Charleroi Locks and Dam – Repair of the Drilled Shafts

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Charleroi Locks and Dam – Circa 2000 and 2014

Issues similar to those requiring reconstruction of the Panama Canal:
- Aging Infrastructure (Existing Project Structures are over 85 yrs old).
- Need to accommodate wider / longer loads

After (2016)
Lower Mon Project:
* Originally scheduled for a 2005 completion.
* Current projection is 2023 (earliest)
“Existing”  Future
Charleroi Locks Replacement

L/D 4

Land Chamber – 56’ x 720’
River Chamber – 56’ x 360’ (closed)
Completed 1932

**Timber Pile Foundations**

Charleroi L/D

Land Chamber – 84’ x 720’
River Chamber – 84’ x 720’
Projected Completion – 2020 (+)
Historic Background
Original Construction:

- Twin Locks (56’x720’ & 56’x360’) (with fixed-crest dam)
  - Contract awarded to Dravo Construction on March 10, 1931.
  - Completed on March 3, 1932 – approximately one year and 8 months ahead of schedule!
  - Lock walls and sills supported on 10” diameter timber piles with sheet pile cut off walls.
Major Renovations in the 1960’s:
• Upper Pool raised by 6 feet (737.5 to 743.5) – resulted in a 50% increase in hydrostatic load on the lock walls.
• Prior to pool change, concrete struts and supporting H-piles were installed across the bottom of the land & river chambers to transmit the hydrostatic loads.
• Gated dam replaced the original fixed-crest dam.
• An underwater diaphragm support wall was installed on the downstream portion of the existing river wall to resist the hydrostatic loads.
• The stub wall was also installed during this work.
• All original and 20th-Century renovation construction was done in the dry.
Timber Piles Driven in the Dry Cir. 1931
Purpose of 2005 Demolition Contract:

The purpose of the Demolition Contract was to remove the existing river chamber floor obstructions so that the new/future middle wall can be constructed in the existing river chamber. However, these “obstructions” were required to keep the lock walls stable.
UNWATERED RIVER CHAMBER (UPSTREAM) (STABILIZATION MEASURES INSTALLED)

UNWATERED RIVER CHAMBER (DOWNSTREAM) (STABILIZATION MEASURES INSTALLED)
Work began in 2006:

**Charleroi Locks**

**Contract 1 – River Wall**

**Major Work Items**

<table>
<thead>
<tr>
<th>Drilled Shafts</th>
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<tr>
<td>Tremie Concrete</td>
<td>6,000 CY</td>
</tr>
<tr>
<td>Steel Casings</td>
<td>2,000 LF</td>
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<tr>
<td>Reinforcing Steel</td>
<td>4,000,000 LB</td>
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<table>
<thead>
<tr>
<th>River Wall</th>
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<tbody>
<tr>
<td>Mass Concrete</td>
<td>27,000 CY</td>
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<tr>
<td>Tremie Concrete</td>
<td>34,000 CY</td>
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<td>Reinforcing Steel</td>
<td>2,000,000 LB</td>
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<tr>
<td>Sheet Piling</td>
<td>8,000 LF</td>
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2006 / 07 - Drilled Shaft Installation (In-the-Wet)
86 6.5’ (78”)-dia. shafts installed to support the new river wall monoliths R8-18; 25-27; 33-35. Shafts embedded 30-40 ft into limestone bedrock.
Drilled Shaft Cleaning
The shafts sockets were hydraulically cleaned prior to placement of mass concrete. Divers were also utilized, as the construction was “in-the-wet” in non-coffer box monoliths. They manually checked and cleaned (if necessary) the top of each shaft; however, cleaning inside the cage was difficult (low visibility and access) as the cage protruded +/- 7’ above the top of the shaft concrete and the river water was murky due to turbidity.
On-Site Mass Concrete Batching Plant:
All river-wall shafts completed by the end of 2007.
River Wall Mass Concrete Prep Work (Upstream Monoliths) cir. 2008
(Upstream) Monoliths R8 thru 18 Site Geotechnical Profile
Non-coffer box monoliths (Tops of shafts cleaned in the wet)

