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US Army Corps of Engineers
Huntington District

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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   e. Foundation Drilling and Grouting

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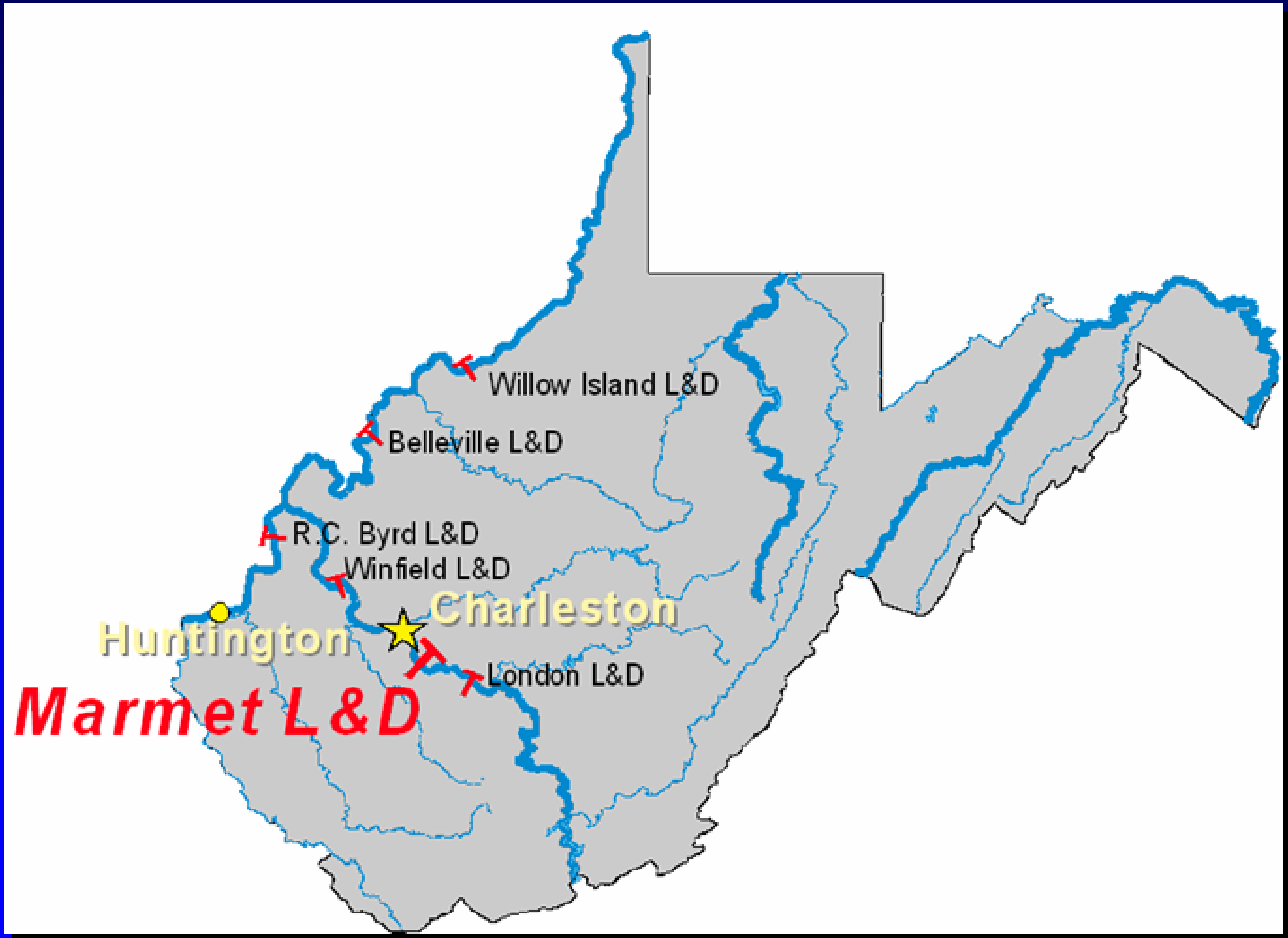
Marmet Lock Replacement – Project Overview



Site Plan

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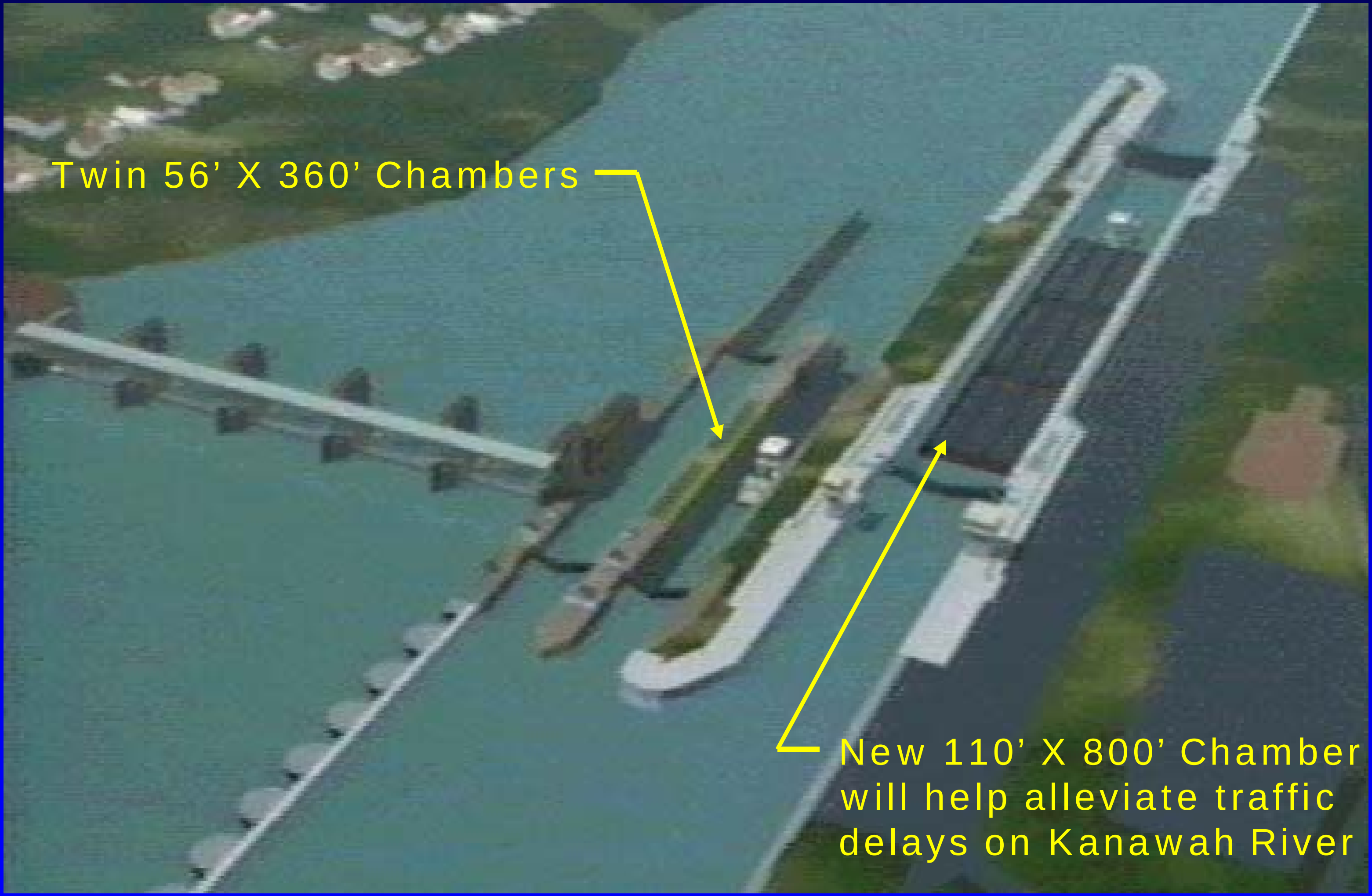
Huntington District

Marmet Lock Replacement – Project Overview

Existing Lock – Prior to Construction

US Army Corps of Engineers
Huntington District

Marmet Lock Replacement – Project Overview



New Lock – Conceptual Drawing

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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

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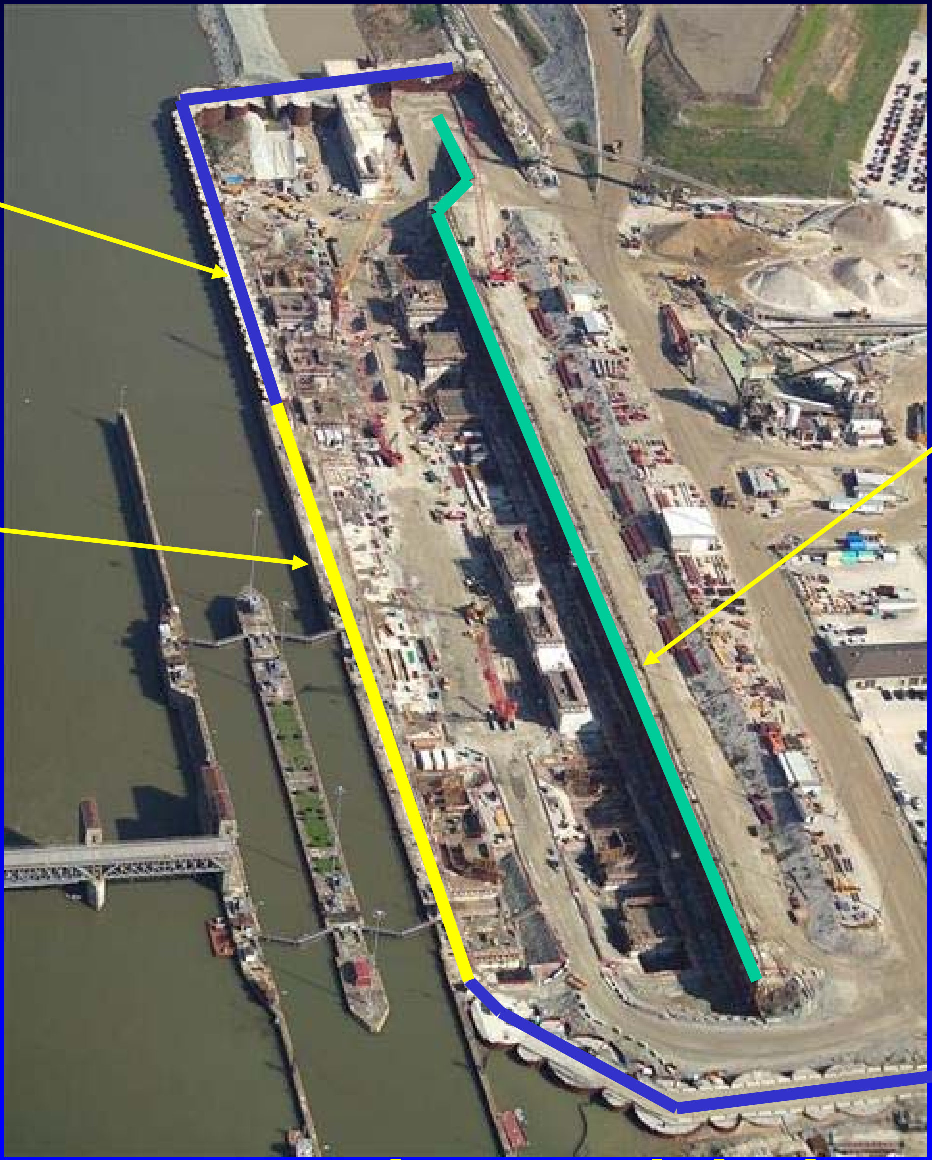
Marmet Lock Replacement – Project Overview



Sheet Pile Cell Cofferdam

Existing Landwall Portion of Cofferdam

Contractor Designed Anchored Retaining Wall

New Lock Construction - Ariel View - May 2005

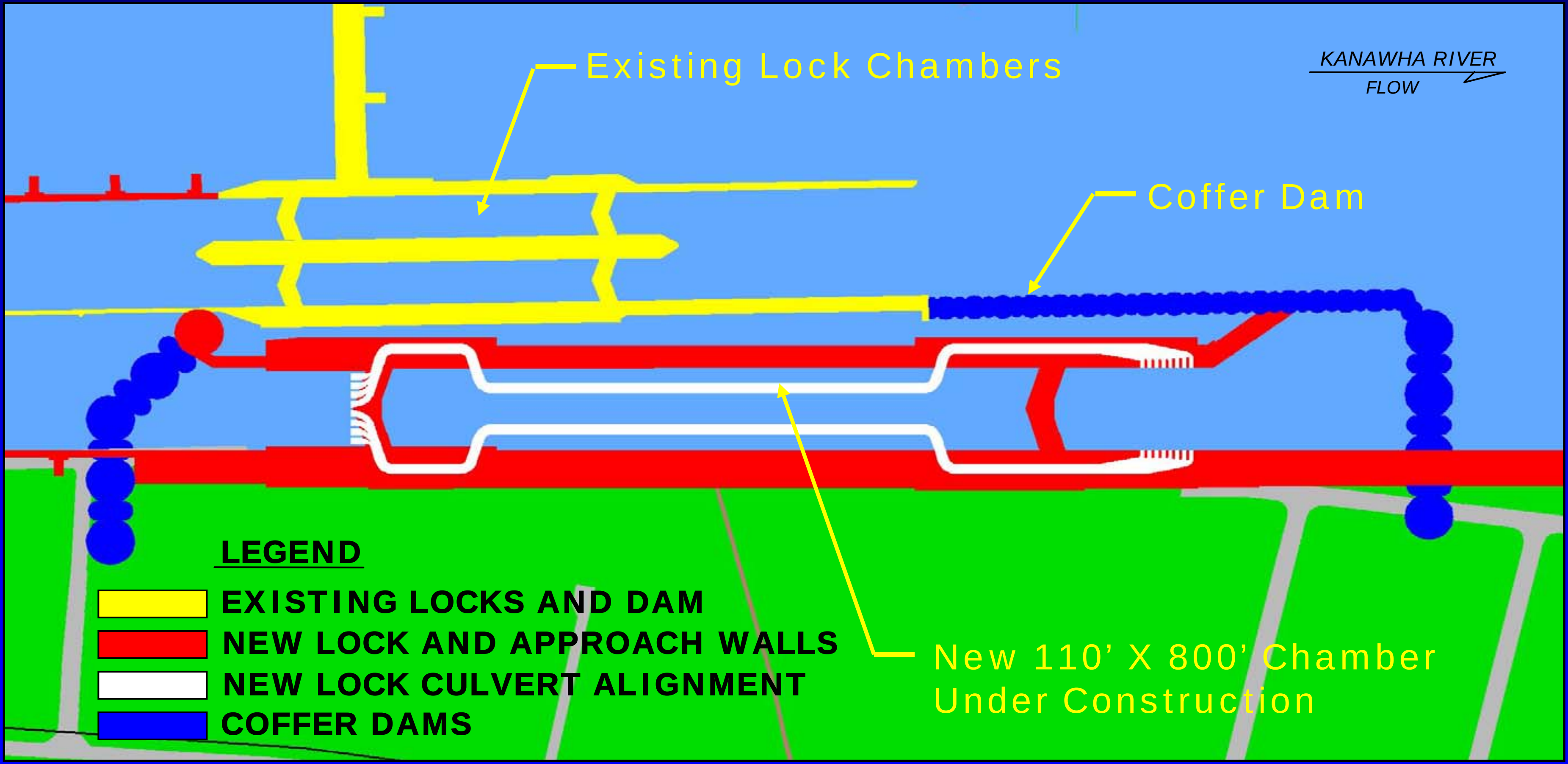
US Army Corps of Engineers
Huntington District

Marmet Lock Replacement – Project Overview

New Lock Chamber and Approach Walls

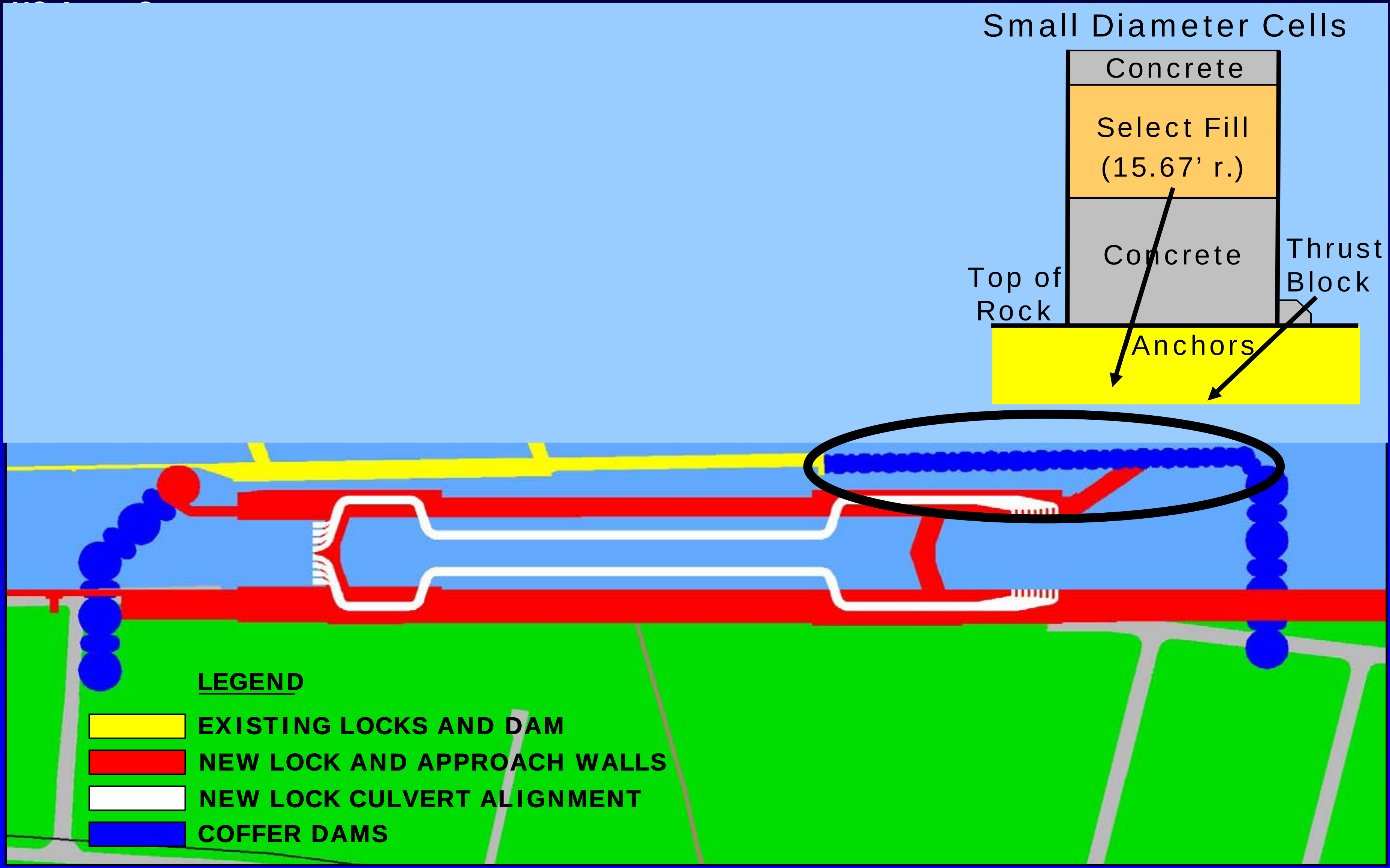
New Lock Construction - Ariel View - May 2005

