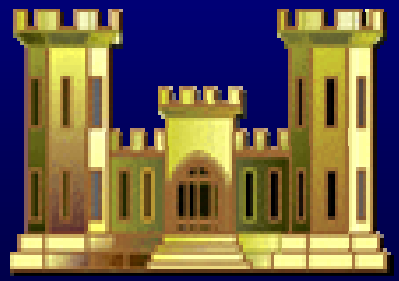
Mississinewa Dam Foundation Rehabilitation

Jeff Schaefer

Geotechnical Regional Technical Specialist

U.S. Army Corps of Engineers

Louisville District



US Army Corps of Engineers
Louisville District

CIVIL WORKS PROJECTS

VICINITY MAP

Constructed – Mid to Late 1960's

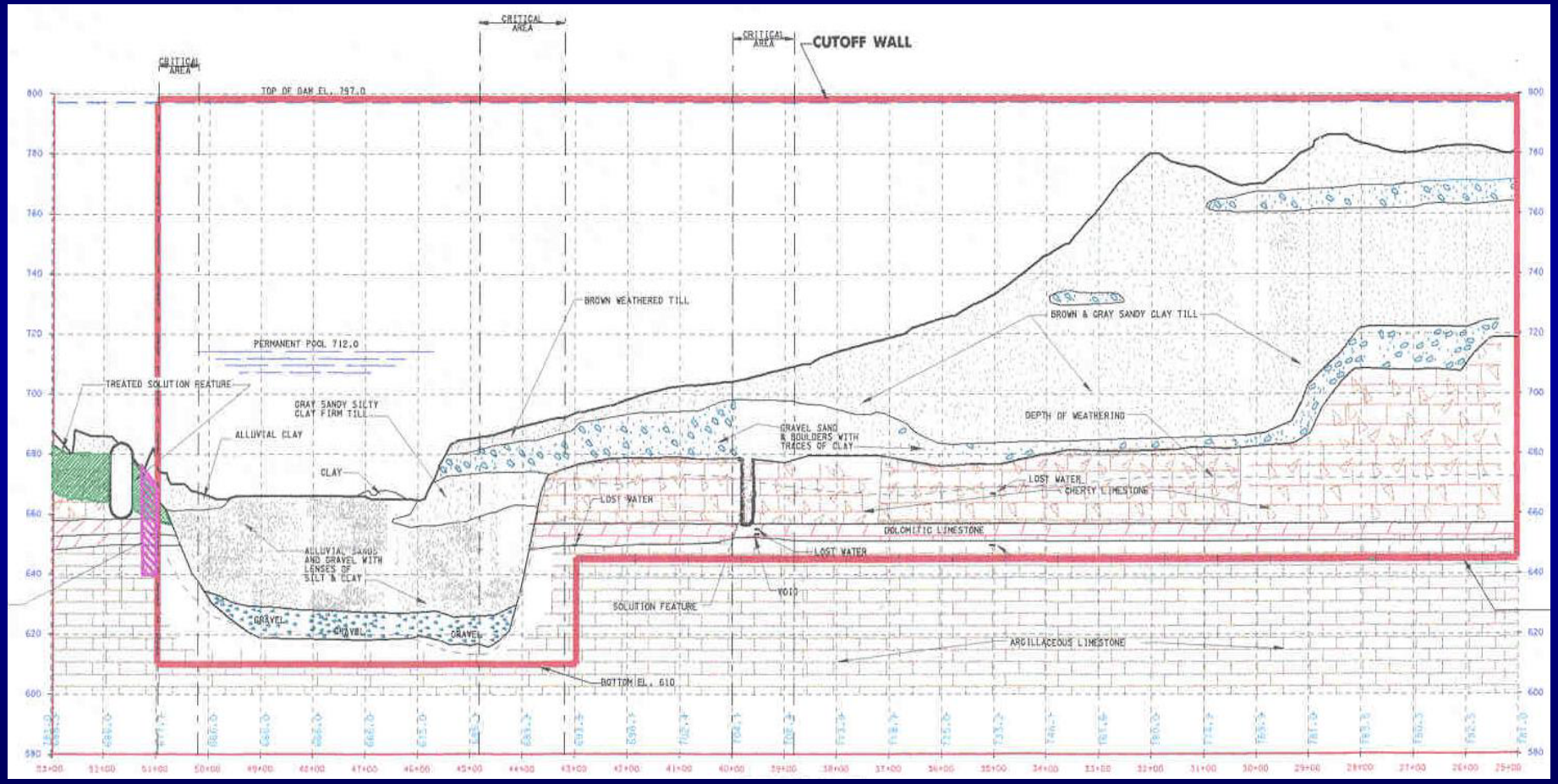
- Total length 8100 feet
- Total height 140 feet

Crest elevation 797

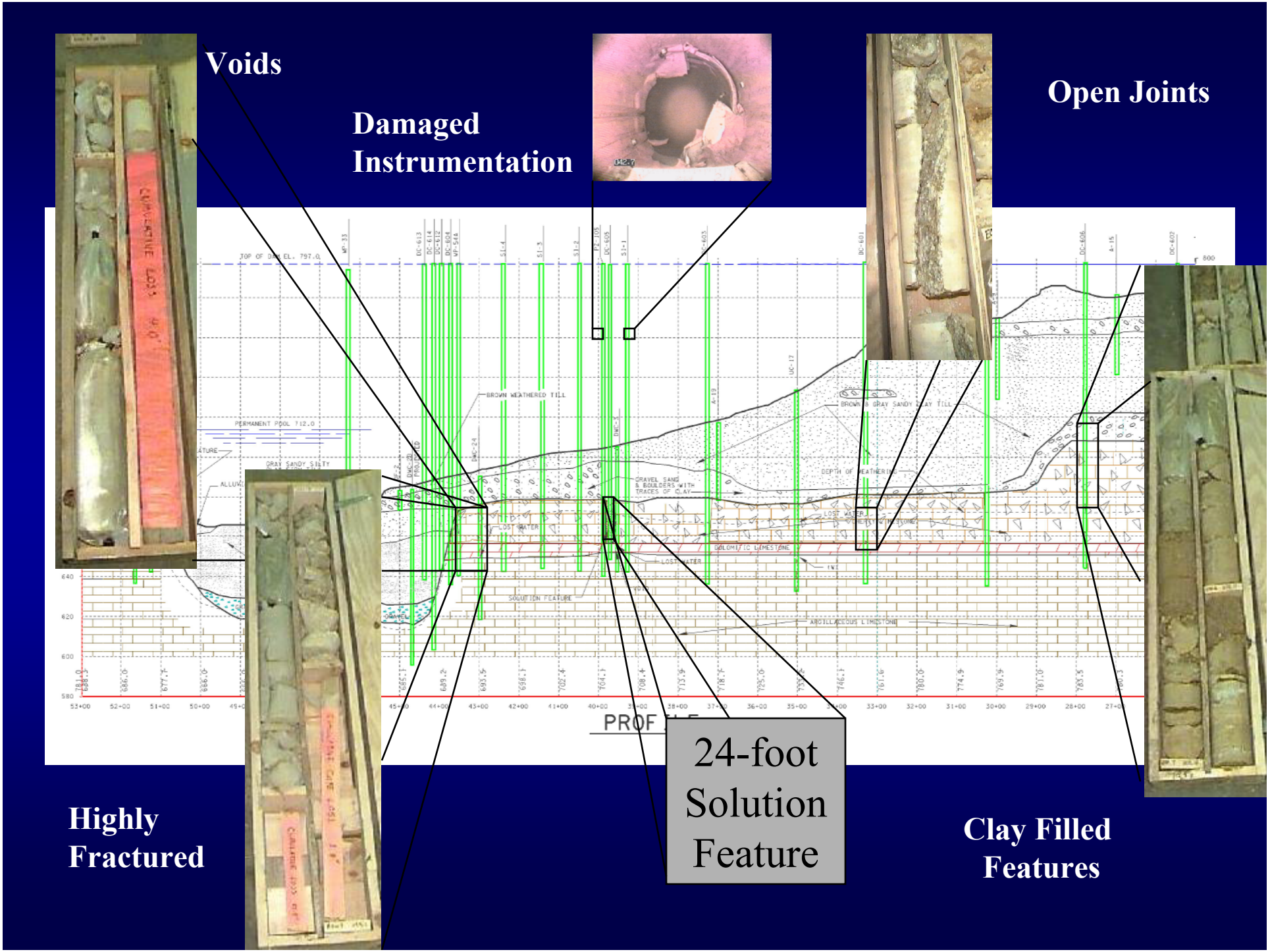
- Spillway elevation 779
- Summer Pool 737 *
- Winter Pool 712

Geology

Glacial Deposits:	10-70 feet	Silty clay overlying sands and gravels
Liston Creek Fm:	0-70 feet	Thinly bedded, cherty, crystalline limestone prone to solutioning.
Mississinewa Fm:	> 30 feet	Thinly bedded argillaceous limestone



Typical geologic cross-section along the dam centerline.


Voids
Damaged Instrumentation
Open Joints
Highly Fractured
24-foot Solution Feature
Clay Filled Features
BROWN WEATHERED TILL
BROWN & GRAY SANDY CLAY TILL
GRAVEL SAND & BOULDERS WITH TRACES OF CLAY
DOLOMITIC LIMESTONE
ARGILLACEOUS LIMESTONE
SOLUTION FEATURE
PERMANENT POOL 712.0
LOST WATER

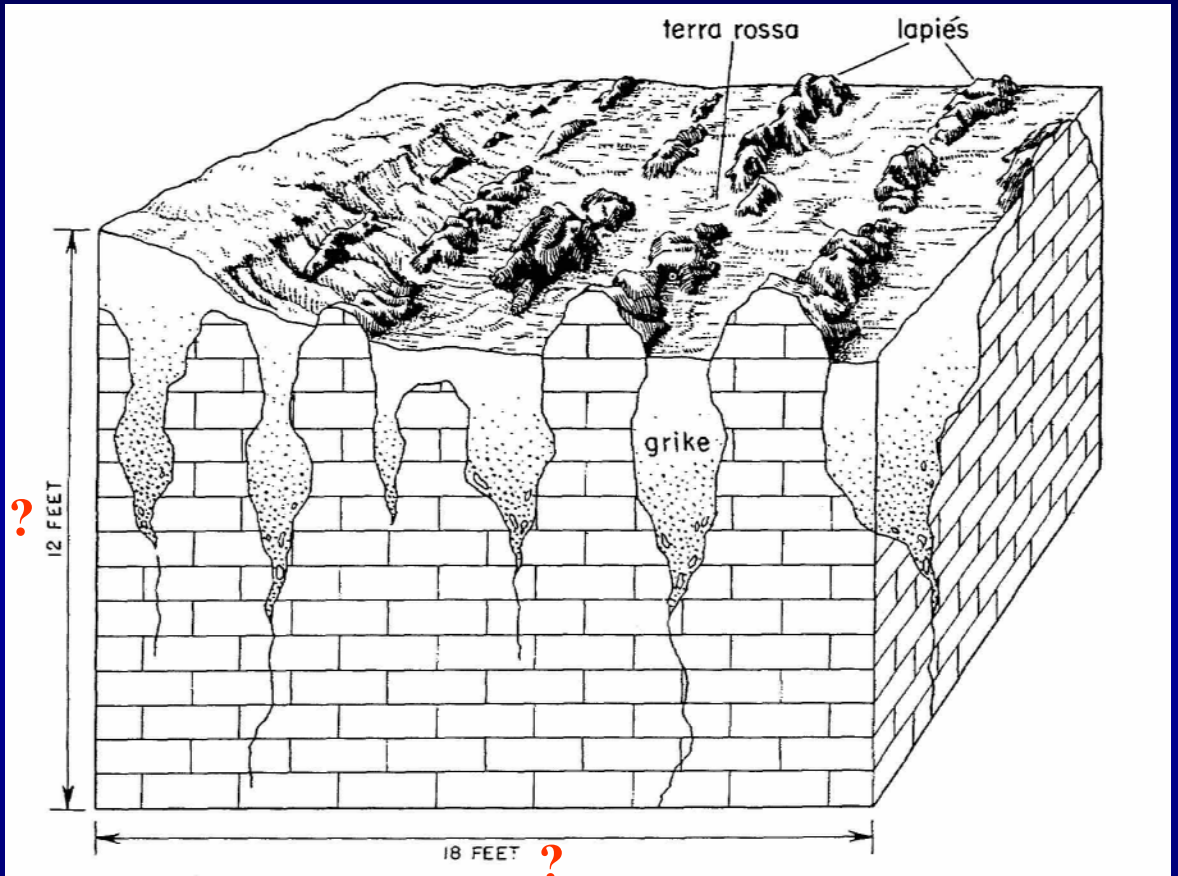
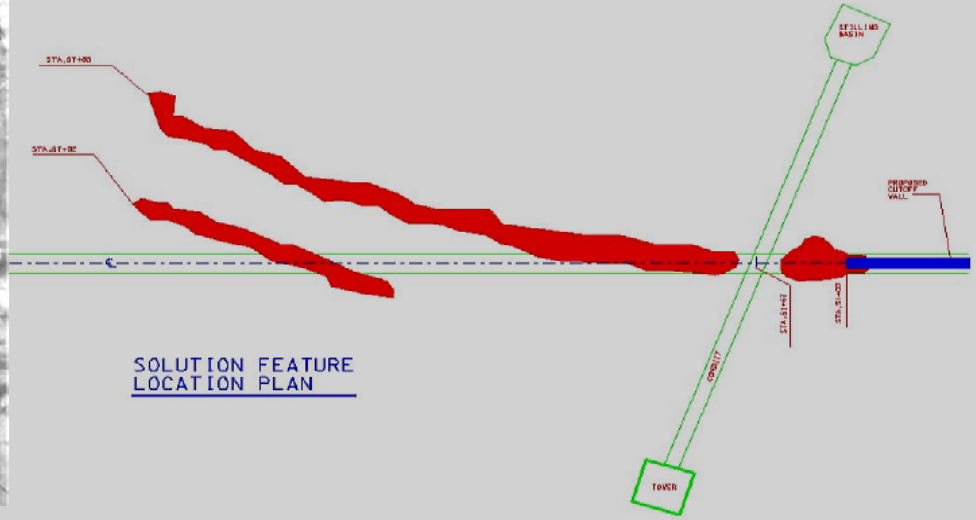


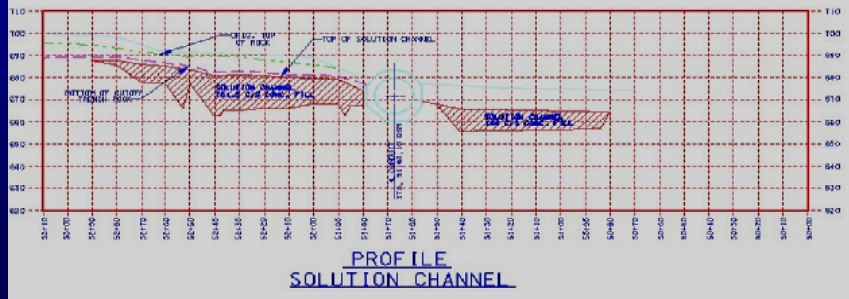
Figure 3.--Block diagram showing the structure of lapies and grikes.

Adapted From Indiana Geological Survey,
Caves of Indiana by Richard L. Powell

Solution feature on left abutment side of conduit excavation

View of solution channel, located at dam station 51+00, on left abutment side of conduit excavation.

