INTRODUCTION

- In 1907, Leonard Metcalf, a Boston civil engineer whose specialty was water supply issues, and Harrison Eddy, superintendent of the sewer department in Worcester, Massachusetts, were introduced by a professor at Worcester Polytechnic. Shortly thereafter, they decided to join forces and create an environmental engineering firm called Metcalf & Eddy.
Design and Construction Considerations of Reinforced Concrete Structures for Water Utilities

Wilmington, Delaware

- 10 million gallon covered water storage tank
- Under construction, completion December 2007
Design and Construction Considerations of Reinforced Concrete Structures for Water Utilities

Atlanta, Georgia

• Complex of three covered water storage tanks
• Age from 10 years to 80 years
Framingham, Massachusetts

- 115 million gallon covered water storage tank
Macon, Georgia

- 1.8 million gallon partially buried covered water storage tank
- Constructed in 1920
ADVANTAGES

• Easily adaptable to a myriad of different shapes & architectural treatments
• Many contractors have the capability to place reinforced concrete
• Reinforced concrete contractor will likely already be on site
• Durability
• Proven track record of over 100 years

DISADVANTAGES

• Owner preferences may dictate against using reinforced concrete
• Cost considerations due to quantity of materials required
• Construction nuances
• Cracking & durability

DESIGN CONSIDERATIONS

• Seismic loads
• Floatation
• Abnormal pressure loads
• Retaining elements
• Influence of adjacent / superimposed structures
• Integration into existing facilities
• Security
• Details, Details, Details!
• Liner systems
### SEISMIC LOADS

#### Seismic Forces on Rectangular Tank Walls and Roofs

<table>
<thead>
<tr>
<th>Component</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof</td>
<td>1.00</td>
</tr>
<tr>
<td>Wall</td>
<td>1.00</td>
</tr>
</tbody>
</table>

#### Seismic Design Parameters

- **Seismic Zone**: Zone 1
- **Soil Profile**: Type A (0.8)
- **Importance Factor**: Normal use (0.5)
- **Location of Maximum Load**: Vertical at middle of tank
- **Type of Structure**: Anchored, flexible base
- **Design Basis**: Emergency service systems (1.25)

#### Seismic Load Calculations

- **Elevation of Base slab**: 10 ft
- **Elevation of Top of Base slab**: 15 ft
- **Elevation of Top of Tank**: 20 ft
- **Thickness of Tank Wall**: 12 in
- **Thickness of Cover Plate**: 18 in
- **Interior Length in North-South Direction**: 30 ft
- **Interior Length in East-West Direction**: 20 ft

#### Additional Information

- Volume stored: 2 million gallons

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Design and Construction Considerations of Reinforced Concrete Structures for Water Utilities

April 12, 2007

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Design and Construction Considerations of Reinforced Concrete Structures for Water Utilities

BUOYANCY

- A reinforced concrete reservoir – or any tank – is a boat. A boat floats if designed right!
- Design checks required:
  - Buoyant force (uplift) on bottom slab
  - Buoyant force causing tank to float
  - Reduced base slab friction if tank sliding (uneven backfill) is a design consideration

SECURITY

- Any reservoir requires security considerations.
  - How will the reservoir be inspected?
  - How will venting be accomplished?
  - Will public access be required of the top slab?

DETAILS

- Minimum Concrete Strength
- Minimum Reinforcing Steel
- Expansion and Construction Joints
- Waterstops
MINIMUM CONCRETE STRENGTH

**TABLE 4.2.3—REQUIREMENTS FOR SPECIAL EXPOSURE CONDITIONS**

<table>
<thead>
<tr>
<th>Exposure condition</th>
<th>Minimum concrete strength factor</th>
<th>Minimum concrete strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slab on grade, down to 1500 psi</td>
<td>0.45</td>
<td>2500 psi</td>
</tr>
<tr>
<td>Joist or beam, down to 1500 psi</td>
<td>0.42</td>
<td>2500 psi</td>
</tr>
</tbody>
</table>

Source: ACI 350-01, Environmental Structures: Code Requirements

MINIMUM CONCRETE STRENGTH

**TABLE 4.3.1—REQUIREMENTS FOR CONCRETE EXPOSED TO SULFATE-CONTAINING SOLUTIONS**

<table>
<thead>
<tr>
<th>Sulfate condition</th>
<th>Maximum water/cement ratio</th>
<th>Minimum specified strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe</td>
<td>0.40</td>
<td>3000</td>
</tr>
<tr>
<td>Very severe</td>
<td>0.42</td>
<td>4000</td>
</tr>
</tbody>
</table>

