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WATER-TIGHT REINFORCED CONCRETE STRUCTURES

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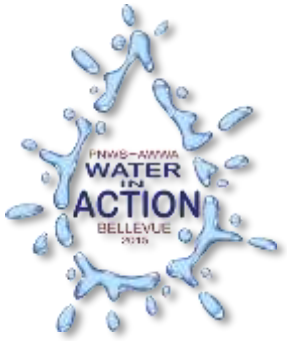

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What is a “Water-Tight” Concrete Structure?

- Not waterproof structures
- Leakage rate is suitable for intended use
  - Contain water
  - Prevent contamination of contents
  - Prevent damage or inconvenience due to leakage
- Other options available for truly waterproof construction
  - Membrane linings/ Waterproofing surfaces (e.g. roofing systems)
  - Steel tanks

Typical Water-Tight Concrete Structures

Above-Ground Process Basin at Water Treatment Plant

Buried Concrete Reservoir

Circular Prestressed Concrete Water Tank

Water-Tight Reinforced Concrete Structures

Causes of Leaks

- Cracks
  - Plastic Concrete
    - Plastic Shrinkage Cracking - Surface moisture evaporates too fast
    - Settlement Cracking – Poor form design, concrete vibration and high slump
  - Hardened Concrete
    - Drying Shrinkage Cracking – Shrinkage and restraint cause tensile stress
    - Thermal Stresses – Temperature differences causes volume changes
    - Chemical Reactions – Alkali-silica reaction (ASR)
- Permeable Concrete Joints
  - Improper waterstop installation or damage
  - Concrete voids

Keys to Water-Tight Reinforced Concrete Structures

Methods to Prevent Leaks

A. Concrete design

B. Concrete detailing

C. Concrete materials

D. Construction practices

E. Crack repair

Special Concrete Design Minimizes Size and Frequency of Cracks

Design philosophy is to minimize the impact of restrained concrete volume changes and the crack widths by directing movement to waterstopped joints.

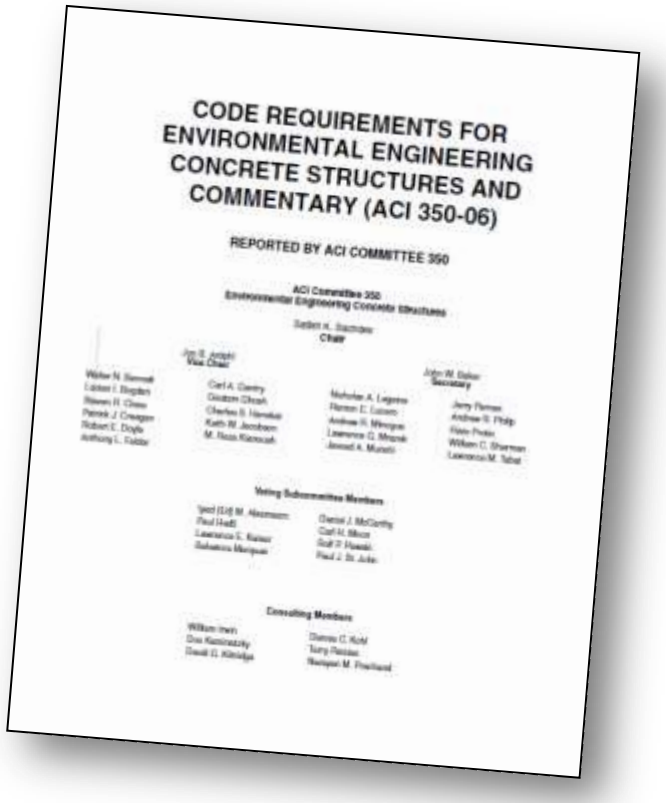
Minimum requirements in accordance to ACI 350

A. Reinforcing steel

- Using Durability Factor (S_d)
  - Encourage closer reinforcement spacing
- Structural wall and reinforcement
  - Thicker section and higher reinforcement requirement
  - Tighter reinforcement spacing for walls
- Shrinkage and temperature reinforcement
  - Higher minimum reinforcement requirement

B. Joint spacing recommendations

- Closer spacing for joints – 20 to 25 ft
- Expansion joints for exposed structures – 120 ft


CODE REQUIREMENTS FOR ENVIRONMENTAL ENGINEERING CONCRETE STRUCTURES AND COMMENTARY (ACI 350-06)

REPORTED BY ACI COMMITTEE 350

Comparison of ACI-318 and ACI-350

Parameter	ACI-318	ACI-350	ACI-350	ACI-350
Full Contraction Joint Spacing	20 ft – 40 ft	20 ft	30 ft	40 ft and Longer
Rebar	#4 @ 18”	#4 @ 11”	#4 @ 8”	#4 @ 6”

Section thickness = 1 ft
Steel yield strength (F_y) = 60,000 psi

Proper Concrete Mix Design Reduces Cracking

Use NSF-61 approved concrete materials (For Potable Water)

