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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

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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

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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

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.

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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)**

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Key EQ Guidance Documents

- ER 1110-2-1806, Earthquake Design and Evaluation for Civil Works Projects, 31 July 1995
- 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**

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Concrete and Steel Hydraulic Structures-Seismic Analysis Progression

Table E-1
Seismic Analysis Progression

Zone	Project Stage				
	Reconnaissance		Feasibility		DM[1]
0 and 1	E	→	SCM	→	RS[2]
2A and 2B	E SCM[2]	→ →	SCM RS[2]	→ →	RS TH[3]
3 and 4	SCM	→	RS	→	TH
	SCM RS[2]	→ →	RS TH[3]	→ →	RS[4] TH[3]

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.

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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

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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

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Gravity Dam Stability and Stress Criteria

Table 4-1
Stability and stress criteria

Load Condition	Resultant Location at Base	Minimum Sliding FS	Foundation Bearing Pressure	Concrete Stress	
				Compressive	Tensile
Usual	Middle 1/3	2.0	≤ allowable	$0.3 f_c'$	0
Unusual	Middle 1/2	1.7	≤ allowable	$0.5 f_c'$	$0.6 f_c'^{2/3}$
Extreme	Within base	1.3	≤ 1.33 × allowable	$0.9 f_c'$	$1.5 f_c'^{2/3}$

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

EM 1110-2-2400, Structural Design and Evaluation of Outlet Works

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

EM 1110-2-2400, Structural Design and Evaluation of Outlet Works (Cont.)

- Appendices
  - Design Example
  - Two Mode Approximate Procedure
  - Hydro Dynamic Added Mass of Water Inside and Out
  - Rotational Stability of Intake Tower

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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

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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

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Post Construction Reports

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

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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

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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?