USACE Seismic Safety Assessment

2006 Northwest Dam Safety Regional Forum
February 14-15, 2006
Portland, Oregon
General Provisions for EQ Design and Evaluation

- EM 1110-2-1806, EQ Design and Evaluation for Civil Works Projects, 31 Jul 95, for new projects and evaluation of existing projects.

- Scope
  - Ground Motions
  - Site Characterization
  - Structural Response
  - Potential Hazards
  - Report Requirements
Project Hazard Potential

- Appendix B, Hazard Potential Classification
- Critical Features are structures, natural site conditions, operation equipment and utilities at high hazard projects where failure during or immediately following an EQ could result in a loss of life.
- EM 1110-2-2100, Stability Analysis of Concrete Structures
Design of New Projects

- ER 1110-2-1150, Engineering and Design of Civil Works Projects
- Analysis is performed in phases in order of increasing complexity.
- Shall include assessments of potential EQ motions and project features to ensure acceptable performance during and after design events.
- Level of design is dependent upon whether or not seismic loading controls the design, complexity of project, and the consequences of losing project service or control of the pool.
Evaluation of Existing Projects

- EC 1110-2-6061, Safety of Dams-Policies and Procedures, 30 Apr 04

- Initiated by the following circumstances:
  - Performance inconsistent with the design intent during a major EQ.
  - Alteration which changes load conditions.
  - Advance in state-of-the-art.
  - Change in project operations impact seismic resistance
  - Conducted a minimum every 15 years.

- Prioritized by Portfolio Risk Analysis
**Dam Safety Assurance Program**

- Provides for special cost sharing per Sec. 1203 of WRDA 1986.
- Allows modifications to completed dams to eliminate safety concerns pertaining to hydrologic and seismic deficiencies.
- Feasibility Type Report
Dam Safety Assurance Program (Cont.)

• EC 1110-2-6061, Appendix G
• Part I-Format and Content of Dam Safety Assurance Program
• Part II-Seismic Safety Evaluation Process for Embankment Dams and Foundations
• Part III-Seismic Safety Evaluation Process for Concrete Structures and Foundations
• Part IV-Hazard Potential Classification
Dam Safety Assurance Program (Con.t)

- Evaluations performed in phases with increasing complexity
  - Seismic Safety Review (SSR)
  - Phase I Special Studies-
  - Phase II Special Studies
- Policy Compliance & Criteria Reviews
- Portfolio Risk Assessment updates
- Central funding for phases following SSR

-------------------------- One Corps Serving The Army and the Nation --------------------------
Estimating Ground Motions

- ETL 1110-2-301, Interim Procedure for Specifying EQ Motions, 26 Aug 83
- Standard Seismic Studies
  - Based on preliminary ground motion values, structural analyses, and soil liquefaction assessments to determine if seismic loadings control.
  - DEQAS, Design EQ Analysis System.
Estimating GM (Cont.)

- **Site Specific Studies**
  - Deterministic Seismic Hazard Analysis (DHSA)
  - Probabilistic Seismic Hazard Analysis (PHSA)
    - Deterministic assessment compared with published data to assess a specified time period.
    - Specific ground motion-structure interactions provided in engineering manuals.
- **Draft EM 1110-2-6000, Selection of Design EQ**
Design Earthquake

• **Maximum Credible EQ (MCE)** - the greatest EQ that can be reasonably be generated by a specific source. **Determined by DSHA.**

• **Maximum Design EQ (MDE)** - the maximum level of ground motion for which a structure is designed. **(DSHA or PSHA.)**

• **Operating Basis EQ (OBE)** - the EQ that can be reasonably expected to occur with a 50% probability of exceedence during the service life. **(PSHA)**
Key EQ Guidance Documents

