US Army Corps
of Engineers
Huntington District

Engineering Geology Challenges During Design and Construction of the Marmet Lock Project

2005 Tri-Service Infrastructure Systems Conference August 2-5, 5005

Ron Adams & Mike Nield

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Main Topics of Discussion

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1. PROJECT OVERVIEW

a. Site Plan
b. Site Geology

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

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2. DEEP SEATED SLIDING

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3. GEOLOGIC ASPECTS OF CONSTRUCTION

a. Anchor Installation
b. Rock Excavation
c. Foundation Preparation & Treatment
d. Drilled Shaft Foundations
e. Foundation Drilling and Grouting

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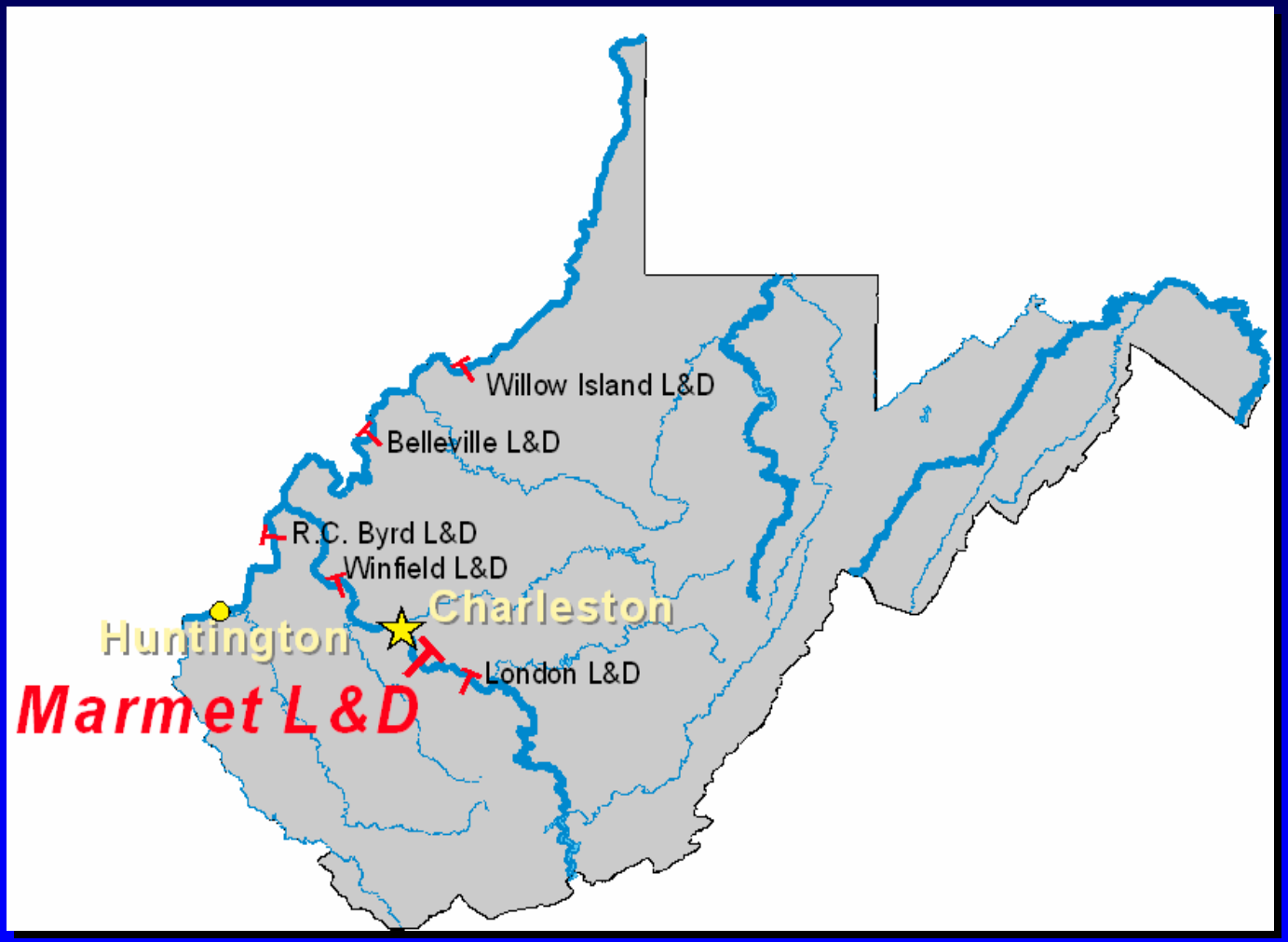
Marmet Lock Replacement – Project Overview



Site Plan

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Marmet Lock Replacement Project

- **Purpose is to alleviate traffic on the Kanawha River**

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Marmet Lock Replacement Project

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- **Existing and smaller 56’ X 360’ lock chambers inhibit river traffic**

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Marmet Lock Replacement Project

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- **Existing and smaller 56’ X 360’ lock chambers inhibit river traffic**
- **Project adds one larger 110’ X 800’ lock chamber and approach walls, located landward of old locks**

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Marmet Lock Replacement Project

- Purpose is to alleviate traffic on the Kanawha River
- Existing and smaller 56’ X 360’ lock chambers inhibit river traffic
- Project adds one larger 110’ X 800’ lock chamber and approach walls, located landward of old locks
- Construction started in summer 2002 with a current contract cost of $232 Million

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Marmet Lock Replacement – Project Overview

Existing Lock – Prior to Construction

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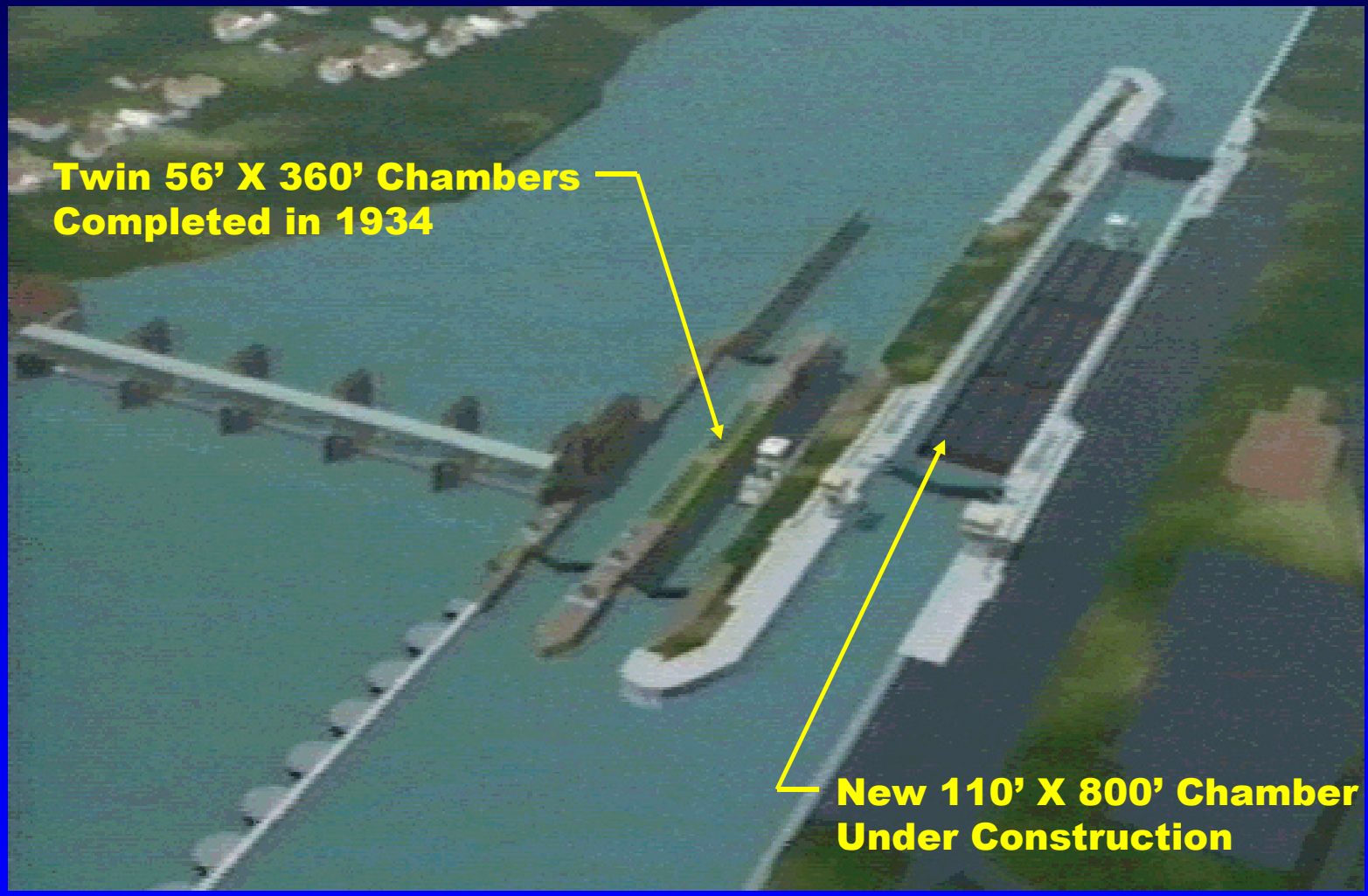
Marmet Lock Replacement – Project Overview



New Lock – Conceptual Drawing

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One Corps, One Regiment, One Team

Marmet Lock Replacement – Project Overview

New Lock Chamber Under Construction

Existing Lock Chambers

New Lock Construction - Ariel View - May 2005

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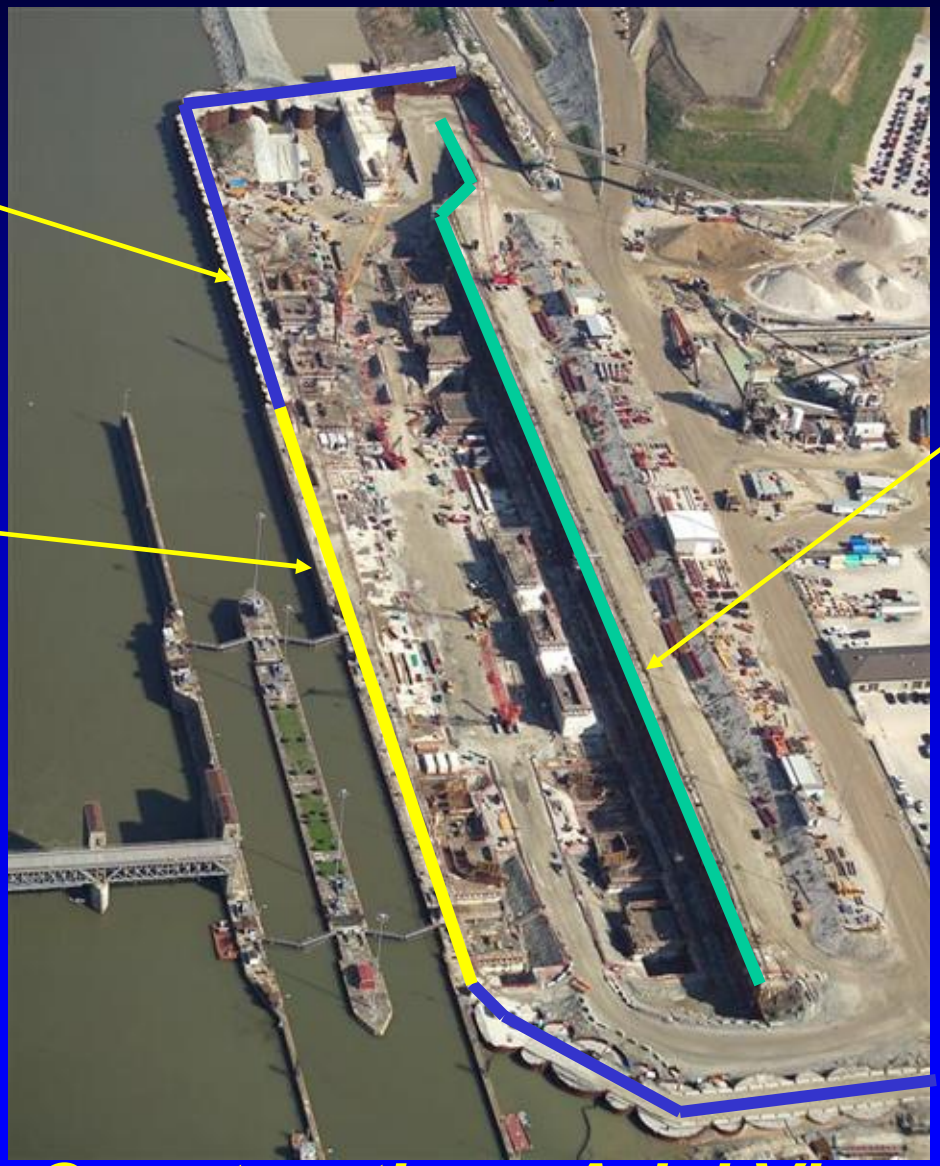
Marmet Lock Replacement – Project Overview



New Lock Construction - Ariel View - May 2005

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One Corps, One Regiment, One Team

Marmet Lock Replacement – Project Overview

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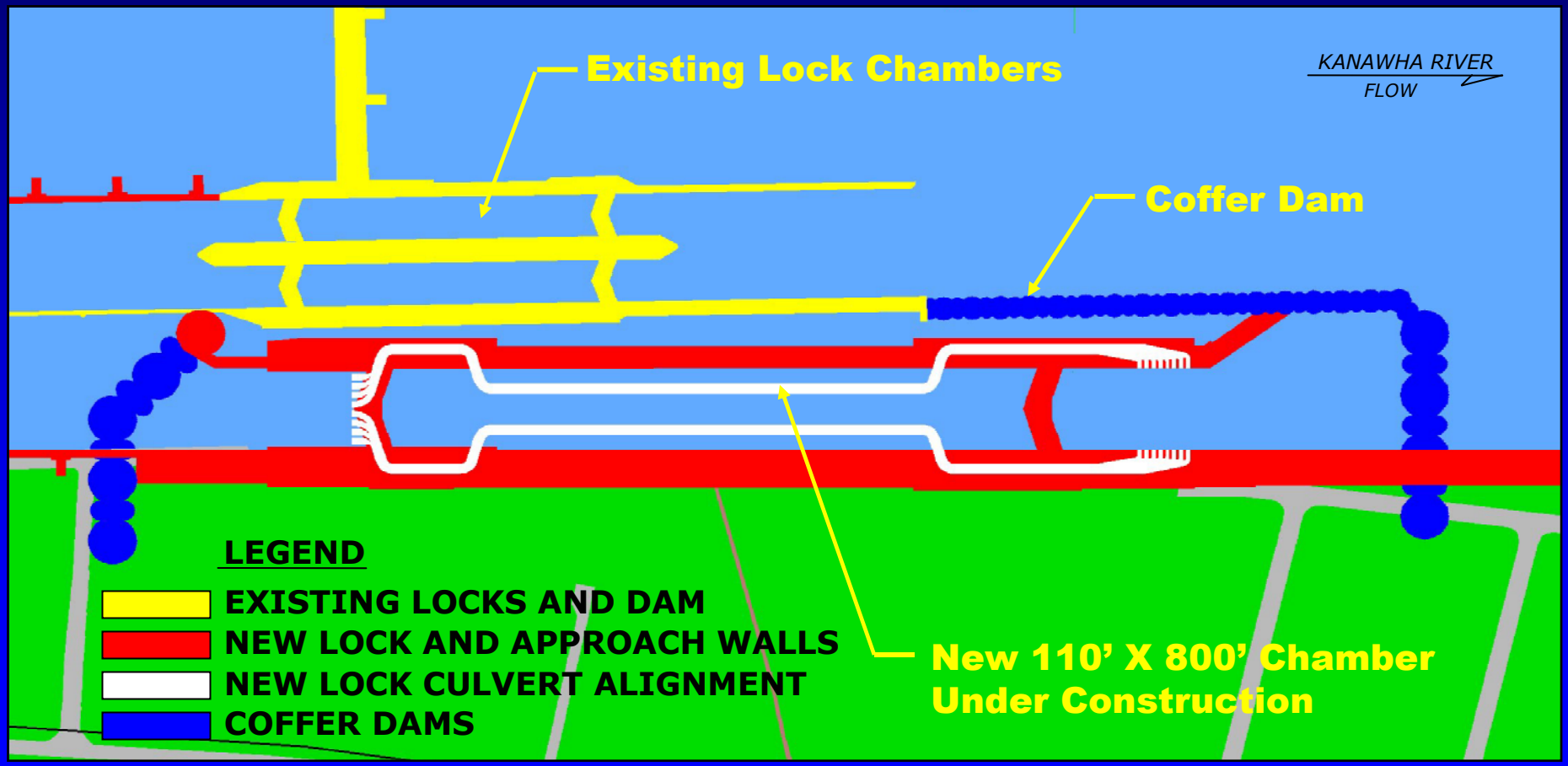
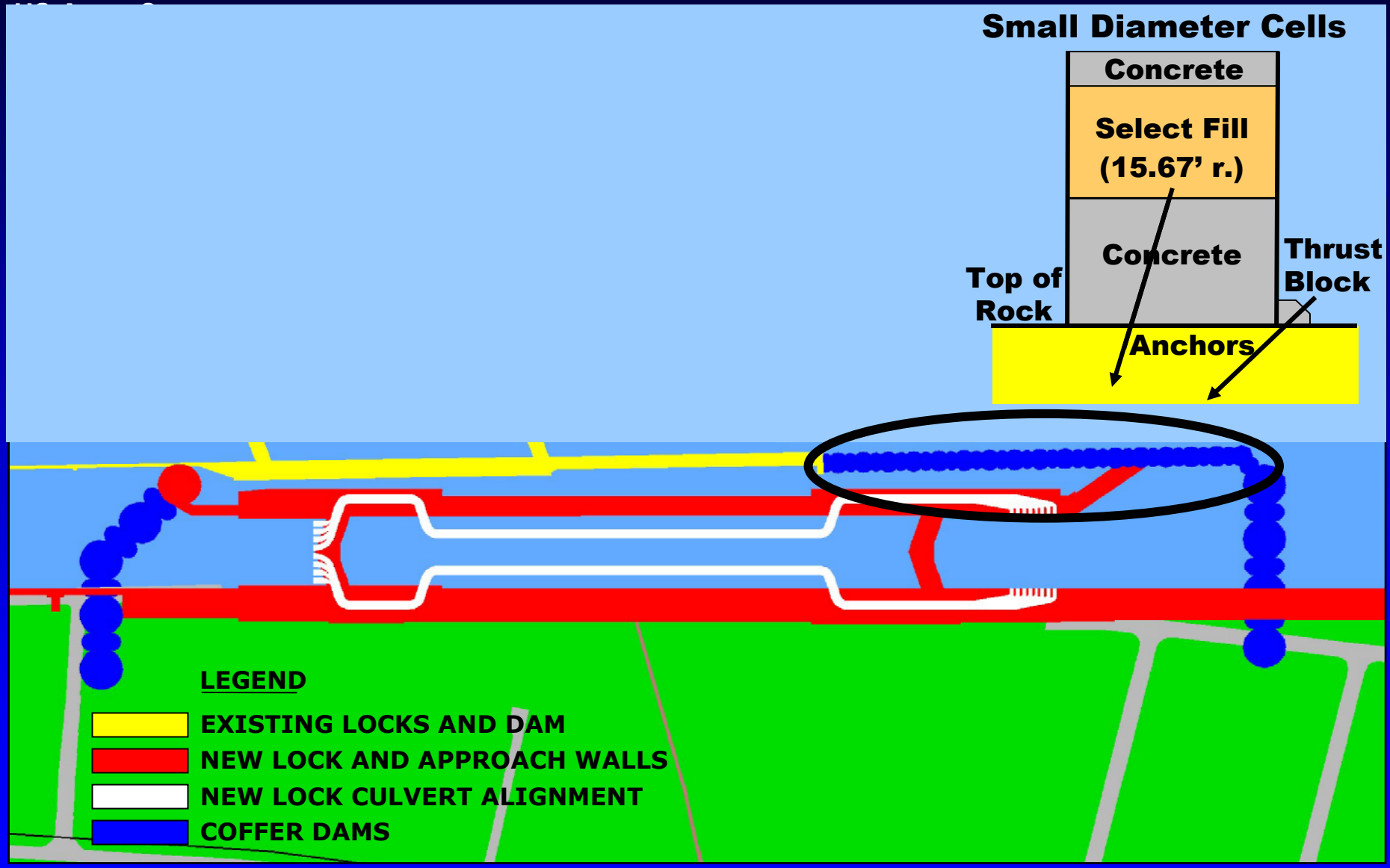


