Engineering Geology Challenges at the Marmet Lock Project

Geohazards in Transportation
6th Annual Technical Forum
August 2-3, 2006

Mike Nield – Corps of Engineers, Huntington District
Main Topics of Discussion
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1. PROJECT OVERVIEW
   a. Site Plan
   b. Site Geology
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2. DEEP SEATED SLIDING
   a. Design Concerns
   b. Cofferdam Foundation Movement
   c. New Chamber Lockwall Monoliths
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1. PROJECT OVERVIEW
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Marmet Lock Replacement – Project Overview

Site Plan

US Army Corps of Engineers
Huntington District
Marmet Lock Replacement – Project Overview

Existing Lock – Prior to Construction

Twin 56’ X 360’ Chambers
Completed in 1934
One Corps, One Regiment, One Team

Marmet Lock Replacement – Project Overview

US Army Corps of Engineers
Huntington District

New Lock – Conceptual Drawing

Twin 56’ X 360’ Chambers

New 110’ X 800’ Chamber will help alleviate traffic delays on Kanawah River
Marmet Lock Replacement – Project Overview

New Lock Chamber
Construction began in summer 2002
Cost $232 million

Existing Lock Chambers

New Lock Construction - Ariel View - May 2005
Marmet Lock Replacement – Project Overview

New Lock Construction - Ariel View - May 2005
Marmet Lock Replacement – Project Overview

New Lock Construction - Ariel View - May 2005

New Lock Chamber and Approach Walls
Marmet Lock Replacement – Project Overview

Site Plan

LEGEND
- ORANGE: EXISTING LOCKS AND DAM
- RED: NEW LOCK AND APPROACH WALLS
- WHITE: NEW LOCK CULVERT ALIGNMENT
- BLUE: COFFER DAMS

- Existing Lock Chambers
- Coffer Dam
- New 110’ X 800’ Chamber Under Construction

KANAWHA RIVER FLOW
Cofferdam Components – Typical Sections

Small Diameter Cells

Concrete

Select Fill (15.67’ r.)

Concrete

Top of Rock

Anchors

Thrust Block

LEGEND

YELLOW
EXISTING LOCKS AND DAM

RED
NEW LOCK AND APPROACH WALLS

WHITE
NEW LOCK CULVERT ALIGNMENT

BLUE
COFFER DAMS
One Corps, One Regiment, One Team

Marmet Lock Replacement – Project

EXISTING LOCKS AND DAM
NEW LOCK AND APPROACH WALLS
NEW LOCK CULVERT ALIGNMENT
COFFER DAMS

LEGEND

EXISTING LOCKS AND DAM
NEW LOCK AND APPROACH WALLS
NEW LOCK CULVERT ALIGNMENT
COFFER DAMS

Cofferdam Components – Typical Sections
One Corps, One Regiment, One Team

Marmet Lock Replacement – Project Overview

EXISTING LOCKS AND DAM

NEW LOCK AND APPROACH WALLS

NEW LOCK CULVERT ALIGNMENT

COFFER DAMS

LEGEND

EXISTING LOCKS AND DAM

NEW LOCK AND APPROACH WALLS

NEW LOCK CULVERT ALIGNMENT

COFFER DAMS

Cofferdam Components – Typical Sections
Marmet Lock Replacement – Project Overview

New Lock Features – Plan View

LEGEND
- EXISTING LOCKS AND DAM
- NEW LOCK AND APPROACH WALLS
- NEW LOCK CULVERT ALIGNMENT
- COFFER DAMS
One Corps, One Regiment, One Team

Marmet Lock Replacement – Project Overview

New Lock Features

EXISTING LOCKS AND DAM
NEW LOCK AND APPROACH WALLS
NEW LOCK CULVERT ALIGNMENT
COFFER DAMS

Lower Approach Wall

Concrete Filled Cells
Founded ~1’ below TOR
**Marmet Lock Replacement – Project**