Marmet Lock Replacement – Project Overview



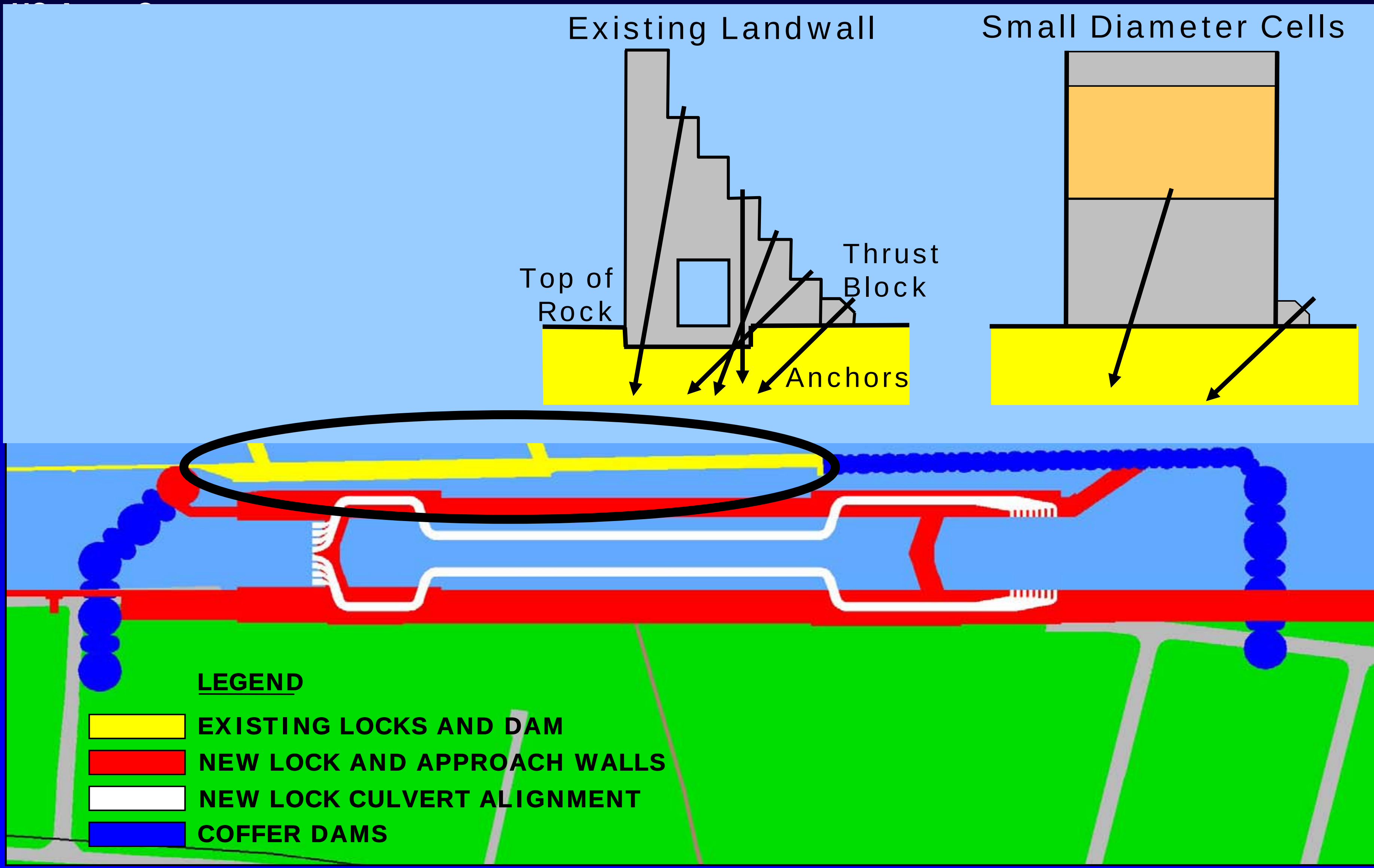
Site Plan

Marmet Lock Replacement – Project



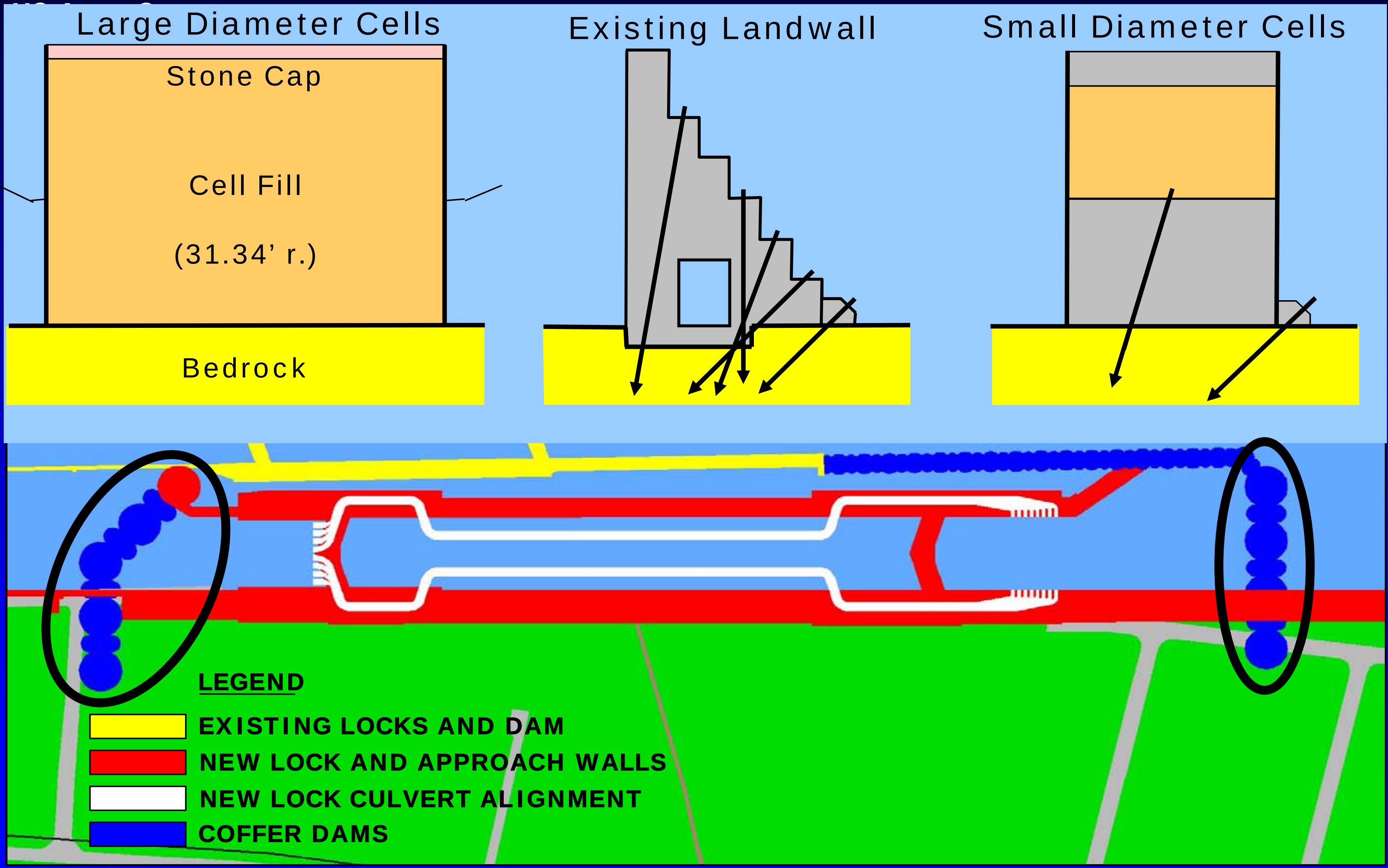
Cofferdam Components – Typical Sections

Marmet Lock Replacement – Project



Cofferdam Components – Typical Sections

Marmet Lock Replacement – Project



Cofferdam Components – Typical Sections

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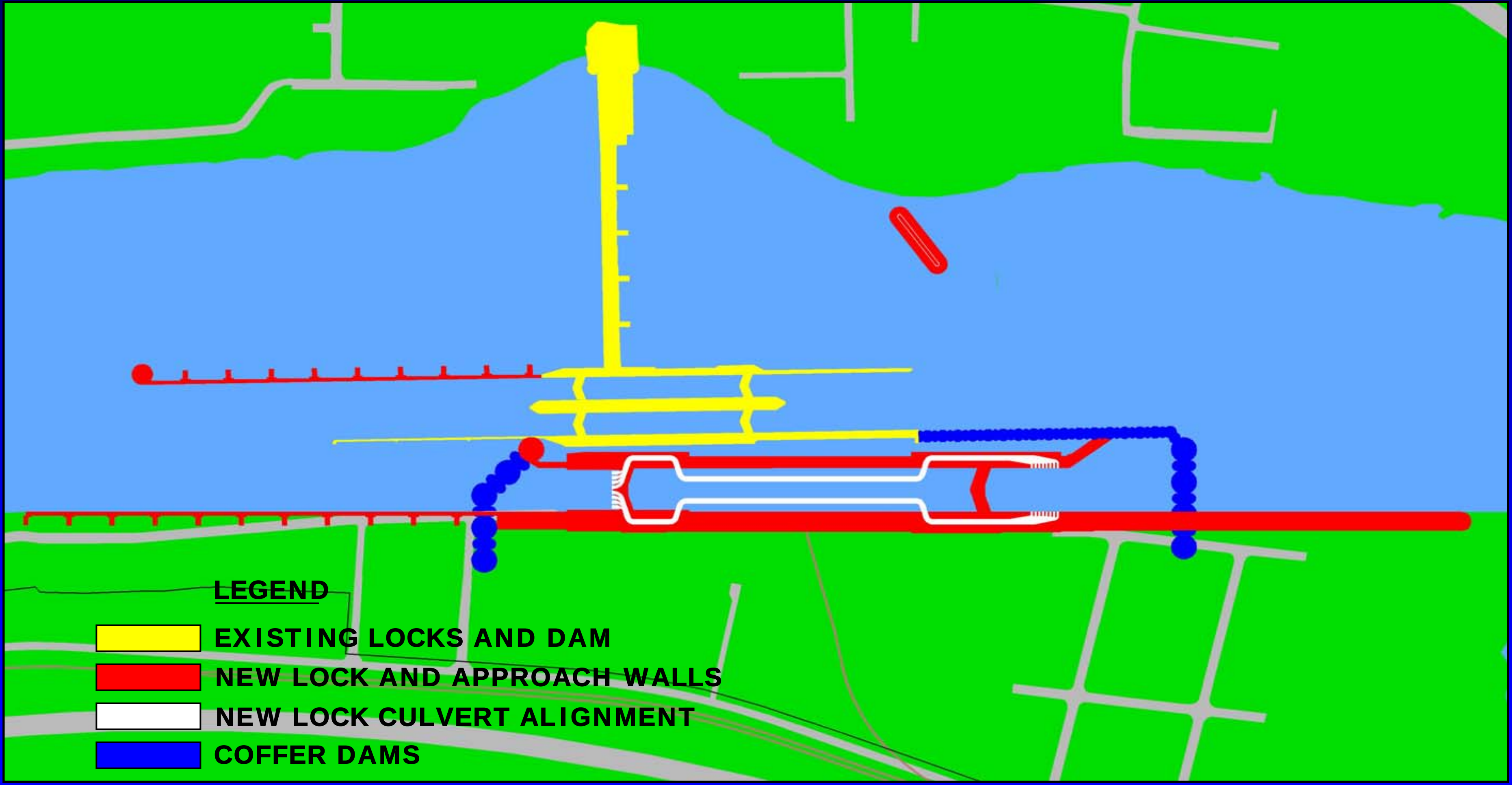
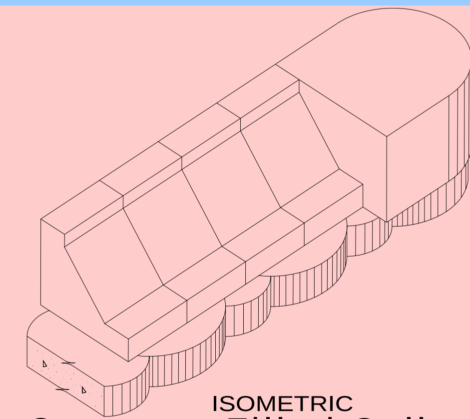
Marmet Lock Replacement – Project Overview



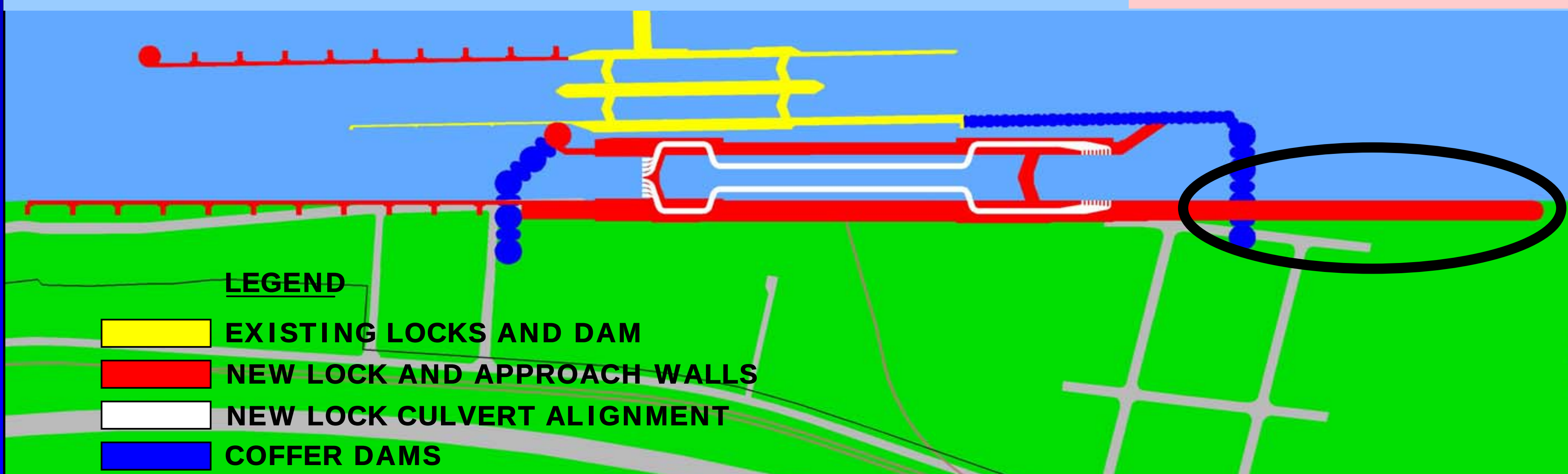
New Lock Features – Plan View

Marmet Lock Replacement – Project

Lower Approach Wall



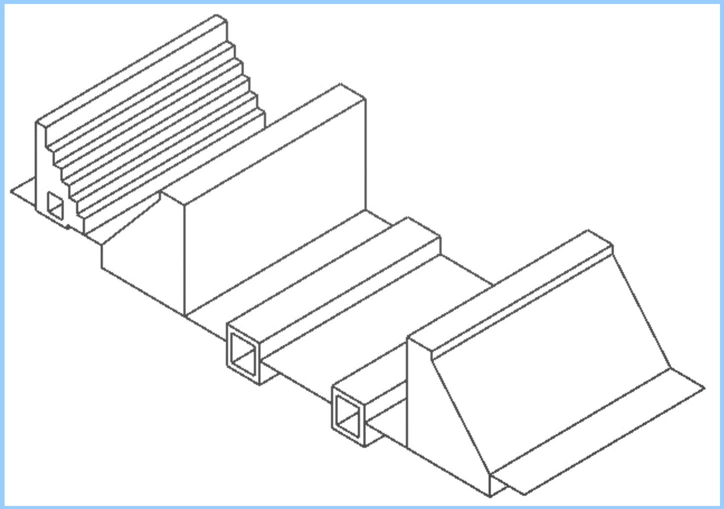
Concrete Filled Cells
Founded ~1’ below TOR



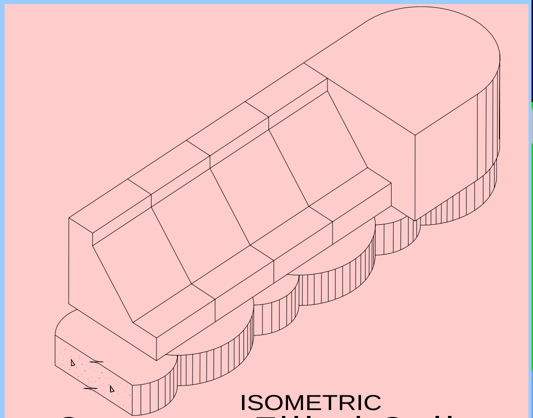
New Lock Features

Marmet Lock Replacement – Project

Lock Chamber



Lower Approach Wall



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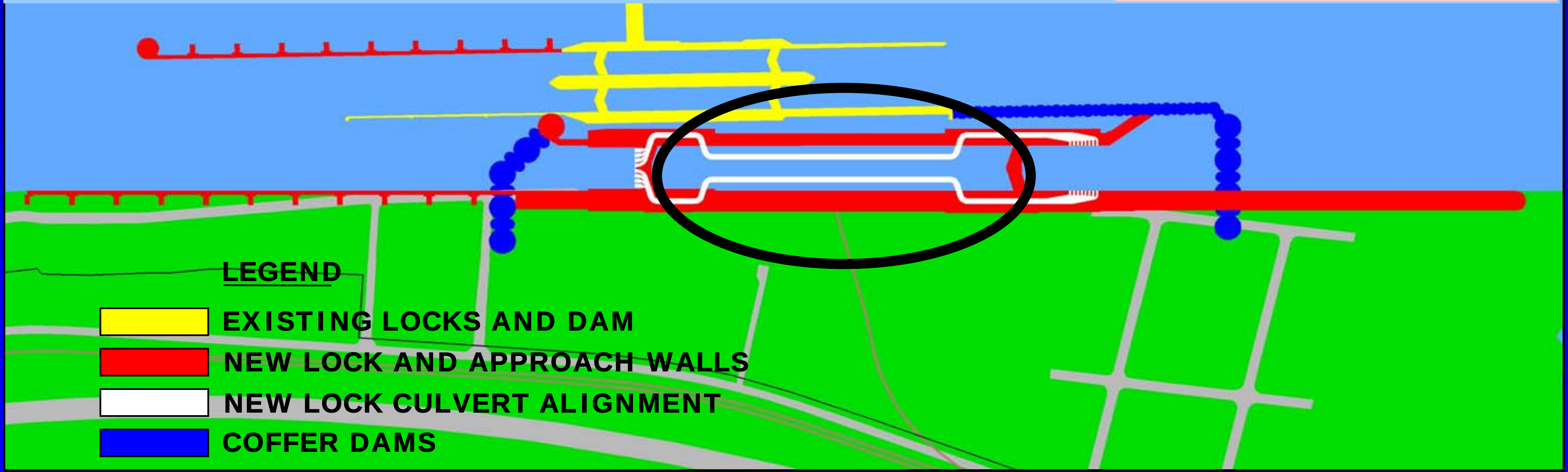
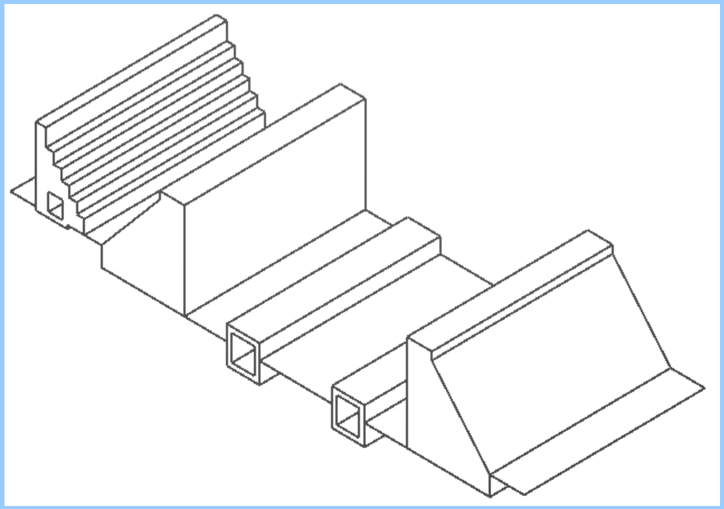


