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TEAMWORK

US Army Corps of Engineers

Los Angeles District

Portland District

SEVEN OAKS DAM

Outlet Tunnel Invert Damage


Santa Ana River Mainstem Project
Drainage Area
US Army Corps of Engineers ®
Los Angeles District
QUALITY
TEAMWORK
Seven Oaks Dam
San Bernardino County
Los Angeles County
Prado Dam
15
10
60
5
Orange County
Santa Ana River
Mill Creek Levee
San Timeteo Creek
91
60
Lower Santa Ana
Oak Street Drain
605
Riverside County
Marsh
55
Santiago Creek
Pacific Ocean

Seven Oaks Dam

- Authorized under WRDA 1986, 99th Congress 2nd Session, P.L. 99-662
- Flood Control Purpose
- Operate in Tandem with d/s Prado Dam
- Non-Federal Sponsors:

  Orange County Flood Control District

  San Bernardino County Flood Control District

  Riverside County Flood Control and Water Conservation District

Seven Oaks Dam

Seven Oaks Dam
Pertinent Data

• River	Santa Ana River
• County and State	San Bernardino County, California
• Purpose	Flood Control
• Drainage Area	177 mi2
• Type	Rolled, zoned, earth and rockfill
• Crest elevation (excluding overbuild)	2,610 feet, NGVD
• Foundation elevation at dam axis	2,060 feet, NGVD
• Maximum height above foundation at dam axis	550 feet
• Freeboard	5.3 feet
• Crest length	2,760 feet
• Crest width	40 feet
• Crest overbuild	varies from 0 to 3 feet
• Downstream	1.8H to IV
• Upstream	2.2H to IV
• Total embankment volume	38,372,510 cubic yards

Seven Oaks Dam
Pertinent Data

• Debris pool (year 1)	2,200 feet, NGVD
• Debris pool (year 100)	2,300 feet, NGVD
• Reservoir design flood pool	2,580 feet, NGVD
• Probable maximum flood pool	2,604.7 feet, NGVD

Gross capacity

• Reservoir design flood pool (spillway crest)	147,970 acre-feet
• Probable maximum flood pool	169,177 acre-feet
• Top of dam	174,609 acre-feet

Storage allocation (below spillway crest)

• Flood control	115,970 acre-feet
• Sedimentation (100 year storage)	32,000 acre-feet

Seven Oaks Dam
Pertinent Data

Reservoir design flood (general storm)

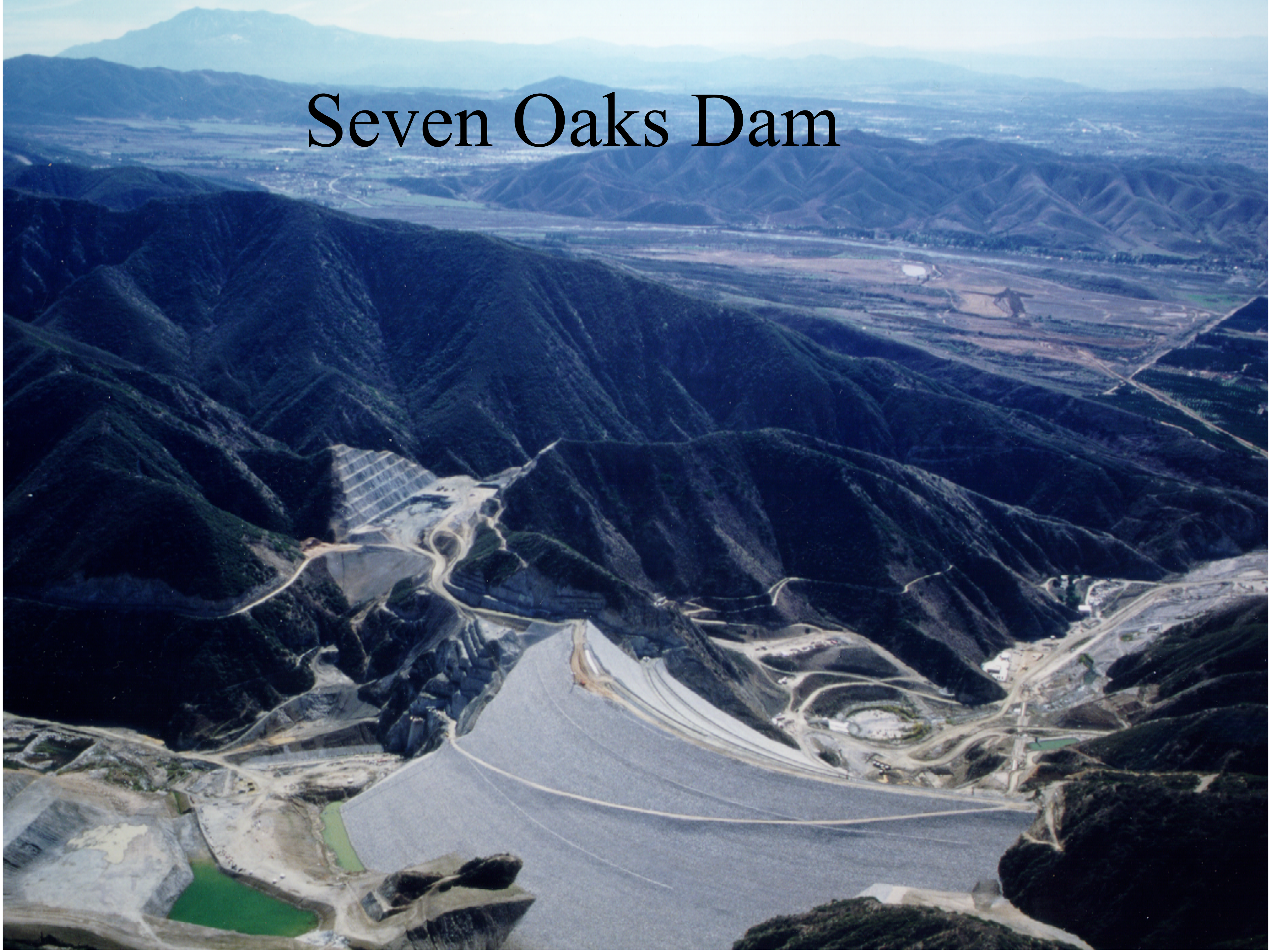
• Total volume (4 day)	115,000 acre-feet
• Peak inflow	85,000 ft3/sec
• Peak outflow	7,000 ft3/sec

Probable maximum flood (general storm)

• Total volume	326,000 acre-feet
• Peak inflow	185,000 ft3/sec
• Peak outflow	180,000 ft3/sec

Chronology

- 1980 Phase I General Design Memorandum
- 1988 Phase II GDM
- 1989 Construction of Pilot Tunnel
- 1991 Partial Intake Structure
- 1992 Diversion Tunnel
- 1999 Dam and Outlet Works
- 2005 High Flow Testing and Tunnel Damage

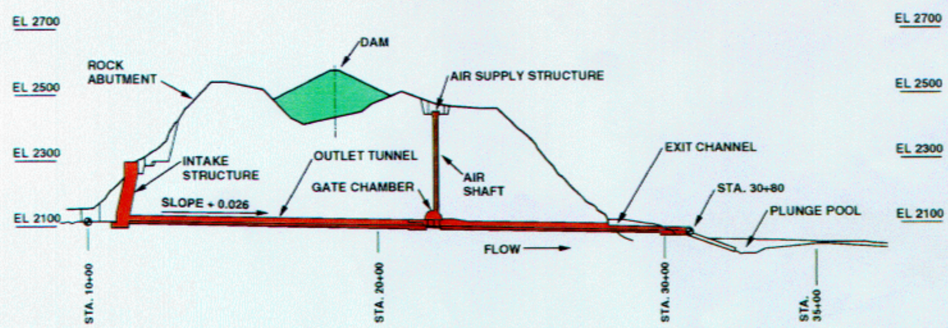

Seven Oaks Dam

SEVEN OAKS DAM

OUTLET WORKS PROFILE

OUTLET WORKS

- 1,600-FOOT LONG TUNNEL
- 200-FOOT HIGH INTAKE STRUCTURE
- 300-FOOT HIGH AIR SHAFT
- GATE CHAMBER
- EXIT CHANNEL
- PLUNGE POOL