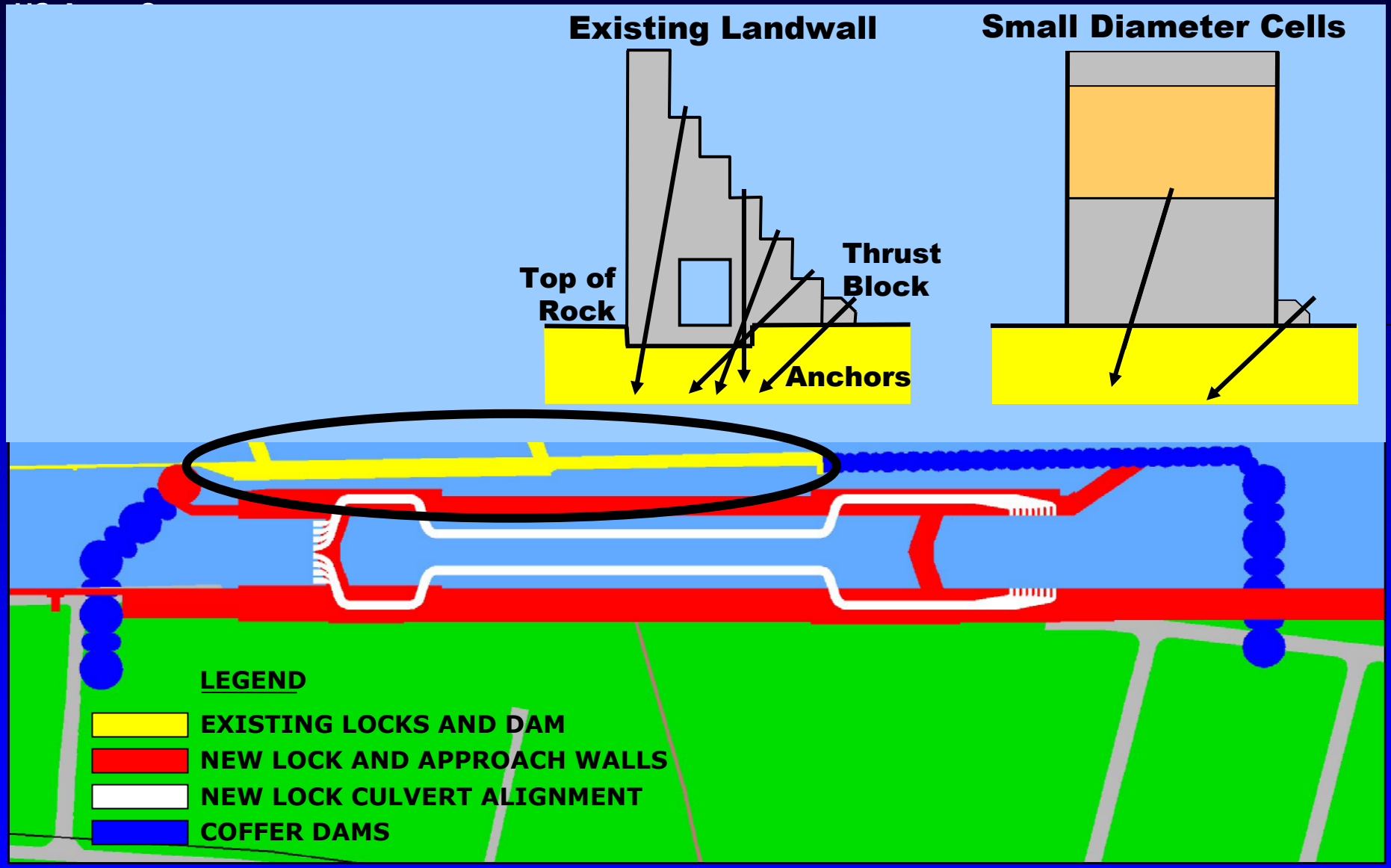
Site Plan

Marmet Lock Replacement – Project Overview



Cofferdam Components – Typical Sections

Marmet Lock Replacement – Project Overview



Cofferdam Components – Typical Sections

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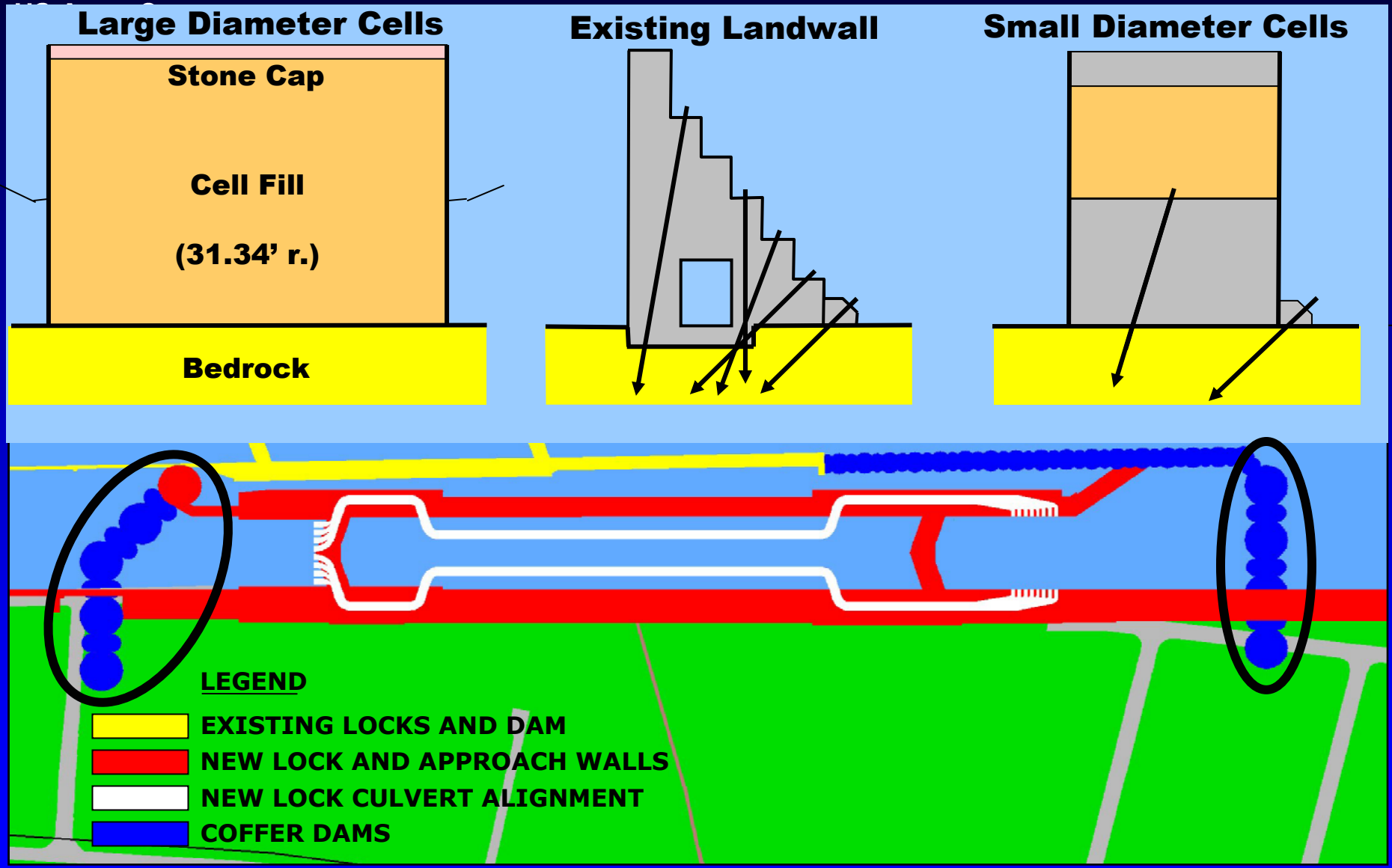

Cofferdam Components – Typical Sections

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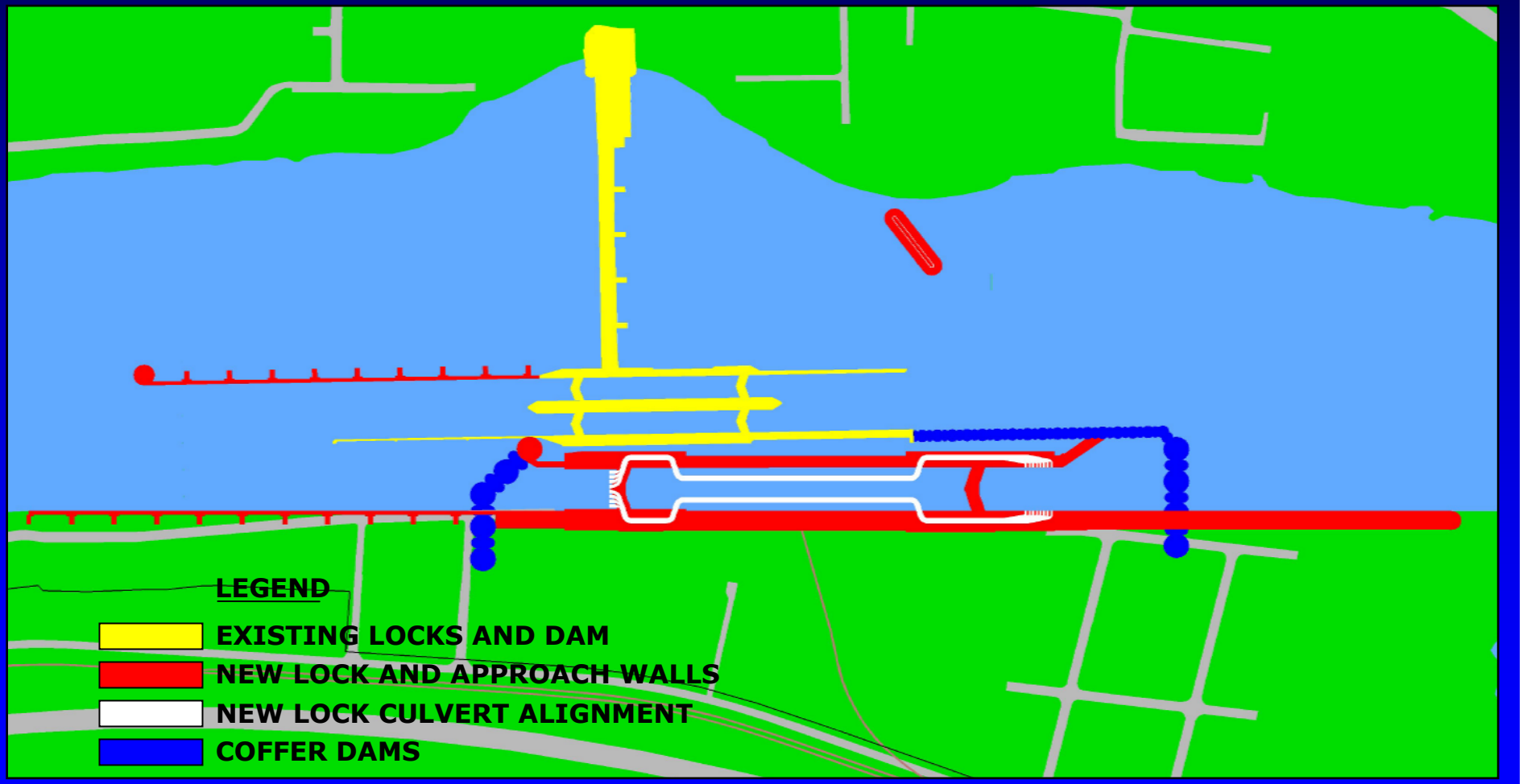
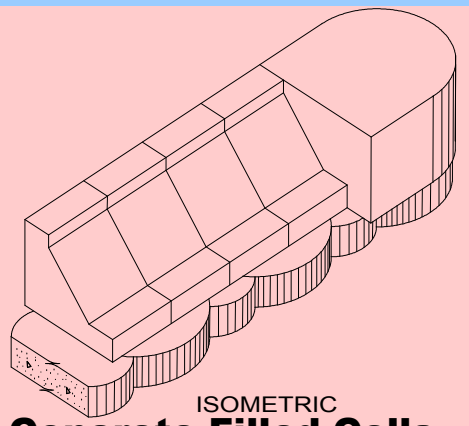
Marmet Lock Replacement – Project Overview



New Lock Features – Plan View

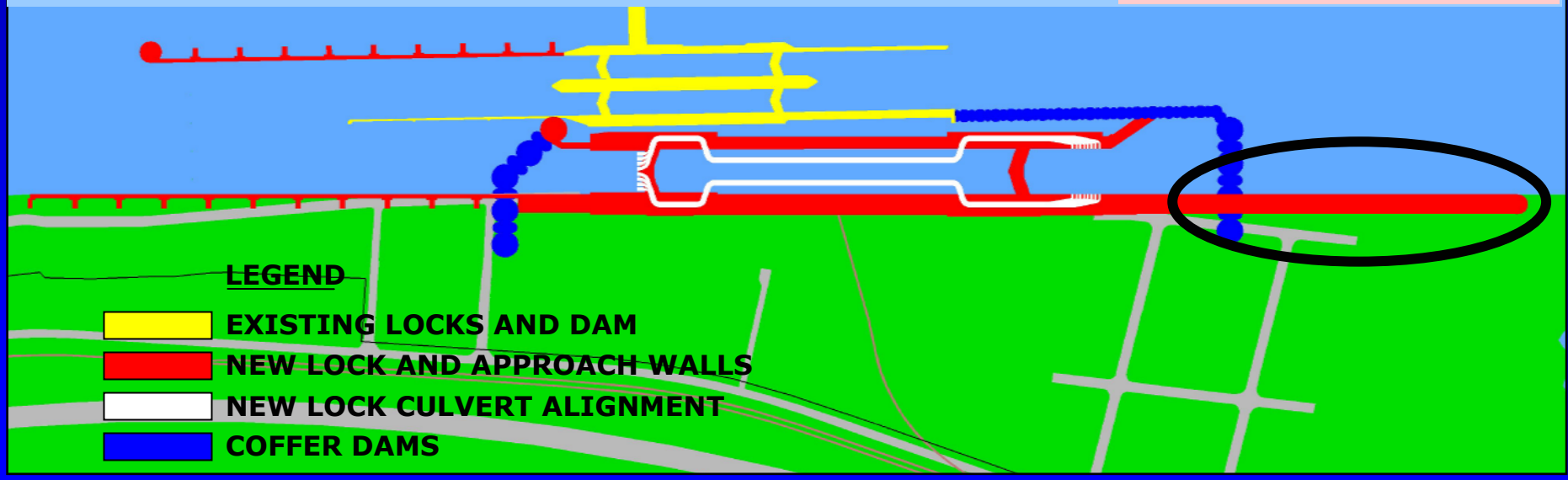
Marmet Lock Replacement – Project Overview

Lower Approach Wall



ISOMETRIC

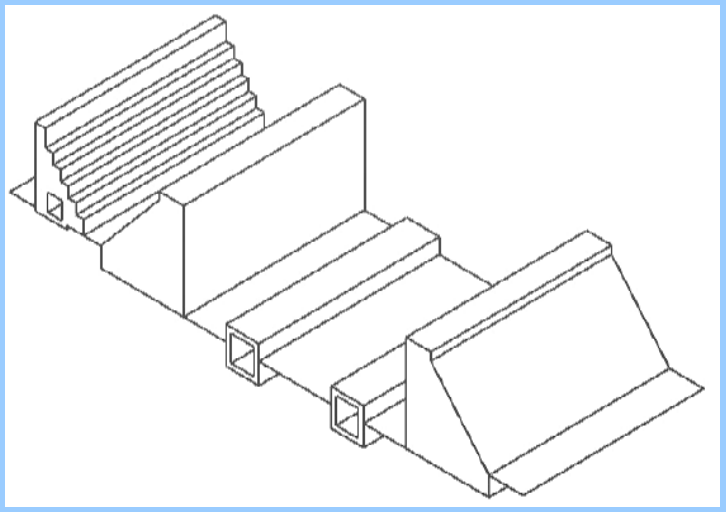
Concrete Filled Cells
Founded ~1’ below TOR



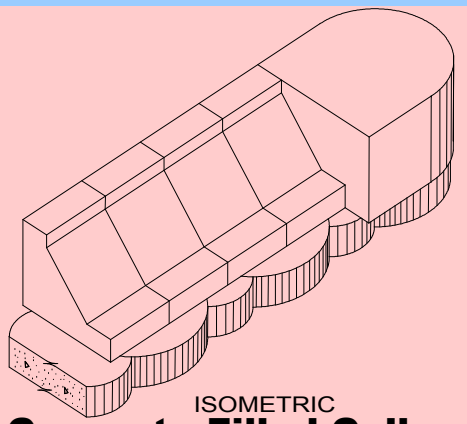
New Lock Features

Marmet Lock Replacement – Project Overview

Lock Chamber



Lower Approach Wall



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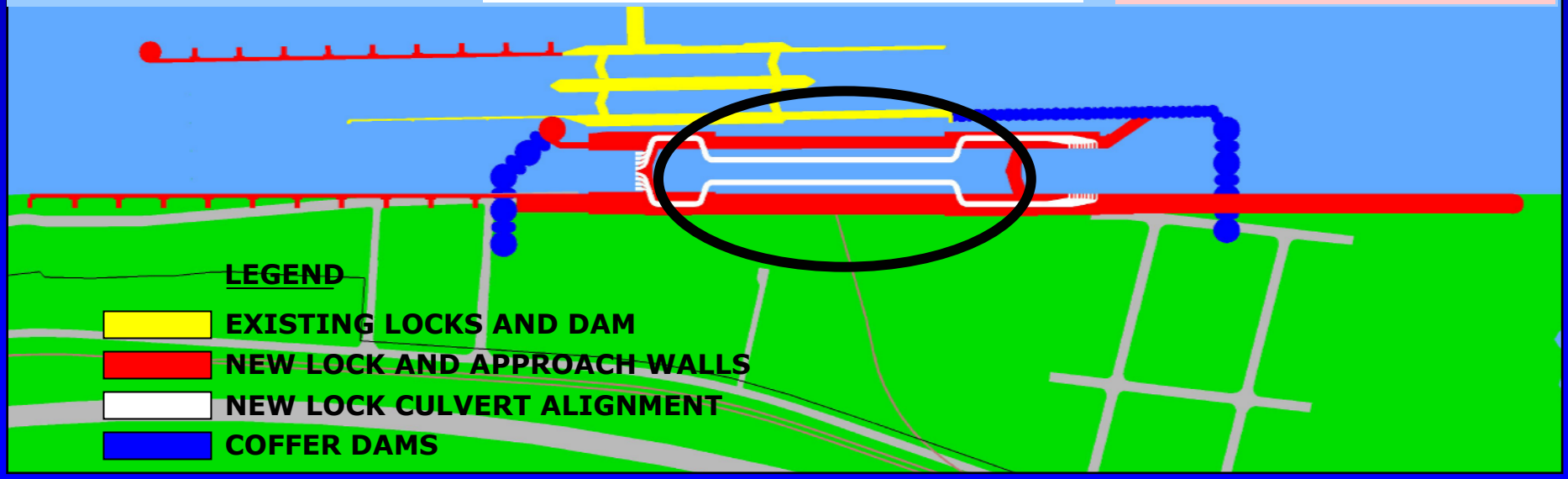
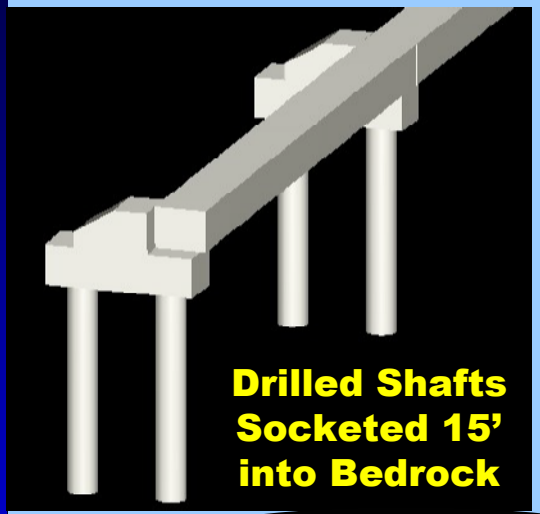


New Lock Features

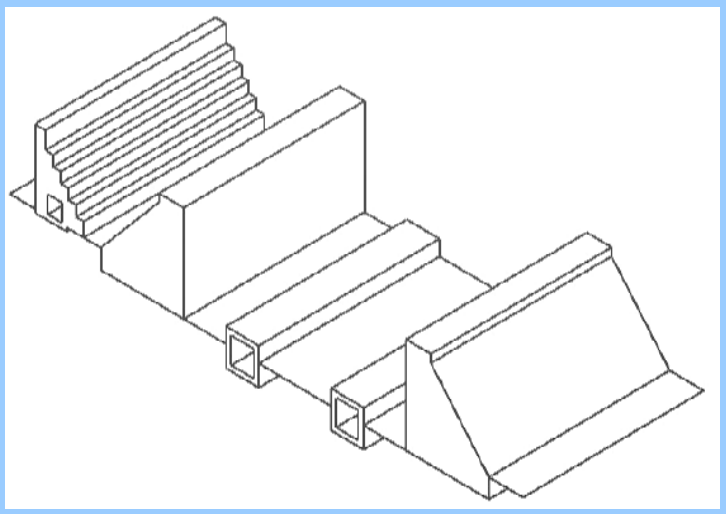
Marmet Lock Replacement – Project Overview

Upper Approach Walls

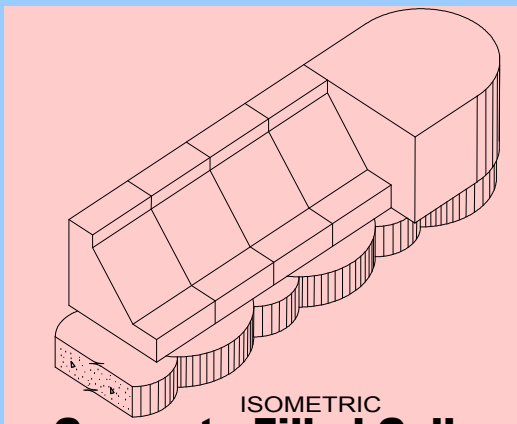


Drilled Shafts Socketed 15' into Bedrock

Lock Chamber

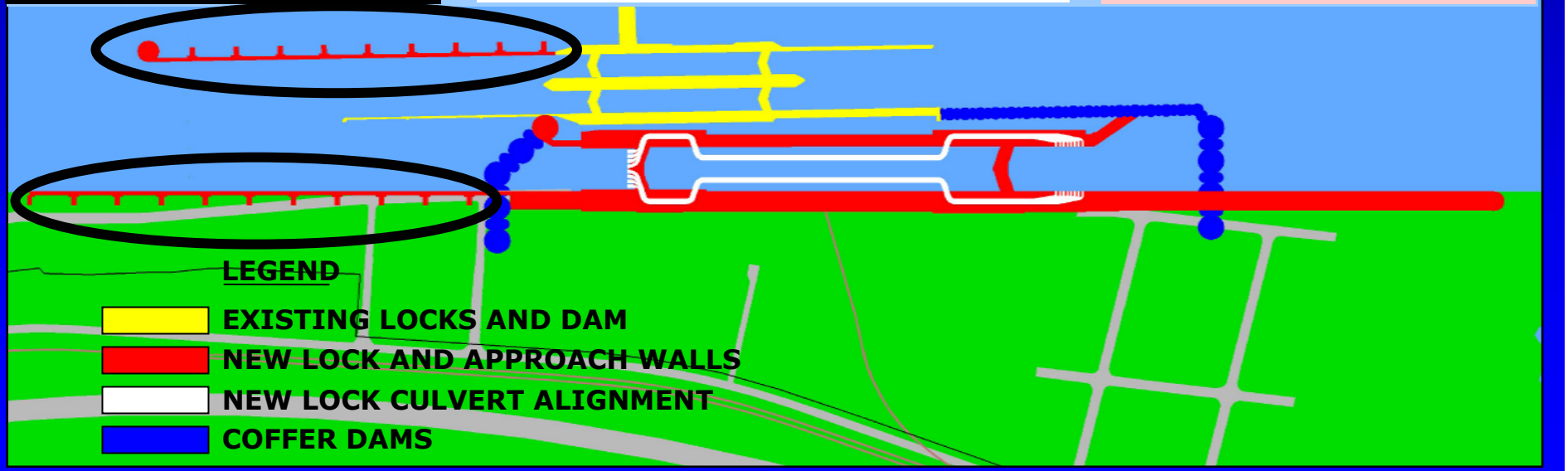


Lower Approach Wall



ISOMETRIC

Concrete Filled Cells Founded ~1' below TOR



New Lock Features

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Site Geology

- Relatively flat top of rock surface
- Sedimentary rock of the Pennsylvanian-aged Kanawha Formation
- Nearly horizontal bedding. **Discovered low angled (5 - 10°) dip to the Northwest during construction with localized stratigraphic dip**
- Rock Units:
  - Sandstone member (23 to 43 feet thick)
  - Shale member (19 to 33 feet thick)
- Sandstone member is competent but interbedded with many thin seams and stringers of coal and shale. **Discovered to be continuous in excavated sidewalls during construction.**