New Lock Features

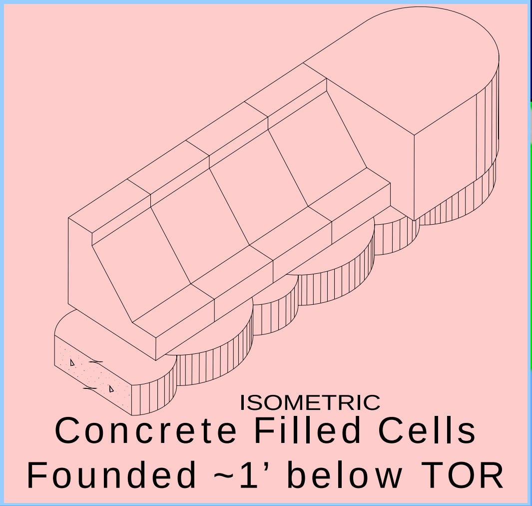
Marmet Lock Replacement – Project

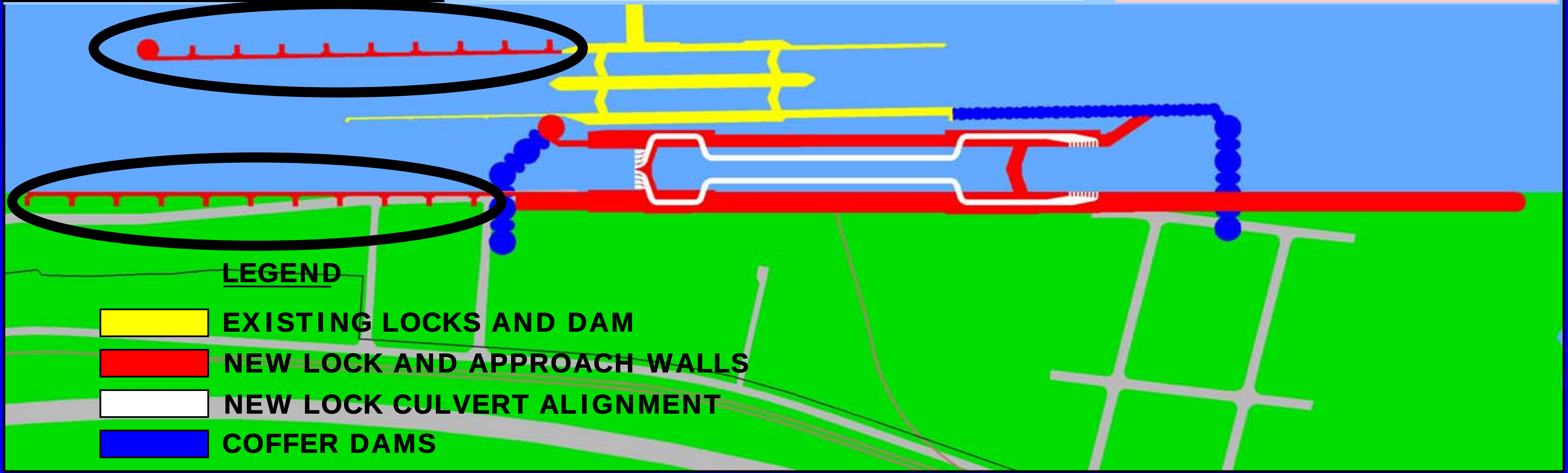
Upper Approach Walls

Lock Chamber



Lower Approach Wall





New Lock Features

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 5º-10º dip to the Northwest
- Slightly fractured with occasional high angled joints (70º-90º)

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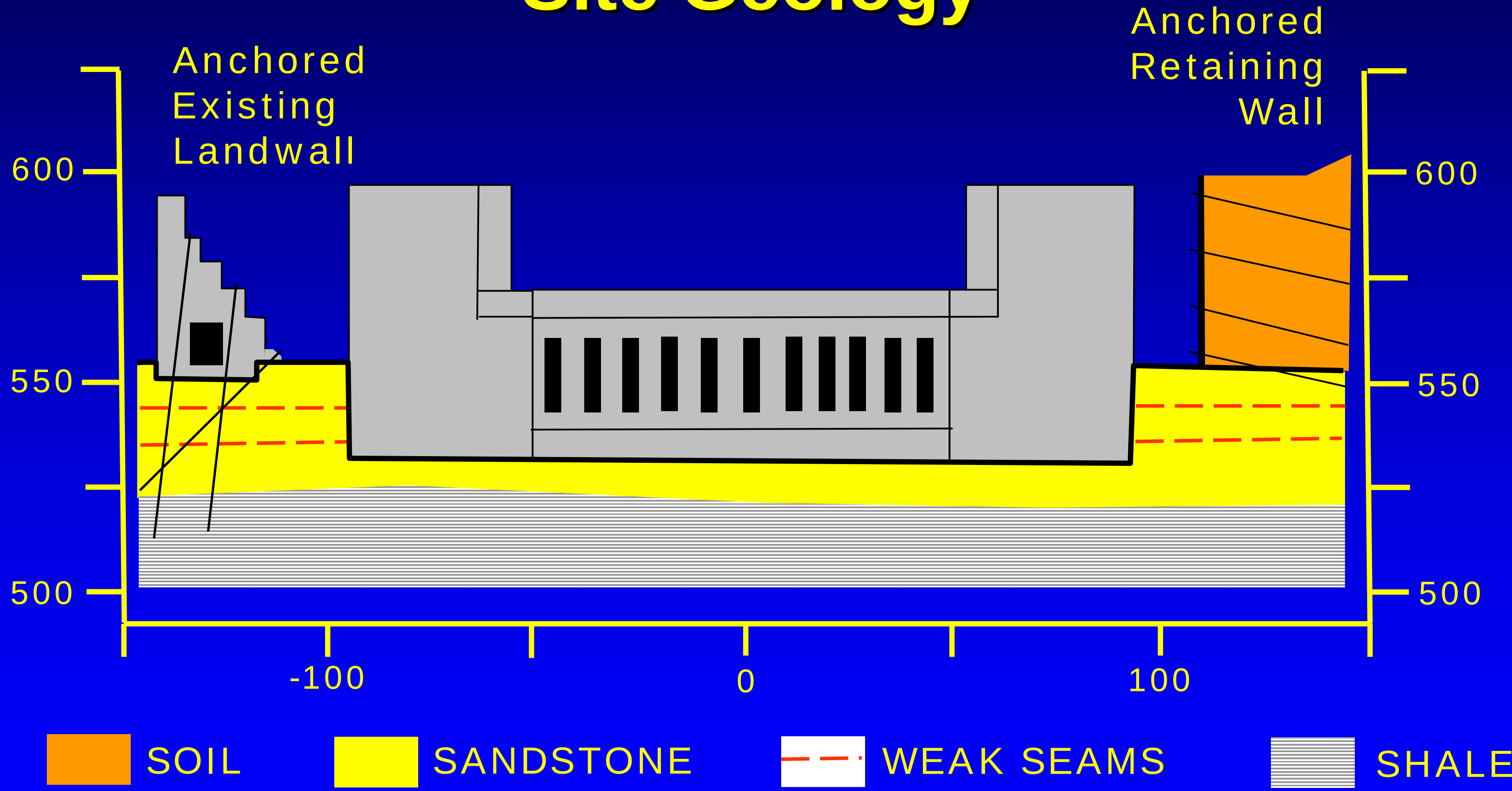
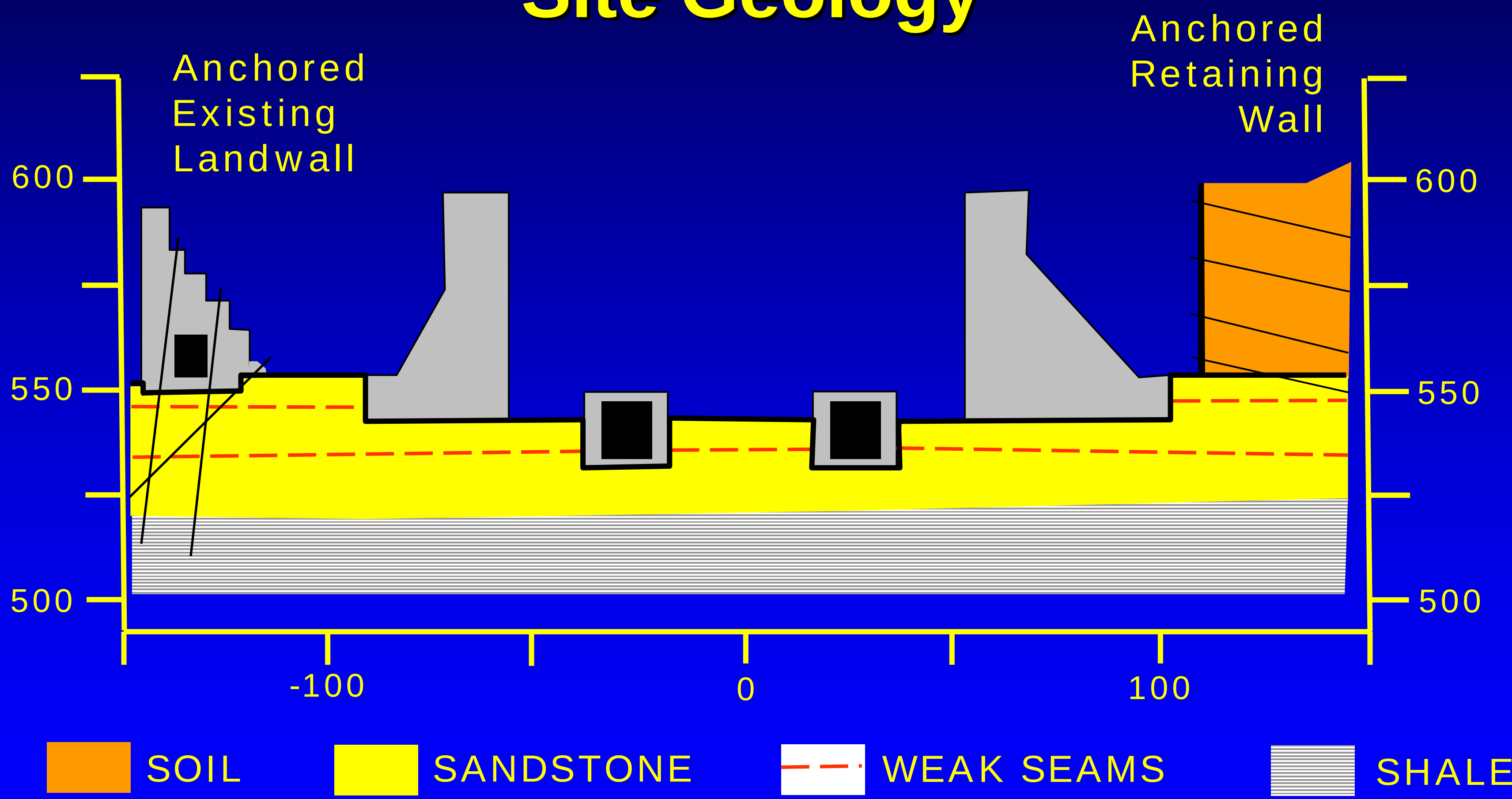
Marmet Lock Replacement – Project Overview

Site Geology



Geologic Cross Section – Upper Miter Gate

Site Geology



Geologic Cross Section – Chamber Monoliths

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

ROCK UNIT	Sliding Friction		Cross Bed Shear		Allowable Bearing Capacity	Working Bond Strength	Modulus of Deformation
	phi degree	c psi	phi degree	c psi	psi	psi	psi X 10^6
Sandstone	30	4	45	73	196	111	1.05
Coal/Shale Seam	23	0	N/A	N/A	N/A	N/A	N/A
Fault Gouge	13	0	N/A	N/A	N/A	N/A	N/A
Shale Member	22	1	30	15	111	56	0.63

Bedrock Strength Parameters

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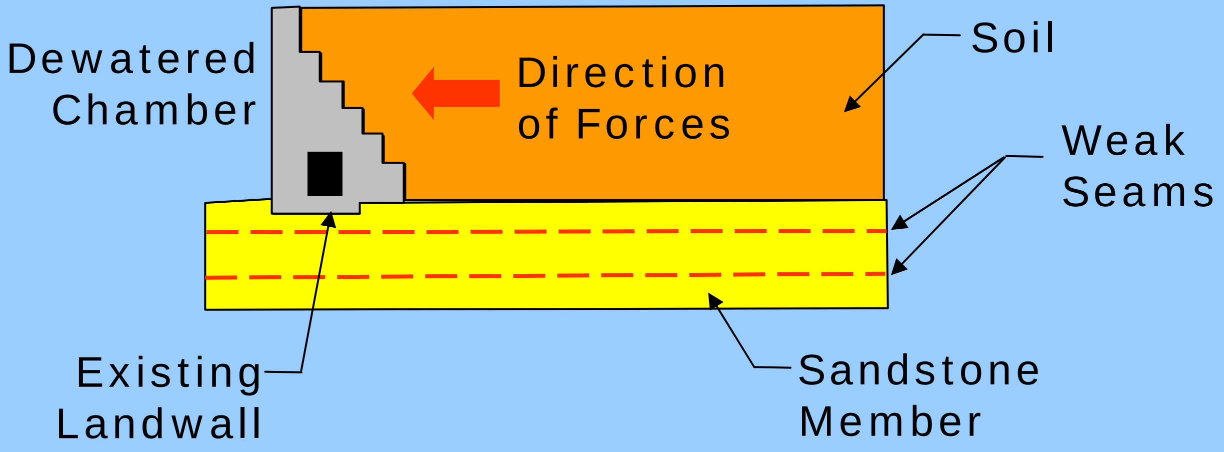
Marmet Lock Replacement – Deep Seated Sliding

Design Concerns

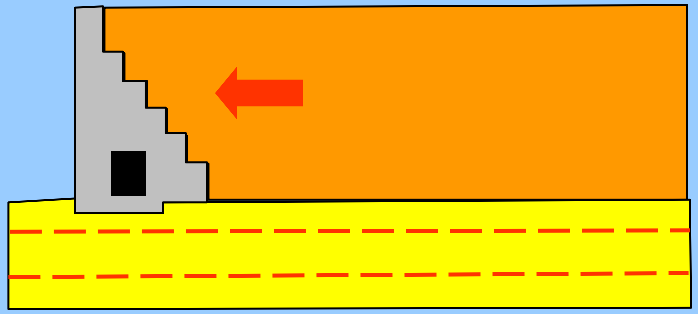
Pre-Construction Condition



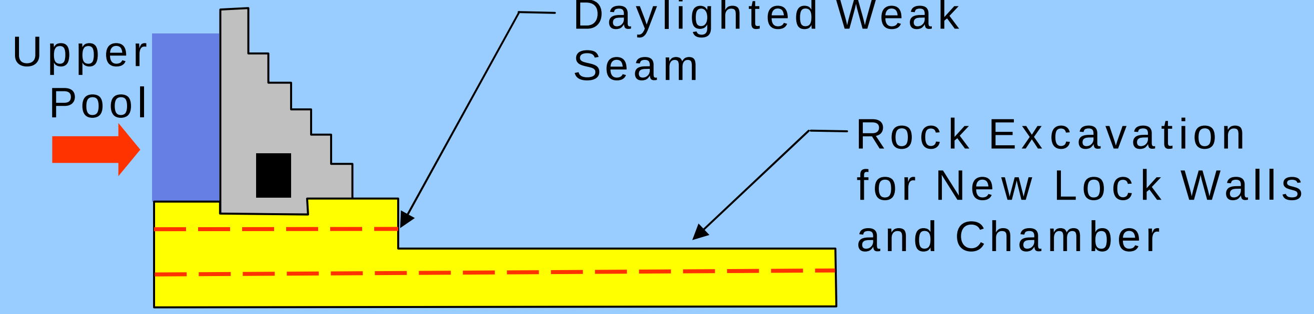
Marmet Lock Replacement – Deep Seated Sliding

Design Concerns

Pre-Construction Condition



Construction Condition



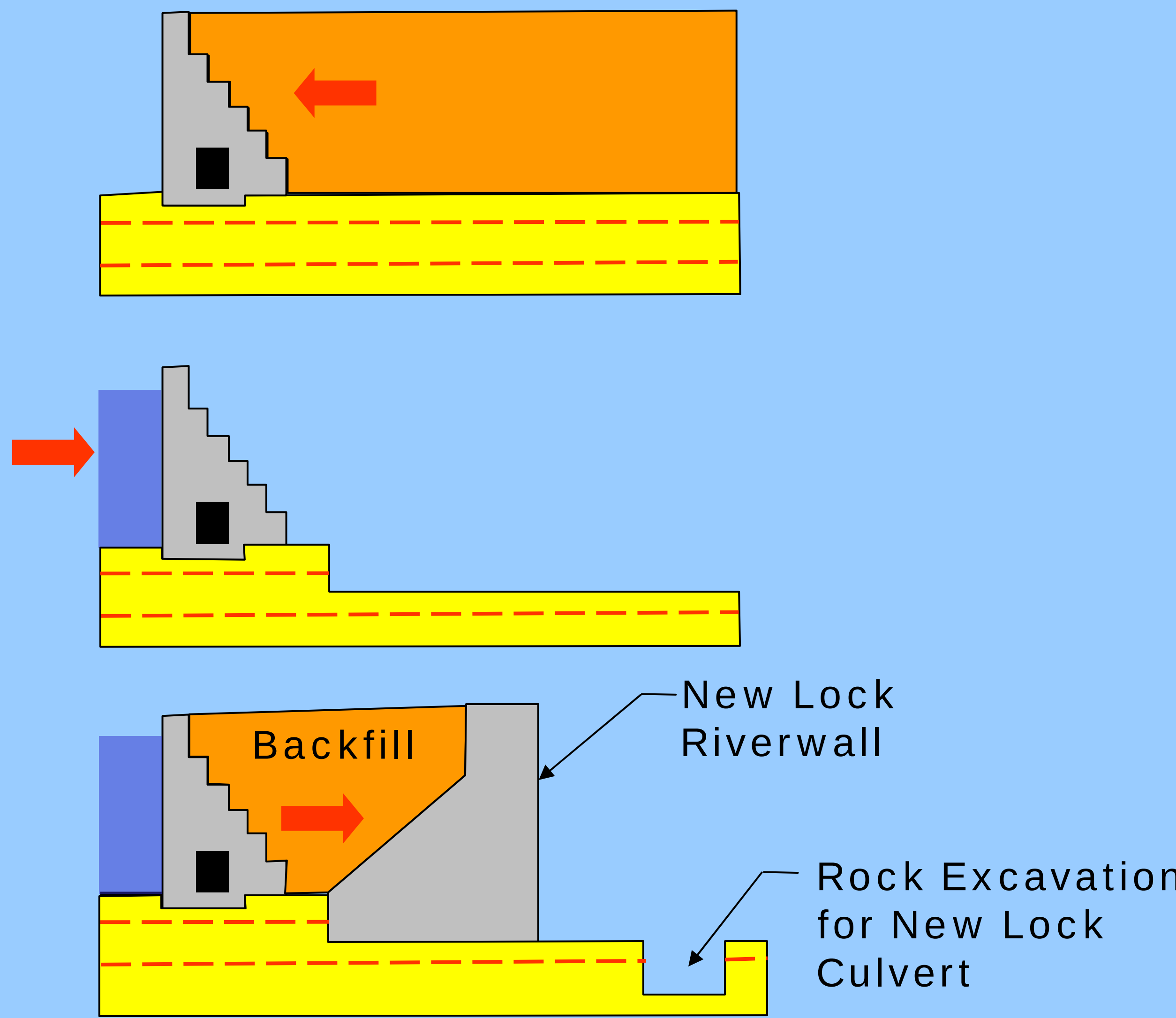
Marmet Lock Replacement – Deep Seated Sliding