Cementitious material (ASTM C 150, TYPE II or V)

- Restrict use of fly-ash (ASTM C 618), *No fly-ash is recommended*
- Limit/minimize cement content to reduce heat of hydration and reduces water content

Water: Concrete mix ratio

- Limit water/cement ratio (W/C) – water content has impact on drying shrinkage

Aggregates

- Non-reactive aggregates (ASTM C 33) to prevent ASR
- Larger size crushed coarse aggregate can reduce drying shrinkage (¾ ” to 1 ½” sizes recommended)
- Smaller size aggregate used where rebar and waterstop are crowded (pea gravel mix)

Proper Concrete Mix Design Reduces Cracking

Admixtures

- Chemical admixtures (water-reducing, ASTM C 494)
  - Increase concrete set time and workability with low water content (reduced restrained movement cracking)
- Air Entraining agent (ASTM C 260) for freeze-thaw cycles locations
  - Increase workability and decrease permeability of the cured concrete
- Shrinkage reducing admixture

Testing prior to concrete mix approval

- NSF-61 testing
- Drying shrinkage testing (ASTM C 157)
  - Trail batch test (Caltrans modified) requires 35 days
  - Allowable maximum percent of 0.042 lab and 0.053 field in 28 days
  - Enforced on 4000 to 5000 psi concrete mixes *except* for the high cement content pea gravel mix

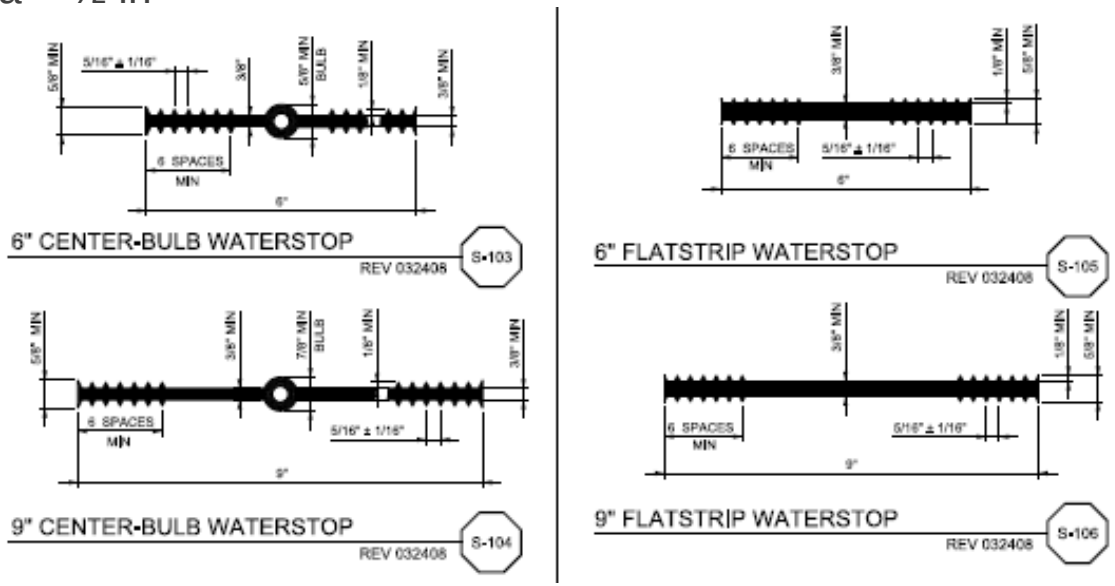
MWH Concrete Mix Design for Water-Bearing Structures

Parameter	Regular	Thick Section	Pea Gravel
Compressive Strength (psi)	4000 - 4500	4000 - 4500	5000
Aggregate Size (in)	1	1½	3/8
Cement (lbs/yd)	535 - 564	515 - 564	752
Water Content	254	254	301
Max W/C Ratio	0.42 – 0.45	0.42 – 0.45	0.40
Slump (+/- 1 in)	4	4	7 (+/- 2 in)
Slump w/ Water Reducer (+/- 2 in)	7	7	

Proper Concrete Joint Detailing

Waterstop

- PVC waterstop
  - Flatstrip and Center-Bulb
- Preformed Hydrophilic
  - Cross-sectional area > ½ in^2
  - Bentonite-Free



Enforcement of Code and Contract Requirements and Industry Best Practices

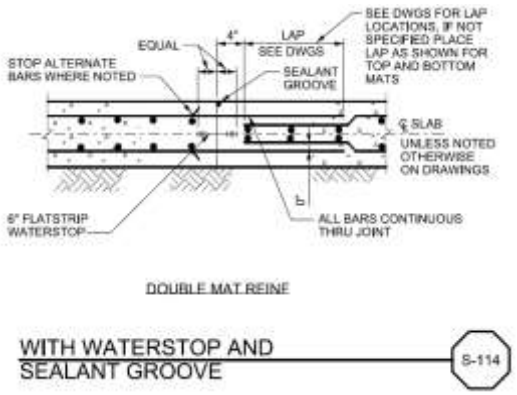
Elements of a successful concrete construction project

