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Evaluation of Stilling Basin Performance for Uplift Loading Due to Historic Flows

US Army Corps of Engineers ®
Sacramento District

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Introduction

- **Built in 1950s**
- **340’ Concrete Section**
- **8 Operating Spillway Gates**
- **Stilling Basin**

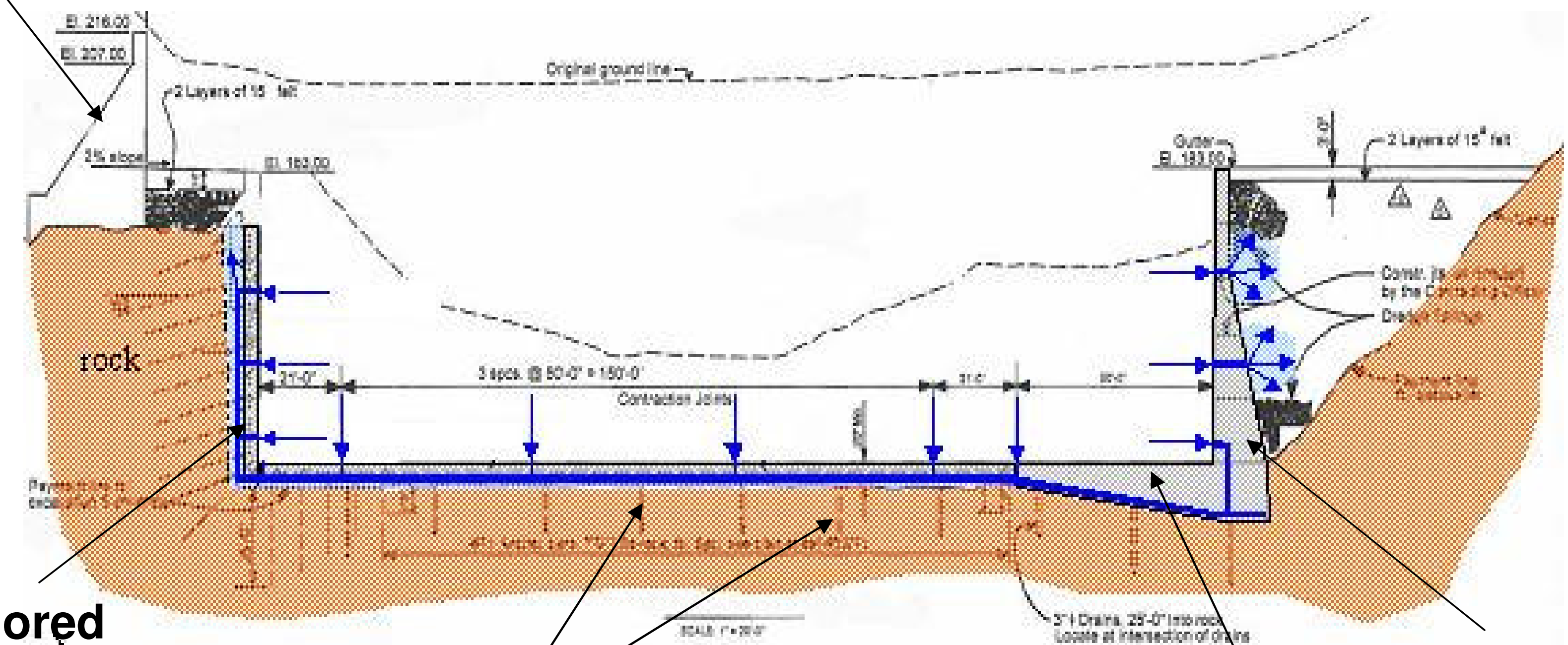
Background

- Outlets - Enlarging 8 existing, adding 2 new upper tier
- Increasing outlet discharge capacity from 25,000 cfs to 115,000 cfs
- Flood control protection from 1 in 100 to 1 in 140