Design Concerns

Pre-Construction Condition

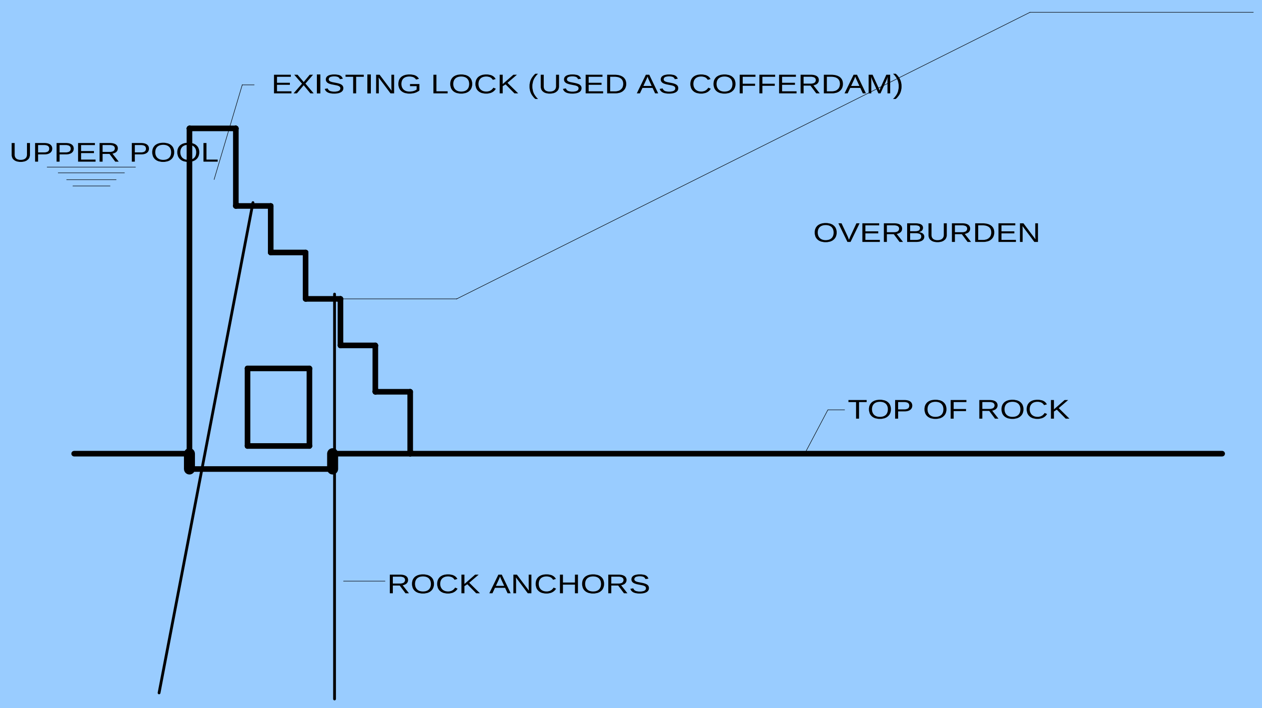
Construction Condition

Permanent Condition



Marmet Lock Replacement – Deep Seated Sliding

Design Concerns

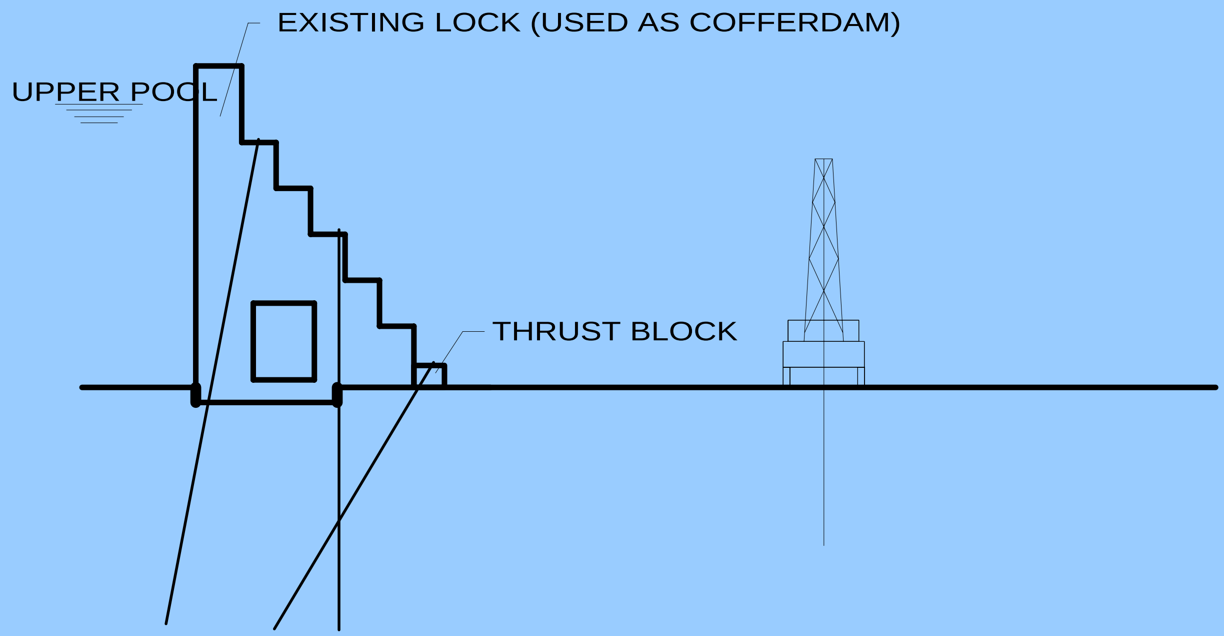


STAGED ANCHORING DURING OVERBURDEN EXCAVATION
Analyzed for coal/shale seam at foundation (phi=23^{o}, c=0psi)

INSTALL INSTRUMENTATION

Marmet Lock Replacement – Deep Seated Sliding

Design Concerns



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

SUBSURFACE EXPLORATION PERFORMED

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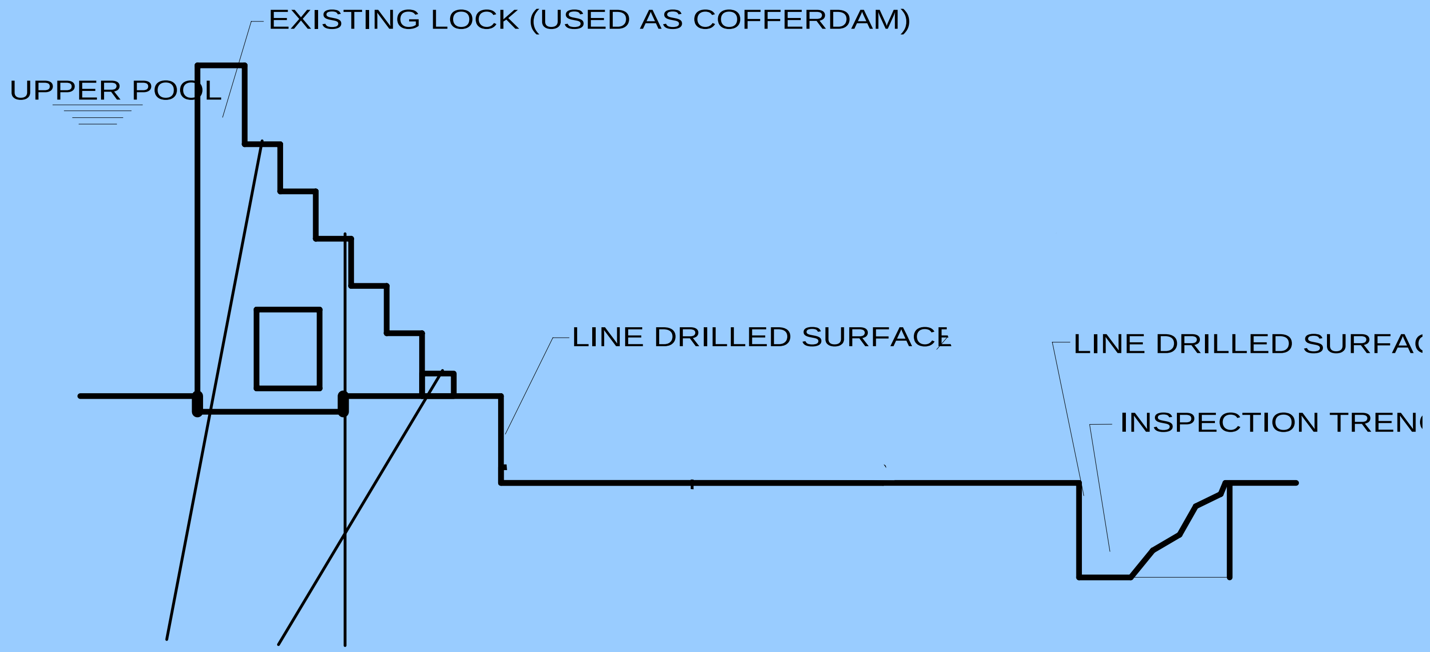
Marmet Lock Replacement – Deep Seated Sliding

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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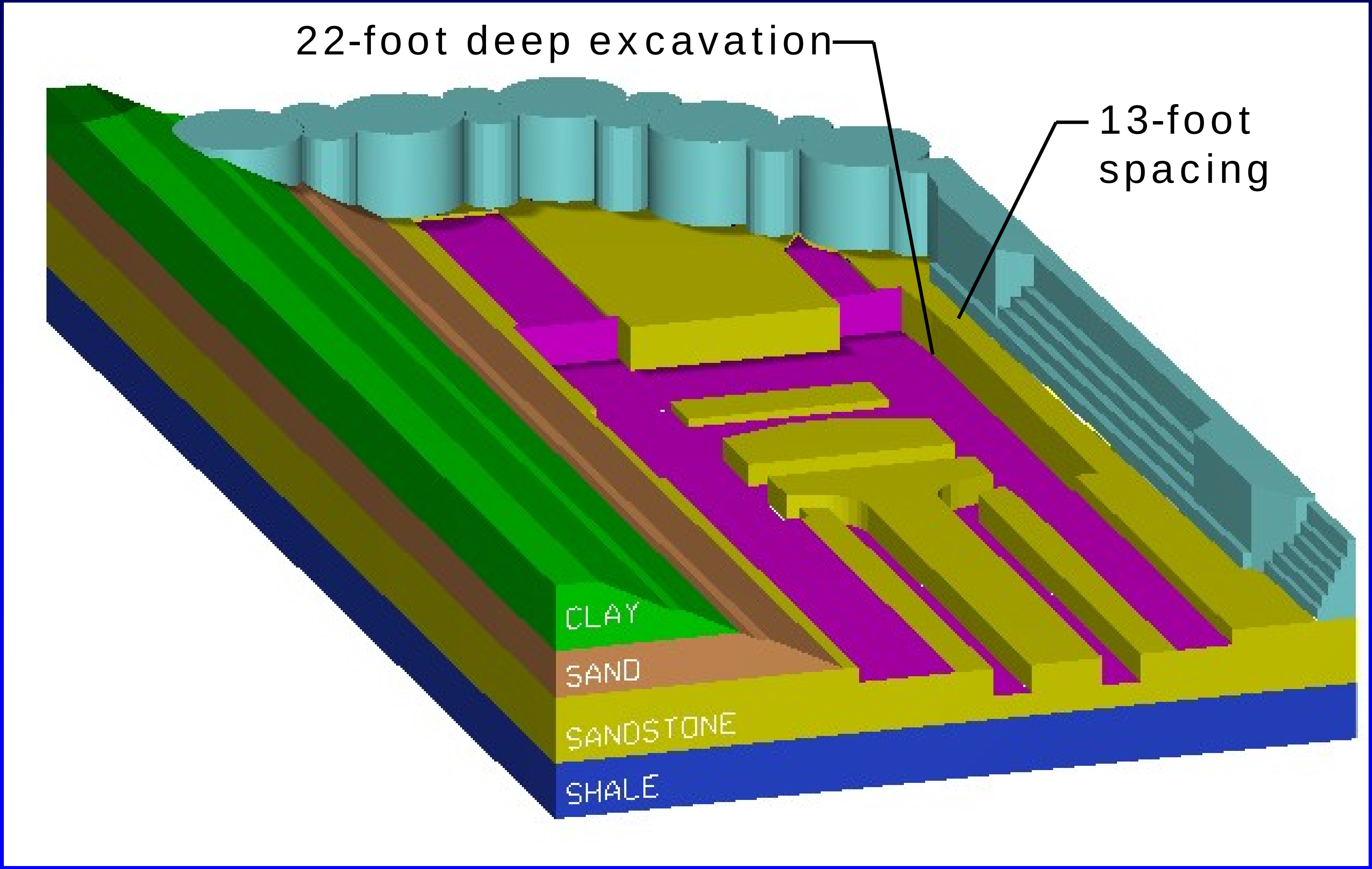
Marmet Lock Replacement – Deep Seated Sliding

Cofferdam



Excavation Adjacent to Cofferdam – 3D view

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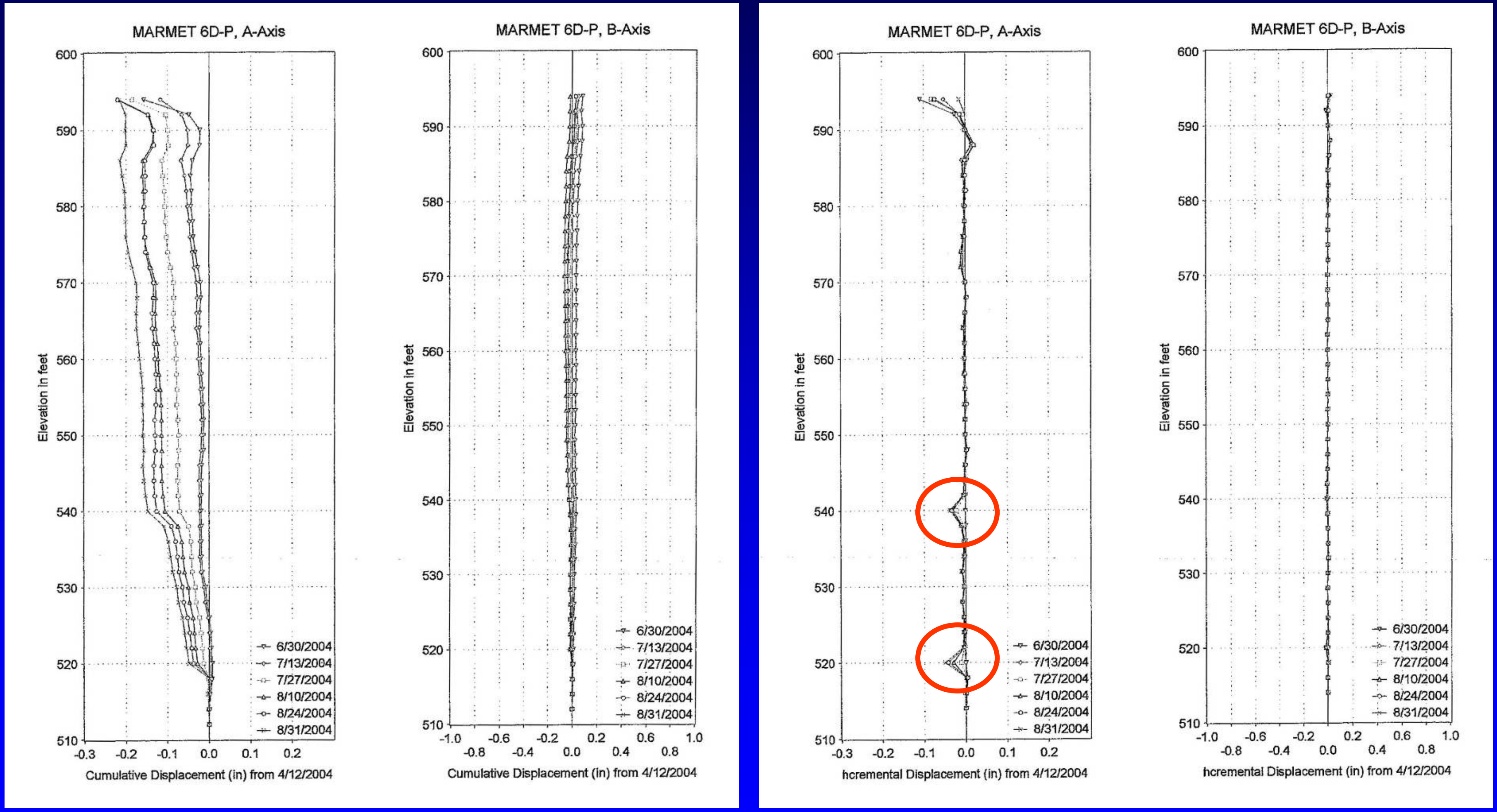
Marmet Lock Replacement – Deep Seated Sliding