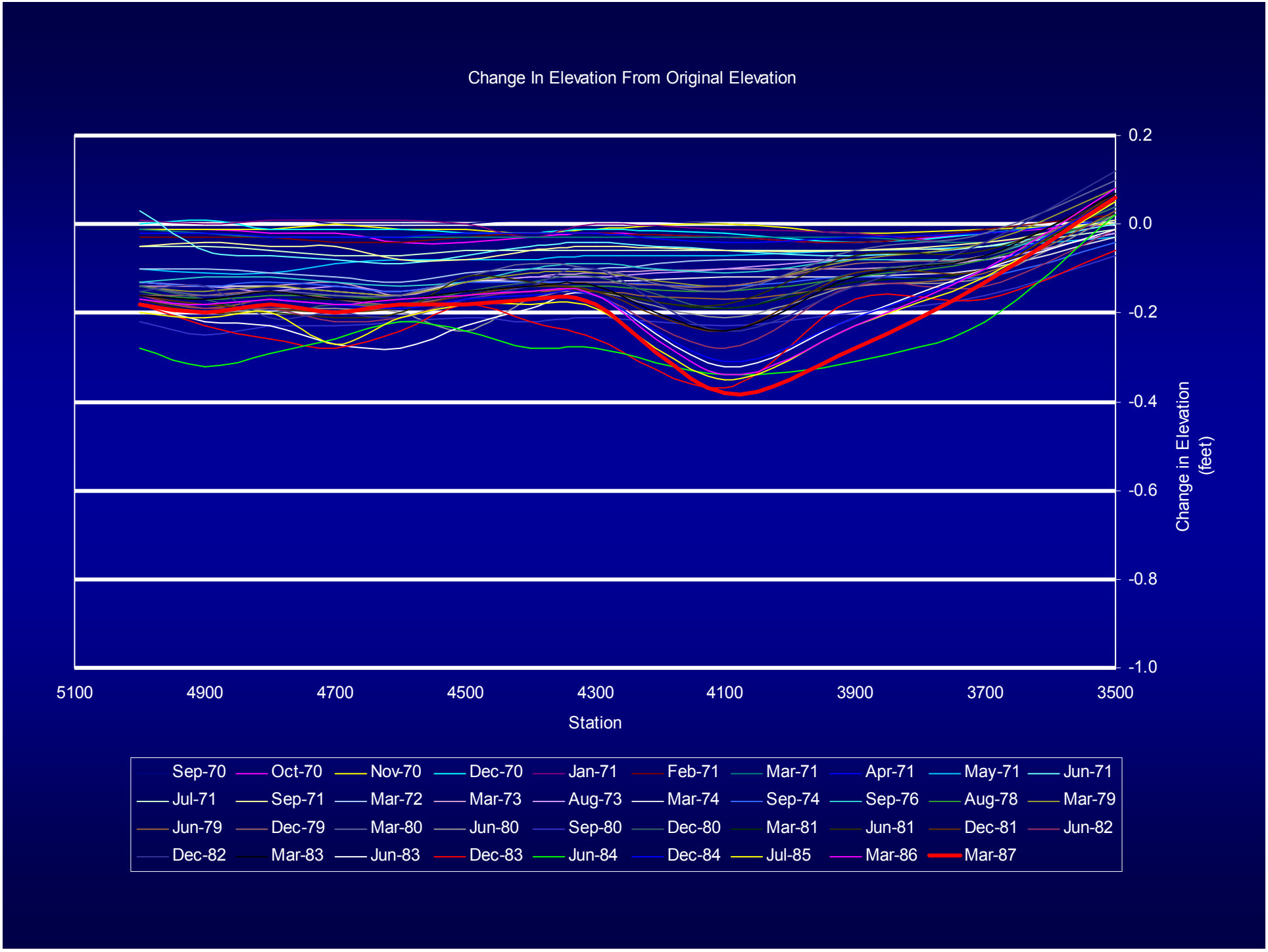

SOLUTION FEATURE
LOCATION PLAN

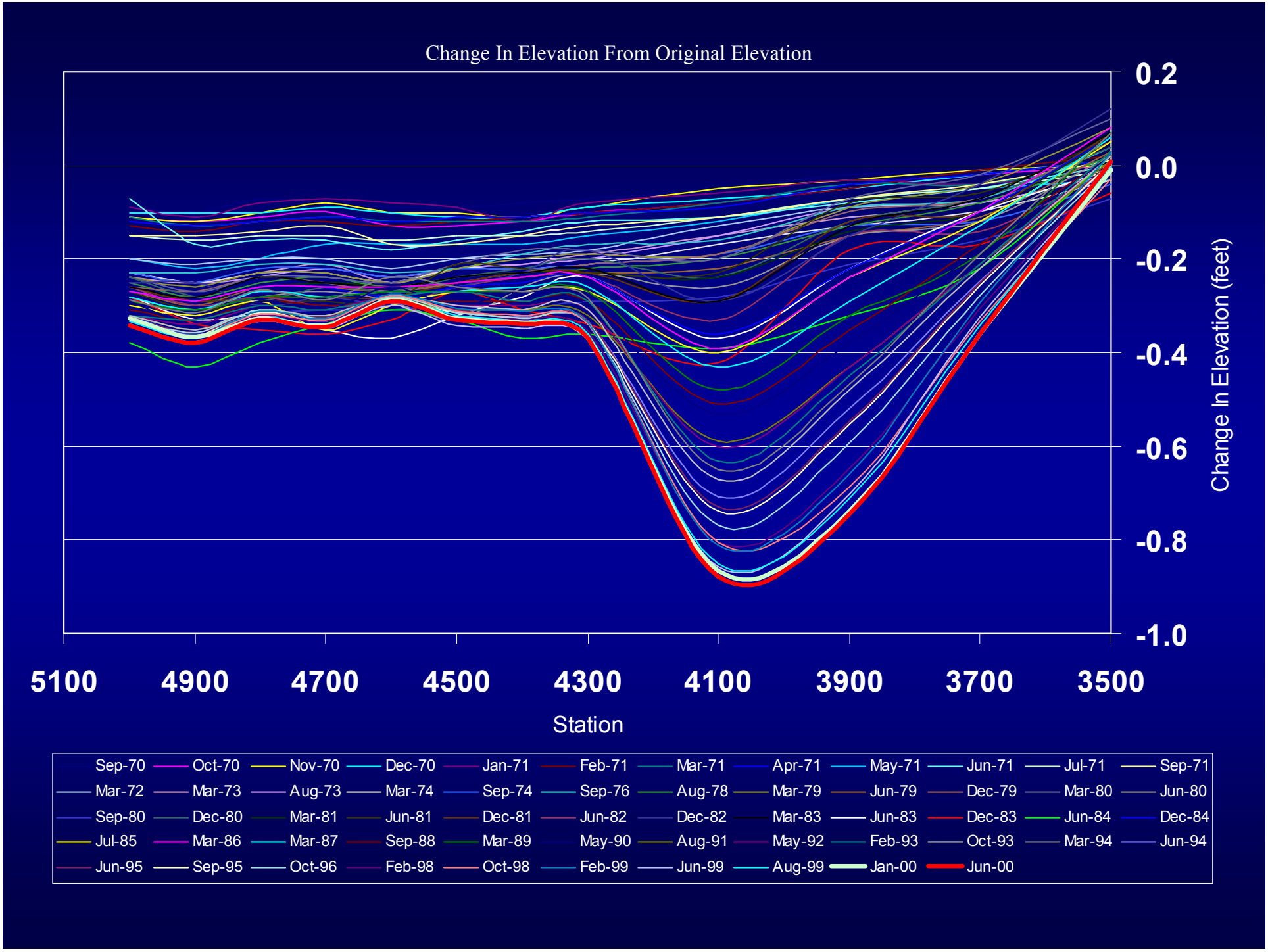

PROFILE
SOLUTION CHANNEL

Features of Interest for the Mississinewa Dam Project

1988

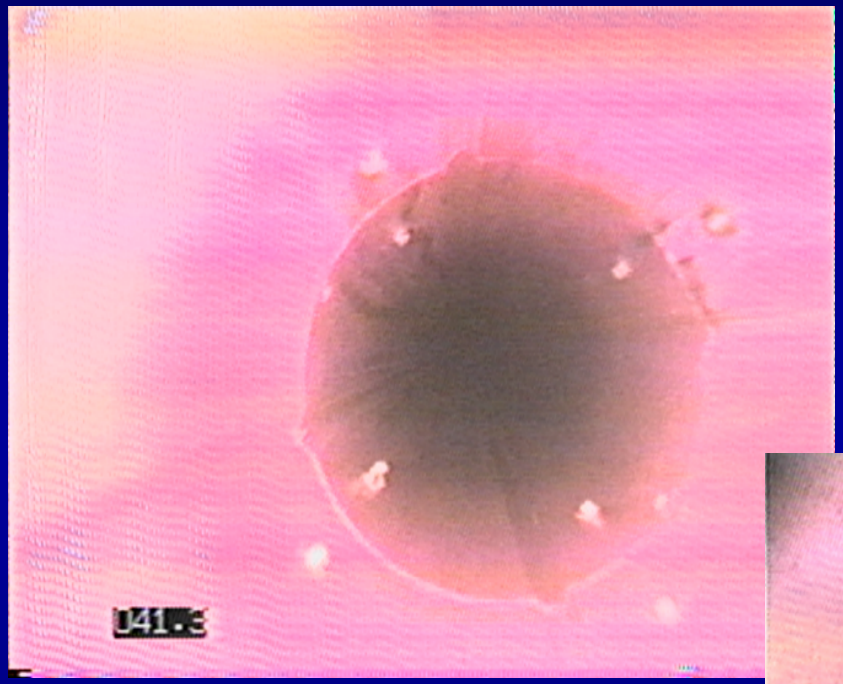
Operations Personnel Identify Guardrail Deflections


Change In Elevation From Original Elevation
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
Change in Elevation (feet)
5100
4900
4700
4500
4300
4100
3900
3700
3500
Station
Sep-70
Oct-70
Nov-70
Dec-70
Jan-71
Feb-71
Mar-71
Apr-71
May-71
Jun-71
Jul-71
Sep-71
Mar-72
Mar-73
Aug-73
Mar-74
Sep-74
Sep-76
Aug-78
Mar-79
Jun-79
Dec-79
Mar-80
Jun-80
Sep-80
Dec-80
Mar-81
Jun-81
Dec-81
Jun-82
Dec-82
Mar-83
Jun-83
Dec-83
Jun-84
Dec-84
Jul-85
Mar-86
Mar-87

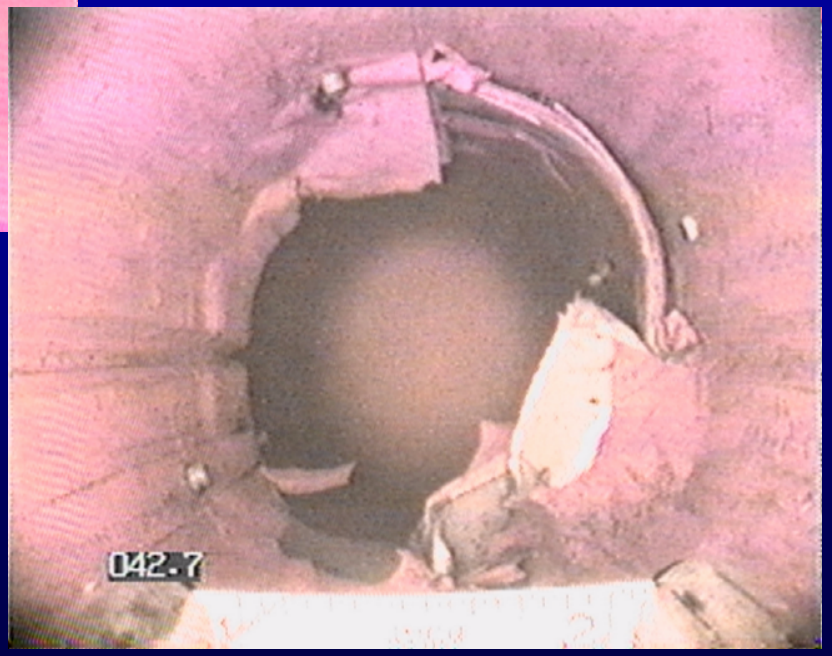

Change In Elevation From Original Elevation
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
Change In Elevation (feet)
5100
4900
4700
4500
4300
4100
3900
3700
3500
Station
Sep-70
Oct-70
Nov-70
Dec-70
Jan-71
Feb-71
Mar-71
Apr-71
May-71
Jun-71
Jul-71
Sep-71
Mar-72
Mar-73
Aug-73
Mar-74
Sep-74
Sep-76
Aug-78
Mar-79
Jun-79
Dec-79
Mar-80
Jun-80
Sep-80
Dec-80
Mar-81
Jun-81
Dec-81
Jun-82
Dec-82
Mar-83
Jun-83
Dec-83
Jun-84
Dec-84
Jul-85
Mar-86
Mar-87
Sep-88
Mar-89
May-90
Aug-91
May-92
Feb-93
Oct-93
Mar-94
Jun-94
Jun-95
Sep-95
Oct-96
Feb-98
Oct-98
Feb-99
Jun-99
Aug-99
Jan-00
Jun-00

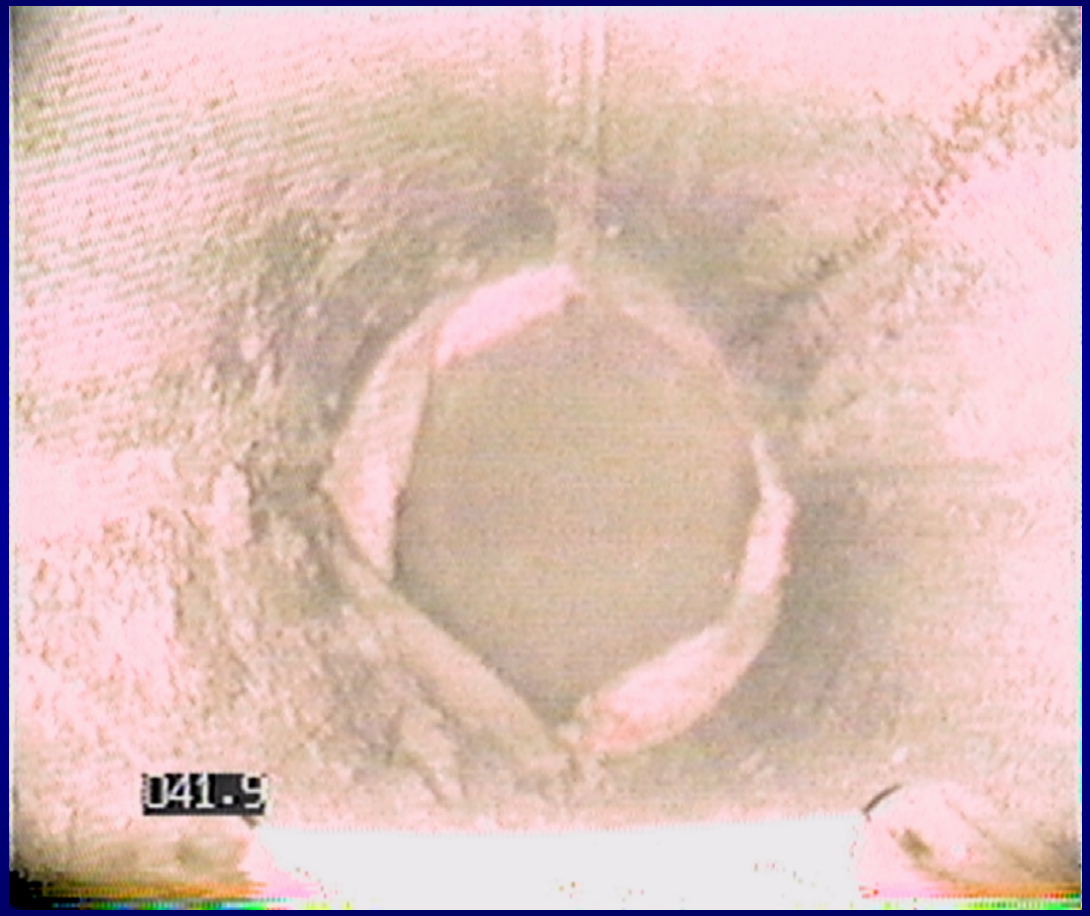
SI-1 (station 40+25), approximately elevation 758