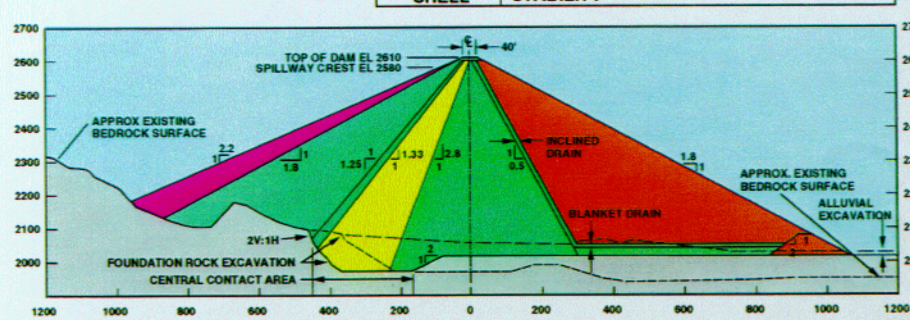


EMBANKMENT CROSS SECTION

DAM

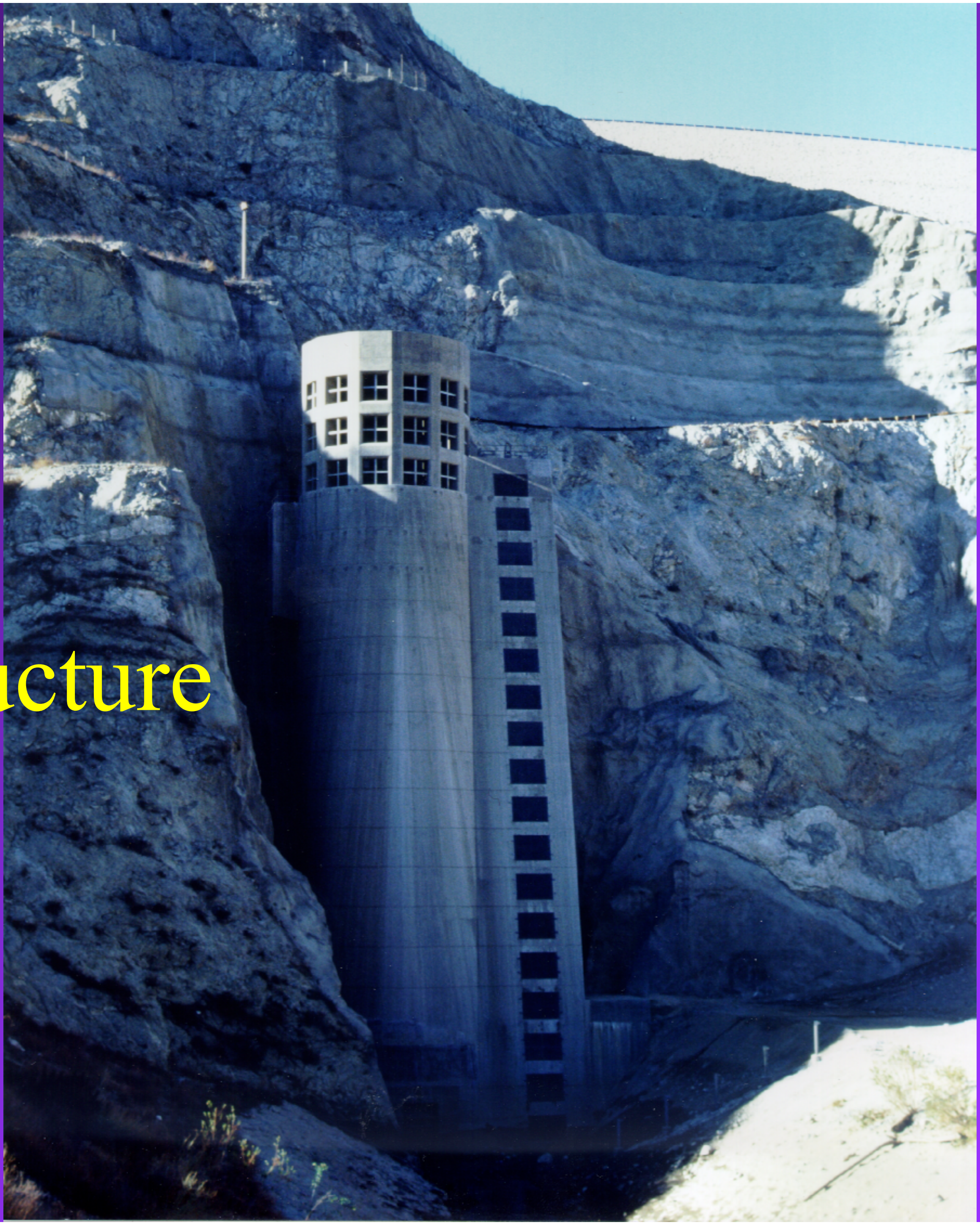
- 550-FOOT HIGH
- 3,000-FOOT LONG
- 40-FOOT WIDE AT CREST
- 2,000 FEET FROM U/S TOE TO D/S DOT

ZONE	PURPOSE
CORE	WATER BARRIER
TRANSITION	DRAINAGE, STABILITY, AND ECONOMICAL USE OF EXCAVATED MATERIALS
ROCKFILL	STABILITY AND ECONOMICAL USE OF EXCAVATED MATERIALS
SHELL	DRAINAGE, EROSION CONTROL, AND STABILITY

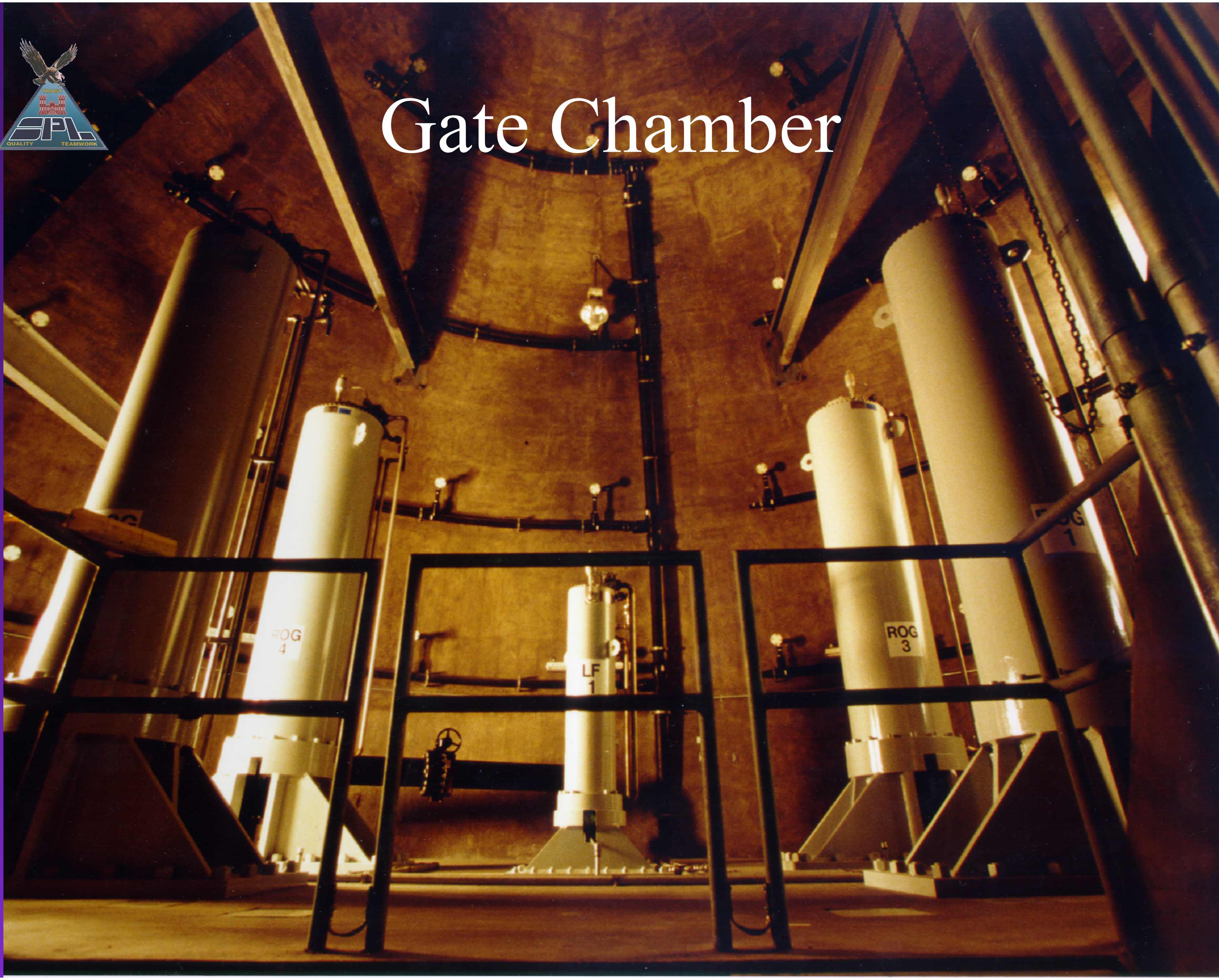


Embankment and Intake Structure

Intake Structure



Gate Chamber



Hydraulic Gates

LOOKING U/S RO GATE FRAMES
& ATTACHED BONNETS & CYLINDERS
FORMWORK FOR GATE PASSAGES

Sep1988

Access Tunnel

Embankment and Plunge Pool

Hydraulic Design Requirements

- High velocity flow cavitation concern
- 1:25 physical model testing at WES/ERDC
- Flow aeration
- Embed pressure transducers in tunnel for flow testing
- High flow testing to verify design

WATER YEAR PRECIPITATION SUMMARY

Summary by River Basin (% of Historic Average)
For the period Oct 1, 2004 to Jun 30, 2005

	Oct-Jun	Season
• Santa Barbara Area	221	217
• Ventura – Los Angeles Area	236	231
• Santa Ana River	226	217
• San Diego Area	190	183

Ref: California Cooperative Snow Surveys
(http://cdec.water.ca.gov/cgi-progs/iodir/PRECIPSUM.2005)


2301


High Pool El.2392(March 2005)


High Pool El.2392(March 2005)


High Pool El.2392(March 2005)

Hydraulic Testing

Table 1 Testing Schedule and Maximum Discharge Rates

Testing Schedule Feb 17 - Mar 9		Testing Pool (ft)	Range of Gate Openings	Maximum Test Flow Rate (cfs)	Maximum Operational Flow Rate* (cfs)
21-Feb	MDL Test	2373	10%-100%	135	120
22-Feb	MDLE Test	2373	100%	115	100
25-Feb	Low Flow Test	2383	0.25' - 3'	560	700
8-Mar	Right RO Gate Test low Openings	2391	0.5' - 3'	1540	
9-Mar	Right RO Gate Test-High Openings	2392	3.5' - ~~8'~~ 5'	~~3000~~ 2520	4900
~~10-Mar~~	~~Combined RO Gate Test**~~	~~2200~~	~~0.5' - 6.8'~~	~~6600~~	8000

* Maximum Operational Flow Rate is stated in the *Seven Oaks Water Control Manual*, Corps of Engineers, Los Angeles District 2003