Coffer box monoliths (tops of shafts cleaned in the dry)

Non-cofferbox Shafts constructed first
RIVERWALL PROJECT TIMETABLE

- 2006-2007 – The Drilled Shafts Are Constructed (86 total)
- 2008-2009 – The Mass Concrete Is Poured (i.e. the Monoliths are Constructed)
- 2010 – concrete cores taken through several shafts encountered “anomalies” on top of each shaft (at the monolith mass tremie concrete / drilled shaft concrete interface)
Relevant Specifications Continued

Section 03053, 3.1.4 Construction Joint Preparation

3.1.4.1 Exposed Construction Joints
Concrete surfaces to which additional concrete is to be bonded shall be prepared for receiving the next horizontal lift by cleaning the construction joint surface with air-water cutting, sandblasting, high-pressure water jet, or other approved method. Concrete at the side of vertical construction joints shall be prepared as approved by Contracting Officer. Air-water cutting shall not be used on formed surfaces or surfaces congested with reinforcing steel. Regardless of the method used, the resulting surfaces shall be free from all laitance and inferior concrete so that clean surfaces of well bonded coarse aggregate are exposed. The edges of the coarse aggregate shall not be undercut. The surface of horizontal construction joints shall be kept continuously wet for the first 24 hours during the 48-hour period prior to placing fresh concrete and then allowed to dry until concrete is placed. The surface shall be dry and completely clean prior to placing the next lift.

3.1.4.2 Underwater Construction Joints
Preparation of underwater construction joints shall be achieved using a combination of air jetting, water jetting, air lifting and any approved methods capable of removing sediment, and laitance or otherwise poor quality concrete from the surface of the previously placed concrete. Mechanical methods may also be used where there is no exposed rebar or other embeds, and provided the methods do not remove or damage sound concrete. Regardless of the methods used, the previously placed concrete shall achieve adequate set and hardness to be cleaned without damaging sound concrete. Divers utilizing suitable underwater camera equipment appropriate for use in heavy sediment-laden water shall be used to confirm that all sediment and laitance or otherwise poor quality concrete are removed immediately prior to placement of subsequent concrete.
Typical Foundation / Monolith Cross-Section

- Non-cofferbox Wall
- Full height form
- Sheet Pile Cut-Off Wall
- Drilled Shafts
- Tremie Concrete
- Water Level
- Anomaly – at top of shaft
Two types of shafts were constructed in the Non-Cofferbox Wall Sections.

**Guide Pipe Shaft**

Guide pipes used for supporting the full-height tremie formwork system were embedded 10 feet into the top of the drilled shaft.

**Non Guide Pipe Shaft**

**86 Total shafts – 52 of the guide pipe type**
Turns out, in the coffer-box shafts (constructed in the dry), similar problems were observed, but could be (and were) corrected during construction.
Shafts Layout
Examples of poor quality concrete detected at the top of the shafts

Deficiencies ranged from several inches to several feet in length
PLAN OF REPAIRS

1. **Exploration Phase**: Accurately determine the presence / extend of anomalies by coring 1 hole in each shaft;

2. **Repair Phase (Cleaning and Grouting)**: a) Core total of 4 (for Guide-Pipe shafts) and 2 (for non-guide-pipe shafts) holes to 5-7’ below the bottom of the anomaly;
   b) Jet-clean the anomaly;
   c) Video-inspect the resulting void (through each of the holes);
   d) Pressure-grout the void;

3. **Verification Phase**: a) Coring – 3 holes per shaft;
   b) Video-inspect the repair zone through each hole;
   c) Strength test the grout cores and the cubes.
THE TEAM

-- (TBJV) – Trumbull / Brayman Joint Venture -- Prime

-- Hayward Baker --- Cleaning Contractor
EXPLORATION PHASE RESULTS

UPSTREAM MONOLITHS:

DOWNSTREAM MONOLITHS:

RESULTS OF EXPLORATORY PHASE

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<th>Type</th>
<th>Count</th>
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<td>THICK</td>
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<tr>
<td>THIN</td>
<td>14</td>
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<tr>
<td>NO ANOMALY</td>
<td>1</td>
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<tr>
<td>REMAINS TO BE DRILLED</td>
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<td><strong>TOTAL</strong></td>
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<tr>
<td>Drilled Shaft Number</td>
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Laitance Encountered in the Core
What approach could effectively clean this matter out of the anomaly cavity?!
Triple-Superjet technology was utilized, with two nozzle inclinations (straight and angled (20-degree) to clean the anomalies from laitance.