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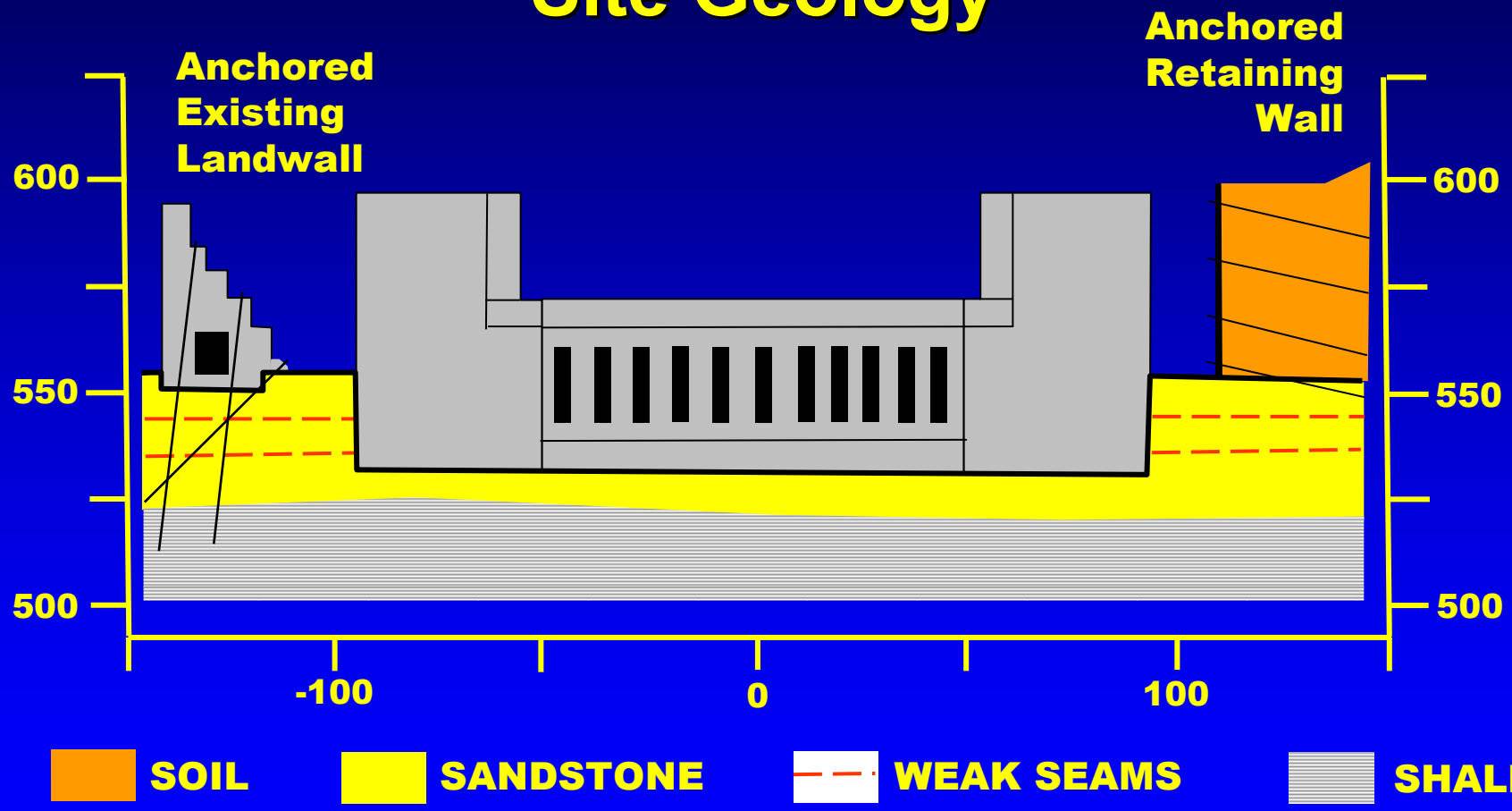
Marmet Lock Replacement – Project Overview

Site Geology



Geologic Cross Section – Upper Miter Gate

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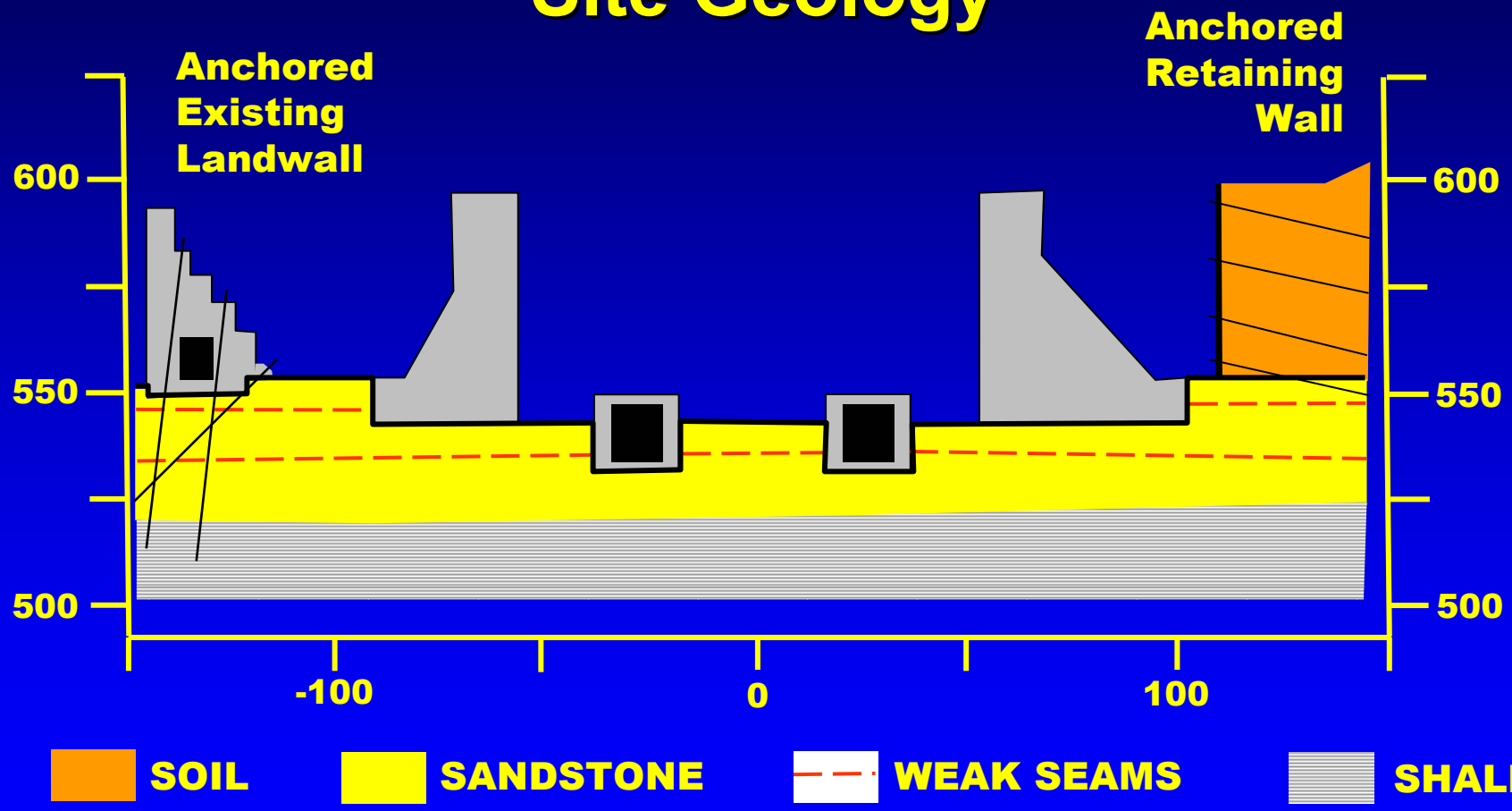
Huntington District

Marmet Lock Replacement – Project Overview

Site Geology



Geologic Cross Section – Chamber Monoliths

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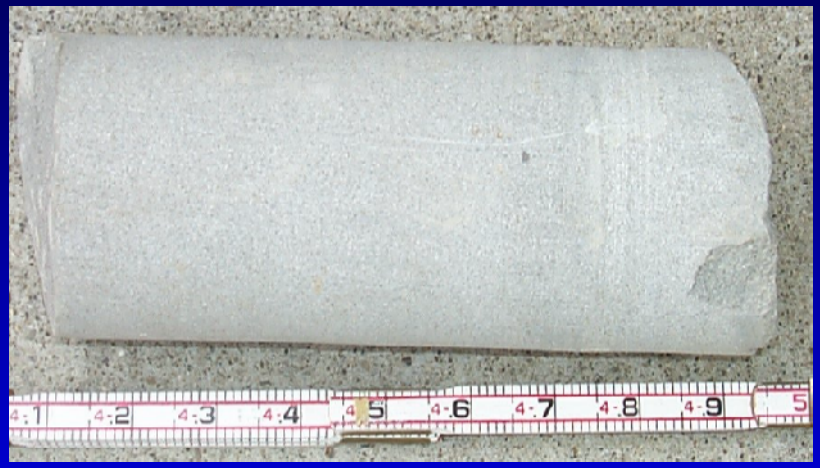
Huntington District

Marmet Lock Replacement – Project Overview

Site Geology



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

Sandstone Member

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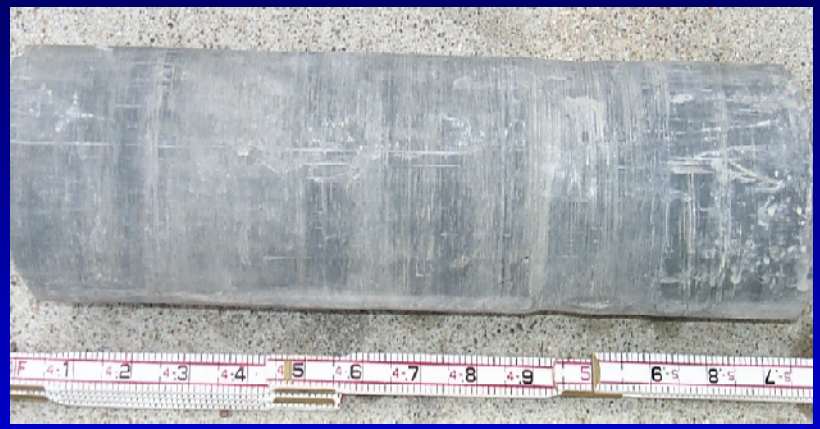
Marmet Lock Replacement – Project Overview

Site Geology



- Gray to dark gray
- Moderately hard to soft
- Silty
- Average unconfined compressive strength 6,678 psi

Shale Member

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Marmet Lock Replacement – Project Overview

Rock Mechanics Testing

- **Design Sliding Friction Strength: phi angle = 30°, cohesion = 4psi**
- **Cross Bed Shear Strength: phi angle = 45°, cohesion = 73psi**

Typical Sandstone Member Bedding Plane

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Marmet Lock Replacement – Project Overview

Rock Mechanics Testing

Design Sliding Friction Strength:
phi angle = 23°, cohesion = 0psi

Thin Shale and Coal Seams within Sandstone

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Marmet Lock Replacement – Deep Seated Sliding

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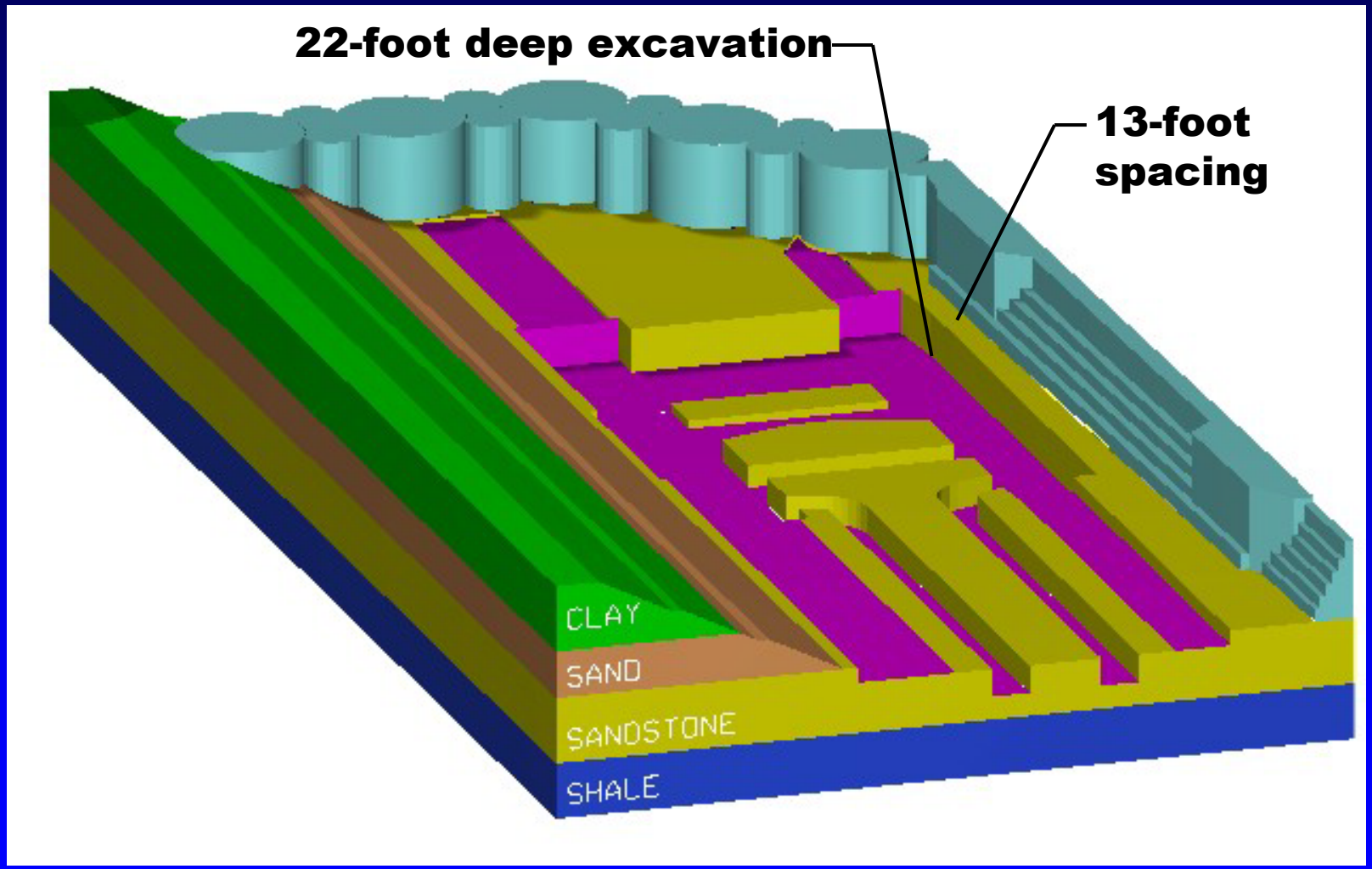

Excavation Adjacent to Structures – 3D view

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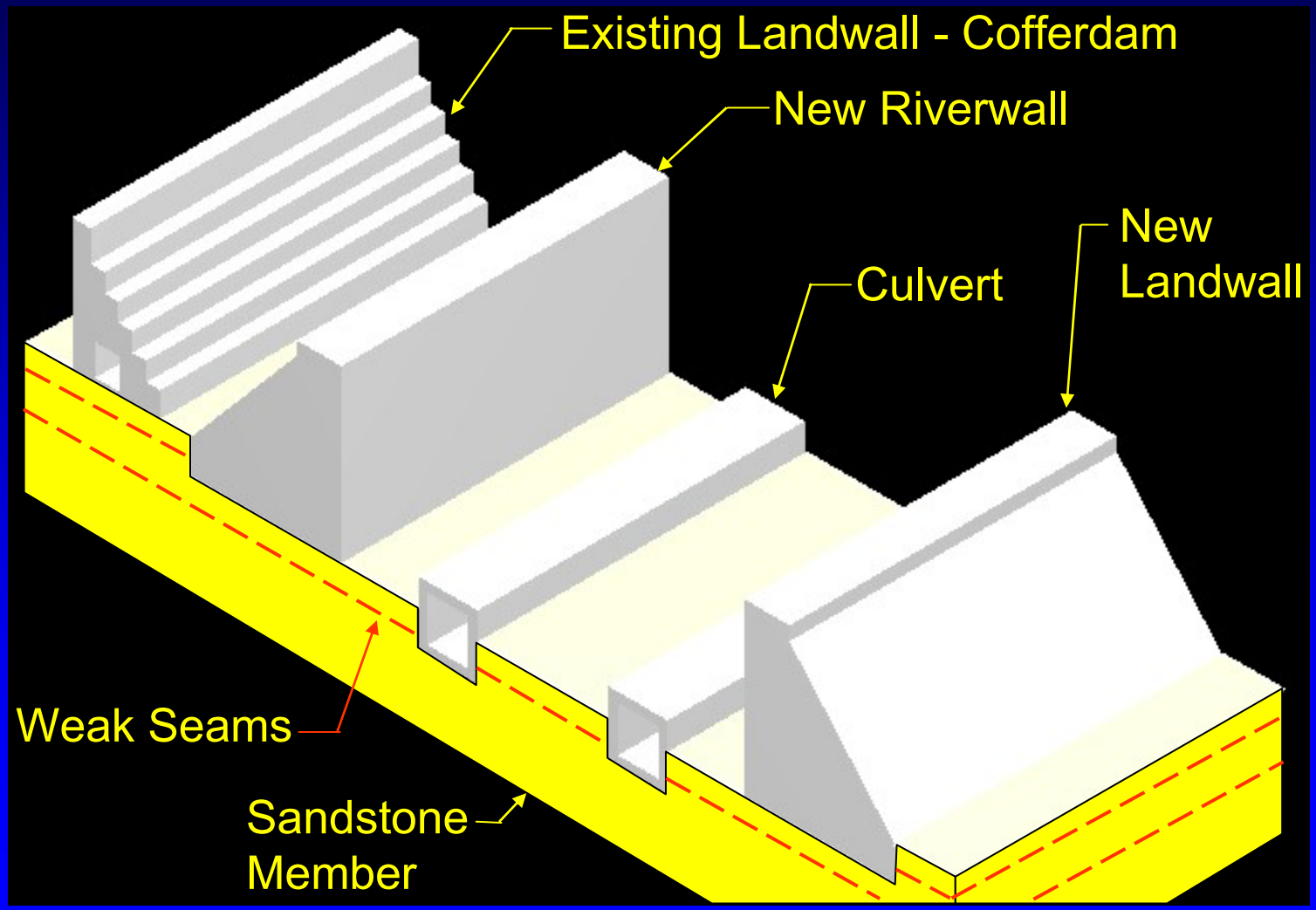
Marmet Lock Replacement – Deep Seated Sliding

Design Concerns

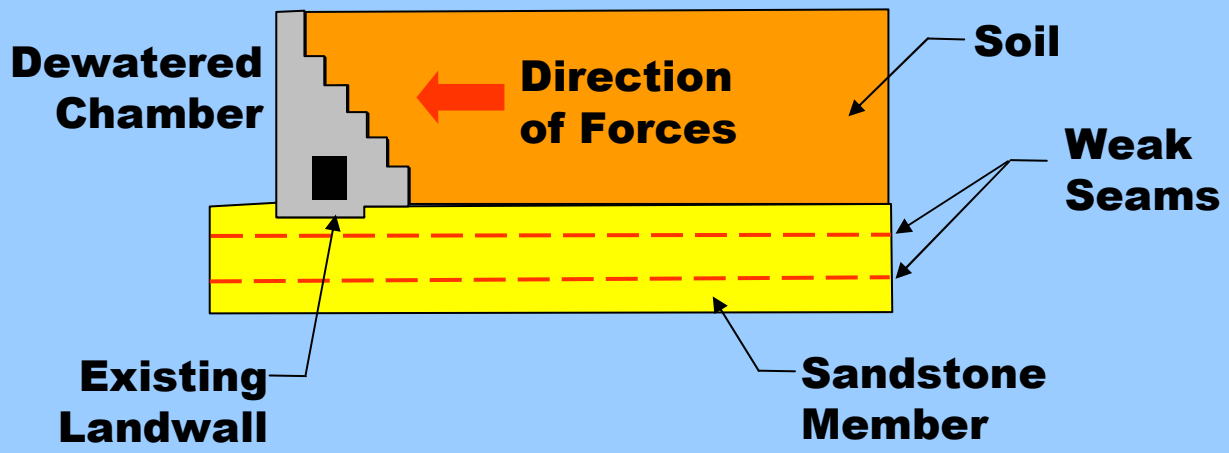


Deep Seated Sliding – Daylighted Weak Seams

Marmet Lock Replacement – Deep Seated Sliding

Design Concerns

Pre-Construction Condition



Marmet Lock Replacement – Deep Seated Sliding

Design Concerns

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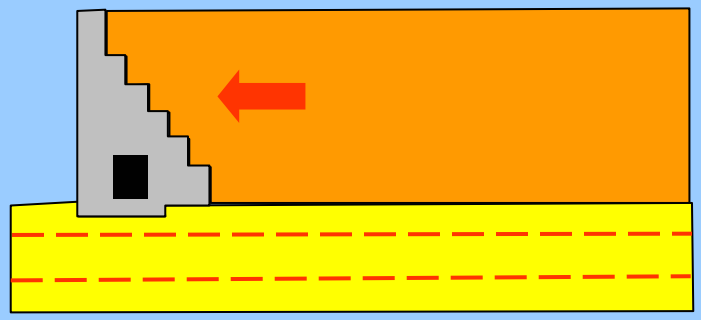
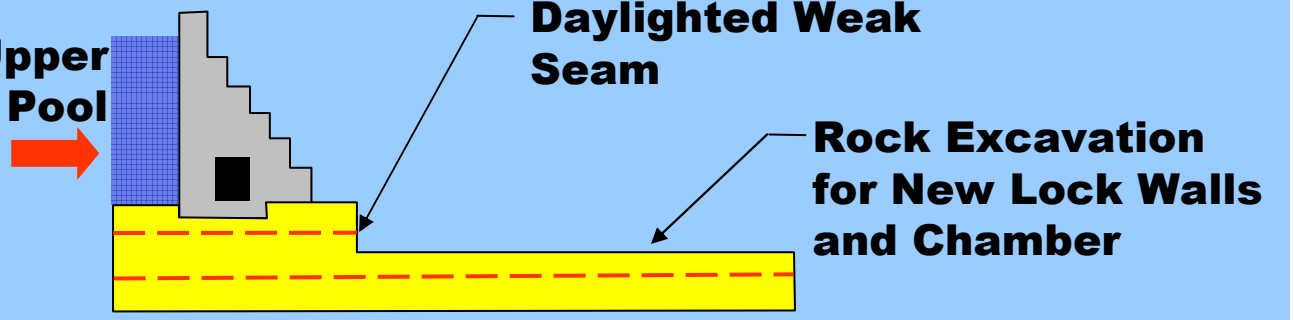