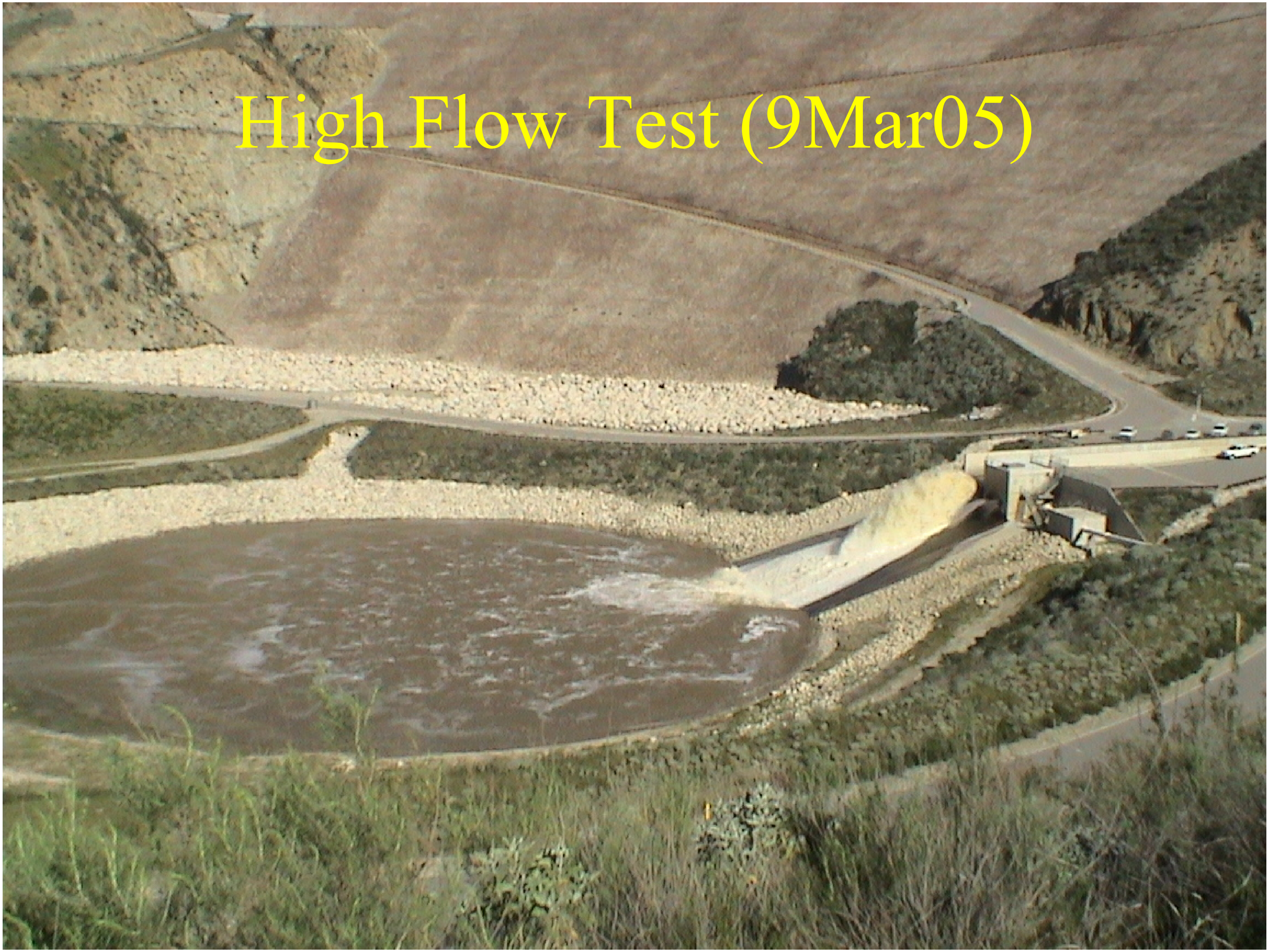
Maximum pool for RO gates is 2580 ft, Maximum pool for MDL and MDLE = 2300 feet

Max. opening for two gate operation = 6.8 feet; max. opening for single gate operation = 8 feet

** stricken items were cancelled due to slab failure


Minimum Discharge Line Flow Test


Cone Valves Flow Jet


High Flow Test (9Mar05)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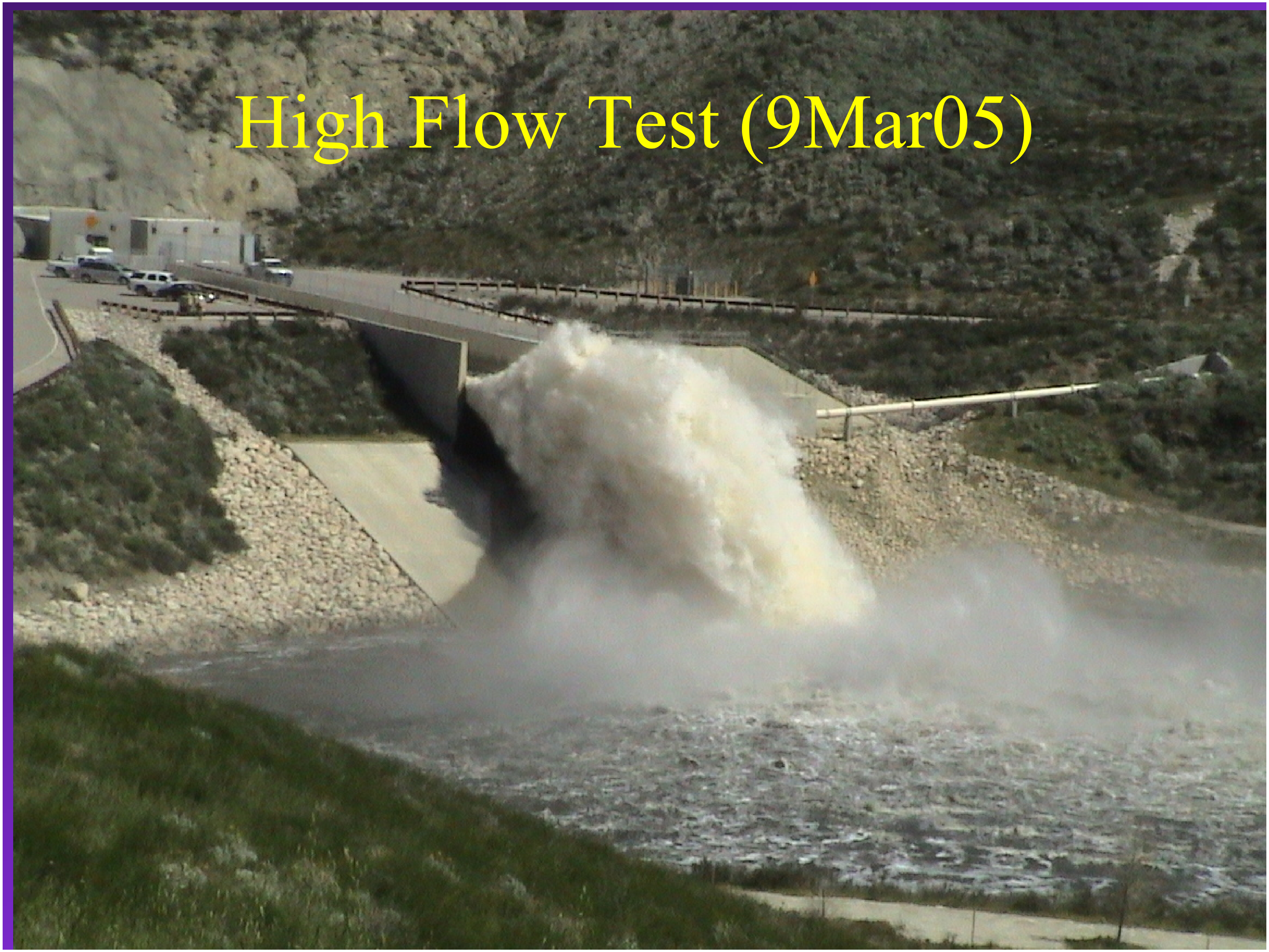
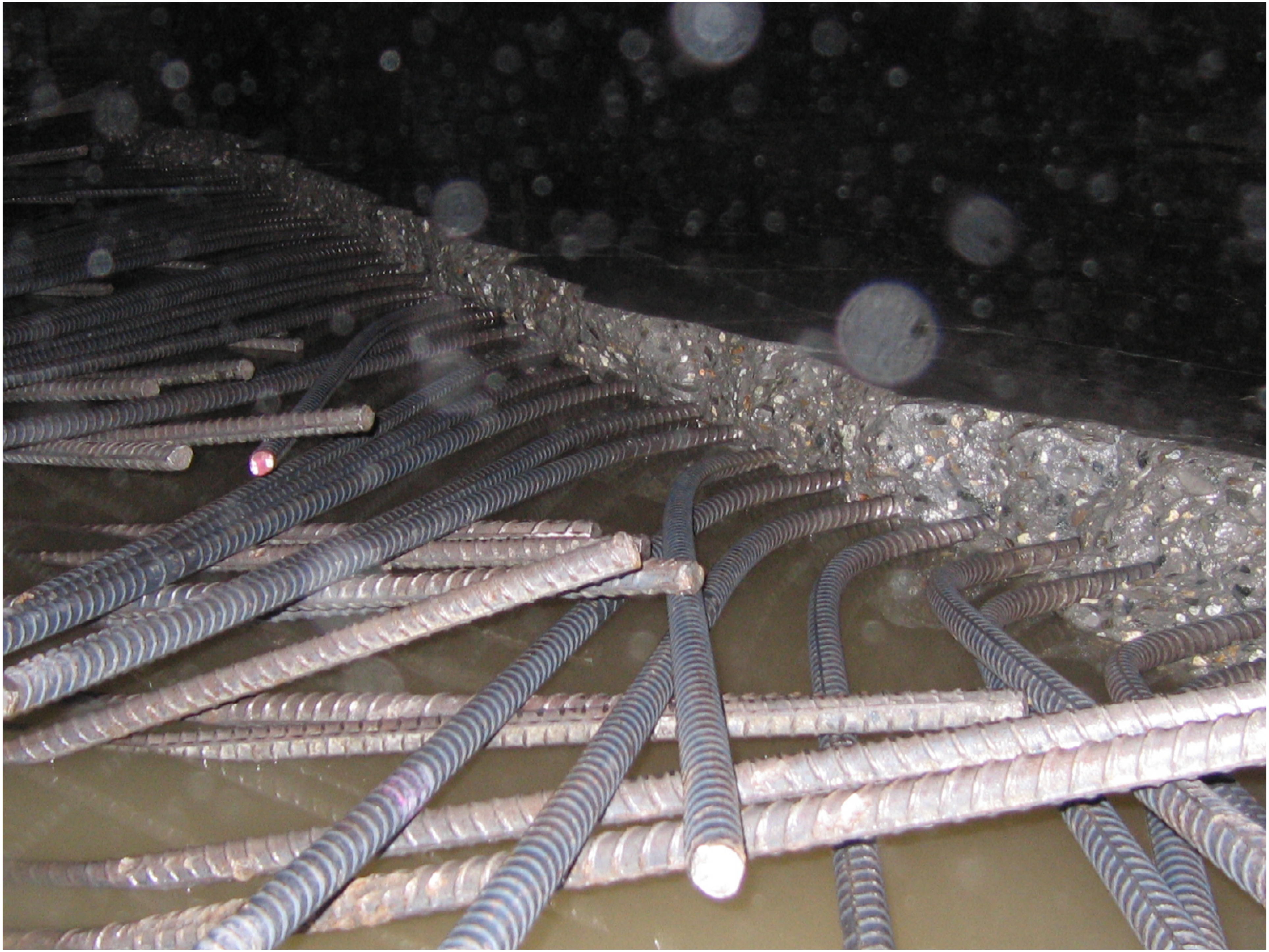
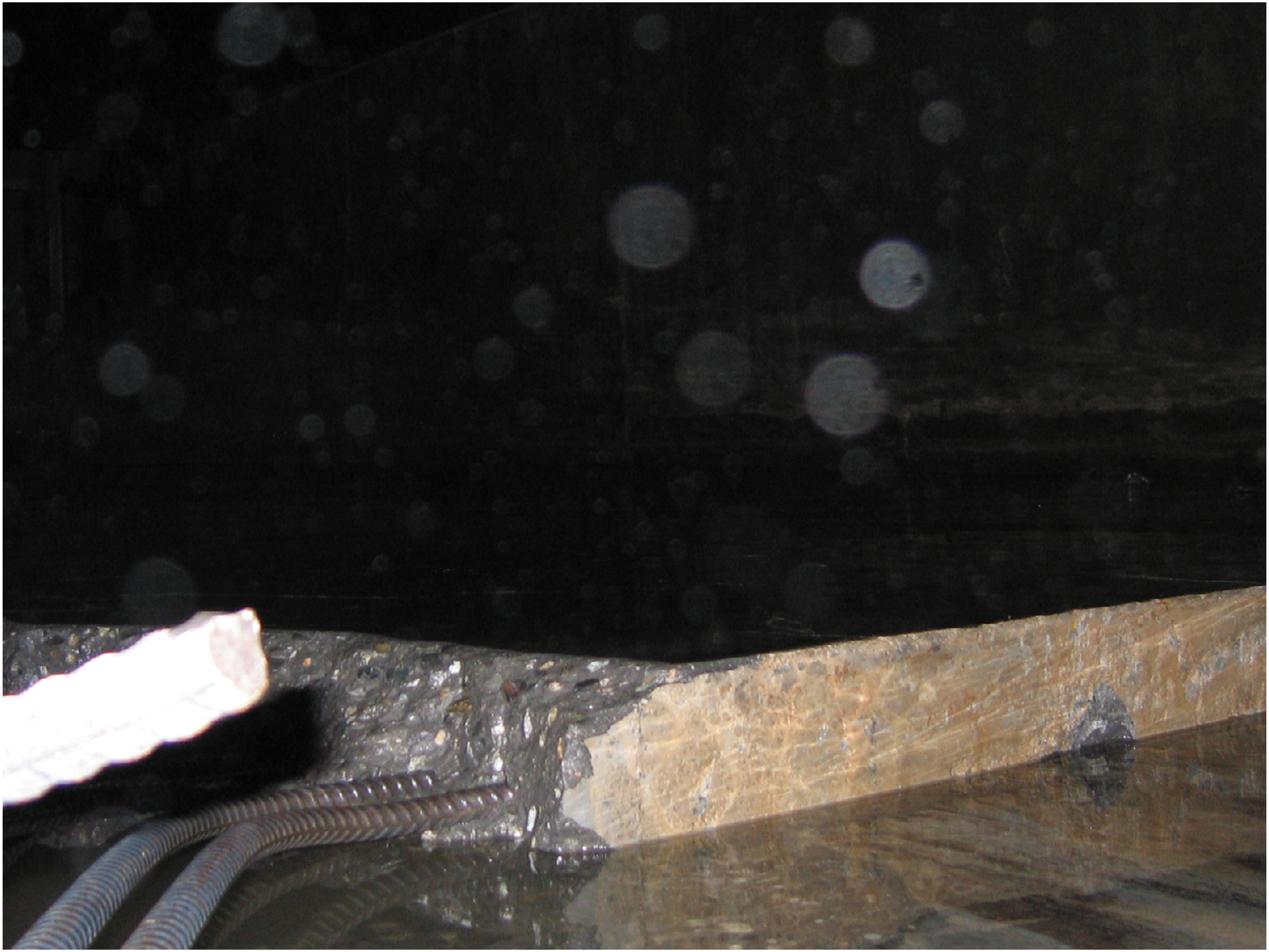



