US Army Corps
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CANTON DAM
SPILLWAY STABILITY

Tulsa District

Is a Test Anchor Program Necessary?

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CANTON DAM
SPILLWAY STABILITY

- Background and History
- Determining Anchor Capacity
- Investigation and Test Anchor Program
- Summary

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CANTON DAM
SPILLWAY STABILITY

- **Background and History**

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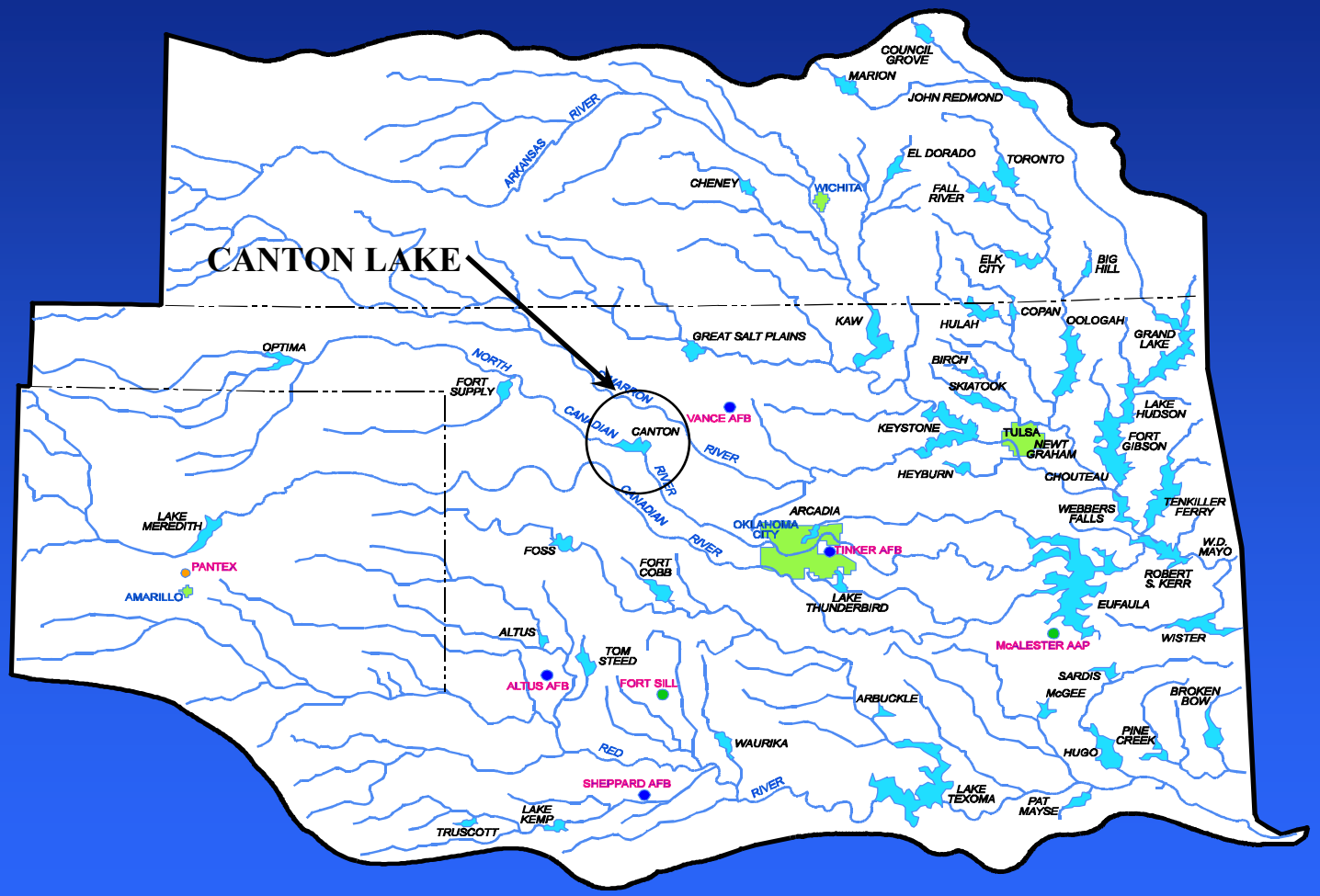
CANTON LAKE
LOCATION



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CANTON DAM

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CANTON DAM

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CANTON DAM

PROJECT DESCRIPTION

- Rolled Earthfill Embankment with a Length of 15,140 ft. and max. height of 73 ft.
- Gate Controlled Concrete Chute Spillway with 16 - 40 ft. wide by 25 ft. high Tainter Gates with a Total Capacity of 274,000 cfs.
- Outlet Works Consists of 3 - 7 ft. wide by 12 ft. high sluice gates.
- Downstream Channel Capacity is Approx. 1000 cfs.

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CANTON DAM

PERTINANT DATA

• Top of Dam	1648.0
• Top of Flood Control Pool and Top of Spillway Gates	1638.0
• Top of Conservation Pool	1615.4
• Pool Restriction	1626.0

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CANTON DAM
DAM SAFETY ISSUES

- HYDROLOGIC DEFICIENCY
- SEISMIC DEFICIENCY
- SEEPAGE DEFICIENCY
- SPILLWAY STABILITY

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CANTON DAM
SPILLWAY STABILITY

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FOUNDATION MATERIALS

- PERMIAN RED BEDS
  - RUSH SPRINGS SANDSTONE
  - DOG CREEK SHALE
    - COMPACTION SHALE
    - POORLY INDURATED
    - GYPSUM LAYERS
    - SOFT LAYERS
  - BLAINE FORMATION
    - COMPACTION SHALE
    - 2 MASSIVE GYPSUM/ANHYDRITE LAYERS

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DOG CREEK SHALE STRENGTH CHARACTERISTICS

- OVERCONSOLIDATED
- DILATES WHEN SHEARED (AT LOWER CONFINING PRESSURE)
- LOWEST STRENGTHS 20-30 FEET, OR 1570-1580 ELEVATION, AND BELOW 50 FEET
- HIGHEST STRENGTHS BETWEEN 30 AND 40 FEET

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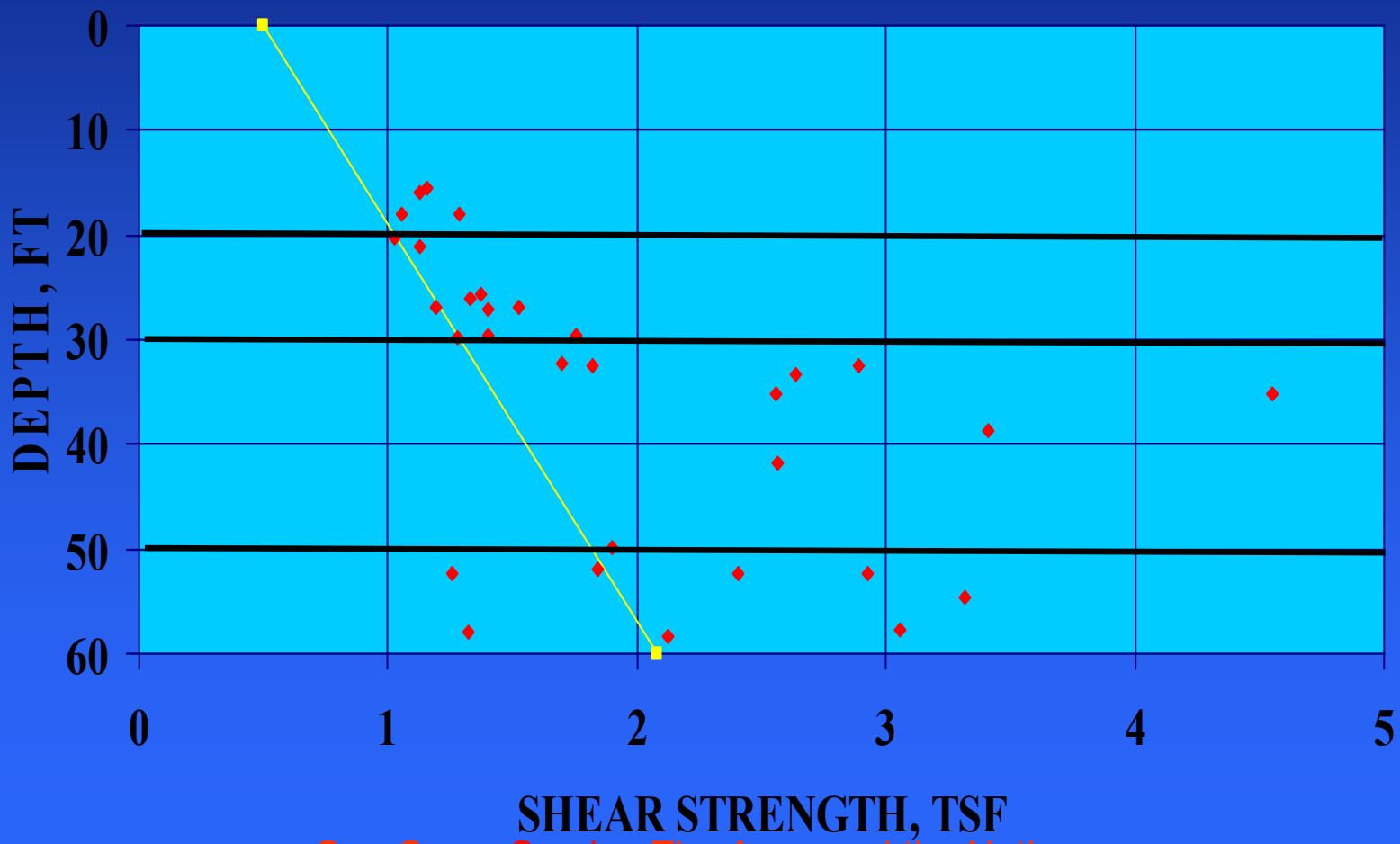
DATA FROM ALL SHEAR TESTS