**New Lock Features**

- New Lock Chamber
- Lower Approach Wall
- Concrete Filled Cells
  Founded ~1’ below TOR

**Legend**
- Existing Locks and Dam
- New Lock and Approach Walls
- New Lock Culvert Alignment
- Coffers Dams
One Corps, One Regiment, One Team

Marmet Lock Replacement – Project

New Lock Features

EXISTING LOCKS AND DAM
NEW LOCK AND APPROACH WALLS
NEW LOCK CULVERT ALIGNMENT
COFFER DAMS

Upper Approach Walls
Lock Chamber
Lower Approach Wall

Drilled Shafts
Socketed 15’ into Bedrock

Concrete Filled Cells
Founded ~1’ below TOR

LEGEND
Site Geology

- Relatively flat top of rock surface

- Sedimentary rock of the Pennsylvanian-aged Kanawha Formation
  - Sandstone member (23 to 43 feet thick)
  - Shale member (19 to 33 feet thick)

- Low angled bedding with 5°-10° dip to the Northwest

- Slightly fractured with occasional high angled joints (70°-90°)
Site Geology

Anchored Existing Landwall

Anchored Retaining Wall

Geologic Cross Section – Upper Miter Gate

SOIL
SANDSTONE
WEAK SEAMS
SHALE
Site Geology

Anchored Existing Landwall

Anchored Retaining Wall

Geologic Cross Section – Chamber Monoliths

SOIL  SANDSTONE  WEAK SEAMS  SHALE
Site Geology

- Light gray
- Moderately hard to hard
- Medium to fine grained
- Average unconfined compressive strength 8,442 psi

Sandstone Member
Site Geology

Thin Shale and Coal Seams within Sandstone
## Site Geology

### Bedrock Strength Parameters

<table>
<thead>
<tr>
<th>ROCK UNIT</th>
<th>Sliding</th>
<th>Friction</th>
<th>Cross Bed Shear</th>
<th>Allowable Bearing Capacity</th>
<th>Working Bond Strength</th>
<th>Modulus of Deformation</th>
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<tr>
<td>Shale Member</td>
<td>22</td>
<td>1</td>
<td>30</td>
<td>15</td>
<td>111</td>
<td>56</td>
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</table>
Main Topics of Discussion

1. PROJECT OVERVIEW
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2. DEEP SEATED SLIDING
   a. Design Concerns
   b. Cofferdam Foundation Movement
   c. New Chamber Lockwall Monoliths

3. GEOLOGIC ASPECTS OF CONSTRUCTION
   a. Anchor Installation
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   c. Foundation Preparation & Treatment
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2. DEEP SEATED SLIDING
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Marmet Lock Replacement - Deep Seated Sliding

Design Concerns

Pre-Construction Condition

- Dewatered Chamber
- Direction of Forces
- Soil
- Weak Seams
- Sandstone Member
- Existing Landwall
Marmet Lock Replacement – Deep Seated Sliding

Design Concerns

Pre-Construction Condition

Construction Condition

Upper Pool

Daylighted Weak Seam

Rock Excavation for New Lock Walls and Chamber
Marmet Lock Replacement – Deep Seated Sliding

Design Concerns

Pre-Construction Condition

Construction Condition

Permanent Condition

New Lock Riverwall

Backfill

Rock Excavation for New Lock Culvert
Marmet Lock Replacement – Deep Seated Sliding

Design Concerns

EXISTING LOCK (USED AS COFFERDAM)

UPPER POOL

OVERBURDEN

TOP OF ROCK

ROCK ANCHORS

STAGED ANCHORING DURING OVERBURDEN EXCAVATION

Analyzed for coal/shale seam at foundation (phi=23°, c=0psi)

INSTALL INSTRUMENTATION
Marmet Lock Replacement – Deep Seated Sliding

Design Concerns

EXISTING LOCK (USED AS COFFERDAM)

UPPER POOL

THRUST BLOCK ANCHORED PRIOR TO ROCK EXCAVATION
Analyzed for daylighted horizontal fault gouge (phi=13°, c=0psi)

