Constructing in Congested Areas Without Damaging Existing Structures

Hugh S. Lacy, PE, D.GE, F.ASCE
Gregg V. Piazza, PE

Mueser Rutledge Consulting Engineers

GeoVirginia 2016
October 10-12, 2016, Williamsburg, VA
Case Studies

WMATA Slope Failure Investigation
Cheverly, MD

Rosslyn Central Place
Arlington, VA

Walter E. Washington Convention Center
Washington, DC

DC Marriott Marquis Convention Center Hotel
Washington, DC
Case Study 1:
WMATA Slope Failure Investigation
Cheverly, MD
Site Conditions

• Movement in a slope flatter than 1V:3H
• 2.3’ lateral movement of a WMATA bridge pier near the base of slope
• Site was underlain by hard fissured clay
• Stability analyses – marginal stability
Cause of Failure

- 18 ft. of fill recently placed for a parking lot at the top of the slope
- Fill placed on private land
Back Calculated Friction Angle $\phi_r = 8.7^\circ$
Material Properties:

<table>
<thead>
<tr>
<th>Name</th>
<th>Moist Unit Weight* (\text{lb/ft}^3)</th>
<th>Cohesion (\text{lb/ft}^3)</th>
<th>Internal Friction Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recent Fill</td>
<td>120</td>
<td>0</td>
<td>28°</td>
</tr>
<tr>
<td>Historic Fill</td>
<td>120</td>
<td>0</td>
<td>28°</td>
</tr>
<tr>
<td>T1, T2, and T3</td>
<td>130</td>
<td>0</td>
<td>30°</td>
</tr>
<tr>
<td>P1</td>
<td>125</td>
<td>0</td>
<td>8.7°</td>
</tr>
<tr>
<td>P2</td>
<td>130</td>
<td>0</td>
<td>36°</td>
</tr>
</tbody>
</table>

*Note: Saturated unit weight is 5 \(\text{lb/ft}^3\) more than moist for all soils.
Solutions Considered

- Several types of ground stabilization
- Remove the fill after negotiation with property owner
- Installation of drilled piers near base of slope to increase F.S.
Lessons Learned

Solutions need not be expensive stabilization of the ground but slopes can often be stabilized by simple means.
Case Study 2:
Rosslyn Central Place at Rosslyn Metro Station
Arlington, VA
Site Conditions

- Construction of office and apartment buildings immediately next to a deep rock subway station
- Construction of a new elevator entrance to the station mezzanine between the new structures
How to Minimize Impacts on the Metro Station

• Determine the number of below ground parking levels to minimize stress change around the Metro Station
• Evaluate stresses both during excavation and for the completed structures
• Use construction methods that would not damage the station while constructing the new elevator/stairway shaft and mezzanine approach to the station
Analysis to Determine Impact

- Analysis Program
- Stress Change in Station Lining
STAGE: INITIAL

SECTION B_HINGED

MODEL GEOMETRY

FILL
DECOMPOSED ROCK
WEATHERED TO MODERATELY JOINTED ROCK
RELATIVELY SOUND ROCK
SOUND ROCK
STAGE: UNLOAD

MODEL GEOMETRY

SECTION B_HINGED

Revised 07/08/2008
Lessons Learned

With the cooperation of the developer, it is possible to build directly next to a subway station by demonstrating successfully to the subway authority that this can be done safely.
Case Study 3:
Walter E. Washington Convention Center
Washington, DC
Site Conditions

1. Six block Site – 550 x 1450 Feet
2. Basement 40 to 65 Feet Deep
4. Groundwater up to 40 Ft. Deep
5. Subway/Apartment Bldgs Along East Side
6. Exhibit Hall at Basement Level – High quality Space
Design Issues

1. Groundwater Cutoff/Underdrainage of Basement
2. Support of High Building Loads on Hard Clay
3. Settlement of Building
4. Column Spacing 90 x 90 Feet
5. Exhibit Hall with 35 Foot Ceilings
6. High Horizontal Loads in Floors
Design Solutions

1. Permanent Slurry Wall Cutoff Around Perimeter
2. 30 x 30 x 9 Foot Deep Spread Footings
3. Slurry Walls Supported Independently of Interior Walls
1) Permanent Buttresses and Temporary Raker Braces
2) Rakers bracing Metro Station
3) Heel Block Test Set Up
4) Spread Footing with Grade Beams
• Innovative dewatering and groundwater cutoff
• Design of the slurry wall for temporary support of excavation and becomes the permanent wall
• Slurry wall relies on a unique combination of tiebacks, rakers, buttresses and shear walls for temporary and permanent lateral earth support
• Design of less costly spread footing founded on the cretaceous clay with steel piles below shear walls and buttresses to reduce wall deflection
• Design of low flow rate underdrainage system
Lateral Support Methods