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TECHNICAL CONCERNS

- WEAK LAYERS IN FOUNDATION
  - GYPSUM SEAMS
  - OTHER SOFT SEAMS
- DESIGN SHEAR STRENGTH
  - USE OF COHESION
- DRAINAGE
  - 50 PERCENT EFFECTIVE
  - 0 PERCENT EFFECTIVE

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LISTING OF SAFETY FACTORS

DATE	C	PHI	UPLIFT	FS
1944	880	31		2.38
1946	0	31		1.40
1973	600	30		1.39
1979	1200	50		2.16
1983	0	39.3	100%	0.88
1983	0	39.3	50%	1.2
1997	0	33	100%	0.7
1999	0	25	100%	0.55
1999	0	25	50%	0.88
2004	0	25	100%	0.50

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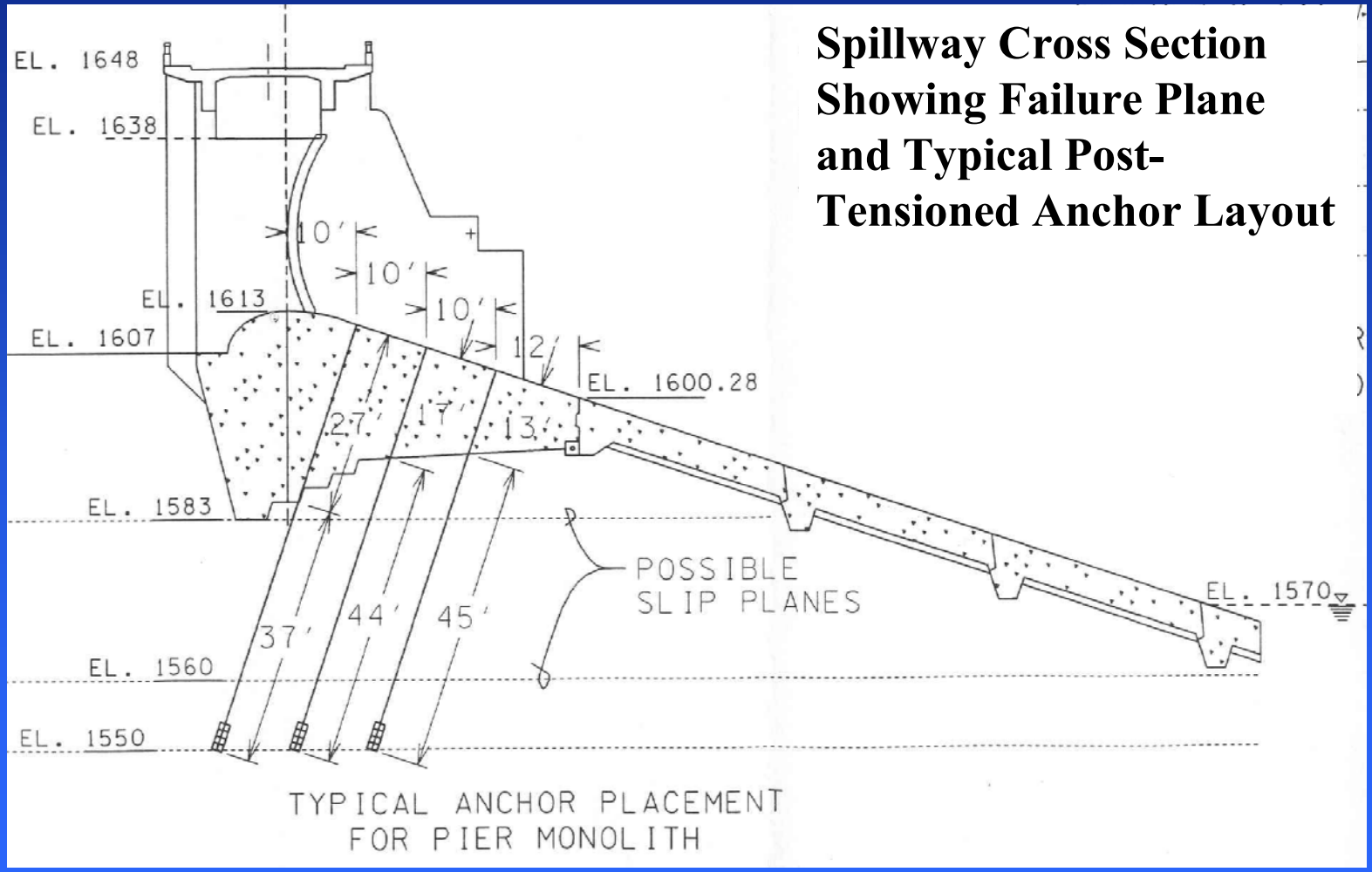
CANTON DAM
SPILLWAY STABILITY

Spillway Cross Section Showing Failure Plane and Typical Post-Tensioned Anchor Layout



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CANTON DAM
SPILLWAY STABILITY

- **Determining Anchor Capacity**

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ANCHOR DESIGN LOAD FORMULA

$$P = \tau_w * L_b * \pi * d$$

P = design load for the anchor

τ_w = working bond stress along the interface between rock and grout

τ_w = 50% of the ultimate bond stress

L_b = bond zone length

d = diameter of drill hole

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RECOMMENDED BOND STRESS VALUES FROM PTI

ROCK	AVERAGE ULTIMATE BOND STRESS-ROCK/GROUT (PSI)
Granite and Basalt	250 – 450
Dolomitic Limestone	200 – 300
Soft Limestone	150 – 200
Slates & Hard Shales	**120 – 200**
Soft Shales	**30 – 120**
Sandstones	**120 – 250**
Weathered Sandstones	**100 – 120**
Chalk	30 – 155
Weathered Marl	25 – 35
Concrete	200 – 400