SUBSURFACE EXPLORATION PERFORMED
Marmet Lock Replacement – Deep Seated Sliding

Design Concerns

EXISTING LOCK (USED AS COFFERDAM)

COMPLETE EXCAVATION FOR CULVER/INSPECTION TRENCH

ESTABLISH PRESENCE AND EXTENT OF WEAK SEAMS – NEW LOCK

DETERMINE CORRECTIVE FOUNDATION TREATMENT – NEW LOCK
Marmet Lock Replacement – Deep Seated Sliding Cofferdam

- 22-foot deep excavation
- 13-foot spacing

Excavation Adjacent to Cofferdam – 3D view
Marmet Lock Replacement – Deep Seated Sliding

Cofferdam - Instrumentation

Inclinometer Readings - August 2004
Marmet Lock Replacement – Deep Seated Sliding

Cofferdam - Instrumentation

Cofferdam Movement Based on Portable Inclinometer Data 10-04 to 4-05

Inclinometer - displacement vs. time
Inclinometer – displacement vs. time
Cofferdam Foundation Movement Response

- Establish Emergency Action Plan Based on Increments of Foundation Movement.
- Increase Instrumentation Readings and Installed Deeper Inclinometers
- Reanalyze Foundation Strength Parameters
- Accelerated Concrete Placement and Installed Additional Rock Anchors
Marmet Lock Replacement – Deep Seated

Sliding

Cofferdam Foundation Movement

Direction of Force

Select Fill

Concrete

Sheet Pile Cell Cofferdam

Thrust Block with Anchors

Weak Seam

Sandstone Member

Shale Member

Foundation Anchors

New Lock Wall

528

552

Cofferdam Foundation Movement - Section
One Corps, One Regiment, One Team

Marmet Lock Replacement – Deep Seated Sliding

Cofferdam Foundation Movement - Section

- Sheet Pile Cell Cofferdam
- Inclinometer Results Incremental Graph
- Direction of Force
- Weak Seam
- Sandstone Member
- Shale Member
- Foundation Anchors
- New Lock Wall Foundation

552
528
Cofferdam Foundation Movement - Section

Weak Seam

Direction of Force

Inclinometer Results Incremental Graph

Thin, Daylighted Carbonaceous Seam at 545+/-

Near Sandstone/Shale Contact at 520+/-

Sheet Pile Cell Cofferdam

Sandstone Member

Shale Member

Marmet Lock Replacement - Deep Seated

Sliding
One Corps, One Regiment, One Team

Marmet Lock Replacement – Deep Seated

SHEET PILE CELL COFFERDAM -1D

Carbonaceous Seam with Slickensided Surfaces
\( \phi = 15^\circ, c = 0 \text{psi} \)
SUITABLE FACTOR OF SAFETY

Clay Coated Sandstone/Shale Contact
\( \phi = 20^\circ, c = 0 \text{psi} \)

Passive Wedge through Fractured Sandstone
\( \phi = 30^\circ, c = 4 \text{psi} \)
ACCELERATED CONCRETE PLACEMENT TO ENHANCE PASSIVE WEDGE

Cofferdam Foundation Movement – Cell 1D
Marmet Lock Replacement – Deep Seated

Cofferdam Foundation Movement

COFFERDAM: EXISTING LOCKWALL MONOLITH M-22

ADDITIONAL 12-STRAND ANCHORS REQUIRED (Bond Zone Founded Below Installed Anchors)

Passive Wedge through Fractured Sandstone phi=30°, c=4psi

Clay Seam at Sandstone/Shale Contact phi=15°, c=0psi

SANDSTONE MEMBER

SHALE MEMBER

Anchors

Cofferdam Foundation Movement – M-22
Cofferdam Foundation Movement

- Some displacement is required to engage rock mass shear strength
- Establish how much movement is acceptable

