Sewers, Section 5 - Sulfur Pits, and Section 6 - Cooling Towers

Design of Concrete Structures for Retaining Aqueous Liquids, British Standard BS 8007

BACKGROUND

In-ground structures pose special design and construction challenges in that they typically must:

- Retain or exclude liquids
- Resist buoyancy due to ground water
- Resist earth pressures on their walls
- Resist deterioration from their contents and from ground water
- Often be constructed well below grade

Further, once built and in operation, repairs can be complicated because the exterior surface, which is mostly underground, is difficult to expose. Some in-ground structures, such as sulfur pits, contain hot liquids and are prone to deterioration from their contents.

This section is intended to assist in addressing the special problems associated with the design and construction of in-ground structures.

GEOTECHNICAL CONSIDERATIONS

In-ground structures are different from most other structures in that they typically impose low soil bearing pressures, and as a consequence, settlement and bearing capacity problems seldom exist. Regardless, since in-ground structures nearly always are required to retain a liquid, or keep ground water from seeping in, soil support and settlements are important considerations.

Site conditions are an important aspect of in-ground structure design and construction, and must be investigated through a soil exploration program if not already known from past projects in the area. Important considerations include:

- Soil types that will be excavated
- Soil strengths and compressibility
- Groundwater level
- Groundwater and soil chemistry

The implications of groundwater level and soil strengths and compressibility will be covered in the **DESIGN** section herein, soil types to be excavated in the **CONSTRUCTION** section, and groundwater and soil chemistry in the **MATERIALS** section.

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DESIGN

Design of in-ground structures requires consideration of lateral pressures, bearing capacity and settlement, buoyancy, materials selection, crack control, and construction and movement joints. These are covered in following sections. Of course, design for normal dead and live loads is also required, as for any other structure. Structural design procedures and considerations for such loads are not covered herein, however, as there is nothing special about this for in-ground facilities.

LATERAL PRESSURES

Lateral pressures arise from the earth and groundwater on the outside of a structure, loadings from adjacent facilities or maintenance equipment, and water on the inside. **Figure 1** depicts each of these, and provides further information. A few general considerations, however:

- Internal water pressures and external soil and water pressures work to counterbalance during operations. However, during construction or maintenance, all of these pressures may not be present. For example, during construction, a sump could be filled for testing purposes before backfill is placed on the exterior. During maintenance, the sump may be empty, while external pressures from soil and groundwater exist. The facility should be designed to support both the full effect of interior water pressure and the full effect of external pressures, without considering the counterbalancing effect.
- High lateral soil pressures can result from compaction of backfill. This is usually more of a problem if cohesive (clay-type) backfill is used rather than non-cohesive (sand, crushed stone, gravel) backfill is used. Thus, backfill type and level of compaction are important design considerations, and should be specified on the drawings.
- Time of backfilling can be important. If the construction schedule requires that backfill be placed soon after concrete walls are poured, then the designer must be aware of this, as the concrete may not have achieved full design strength. High early strength cement (Type III) could be used; however, this cement generates extra heat during hydration, and may aggravate cracking.
- Where the level of backfill is not uniform around the structure, or if the structure is near a load from an adjacent facility, lateral stability of the structure should be checked.

BEARING CAPACITY AND SETTLEMENT

Bearing capacity and settlement do not normally pose major problems for in-ground facilities, however, the designer should still carefully consider these issues for the particular facility and site conditions at hand. Methods for designing for bearing capacity and settlement are the same for in-ground structures as for other facilities. Although bearing capacity and settlement should be considered:

- Bearing capacity should seldom be a problem because net bearing pressure increases are usually low. This is because the pressure imposed by the structure is partially or fully counterbalanced by the weight of the soil removed from the excavation. Until the weight of the soil removed is replaced by the structure, there is no net increase in pressure on the subsoil.
- Settlement should seldom be a problem for small in-ground structures like catch basins, manholes, rainwater sumps, and similar. This also is because of the normally low net increase in bearing pressure. For large facilities, however, such as large cooling tower basins, differential settlement could be a problem because the basin could span soils of varying compressibility. If a soil of high compressibility is spanned, then even a low bearing pressure increase could cause settlement of consequence. Differential settlements can lead to cracking, and must be considered in the structural design. For large facilities, it may be appropriate to model the slab as a beam on an elastic foundation with support displacement.