Construction Condition



Marmet Lock Replacement – Deep Seated Sliding

Design Concerns

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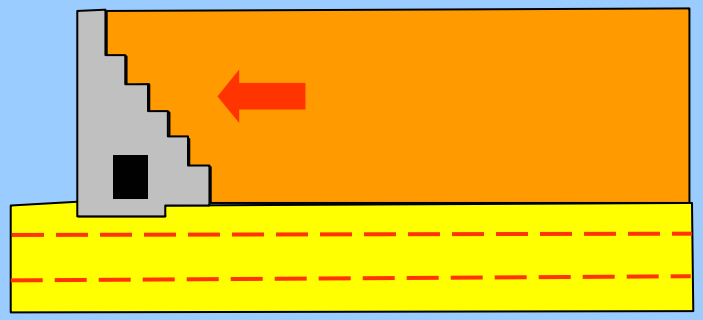
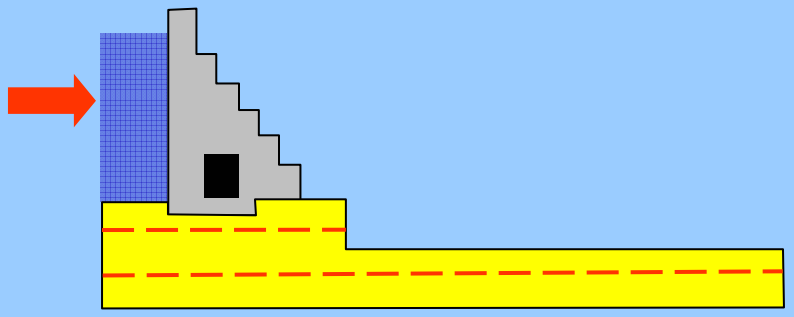
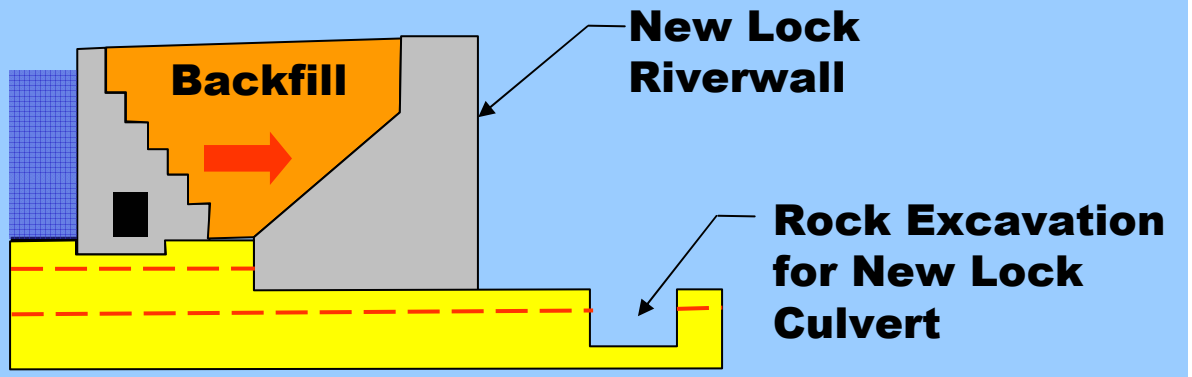


Construction Condition

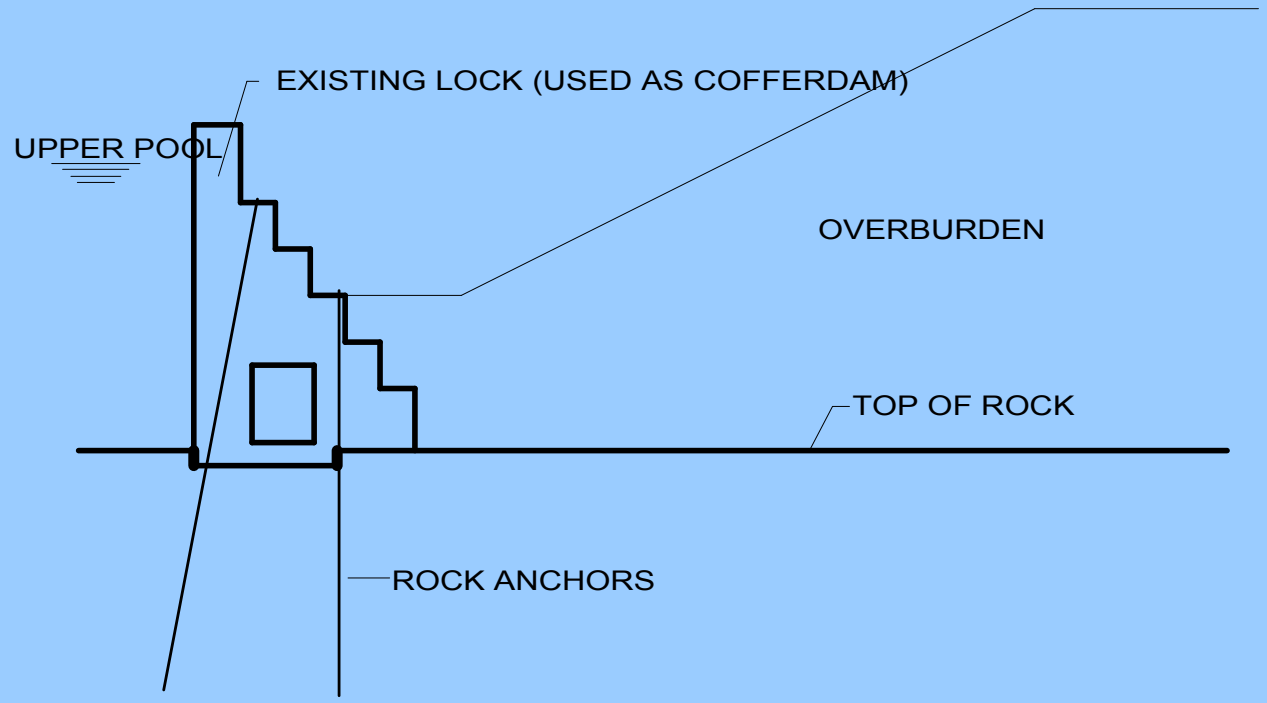


Permanent Condition



Marmet Lock Replacement – Deep Seated Sliding

Design Concerns

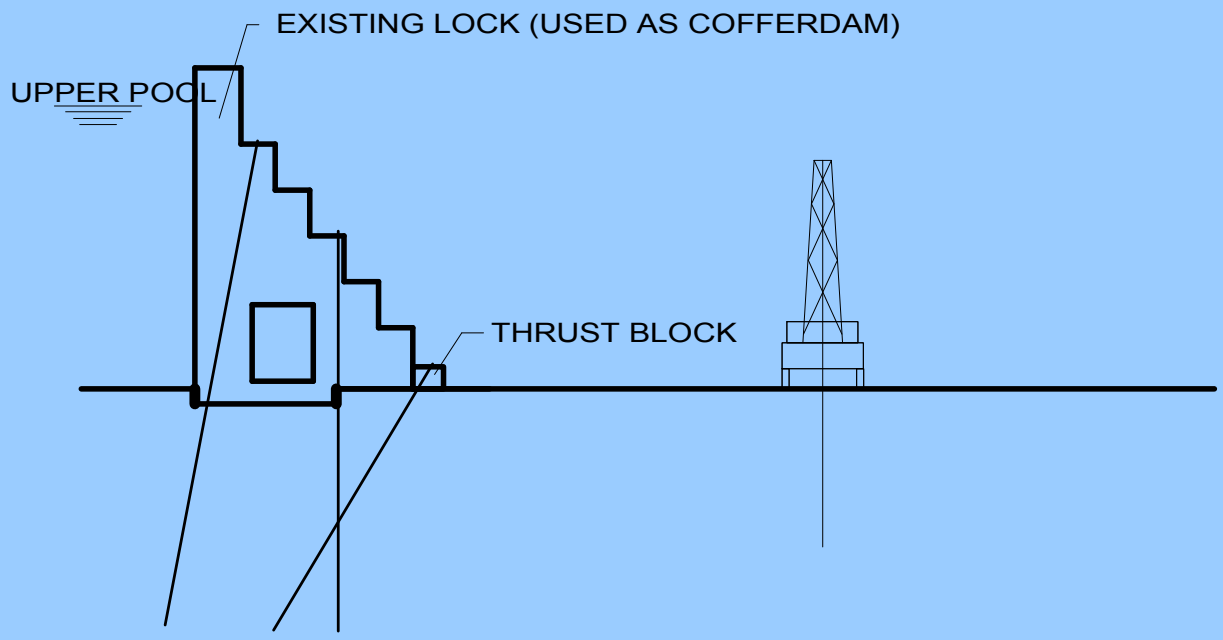


STAGED ANCHORING DURING OVERBURDEN EXCAVATION
Analyzed for coal/shale seam at foundation (phi=23°, c=0psi)

INSTALL INSTRUMENTATION

Marmet Lock Replacement – Deep Seated Sliding

Design Concerns

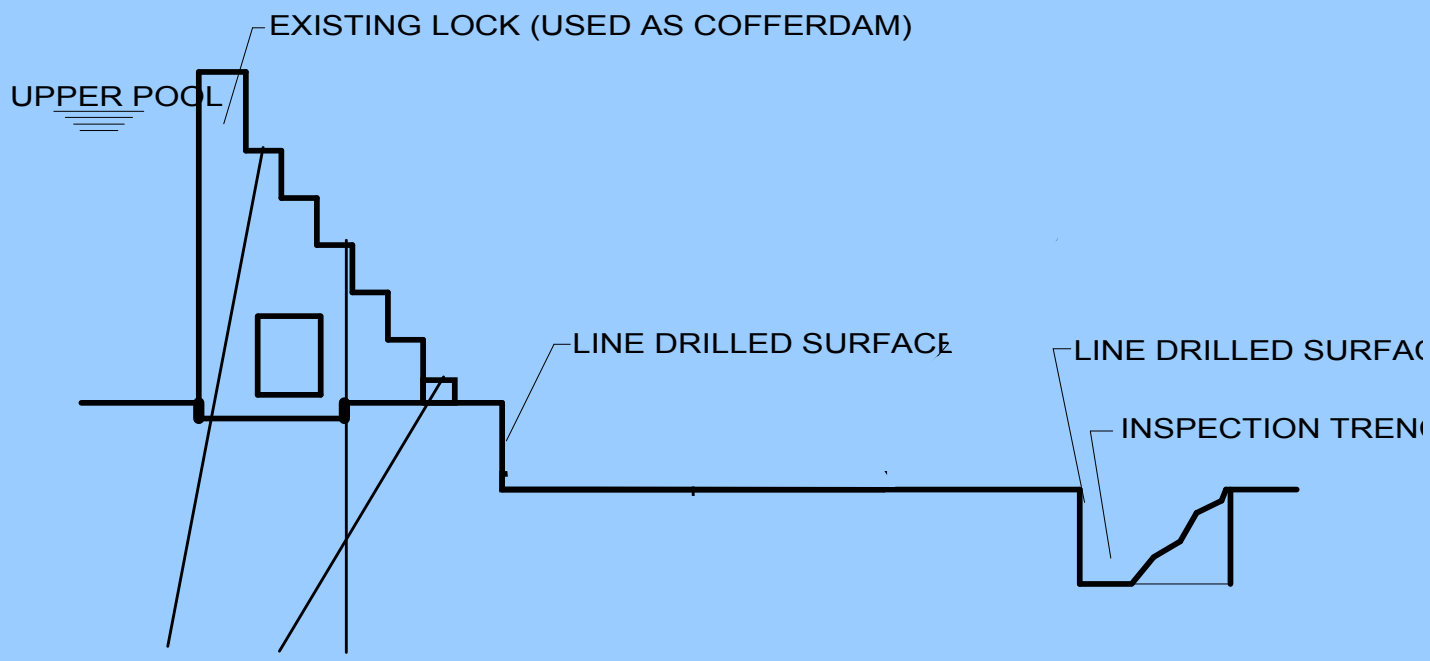


THRUST BLOCK ANCHORED PRIOR TO ROCK EXCAVATION
Analyzed for daylighted horizontal fault gouge (phi=13°, c=0psi)

SUBSURFACE EXPLORATION PERFORMED

Marmet Lock Replacement – Deep Seated Sliding

Design Concerns



COMPLETE EXCAVATION FOR CULVER/INSPECTION TRENCH

ESTABLISH PRESENCE AND EXTENT OF WEAK SEAMS – NEW LOCK

DETERMINE CORRECIVE FOUNDATION TREATMENT – NEW LOCK

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Manual Instruments

Manually Read Instruments

- Portable Inclinometers
- Settlement And Alignment Pins
- Joint Monitoring Pins
- Saw Cuts

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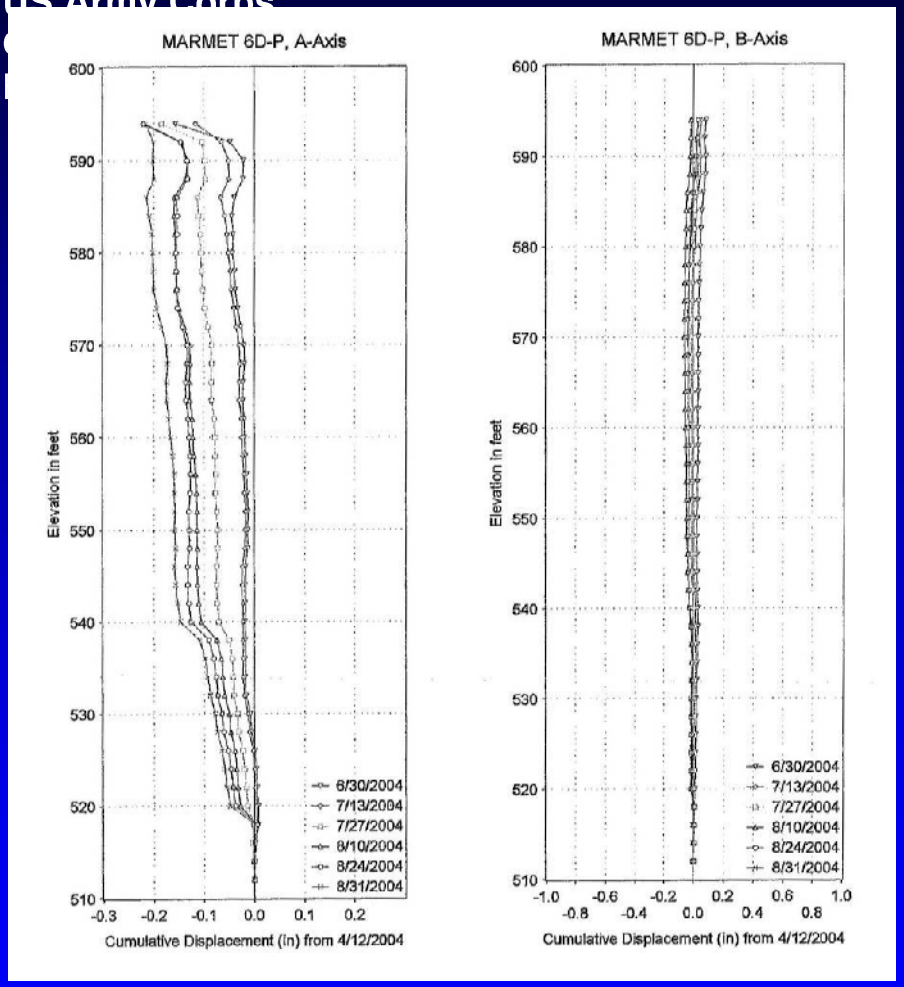
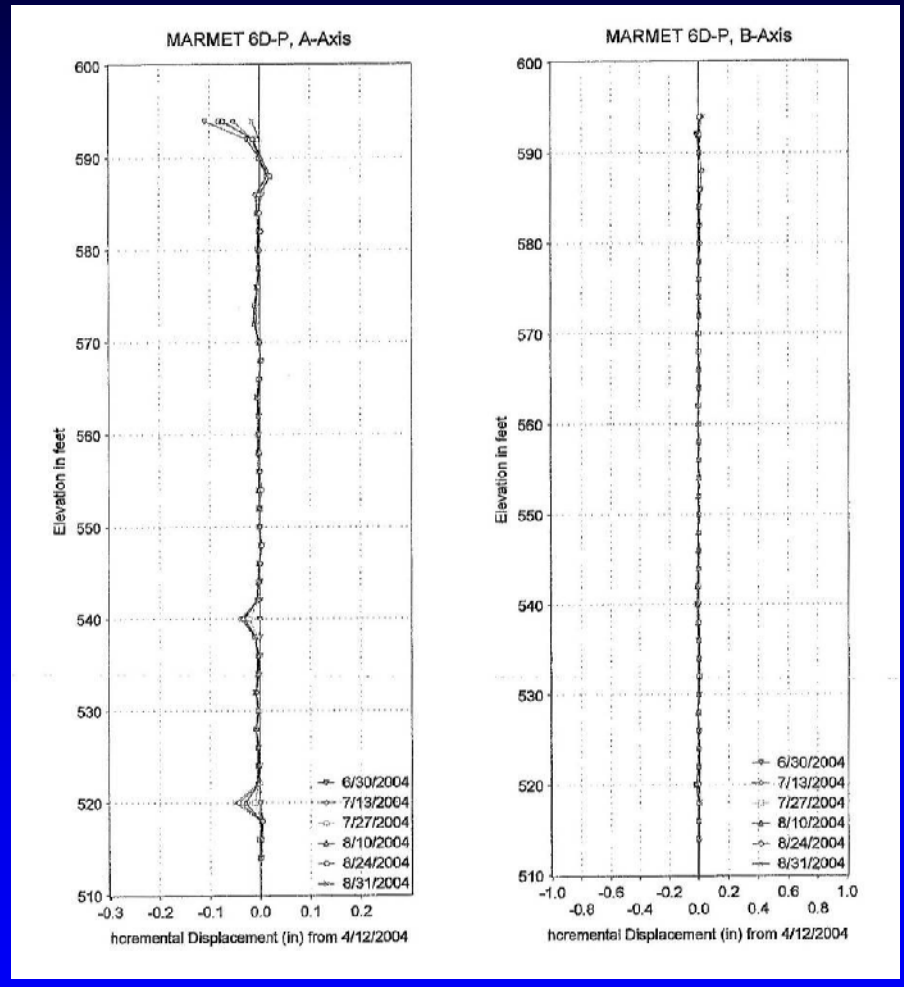
Deep Seated Sliding Occurs

- **Initial Downstream Movement**
  - **August 2004 Movement Occurred Along Two Weak Planes**
    - **El 540 +/- Where There Is A Series Of Thin Seams Of Carbonaceous Shale And Coal Within An Otherwise Generally Competent Sandstone Formation**
    - **El 520 +/- Where There Is A Discontinuous Thin Seam Of Clayey Material Near The Bottom Of The Sandstone Unit And An Underlying Shale Formation. This Seam Is Slightly Lower Than Any Required Excavation**

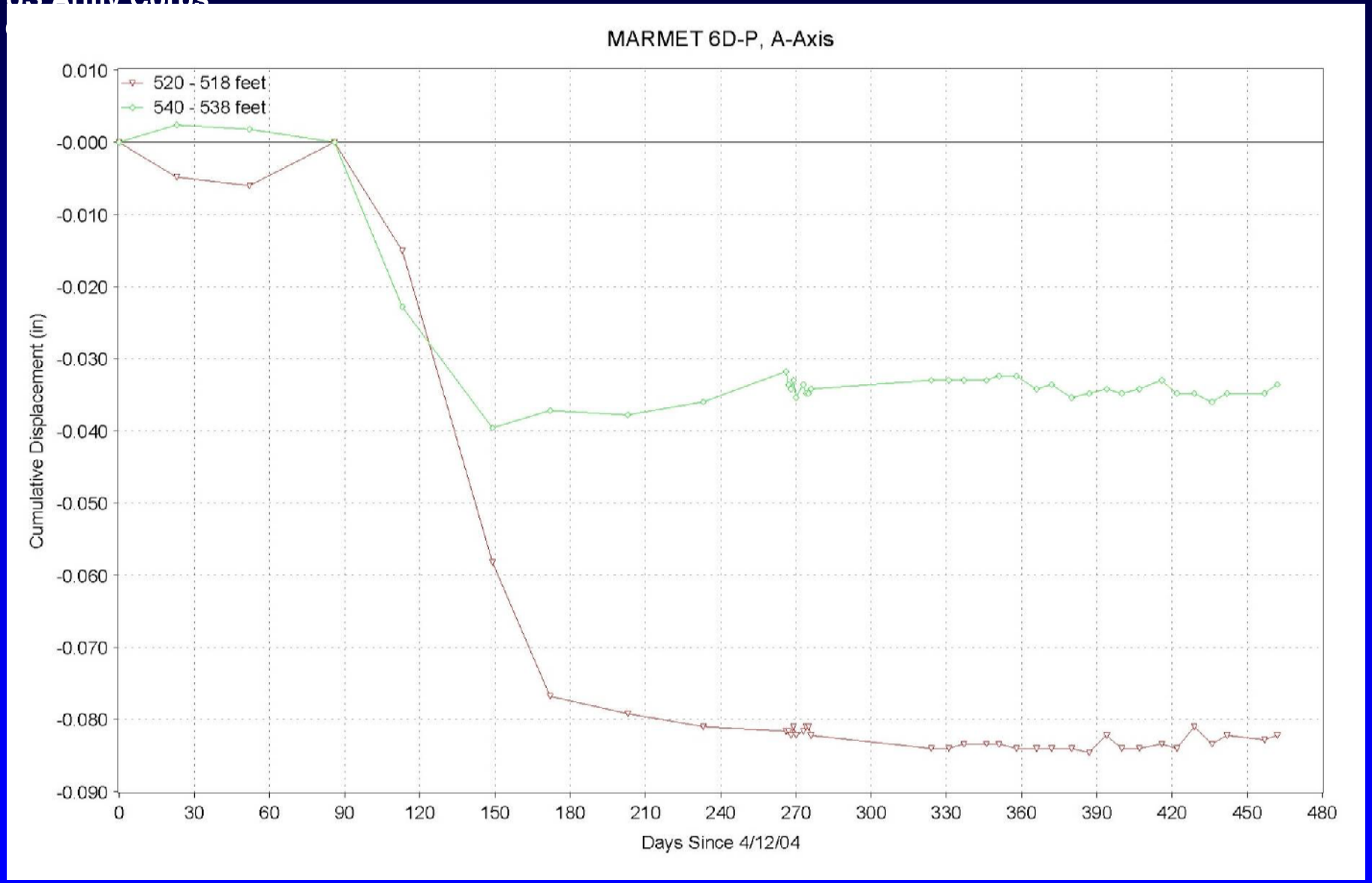
US Army Corps





Initial Movement – Cell 6D

August 2004


MARMET 6D-P, A-Axis
520 - 518 feet
540 - 538 feet
Cumulative Displacement (in)
0.010
-0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
-0.070
-0.080
-0.090
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
Days Since 4/12/04