High Flow Test (9Mar05)





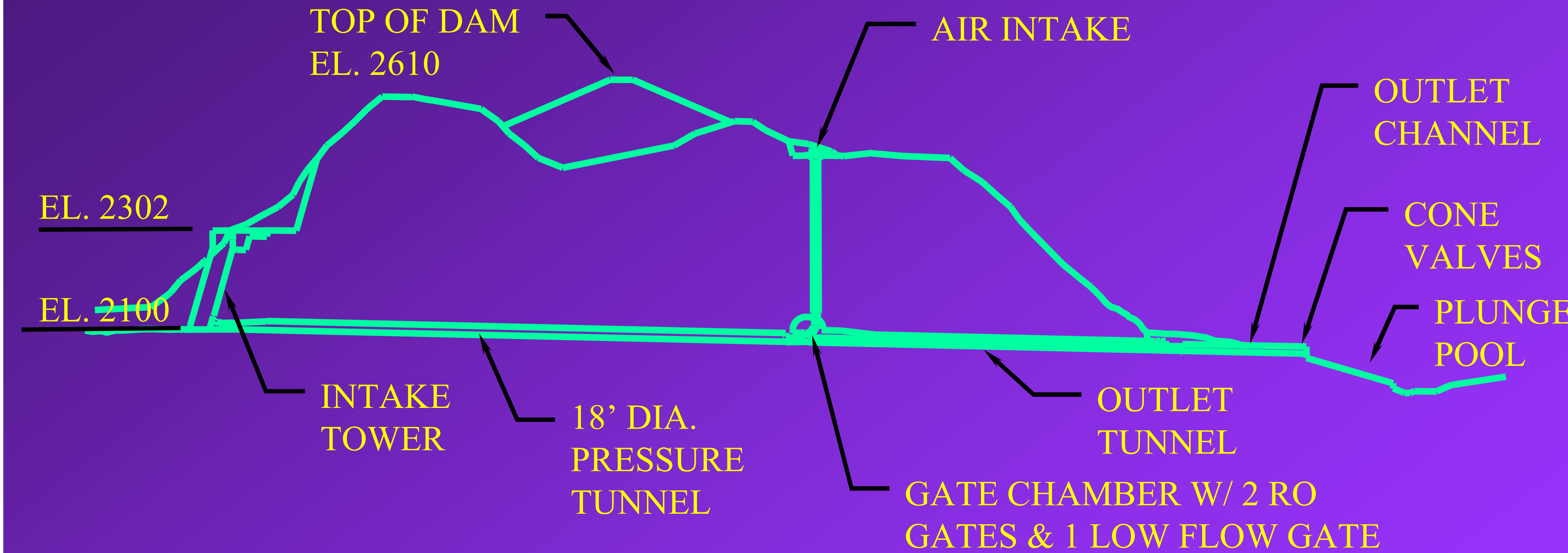
What Happen?

- Was it caused by cavitation?
- Debris impact?
- Groundwater uplift?
- Negative air pressure?
- Differential concrete shrinkage?
- Design deficiency?
- Construction defect?
- Earthquake?

“Just the Facts, Ma’am”

