Underwater Concrete Technologies in Marine Construction Projects

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Concrete Production from a Floating Batch Plant
Conventional Tremie Placement
Concrete Delivery on Transit Mixers
Placing Concrete from a Delivery Barge
Tremie Placement with Suspended Pipes
Underwater Concrete Construction Technologies

Concrete Mix Proportions
  - Workability and Rheology
  - Strength Development

Mass Tremie Concrete Properties
  - Thermal Behavior
  - Form Pressure
  - Laitance, Bleeding, Segregation

Underwater Concrete Construction
  - Concrete Placement Planning
  - Concrete Production/Transportation
  - Concrete Placement Procedures
  - Finish and Protection
  - Inspection and Quality Control
Performance Requirements for Underwater Concrete in Structural Applications

- Flowability and Self-Compaction
- Workability Retention within Work Window
- Cohesion Against Washout, Segregation, and Laitance Formation
- Low Bleeding
- Low Heat of Hydration
- Controlled Set Time
- Compressive Strength
- Adequate Bond
Washout Test and Slump Test
Slump vs. Slump Flow

![Graph showing the relationship between slump and slump flow with measured and predicted data points.](image-url)
Mock-up Tremie Concrete Test
Mock-up Tremie Concrete Test
Principal Parameters in Mix Design

- **Particle Packing Characteristics** - Sand Content, Gradation, Size, and Shape
- **The water-to-fine ratio** - Enough Fine to Make It Flowable and Cohesive (0.85-1.0 by volume)
- **Cementitious Material Content** – High Volume Fly Ash plus Silica Fume
- **Dispersion characteristics** - Proper Use of Chemical Admixtures – HRWR and Set-retarder
Tremie Concrete Placement Planning – An Overview

Allowable Work Window
Concrete Production & Delivery: Method & Rate
Allowable Flow Distance
Concrete Placement Sequence
Placement Area Configuration
Tremie Pipe Layout
Concrete Placement Rate & Procedure
Form Pressure
Concrete Flow Pattern

RISK FACTORS
• Production & Delivery Logistics
• Loss of Flowability
• Washout - Laitance
• Segregation, Bleeding
• Trapping of Water
• Excessive Disturbance
• Erosion

Form Design
Slope, Vent, Laitance Collector
Quality control plan:
Testing, sounding, inspection
Concrete Protection

Quality of In-Situ Concrete Strength
Uniformity Bond
Initiation of Tremie Placement

Initiation of Placement using the Dry Pipe Method with an End Plate as the Seal.
Hydrostatic Balance Point

\[ H = \frac{W_c h + W_w D + F_R}{W_c} \]

- \( H \): The height of concrete inside tremie
- \( h \): The tremie embedment depth in concrete
- \( D \): Water depth above the concrete

Diagram showing the hydrostatic balance point with annotations for different parts.
Flow Patterns of Tremie Concrete

Layered Flow - Excessive Laitance

Bulging Flow - Minimum Laitance
Tremie Pipe Spacing

3-5 Times Depth of Tremie Pours
Placement Sequence

Simultaneous Placement Method

Advanced Slope Method
Removal of Laitance Underwater

Figure 31. Diver operated airlift
Lower Monumental Dam
Hydraulic Flow Pattern in Stilling Basin
Pomona Dam Stilling Basin
Hydraulic Model Study
Kinzua Stilling Basin

18 months after repair
Erosion Damage
Erosion Repair within a Cofferdam
Undrewater Repair of a Dam
Tremie Concrete over Rock Anchor
Coarse Aggregates

Specific Gravity: 2.85
Absorption: 1.1%
Maximum Nominal Size: 3/4-inch
Appearance: Clean and round-shaped with smooth surface texture
Fine Aggregates

Specific Gravity: 2.72
Fineness Modulus: 2.9"
Absorption: 3.0%
Natural River Sand
Gradations of Aggregates

Volume Ratio of Fine Aggregates to Total Aggregates: 47%

Volume Ratio of Coarse Aggregates to Total Solids: 42%
High Volume Fly Ash Concrete for Underwater Repair

- Reducting the heat of hydration in mass concrete
- Increasing concrete flowability without compromising cohesion
- Facilitating concrete flowability retention and extended set time
## Mix Proportions

<table>
<thead>
<tr>
<th></th>
<th>Mix No. 1 (52% F.A)</th>
<th>Mix No. 2 (25% F.A)</th>
<th>Mix No. 3 (control)</th>
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<tbody>
<tr>
<td>Cement Type II, lb./cy</td>
<td>390</td>
<td>580</td>
<td>740</td>
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<tr>
<td>Fly Ash, lb./cy</td>
<td>350</td>
<td>160</td>
<td>0</td>
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<tr>
<td>Micro Silica, lb./cy</td>
<td>40</td>
<td>40</td>
<td>40</td>
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<tr>
<td>Coarse Agg, lb./cy</td>
<td>1.625</td>
<td>1,659</td>
<td>1,688</td>
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<tr>
<td>Fine Agg, lb./cy</td>
<td>1,367</td>
<td>1,396</td>
<td>1,420</td>
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<tr>
<td>Water, lb./cy</td>
<td>301.8</td>
<td>302.5</td>
<td>303.3</td>
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<tr>
<td>Rheomac UW, oz/cwt</td>
<td>85.8</td>
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<tr>
<td>Delvo, oz/cwt</td>
<td>117</td>
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<td>117</td>
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<tr>
<td>Glenium, oz/cy</td>
<td>102.6</td>
<td>156</td>
<td>189</td>
</tr>
</tbody>
</table>
Compressive Strength Development