Table 6.1, Recommendations for Prestressed Rock and Soil Anchors, PTI, 1996

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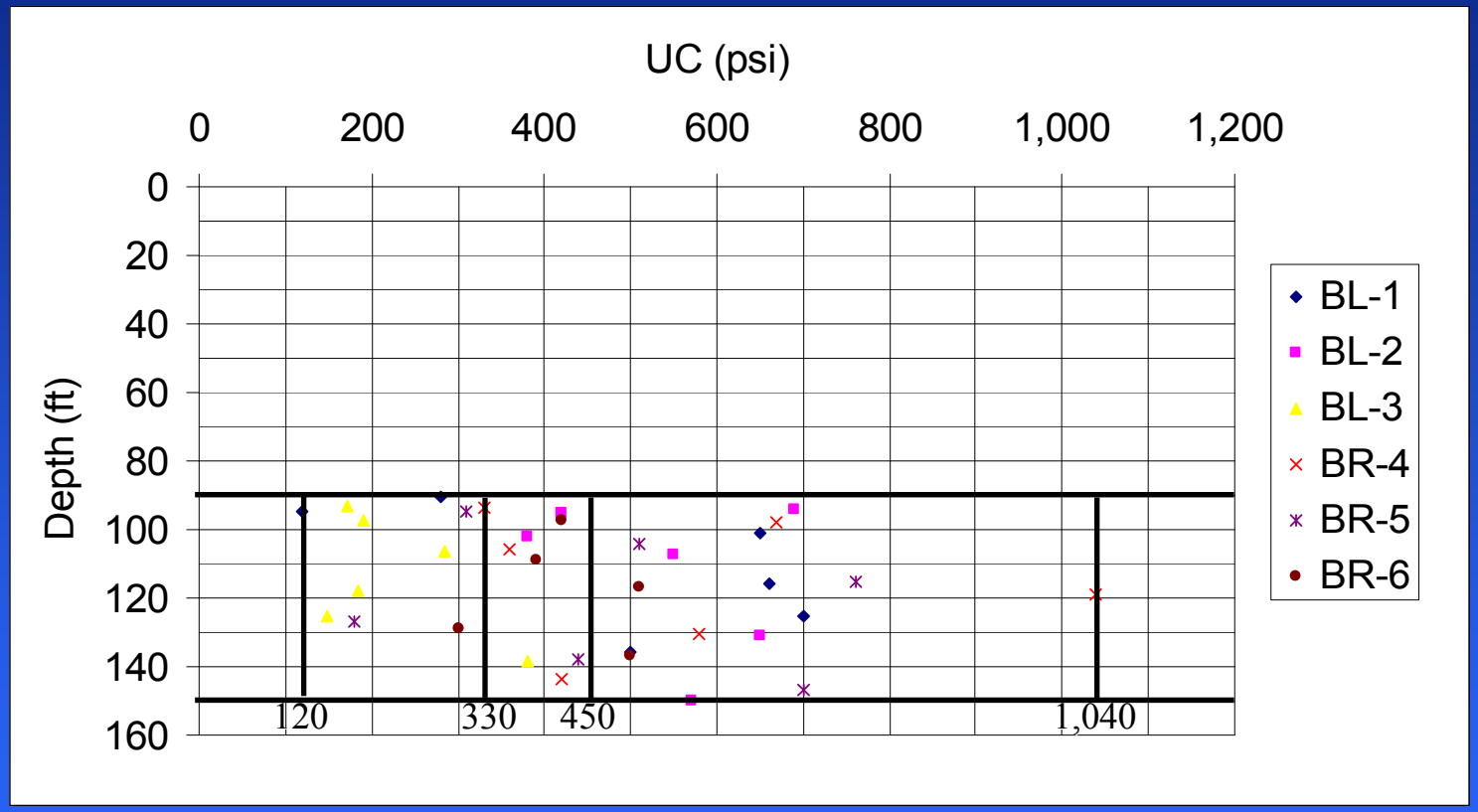
TEST ANCHOR PROGRAM
PHASE I CORE STRENGTHS



Minimum = 120 psi **Maximum = 1,040 psi**

One Third = 330 psi

Median = 420 psi **Average = 456 psi**

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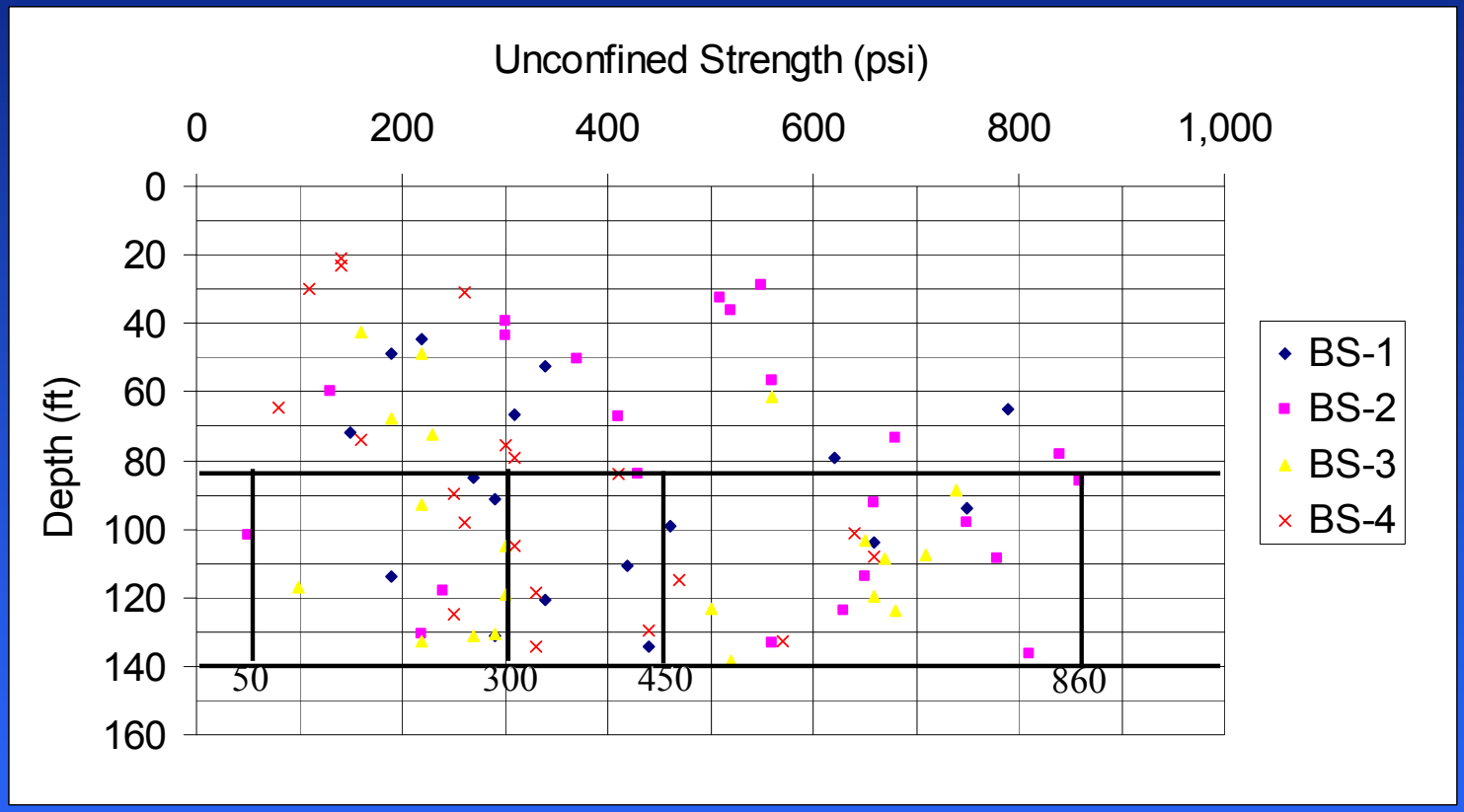
TEST ANCHOR PROGRAM
PHASE II CORE STRENGTHS



Minimum = 50 psi **Maximum = 860 psi**

One Third = 300 psi

Median = 440 psi **Average = 460 psi**

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TEST ANCHOR PROGRAM
PHASE I & II SUMMARY

- Ultimate Bond Stress = 10% of the Unconfined Compressive Strength of the Rock
- Minimum Value = 5 to 12 psi
- One Third Value = 30 to 33 psi
- Median Value = 42 to 44 psi
- Average Value = 46 psi
- Maximum Value = 86 to 104 psi