Courtesy of Sgt. Joe Friday
“Dragnet” Detective Drama Series
1952-59,1967-70

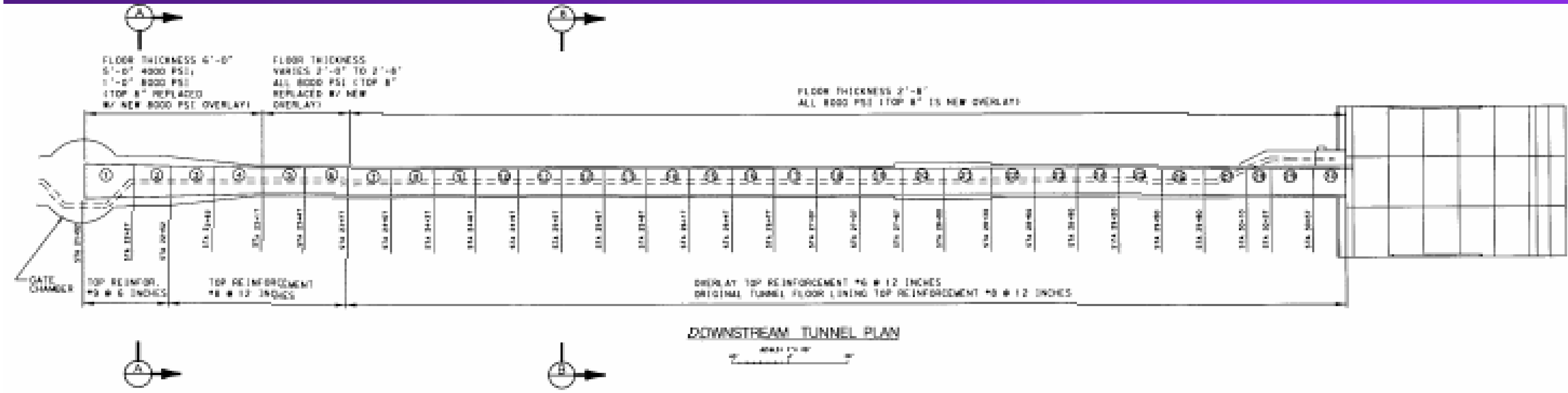
SEVEN OAKS DAM



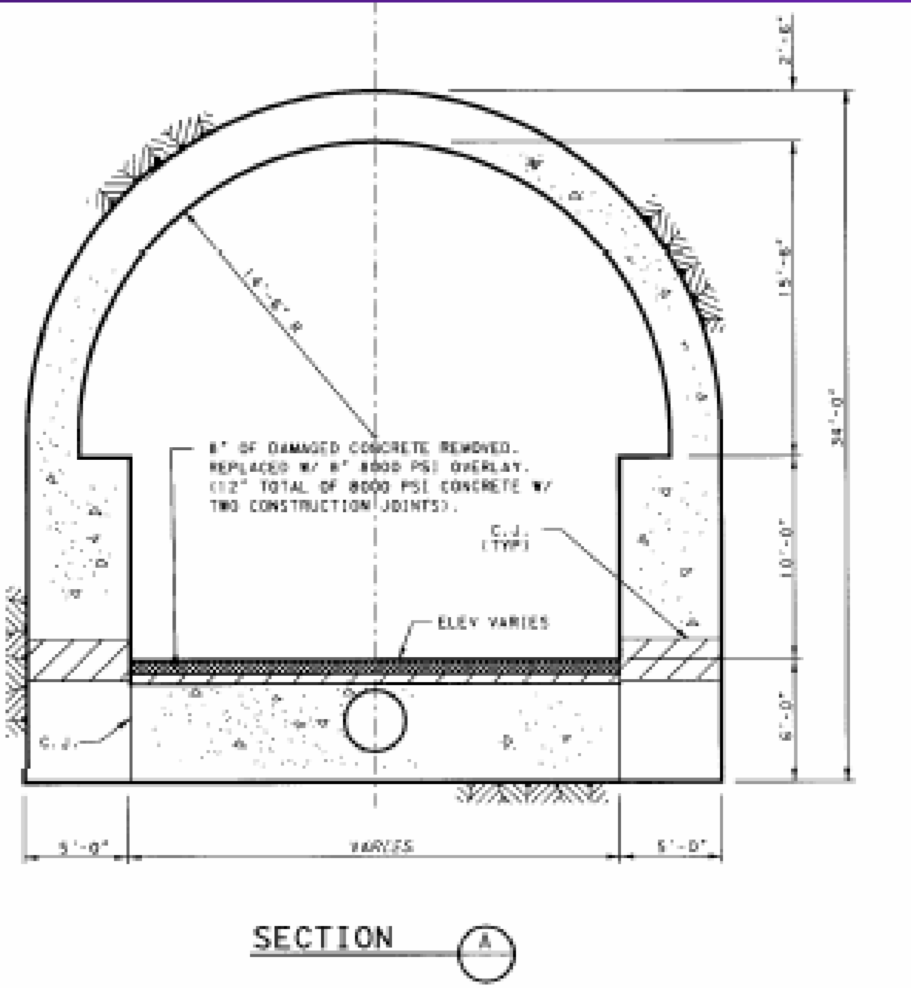
SEVEN OAKS DAM

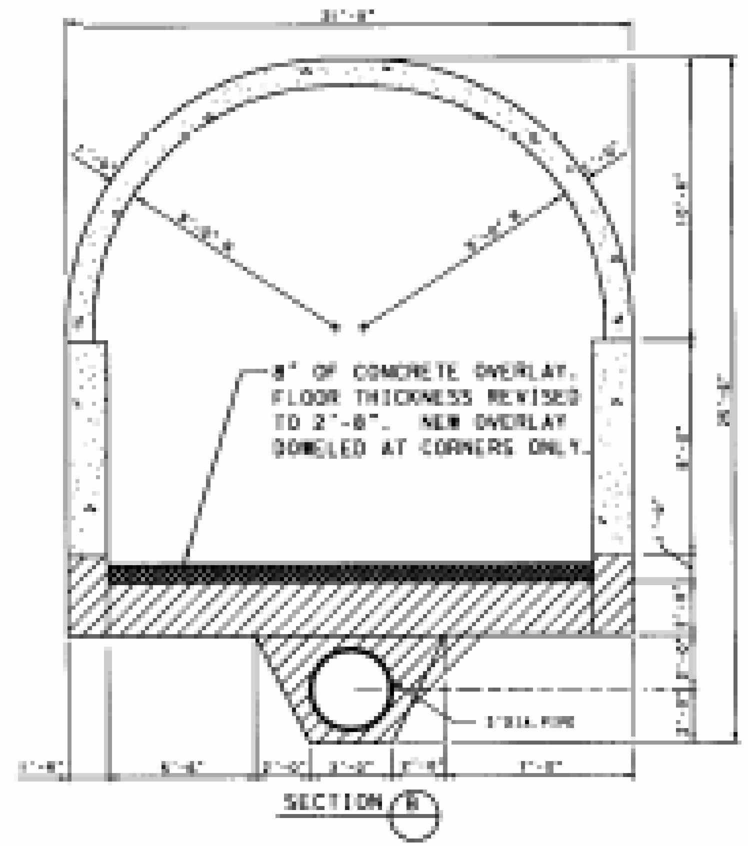
- Reservoir Height - 291 ft.
- Tower Height - 200 ft.
- U/S Tunnel - 18’ dia., 1000’ long
- D/S Tunnel - 18’ X 18.5’, 600’ long
- Gate Chamber - 50’ dia.
- Air Shaft - 11’ dia., 320’ vertical, max. v=140 fps
- 2 RO Gates - 5’ wide X 8.5’ high
- 1 Low Flow Gate – 2’ wide X 3.5’ high
- Max. Q=8,000 cfs, max. v=115 fps @ RO gates

Downstream Tunnel Plan



Downstream Tunnel
Section 1 and Section 2





Instrumentation

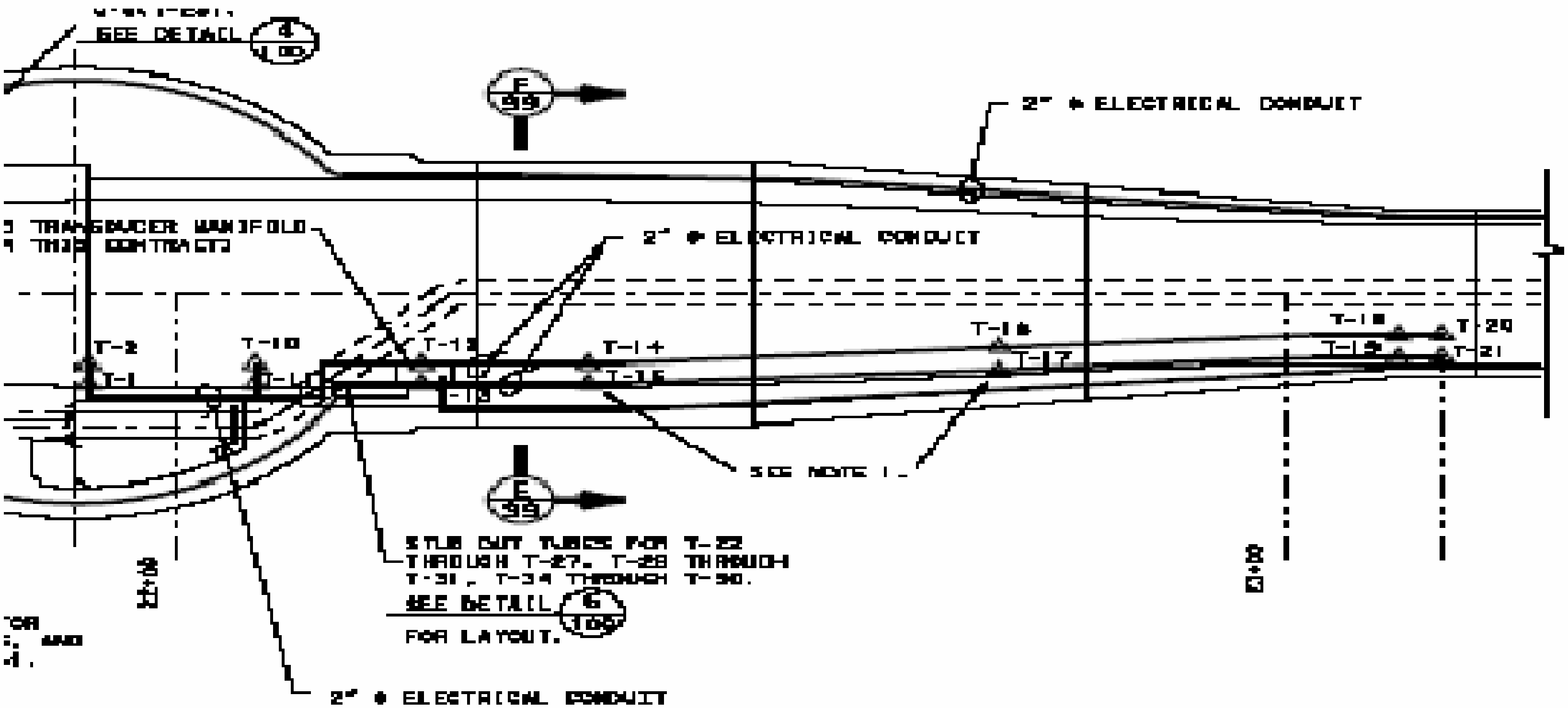


Figure 3 Plan View of Instrumentation (Flush Mounted Pressure Transducers)

Design Assumptions

- Resist external rock and groundwater
- Invert designed as full-depth beam
- High strength silica fume topping for erosion resistance of high velocity flow
- Silica fume bond to base concrete and act monolithically
- No epoxy bonding agent
- No reinforcement across transverse joints

