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

Rick L Poeppelman, P.E. – USACE

Peter J Hradilek, Ph.D., P.E., G.E.
Yunjing (Vicky) Zhang, P.E.
HDR Engineering

Aug. 2005
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
- Anchored Wall
- Looking Upstream
- #11 bars @ 5 ft, 7’ into rock
- No anchor
- L-Wall
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
Piezometer Location
Theoretical Uplift Curve at 1986

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

Piezometer Readings

- Piezometer 1
- Piezometer 2
- Piezometer 3
- Drain Panel 1

$E_{\text{Gallery}} = 0.5$ and $E_{\text{Stilling Basin}} = 0.5$
Theoretical Uplift Curve at 1997

E_{Gallery} = 0.5 \quad E_{Stilling\ Basin} = 0.5

Distance (ft)

Elevation (ft)

Piezometer Readings

Calculated Uplift

Piezometer 1

Piezometer 2

Piezometer 3

Piezometer 4

Gallery Drains

Drain Panel 1

Heel of Monolith

E_{Gallery} = 0.5 \quad E_{Stilling\ Basin} = 0.5
Best fit actual uplift curve at 1986

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

Piezometer Readings
Calculated Uplift

Distance (ft)

Elevation (ft)

Piezometer 1
Piezometer 2
Piezometer 3

Gallery Drains
Drain Panel 1

Heel of Monolith

$E_{\text{Gallery}} = 0.8$ and $E_{\text{Stilling Basin}} = 1.0$
Best fit actual uplift curve at 1997

$E_{\text{Gallery}} = 0.7 \quad E_{\text{Stilling Basin}} = 1.0$

Piezometer Readings

Calculated Uplift

Distance (ft)

Elevation (ft)

Piezometer 1

Piezometer 2

Piezometer 3

Piezometer 4

Drain Panel 1

Gallery Drains

Heel of Monolith

Elevation (ft)

Distance (ft)

E_{\text{Gallery}} = 0.7 \quad E_{\text{Stilling Basin}} = 1.0
Comparison of Design Loading and Historic Flows

*Peak Net Uplift Loading (ft) for Upstream Portion*

<table>
<thead>
<tr>
<th>Row 1 Station</th>
<th>Operating Case 1B</th>
<th>Dec. 1964 Loading</th>
<th>Feb. 1986 Loading</th>
<th>Jan. 1997 Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>49.5</td>
<td>49.0</td>
<td>50.9</td>
<td>48.9</td>
</tr>
<tr>
<td>E</td>
<td>58.7</td>
<td>57.8</td>
<td>60.0</td>
<td>57.7</td>
</tr>
<tr>
<td>D</td>
<td>67.8</td>
<td>66.6</td>
<td>69.1</td>
<td>66.5</td>
</tr>
<tr>
<td>C</td>
<td>66.5</td>
<td>65.4</td>
<td>67.9</td>
<td>65.3</td>
</tr>
<tr>
<td>B</td>
<td>51.3</td>
<td>50.7</td>
<td>52.6</td>
<td>50.6</td>
</tr>
<tr>
<td>A</td>
<td>40.4</td>
<td>40.3</td>
<td>41.8</td>
<td>40.1</td>
</tr>
</tbody>
</table>
Comparison of Design Loading and Historic Flows

*Peak Net Uplift Loading (ft) for Downstream Portion*

<table>
<thead>
<tr>
<th>Row 5 Station 14+46</th>
<th>Maintenance Case</th>
<th>1965 Dewatering</th>
<th>1997 Dewatering</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>15.9</td>
<td>15.9</td>
<td>15.9</td>
</tr>
<tr>
<td>E</td>
<td>16.5</td>
<td>16.4</td>
<td>16.4</td>
</tr>
<tr>
<td>D</td>
<td>17.1</td>
<td>17.0</td>
<td>17.0</td>
</tr>
<tr>
<td>C</td>
<td>17.0</td>
<td>17.0</td>
<td>17.0</td>
</tr>
<tr>
<td>B</td>
<td>16.0</td>
<td>16.0</td>
<td>16.0</td>
</tr>
<tr>
<td>A</td>
<td>15.3</td>
<td>15.3</td>
<td>15.3</td>
</tr>
</tbody>
</table>
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?