Transverse Cross-Section of Stilling Basin Geometry

Gravity Wall

Looking Upstream



Anchored Wall

L -Wall

#11 bars @ 5 ft, 7' into rock

No anchor

Design Criteria

USACE Engineer Circular and Manuals

- EC 1110-2-6058 “Stability Analysis of Concrete Structures”
- EM 110-2-2104 “Strength Design for Reinforced-Concrete Hydraulic Structures”
- EM 1110-2-2200 “Gravity Dam Design”

Parameters in New Anchor Design

- Load Condition: Unusual
- 0.9-Strength design factor for tension (ACI 318-99)
- 1.7-Single load factor for (D+L) (EM 1110-2-2104)
- 1.65-Hydraulic load factor in tension (EM 1110-2-2104)
- 0.75-Short duration/Low probability loading condition

New Anchors for Stilling Basin

- Hydrodynamic pressure decides the strength of anchor
  - Pre-stressed 1-3/8”, 25’ long @ 5’ o.c

- Hydrostatic pressure decides the length of anchor

Historic Flows

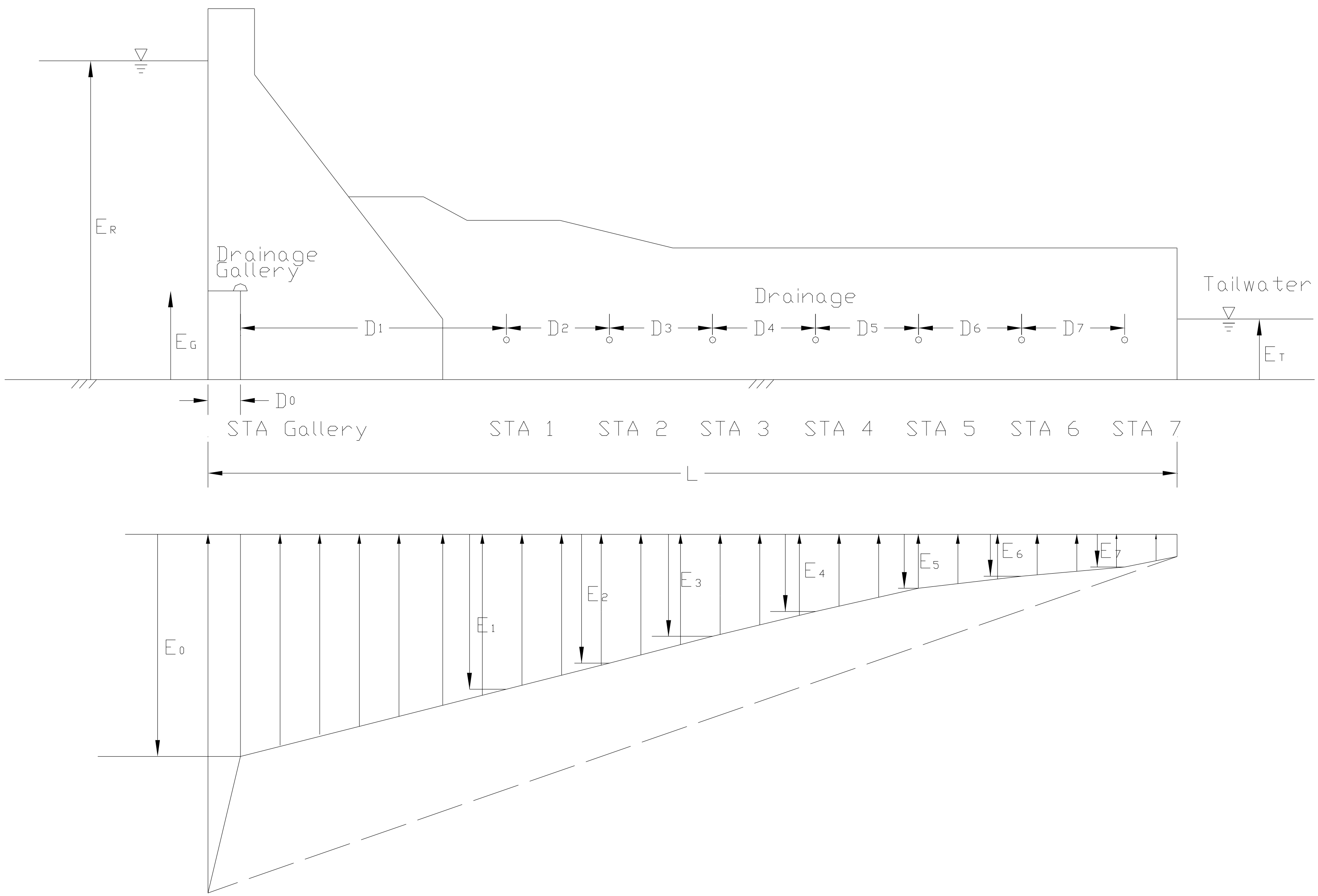
1. 115,000 cfs spillway flows; reservoir elevation 466
   - Dec. 64: 115,000 cfs; high flows over a 50 hour period; reservoir elevation 456
   - Feb. 86: 130,000 cfs; high flows over a 64 hour period; reservoir elevation 466
   - Jan. 97: 116,100 cfs; high flows over a 35 hour period; reservoir elevation 456