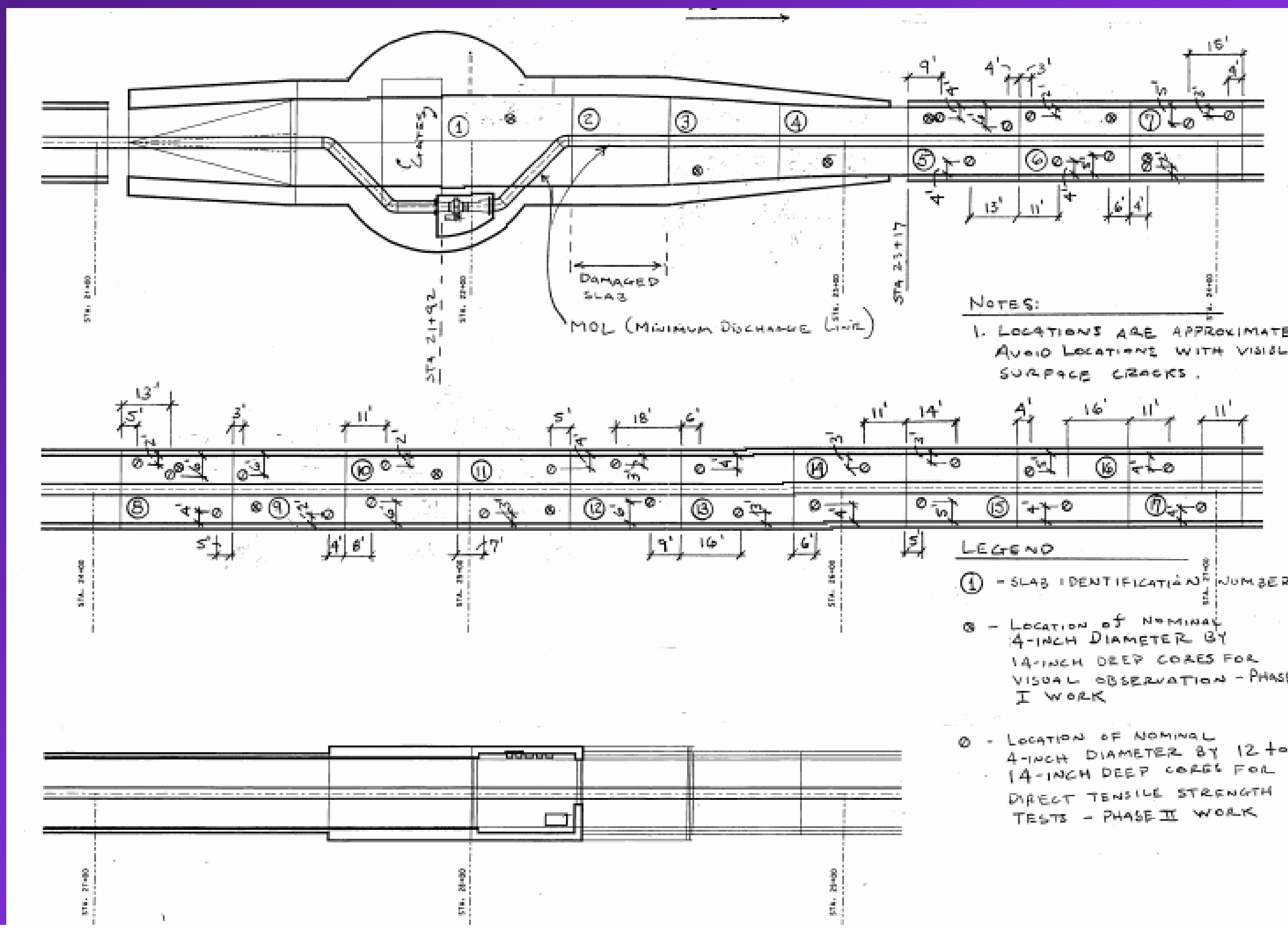
SEVEN OAKS DAM
Investigation and Repair

- Phase 1- Concrete Cores for Visual, Petrography, and Strength Tests
- Phase 2 – Additional Concrete Cores for Visual, Detail Petrography, and Tensile Tests
- Phase 3 – Demolition of Critical Slabs
- Phase 4 - Repair of Critical Slabs
- Phase 5 – Repair of Additional Slabs

Concrete Coring Investigation

(Apr & May05)

67% Cores Debonded



Slab 1 Damage Surface

Fig. 3a – Cracking, delamination, and erosion of Slab 1 surface

Slab 2 Concrete Cores

Fig. 6 – Top surfaces (SFC-CC interface) of Slab 2 cores

Slabs 1 to 17 Typical Concrete Cores

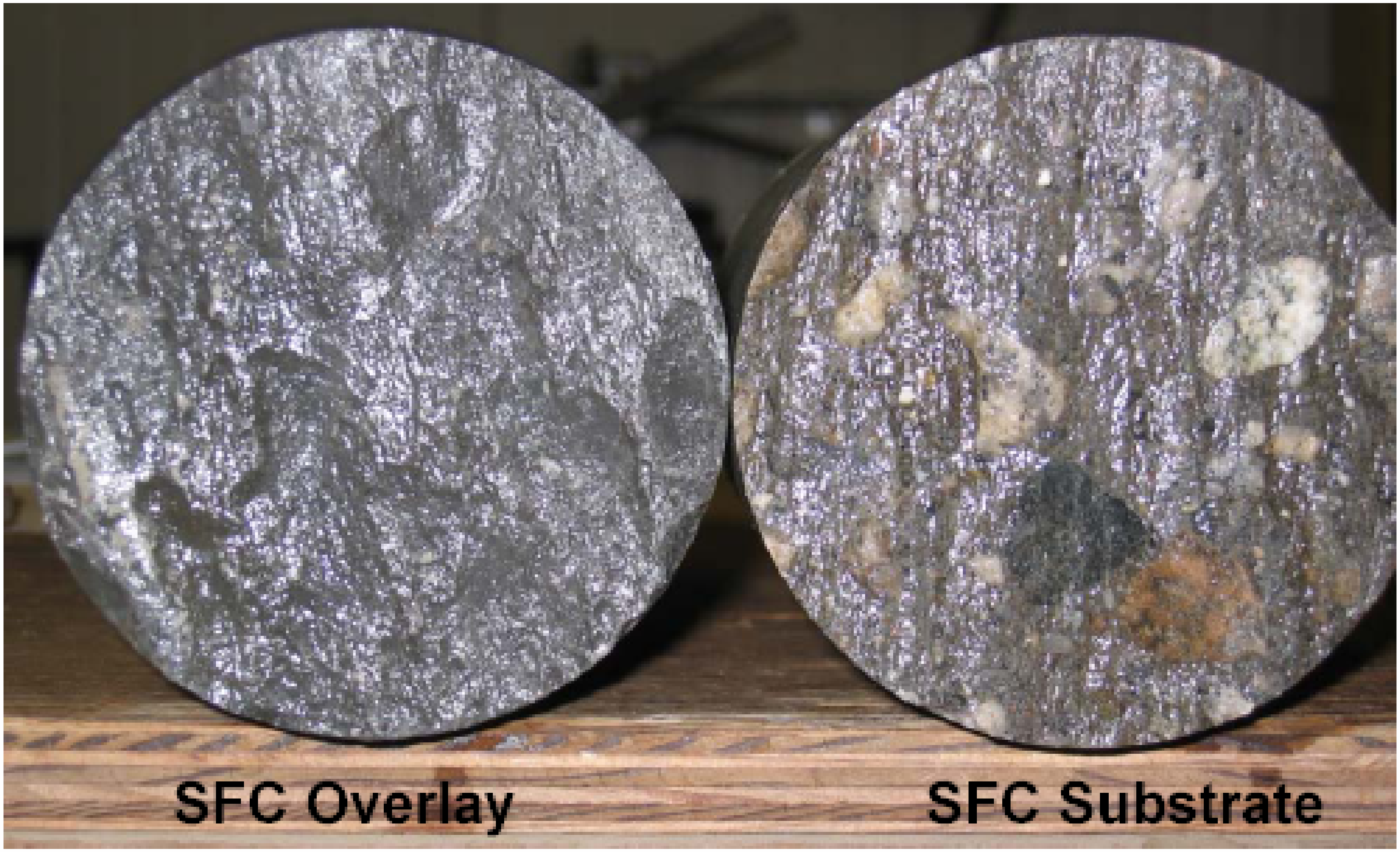


Fig. 9 – Typical failure surfaces on cores from Slabs 7-17

Concrete Cores Investigation

- Phase 1- Concrete Core Testing

  > Completed – 27 Apr 05

  > 67 % cores debonded

  > Compressive strength tests pending

  > Cursury petrography suggests tensile failure from incomplete bond development due to improper surface preparation or cold joint formation;

  > Veneer of carbonate deposit

Concrete Cores Investigation

- Phase 2 – Additional Concrete Core Testing

  > Completed – 4 May 05

  > 63 % cores debonded

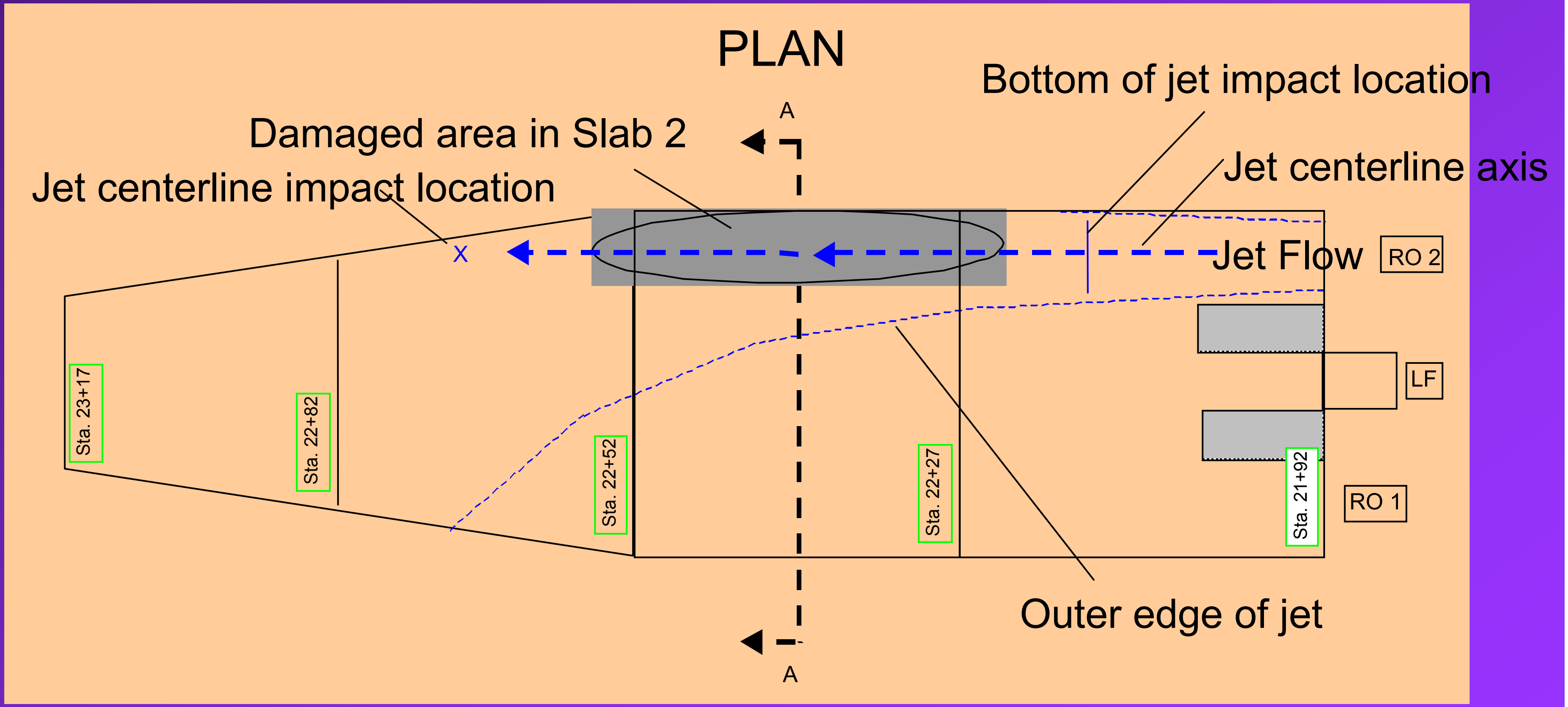
  > Prelim detailed petrography confirms SC/CC interface exhibits layer of solidified carbonate-based residue;