Because bearing pressures are normally low, poor soil conditions often can be sufficiently upgraded by a nominal soil improvement program. For instance, a cooling tower with an underground sump typically will impose less than 500 psf (24 kPa) on the subsoil. The 500 psf (24 kPa) can be simulated by a soil preload only 4 ft (1.2 m) high, so preloading can be a viable improvement scheme if settlement is a concern. It may take some time for the preload to remove settlements from the subsoil, however, so advance planning is required. Because of low bearing pressures and potentially simple improvement of poor soils, less than ideal soil conditions may not impact the design of in-ground structures. They may complicate construction however.

BUOYANCY

The consequences of an in-ground structure floating out of the ground due to buoyancy would be severe. Accordingly, **IP 4-1-1** requires that for design purposes the groundwater level be considered at finished grade. Buoyancy resistance is usually accomplished with dead weight (note **Figure 2**). In some cases, piles or special tension anchors could be required.

For structures with a large floor slab, buoyant forces may affect structural design by upward bending of the floor slab. See **Figure 2**.

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DESIGN (Cont)

IP 4-1-1 requires a minimum factor of safety of 1.2 against flotation during erection and operations. If considering the groundwater level at finished grade is impractical or overly expensive, then special measures can be used upon approval. These measures may include:

- Installation of drainage features beneath the structure, thereby ensuring that groundwater cannot rise above some reduced level. Drainage must be reliable; systems relying on pumps should be avoided.
- Groundwater level monitoring, along with a plan for groundwater lowering or deliberate basin flooding, if the groundwater approaches a critical level. (This should normally be considered only if buoyancy resistance is a concern for a short period of time, such as during construction or maintenance.)
- Standpipes that automatically allow water entry into the basin when a predetermined groundwater level is reached.

It should be noted that groundwater level is typically measured during a geotechnical investigation program. The level measured, however, could easily change seasonally, due to a severe storm event, or over the life of the plant due to regional factors. Thus, the level measured during the soils investigation usually cannot be considered as appropriate for design.

MATERIALS SELECTION

Reinforced concrete is normally used for in-ground structures. Concrete can be attacked by aggressive soil or groundwater conditions such as a low pH or high sulfates, or by the stored contents of the structure. High chloride concentrations lead to corrosion of the reinforcing steel, which in turn causes deterioration of the concrete by spalling.

Sulfate Protection

High sulfates are addressed by appropriate selection of cement type and additives. Requirements are provided in **Table 1**.

TABLE 1
SELECTION OF CEMENT TYPE FOR CONCRETE IN SULFATE EXPOSURES

SULFATE EXPOSURE	SULFATE CONCENTRATION as SO_4		TRICALCIUM ALUMINATE IN CEMENT, MAX.%	MAXIMUM WATER-CEMENT, RATIO (by wt)
	In Soil % (wt)	In Solution ppm (mg/L)		
Moderate	0.01 - .20	150 - 1500	8	0.45
Severe	> 0.20 - 2.00	> 1500 to 10000	5	0.45
Very Severe	> 2.00	> 10000	5 plus pozzolan (Note)	0.45

Note: Use a pozzolan that has been determined by tests to improve sulfate resistance when used in concrete containing a cement with a maximum tricalcium aluminate content of 5% or less.

Acid Protection

Portland cement concrete is high in calcium compounds, which are attacked by acids. For concrete exposed to low pH (less than 5.0 if there is continuous replenishment of acidity), special cement types or coatings may be required. These situations should be handled on a case by case basis.

Low pH can be caused by the decomposition of natural organic materials in the soil. The organic acids created, however, are not aggressive at ambient temperature. In these cases, the low pH is not expected to cause concrete deterioration.

A common in-ground structure found in refineries is a molten-sulfur pit. Such pits can have special deterioration problems due to water intrusion and acid formation. The *Civil Works Maintenance Manual*, Section 5, contains considerable information on various causes and prevention of sulfur pit deterioration. The use of sulfate resistant cement for concrete, and special acid resistant concrete liners, can be of great benefit.

Chloride Protection

For corrosion protection, maximum water-soluble chloride concentrations in hardened concrete contributed from all of the ingredients in the concrete, should not exceed the limits in Table 2. Testing for chloride concentration should be per AASHTO T 260.

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