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TEST ANCHOR PROGRAM
LAB BOND TESTS

Boring	Maximum Bond Stress (psi)	Boring	Maximum Bond Stress (psi)
BL-1	102	BR-4	104
BL-1	57	BR-4	233
BL-2	81	BR-5	176
BL-2	84	BR-5	62
BL-2	141	BR-6	154
BL-3	98	BR-6	65
BL-3	76	BR-6	300

Minimum = 57 psi

Maximum = 300 psi

One Third = 80 psi

Median = 100 psi

Average = 109 psi

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TEST ANCHOR PROGRAM
PHASE I PULLOUT TESTS

Boring	Bond Zone Length (ft)	No. of Strands	Percent of Design Load (%)	Bond Stress (psi)
A-1LA	15	7	118	63
A-1RA	15	7	165	97
A-3L	15	7	160	94
A-3R	15	7	155	91
A-2L	15	16	188	221
A-2R	15	16	190	224
A-5L	15	16	188	221
A-5R	15	16	190	224
A-4L	40	16	133	83
A-4R	40	16	133	83

No anchors failed during pullout tests

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CANTON DAM
SPILLWAY STABILITY

- **Investigation and Test Anchor Program**

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INVESTIGATION AND TEST PROGRAM

- Two phase test program required due to lack of funding
- Phase I – abutment drilling
  - 6 core holes
  - 8 anchor pullout tests
  - 2 anchor creep tests
- Phase II – spillway drilling
  - 4 core holes
  - 2 full scale anchor tests
- Awarded task orders for investigations and test anchors to MACTEC (Prime) and Hayward Baker (Sub)

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TEST ANCHOR PROGRAM
PHASE I

- 3 core holes on each side of the spillway
  - 2 to 140 feet
  - 1 to 180 feet (top of gypsum)
- 2 test anchors on each side of spillway
  - 105 and 140 feet deep
  - 6 inch diameter hole
  - 7 strand tendon instrumentation
  - 15 foot bond zone
  - Perform pullout test to failure
    - Could not fail anchors

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TEST ANCHOR PROGRAM
PHASE I - INVESTIGATION

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TEST ANCHOR PROGRAM
PHASE I - INVESTIGATION

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TEST ANCHOR PROGRAM
PHASE I - INVESTIGATION

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TEST ANCHOR PROGRAM
PHASE I - INVESTIGATION

FINDINGS

- Original boring logs indicated caved material
- Caved material turned out to be the result of dissolution and collapse
- Noticeable increase in core recovery, RQD, and strength of core below 90 feet
- Rock dips slightly to the southwest

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TEST ANCHOR PROGRAM
PHASE I

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TEST ANCHOR PROGRAM
PHASE I

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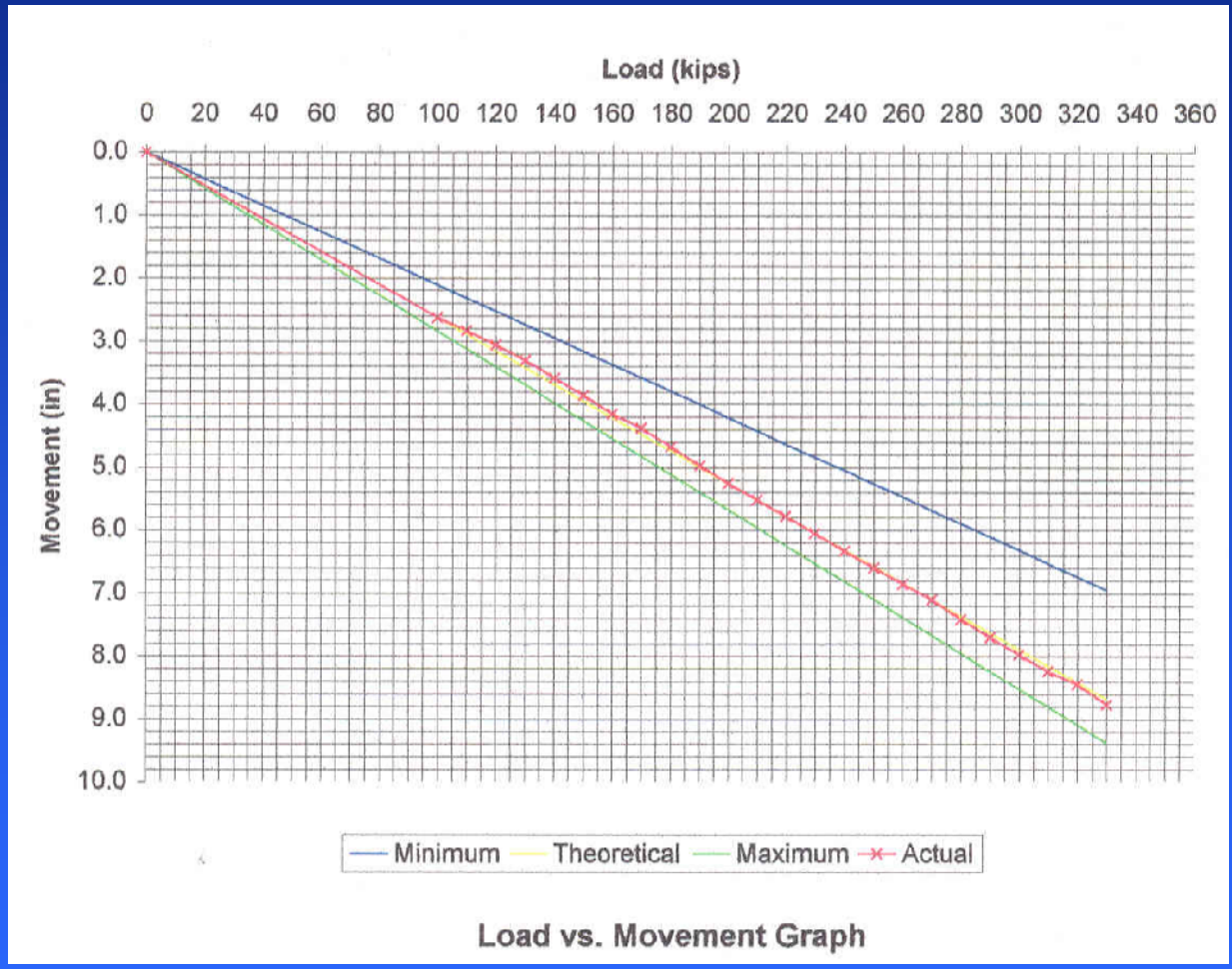
TEST ANCHOR PROGRAM
PHASE I



Load vs. Movement Graph

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TEST ANCHOR PROGRAM PHASE I REVISED

- 2 test anchors on each side of spillway
  - 105 feet deep (one grouted and one not grouted)
  - 6 inch diameter hole
  - 16 strand tendon
  - 15 foot bond zone
  - Perform pullout test to failure
- 2 test anchor on each side of spillway
  - 105 feet deep
  - 6 inch diameter hole
  - 16 strand tendon with instrumentation
  - 40 foot bond zone
  - Conduct performance test and creep test

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TEST ANCHOR PROGRAM
PHASE I REVISED