Historic Flows

2. Maintenance Condition (stilling basin dewatered; reservoir elevation 450)
   - Sep. 65: reservoir elevation 442
   - Jun. 97: reservoir elevation 442

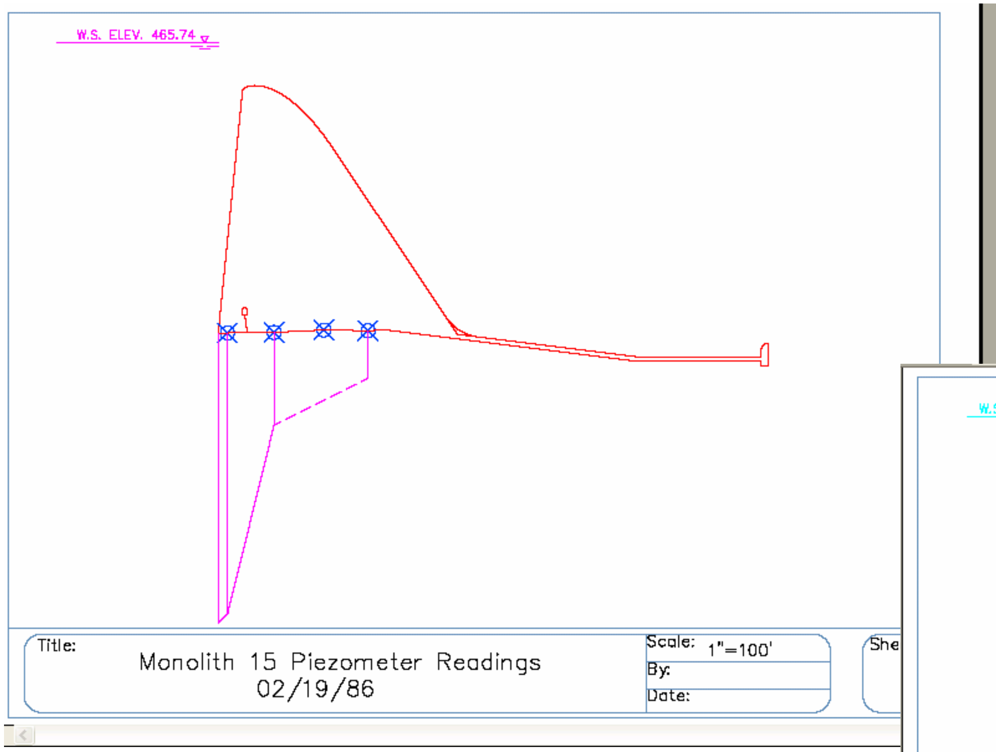
Stilling basin did NOT exhibit any flotation stability problems either during or after any of these events