View in May 1995



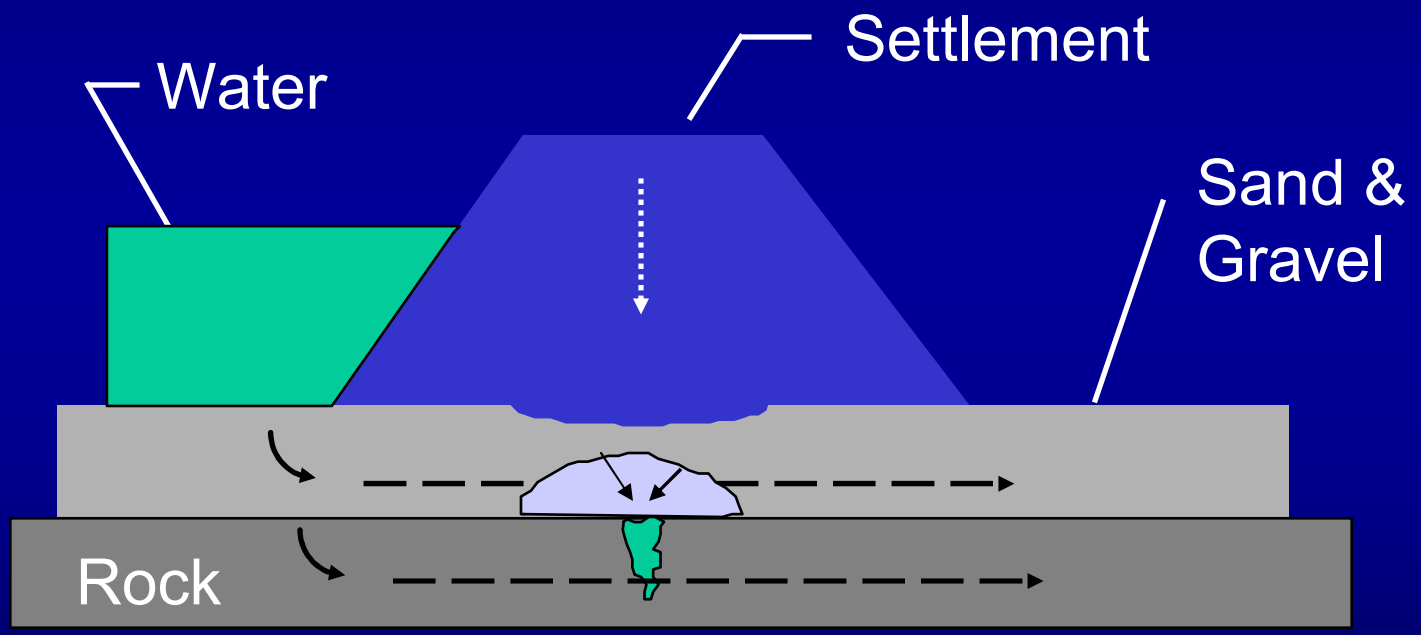
View in June 1999





June 1999 view of SI-2 (station 40+25) at approximately elevation 758

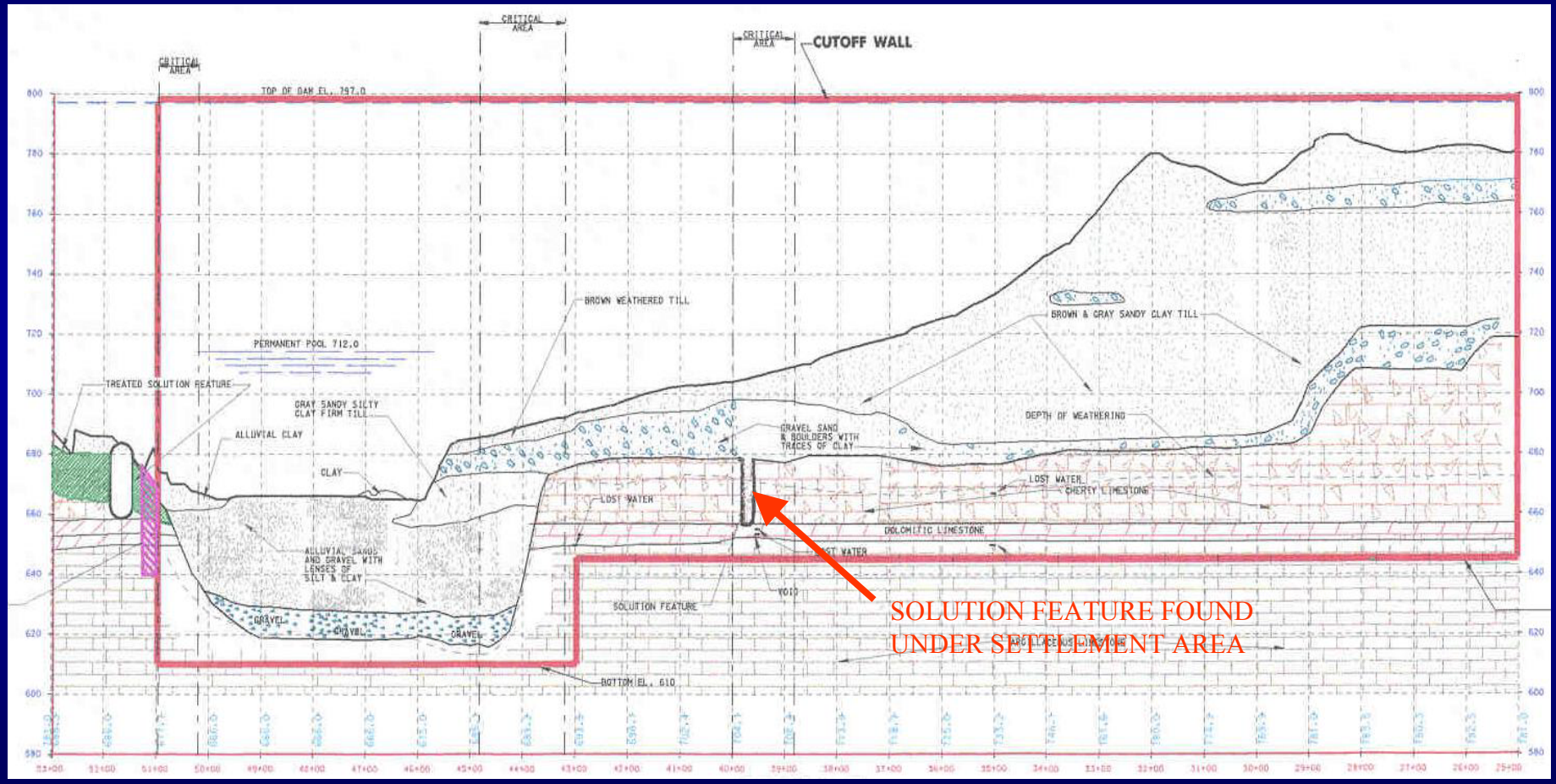
Settlement Mechanism
Foundation Piping



Not To Scale

Cut-off Wall

A cut-off wall was selected as the only practical and certain method of repairing the foundation for the dam. The cutoff wall would extend to depths of 180 feet and up to 80' into rock.



Typical geologic cross-section along the dam centerline.