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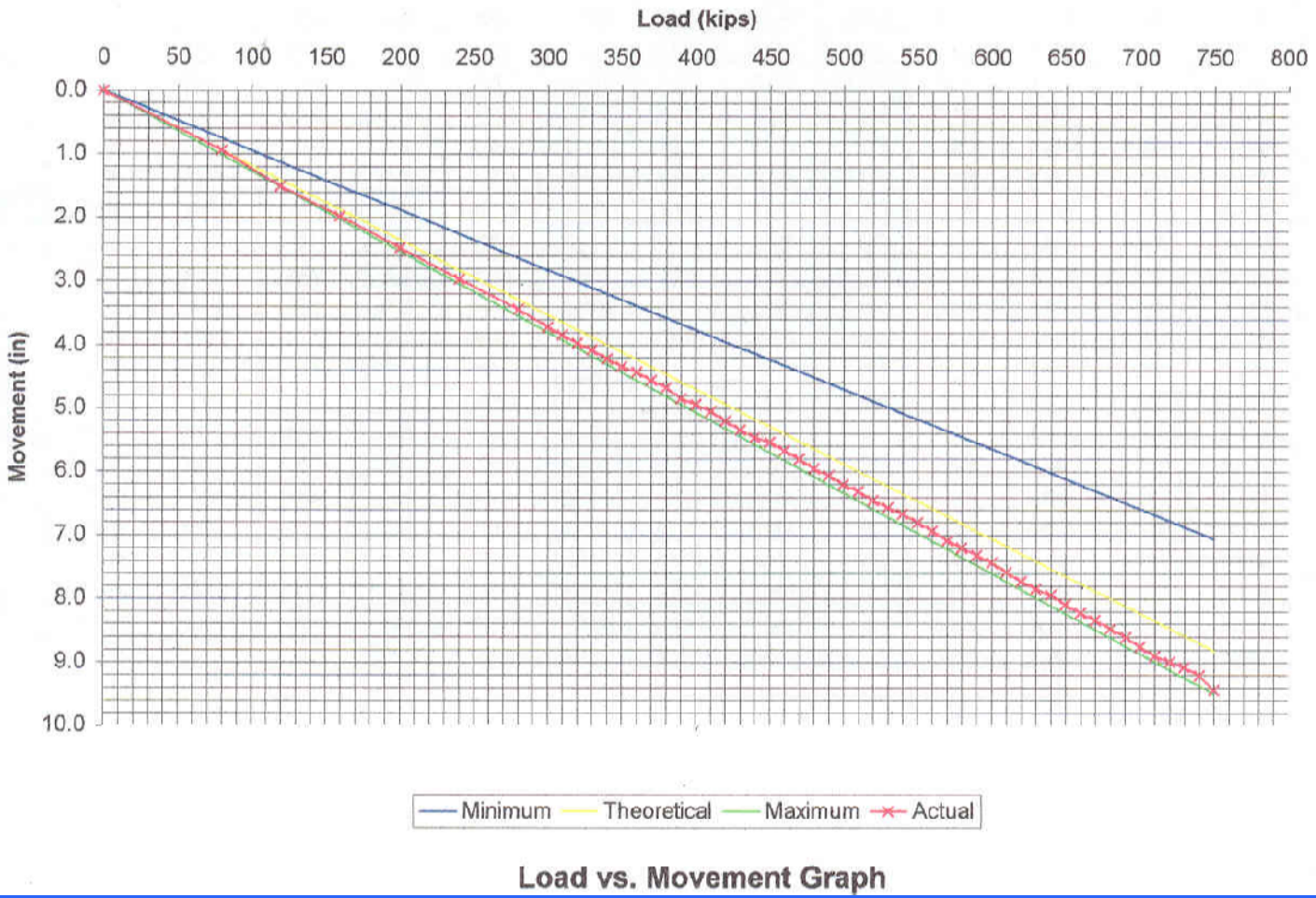
TEST ANCHOR PROGRAM
PHASE I REVISED



Load vs. Movement Graph

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TEST ANCHOR PROGRAM
PHASE I REVISED

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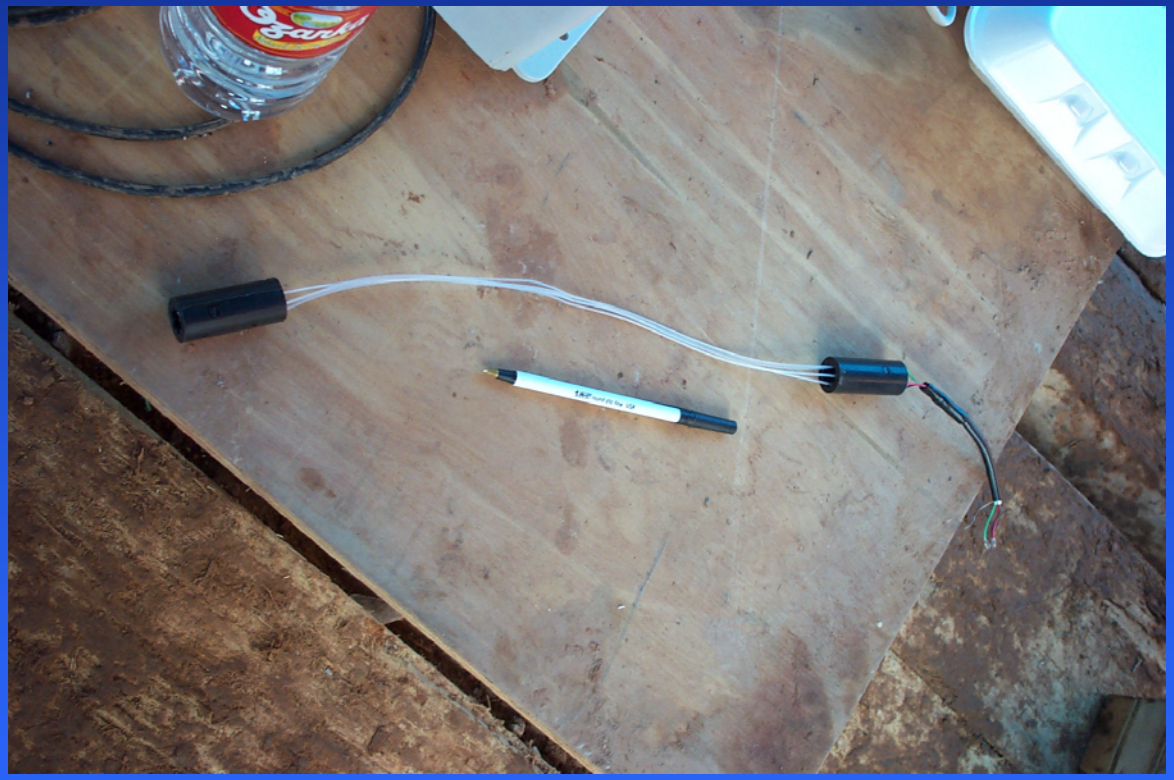
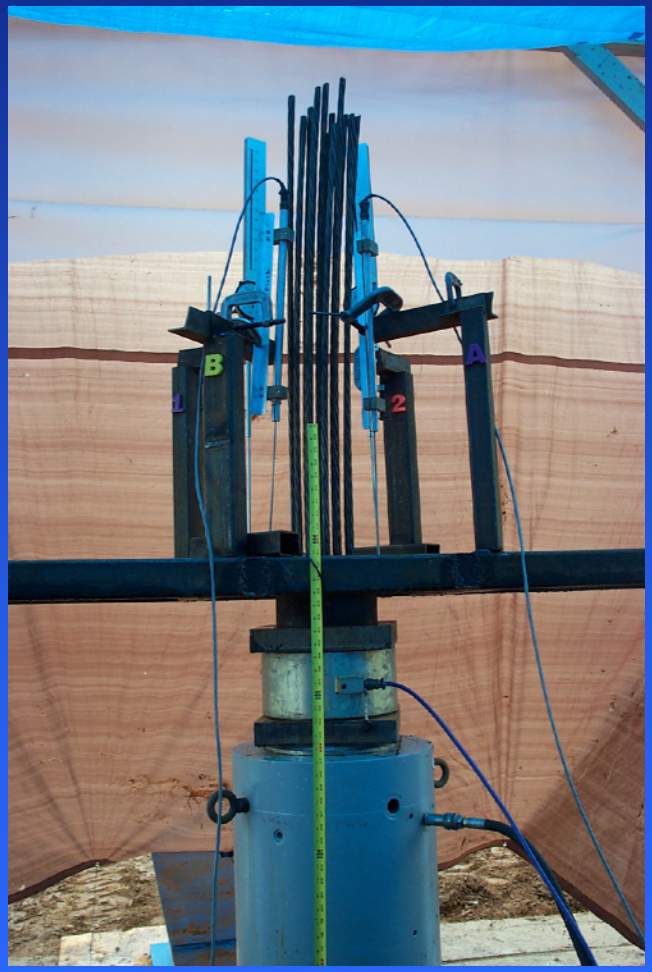
TEST ANCHOR PROGRAM
PHASE I REVISED