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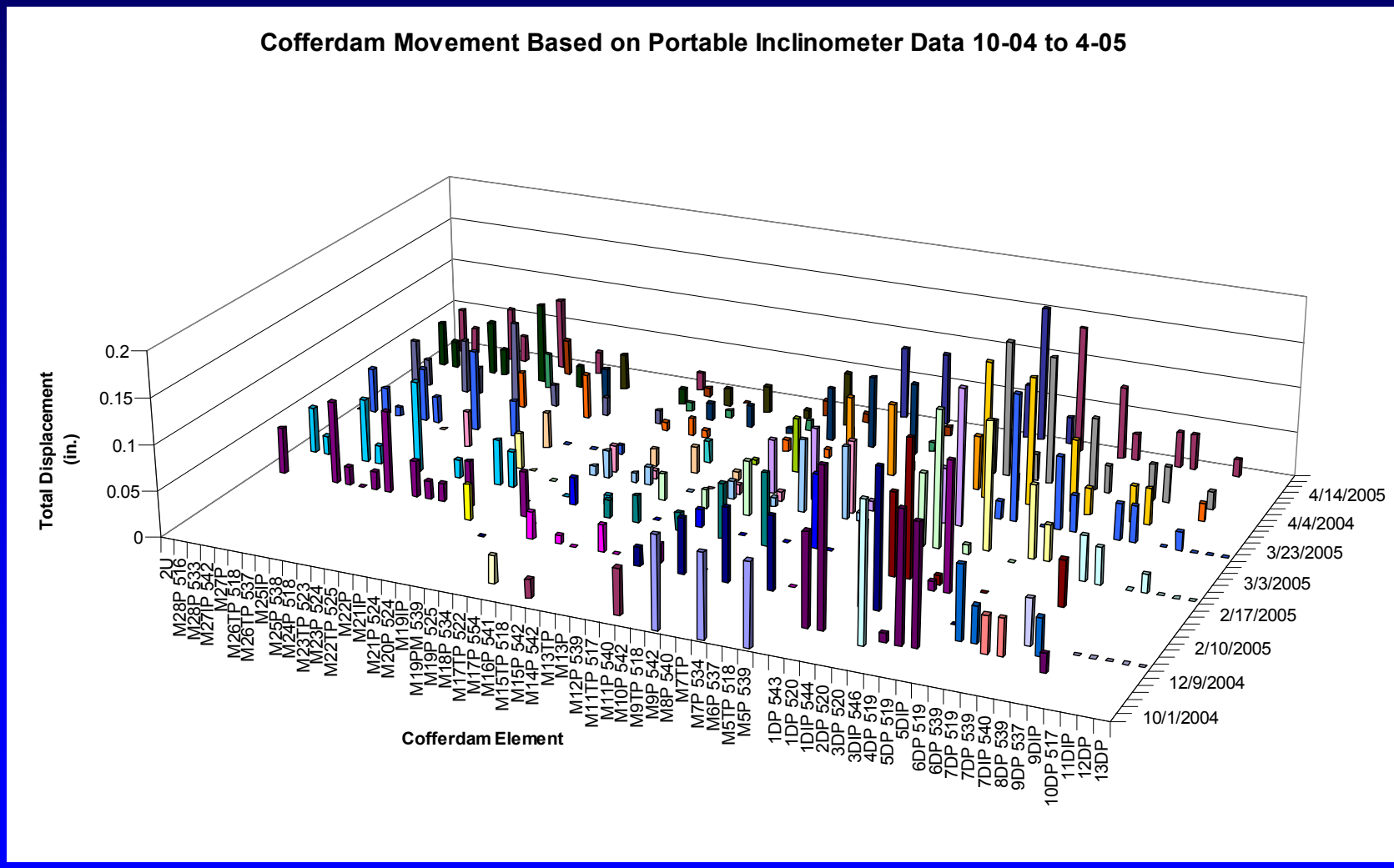
Portable Inclinometer Displacement



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E.A.P. Response

- **Recommended Actions Of The PDT**
  - Increase Frequency Of Instrumentation Readings And Evaluation Of Data
  - Reanalyze Additional Failure Planes Within The Rock Foundation
  - Add Additional Upstream Anchors
  - Add Additional Inclinometers Of Greater Depth And At Additional Locations

    Obtained Contingency Anchors

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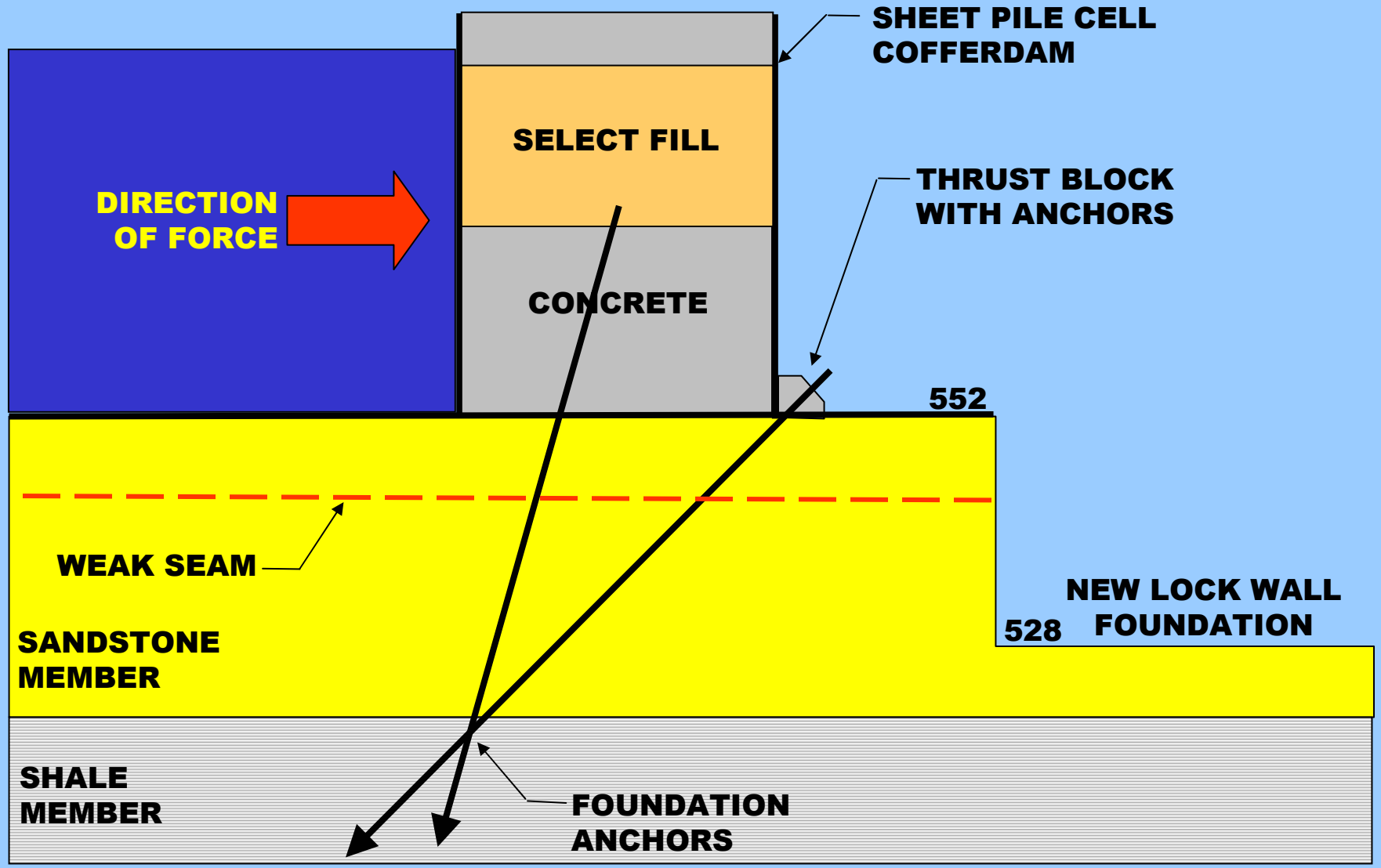
EAP Movement Action Levels

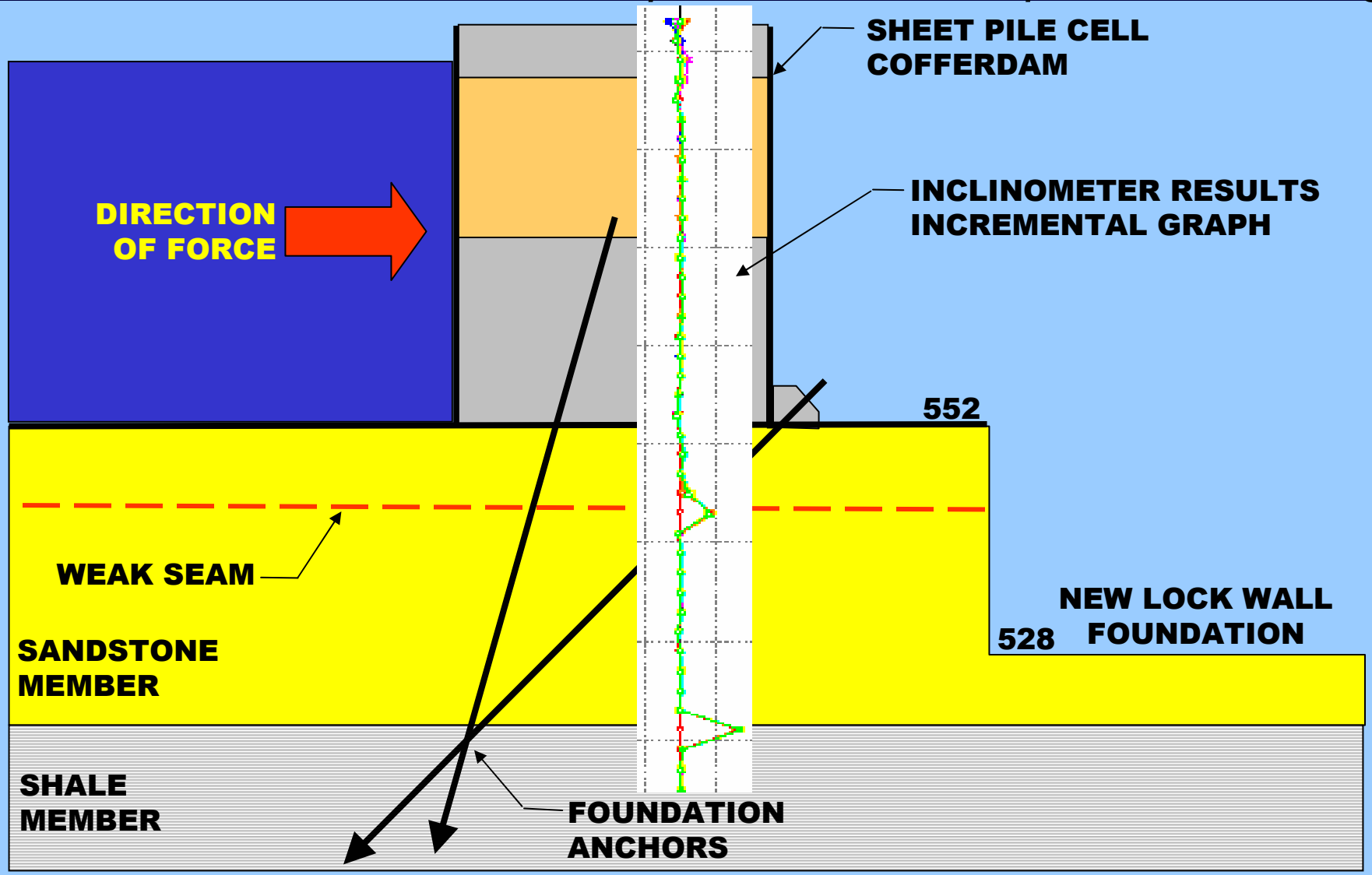
- 0.20 in. Displacement
  - Mobilize Contractor to Install “Contingency” Anchors
  - Accelerate Placement of Concrete on Deep Excavation Monoliths
  - Partial Flood and/or Backfill Chamber Work Area
  - Limit Rock Excavation
- 0.25 in. Displacement
  - All Non-remediation Work Stopped and Evacuated
  - Work Area Partially or Completely Flooded and/or Backfill
- 0.35 in. Displacement
  - Failure Immenent
  - Evacuate Excavation

Marmet Lock Replacement – Deep Seated Sliding



Cofferdam Foundation Movement - Section

Marmet Lock Replacement – Deep Seated Sliding



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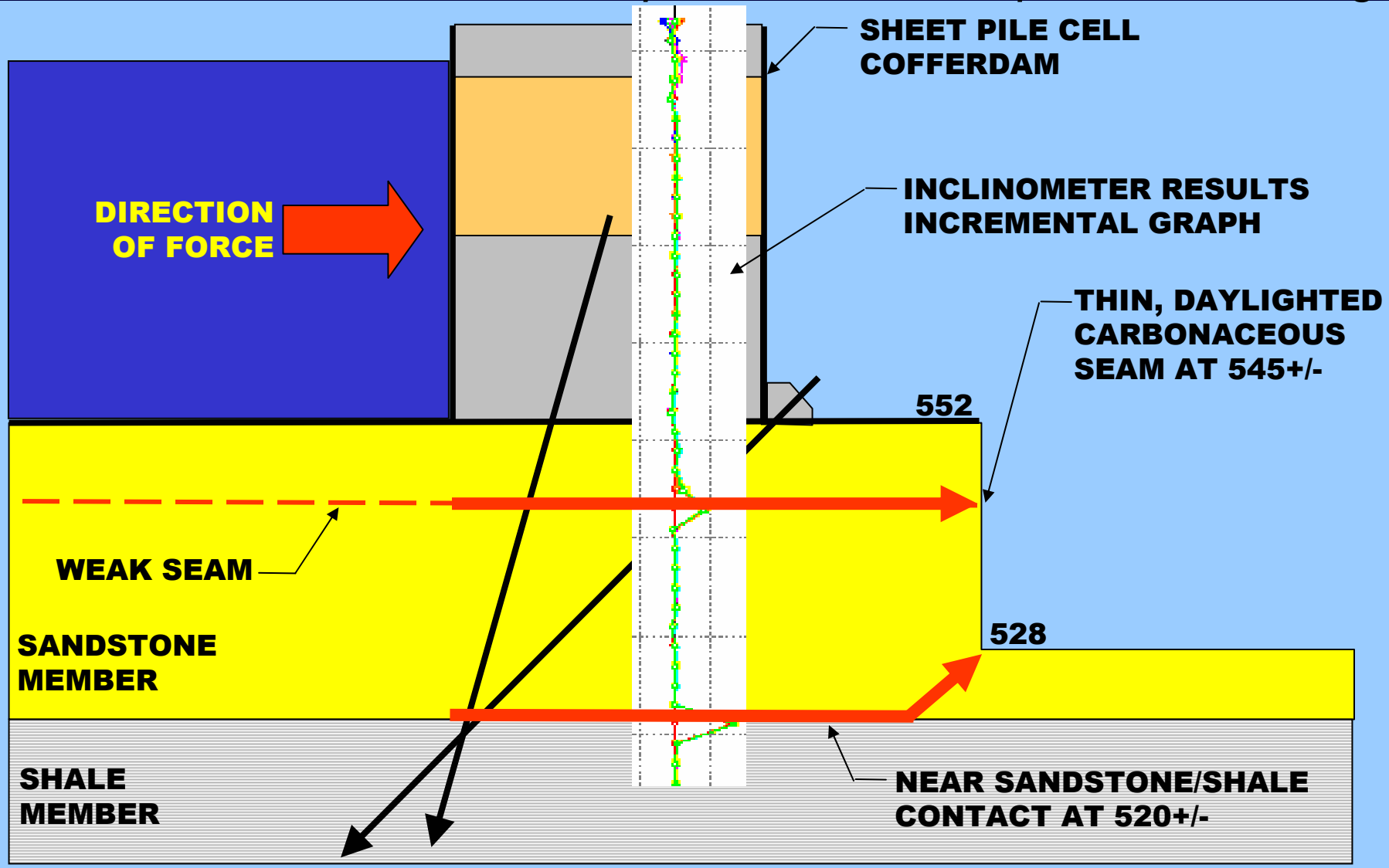

Cofferdam Foundation Movement - Section

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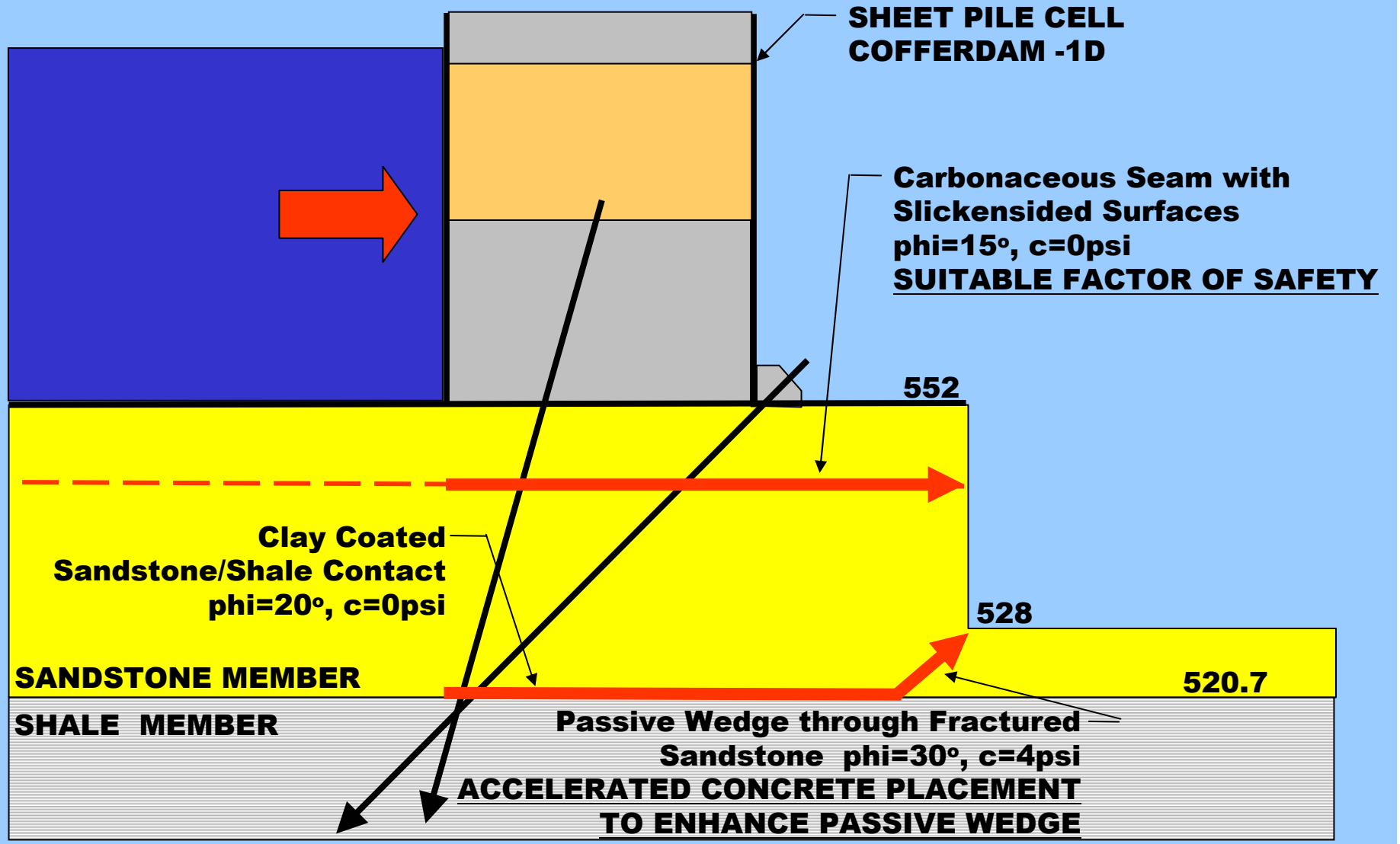
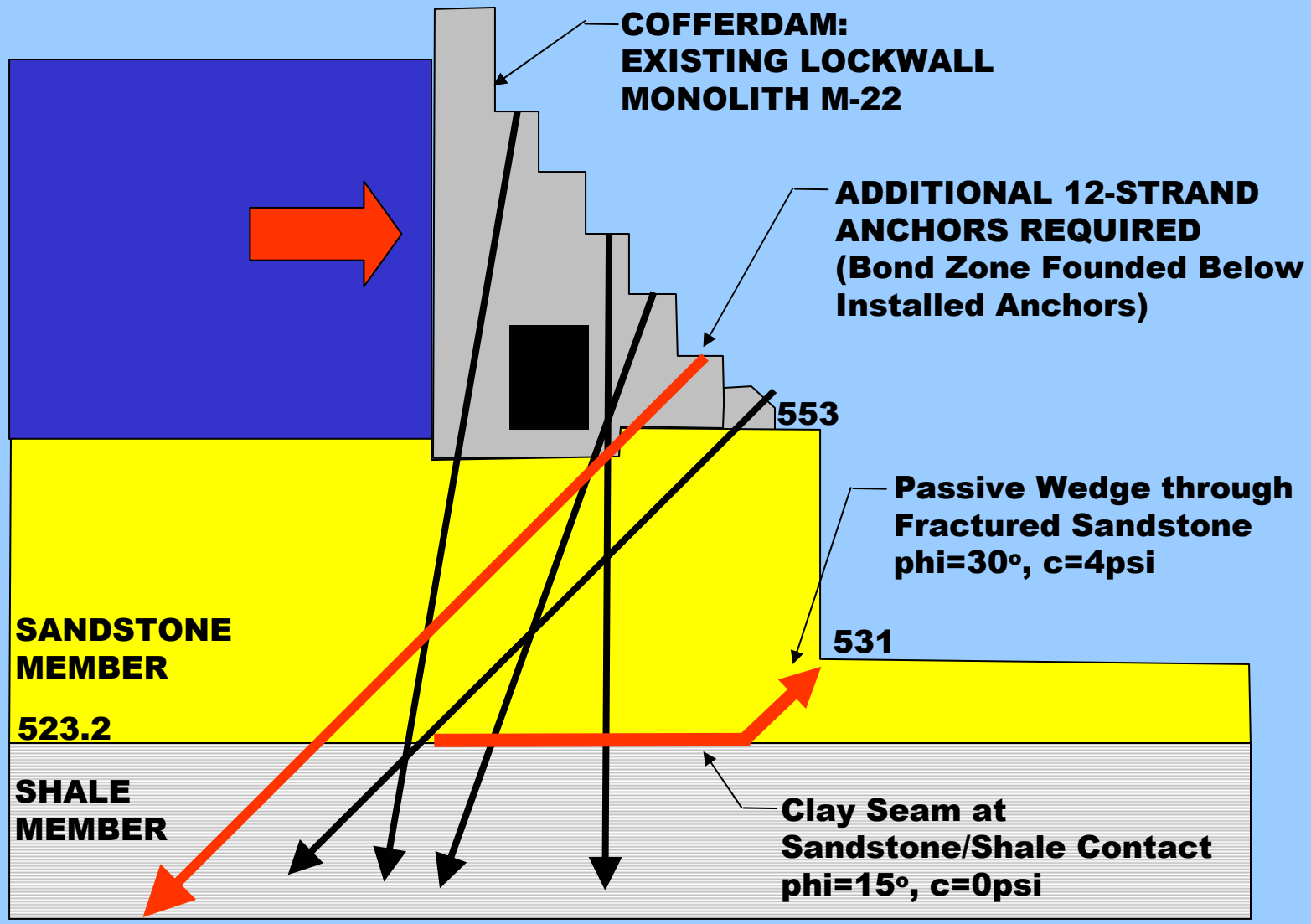