Construction Contract

RFP Performance Specification

Requirements Specified & Methods Restricted

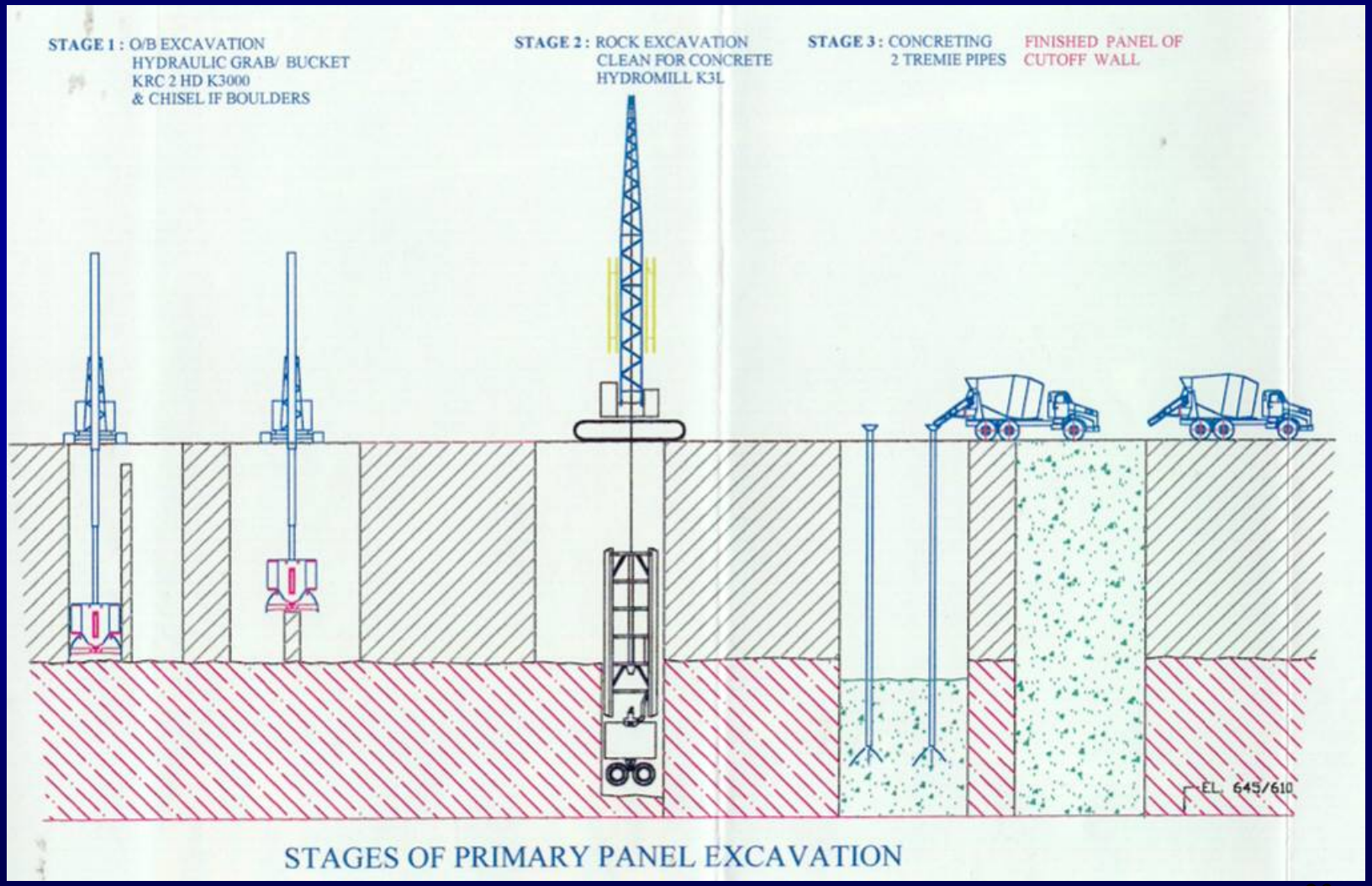
Methods Selected by Contractor

Technical Factors More Important Than Price

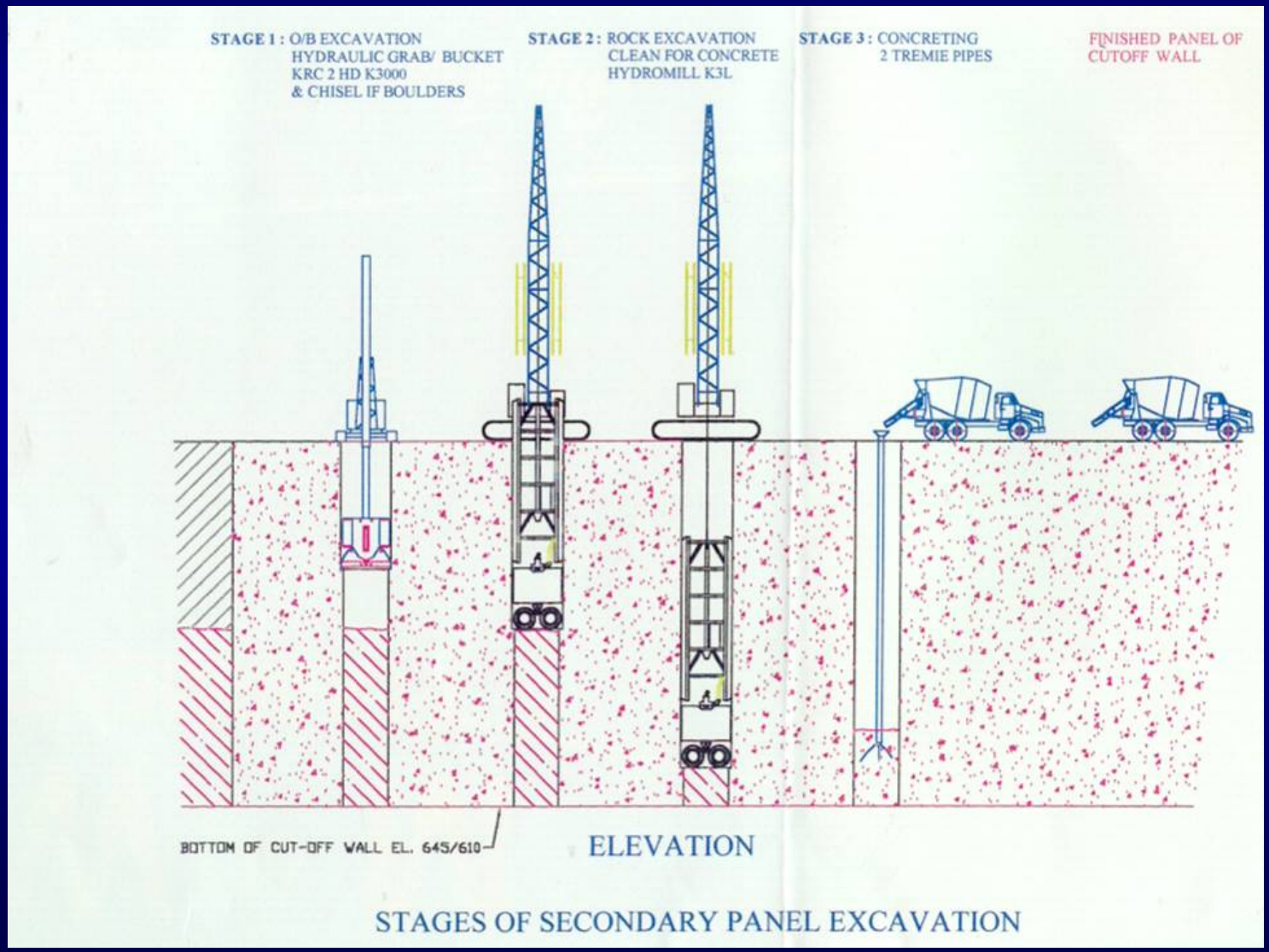
Contract Award

All 3 Proposed Clamshell/ Hydrofraise Backup Method – Chisel Supplement

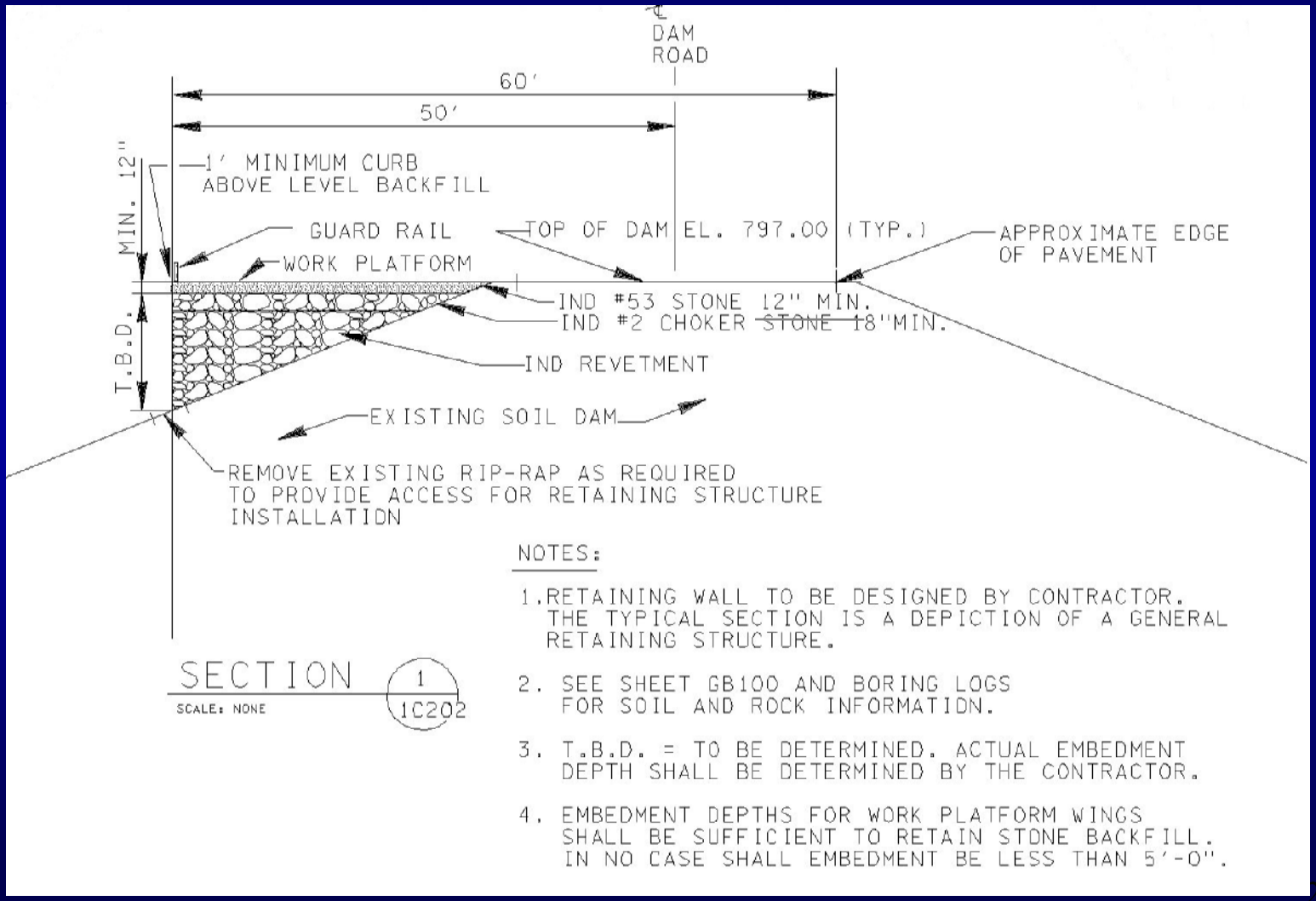
Award to Bencor/Petrifond JV for $29,800,000 September 2000



STAGES OF PRIMARY PANEL EXCAVATION

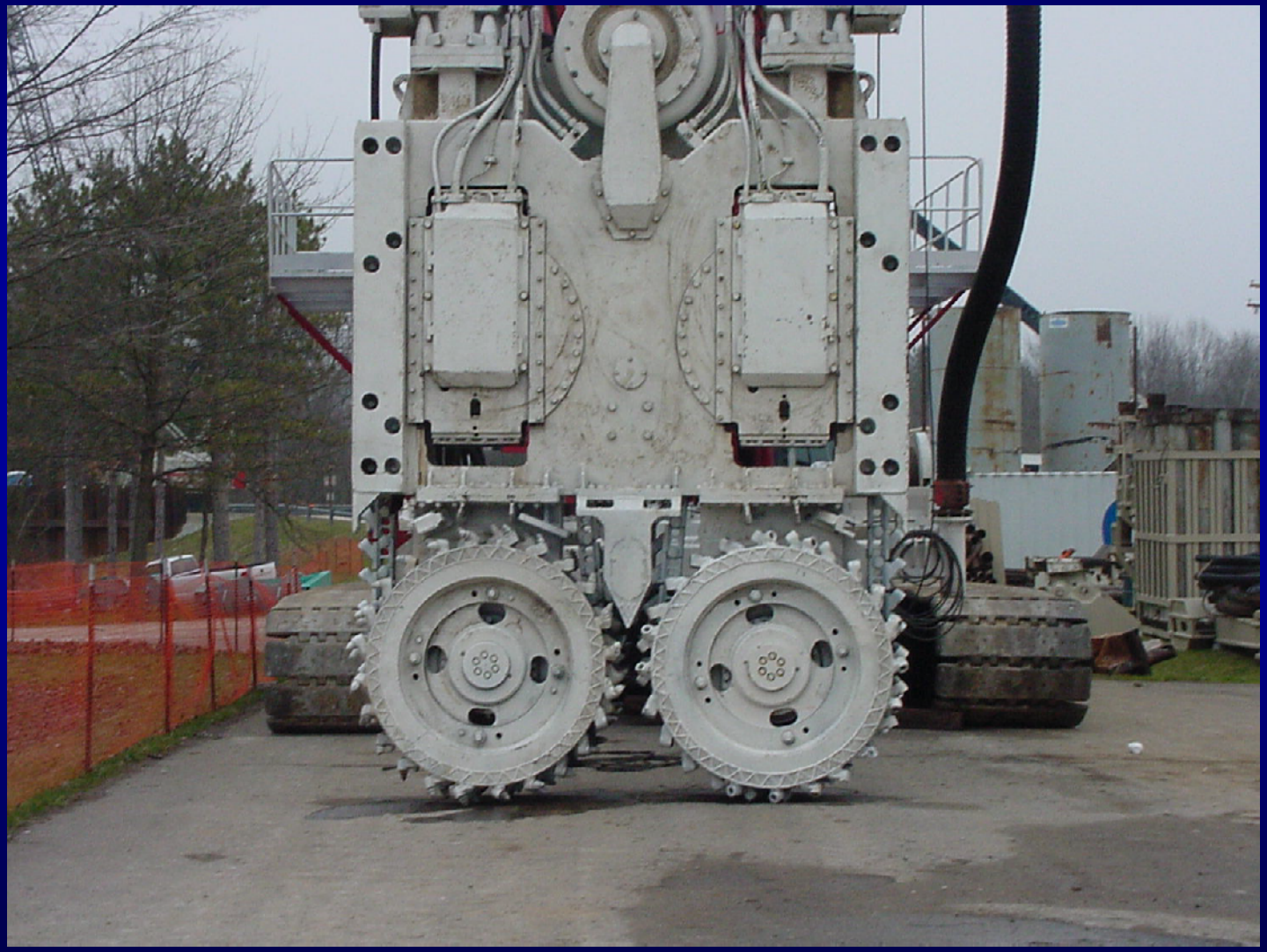

STAGE 1 : O/B EXCAVATION
HYDRAULIC GRAB/ BUCKET
KRC 2 HD K3000
& CHISEL IF BOULDERS
STAGE 2 : ROCK EXCAVATION
CLEAN FOR CONCRETE
HYDROMILL K3L
STAGE 3 : CONCRETING
2 TREMIE PIPES
FINISHED PANEL OF
CUTOFF WALL
BOTTOM OF CUT-OFF WALL EL. 645/610
ELEVATION
STAGES OF SECONDARY PANEL EXCAVATION

Site Map Showing Major Areas of Interest

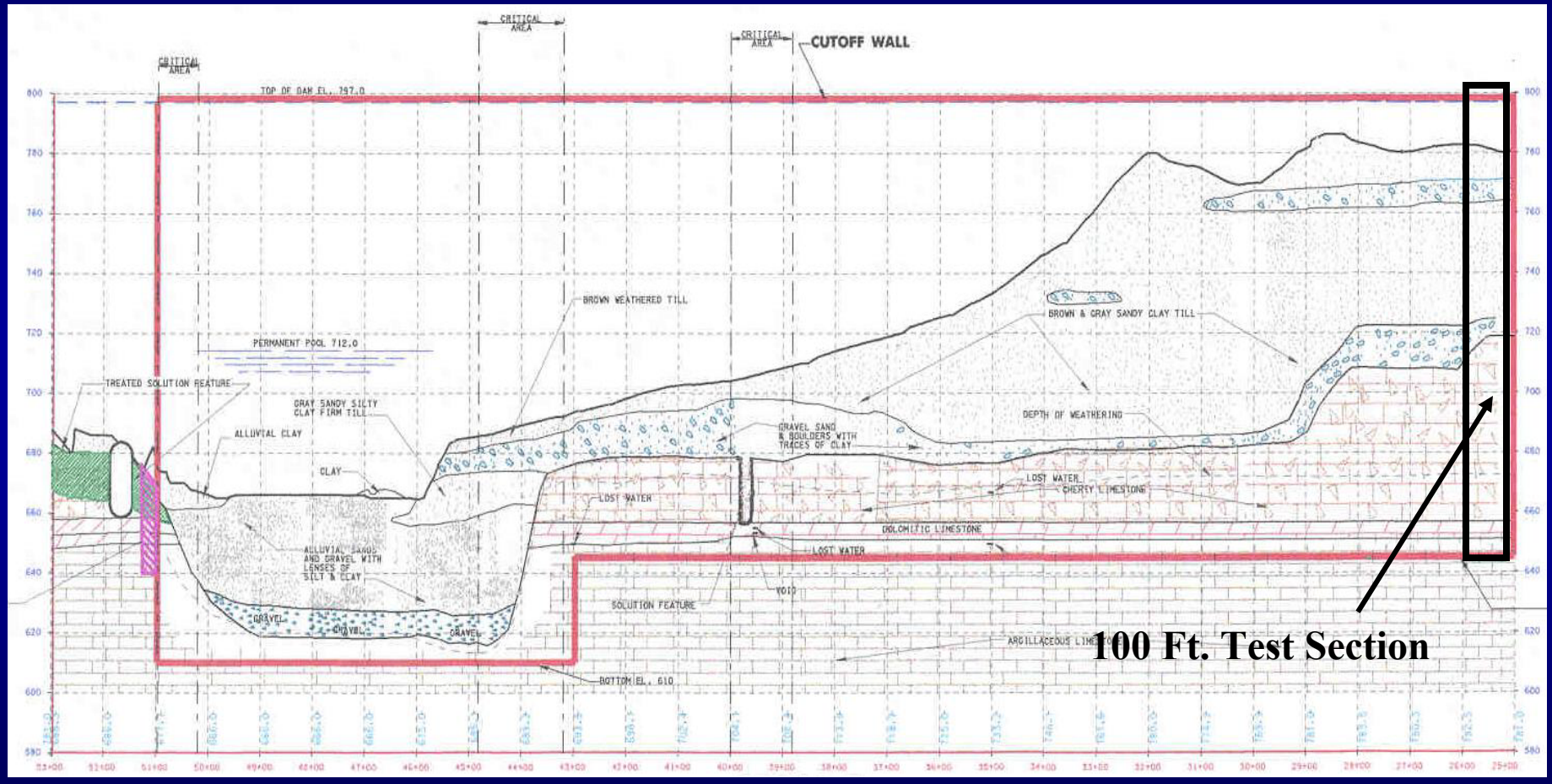

℄
DAM
ROAD
60'
50'
MIN. 12"
1' MINIMUM CURB
ABOVE LEVEL BACKFILL
GUARD RAIL
TOP OF DAM EL. 797.00 (TYP.)
APPROXIMATE EDGE
OF PAVEMENT
WORK PLATFORM
IND #53 STONE 12" MIN.
IND #2 CHOKER STONE 18"MIN.
T.B.D.
IND REVETMENT
EXISTING SOIL DAM
REMOVE EXISTING RIP-RAP AS REQUIRED
TO PROVIDE ACCESS FOR RETAINING STRUCTURE
INSTALLATION
SECTION
1
1C202
SCALE: NONE
NOTES:
1.RETAINING WALL TO BE DESIGNED BY CONTRACTOR.
THE TYPICAL SECTION IS A DEPICTION OF A GENERAL
RETAINING STRUCTURE.
2. SEE SHEET GB100 AND BORING LOGS
FOR SOIL AND ROCK INFORMATION.
3. T.B.D. = TO BE DETERMINED. ACTUAL EMBEDMENT
DEPTH SHALL BE DETERMINED BY THE CONTRACTOR.
4. EMBEDMENT DEPTHS FOR WORK PLATFORM WINGS
SHALL BE SUFFICIENT TO RETAIN STONE BACKFILL.
IN NO CASE SHALL EMBEDMENT BE LESS THAN 5'-0".


TL 50

Cable-Clam Bucket



Test Section



Typical geologic cross-section along the dam centerline.

Test Section

Attempts to Excavate Rock in Test Section Resulted in Sudden Complete Slurry Loss

Test Section

Change To Construction Approach

Pregrouting Required to Enable Cutoff Wall Construction

RFP type selection of the Grouting Subcontractor (ACT)

