PORTUGUES DAM

- Alberto Gonzalez, P.E. – Project Manager
- Jim Mangold, P.E. – Project Engineer
- Dave Dollar, P.E. – Structural Designer
- Geotechnical, Geology, Materials, Hydraulic, Civil, Mechanical, Electrical, ITR Team
PORTUGUES DAM

- Jim Hinds - CENWP – RCC Mix Design
- Tony Bombich and Billy Neeley – CEERD – Materials Testing
- Ahmed Nisar, Paul Jacob – MMI Engineering – Thermal Stress/Strain Analysis (NISA)
PORTUGUESES DAM

I. Project Overview
II. ITR Process
III. Current Schedule
IV. MCE Update
V. Dam Design
PORTUGUES DAM

I. Project Overview
PORTUGUES DAM

I. Project Overview
PORTUGUES & BUCANA RIVERS PROJECT

I. Project Overview

- CHANNEL IMPROVEMENTS
  - CONCRETE U-CHANNEL
  - GABION LINED
  - UNLINED
- DROP STRUCTURES
- CONTROL STRUCTURES
- DEBRIS BASINS
- CERRILLOS DAM
- PORTUGUES DAM
PORTUGUES DAM

I. Project Overview
PORTUGUESES DAM

I. Project Overview

Portugues Dam Site Prior to Start of Construction
PORTUGUESES DAM

I. Project Overview

Concrete Thin Arch Dam was advertised in September 2000 and the bid was outside the awardable range.

Design changed to RCC
PORTUGUESES DAM

I. Project Overview

Pertinent Data:

- HEIGHT: 219.6 FT
- CREST LENGTH: 1300 FT
- SPILLWAY CREST WIDTH: 150 FT*
- FLOOD CONTROL STORAGE: 9484 AF
- MAX POOL AREA: 215 ACRES
PORTUGUES DAM

I. Project Overview

Portugues Dam - Thick Arch
PORTUGUES DAM

I. Project Overview
PORTUGUES DAM

I. Project Overview
PORTUGUES DAM

1. Project Overview

- **TYPE OF SECTION**
- **CUT CONTRACTION JOINTS**
- **GROUT CONTRACTION JOINTS?**
- **GERCC FACING**
- **TEST PLACEMENT**
- **MIX DESIGN**
  - 18 sec VEBE
  - 340 lbs cementitious mat’ls, 40% class F fly ash
- **VOLUME ~ 375,000 CU. YDS.**
PORTUGUESES DAM
II. ITR Process

- THIN ARCH
- RCC
  - FORMALIZED PROCESS
  - CONSISTENT WITH INDUSTRY PRACTICE
PORTUGUESES DAM

II. ITR PROCESS

• Multidiscipline ITR team.
  – Concrete dam design, RCC mix design, seismology of the Caribbean, engineering geology, geotechnical engineering, hydraulics, electrical and mechanical engineering.
## PORTUGUESES DAM
### II. ITR PROCESS

<table>
<thead>
<tr>
<th>Multidiscipline ITR team:</th>
<th>Individuals:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete dam design</td>
<td>Glenn Tarbox</td>
</tr>
<tr>
<td>RCC mix design</td>
<td>Gary Mass</td>
</tr>
<tr>
<td>Seismology of the Caribbean</td>
<td>Dr. William McCann</td>
</tr>
<tr>
<td>Engineering geology</td>
<td>Alan O’Neil</td>
</tr>
<tr>
<td>Geotechnical engineering</td>
<td>Dr. Gregg Korbin, Dr. Don Banks</td>
</tr>
<tr>
<td>Hydraulics</td>
<td>MWH staff</td>
</tr>
<tr>
<td>Electrical engineering</td>
<td>MWH staff</td>
</tr>
<tr>
<td>Mechanical engineering</td>
<td>MWH staff</td>
</tr>
</tbody>
</table>
PORTUGUESES DAM

III. Current Schedule*

• COMPLETE P&S – MAY 2006
• ADVERTISE – MAY 2006
• AWARD – AUG 2006

*THIS SCHEDULE IS DEPENDENT ON AVAILABILITY OF PROJECT FUNDING
PORTUGUESES DAM

IV. MCE Update

MCE – Controlling Events:

- Thin Arch Dam
  - M6.5 @ 18km – Salinas Fault – 1988

- RCC Thick Arch Dam
  - M8.25 @19.6km – Muertos Trough – 2004

“Deterministic and Probabilistic Seismic Hazard Analysis for Portugueses Dam, Puerto Rico,” 6 April 2004, prepared by URS Corporation; reviewed by ITR Team (particularly Dr. William McCann), Dr. Greg Fenves, ERDC (Dr. Donald Yule), USGS (Dr. Charles Mueller)
REGIONAL GEOLOGY
PORTUGUES DAM
IV. MCE Update

Portugues Dam - MCE

- Thin Arch Dam
- Current
- Intermediate

![Graph showing spectral acceleration vs. period for Portugues Dam - MCE.](image)
PORTUGUESES DAM
IV. MCE Update

Significance to dam design:

- Peak ground acceleration: 0.38g’s.
- Plateau on the response spectrum throughout the range concrete dam frequencies of vibration.
PORTUGUES DAM

V. Dam Design

Sequencing of Design Activities:

Construction for the thin arch dam had begun (excavation & grout curtain); therefore, there was a need to minimize the time required to redesign the dam. Activities that would normally run sequentially were performed in parallel.
PORTUGUESES DAM
V. Dam Design

Parallel Activities:
- Site Seismicity
- Determination of Foundation Properties
- Foundation and Slope Stability
- Concrete Mix Design and Property Testing
- Dam Design
- Thermal Analysis
### PORTUGUESES DAM

#### V. Dam Design

**DISADVANTAGES OF PARALLEL ACTIVITIES**

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>INPUT REQUIREMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Dam Design</td>
<td>1. Foundation Properties, Seismic Input, Concrete Properties.</td>
</tr>
<tr>
<td>2. Foundation Stability</td>
<td>2. Dam Shape and Loads, Seismic Input</td>
</tr>
<tr>
<td>3. Thermal Analysis</td>
<td>3. Dam Shape, Construction Sequencing, Concrete Properties</td>
</tr>
<tr>
<td>4. Mix Design</td>
<td>4. Target Parameters</td>
</tr>
</tbody>
</table>
PORTUGUESES DAM

V. Dam Design

Design Approach:

Based on expected magnitude of seismic loading; design a workable mix with reasonable bond strength (tensile strength) and design the dam to maximize cantilever compression on the upstream face under usual loadings and arch compression during the seismic loading.
PORTUGUES DAM

V. Dam Design

Design Progression:

- Corps experience with RCC has typically been associated with gravity dams.
- The district considered an RCC gravity structure in the 1980’s but ruled it out, not based on cost, but on the “newness” of the technology.
PORTUGUES DAM

V. Dam Design

Design Progression:

- Gravity dam alignments and sections were evaluated.
- Detailed cost estimates, which included the quantities of RCC and excavation for the gravity dam designs, indicated a cost savings compared to the thin arch dam.
PORTUGUES DAM

V. Dam Design

Design Progression:

- Now that a more economical construction method was adopted could further savings be realized by minimizing the volume by designing a thick arch structure?
- Preliminary layouts indicated that a thick arch dam could be designed with less than 3/4 the volume of the gravity dam.
PORTUGUES DAM

V. Dam Design

Design Progression:

- To maintain simplicity during construction a section was adopted with a vertical u/s face and a d/s face with a single slope.
- Sensitivity analyses were performed to evaluate:
  - Relative stiffness of the arches and cantilevers
  - Effect of varying the horizontal curvature
  - Effect of stiffening the upper arches
  - Magnitude of temperature and reservoir load compared to gravity load
PORTUGUES DAM

V. Dam Design

Design Progression:

- Based on the water supply dam, a full reservoir and the foundation properties from the thin arch analysis; the horizontal curvature and alignment were set prior to having the final seismic loading. The left abutment was shifted upstream to avoid highly weathered rock exposed during the thin arch excavation.
PORTUGUES DAM

V. Dam Design

Design Progression:

- The section was refined to increase u/s cantilever compression; mainly from gravity load, which was applied to cantilevers only.
- The final layout was selected and a dynamic analysis performed.
- The dynamic response was acceptable.
PORTUGUESES DAM
V. Dam Design

Design Progression:

- The foundation properties were determined for the final layout. (In progress)
- All load cases analyzed for the final properties and loadings. (In progress)
PORTUGUES DAM

V. Dam Design

PORTUGUES DAM RCC
MIX 6D - TENSILE STRENGTH

TENSILE STRENGTH (PSI)