Cofferdam Foundation Movement – Cell 1D

Marmet Lock Replacement – Deep Seated Sliding



Cofferdam Foundation Movement – M-22

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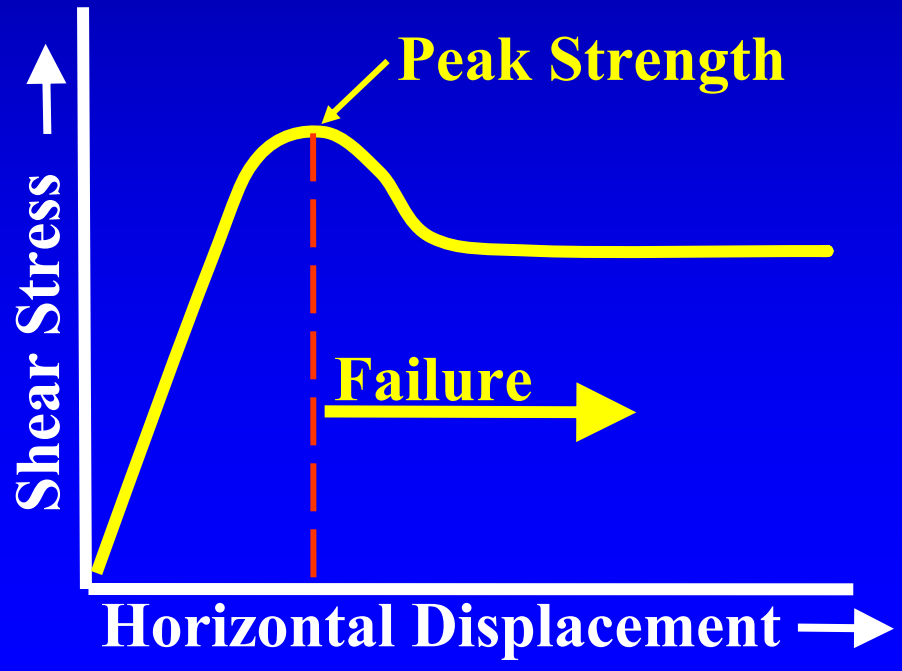
Marmet Lock Replacement – Deep Seated Sliding

Cofferdam Foundation Movement

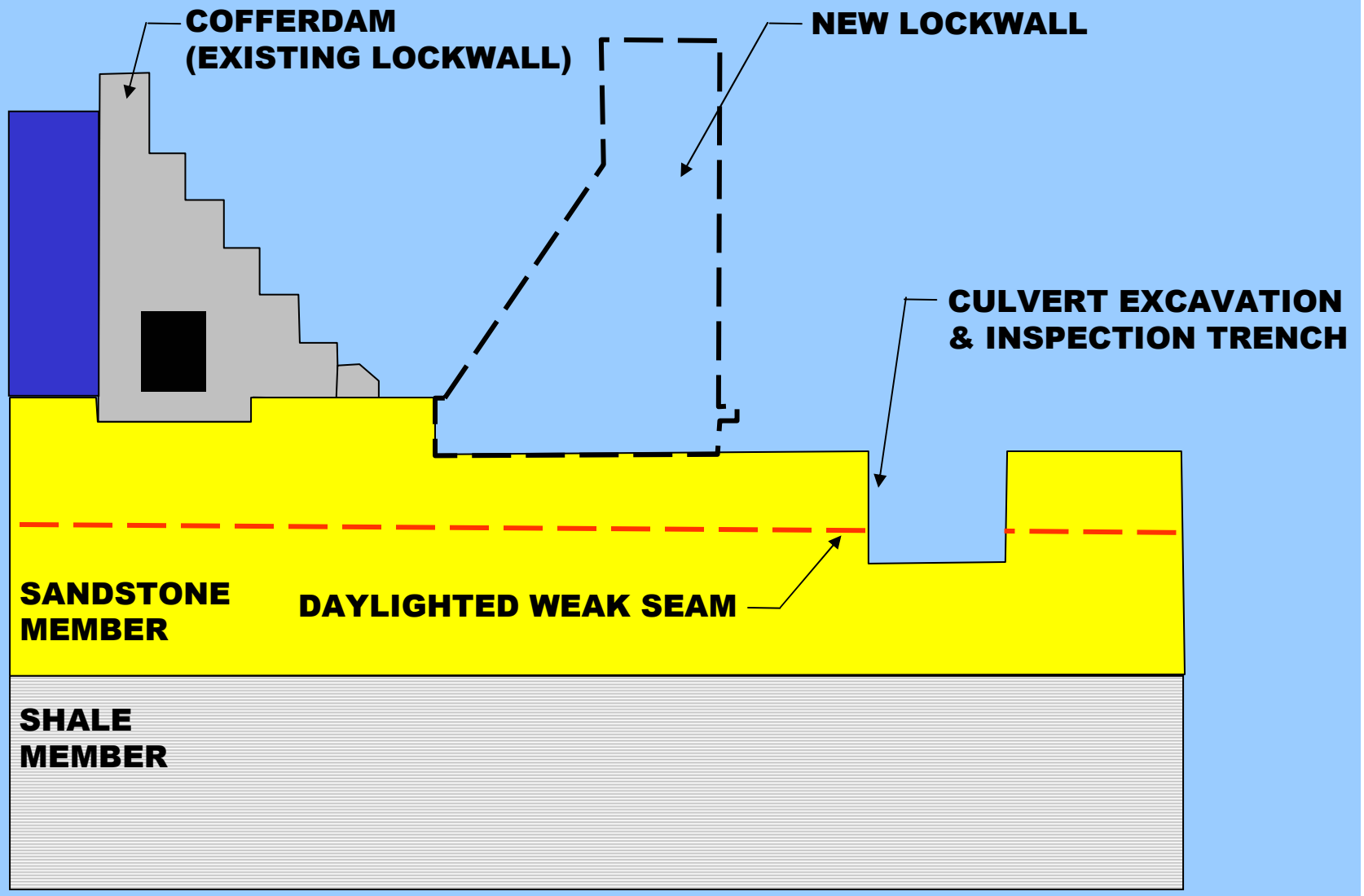
- **Some displacement is required to engage rock mass shear strength**
- **Establish how much movement is acceptable**



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 Chamber Lockwall Monoliths

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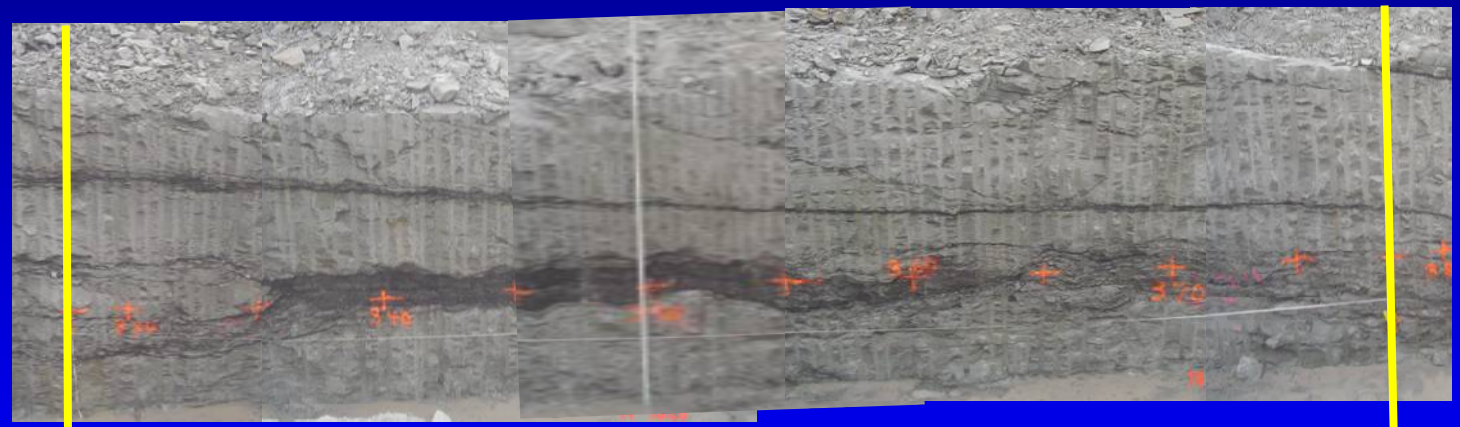
Marmet Lock Replacement – Deep Seated Sliding

Inspection Trench Sidewall - Photo

MONOLITH R-15A



New Chamber Lockwall Monoliths

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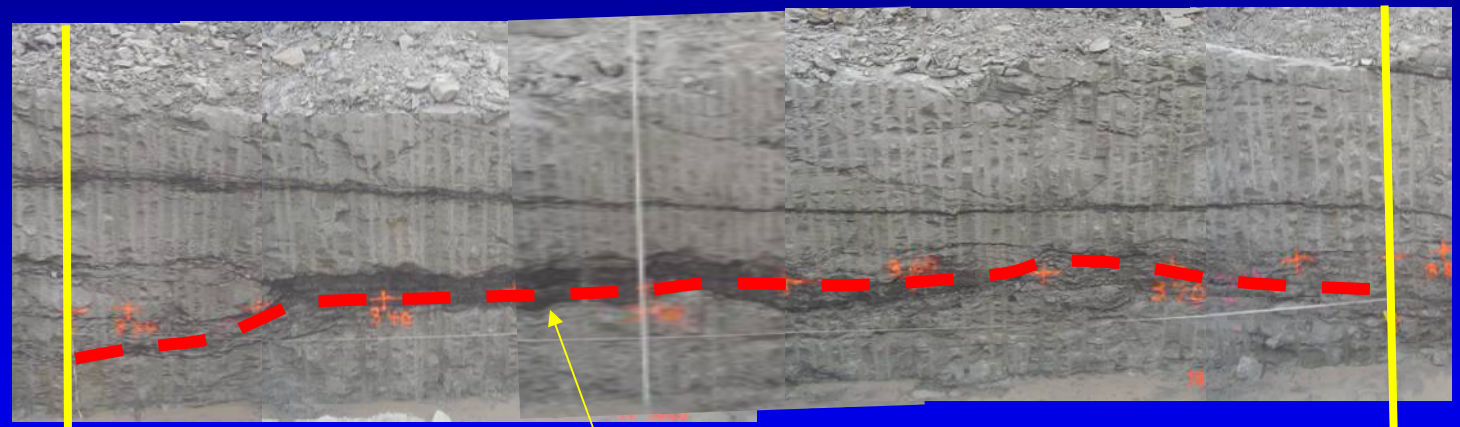
Marmet Lock Replacement – Deep Seated Sliding

Inspection Trench Sidewall - Photo

MONOLITH R-15A



New Chamber Lockwall Monoliths

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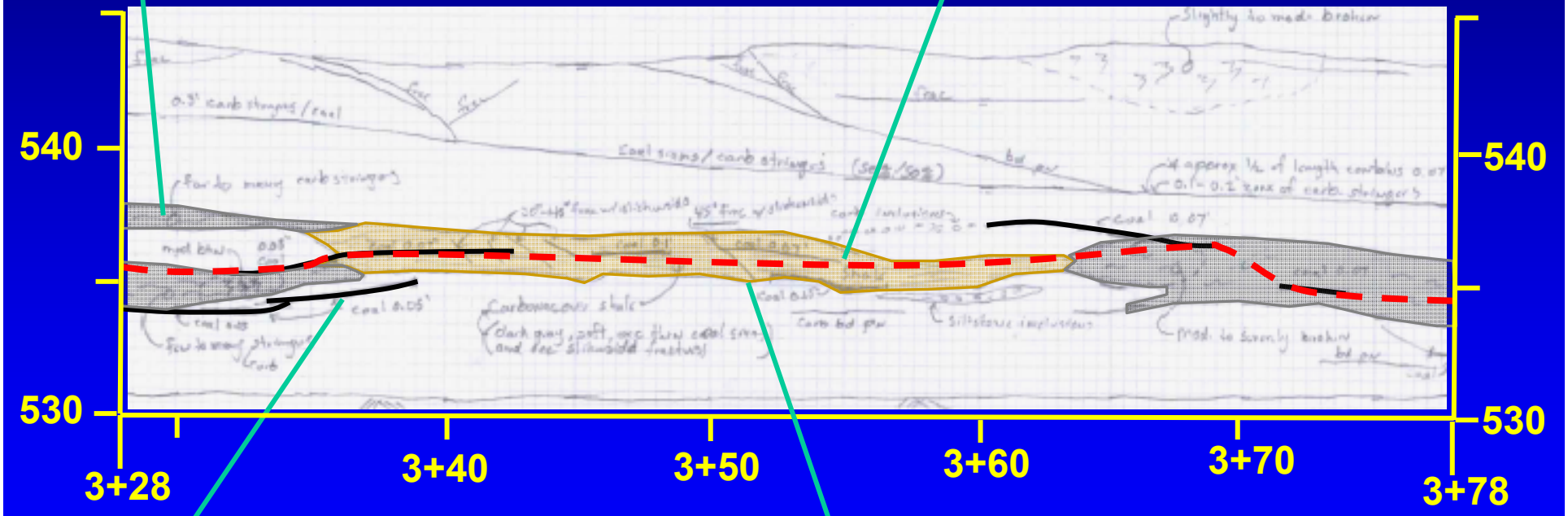
Marmet Lock Replacement – Deep Seated Sliding

Inspection Trench Sidewall - Map

Zones of Carbonaceous Stringers & open bedding planes (phi=30°, c=0psi)

Potential Sliding Failure Plane through various materials

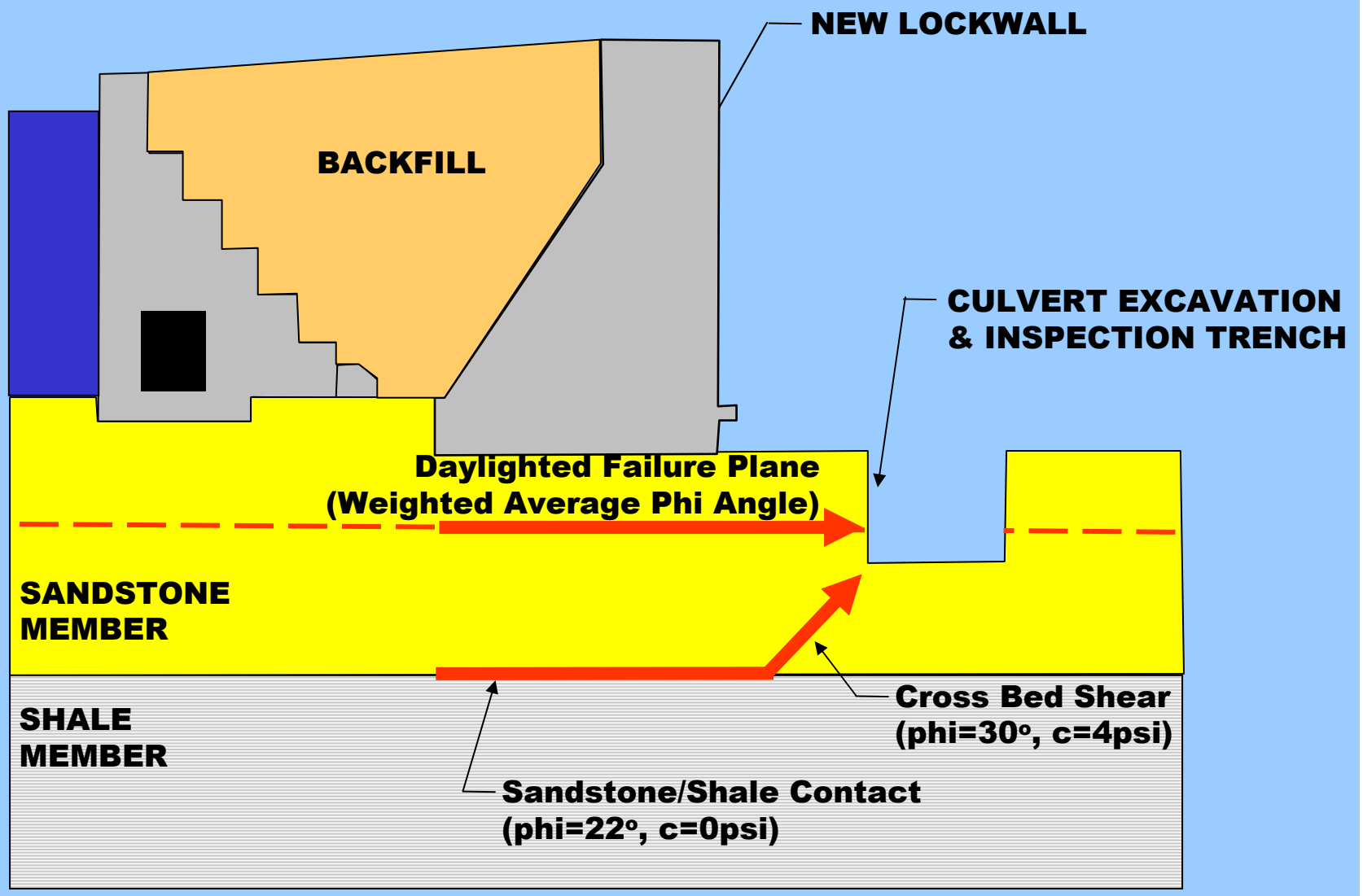


Thin Coal Seams (phi=23°, c=0psi)

Carbonaceous Shale w/ many slickensided fractures (phi=17°, c=0psi)

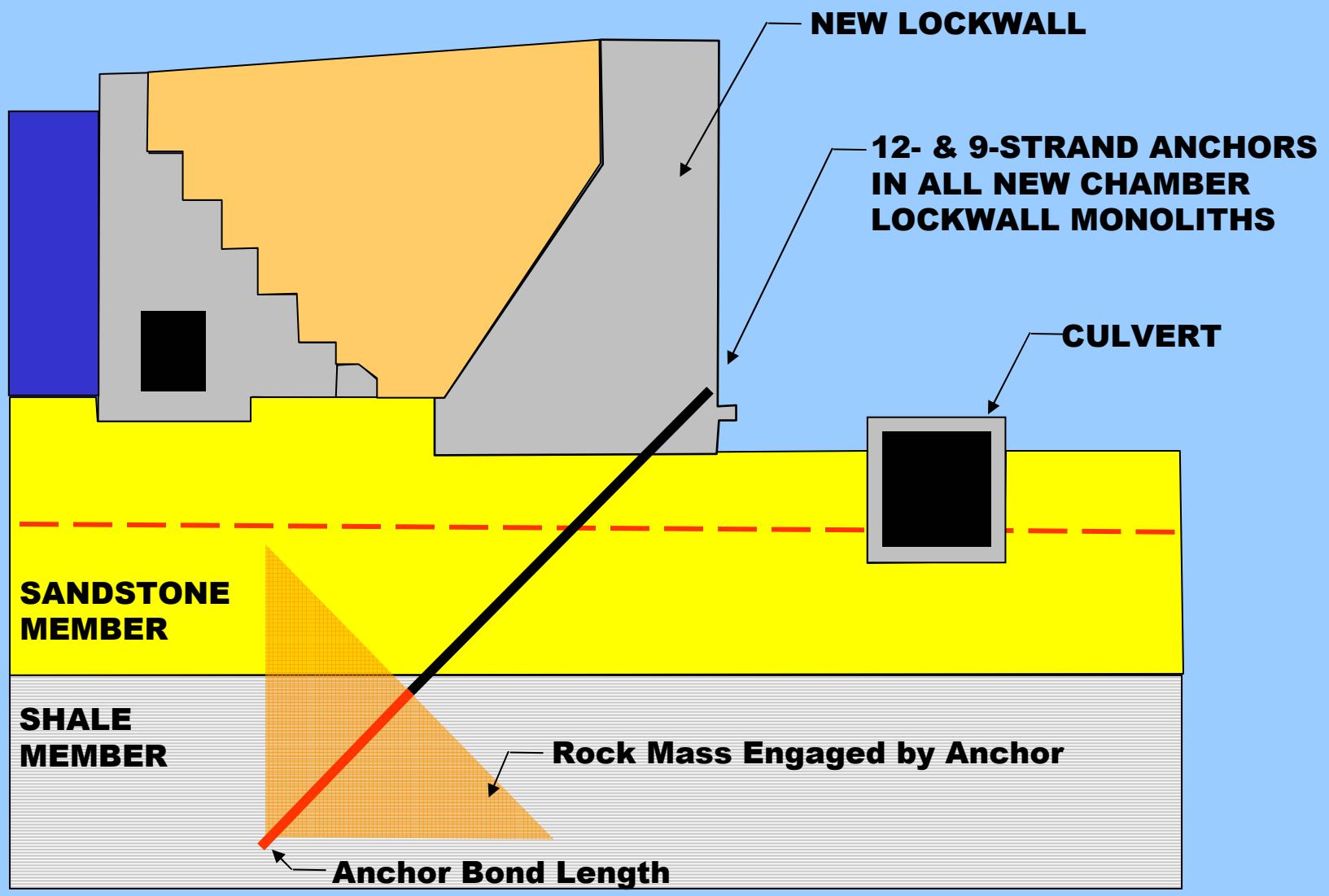
New Chamber Lockwall Monoliths

Marmet Lock Replacement – Deep Seated Sliding



New Chamber Lockwall Monoliths

Marmet Lock Replacement – Deep Seated Sliding



New Chamber Lockwall Monoliths

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Main Topics of Discussion

1. PROJECT OVERVIEW

a. Site Plan
b. Site Geology

2. DEEP SEATED SLIDING

a. Design Concerns
b. Cofferdam Foundation Movement
c. New Chamber Lockwall Monoliths