Grouting ITR by Dr. Donald Bruce

Rotosonic Drill Rig

Sample Extrusion

Rotosonic Samples

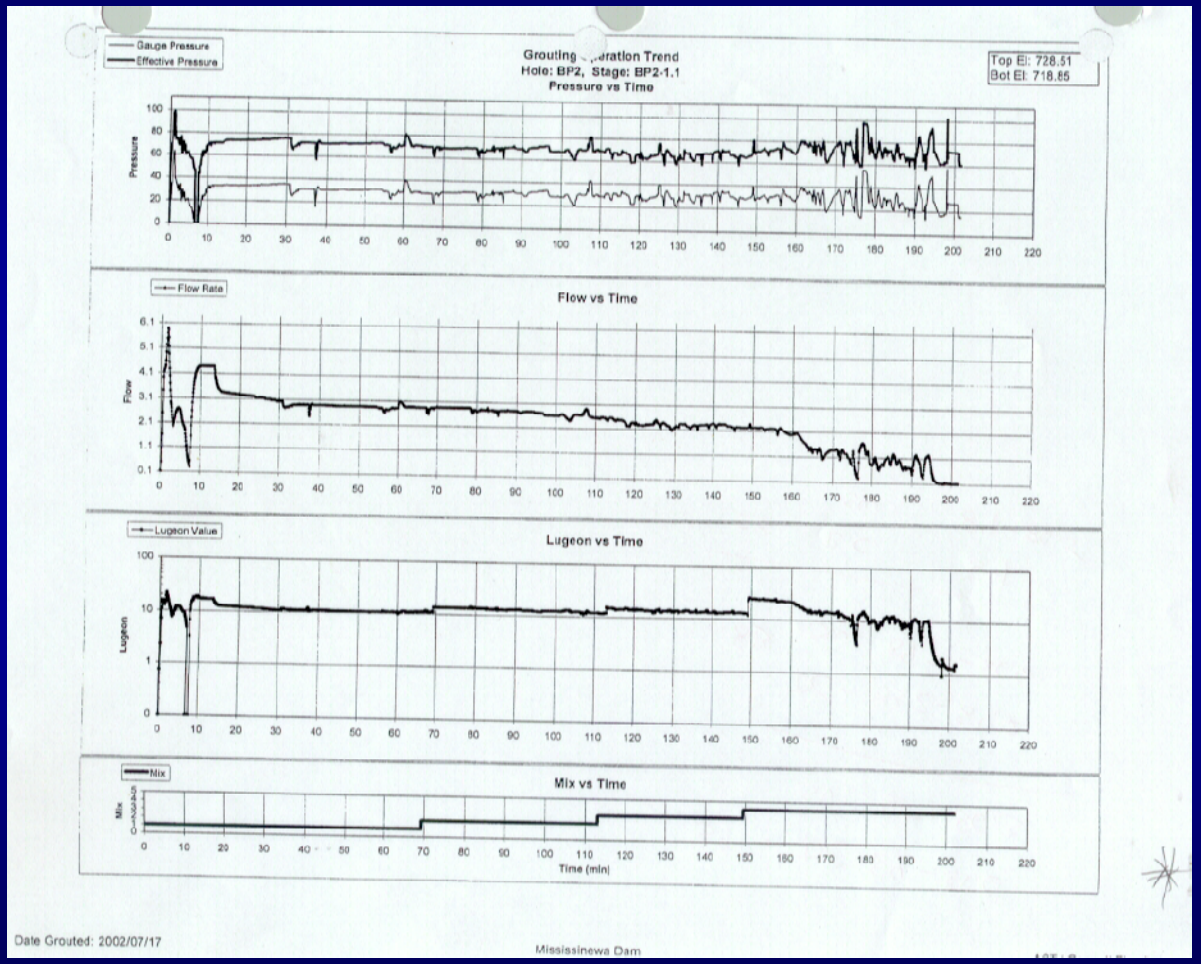
Rock Drill

Two High Speed/High Volume Grout Plants

Grout Header Controls

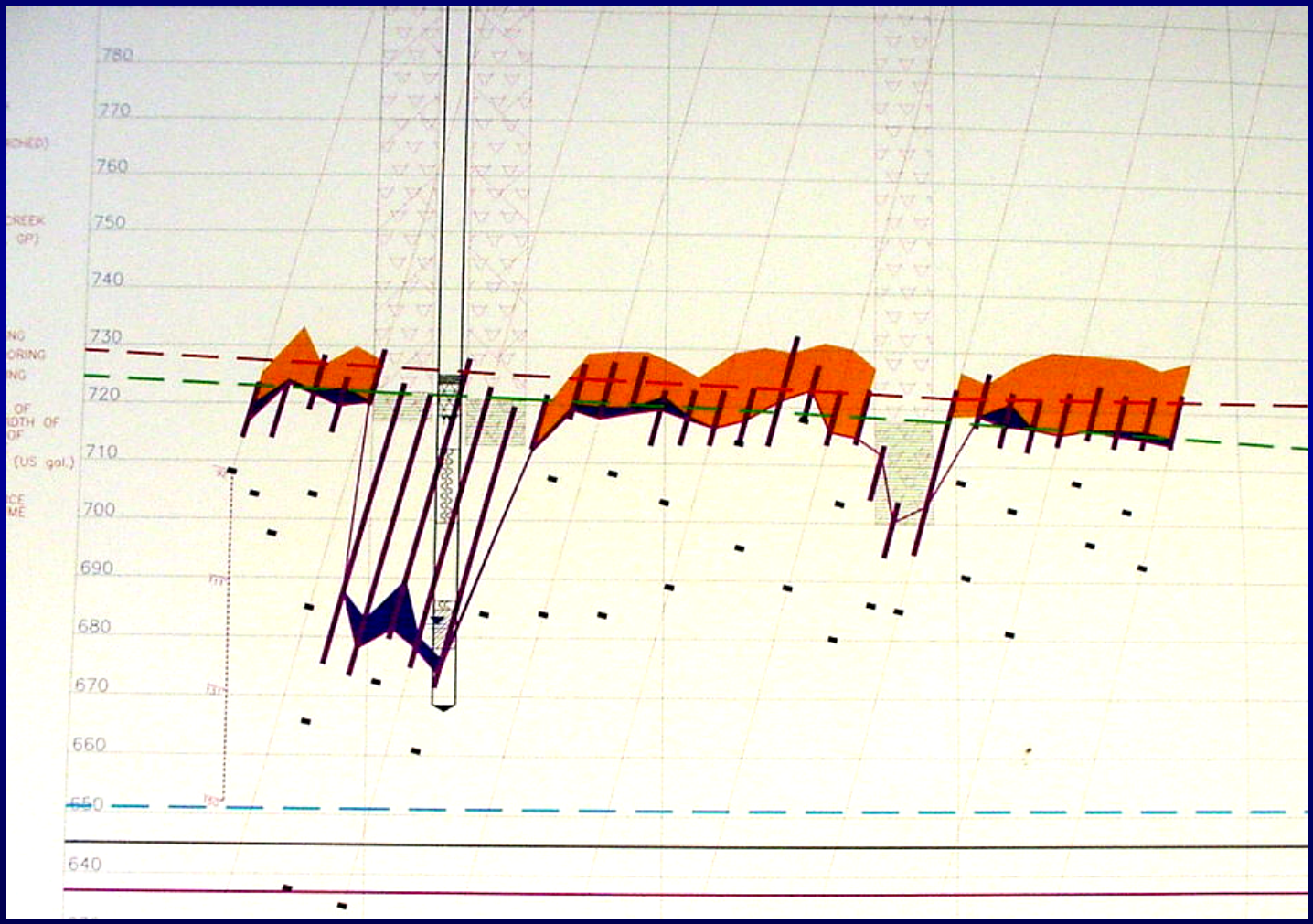
IntelliGrout

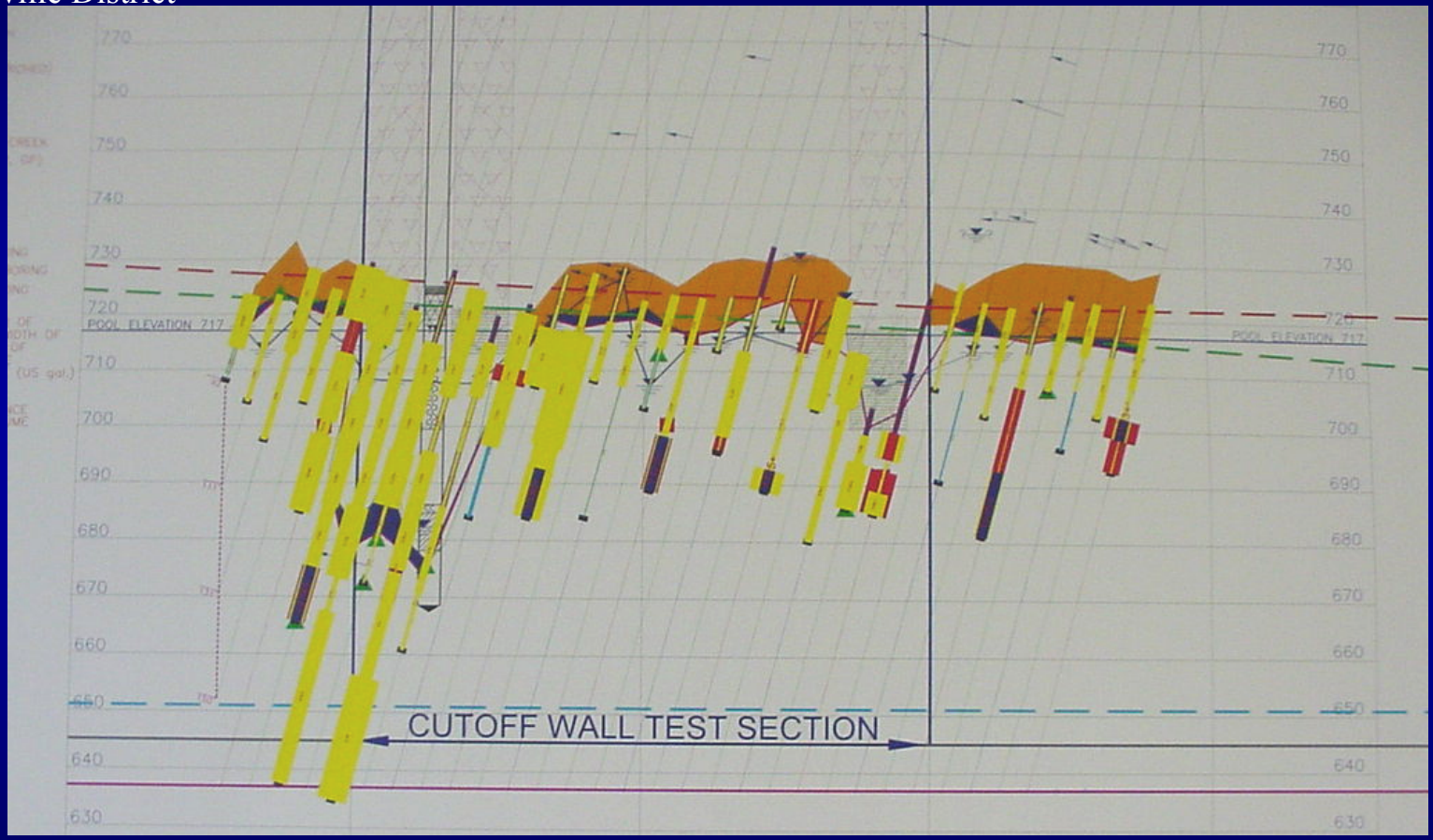
IntelliGrout Operator's Station



Typical Void Refusal, Refined "D Mix"

Test Section



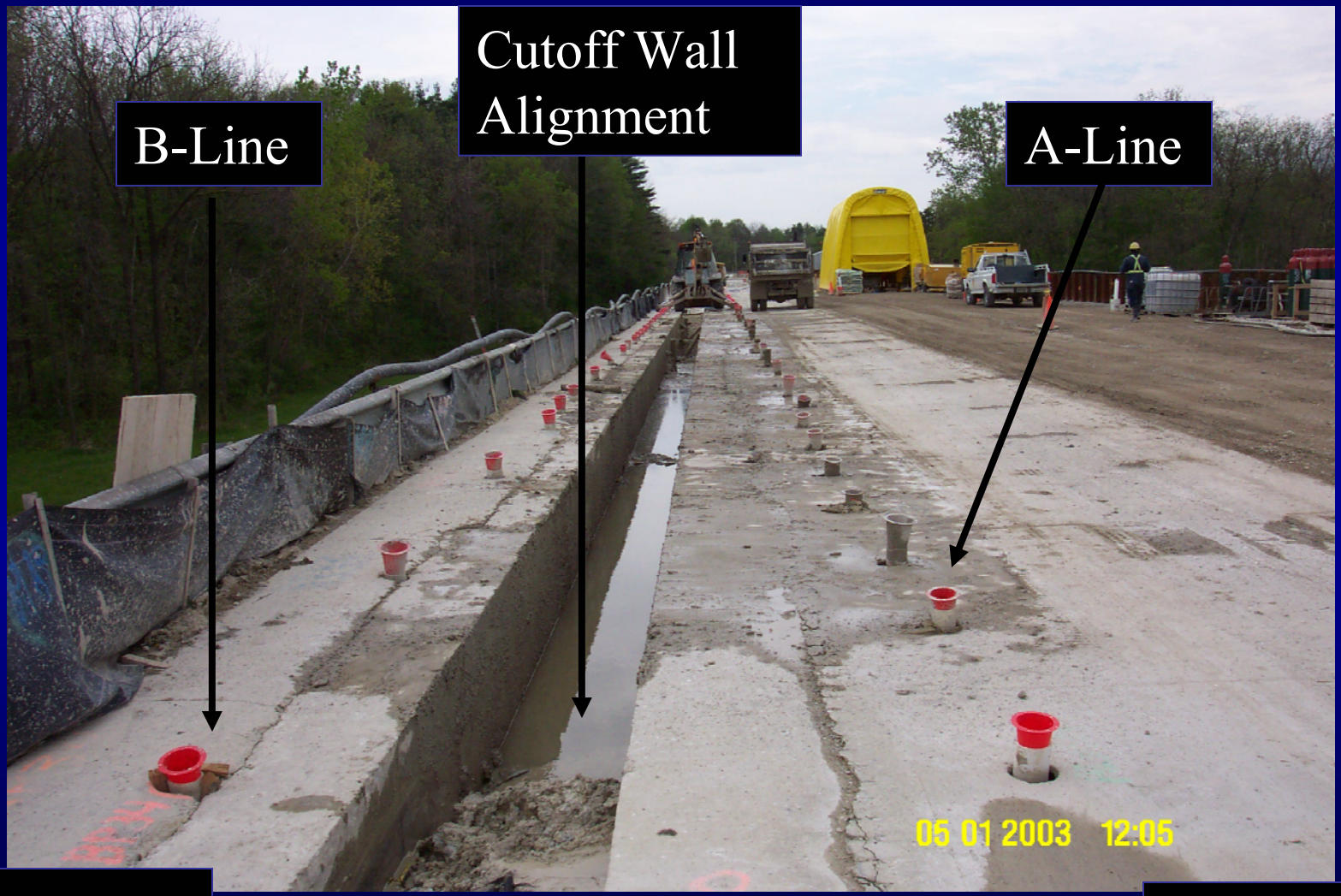


B Line Master Drawing

US Army Corps of Engineers
Louisville District

Geotechnical and Dam Safety Section
MISSISSINEWA DAM

Grout Line Layout




PETRIFOND

Tremie Concrete Placement

Test Section

Test section is complete.

Pregrouting was successful. NO SLURRY LOSSES

An optimum program for production was developed.

Drilling for grouting will provide a preview to problems.

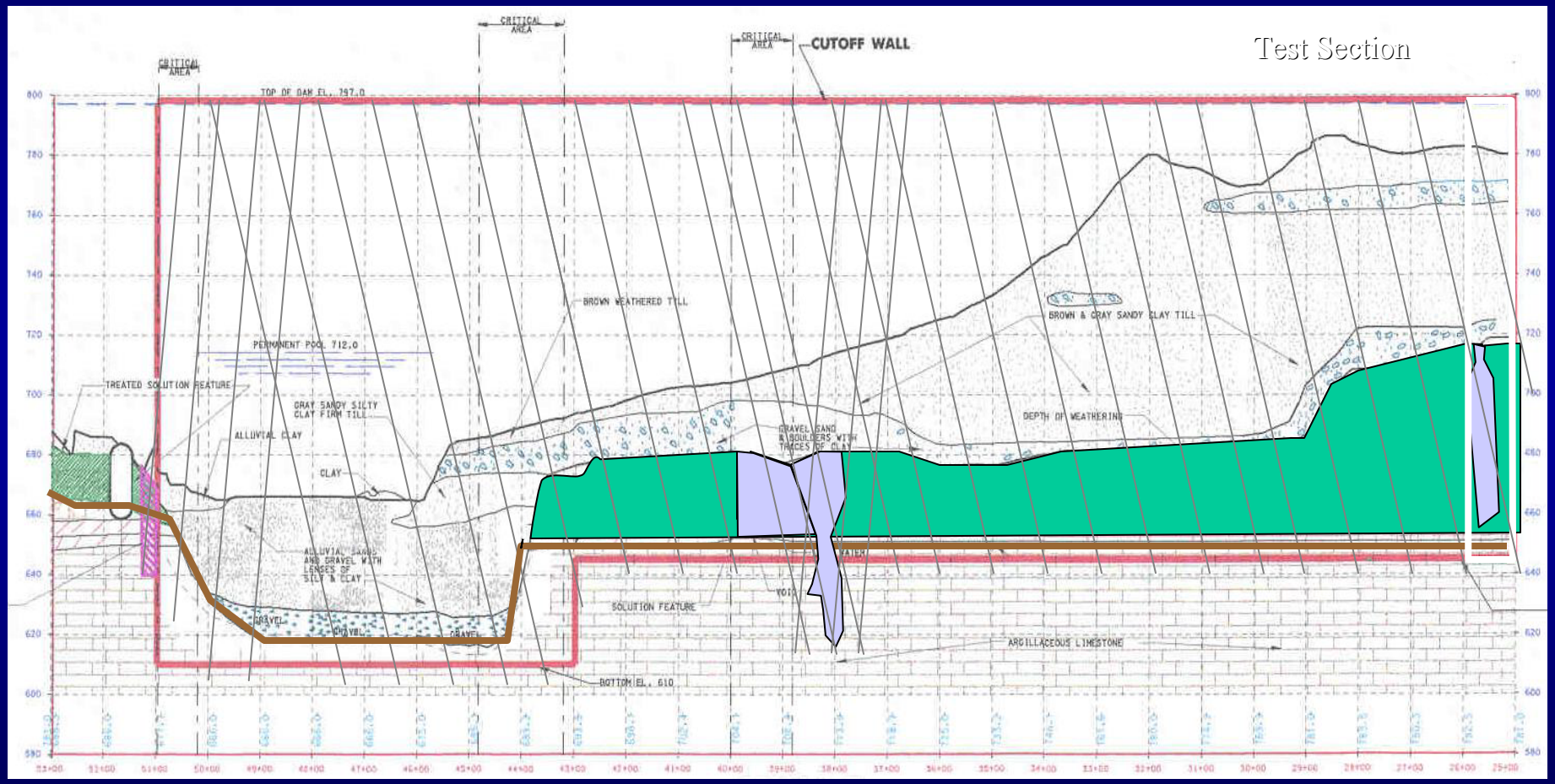
Cost growth due to grouting is unknown.