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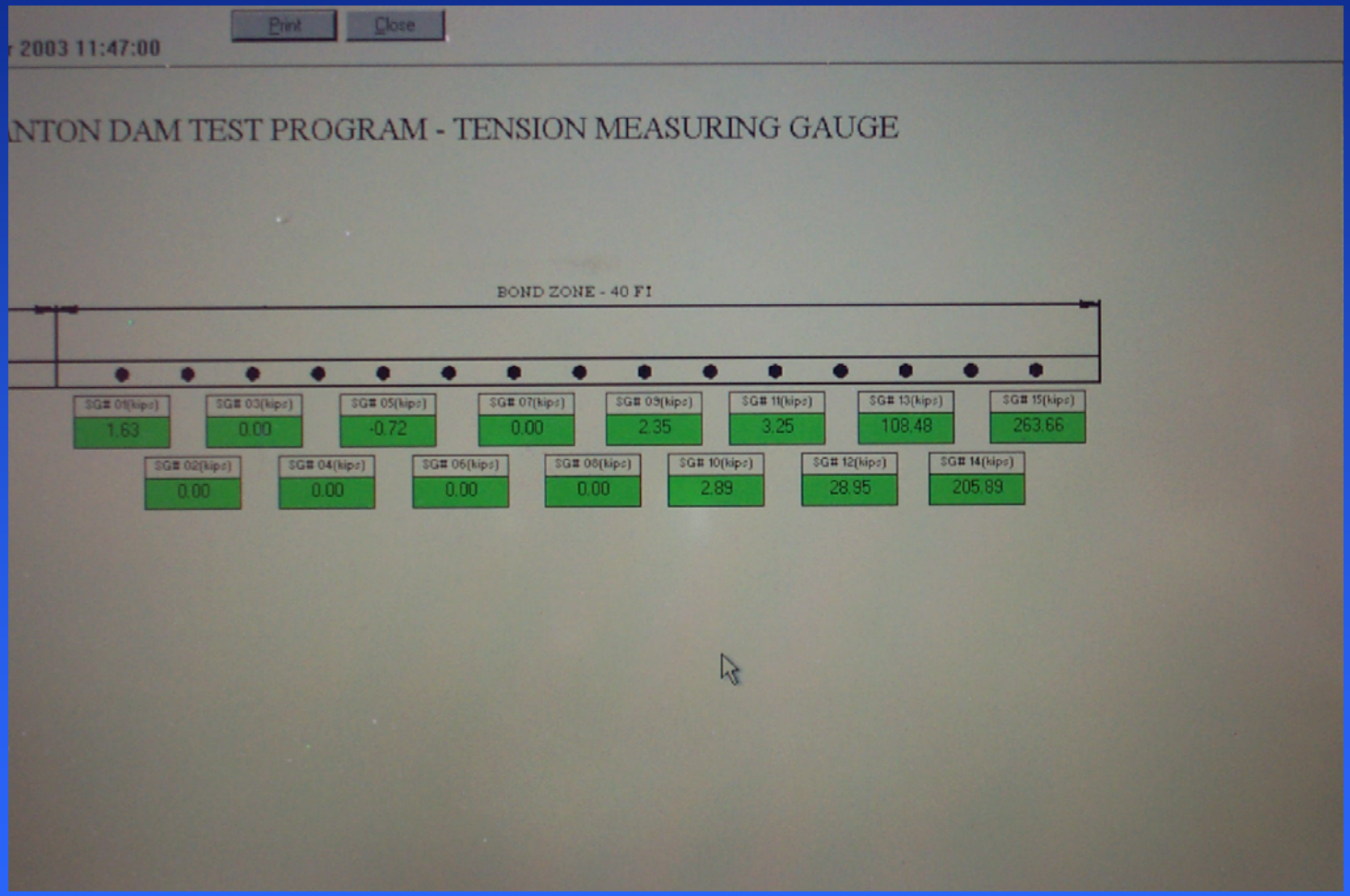
TEST ANCHOR PROGRAM
PHASE I REVISED



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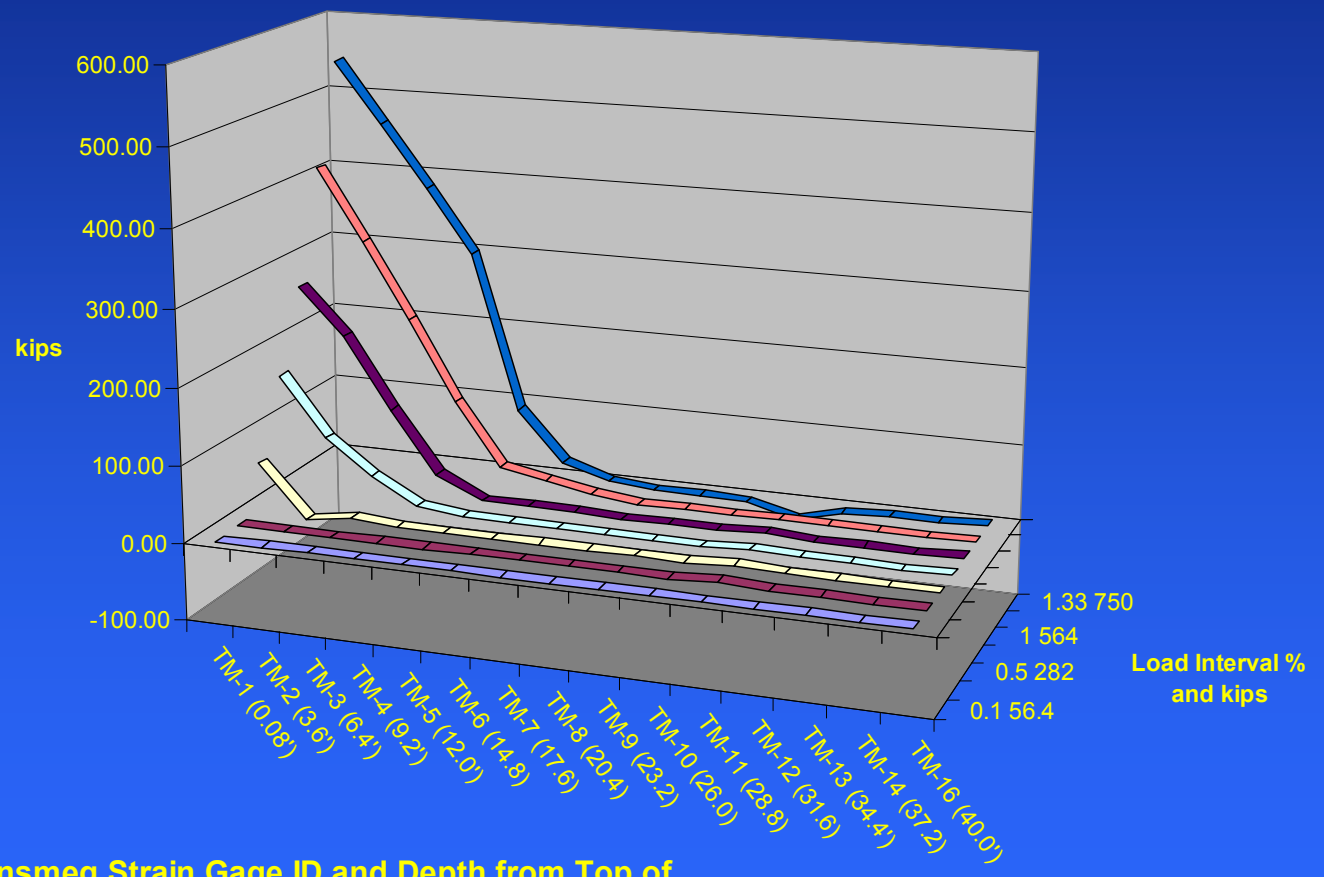
TEST ANCHOR PROGRAM PHASE I REVISED