1. Staircase Shear Walls Against East Wall Supported on Battered Piles to Minimize Wall Movement

2. Shear Walls Supported on Battered Piles Between Truck Bays With Steel Braces Against the Eastern Slurry Walls

3. Permanent Tie-back Anchors for the Tall North Wall and the Northern Part of the East Wall
Construction Constraints

1. Western Side of Convention Center extends below 9th Street Leaving Only 25% of the Street for Relocated Utilities. This Provides Space for the Truck Ramp

2. Installation of the Slurry Wall in 9th Street Required

3. The Subway Along the East Side of the Site Restricted Tie-back Anchors to Shallow Depths Above the Subway Resulting in Heavier Reinforcing and Temporary Interior Raker Bracing Using Large Heel Blocks for Reaction
Lesson Learned

This project demonstrates that, when needed for unusual structures, it is practical support perimeter walls up to 70 feet deep without interior support from floors. This solution required several different methods of support.
Case Study 4: DC Marriott Marquis Convention Center Hotel
Washington, DC
Location

Walter E. Washington Convention Center

Marriott Marquis Site
DC Marriott Marquis
Opened September 2014

Photos courtesy of Thornton Tomasetti
Soil Profile

- **FILL**
  - EL. 70 to 77

- **TERRACE SAND**
  - EL. 50 to 65
  - Groundwater EL. 35±
  - EL. 22 to 40

- **DENSE SAND**
  - EL. 30 to -20

- **HARD CLAY**
  - EL. -50 to -60
  - Top of Rock

- **BEDROCK**
  - EL. -50 to -60
Looking North at West End of Site

PEPCO Building
Helical Ramp Shaft
Hydro-Mill
Drilled Shaft Rig
Tieback Drill
Convention Center
Massachusetts Avenue
Duct Bank

September 15, 2011
Alternative Methods of Bracing and Protection Considered

- Underpinning Adjacent Structures
- Cross Lot Bracing
- Tie-Back Soil Anchors
- Raker Braces
- Top-Down Construction
Top-Down Method of Construction: **Sequence**

- Install slurry wall & drilled shafts / basement plunge columns
- Excavate to 1\textsuperscript{st} basement level & construct basement floor as brace
- Excavate below floor; install 2\textsuperscript{nd} basement floor
- Install plate girders above ballrooms
- Begin superstructure construction
- Continue to progressively excavate & construct permanent underground floors as bracing
Top-Down Method of Construction: **Benefits**

- Ideal for urban sites, deep excavations & wide construction sites
- Stiff bracing system minimizes impact on adjacent structures
- Avoids costly underpinning of adjacent structures
- Speeds up project completion as superstructure starts before excavation is completed
- Reduces project financing costs
Diaphragm Wall & Drilled Shafts Layout Plan

- Drilled-In Shafts with Plunged Steel Columns
- Temporary Detensioned Tiebacks used during Convention Center Construction
- "L" Street N.W.
- 9th Street N.W.
- 10th Street N.W.
- PEPCO Building
- Walter E. Washington Convention Center
- Massachusetts Avenue N.W.
- Temporary New Tiebacks (Anchors) EL. +66 only

Diaphragm (Slurry) Wall

Property Line
1. Construct guide walls
2. Excavate panel
3. Desand excavated panel
4. Install rebar cage
5. Place concrete
End Stops Used In Slurry Wall Construction

**Typical Joint**
20’ to 24’ Primary and 9’-3” Secondary

**Water Stop Joint**
(Used Along 9th Street)
(20’ to 24’ Panels)

**Steel Beam (w) Joint**
(used below shallow utilities)

**KEY**
P = Primary Panel
S = Secondary Panel
F = Follow-up Panel
Diaphragm (Slurry) Wall Construction
(Supports Exterior of Building)

Guide Walls

EL. 70 to 77
FILL

EL. 50 to 65
TERRACE SAND

EL. 22 to 40
DENSE SAND

EL. 30 to -20
HARD CLAY

Tip EL. -38 to -47

EL. -50 to -60
Final Subgrade

Groundwater EL. 35±

Top of Rock

BEDROCK
Drilled Shaft Construction and Plunge Columns Installation

- Drilled Shaft Concreted to Final Excavation Subgrade
- Plunge Steel Column (Interior Support Columns)
- Groundwater EL. 35±
- Final Subgrade

