Structural Design Considerations

By Gene Gopenko, P.E.
GOALS:

• Serviceability
• Durability
• Low Permeability
• Limiting Deflections and Cracks
References

• ACI 318-89. Building Code Requirements for Reinforced Concrete
• ACI 350R-89. Environmental Engineering Concrete Structures
• “Strength Design for Reinforced Concrete Hydraulic Structures” by ASCE, (adapted from COE Manual)
References (cont.)

- “Rectangular Concrete Tanks” by Portland Cement Association
- “Moments and Reactions for Rectangular Plates” by US Bureau of Reclamation
ACI 350R-89:

“This report presents recommendations for structural design, materials, and construction of concrete tanks, reservoirs, and other structures commonly used in water containment, industrial and domestic water, and wastewater treatment works, where dense, impermeable concrete with high resistance to chemical attack is required.”

Among Types of Structures: intakes and conduits.
START WITH RIGHT INGREDIENTS!
Concrete Requirements

- Min. Concrete Strength = 4000 psi at 28 days
- Air Entrainment = 5% ± 1%
- Maximum Water-cement Ratio = 0.45
- Maximum Slump = 4 inches
- Aggregates per ASTM C33, max. aggregate size = 1 inch
- No admixtures containing calcium chloride
Steel Reinforcing

- New Billet Steel to Confirm to ASTM A615 Grade 60
- Epoxy Coated Rebars

**Minimum Concrete Cover:**
- Concrete Base=3 inches (4” COE)
- Concrete Walls=2 inches (3” COE)
- Stilling Basin=6” (COE)
Temperature and Shrinkage Reinforcing

ACI 318 for Grade 60 Steel:

\[ A_s = 0.0018bh \]

ACI 350R (use chart), but

\[ A_s(\text{min.}) = 0.0024bh \]
Concrete Joints

- Construction Joints
- Expansion Joints
- Separation Joint
Waterstops
Crack Reduction

- Joint Spacing
  “Joint is controlled crack. Crack is uncontrolled joint”
- Reinforcing Distribution-try to reduce bar spacing!
  “Where the structure must be watertight, bar spacing should not exceed 12 inches”.
Minimum Thickness

ACI 350R:

“Walls with height greater than 10 feet shall be a minimum of 12 in thick and shall contain reinforcement on both faces.“

“A minimum of 8 in is required where 2 in concrete cover is desired”- criteria for top slabs.
Flotation Criteria
(Structural Design of Covered Risers, SCS TR 30)

FS=1.5

• Riser Located in Reservoir-
  Low stage inlets plugged

• Riser Located in Embankment
  Add buoyant weight of fill over base
Flotation Criteria
(Flotation Stability Criteria for Concrete Hydraulic Structures, US Army COE)

Loading Conditions       FS

- Construction           1.3
- Normal Operation       1.5
- Extreme (max. pool)    1.1
Design Loads

• Dead Loads:
  – Weight of Concrete
  – Weight of Equipment

• Live Loads:
  – Earth and Silt Pressure
  – Water (Hydrostatic Load)
  – Surcharge
  – Cover slab LL=100 psf
  – Wind Load=50 psf, for risers in reservoir only
  – Ice Load (max. 2’ thick, 5 kips/sq. ft)
LOAD DIAGRAM FOR
CONCRETE RISER WALLS

R_s

R_w

P_s

P_w
Hydrostatic Load:

\[ P_w = \gamma_w H_w, \text{ in lb/ft}^2, \quad \gamma_w = 62.4 \text{ lb/ft}^3, \]

Soil Load:

\[ P_s = (K_r)(\gamma_s - \gamma_w)H_s, \text{ where} \]

\[ K_r = 0.5 \text{ (soil assumed at rest condition)} \]

\[ \gamma_s = 126 \text{ lb/ft}^3 \text{ (soil weight available from Soil Report)} \]
Strength Design

U = R * Load Factors

U = 1.4(DL) + 1.7(LL), from ACI 318

ACI 350: In Hydraulic Structures, when reinforcing in flexure, the required strength 1.3U.

Strength Reduction Factor \( \phi \) - Second Safety Provision in ACI.

\[ M_r = \phi M_n, \quad \phi = 0.9 \text{ for bending, } \phi = 0.85 \text{ for shear} \]
Moment Diagram

$N_K = \text{resultant of components of} \; N_B \; \text{and} \; N_S \; \text{which are perpendicular to the cut section.}$
Analysis for Plates (vs Simple Beam)

- Finite Elements Computer Model
- Tables of Moments and Reactions Coefficients
- Moment Balance using Distribution Factors
### Moments and Reactions for Rectangular Plates

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### Positive Sign Convention

- Moment: \( (\text{Coefficient}) \times (\text{ps}^3) \)
- Reaction: \( (\text{Coefficient}) \times (\text{ps}) \)
SECTION 1/S-1

NOTES:
1. IF RISER WALLS ARE POURED IN MORE THAN (1) FOUR, PROVIDE 2"x4" SHEAR KEY AND CONT. BENTONITE WATERSTOP AT EACH CONSTRUCTION JOINT.
SECTION 2/S-1

SEE SECTIONS 1/S-1 AND 3/S-1 FOR REINF.
Precast vs Cast-in-Place
Pros and Cons
Dam Statistics

- Significant Hazard Dam
- Built in 1974 on tributary to Little Patuxent
- 18 high earthfill dam with 145 ft long ogee spillway
- Drainage Area 3.6 sq. miles
ASSUMED CRACK DIRECTION
BASED ON OBSERVATION OF
CRACK AT THE SIDE OF THE
UPPER CREST.

ASSUMED CRACK DIRECTION
BASED ON THE FINDINGS
FROM CORE #8.

SHEET PILE CUT
OFF WALL

ASSUMED DIRECTION OF CRACK
THROUGH THE WEIR CROSS SECTION

SCALE: 1/4" = 1'-0"