Canton Dam, A4 Left Load Test - Load Per Depth in Bond Zone



Tensmeg Strain Gage ID and Depth from Top of Bond Zone

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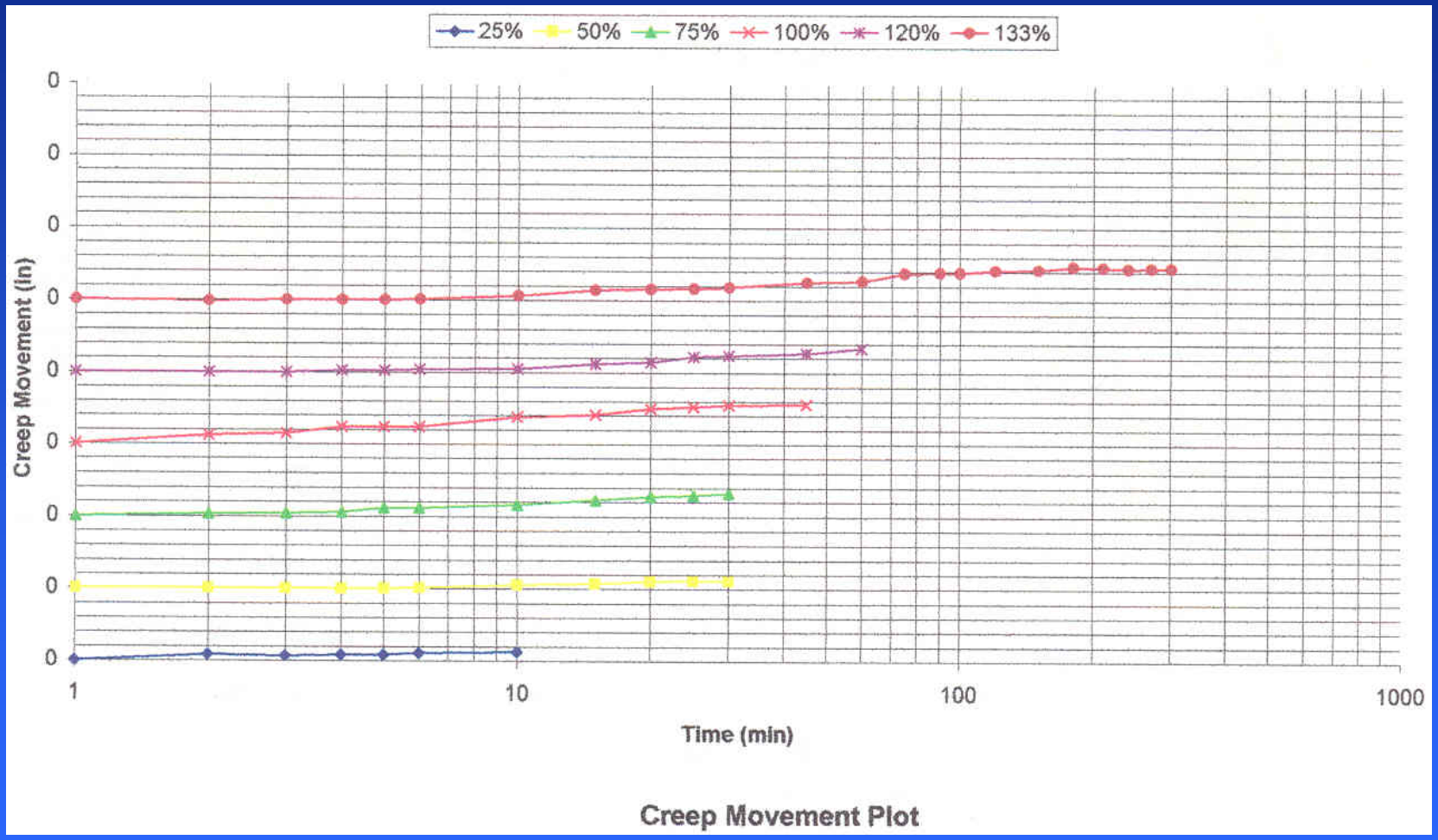
TEST ANCHOR PROGRAM
PHASE I REVISED



Creep Movement Plot

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TEST ANCHOR PROGRAM
PHASE II

- Core 4 investigation holes in spillway to an elevation of 1460
  - Collect and test samples for strength and consolidation
- 2 production anchors at gate 16 in existing spillway
  - One 32 strand anchor drilled at 18.4^{o} to elevation 1470
  - One 28 strand anchor drilled at 30.0^{o} to elevation 1470
  - 12 inch diameter hole
  - 40 foot bond zone
  - Conduct performance test and creep test

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ANCHOR INVESTIGATION
PHASE II

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ANCHOR INVESTIGATION
PHASE II

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ANCHOR INSTALLATION
PHASE II

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ANCHOR INSTALLATION
PHASE II

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ANCHOR INSTALLATION PHASE II

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ANCHOR INSTALLATION
PHASE II

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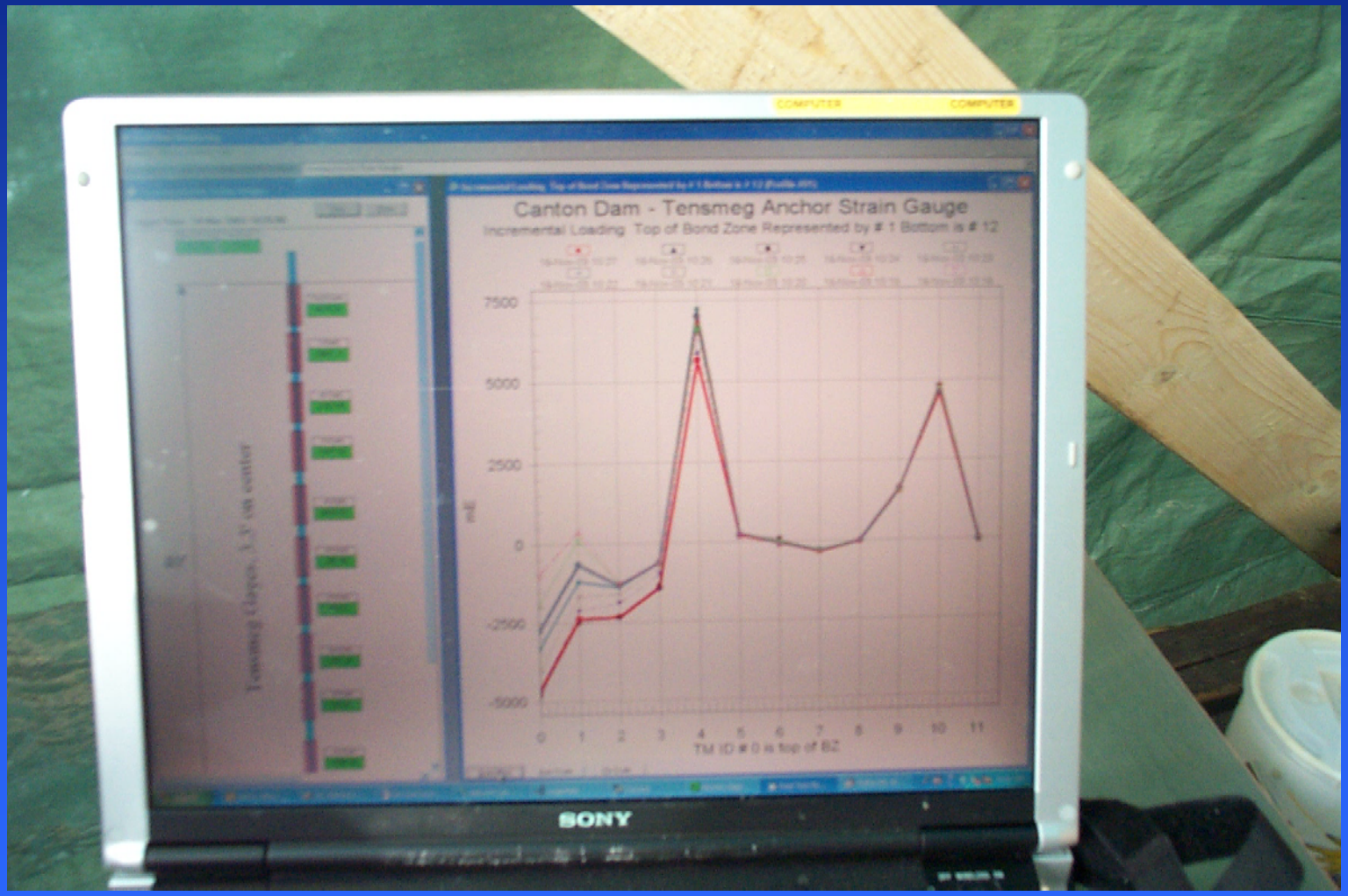
ANCHOR INSTALLATION
PHASE II