- ETL 1110-2-301, Interim Procedure for Specifying Earthquake Motions, 26 Aug 83
- EC 1110-2-6061, Safety of Dams-Policy and Procedures, 30 Apr 04
- Draft EM 1110-2-6000, Selection of Design EQ
- Draft EM 1110-2-6001, Seismic Stability of Earth and Rock Fill Dams
- EM 1110-2-6050, Response Spectra and Seismic Analysis for Concrete Hydraulic Structures, 30 Jun 99
- EM 1110-2-6051, Time History Dynamic Analysis of Concrete Hydraulic Structures, 22 Dec 03
Concrete and Steel Hydraulic Structures - Performance and Load Criteria

- Should respond elastically to the OBE with no disruption to service.
- Can respond inelastically to the MDC event, which may result in significant structural damage and limited disruption of services, but should not collapse or endanger lives.
- For critical structures, the MDE = MCE.
- OBE = Usual Loading Condition
- MCE = Extreme Loading Condition
## Concrete and Steel Hydraulic Structures - Seismic Analysis Progression

### Table E-1
Seismic Analysis Progression

<table>
<thead>
<tr>
<th>Zone</th>
<th>Project Stage</th>
<th>Reconnaissance</th>
<th>Feasibility</th>
<th>DM¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>E</td>
<td>SCM</td>
<td>RS²</td>
</tr>
<tr>
<td>0 and 1</td>
<td></td>
<td>→</td>
<td>→</td>
<td></td>
</tr>
<tr>
<td>2A and 2B</td>
<td></td>
<td>E</td>
<td>SCM</td>
<td>RS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SCM²</td>
<td>RS²</td>
<td>TH³</td>
</tr>
<tr>
<td>3 and 4</td>
<td></td>
<td>SCM</td>
<td>RS</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>RS²</td>
<td>TH³</td>
<td></td>
</tr>
</tbody>
</table>

**Note:**

- E = Experience of the structural design engineer.
- SCM = Seismic coefficient method of analysis.
- RS = Response spectrum analysis.
- TH = Time-history analysis.

¹ If the project proceeds directly from feasibility to plans and specifications stage, a seismic design memorandum will be required for all projects in zones 3 and 4, and projects for which a TH analysis is required.

² Seismic loading condition controls design of an unprecedented structure, or unusual configuration or adverse foundation conditions.

³ Seismic loading controls the design requiring linear or nonlinear time-history analysis.

⁴ RS may be used in seismic zones 3 and 4 for the feasibility and design memorandum phases of project development only if it can be demonstrated that phenomena sensitive to frequency content (such as soil-structure interaction and structure-reservoir interaction) can be adequately modeled in an RS.
Key Structural Design Guidance

- EM 1110-2-2200, Gravity Dam Design, 30 Jun 95
- EM 1110-2-2201, Arch Dam Design, 31 May 94
- EM 1110-2-2400, Structural Design and Evaluation of Outlet Works, 2 Jun 03
- EM 1110-2-6050, Response Spectra and Seismic Analysis for Concrete Hydraulic Structures, 30 Jun 99
- EM 1110-2-6051, Time History Dynamic Analysis of Concrete Hydraulic Structures, 22 Dec 03
- EC 1110-2-6058, Stability Analyses of Concrete Structures, 30 Nov 03
EM 1110-2-2200, Gravity Dam Design

- Stability requirements
- Static and Dynamic Stress Analysis
- Temperature Control of Mass Concrete
- Evaluation Criteria
- Use of Roller Compacted Concrete
# Gravity Dam Stability and Stress Criteria

<table>
<thead>
<tr>
<th>Load Condition</th>
<th>Resultant Location at Base</th>
<th>Minimum Sliding FS</th>
<th>Foundation Bearing Pressure</th>
<th>Concrete Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Compressive</td>
</tr>
<tr>
<td>Usual</td>
<td>Middle 1/3</td>
<td>2.0</td>
<td>≤ allowable</td>
<td>0.3 f'_c</td>
</tr>
<tr>
<td>Unusual</td>
<td>Middle 1/2</td>
<td>1.7</td>
<td>≤ allowable</td>
<td>0.5 f'_c</td>
</tr>
<tr>
<td>Extreme</td>
<td>Within base</td>
<td>1.3</td>
<td>≤ 1.33 x allowable</td>
<td>0.9 f'_c</td>
</tr>
</tbody>
</table>