Cofferdam - Instrumentation



Inclinometer Readings - August 2004

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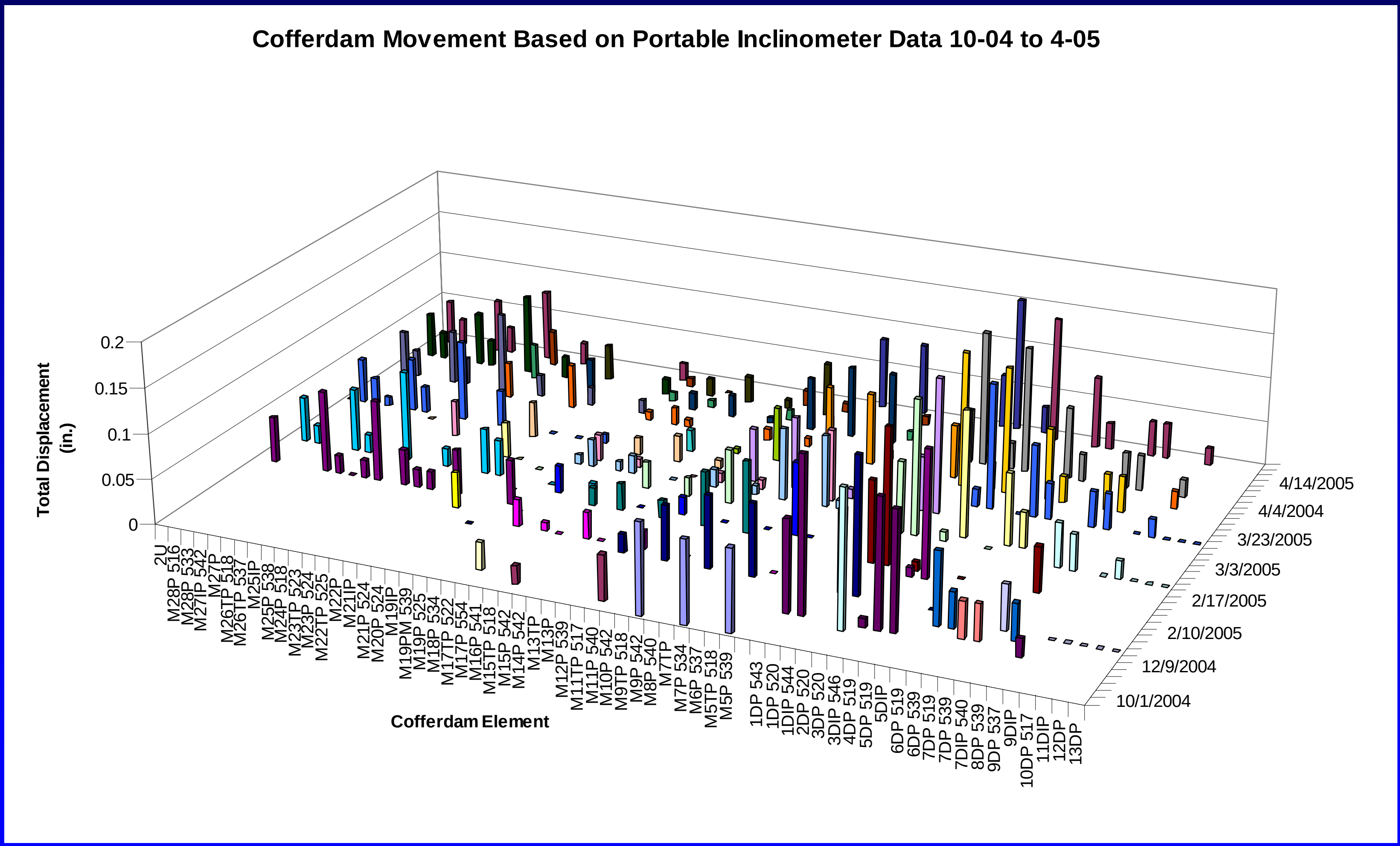
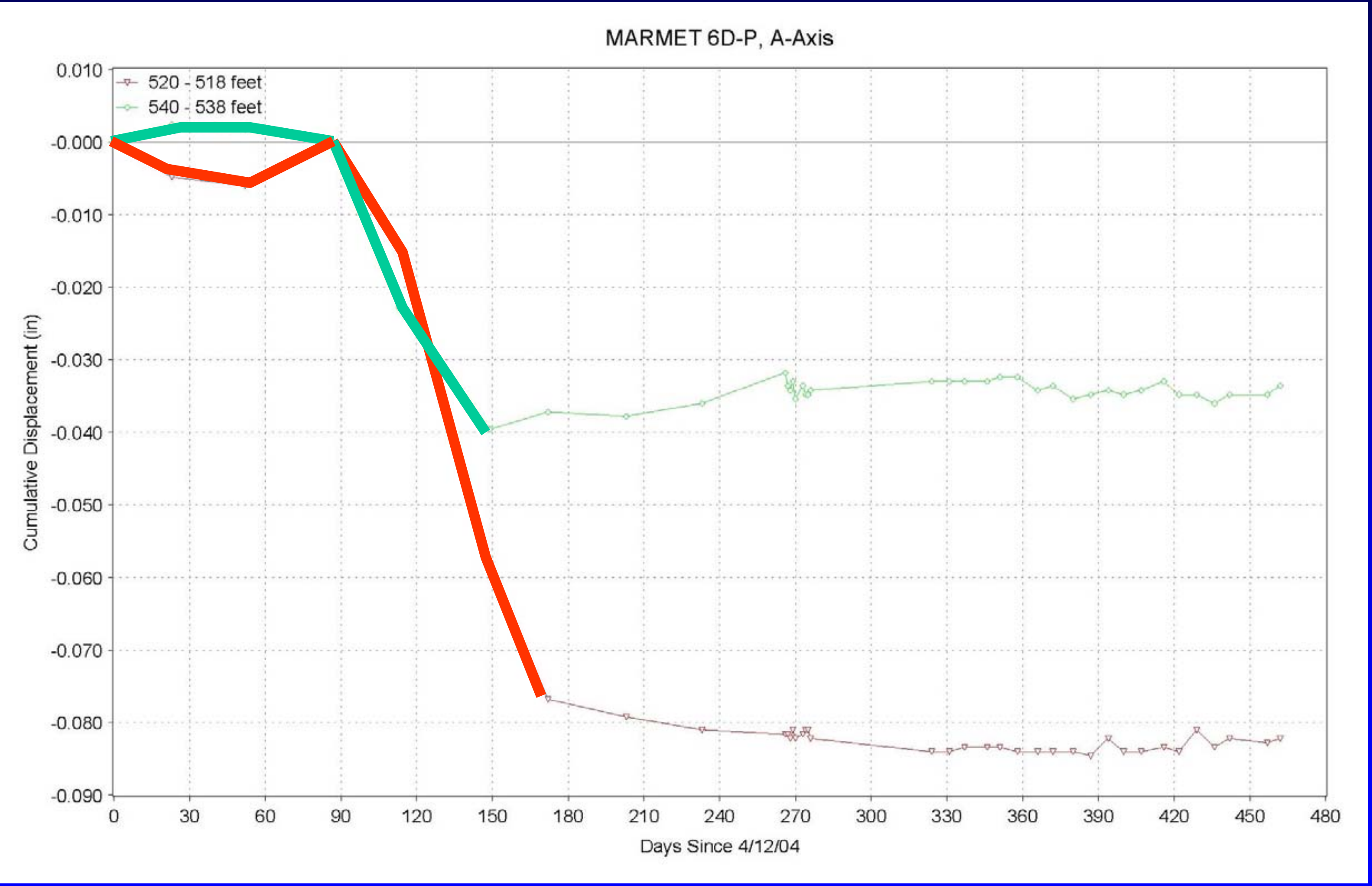
Marmet Lock Replacement – Deep Seated Sliding

Cofferdam - Instrumentation



Inclinometer - displacement vs. time

Cofferdam - Instrumentation



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

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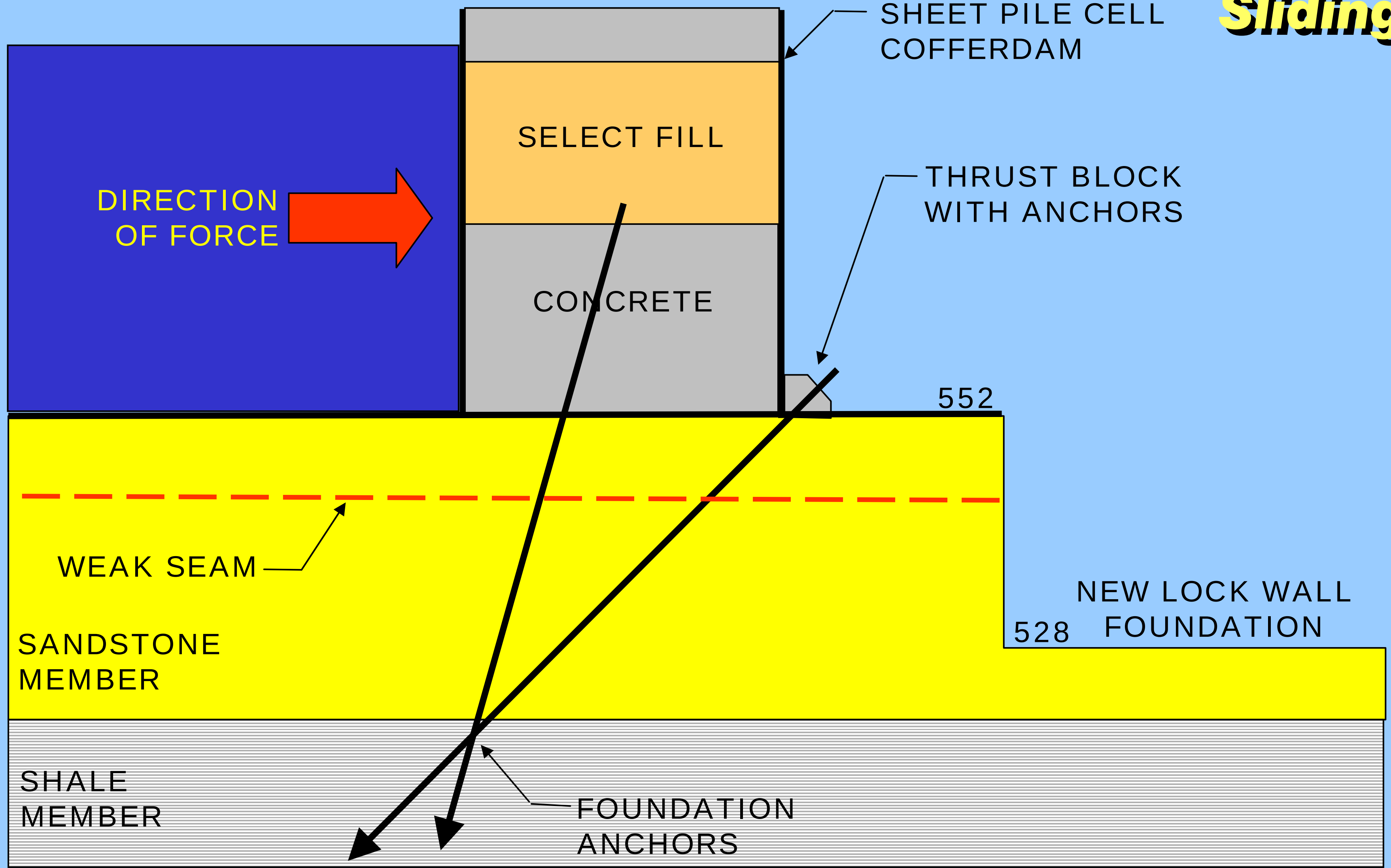
Marmet Lock Replacement – Deep Seated Sliding



Cofferdam Foundation Movement - Section

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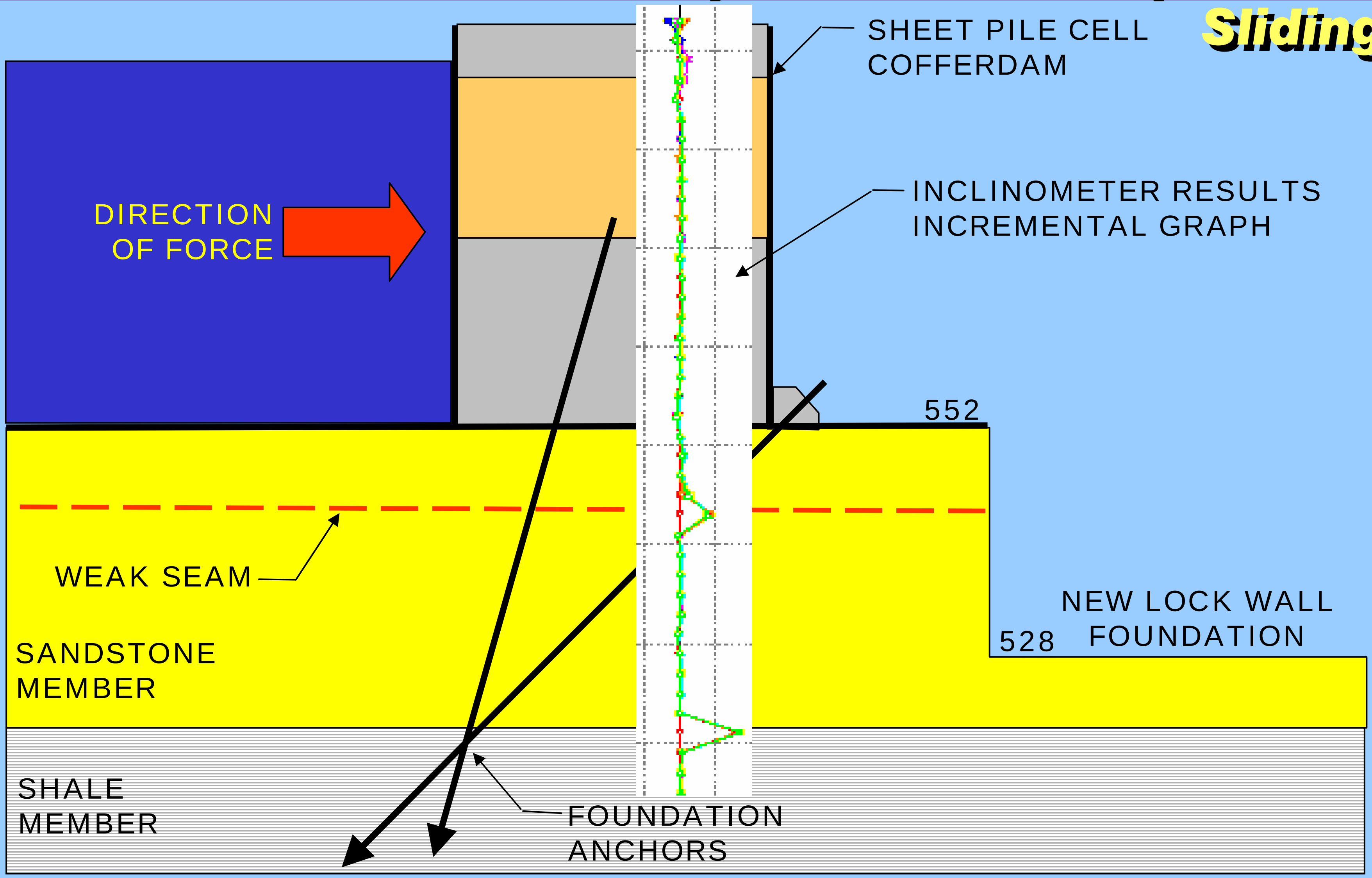
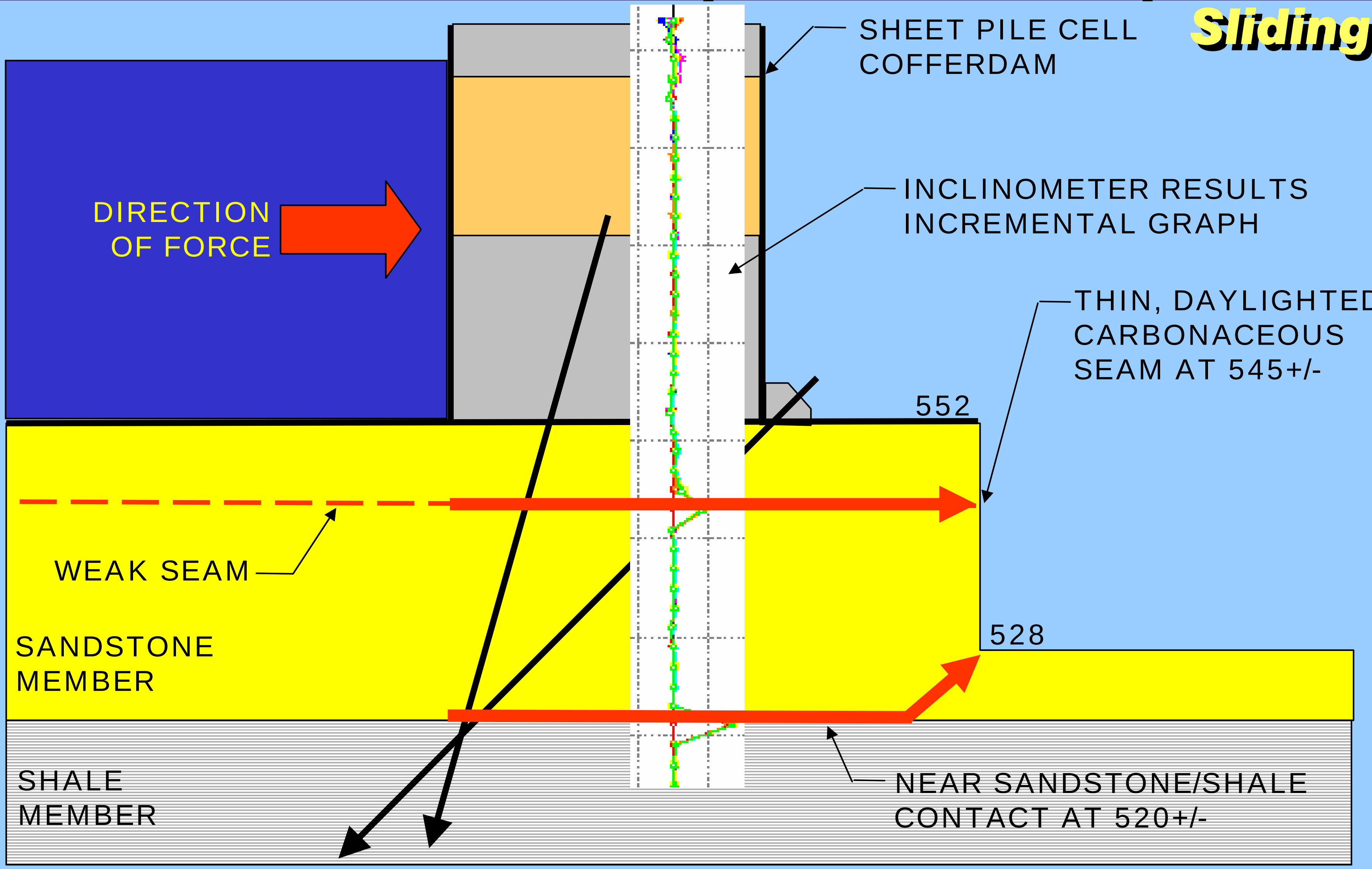
Marmet Lock Replacement – Deep Seated Sliding