Shear Stress

Horizontal Displacement

Peak Strength

Failure

SCALE EFFECT OR LENGTH OF SHEARED BLOCK WAS TAKEN INTO CONSIDERATION

0.35 INCHES ESTABLISHED AS APPROACHING FAILURE
Marmet Lock Replacement – Deep Seated Sliding

New Lockwall

Existing Landwall - Cofferdam

New Riverwall

Culvert

Weak Seams

Sandstone Member

Deep Seated Sliding – Culvert Excavation
Marmet Lock Replacement – Deep Seated

**Sliding**

- **Cofferdam (Existing Lockwall)**
- **New Lockwall**
- **Culvert Excavation & Inspection Trench**
- **Sandstone Member**
- **Daylighted Weak Seam**
- **Shale Member**

**New Chamber Lockwall Monoliths**
Marmet Lock Replacement – Deep Seated Sliding

Inspection Trench Sidewall - Photo

MONOLITH R-15A

EL 545
EL 531
EL 545
EL 531
STA 3+28
STA 3+78

New Chamber Lockwall Monoliths
Inspection Trench Sidewall - Photo

MONOLITH R-15A

DAYLIGHTED WEAK SEAM

New Chamber Lockwall Monoliths
Marmet Lock Replacement – Deep Seated Sliding

Inspection Trench Sidewall - Map

- Zones of Carbonaceous Stringers & open bedding planes (phi=30°, c=0psi)
- Potential Sliding Failure Plane through various materials
- Thin Coal Seams (phi=23°, c=0psi)
- Carbonaceous Shale w/ many slickensided fractures (phi=17°, c=0psi)

New Chamber Lockwall Monoliths
**Marmet Lock Replacement – Deep Seated Sliding**

- **NEW LOCKWALL**
- **CULVERT EXCAVATION & INSPECTION TRENCH**

**New Chamber Lockwall Monoliths**

- Daylighted Failure Plane (Weighted Average Phi Angle)
- Sandstone/Shale Contact (phi=22°, c=0psi)
- Cross Bed Shear (phi=30°, c=4psi)

- **SANDSTONE MEMBER**
- **SHALE MEMBER**
- **BACKFILL**
Marmet Lock Replacement – Deep Seated Sliding

NEW LOCKWALL

12- & 9-STRAND ANCHORS IN ALL NEW CHAMBER LOCKWALL MONOLITHS

CULVERT

NEW CHAMBER Lockwall Monoliths

SANDSTONE MEMBER

SHALE MEMBER

Rock Mass Engaged by Anchor

Anchor Bond Length
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Marmet Lock Replacement – Construction

Construction Sequence

COFFERDAM – ANCHORS – SOIL EXCAVATION
Marmet Lock Replacement – Construction

Construction Sequence

SUBSURFACE EXPLORATION – ROCK EXCAVATION
One Corps, One Regiment, One Team

Marmet Lock Replacement – Construction

Construction Sequence

ROCK EXCAVATION – FOUNDATION PREPARATION

01/09/2005
Marmet Lock Replacement – Construction

Construction Sequence

CONCRETE – FOUNDATION GROUTING
Marmet Lock Replacement – Construction

FOUNDATION ANCHORS

560 ANCHORS INSTALLED IN COFFERDAM
Marmet Lock Replacement – Construction

FOUNDATION ANCHORS

DOWN-THE-HOLE HAMMER

6 TO 10 INCH DIA. HOLES

DRILLING ANCHOR HOLES
Marmet Lock Replacement – Construction

FOUNDATION ANCHORS

- WITHIN 0.5° AZIMUTH AND INCLINATION
- LESS THAN 1 INCH DEVIATION PER 10 FEET OF HOLE

ANCHOR ALIGNMENT TESTING
Marmet Lock Replacement – Construction

FOUNDATION ANCHORS

- Anchor holes pressure tested
- Consolidation grouted
- Anchor installed
- First stage grouting of bond zone
- Tensioned and tested
- Second stage grouting of free length