  >Inadequate surface roughness for mechanical bonding; weak concrete at interface due higher W/C;
  >Final report pending

Analysis

- Reservoir at el.2392
- Gate opening at 5.0 ft
- Flow rate 2,520 cfs
- Velocity 130 ft/s
- Stagnation pressure 120 psi, but jet impingement pressure estimated 5 to 10 psi
- Pressure highest at invert joint with wall
- Only 0.7 psi to uplift silica fume layer

Plan View of Damaged Slab Area



Free-Body Diagram of Damaged Slab Cross-section

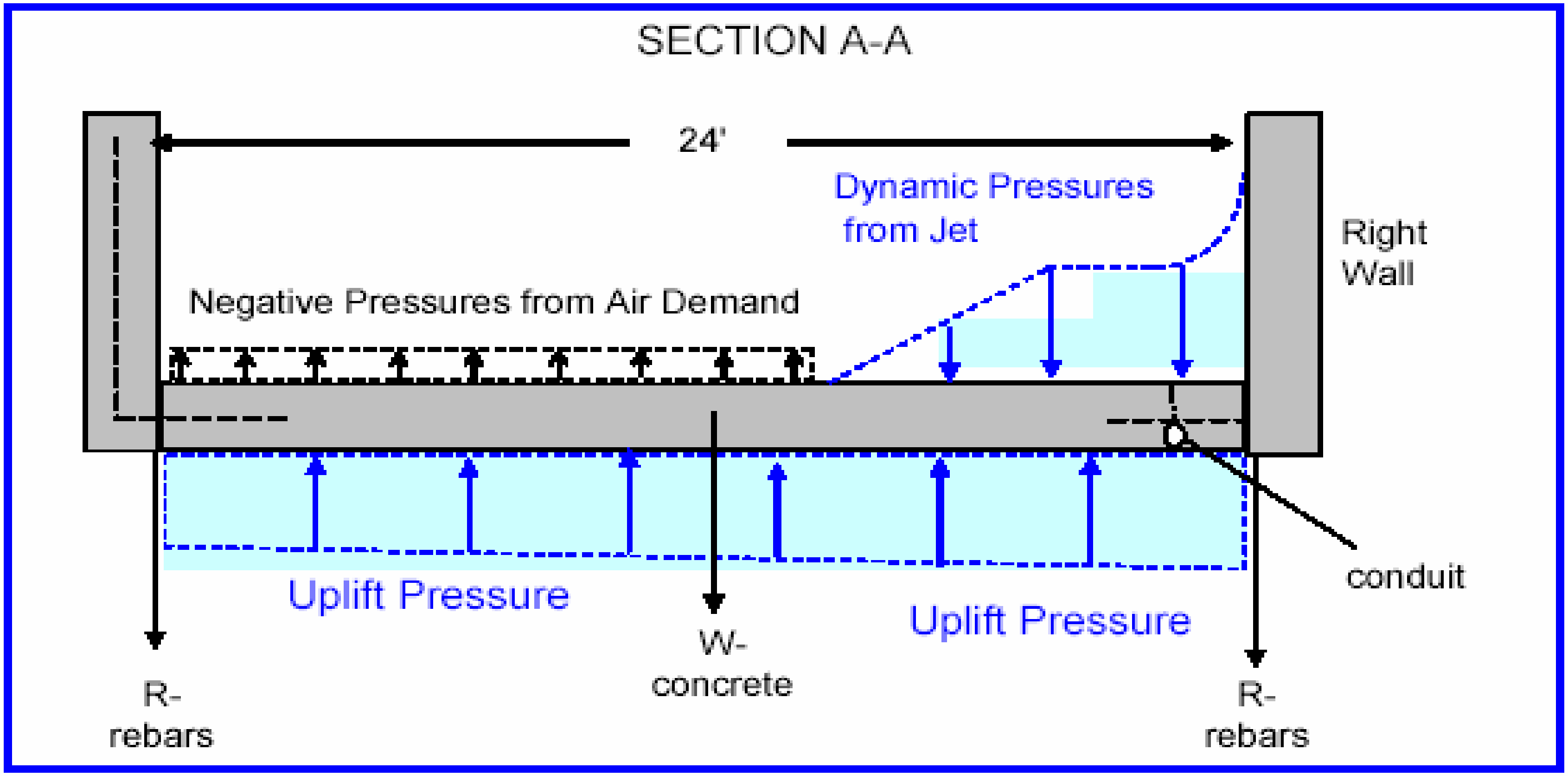


Figure 24 Tunnel Floor Free Body Diagram

Flow Jet Trajectory

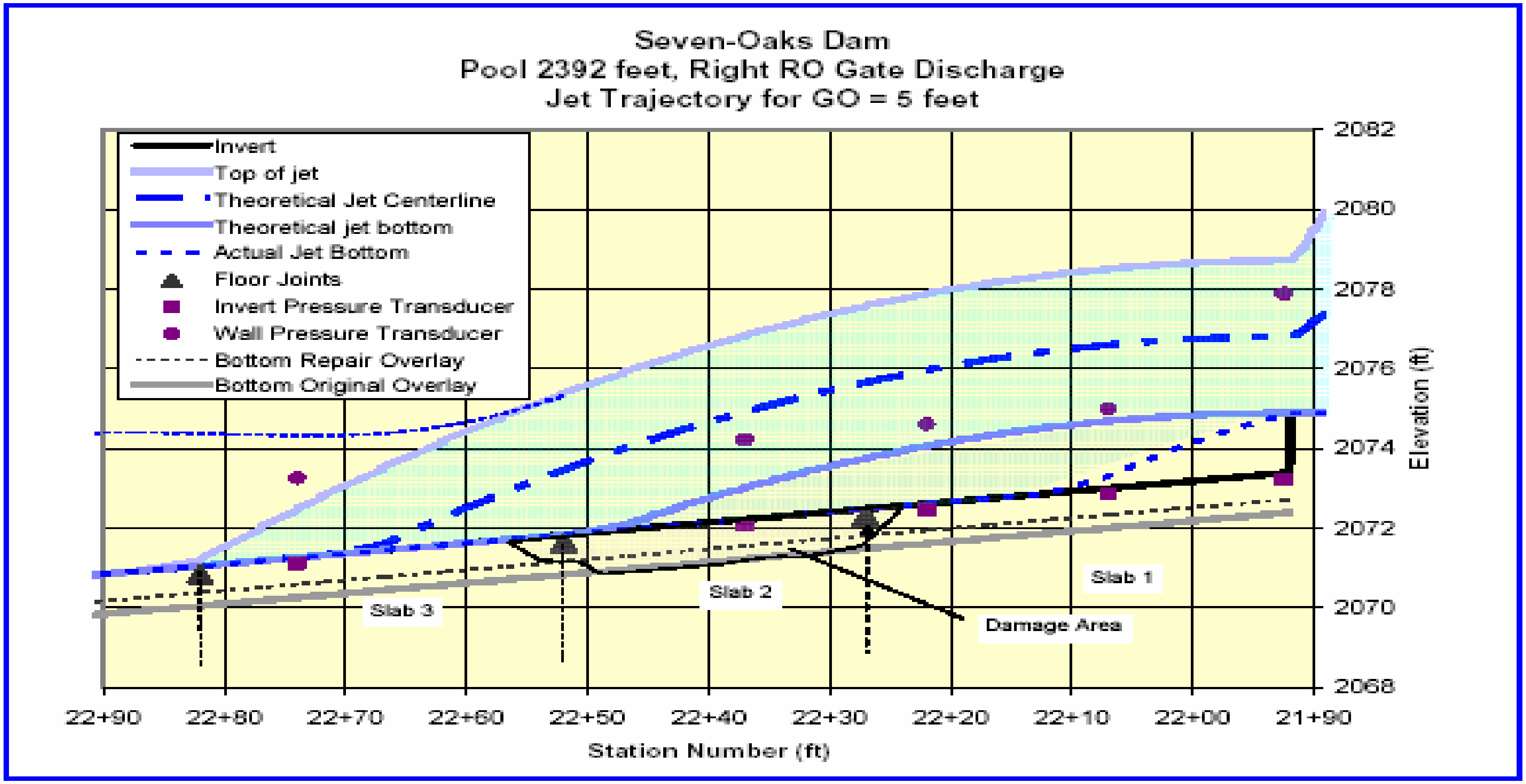


Figure 23 Schematic of Jet Trajectory at Gate Opening 5 feet, Prior to Failure Event

SEVEN OAKS DAM
Tunnel Invert Damage - Cause

- Water Pressure from high velocity flow jet penetrates construction joints.

Tunnel Invert Damage - Cause

- Pressure migrates through seams between poorly bonded to debonded silica fume concrete overlay and substrate concrete and increases.

Tunnel Invert Damage - Cause

- Water pressure under overlay combined with reduced air pressure breaks bond between overlay and substrate concrete, and lifts up overlay.