3. GEOLOGIC ASPECTS OF CONSTRUCTION

a. Anchor Installation
b. Rock Excavation
c. Foundation Preparation & Treatment
d. Drilled Shaft Foundations
e. Foundation Drilling and Grouting

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Main Topics of Discussion

3. GEOLOGIC ASPECTS OF CONSTRUCTION

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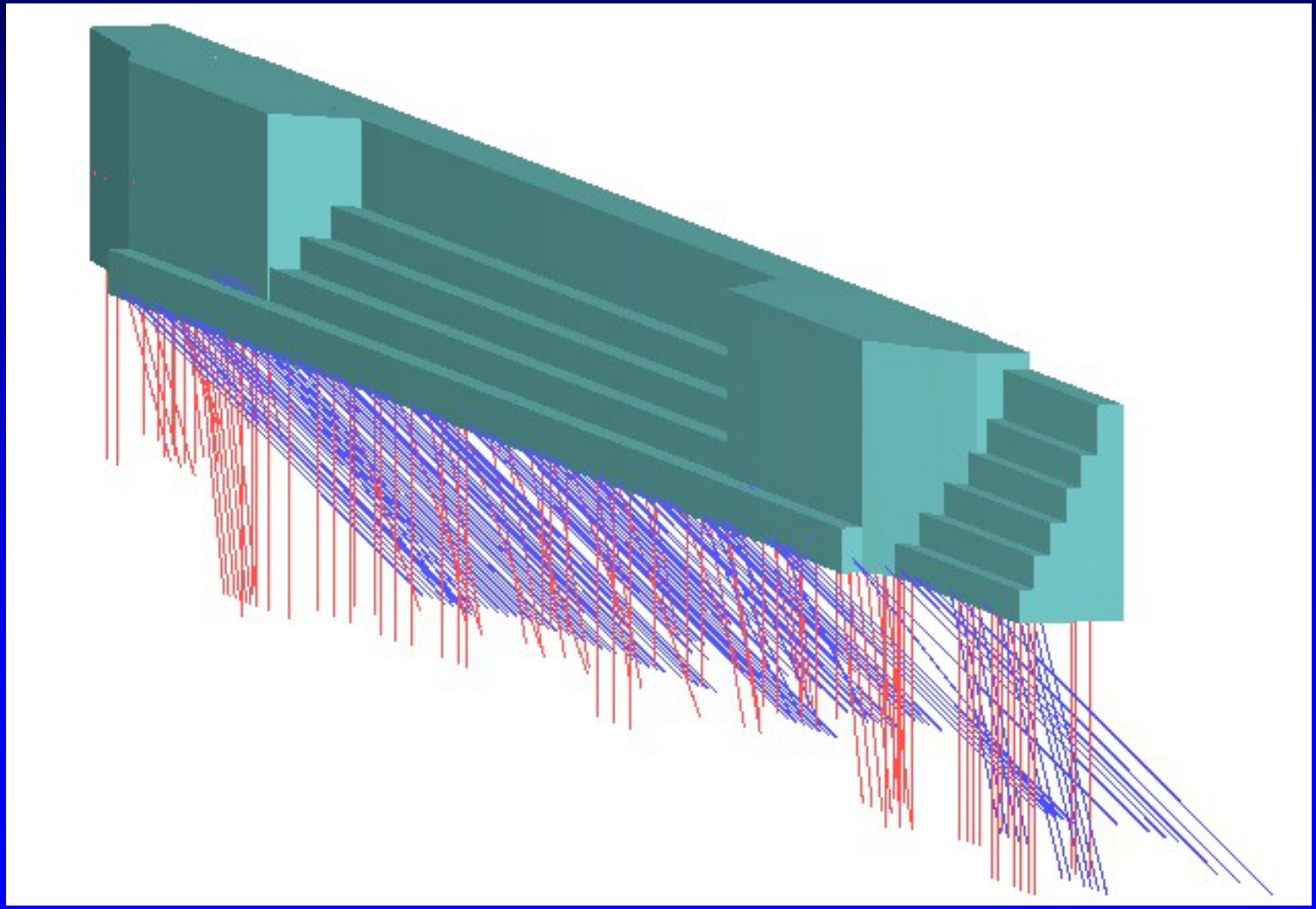
Over 560 anchors required



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Anchor Drilling

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Anchor Alignment Specifications

- **Initial Alignment**
  - Within 0.5° of Specified Azimuth
  - Within 0.5° of Specified Inclination
- **Drilling Alignment**
  - Within 0.5° Starting Azimuth
  - Within 0.5° Specified Inclination
  - Less than 1 in. Deviation per 10 ft. of Drilling

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Anchor Alignment Testing

Tropari

Maxibor

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Anchor Tensioning

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Anchor Tensioning Loads

	GUTS	Design Load	Lock Off Load (70% GUTS)
9 Strand	527 kips	316 kips	369 kips
12 Strand	703 kips	422 kips	492 kips
15 Strand	879 kips	527 kips	615 kips

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Specified Anchor Testing

- Followed PTI
- Performance Tests
  - One Anchor per Cofferdam Element
- Proof Tests
  - All Remaining Anchors in each Cofferdam Element
- Extended Creep Tests
  - Due to Shale in Bond Zone
  - Conducted on All Performance Tested Anchors

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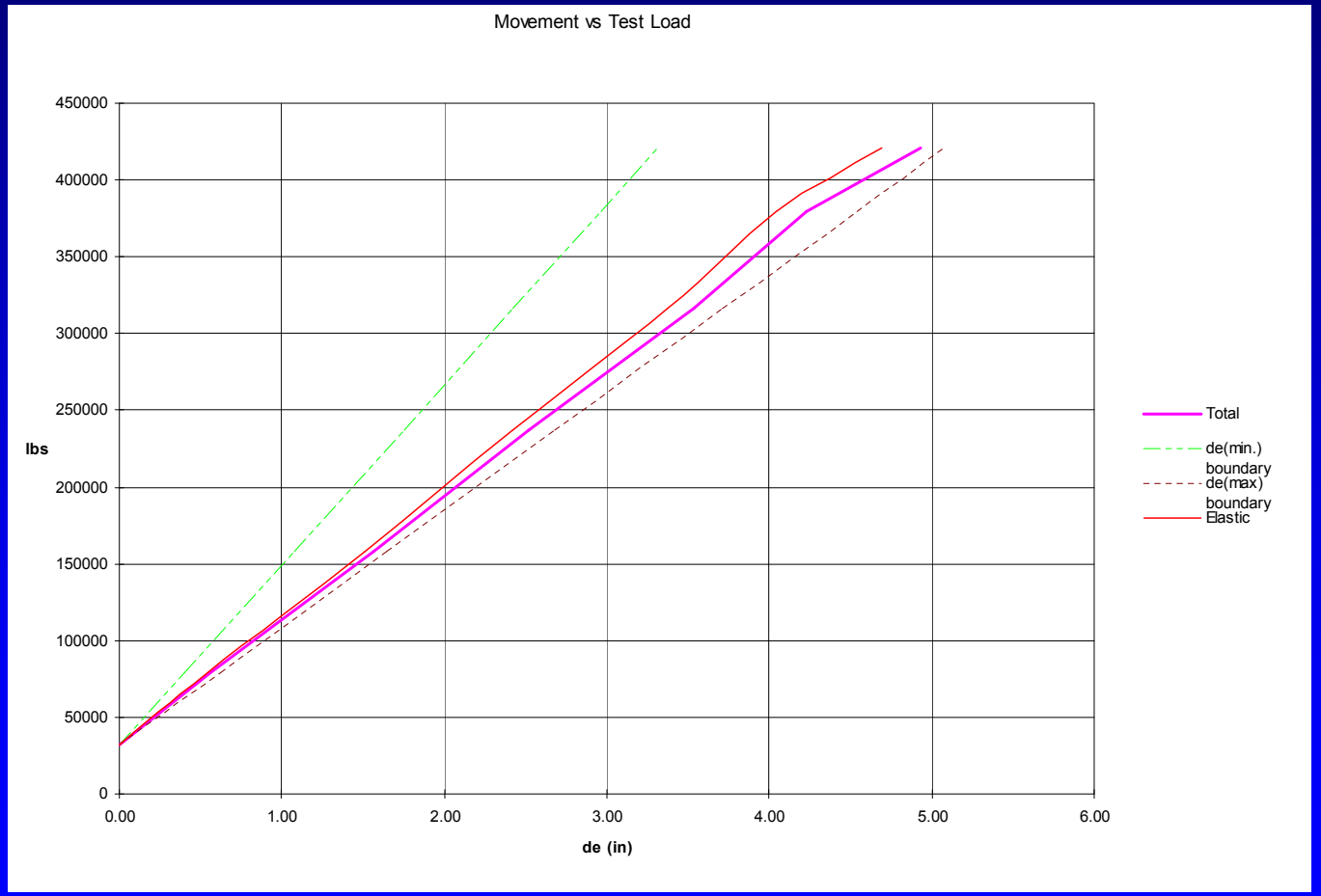
Performance Test Results



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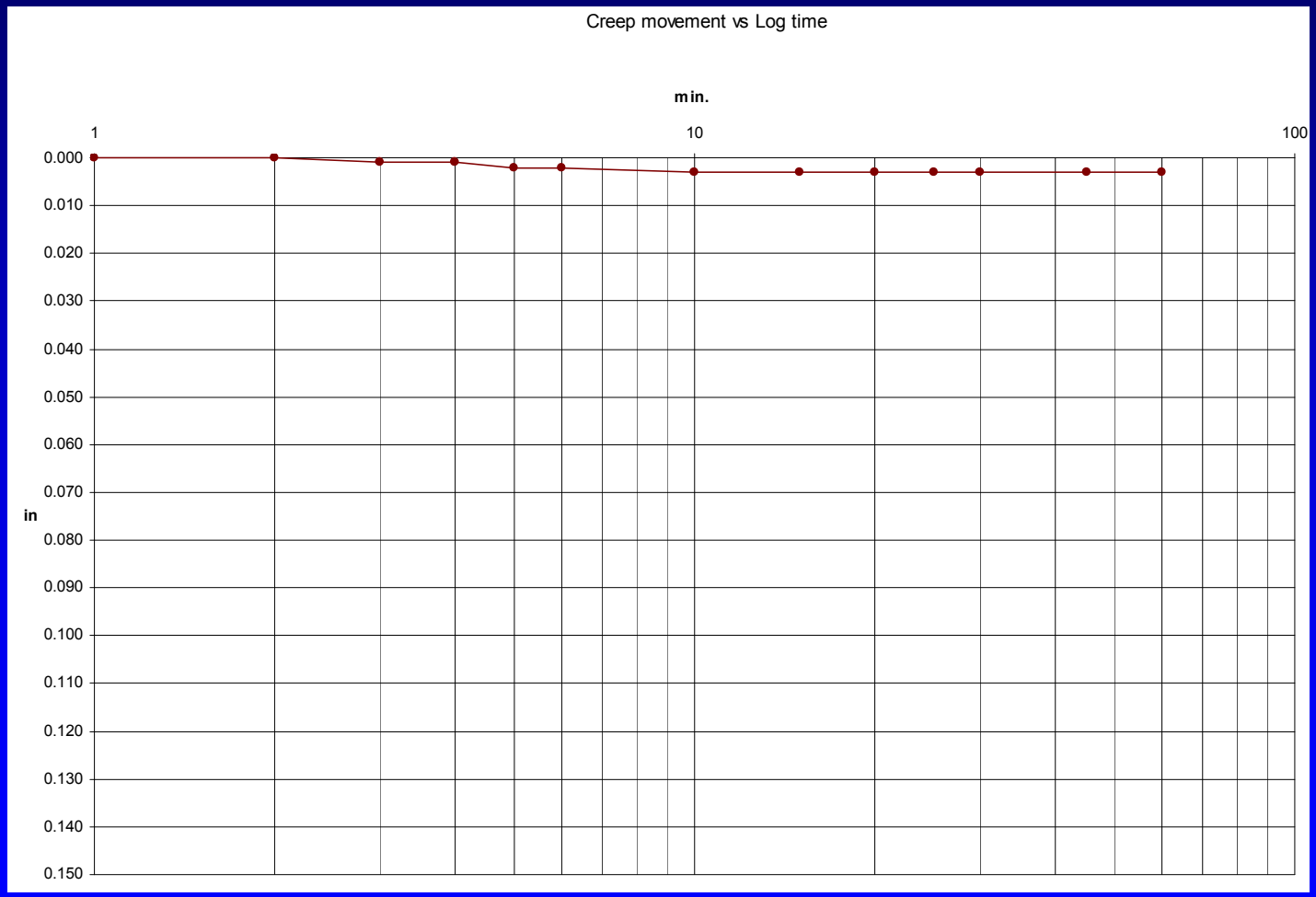
Creep Test Results



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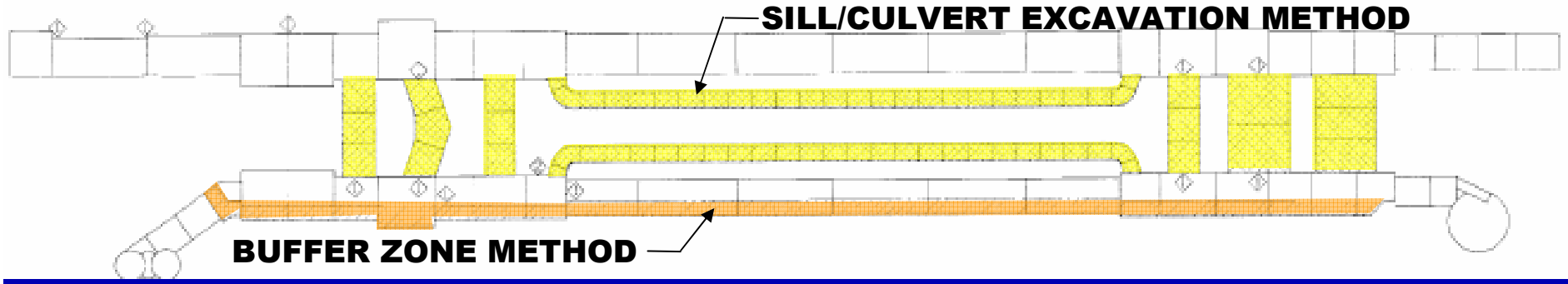
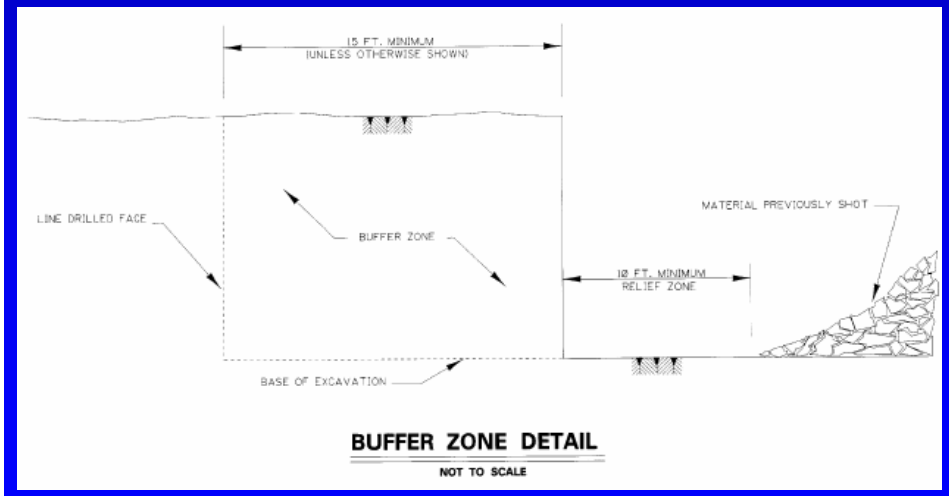
Marmet Lock Replacement – Rock Excavation

Excavation Restrictions





- **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**

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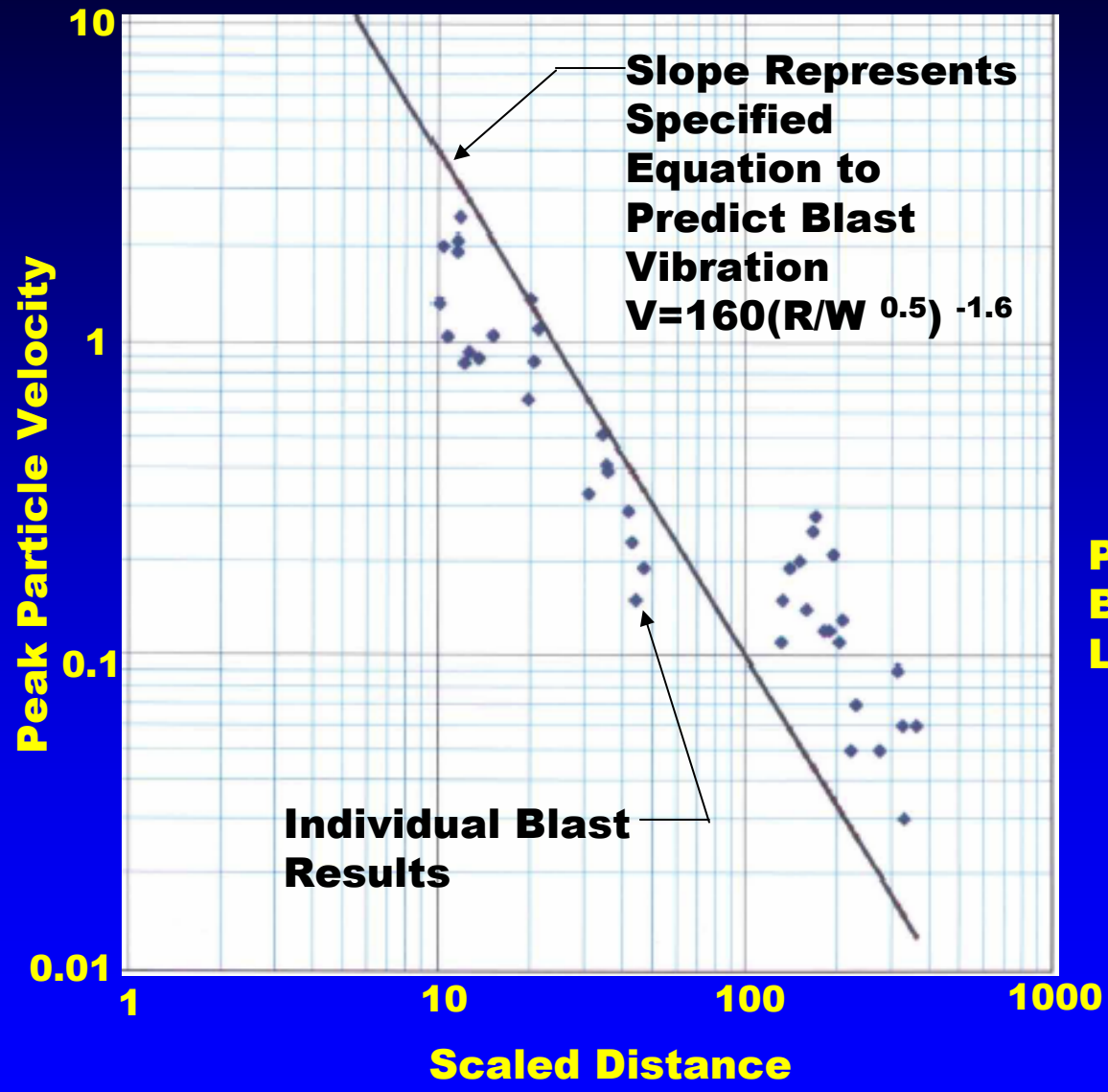
Marmet Lock Replacement – Rock Excavation



Plot Individual Blast Results on Log/Log Graph

Evaluating Specified Vibration Equation

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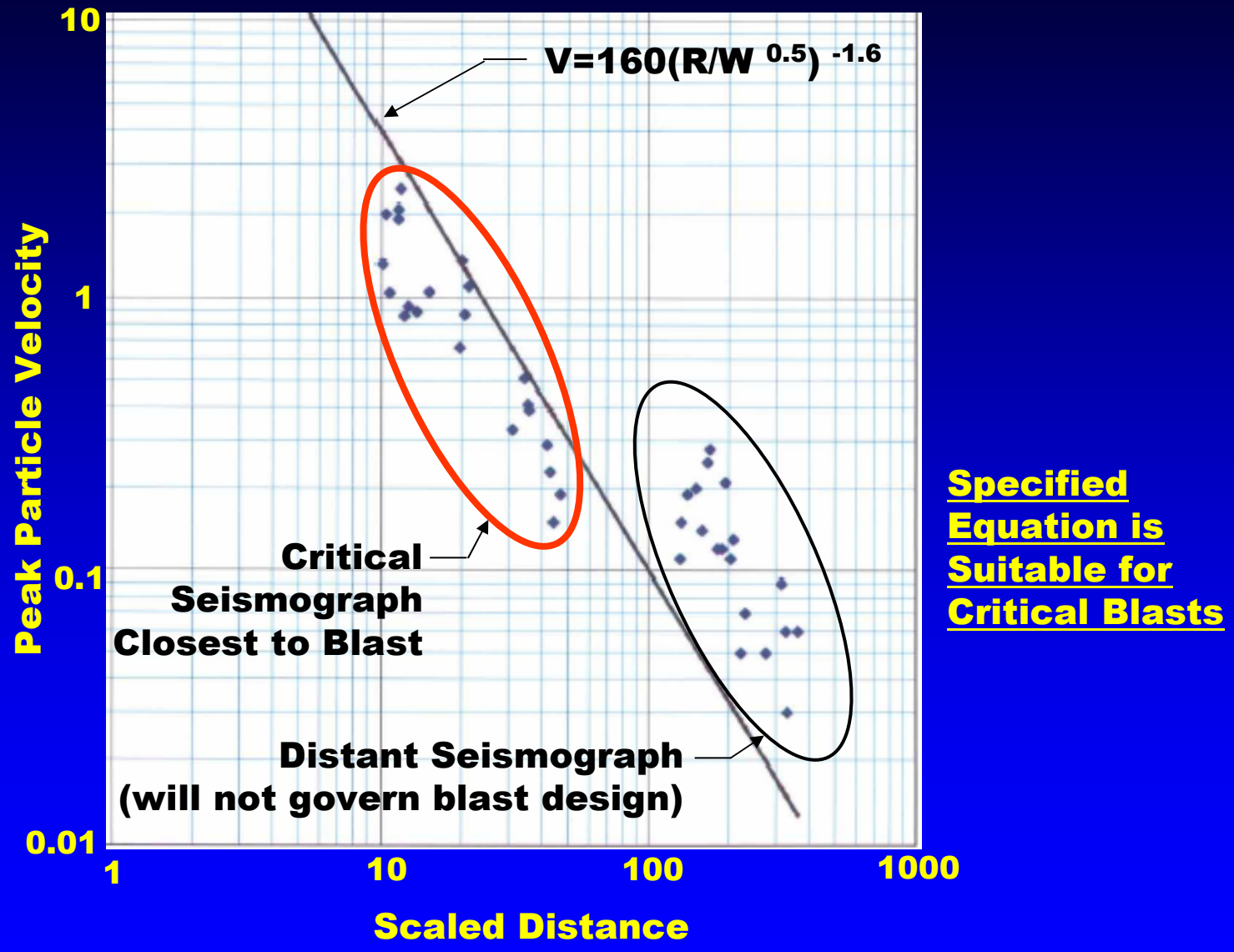
Marmet Lock Replacement – Rock Excavation