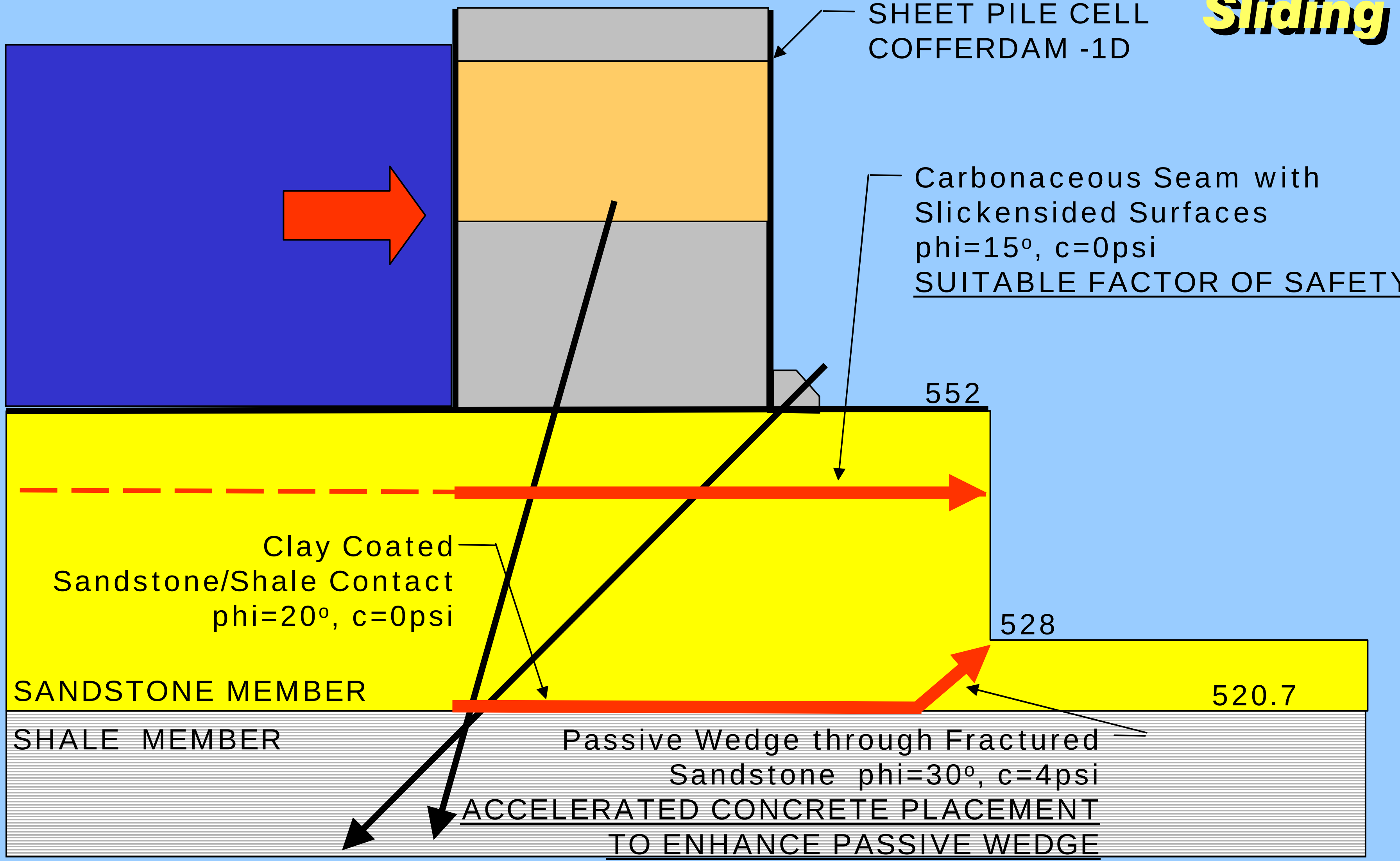
Cofferdam Foundation Movement - Section

Marmet Lock Replacement – Deep Seated Sliding



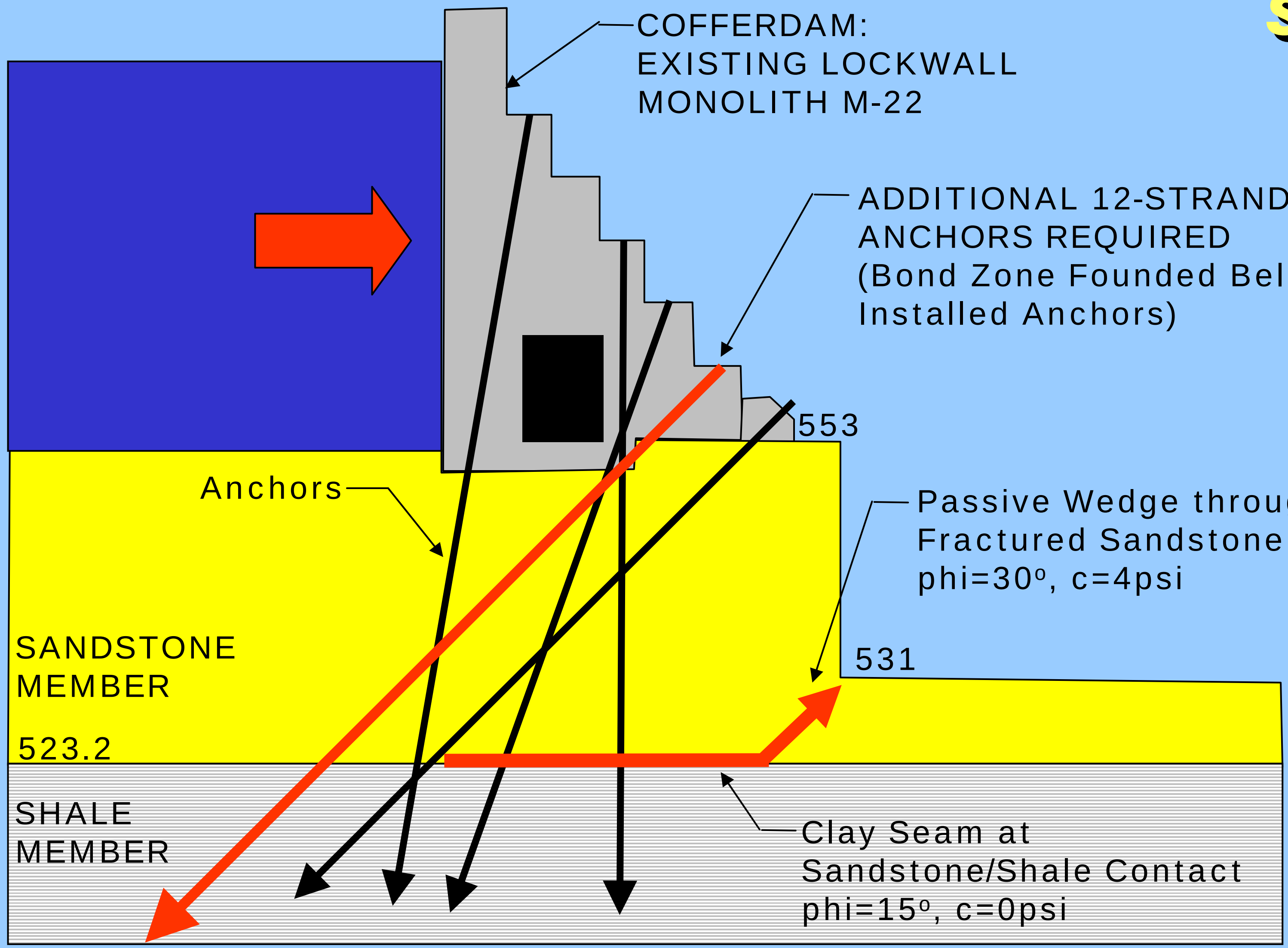
Cofferdam Foundation Movement - Section

Marmet Lock Replacement – Deep Seated Sliding



Cofferdam Foundation Movement – Cell 1D

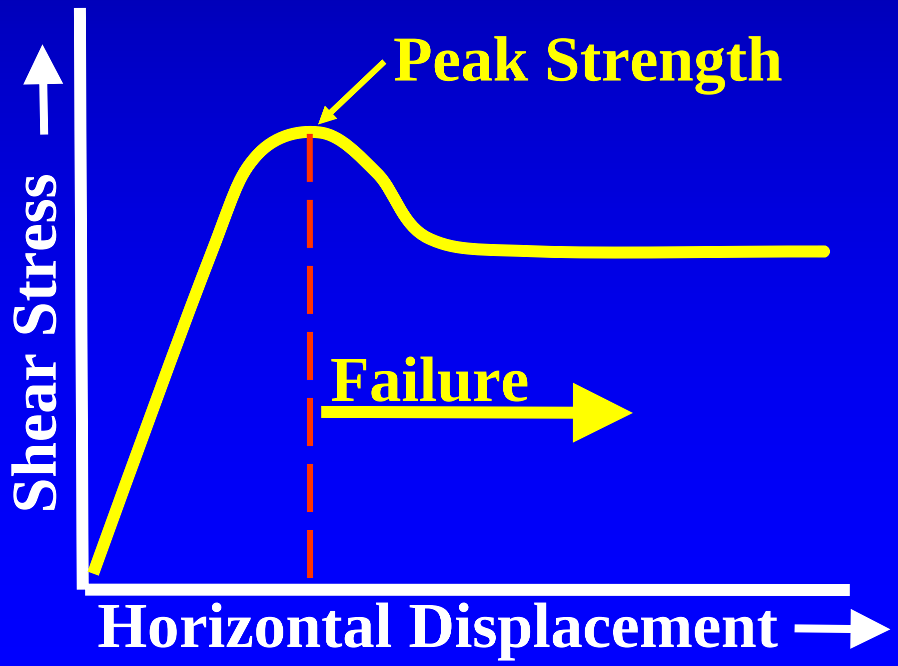
Marmet Lock Replacement – Deep Seated Sliding



Cofferdam Foundation Movement – M-22

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

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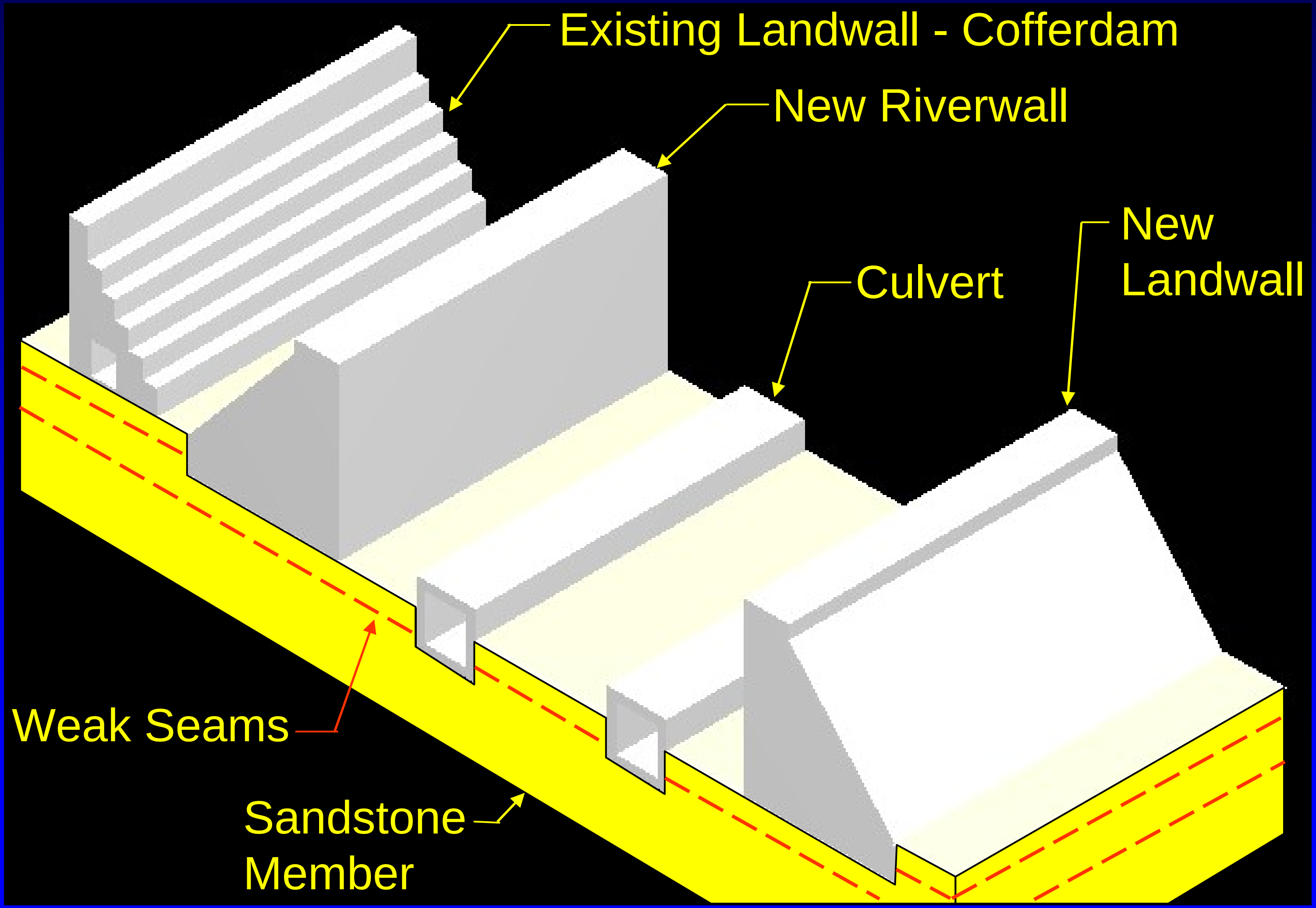
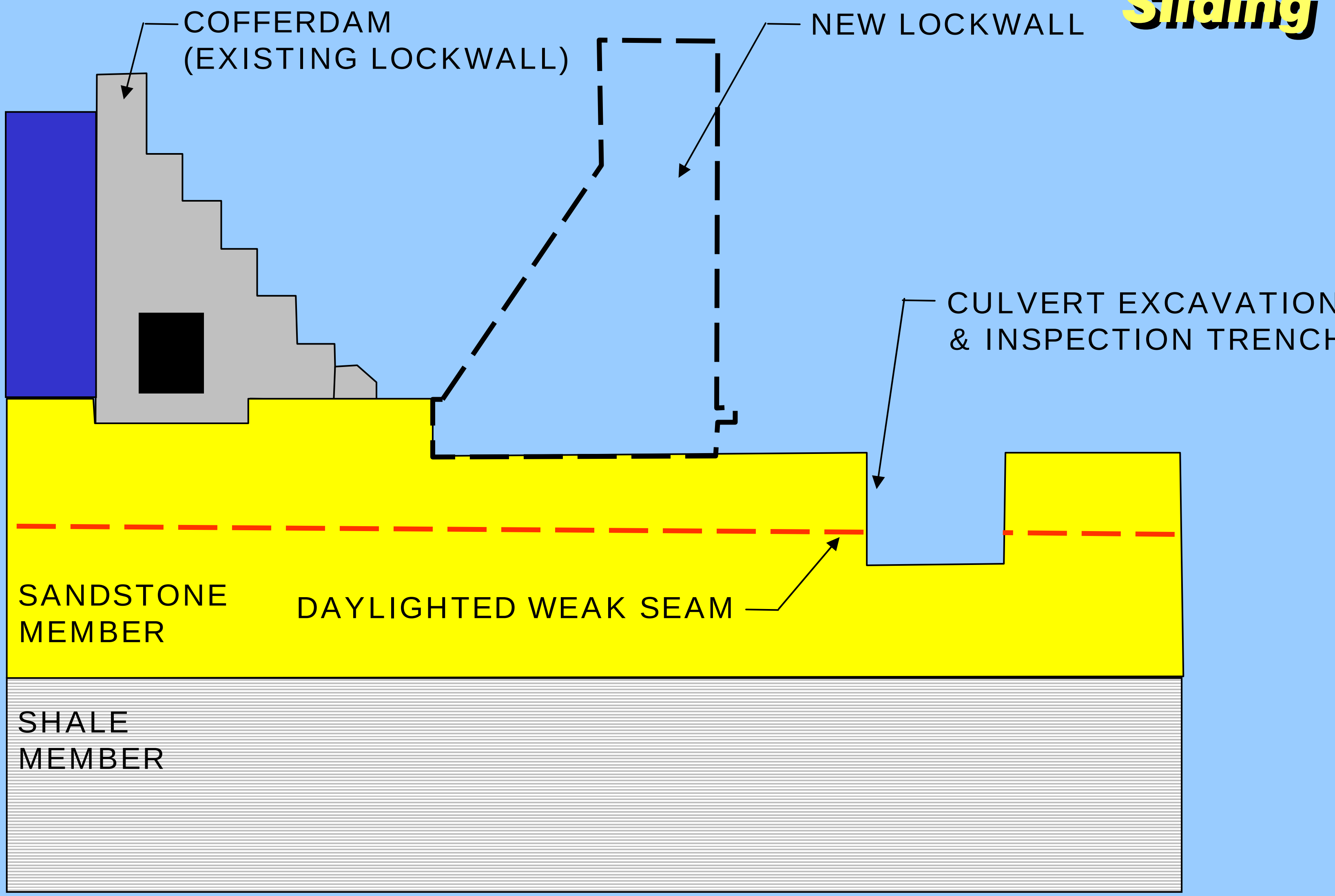
Marmet Lock Replacement – Deep Seated Sliding

New Lockwall



Deep Seated Sliding – Culvert Excavation

Marmet Lock Replacement – Deep Seated Sliding



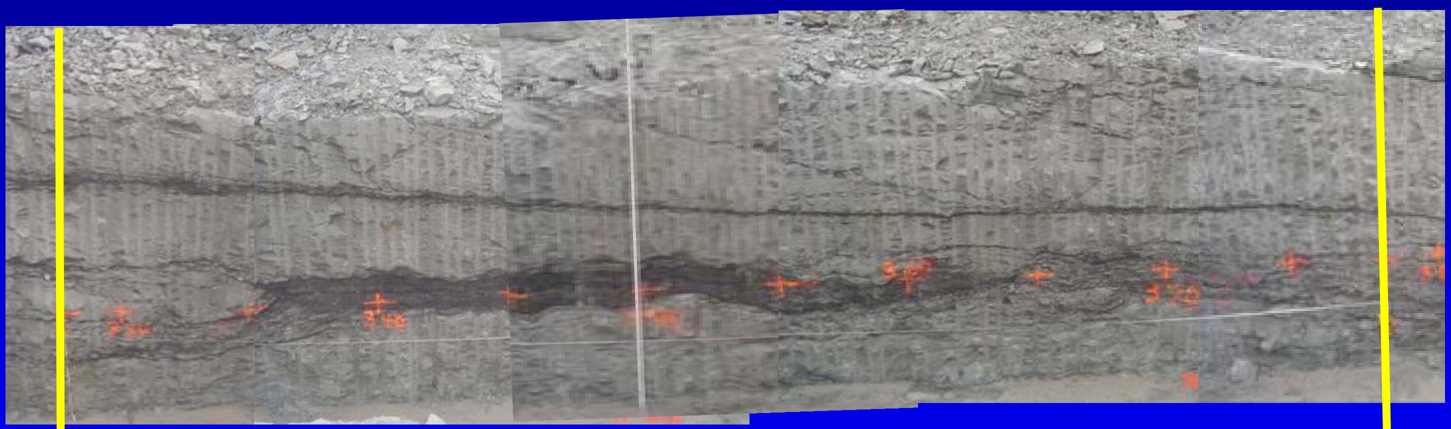
New Chamber Lockwall Monoliths

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

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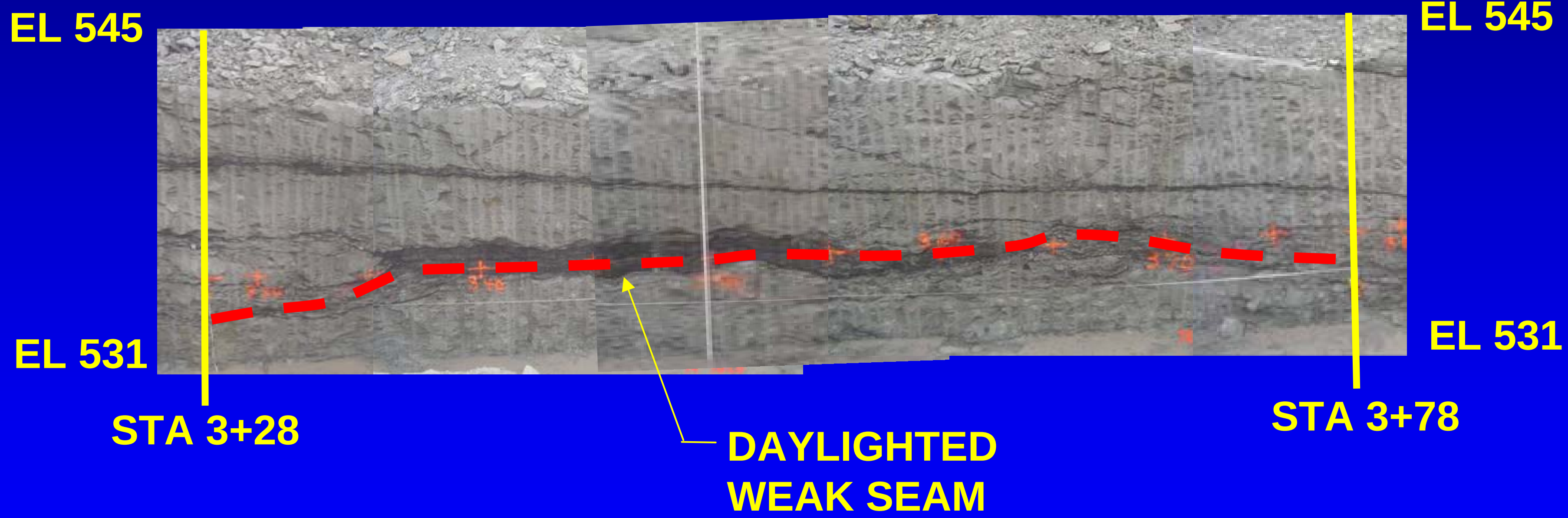
Marmet Lock Replacement – Deep Seated Sliding