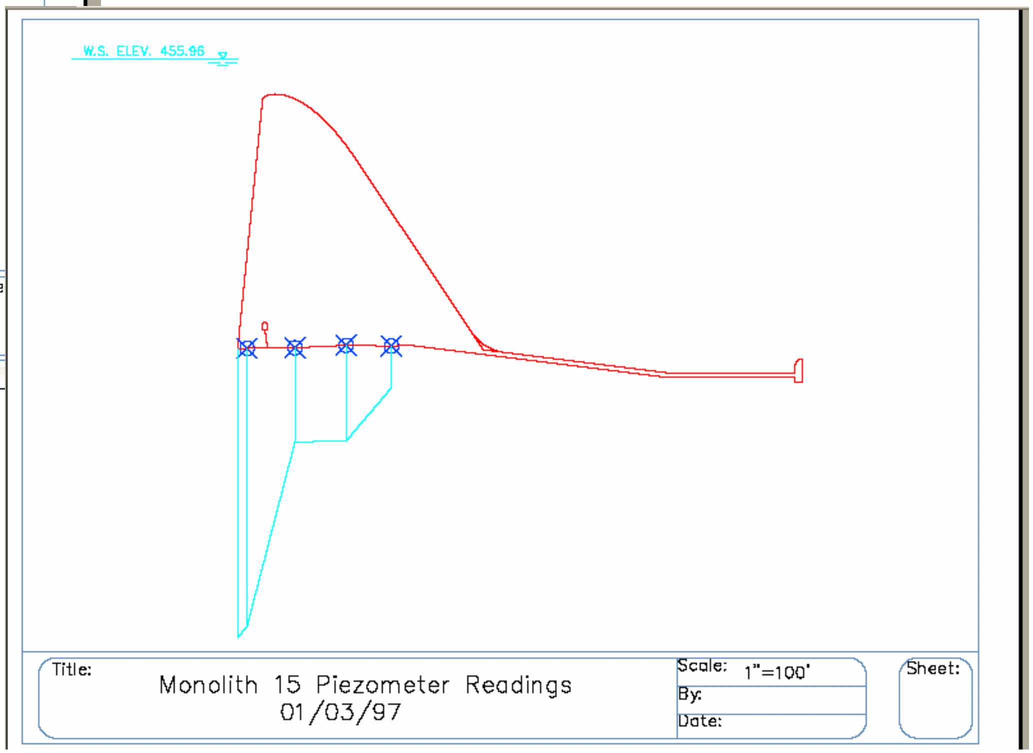
Uplift



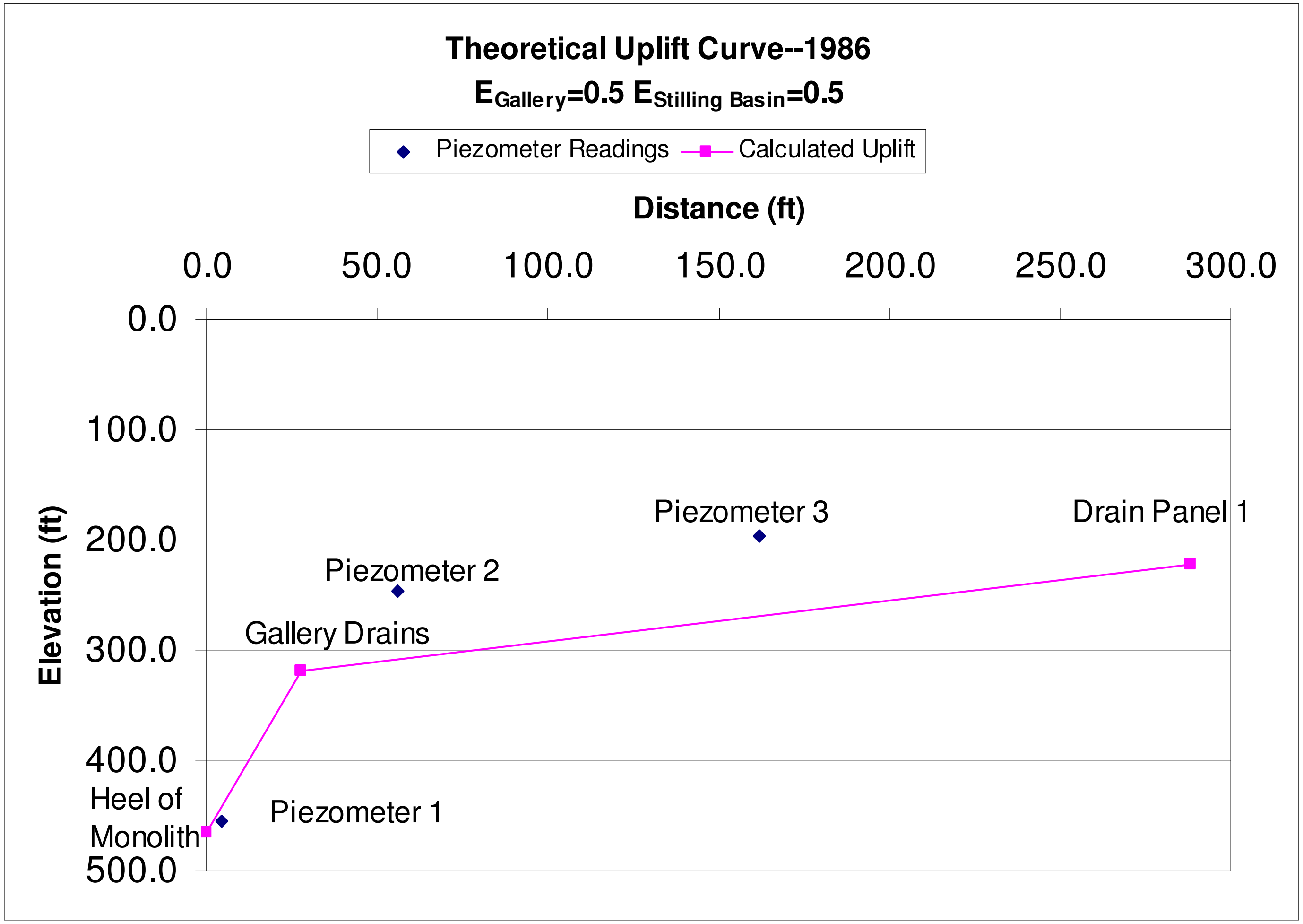
ER
Drainage Gallery
EG
D1
D2
D3
D4
D5
D6
D7
Drainage
Tailwater
ET
D0
STA Gallery
STA 1
STA 2
STA 3
STA 4
STA 5
STA 6
STA 7
L
E0
E1
E2
E3
E4
E5
E6
E7