Specified Equation is Suitable for Critical Blasts

Evaluating Specified Vibration Equation

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Marmet Lock Replacement – Rock Excavation

Line Drilled Perimeter

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Marmet Lock Replacement – Rock Excavation

Production Shot

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Foundation Preparation Challenges

- Lenticular Shale Bedding
- Blast Damage
- Thin Bedded Carbonaceous Laminations and Tree Fossils
- Artesian Joints

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Lenticluar Beds

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Lenticular Shale Bed Plan View

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Blasting Damage Types

- Over Break Behind Line Drilled Faces
- Sub Drilling

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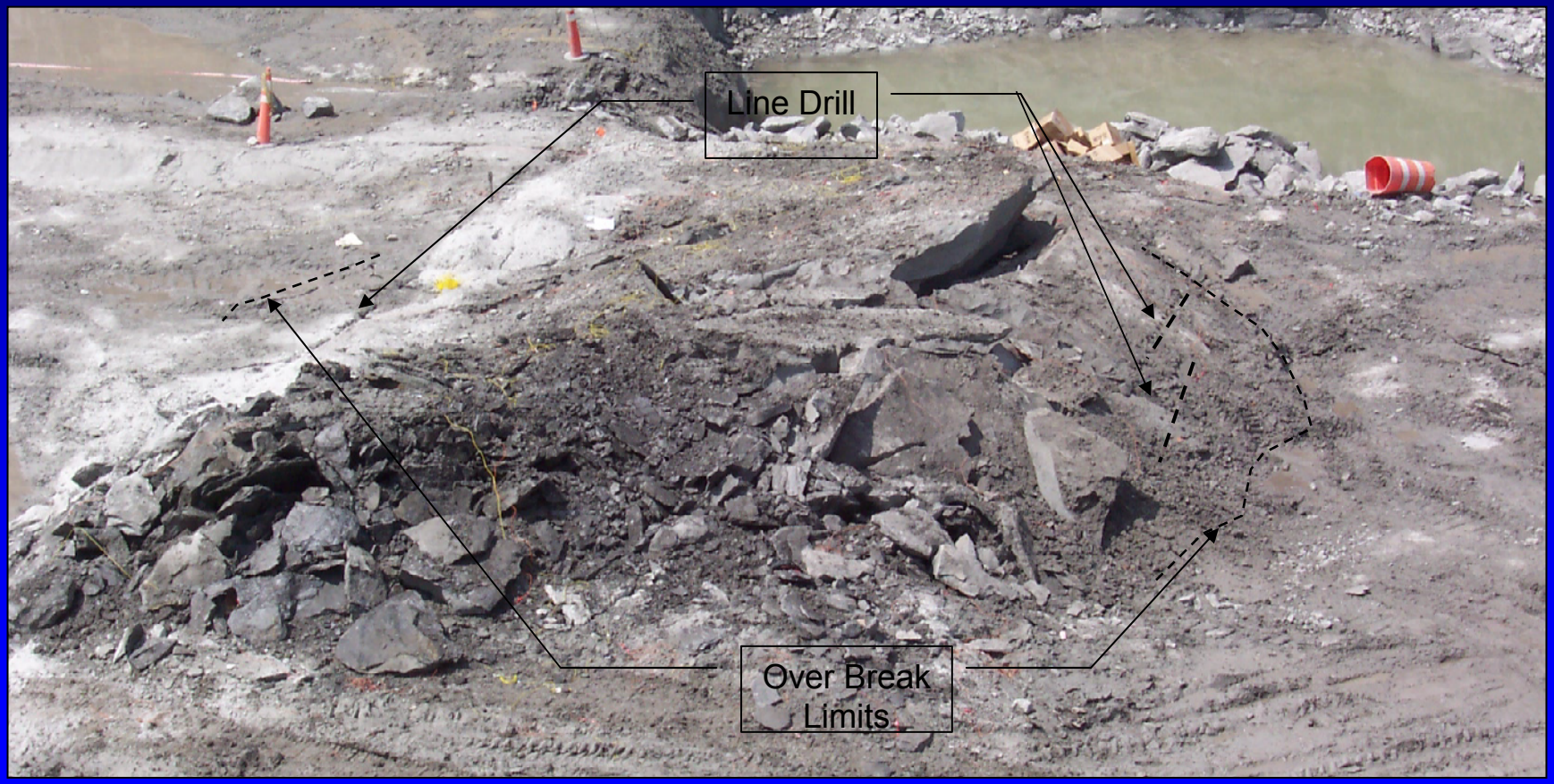
Over Break Behind Line Drilled Face



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Over Break Behind Line Drilled Face

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Sub Drilled Shot Hole Damage

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Shot Hole Damage

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Shot Damage Post Foundation Prep.

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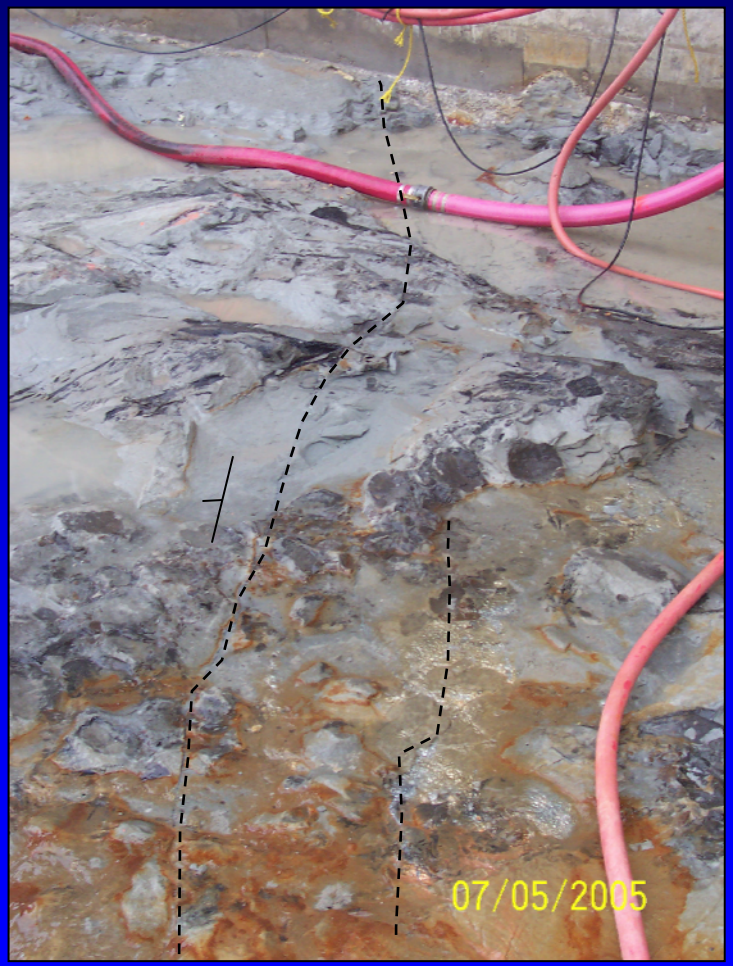
Artesian Joints



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Joints Excavated

Pipes Placed

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Concrete Placed

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Carbonaceous Laminations and Tree Fossils

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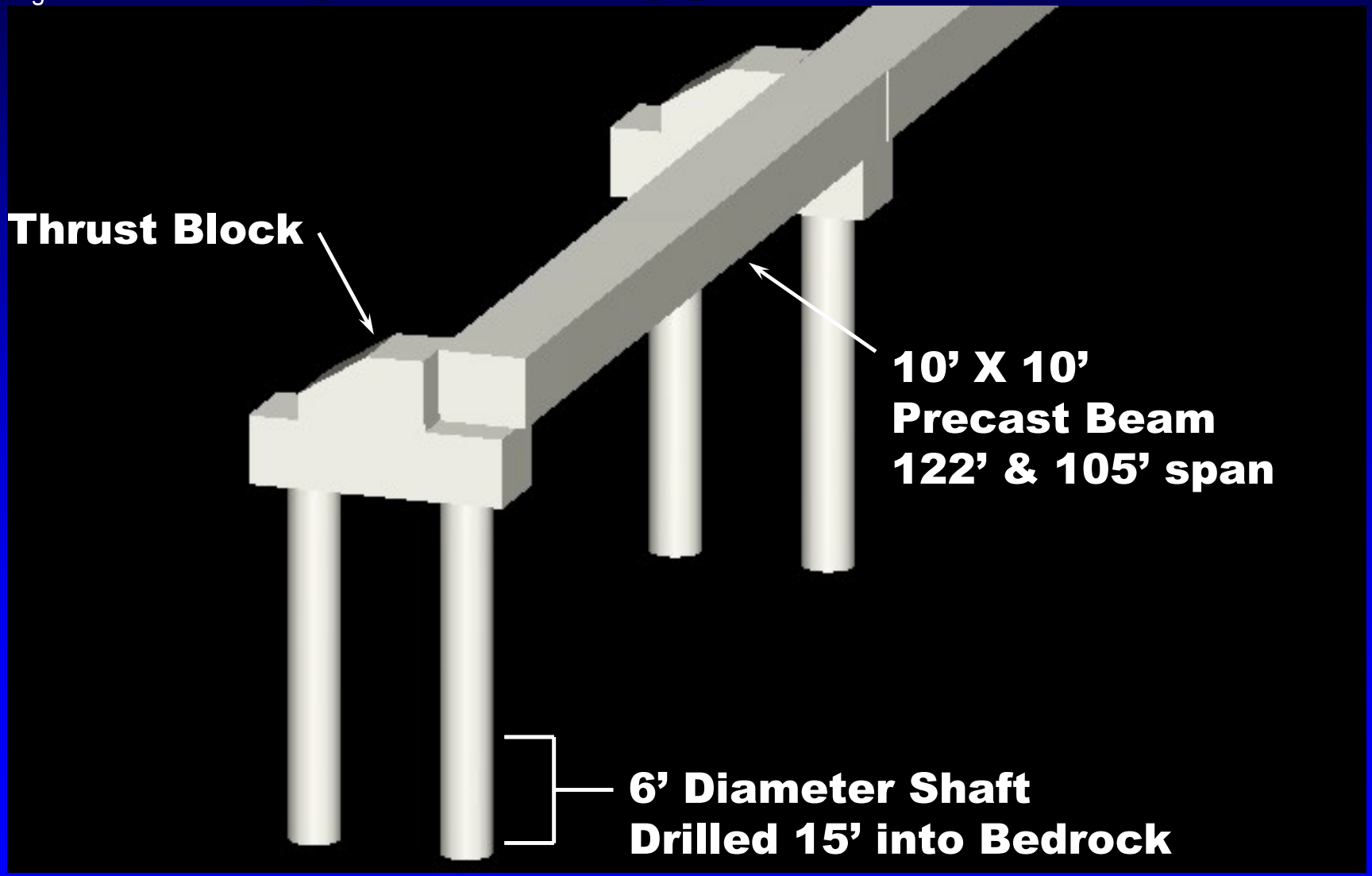
Marmet Lock Replacement – Drilled Shafts

Upstream Approach Walls

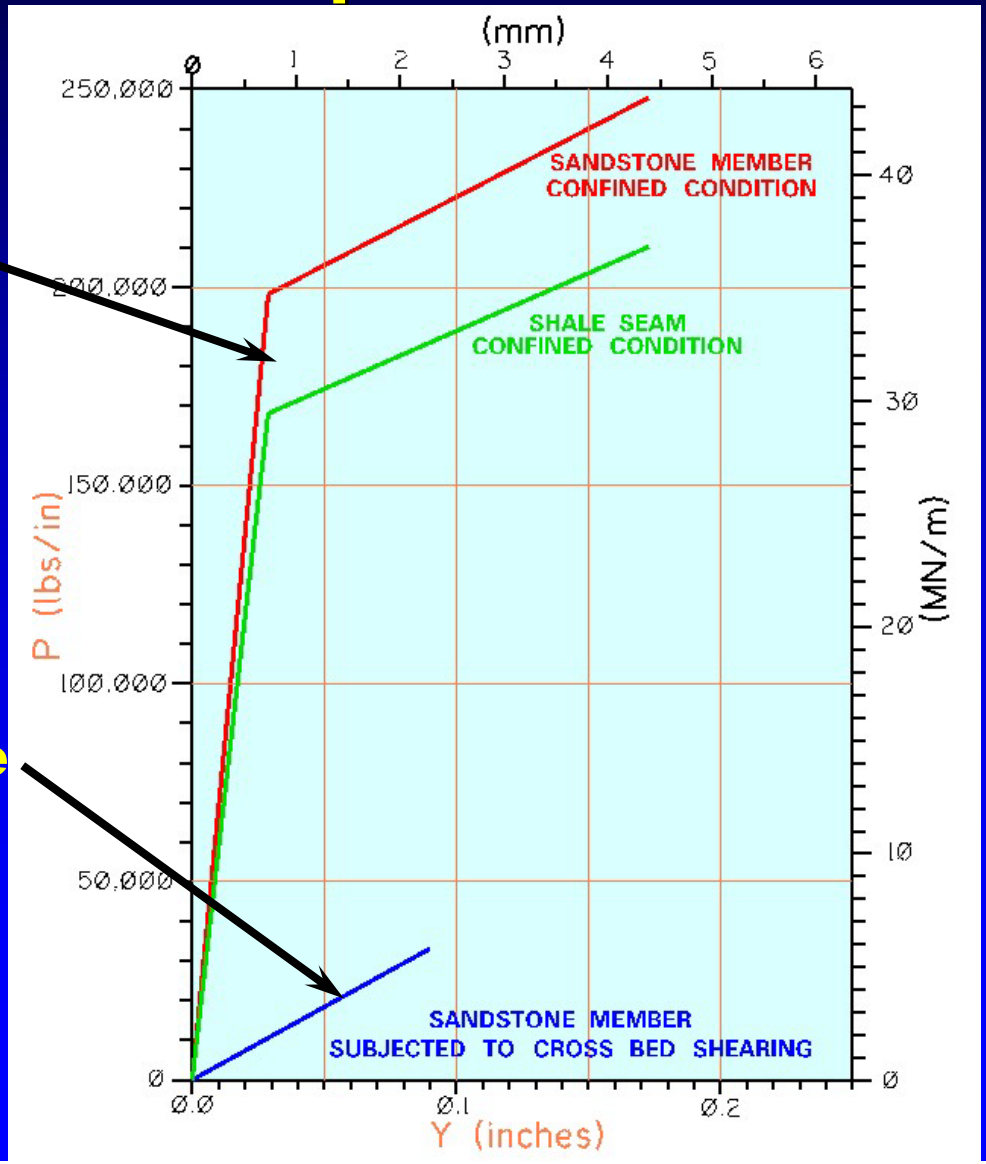


Marmet Lock Replacement – Drilled Shafts

Developed PY Curves

Utilized Borehole Jack Results

Utilized Passive Wedge Results



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Drilled Shaft Drill Rig

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Auger Drill Bits

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Drilled Shaft Core Bit

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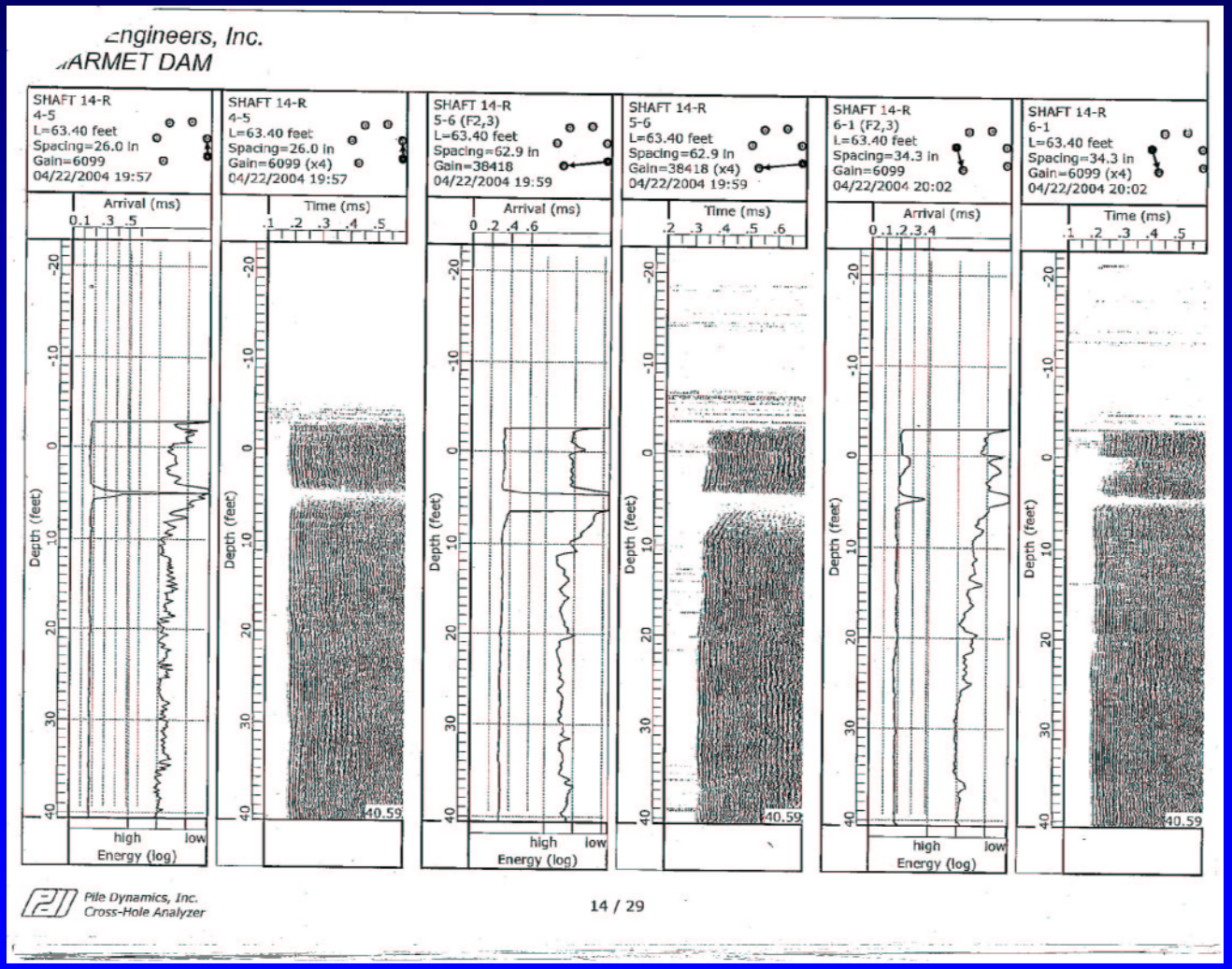
Rebar and Concrete Placement

Drilled Shaft CSL Test Results



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Drilled Shaft Low Density Concrete

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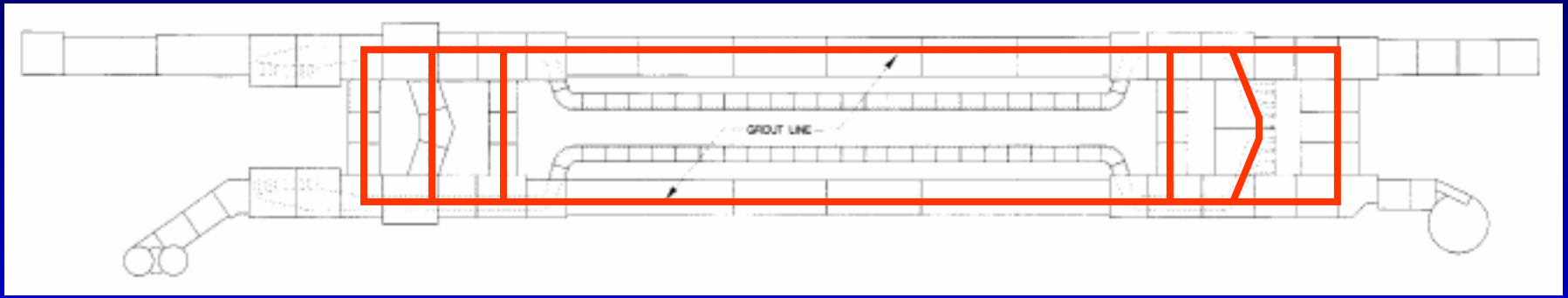
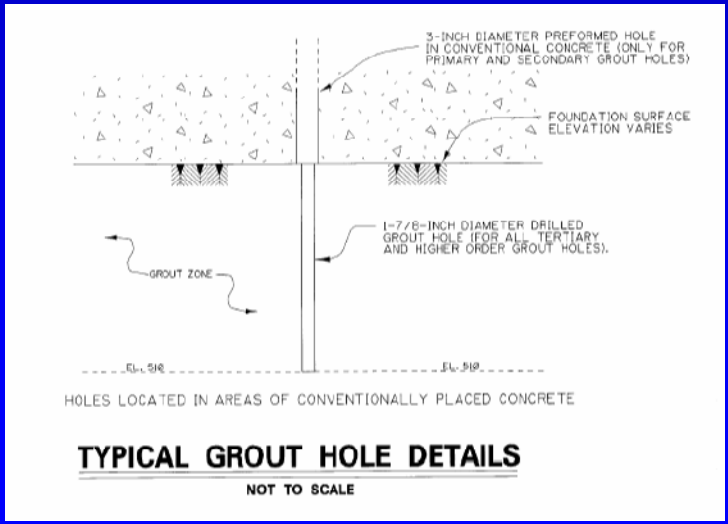
Marmet Lock Replacement – Drilling & Grouting

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**

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Marmet Lock Replacement – Conclusion

QUESTIONS AND ANSWERS

Contact Information

Mike Nield
304-399-5056
michael.c.nield@lrh01.usace.army.mil

Ron Adams
304-529-5279
ronnie.l.adams@lrh01.usace.army.mil