ANCHOR TENSIONING
FOUNDATION ANCHORS

- Performance Testing
- Proof Testing
- Extended Creep Testing

<table>
<thead>
<tr>
<th>MUTS</th>
<th>Design Load</th>
<th>Lock Off Load (70% Des. Load)</th>
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<tbody>
<tr>
<td>9 Strand</td>
<td>527 kips</td>
<td>316 kips</td>
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<tr>
<td>12 Strand</td>
<td>703 kips</td>
<td>422 kips</td>
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<tr>
<td>15 Strand</td>
<td>879 kips</td>
<td>527 kips</td>
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ANCHOR TENSIONING AND TESTING
Marmet Lock Replacement – Construction

ROCK EXCAVATION

- Pre-blast Survey of Community
- 50’ Maximum Blasting Dimension Along Axis
- Buffer Zone and Sill Excavation Methods
- 3 in/sec Peak Particle Velocity at Nearest Structure
- Line Drilled Perimeters
Marmet Lock Replacement – Construction

ROCK EXCAVATION

LINE DRILLED PERIMETER
Marmet Lock Replacement – Construction

ROCK EXCAVATION

PRODUCTION SHOT

12/29/2004
Marmet Lock Replacement – Rock Excavation

Scaled Distance

Peak Particle Velocity

Individual Blast Results

Slope Represents Specified Equation to Predict Blast Vibration

\[ V = 160 \left( \frac{R}{W}^{0.5} \right)^{-1.6} \]

Evaluating Specified Vibration Equation

Plot Individual Blast Results on Log/Log Graph

Evaluating Specified Vibration Equation
Evaluating Specified Vibration Equation

Specified Equation is Suitable for Critical Blasts

Critical Seismograph Closest to Blast

Distant Seismograph (will not govern blast design)

\[ V = 160(R/W^{0.5})^{-1.6} \]
Marmet Lock Replacement – Construction

FOUNDATION PREPARATION

OVER BREAK BEHIND LINE DRILLED FACE
One Corps, One Regiment, One Team

Marmet Lock Replacement – Construction

FOUNDATION PREPARATION

SHOT HOLE DAMAGE

05/25/2005
One Corps, One Regiment, One Team

Marmet Lock Replacement – Construction

FOUNDATION PREPARATION

SHALE LENS AND SEAMS
One Corps, One Regiment, One Team

Marmet Lock Replacement – Construction

FOUNDATION PREPARATION

JONTS WITH ARTESIAN GROUNDWATER FLOW

US Army Corps of Engineers
Huntington District
**Marmet Lock Replacement - Construction**

**DRILLED SHAFT FOUNDATION**

- Thrust Block
- 10’ X 10’ Precast Beam
- 122’ & 105’ span
- 6’ Diameter Shaft
- Drilled 15’ into Bedrock

**UPSTREAM APPROACH WALLS**
Marmet Lock Replacement – Construction

DRILLED SHAFT FOUNDATION

BOREHOLE JACK TESTING
Marmet Lock Replacement – Construction

US Army Corps of Engineers
Huntington District

One Corps, One Regiment, One Team

MARMET LOCK REPLACEMENT – CONSTRUCTION

DRILLED SHAFT FOUNDATION

DRILLING 6-FOOT DIAMETER SHAFT
Marmet Lock Replacement – Construction

DRILLED SHAFT FOUNDATION

INSTALLING REBAR CAGE & PLACING CONCRETE
Marmet Lock Replacement – Construction

One Corps, One Regiment, One Team

DRILLED SHAFT FOUNDATION

CSL TESTING AND LOW DENSITY CONCRETE
Foundation Drilling and Grouting

- Grout Curtain Extends to Elevation 510
- 10’ Spacing Between Primary and Secondary Holes
- Optional Tertiary and Higher Order Holes
- All Holes Pressure Testing
- Neat Cement Grout
One Corps, One Regiment, One Team

Marmet Lock Replacement – Construction

Foundation Drilling and Grouting

Drilling Grout Holes

Grouting Plant

Grout Header
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QUESTIONS AND ANSWERS

Contact Information

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