The system consists of high pressure water jet sheathed in air being lowered into each hole in sequence, while an air lift in lowered into another (vacant) hole to evacuate water / eroded solids. Two separate setups (straight and angled nozzles) were used.
The Jet Cleaning Tool:
Jetting Pressure: 4,500 psi;
Flow Rate: high pressure water at 125 gpm; high volume water at 40 gpm;
Lift Rate: 0.33 ft/min;
Rotational Speed: 1-3 rpm;
Jetting Time: as needed (average approx. 7 hrs total) for both of the two nozzle setups. Longest time on hole: 42 hr, shortest: 4 hr.
Lay-Out of Cleaning Holes (Theory vs. Reality)
VIDEO INSPECTION OF CLEANING PHASE

By TBJV – A down-hole camera with the following capabilities will be utilized to inspect the anomaly:

i. GeoVision Deluxe Dual Scan (or equal) Camera
ii. High resolution (550 horizontal lines), color video
iii. High intensity LED lights
iv. 360 degree vertical and horizontal tilt and pan
v. Live video readout of camera depth
vi. Digital recording of video and user audio data
vii. A color video observation screen with a minimum diagonal dimension of 12” shall be provided during the video recording operations to provide adequate scale of observation in real time.
Typical Cleaning Results:

**APPROVED**

**DISAPPROVED**
Holes were dewatered prior to video inspection. On some occasions, this was impossible due to influx of water through upper joints in the monolith (the monolith concrete was poured in 5’-lifts), so the video inspection occurred in the wet.

As a result, anomalies in all but four (4) shafts were deemed cleaned satisfactory. Shafts 17-3, 28-3, 28-4, and 35-4 were kicked to our structural section for analysis of alternative repair(s). They would be subject to STRUCTURAL REPAIRS later on.
Repair Grouting Phase

Using Masterflow 1341 Grout
In many cases, locations had to be off-set due to structural steel hits by the core bit.
Cores of Grout-Repaired Anomaly Voids:
Repair Verification Videos

For acceptable cleaning:

For unacceptable cleaning – secondary repairs:

R33-6-1 Verification Video

Link:

https://youtu.be/He9PLdSDCU0

For secondary repairs, three (3) more repair holes were drilled, cleaned, and pressure-grouted. No verification holes were drilled upon completion of secondary repair grouting (we simply ran out of room to put the holes in).
Structural Repair Of the Four (4) Shafts (which Failed to Be Adequately Cleaned)

Theoretical Compression / Tension Zones:

Typical Repair:
Structural Shaft Repairs – MISSION ACCOMPLISHED.
LESSONS LEARNED:

1. Working “in-the-dry” provides a much better QC/QA success;
2. Small-dia. coring in reinforced concrete can be executed vertically with great precision (3”-verticality requirement was 95% met) to depths of up to 60’;
3. Non-shrink grouts are applicable to underwater repairs (filling-in voids);
4. Air/water mix jets are effective in loosening, breaking off, and removing debris from large flooded voids in concrete;
5. Communication between QC and QA personnel on a large complicated project is critical.
6. Account for unforeseen circumstances (flooding, equipment breakdowns) in the construction schedule.
All original (1947) work was done in the dry with great success. ➔ Do not reinvent the wheel (i.e. continue all subsequent work in the dry)
March 2015 Flood. Worked interrupted for about 1.5 month due to flooding.
The ongoing and future work

- Emptying Basin (completed summer 2016)
- Stilling Basin (to start in 2018)
- River Chamber Completion (2018)
- Construction complete or ongoing
The last spike. Shaft anomalies left to grout: 1

QUESTIONS?