EL. 70 to 77
EL. 50 to 65
EL. 22 to 40
EL. 30 to -20
EL. -50 to -60

- FILL
- TERRACE SAND
- DENSE SAND
- HARD CLAY
- BEDROCK
Excavation for 1<sup>st</sup> Basement Slab Construction

- Compact Soil and Apply Bond Breaker
- Weld Steel Bracket to Column
- Slab Key In Wall
- Groundwater EL. 35±

**SOIL LAYERS:**
- **FILL**
- **TERRACE SAND**
- **DENSE SAND**
- **HARD CLAY**
- **BEDROCK**

**LEVELS:**
- EL. 70 to 77
- EL. 50 to 65
- EL. 22 to 40
- EL. 30 to -20
- EL. -50 to -60
Construct 1st Basement Slab

- Create Opening in Slab for Underslab Excavation

- Groundwater EL. 35±

Layers:
- EL. 70 to 77
- EL. 50 to 65
- EL. 22 to 40
- EL. 30 to -20
- EL. -50 to -60

- FILL
- TERRACE SAND
- DENSE SAND
- HARD CLAY
- BEDROCK
Excavation for 2nd Basement Slab Construction

Excavate Under Slab and Construct 2nd Basement Slab

Groundwater EL. 35±

EL. 70 to 77
EL. 50 to 65
EL. 22 to 40
EL. 30 to -20
EL. -50 to -60

FILL
SAND
DENSE SAND
HARD CLAY
BEDROCK
Protection & Monitoring of Existing Building During Slurry Wall Construction

- Tilt Meters (Monitoring Points)
- Plywood on 2" x 4" Spaced at 4' c.c.
- Strain Gages & Crack Gages
- Seismographs
- Slurry Wall Under Construction
- Belled Pier

PEPCO Building
Section Looking West

Upper Ballroom

Steel Plate Girders

Lower Ballroom

Parking Garage

Parking

Steel Girders

Mass. Ave.

"L" Street

EL. +70

EL. -16

EL. -22
Underslab Drainage System – Lower Level

Finish Floor
EL -7.0

Mechanical
F. F. EL -22.0

Finish Floor
EL -16.0

Clean Up Point

Drain Lines
Under Slab
On Grade
Truck Loading Dock Cut-Off Openings in Slurry Walls

9th Street Above

Convention Center Slurry Wall with Cut-Off Openings for Loading Dock

Existing Bracing Struts for Convention Center Slurry Wall

Truck Bays

Hotel Slurry Wall with Cut-Off Openings for Loading Dock

Excavation Sequence

1. Install paired hydraulic jacks for each strut
2. Incrementally load jacks to full load
3. Disconnect the bracing system from slurry wall
4. Sequentially excavate in 5-foot lifts. Release jack loads 5 kips for each 5 feet of excavation.
5. After excavation is complete, shim and grout between wall and wales and remove jacks.
Convention Center Slurry Wall – Looking West

Construction Procedure
1. Cut 4’0” Wide Slot at Panel Joints
2. Place Stub Columns in Slots for Panel Support
3. Cut-Off and Form Openings
Looking North at West End of Site

September 15, 2011
Helical Ramp Shaft: *Inner Shaft Constructed*
Excavation Openings

5-1 Slab Completed

Preparation for 5-2 Slab
Plate Girders Spanning Ballroom Below

Helical Ramp Shaft

Tieback Anchors
Conclusions

- Innovative use of Top-Down Construction resulted in the successful 97' deep excavation.

- Use of “hydro-mill” to install “water stop” shear keys simplified slurry wall construction.

- Benefits of Top-Down Construction include:
  - Resulting stiff bracing system eliminating need to underpin adjacent structures.
  - Simultaneous construction below and above grade resulting in shorter construction schedule and lower project costs.
Owner: Marriott International

Architect: Cooper Carry Architects
TVS Architects JV

Construction Manager: Hensel Phelps Construction Co.

Structural Engineering: Thornton Tomasetti

Slurry Wall / Tie back anchor Subcontractor: East Coast Slurry Company / Trevi Icos JV

Foundation Engineer: Mueser Rutledge Consulting Engineers

Geotechnical Engineer: Schnabel
Thank you!

Mueser Rutledge Consulting Engineers
New York, NY   | Washington, DC
www.mrce.com