Piezometer Location



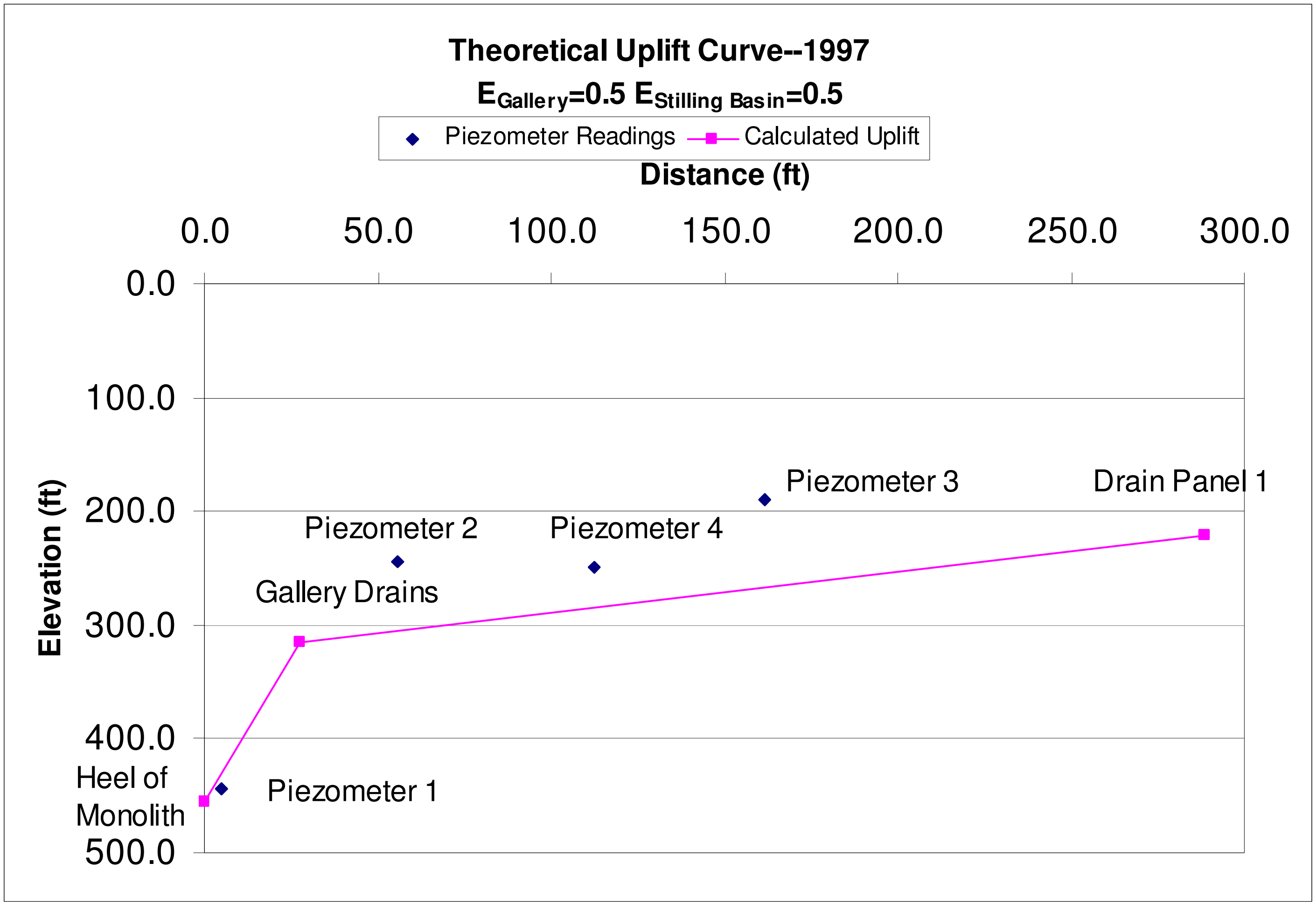


Theoretical Uplift Curve at 1986