![Graph showing the development of compressive strength over age for three different mixes (Mix 1, Mix 2, Mix 3). The x-axis represents age (days) ranging from 0 to 90, and the y-axis represents average compressive strength (psi) ranging from 0 to 12000. The graph demonstrates that Mix 3 develops the highest compressive strength, followed by Mix 2 and then Mix 1.]
Workability Test

Initial Concrete Slump
– 10” to 10-3/4”

Initial Slump Flow
– 21” to 26”

Minimum Requirement for Achieving 1:10 Slope on Top Surface of the Concrete Pours
– 10” Slump and 20” Slump Flow
Workability Retention Test

Slump after 60 minutes
- 10” to 10-3/4”

Slump flow after 60 min.
- 21” to 26”

Anticipated work window for a truck of concrete
- 45 minutes
Set Time Test

Mix No. 1
Set Time $> 12$ hour

Mix No. 2 and No. 3
Set Time $= 7$ hour

Anticipated Concrete Placement Duration: 12 hours
Tremie Concrete Placement at the Dam Site
Tremie Concrete Placement Sequence
Tremie Concrete Slump
Tremie Concrete Placement
Concrete Cores
Conventional Dam Construction
Cofferdam Failure
Conventional Lock Construction
Cofferdam Overtopping
Cleanup After the Flood
Braddock Dam
Braddock Dam - Illustration

Towing and Positioning
Braddock

Grouting
Braddock Dam – Stage 5

Concrete Infill
27.5 River Miles from Fabrication Site to Outfitting Pier

- Mile 0.0: Pittsburgh (Outfitting Pier)
- Mile 11.2: Monongahela River
- Mile 12.8: Braddock L/D
- Mile 13.3: Dashields L/D
- Mile 14.7: Pittsburgh
- Mile 6.2: Emsworth L/D
- Mile 3: Leetsdale (Fabrication Site)
In-the-Wet Foundation Preparation
Underwater Foundations

Concurrent Operations:
- Dredge/Backfill
- Place Base Stone
- Screed Stone
- Install Piers
Fabrication Site

Launch Basin
Segment 1
Segment 2
Braddock Dam
Top Slab Fabrication
Segment 1 in Launch Basin
Transport of Dam Segment 1
Towing and Setting a Float-in Dam
Braddock Dam

Savings:
1 Year
$5 Million
Florida Keys
Coral Reef in Florida Keys

Florida Keys National Marine Sanctuary
One of the Ground Sites
Damaged Coral Reef
REPAIR DESIGN

**Diagram Note:**
- **Perimeter Chinking:** Held in place by vise (not shown). Chinking (and boulders) shall be sufficient to completely contain concrete trebe fill.
- **Each Perimeter Boulder:** To be placed touching adjacent perimeter boulders, with longest dimension oriented into the damage site.
- **Reef Crest:**
- **Damage Site:**
- **Sand Channel:**

**Legend:**
- **Undamaged Reef Spur**

**Notes:**
1. Boulder and chinking placement locations shown are approximate and for demonstration only.
2. Damage site, boulder and chinking placement are idealized. Field decisions will determine the placement that will best achieve these goals.
3. Chinking is quarry stone.

**Idealized Damage Site Plan View Showing a Layer's Perimeter Fill**
Repair of Corral Reef in Florida Keys
Setting a Precast Module
Floating Batch Plants
Adding Nitrogen Cooling Agent
Repair of Coral Reef in Florida Keys
Pumping Concrete Underwater
Placing Underwater Concrete

Florida Keys National Marine Sanctuary
Placing Concrete in Large Holes of Corral
Finishing Underwater Concrete
Coachella Canal Engineering Data

- Construction period: 1938-1948
- Length: 123 mi
- Diversion capacity: 2,500 cfs
- **Typical section, earth lined:**
  - Bottom width: 40-60 ft
  - Side slopes: 2:1
  - Water depth: 10.3 ft
  - Lining, clay-blanket: 12 in
- **Typical section, concrete lined:**
  - Bottom width: 12 ft
  - Side slopes: 1.5:1
  - Water depth: 10.8 ft
  - Lining thickness: 3.5 in
Salton Sea/Coachella Canal

One of numerous geothermal plants on the eastern side of the Salton Sea.

Bombay Beach at Salton Sea.

The Coachella Canal.

Coachella Canal Bathers.
Installation of Liner and Concrete Overlay

- Kiewit received a $5.2 Million Contract to Install 1.5 miles test section at Coachella Canal.
- Paving half of a section at a time
- Average Speed: 4-ft per minute
Canal Lining Design

Animal Escape Curbs & Longitudinal Joints
Trial Testing

- Liner: 30 mil thick PVC geomembrane backed with a nonwoven geotextile
- Nonwoven fabric prevent slippage of concrete during placement and strengthen the liner
- Vibrator on slip form to consolidate and maintain concrete flow
Completion of the Lining Construction