Actual quantities required to treat features will govern.

$10 - 15 Million (Likely)

$25 Million (Worst Case)

Production Grout Hole Alignment



Holes were drilled on both sides of the cutoff wall

Crane Mod For Deep Section

Bencor-Petrifond, J.V.

Extended Hydromill
June, 2004
Dam Foundation Remediation
Contract No. DACW27-01-C-0018

U.S. Army Corps of Engineers

Crane Boom Failure

Crane Fire

Mill Recovery

Bencor-Petrifond, J.V.

BENCOR PETRIFOND

Mill Retrieval With Dywidag Bars
September, 2004
Dam Foundation Remediation
Contract No. DACW27-01-C-0018

U.S. Army Corps of Engineers

Mill Recovery

Bencor-Petrifond, J.V.

Mill Retrieval Hydraulic Jacks
September, 2004
Dam Foundation Remediation
Contract No. DACW27-01-C-0018

U.S. Army Corps of Engineers

Mill Recovery

Bencor-Petrifond, J.V.

Mill Removal From Panel P-121
September, 2004
Dam Foundation Remediation
Contract No. DACW27-01-C-0018

U.S. Army Corps of Engineers

Mill Recovery

Additional Mills Mobilized

Bencor-Petrifond, J.V.
BENCOR PETRIFOND

Sennebogen Rig #2 Rock Excavation
October, 2004
Dam Foundation Remediation
Contract No. DACW27-01-C-0018

U.S. Army Corps of Engineers

Soil Cutting Wheels

Bencor-Petrifond, J.V.
BENCOR PETRIFOND

Hydromill Soil Wheels
December, 2004
Dam Foundation Remediation
Contract No. DACW27-01-C-0018

U.S. Army Corps of Engineers

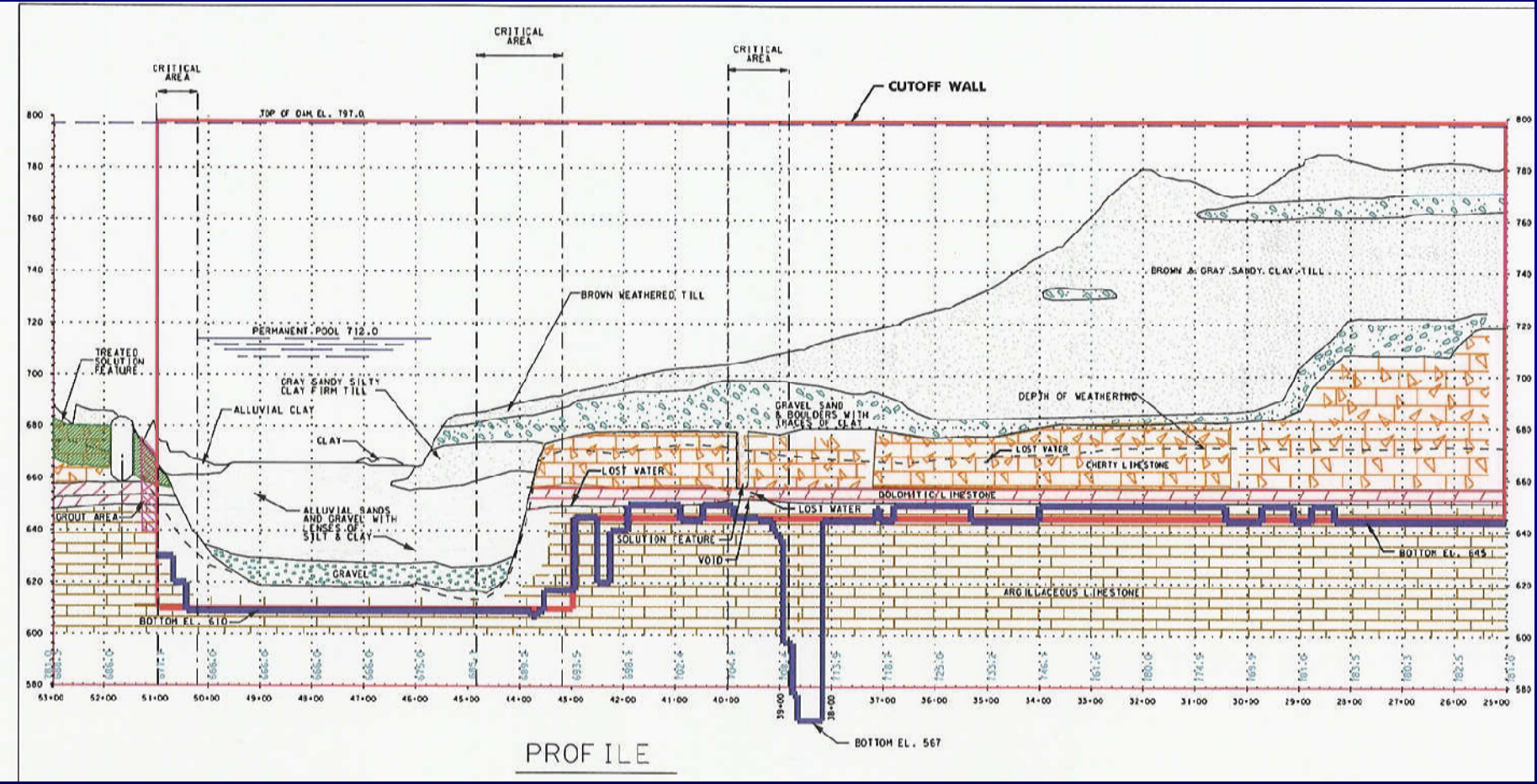
Mill Fest

Bencor-Petrifond, J.V.

Hydromills On Platform
December, 2004
Dam Foundation Remediation
Contract No. DACW27-01-C-0018

U.S. Army Corps of Engineers

Final Wall Profile



Quality Control

- Bentonite Testing
- Panel Embedment & Continuity
- Panel Verticality
- Concrete Testing
- Verification Drilling
- Dam Instrumentation

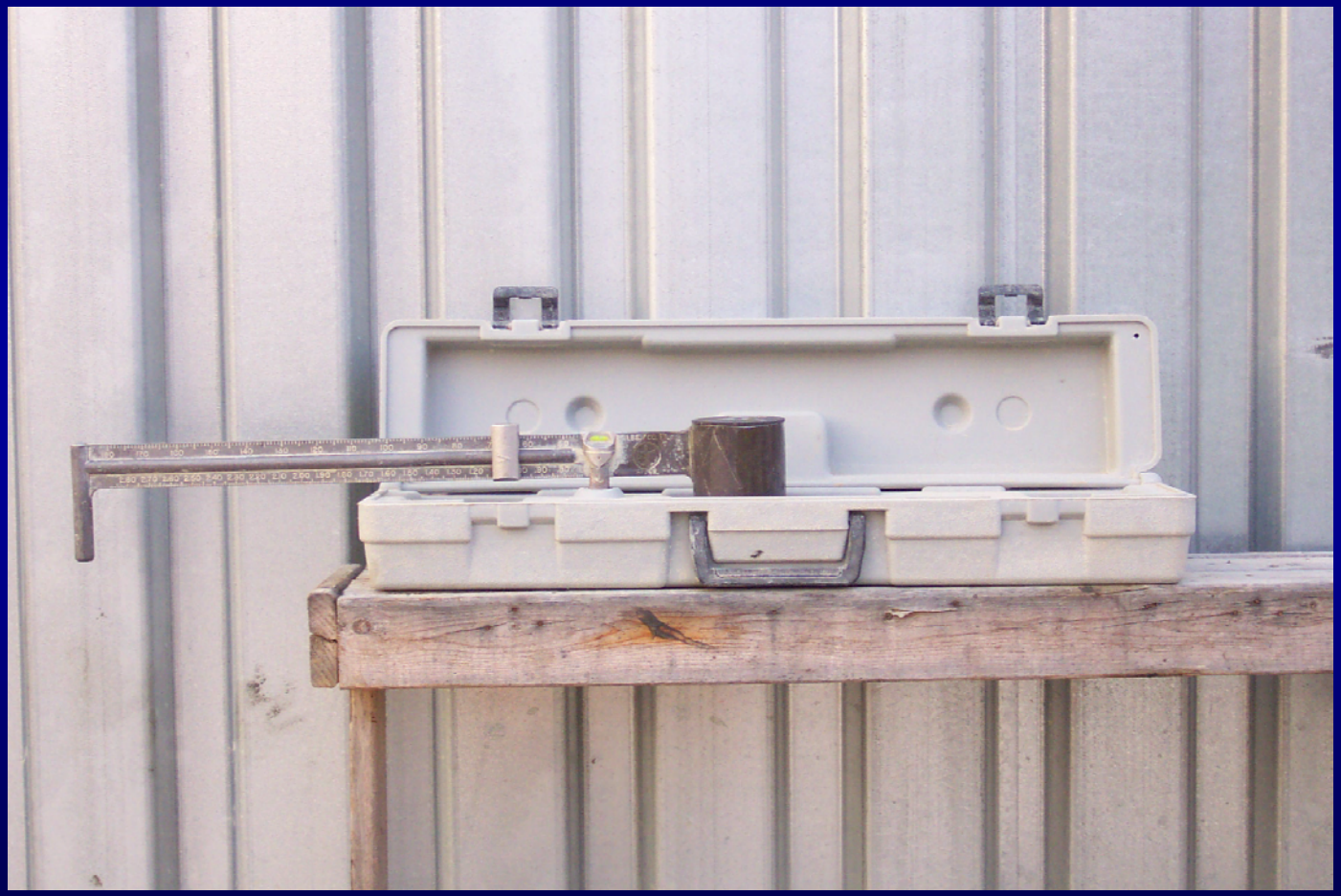
Bentonite Testing Equipment

Mud Balance and Marsh Funnel Cone

Pressure Filtration Machine

Marsh Funnel Test

Density Test



Pressure Filtration Testing

US Army Corps of Engineers
Louisville District

Geotechnical and Dam Safety Section
MISSISSINEWA DAM

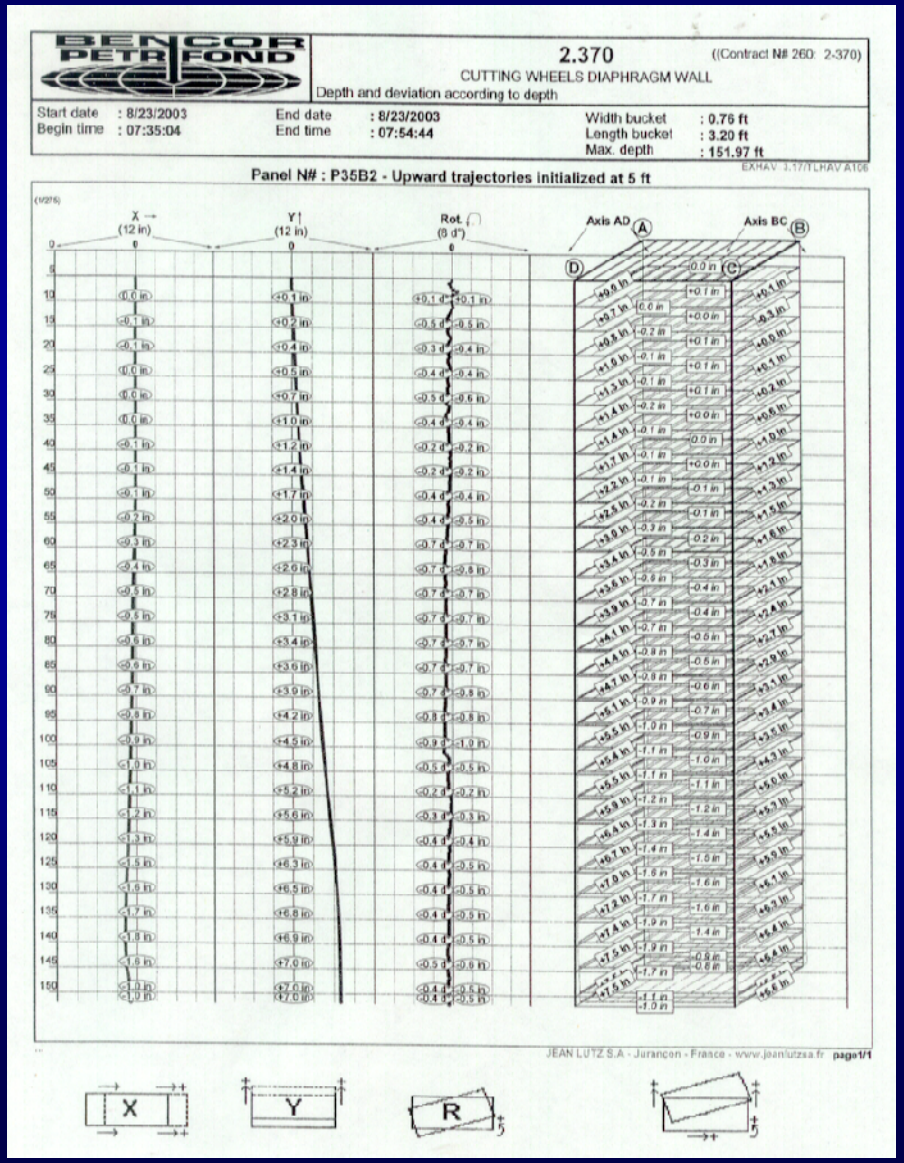
Sand Content Testing

Cuttings Observations for Panel Embedment

Verticality Checks

- Hydromill Inclinometer
- Jean Lutz® Inclinometer/Gyroscope
- Plumb Bob
- Koden® 682/684