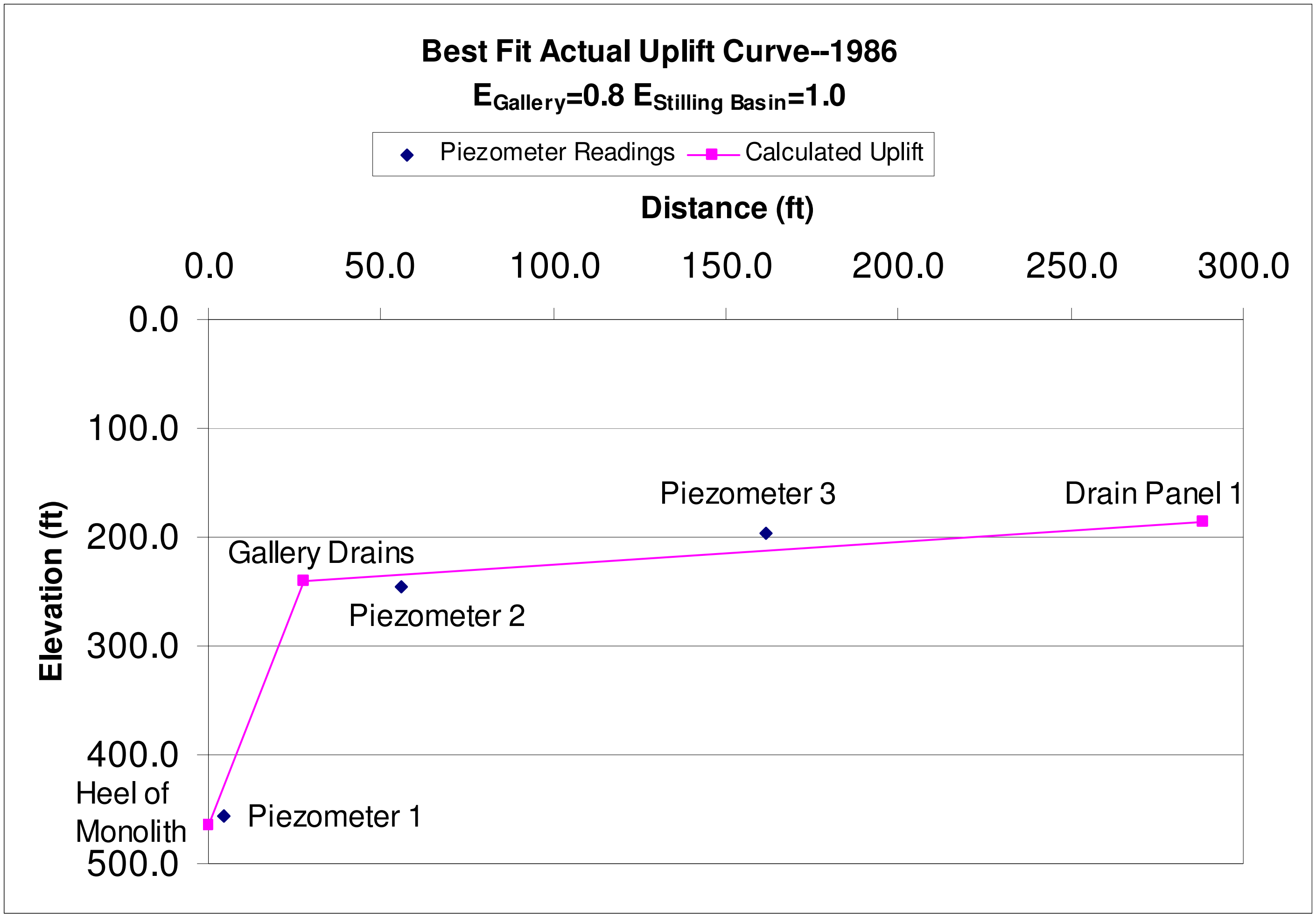
$E_{Gallery}$= 0.5 and $E_{Stilling\ Basin}$= 0.5