Source: ACI 350-01, Environmental Structures: Code Requirements

EXPANSION JOINTS

Expansion Joint

Cell 2

Cell 1
Base slab to wall interface is most critical and most difficult to construct of all construction joints:

1. Raised starter wall
2. Bend top steel down at wall
3. Drop top steel down below waterstop for entire slab

Options 2 & 3 easier to construct than option 1 but require relatively more material
CONSTRUCTION CONSIDERATIONS

Proper adherence to specifications
- Mix design
- Placement
- Curing

• Details, Details, Details
• Integration into existing facilities

MIX DESIGN

Adding 1 gallon of water to 1 yd³ of concrete will:
1. Increase slump about 1 inch
2. Increase air content about 1%
3. Increase shrinkage about 10% and increase cracking
4. Reduce compressive strength about 200 psi
5. Waste about 25 lbs of cement per cubic yard
6. Increase shrinkage about 10% and increase cracking
7. Decrease freeze-thaw durability about 20%
8. Decrease wear resistance to traffic
9. Increase dusting and other surface defects
10. Increase time needed to finish the concrete

Source: Dick Martin, Engineering Services Group, Grace Performance Chemicals.

CURING

“Minimum permeability of the concrete will be obtained by using water-cementitious materials ratios as low as possible, consistent with satisfactory workability and consolidation. Impermeability increases with the age of the concrete and is improved by extended periods of moist curing.”

Source: ACI 350.1-01, Environmental Structures: Code Requirements
CURING

DETAILS
  - Waterstops & joint construction
  - Rebar cover
  - Leak testing
  - Backfilling procedure

WATERSTOPS
Design and Construction Considerations of Reinforced Concrete Structures for Water Utilities

WATERSTOPS

VS.

REINFORCING STEEL COVER

7.7.1 - Cast-in-place concrete (exposed/recessed)

The following minimum concrete cover shall be provided for reinforcement:

<table>
<thead>
<tr>
<th>Minimum cover, in.</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slices and joints</td>
<td>Shrinkage, spirals, and ties</td>
<td>Primary reinforcement</td>
</tr>
<tr>
<td>(a) Concrete cast against and permanently exposed to earth</td>
<td>2</td>
<td>1-1/2</td>
<td>2</td>
</tr>
<tr>
<td>(b) Concrete exposed to earth, liquid, weather, or cast against a concrete wall in place</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Sheets, tubes, plate members:
- #4 bars and smaller: 1-1/4
- #6 and #8 bars: 1-1/2
- #10 bars and larger: 1

Source: ACI 350-01, Environmental Structures: Code Requirements
REINFORCING STEEL COVER

LEAK TESTING

1.1.3—Each cell of multi-cell tanks shall be considered a single tank and tested individually unless otherwise directed by the engineer.

1.2.3—Unless specifically allowed by the engineer, the tank shall not be tested before all of the structure is complete and the tank's concrete has attained its specified compressive strength.

Source: ACI 350.1-01. Tightness Testing of Environmental Engineering Concrete Structures

LEAK TESTING

2.3.5—The water shall be kept at the test level of unlined concrete tanks for at least three days prior to the actual test.

2.3.6—The exterior surfaces of the tank shall be inspected during the period of filling the tank. If any flow of water is observed from the tank exterior surfaces, including joints or cracks, the defect causing the leakage shall be repaired.

Source: ACI 350.1-01. Tightness Testing of Environmental Engineering Concrete Structures,
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BACKFILLING

SUMMARY

- Engineer helps the owner determine best structural system for the facility.

SUMMARY

- Proper engineer detailing is a major contributor to the long-term success of the project.
### SUMMARY

- Proper concrete mix design, placement, and curing practices is the single most important factor toward the long-term durability of the structure.

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### SUMMARY

- Reinforced concrete is not a “forever” material. It requires on-going care and maintenance. A well-defined asset management program will contribute to the long-term operation of the structure.

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### SUMMARY

The answer to the question of “What material best suits my project?” is: “Please tell me a little more about your project.”

Michael E. Malenfant, P.E.  
Metcalf & Eddy  
Michael.malenfant@m-e.com  
781-224-6277