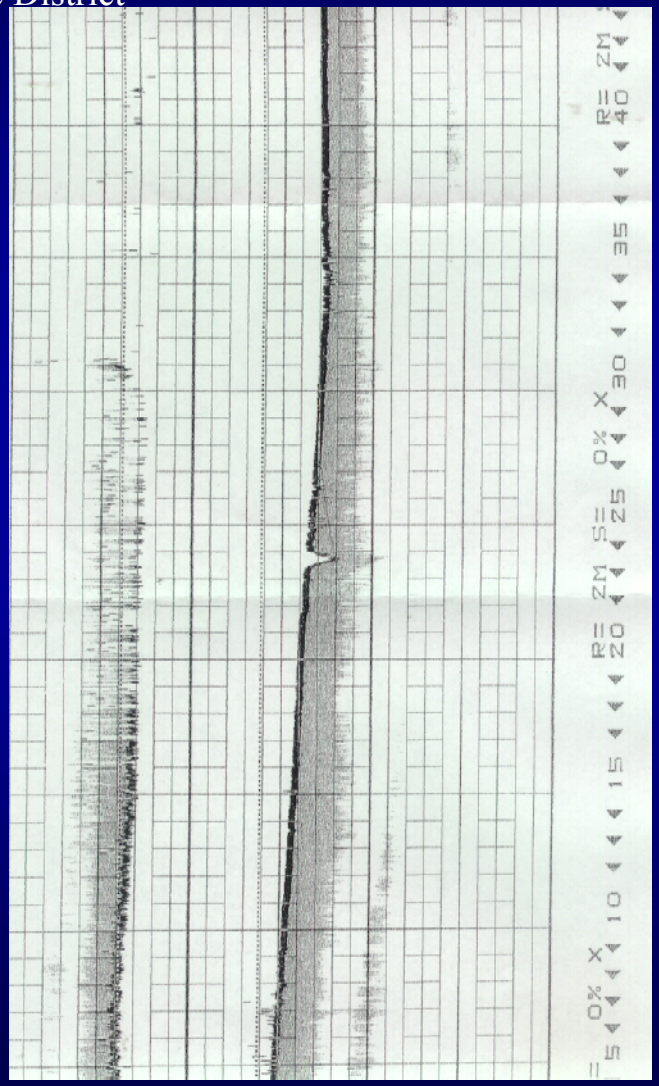
Jean Lutz® Plot

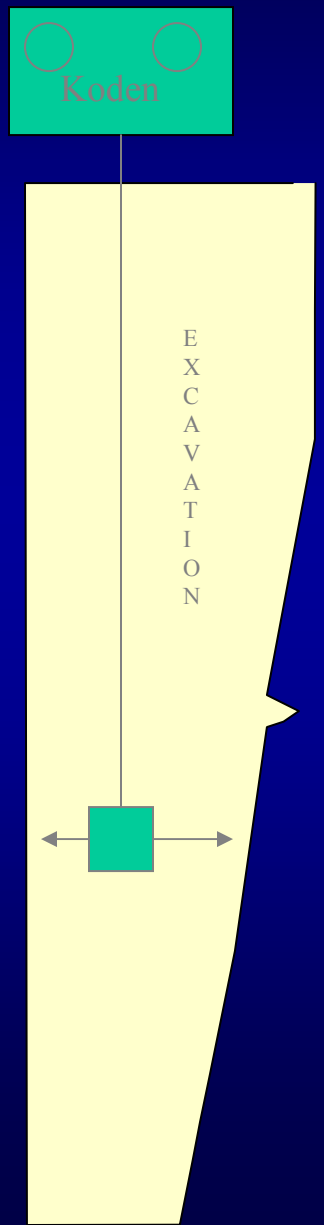


US Army Corps of Engineers
Louisville District

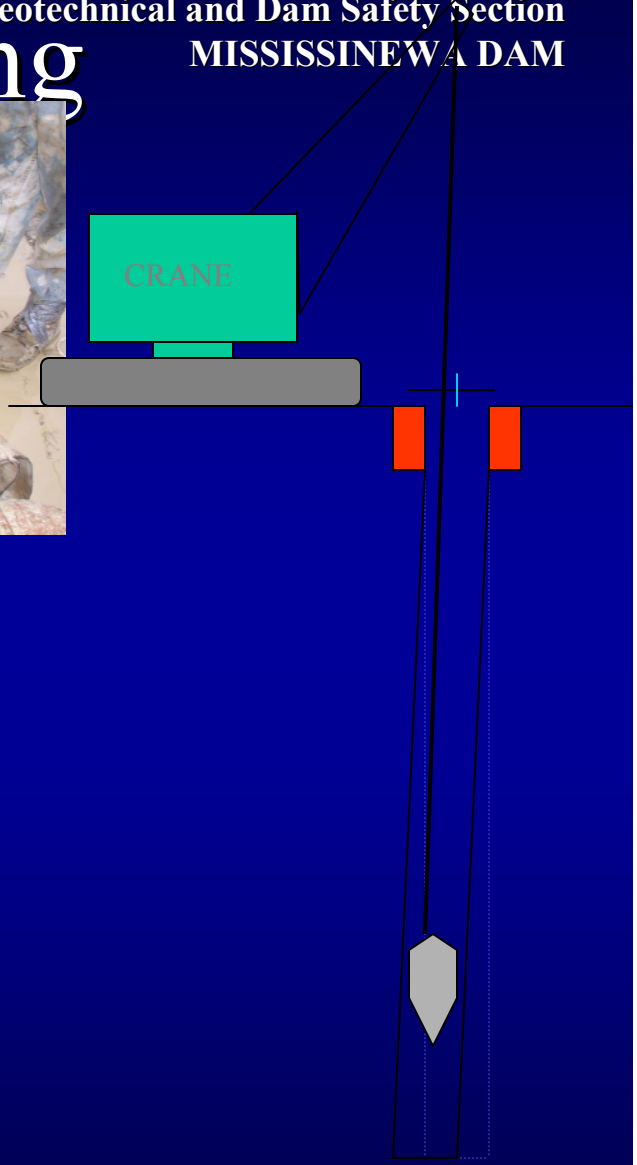
Koden® Verticality Machine

Koden® Plot





Plumb Bob Reading



Plumb Bob Results

Bencor-Petriford, JV
Dam Foundation Remediation, Mississinewa Dam
18-Aug-03

Panel P-11 - Bite #1 - Verticality - Plumb Bob

Height of Boom = 46'	Depth (Ft.) Below Guide Wall	Readings at Guide Wall (Inches)	Panel Deviation (Inches)
	0.00	0.00	0.00
	20.00	0.00	0.00
	30.00	0.13	0.21
	40.00	0.13	0.23
	50.00	0.38	0.78
	60.00	0.38	0.86
	70.00	0.20	0.50
	80.00	0.20	0.55
	90.00	0.63	1.85
	100.00	0.63	1.98
	110.00	1.00	3.39
	120.00	1.00	3.61
	130.00	1.00	3.83
	140.00	1.00	4.04
	150.00	1.13	4.79

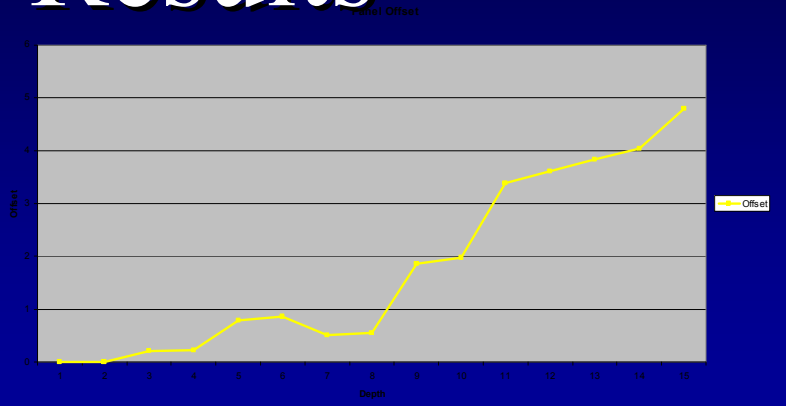
Panel P-11 - Bite #2 - Verticality - Plumb Bob

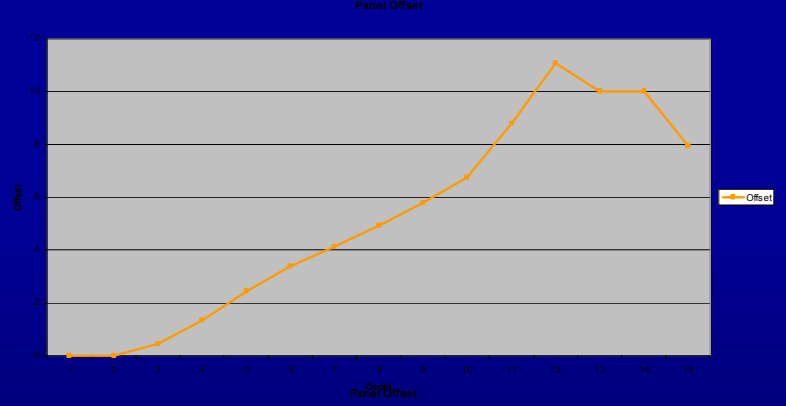
Height of Boom = 35'	Depth (Ft.) Below Guide Wall	Readings at Guide Wall (Inches)	Panel Deviation (Inches)
	0.00	0.00	0.00
	20.00	0.00	0.00
	30.00	0.25	0.46
	40.00	0.63	1.34
	50.00	1.00	2.43
	60.00	1.25	3.39
	70.00	1.38	4.13
	80.00	1.50	4.93
	90.00	1.63	5.80
	100.00	1.75	6.75
	110.00	2.13	8.80
	120.00	2.50	11.07
	130.00	2.13	10.02
	140.00	2.00	10.00
	150.00	1.50	7.93

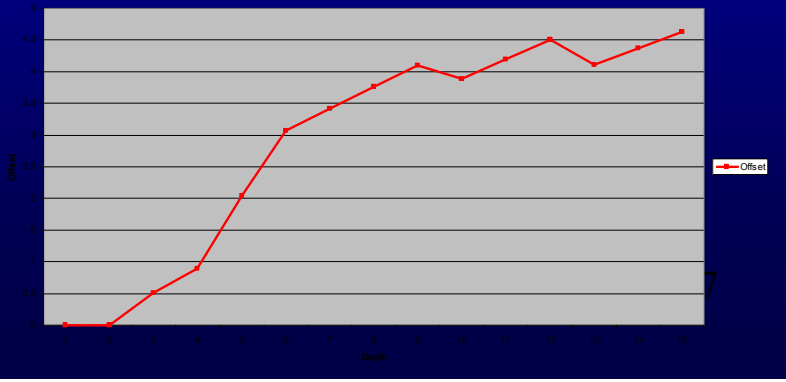
Panel P-11 - Bite #3 - Verticality - Plumb Bob

Height of Boom = 29'	Depth (Ft.) Below Guide Wall	Readings at Guide Wall (Inches)	Panel Deviation (Inches)
	0.00	0.00	0.00
	20.00	0.00	0.00
	30.00	0.25	0.51
	40.00	0.38	0.89
	50.00	0.75	2.04
	60.00	1.00	3.07
	70.00	1.00	3.41
	80.00	1.00	3.76
	90.00	1.00	4.10
	100.00	0.88	3.89
	110.00	0.88	4.19
	120.00	0.88	4.50
	130.00	0.75	4.11
	140.00	0.75	4.37
	150.00	0.75	4.63

Note: (-) Upstream, (+) Downstream





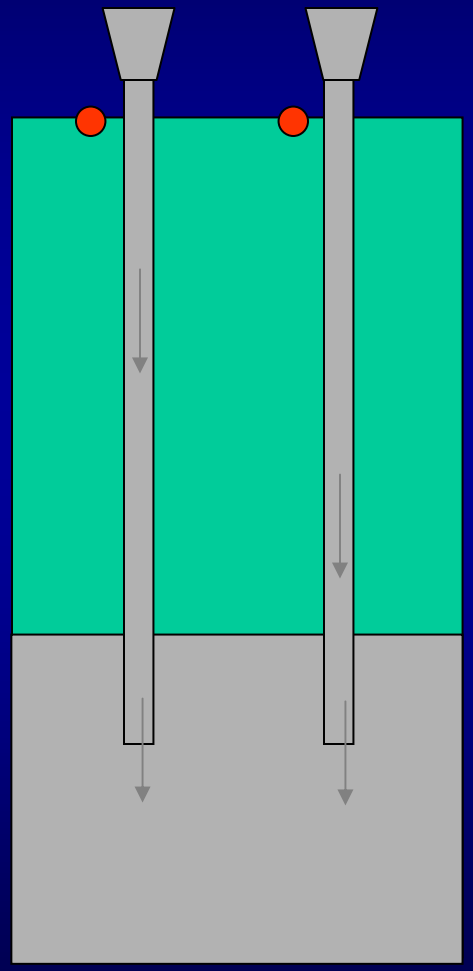


Concrete Quality Checks

- Batch Plant
  - Scale Calibration quarterly
  - Electronic Moisture meter calibration
  - Sieve Analysis on aggregates
  - Gradation analysis on aggregates
  - Moisture on sand and aggregate
  - Fly-ash grain size analysis

Tremie Procedures

- Go-Devil utilized
- Tremie Pipe Embedment
- Chart tremie progress and quantities
  - (in real time)
- Count tremie pipe lengths



Concrete Quality Testing

During Placement--

- Slump
- Air Content
- Temperature

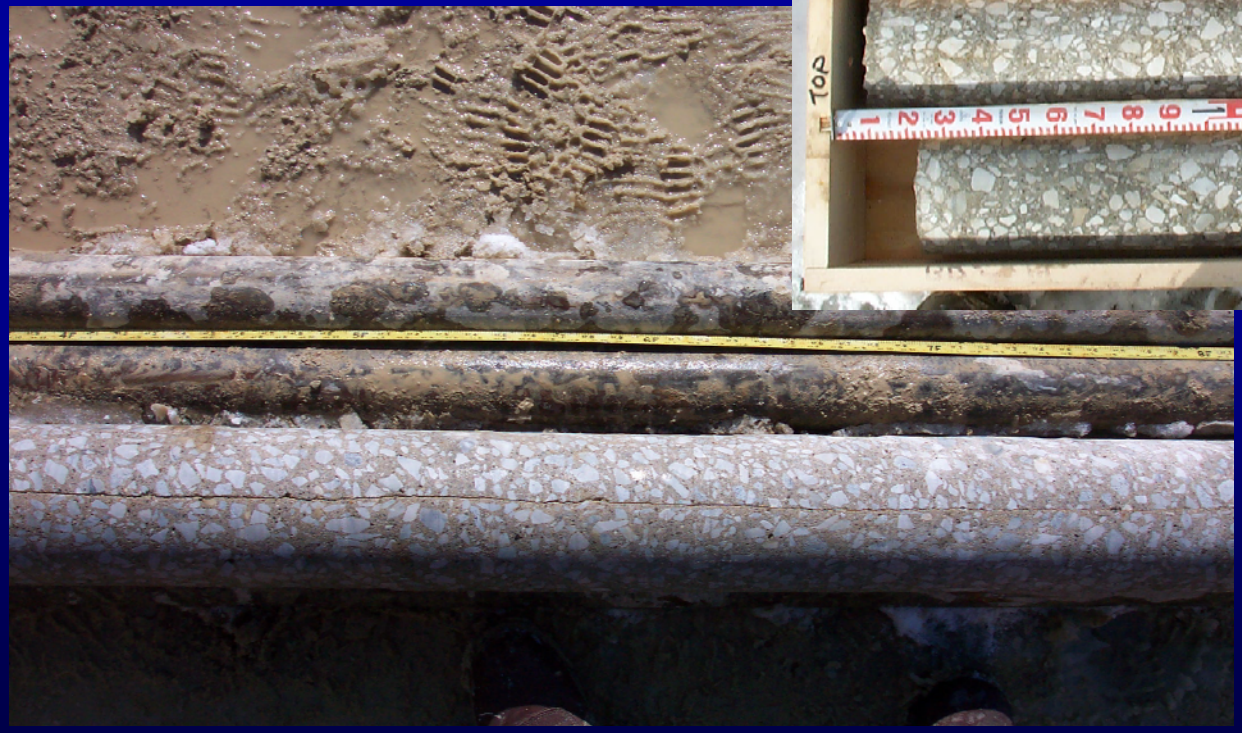
Verification Drilling

- Purposes:
  - Concrete Quality
  - Panel Contact/Joint Quality
  - Cutoff-Wall---Rock Bottom Contact
- Techniques:
  - 4 inch core for Panels
  - 6 inch core for Panel Joints