Theoretical Uplift Curve at 1997



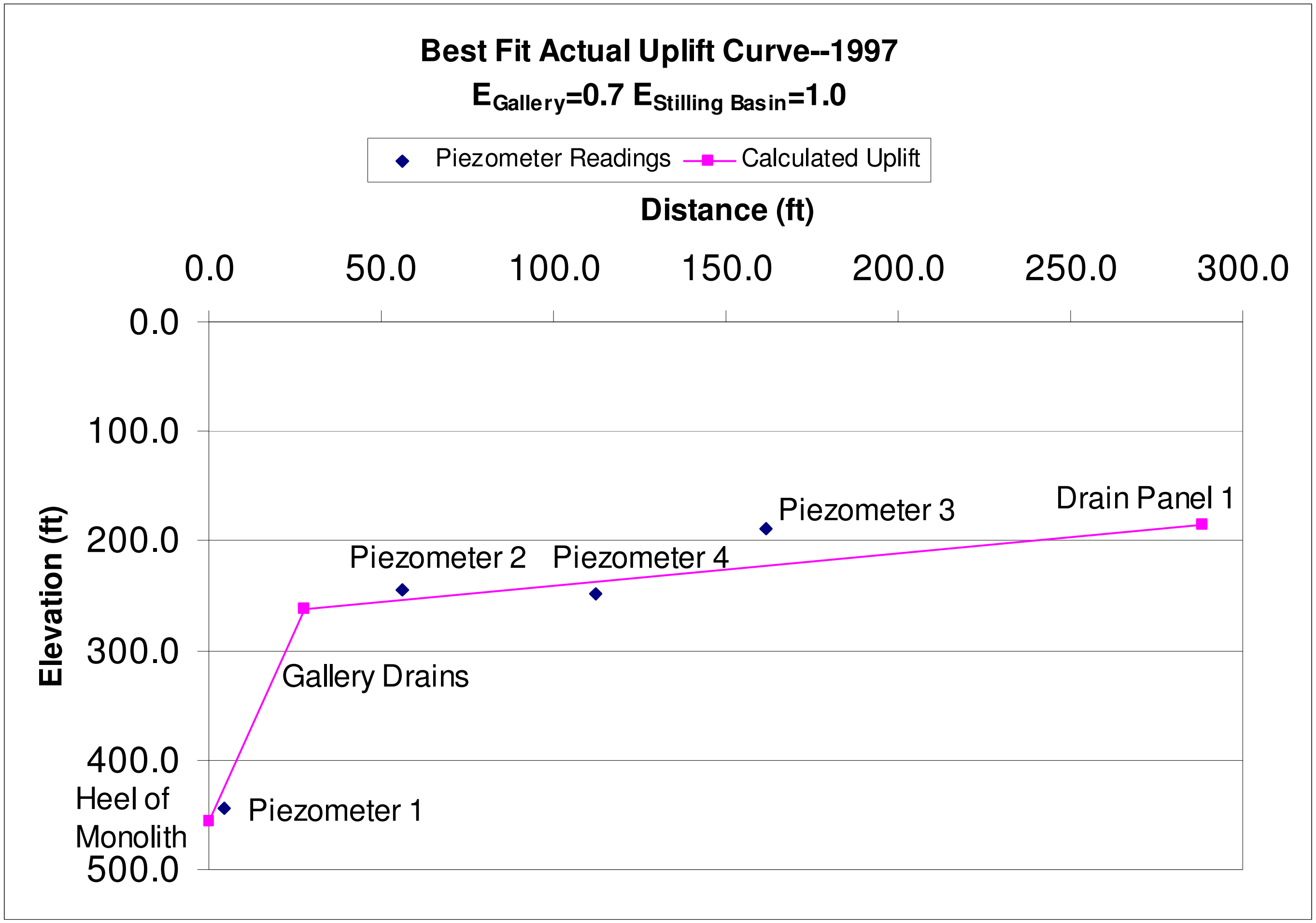
$E_{Gallery}$= 0.5 and $E_{Stilling\ Basin}$= 0.5

Best fit actual uplift curve at 1986



$E_{Gallery}$= 0.8 and $E_{Stilling\ Basin}$= 1.0

Best fit actual uplift curve at 1997



$E_{Gallery}$= 0.7 and $E_{Stilling\ Basin}$= 1.0

Comparison of Design Loading and Historic Flows

Peak Net Uplift Loading (ft) for Upstream Portion

Row 1 Station 12+46.5	Operating Case 1B	Dec. 1964 Loading	Feb. 1986 Loading	Jan. 1997 Loading
L	49.5	49.0	50.9	48.9
E	58.7	57.8	60.0	57.7
D	67.8	66.6	69.1	66.5
C	66.5	65.4	67.9	65.3
B	51.3	50.7	52.6	50.6
A	40.4	40.3	41.8	40.1

Comparison of Design Loading and Historic Flows

Peak Net Uplift Loading (ft) for Downstream Portion

Row 5 Station 14+46	Maintenance Case	1965 Dewatering	1997 Dewatering
L	15.9	15.9	15.9
E	16.5	16.4	16.4
D	17.1	17.0	17.0
C	17.0	17.0	17.0
B	16.0	16.0	16.0
A	15.3	15.3	15.3

Are the criteria conservative?

- The actual uplift forces are NOT as high as the calculated theoretical ones
- There are no continuous cracks in the block of rock at a plane near the end of the anchors to allow the block to readily separate from the rock mass underneath
- The drain effectiveness is more than the assumed 50%

Conclusions

- The existing anchorage of the stilling basin slab has demonstrated repeatedly to be sufficient to withstand the design hydrostatic uplift loading
- The standard assumptions in the criteria for new designs are overly conservative
- Adding new anchors and drains will increase the stilling basin's resistance to uplift forces

Recommendation

"*It may not be necessary to modify an existing structure that does not satisfy the requirements for new structures, when there are no indications of any stability problem.*"

USACE EC 1110-2-6058 "Stability Analysis of Concrete Structures", Chapter 7 "Evaluating and Improving Stability of Existing Structures"

Questions?