Note: f'_c is 1-year unconfined compressive strength of concrete. The sliding factors of safety (FS) are based on a comprehensive field investigation and testing program. Concrete allowable stresses are for static loading conditions.
EM 1110-2-2201, Arch Dam Design

• Special Considerations for Abutments and Foundations
• Loading Combinations
• Details on Dynamic Seismic Analysis
• 3D-Dam-Water-Foundation Interaction
• Criteria for Static and Dynamic Performance Evaluation

One Corps Serving The Army and the Nation
Chapter 4, Seismic Design and Evaluation of Intake Tower, Design Considerations:

- Loading Conditions
- Design of Reinforcements
- Design Earthquake
- Stability Requirements
- Displacement Based Procedure Analysis for Evaluation
Appendices

- Design Example
- Two Mode Approximate Procedure
- Hydro Dynamic Added Mass of Water Inside and Out
- Rotational Stability of Intake Tower
EM 1110-2-6050, Response Spectra and Seismic Analysis of Concrete Hydraulic Structures

- Introduction and Methodology of Seismic Analysis of Concrete Hydraulic Structures (CHS)
- Design Criteria for CHS
- Structural Modeling and Analysis for CHS
- Interpretation of Results
EM 1110-2-6050, Response Spectra and Seismic Analysis of Concrete Hydraulic Structures (Cont.)

- Earthquake Ground Motions
- Developing Response Spectra using PHSA
- Equal Hazard Spectra
- Design Response Spectra
EM 1110-2-6051, Time-History Dynamic Analysis for Concrete Hydraulic Structures

- Procedure for linear elastic time-history dynamic analysis
- Qualitative estimate of the damage
- EQ input acceleration time-history
- Examples
  - Arch Dam and Gravity Dam
  - Intake Tower
  - W-Frame Lock
EM 1110-2-2100, Stability Analysis of Concrete Structures

- Table 3-1, Load Conditions and Probabilities
- Table 3-3, Required Factors of Safety for Critical Structures
- Table 3-4, Required Factors of Safety for All Structures
- Table 3-5, Requirements of the Locations for All Structures
Embankments, Slopes, and Foundations

- Draft EM 1110-2-6001, Dynamic Stability of Earth and Rock Fill Dams
- Pool Elevation at 90% duration of the highest seasonal or normal pool, whichever governs.
- Selecting Design EQ and Ground Motions
- Analyses for New and Existing Dams and Foundations
- Validation Processes
- Highlights Areas of Concern and Recommendations
Post Construction Reports

- Foundation Completion Report
- Embankment Materials and Performance Report
- Concrete Materials Report
Research Needs

• For Ground Motions
  – EQ Hazard Estimation
  – Site Characterization

• For Concrete and Steel Structures
  – Constitutive Behavior and Material Parameters for Dynamic loads
  – Lift Joints and Foundation Interaction
  – Improved Analysis Procedure Mode of Failure for Intake Towers
  – Cyclic Loading Test for Gravity Dams
  – Tainter Gate Pier Ductility and Seismic Performance
Research Needs (Cont.)

- For Embankments and Foundations
  - Validation of Deformation Technologies
  - Partially Saturated Soils
  - Residual Strength
  - Fine Grained Soils
  - Large Penetration Testing
  - 3-D Effects
Points of Contact

• Headquarters
  - David Pezza, PE, Embankment Guidance
  - Jack Berezniak, PE, Ground Motion Guidance
  - Anjana Chudgar, PE, Structural Guidance

• ERDC
  - Joe Koester, PhD, PE, Embankment Performance
  - Mike Sharp, PhD, PE, Geotechnical Numerical Analyses
  - Enrique Matheu, PhD, PE, Structural Numerical Analyses
  - Don Yule, PE, Ground Motions and DEQAS Software

• Field
  - Dale Munger, PE, Draft EM 1110-2-6001
  - Jeff Schaefer, PhD, PE, Portfolio Risk Analyses
Questions?