US Army Corps of Engineers
Louisville District

Geotechnical and Dam Safety Section
MISSISSINEWA DAM

Verification Drilling

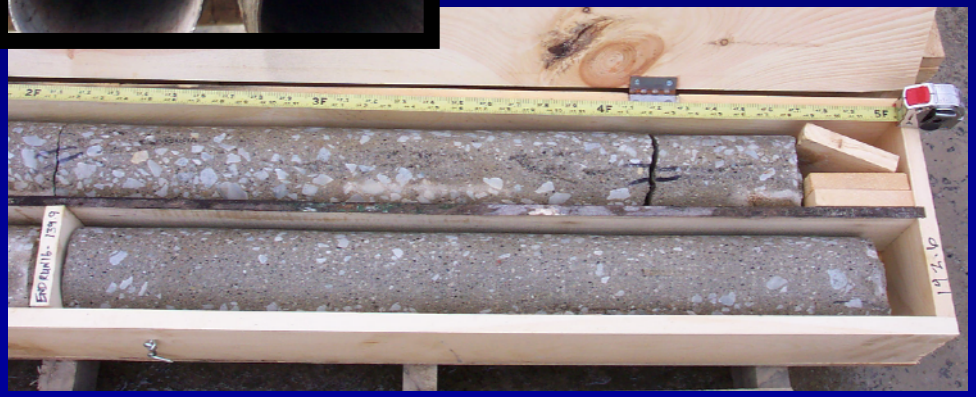


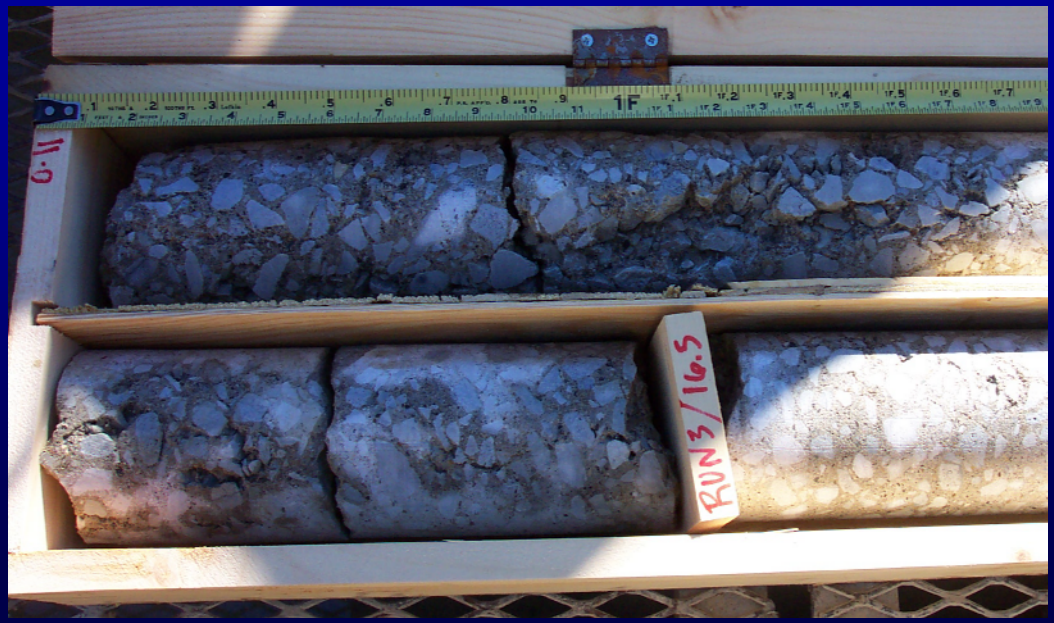
US Army Corps of Engineers
Louisville District

Geotechnical and Dam Safety Section
MISSISSINEWA DAM

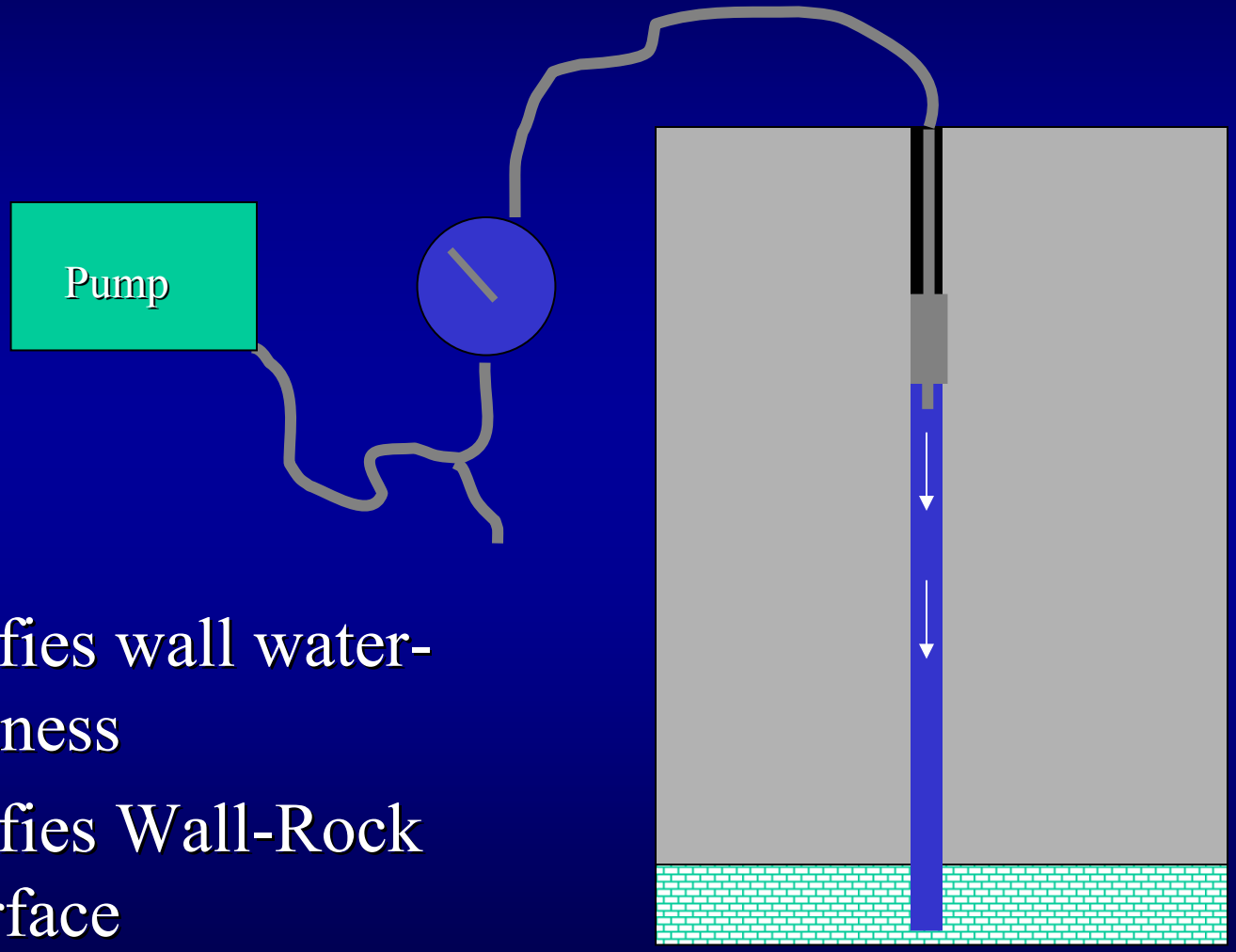
Panel-Rock Contact

What we don't want!





Borehole Pressure Testing

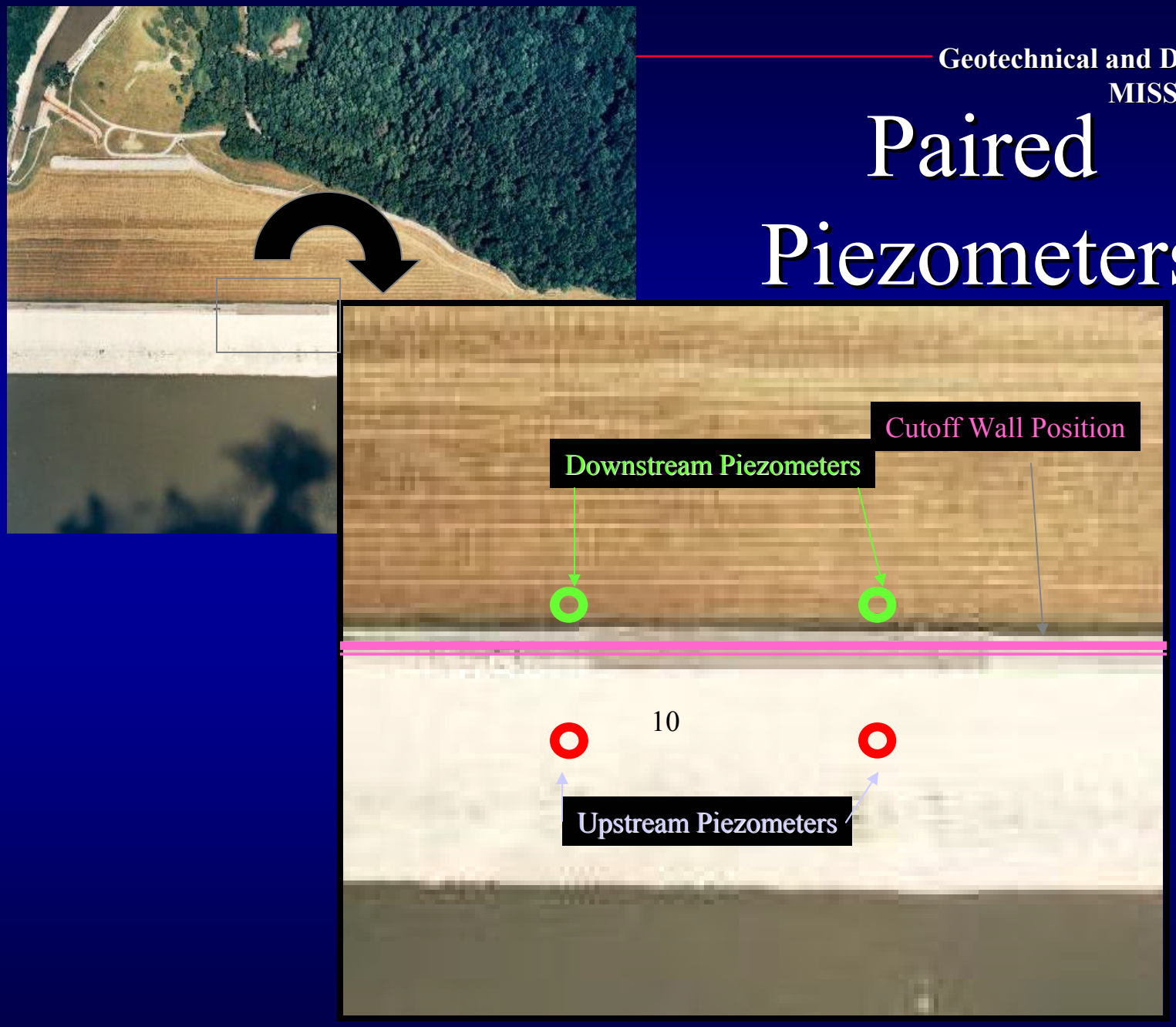


- Verifies wall water-tightness
- Verifies Wall-Rock Interface

Dam Instrumentation

- Purposes
  - Verify dam integrity
  - Check effectiveness of grouting
  - Check effectiveness of concrete cutoff wall
  - Historical record for future use

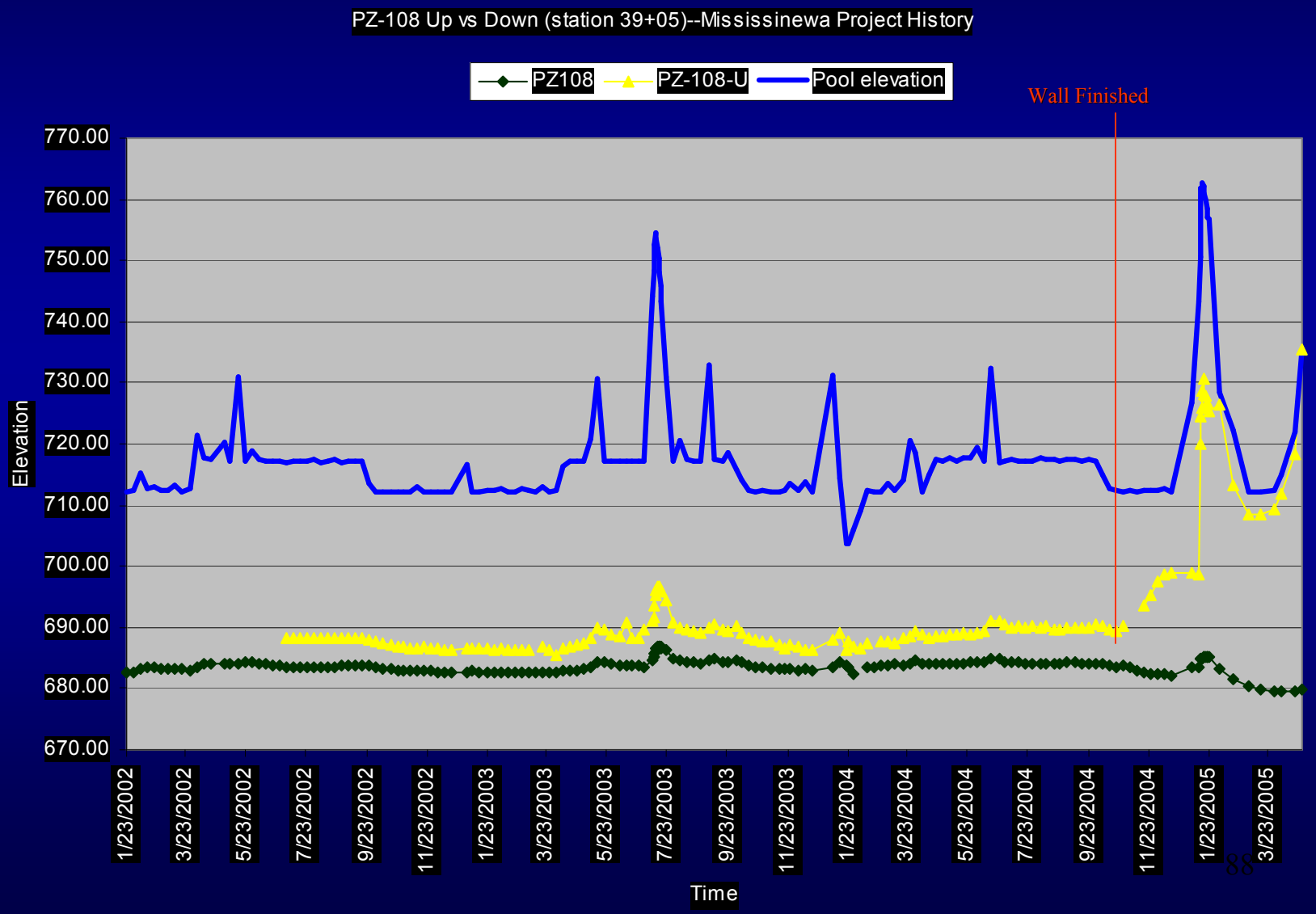
Paired Piezometers



US Army Corps of Engineers
Louisville District

Geotechnical and Dam Safety Section
MISSISSINEWA DAM

Paired Piezometer Plot



What have we learned?

- Solution Features are worse than expected.
- Clearly we were in a failure mode, reinforcing the need for remediation.
- Need for Pool restriction reinforced.
- Pregrouting is required to control slurry loss.
- Need to adjust design to field conditions.
- Cost and Schedule Growth will be governed by Geology.
- Large Contingencies are required for foundation repair projects.

- Final Price Approx. $50 Million.
- Most of the cost growth due to pretreatment grouting.
- No milling production issues related to rock strength.


LOUISVILLE
DISTRICT
ESSAYONS
ENGINEER