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ANCHOR INSTALLATION PHASE II FINDINGS

- Weir access is difficult
  - Slick surface
  - Tight workspace
  - Load limit on spillway bridge
- Continuous flow of cuttings is required
  - Falling cuttings blocked hole and drill tools
- Hole will cave in 12 to 24 hours
  - Duplex type casing would be ideal but none exists for this size of hole
- Control elongation of corrugated pipe
- Drill one hole and install corrugated pipe in that hole before starting another one

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ANCHOR INSTALLATION PHASE II FINDINGS

- Stage grout to avoid buckling corrugated pipe
- Measure top of grout accurately to avoid clogging of other grout tubes
- Consider single stage vs. two stage grouting
- Label grout and flush tube adequately

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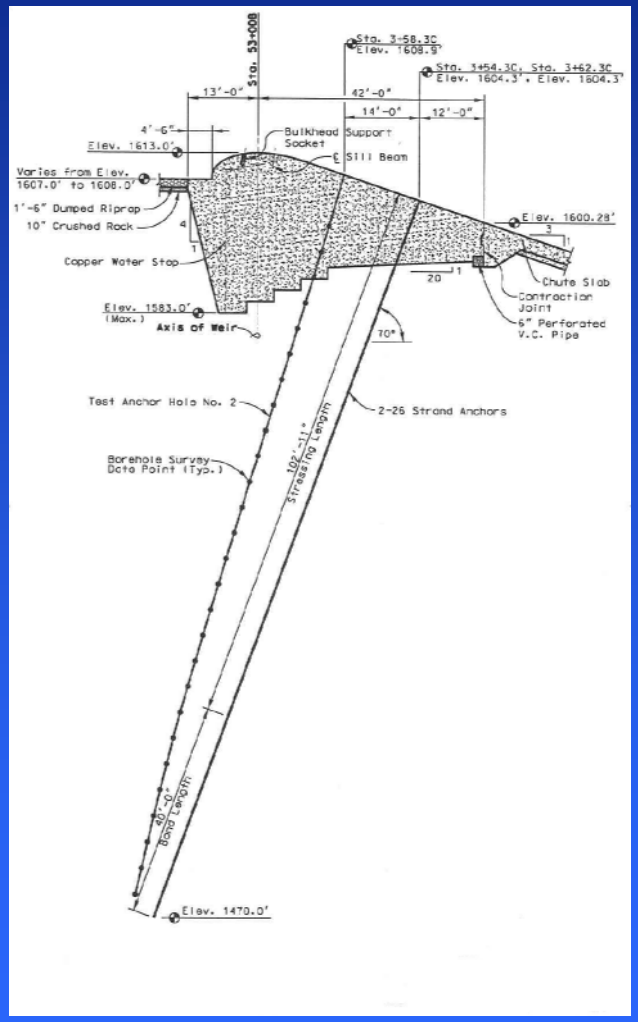
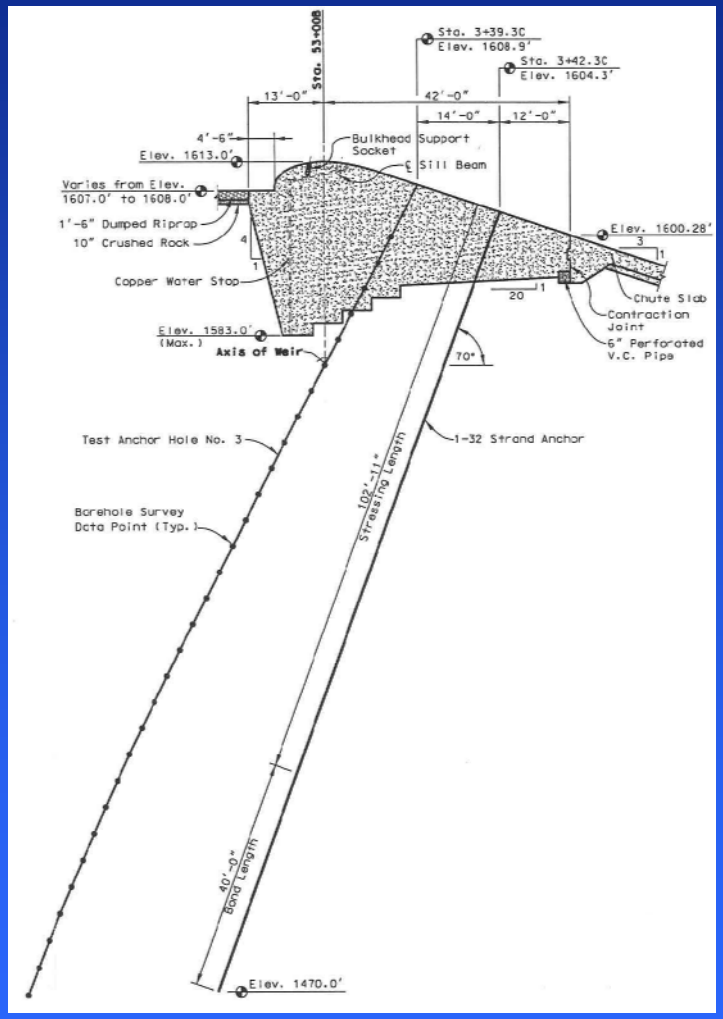
ANCHOR DESIGN





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CANTON DAM
SPILLWAY STABILITY

- **Summary**

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TEST ANCHOR PROGRAM SUMMARY

- **Ultimate Bond Stress Values**
  - **From PTI Table = 30 to 120 psi**
  - **From Unconfined Compressive Strength Tests = 30 to 45 psi**
  - **From Lab Bond Tests = 80 to 110 psi**
  - **From Pullout Tests = 100 to 220 psi**
    - No anchors failed during pullout test
  - **Full scale anchor tests loaded to 133% of design load = 83 psi working bond stress**

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TEST ANCHOR PROGRAM SUMMARY

- Total force required for weir section = 1,550 kips
  - 12 anchors would be required for an ultimate bond stress of 30 psi
  - 2 anchors are be required for an ultimate bond stress of 120 psi

- Total force required for pier section = 1,830 kips
  - 14 anchors would be required for an ultimate bond stress of 30 psi
  - 2 anchors are be required for an ultimate bond stress of 120 psi

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TEST ANCHOR PROGRAM
PHASE I & II SUMMARY

- **Phase I**
  - Cost approximately $700,000
  - Reduced the number of anchors from over 400 to 112
  - Cost savings of over $6,000,000
- **Phase II**
  - Cost approximately $800,000
  - Reduced the number of anchors from over 112 to 64
  - Cost savings of over $2,000,000
- **Total cost of $1,500,000**
- **Total savings over $8,000,000**
- **Return on the investment of more than 5 to 1**

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SPILLWAY STABILITY

CANTON LAKE

Is a Test Anchor Program Necessary?

It certainly was for us

Some considerations if you are thinking about a test program

- **Consider the total load required per monolith**
- **Consider the type of rock**
- **Consider the configuration of the structure**

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SPILLWAY STABILITY

CANTON LAKE

Tulsa District

Dam Safety Assurance Project
Is a Test Anchor Program Necessary?

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