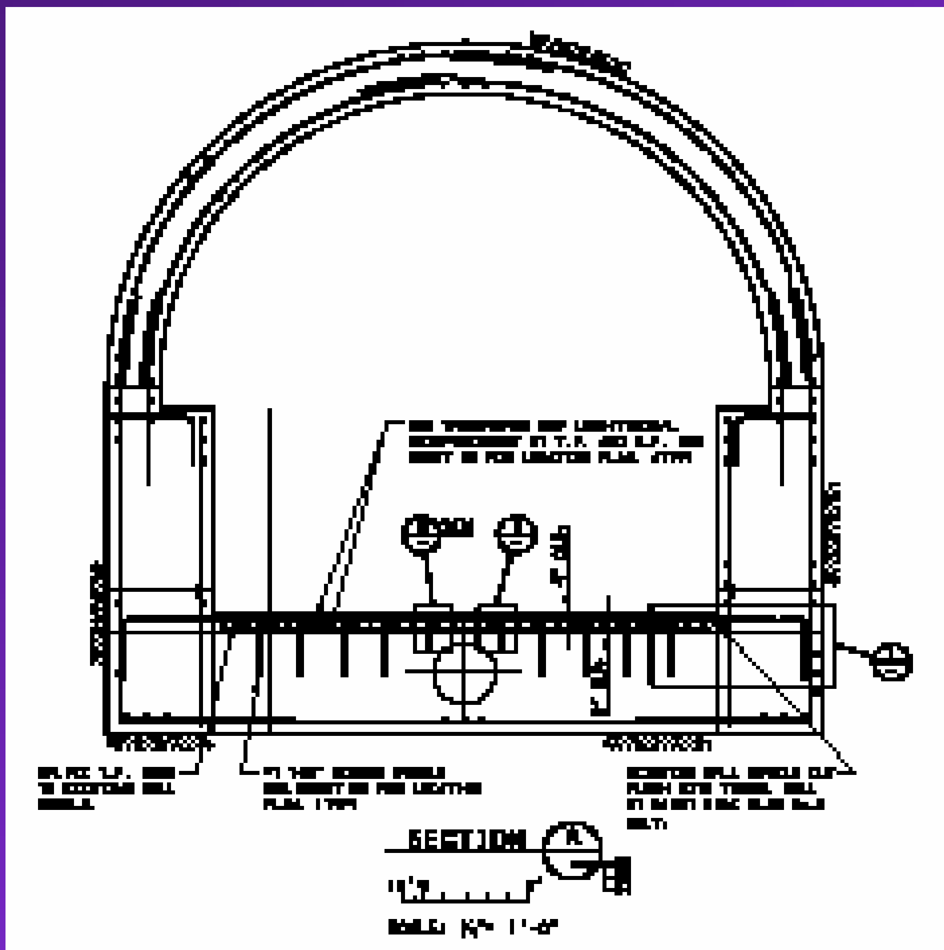
Tunnel Invert Damage - Cause

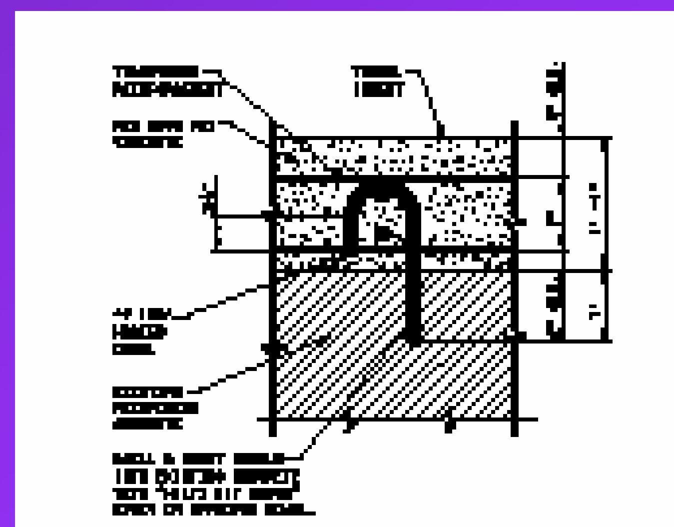
- Impact from jet breaks up overlay slab, pulverizes slab into smaller pieces, and completely erodes away edge of overlay.

SEVEN OAKS DAM
Tunnel Invert Repair Plan

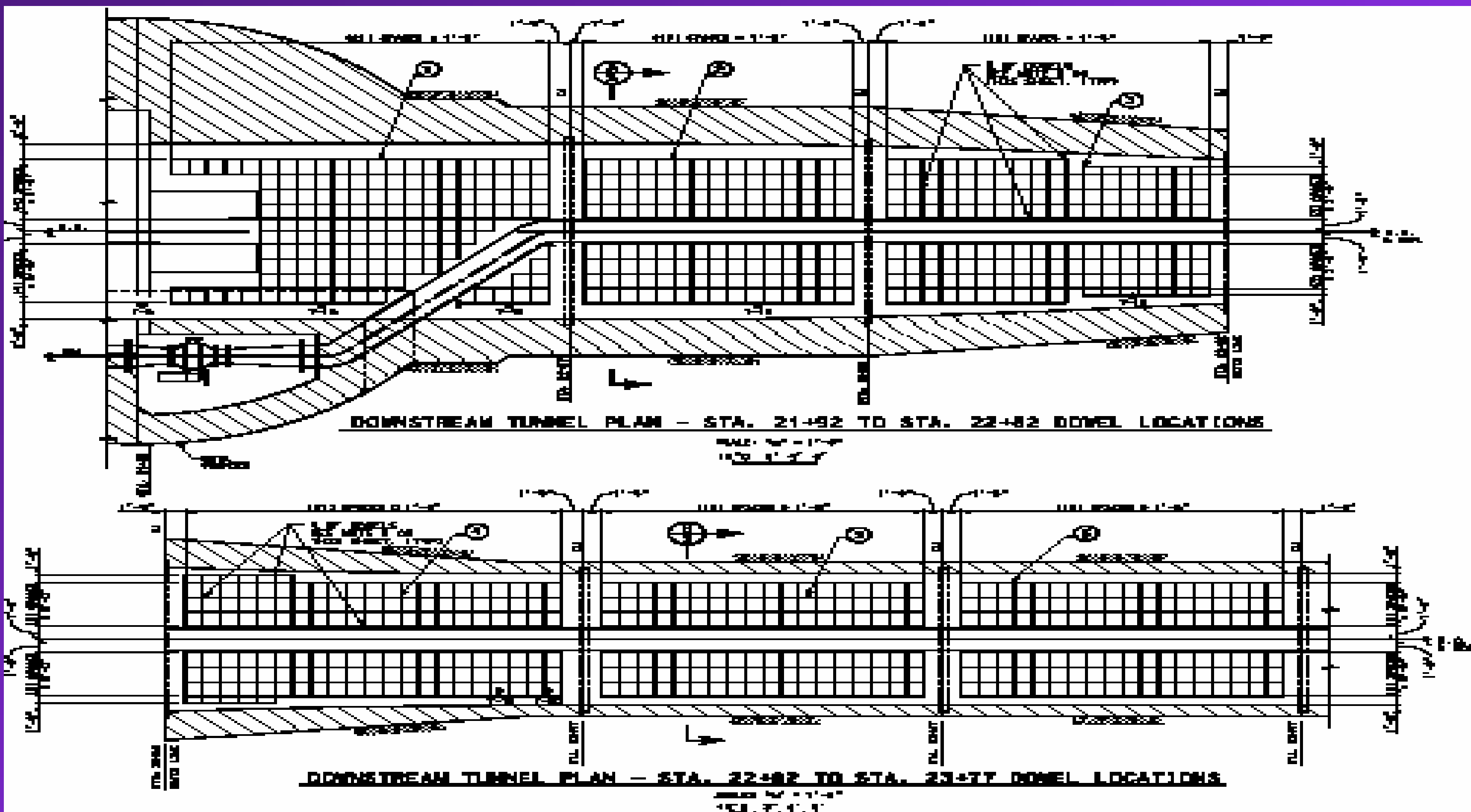
- Remove Damaged and Suspect Slabs
- Anchor New Overlay to Base Concrete
- Assure Proper Joint Preparation & Bond Enhancement
- Use Non-Shrink High Strength Concrete

Slab Repair Plan





Slab Repair Plan



SEVEN OAKS DAM
Repair Schedule

- Phase 3 – Demolition Critical Slabs 1 to 6

  Construction Complete – 5 Aug 2005

- Phase 4 – Repair Critical Slabs 1 to 6

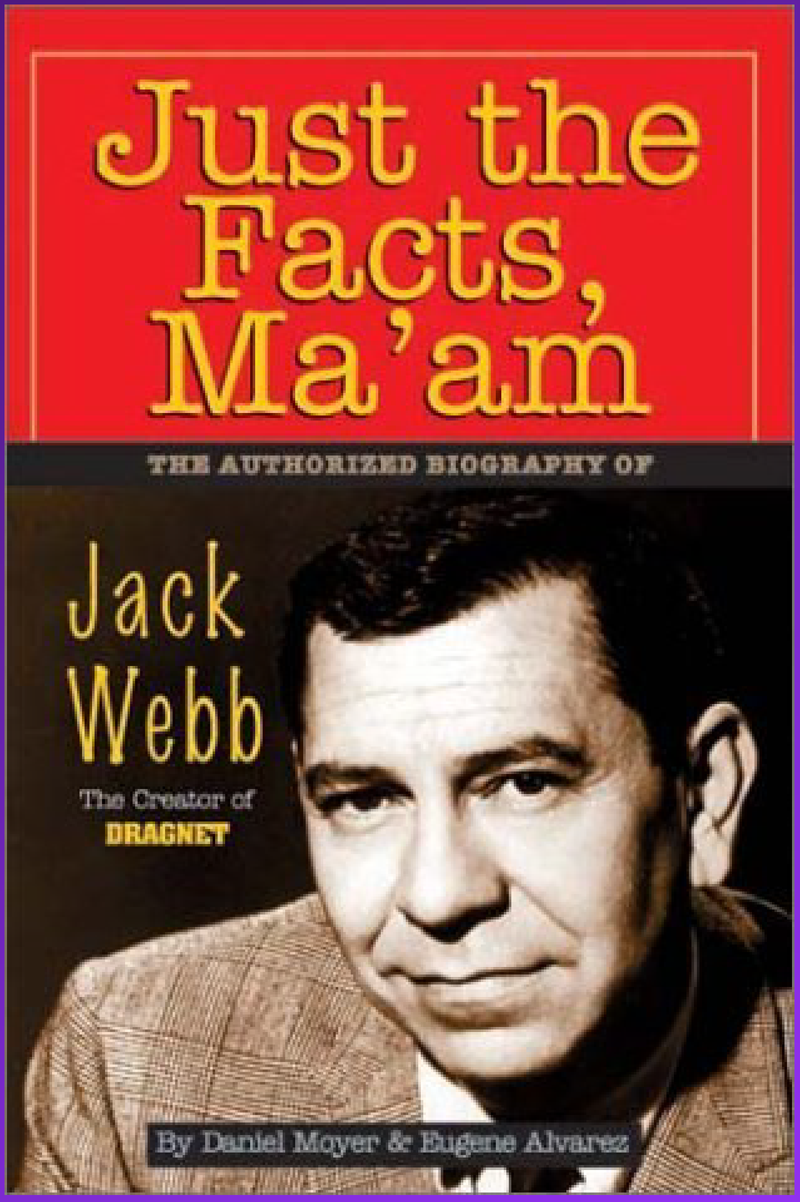
  Construction Complete – 30 Sep 2005

- Phase 5 – Demolition and Repair Additional Slabs as Required

  Construction Complete – 30 Sep 2006

"Dum Dee Dum Dum Dum Dee Dum Dum Dum"

Music Theme
"Dragnet" Detective Drama Series
1952-59,1967-70



1920 - 1982

Creator and

Main Character of

"Dragnet"

TV Series

Picture Courtesy of:
http://www.amazon.com/exec/obidos/ASIN/092976529X/thefiftieswebsit/

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