AGE (DAYS)

0 50 100 150 200 250 300 350 400

0 100 200 300 400 500 600 700 800

MIX 6D CYLINDER SPLITTING TENSILE STRENGTH
PANEL G DIRECT TENSION ON HORIZONTAL CORE
PANEL G DIRECT TENSION ON VERTICAL CORE
PANEL G SPLITTING TENSION ON HORIZONTAL CORE
PANEL A DIRECT TENSION ON VERTICAL CORE
PANEL A SPLITTING TENSION ON HORIZONTAL CORE
PANEL B DIRECT TENSION ON VERTICAL CORE
PANEL B SPLITTING TENSION ON HORIZONTAL CORE
RAPID LOAD STRAIN CAPACITY BEAMS

432
385
350
330
227
188
140
150
## PORTUGUESES DAM

### V. Dam Design

<table>
<thead>
<tr>
<th>LAYOUT:</th>
<th>VOLUMES:</th>
</tr>
</thead>
<tbody>
<tr>
<td>G - Raxis = 825 ft, S=0.50, Crest Thickness = 25 ft</td>
<td>257710 CU.YDS.</td>
</tr>
<tr>
<td>H - Raxis = 825 ft, S=0.40, Crest Thickness = 30 ft</td>
<td>356284 CU.YDS.</td>
</tr>
<tr>
<td>I - Raxis = 825 ft, S=0.40, Crest Thickness = 35 ft</td>
<td>379937 CU. YDS.</td>
</tr>
<tr>
<td>J - Raxis = 825 ft, S=0.30, Crest Thickness = 35 ft</td>
<td>343610 CU.YDS.</td>
</tr>
<tr>
<td>K - Raxis = 825 ft, S=0.20, Crest Thickness = 35 ft</td>
<td>301013 CU.YDS.</td>
</tr>
<tr>
<td>L - Raxis = 825 ft, S=0.35, Crest Thickness = 35 ft</td>
<td>367141 CU. YDS.</td>
</tr>
</tbody>
</table>
PORTUGUESES DAM
V. Dam Design

WATER TO EL. 523 FT, LOW TEMPS, AND GRAVITY

August 3, 2005 2005 Tri-Service Infrastructure Systems Conference
PORTUGUESES DAM

V. Dam Design

Portugues Dam
Natural Frequencies (Reservoir at El. 439.8 ft) of Layouts Compared to MCE Response Spectra

- h2 - x
- h1 - y
- v - z
- Layout H
- Layout I
- Layout J
- Layout K
- Layout L

Acceleration (g's)
Period (Seconds)
PORTUGUES DAM
V. Dam Design

• **MAXIMUM TENSILE STRESSES**
  - #1- 61, Dir: u/s, Str: arch, Max: 399.474 @ 14.010Sec
  - #1- 53, Dir: u/s, Str: cant1, Max: 476.163 @ 20.240Sec
  - #1-296, Dir: d/s, Str: arch, Max: 249.882 @ 14.010Sec
  - #1-271, Dir: d/s, Str: cant1, Max: 384.474 @ 20.370Sec
PORTUGUESES DAM

V. Dam Design–Demand/Capacity Curves

Tensile strength = 260 psi
PORTUGUESES DAM

V. Dam Design–Demand/Capacity Curves

Tensile strength = 260 psi
PORTUGUESES DAM

V. Dam Design

Factors affecting dam design:

- Earthquake loading
- Much of the dam design work and mix design preceded the determination of the earthquake loading
- Tensile strength of RCC structures
- Post thin arch excavation site conditions
- Use of existing thin arch grout curtain
PORTUGUES DAM

V. Dam Design

Factors affecting dam design (continued):

- Horizontal curvature compatible with either a flood control or water supply dam
- Need axis before MCE was determined
- Left abutment weathered rock
- Delays and costs associated with exploration upstream of the thin arch left abutment
- Mix design program preceded determination of MCE.
RCC Placement - Saluda
Cutting Contraction Jt. - Saluda
GERCC - Olivenhain
Pre-cast Facing Panels - Saluda
Pre-cast Facing Panels - Saluda
Contraction Joint Details - Saluda
THANK YOU

- Dave Dollar, P.E. – Structural Designer
- Jim Mangold, P.E. – Project Engineer
- Alberto Gonzalez, P.E. – Project Manager

(904) 232-2459