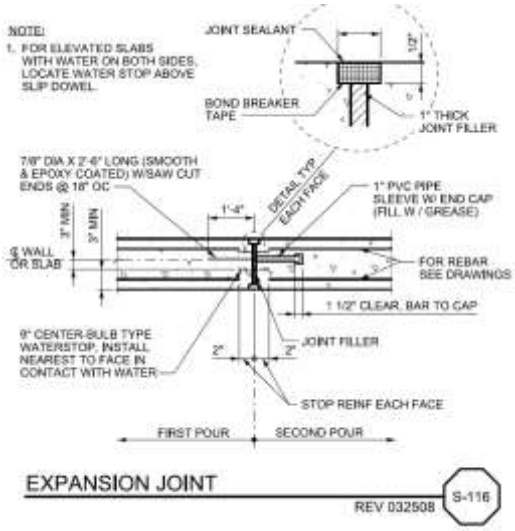
- Pre-Construction conference
  - Understanding and commitment from Owner, Contractor, Engineer, Construction Manager and Inspector(s)
    - Proper placement of concrete
    - Proper concrete curing methods
- Special inspections
  - Qualified Special Inspectors
- Structural observations
  - Engineer of Record

The Role of the Engineer of Record during Construction

Requirement of Special Inspection and Structural Observation

- In accordance with the IBC – Chapter 17
  a) Continuous Inspections
  b) Periodic Observations





Inspector and Contractor Must Coordinate Proper Concrete Placement

Pre-Pour Checklist

- Rebar
- Waterstop – position, connection and condition

When the Truck Arrives

- Verify that the approved mix has been provided
- Check travel times (Recommend max. 60 min.)

As the Concrete is Placed

- Placement sequence and timing (no cold joints!)
- Monitor and protect waterstop
  - For thin slab make sure that concrete is well consolidated underneath the waterstop
- Proper vibration procedure
- Proper surface concrete finishing

Inspection Checklist

Concrete Placement **Project No.**_____

1. Shop drawings approved and on site. _____
2. Verify correct psi ordered from plant. _____
3. Chutes, elephant trunks required? _____
4. Verify approval of forms and rebar prior to pour. _____
5. Requirements for testing, mix design, ingredients. _____
6. Test lab notified and tests required. _____
   - Slump _____
   - Number of cylinders _____
   - Temperature/truck waiting time _____
7. Testing required at plant. _____
8. Vibrators to be used during pour. _____
9. Temporary form openings O.K.? _____
10. Arrange for specified curing and saw cut joints. _____
11. Arrange for cold weather protection. _____

-or-

12. Arrange for hot weather protection. _____
13. Embeds available for insertion in pour. _____
14. Box-out properly installed in form work. _____
15. Verify finishes—smooth troweled, broom. _____
16. No troweling while bleed water is on surface. _____
17. Slopes to drain properly designated. _____
18. Wet spray or curing compound adequately performed. _____
19. Traffic over area controlled. _____
20. Preparations for repairs at hand. _____

General Notes: _____

Inspected by: _____ Date: _____

Proper Curing is Essential for Minimizing Cracks

Contractor and inspectors must commit to proper curing to avoid later crack repairs

- Forms to be kept damp until removed
- Removal of formwork (48 hours minimum)
- Recommend minimum of 7 days wet curing
- Curing compound (Reflective)
- Monitor curing blanket
- Monitor the weather and contractor during the curing procedure

Concrete Cracks. Repair It.

Autogenous Healing (Self-Healing)

- Natural process of crack repair in the presence of moisture and the absence of tensile stress
- Healing occurs through chemical reaction in the cement paste by CO_2
- Crystals precipitate, accumulate and grow within cracks
- Fly-ash reacts with and destroys the compound that participate in this process, *NO Fly-Ash*
- Will not occur if the crack is active and subject to movement and also positive flow of water through the crack
- Slow first fill of the tanks during Hydrostatic Testing (2 ft per day)

Concrete Cracks. Repair It.

Crack Injection

- Polyurethane
- Epoxy

Surface Treatments

- Membranes

Epoxy vs. Polyurethane Injection

	Polyurethane	Epoxy
Advantages	Long-term repair, Easy Installation, Flexible Joints	Permanent structural repair, Durable Comparable With Concrete (Same As Concrete)
Limitations	Nonstructural (For Expansion and Contraction Joints)	Installation Complexity

The skill and experience of the installers is critical for the success of any crack injection method.

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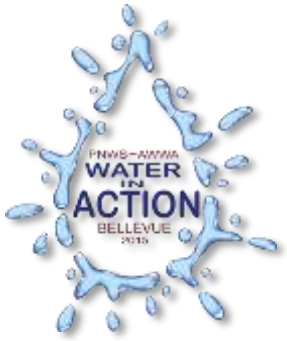
THANK YOU AND QUESTIONS



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