Inspection Trench Sidewall - Photo

MONOLITH R-15A



New Chamber Lockwall Monoliths

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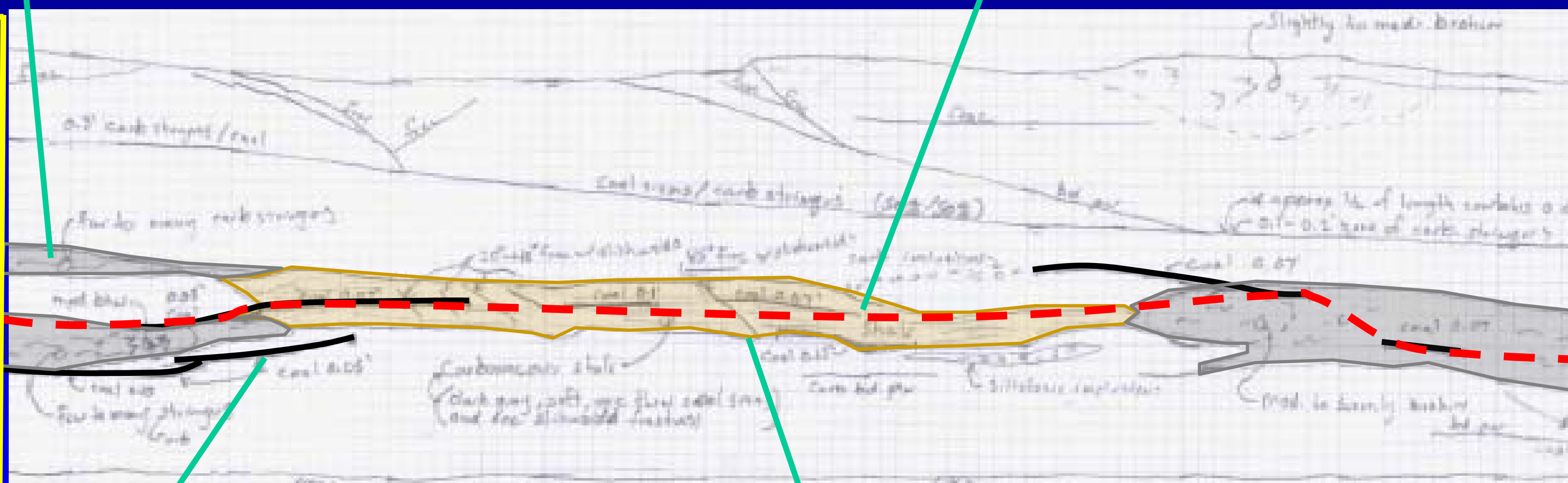
Marmet Lock Replacement – Deep Seated Sliding

Inspection Trench Sidewall - Map

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

Potential Sliding Failure Plane through various materials



540

530

3+28

3+40

3+50

3+60

3+70

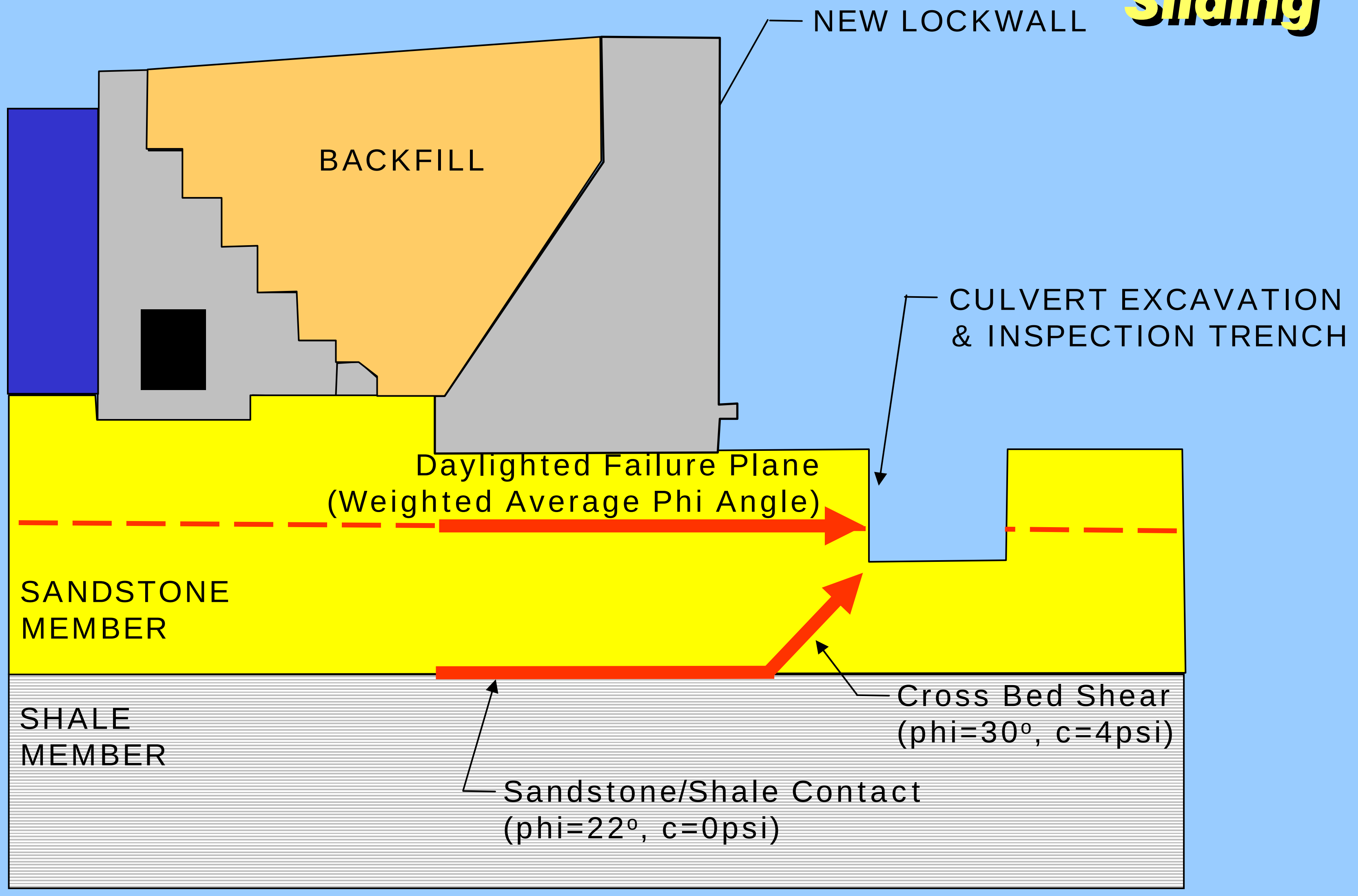
3+78

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

Thin Coal Seams (phi=23º, c=0psi)

New Chamber Lockwall Monoliths

Marmet Lock Replacement – Deep Seated Sliding



New Chamber Lockwall Monoliths

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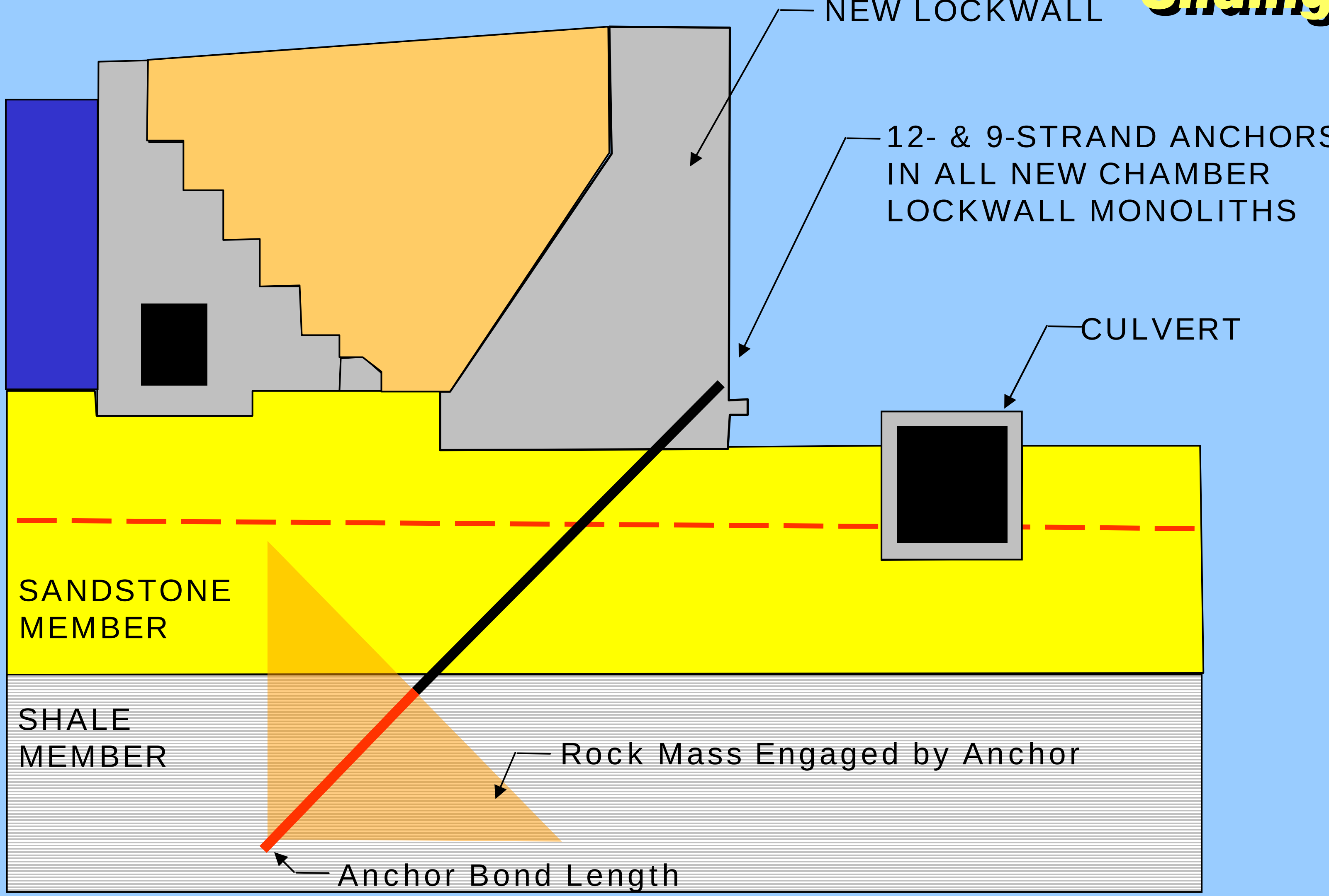

New Chamber Lockwall Monoliths

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Construction Sequence

COFFERDAM – ANCHORS – SOIL EXCAVATION

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Marmet Lock Replacement – Construction

Construction Sequence

SUBSURFACE EXPLORATION – ROCK EXCAVATION

Marmet Lock Replacement – Construction

Construction Sequence

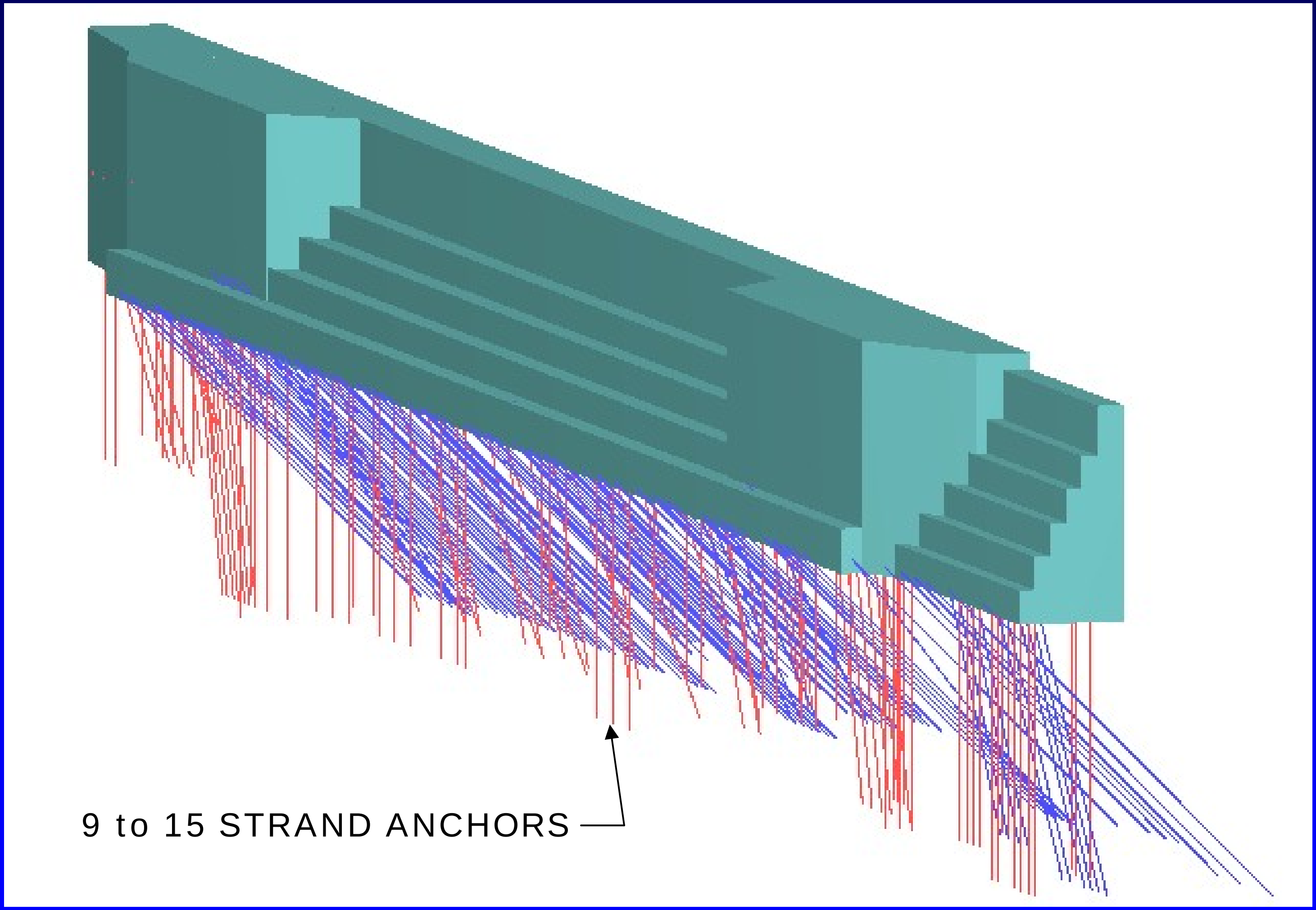
ROCK EXCAVATION – FOUNDATION PREPARATION

Construction Sequence

CONCRETE – FOUNDATION GROUTING

Marmet Lock Replacement – Construction

FOUNDATION ANCHORS



560 ANCHORS INSTALLED IN COFFERDAM

FOUNDATION ANCHORS

DOWN-THE-HOLE HAMMER

6 TO 10 INCH DIA. HOLES

DRILLING ANCHOR HOLES

FOUNDATION ANCHORS

Tropari

Maxibor

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

ANCHOR ALIGNMENT TESTING

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

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

ANCHOR TENSIONING AND TESTING

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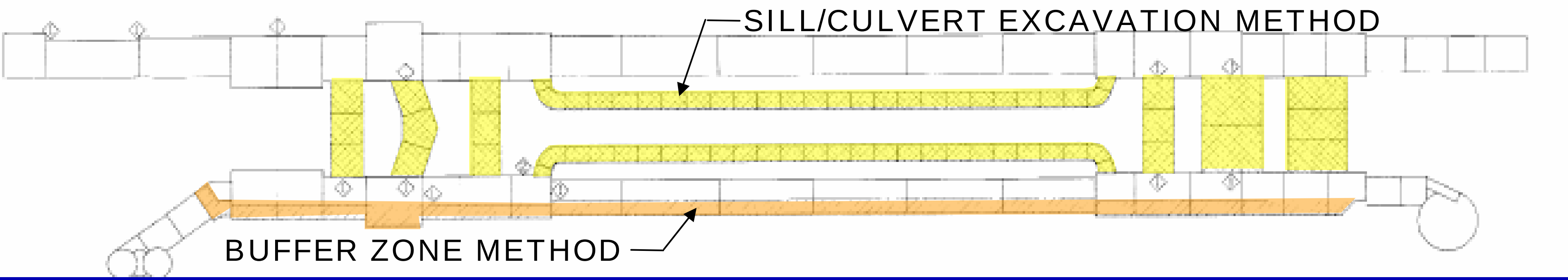
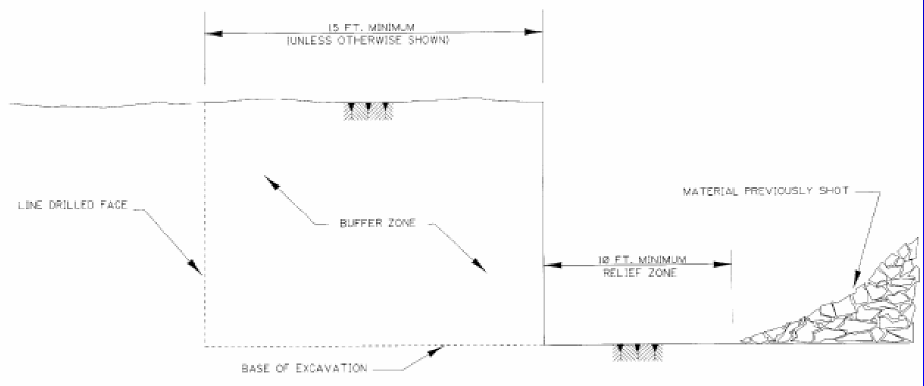
Marmet Lock Replacement – Construction

ROCK EXCAVATION





BUFFER ZONE DETAIL

NOT TO SCALE

- 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

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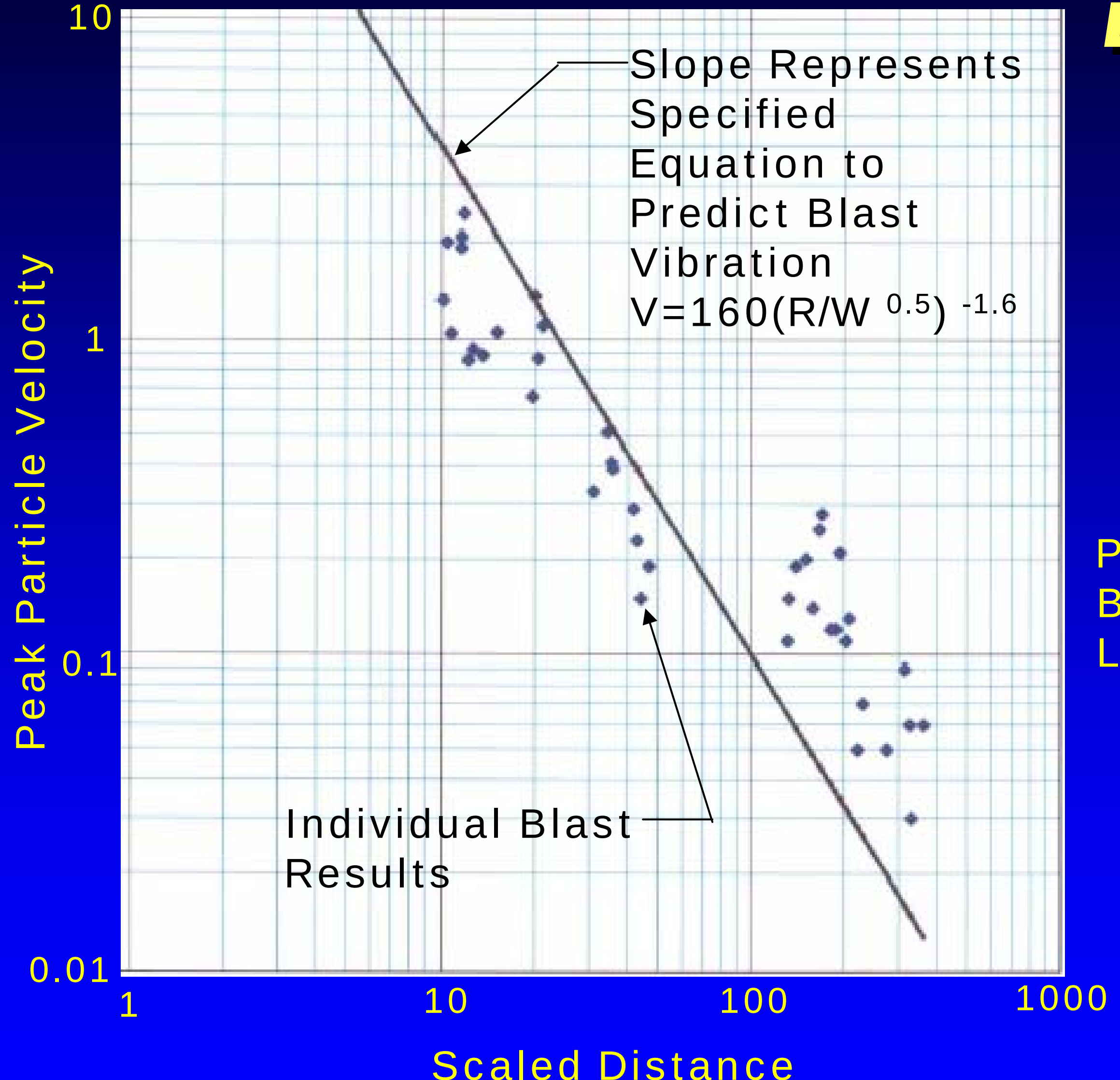
Huntington District

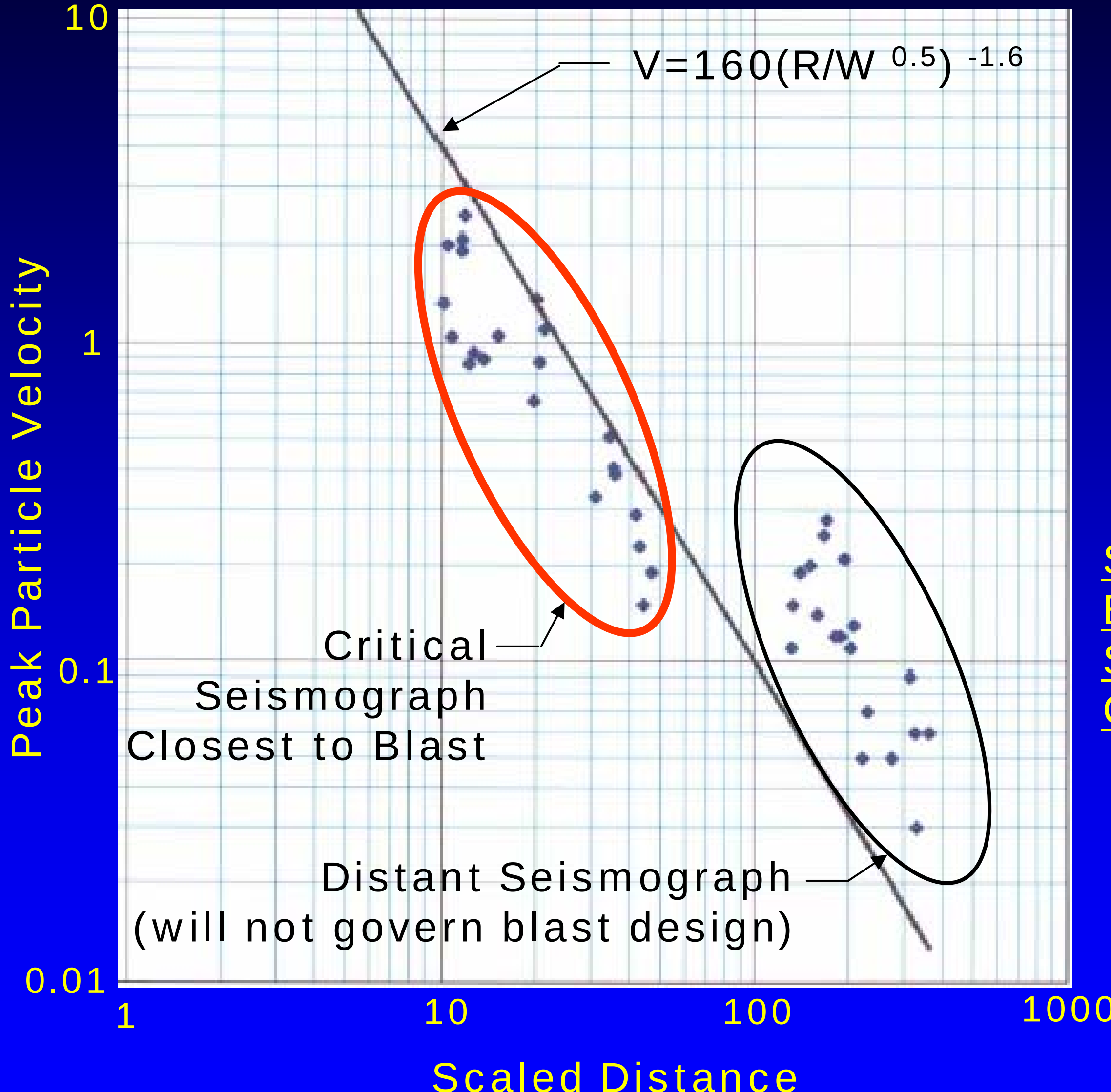
Marmet Lock Replacement – Rock Excavation



Plot Individual Blast Results on Log/Log Graph

Evaluating Specified Vibration Equation

Marmet Lock Replacement – Rock Excavation



Specified Equation is Suitable for Critical Blasts

Evaluating Specified Vibration Equation

FOUNDATION PREPARATION

OVER BREAK BEHIND LINE DRILLED FACE

FOUNDATION PREPARATION

SHOT HOLE DAMAGE

One Corps, One Regiment, One Team

US Army Corps of Engineers
Huntington District

Marmet Lock Replacement – Construction

FOUNDATION PREPARATION

CARBONACEOUS LAMINATIONS TREE FOSSILS

FOUNDATION PREPARATION

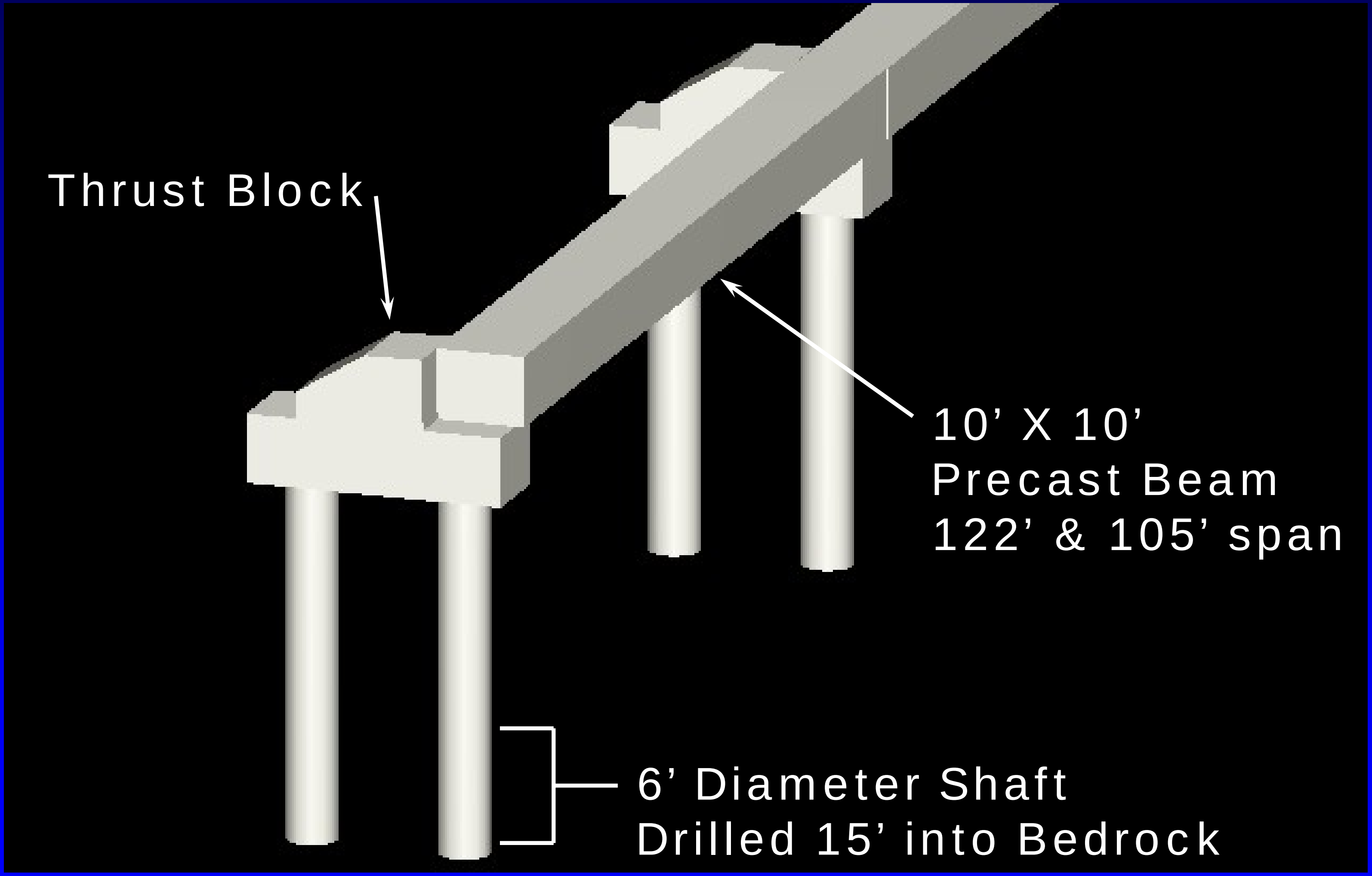
SHALE LENS AND SEAMS

FOUNDATION PREPARATION

JONTS WITH ARTESIAN GROUNDWATER FLOW

Marmet Lock Replacement – Construction

DRILLED SHAFT FOUNDATION



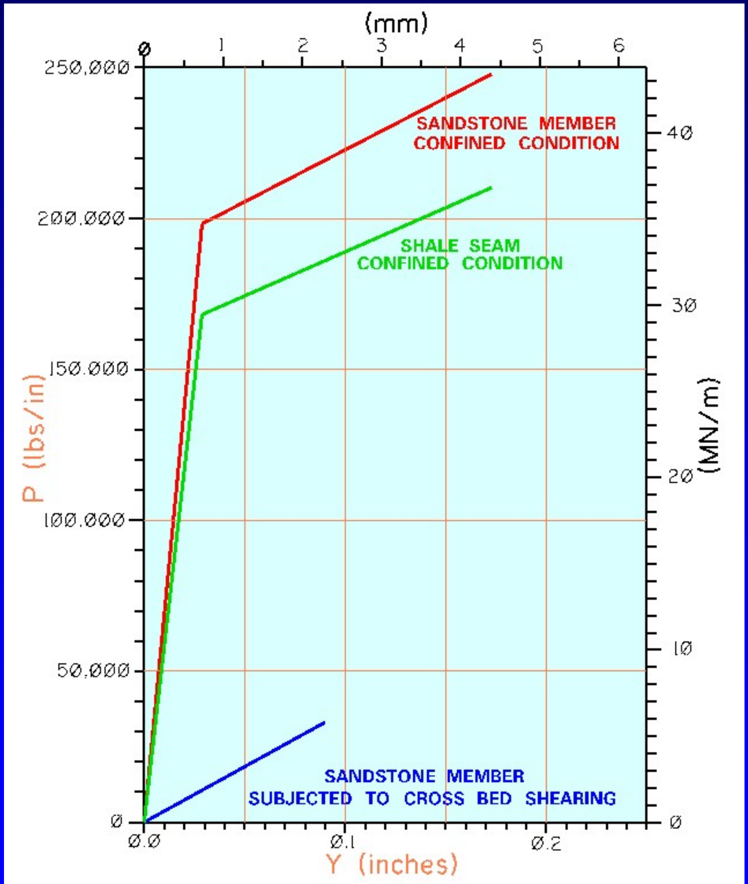
UPSTREAM APPROACH WALLS

One Corps, One Regiment, One Team

US Army Corps of Engineers
Huntington District

Marmet Lock Replacement – Construction

DRILLED SHAFT FOUNDATION



BOREHOLE JACK TESTING

Marmet Lock Replacement – Construction

DRILLED SHAFT FOUNDATION

DRILLING 6-FOOT DIAMETER SHAFT

Marmet Lock Replacement – Construction

DRILLED SHAFT FOUNDATION

INSTALLING REBAR CAGE & PLACING CONCRETE

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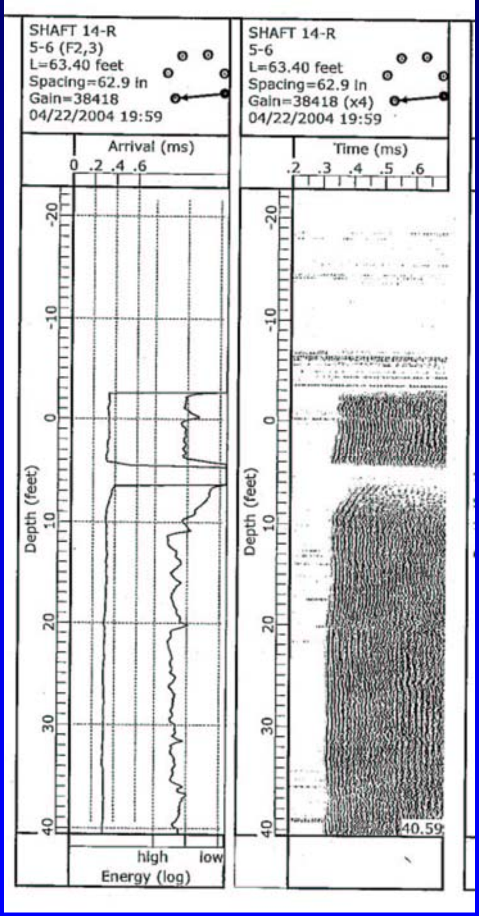
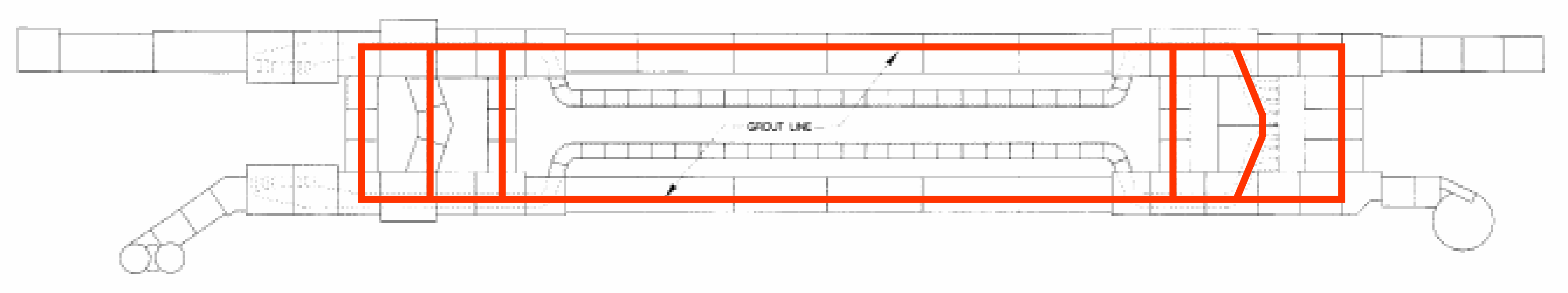
Marmet Lock Replacement – Construction

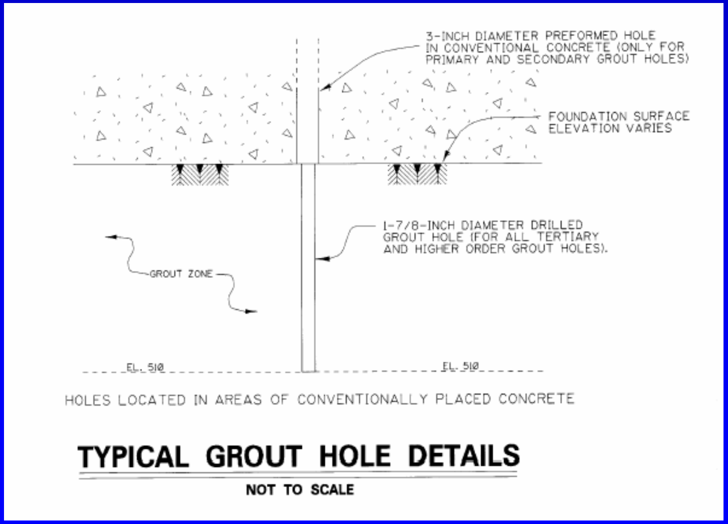
DRILLED SHAFT FOUNDATION



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

Marmet Lock Replacement – Construction

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Foundation Drilling and Grouting

Drilling Grout Holes

Grout Plant

Grout Header

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

Marmet Lock Replacement – Conclusion

QUESTIONS AND ANSWERS

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