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INTERAGENCY WORKING GROUP MEETING (2ND) EARTHQUAKE ENGINEERING --ETC(U)

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Second Interagency Working Group Meeting
For
Earthquake Engineering Research Coordination

Knoxville, Tennessee
September 18 and 19, 1980

W. F. Marcuson III, Chairman
J. P. Koester, Recorder

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Meeting of Steering Committee

Executive Summary

The Second Working Group Meeting for Earthquake Engineering Research Coordination for the Interagency Research Coordination Conference (IRCC) was held in Knoxville, Tennessee, on 18-19 September 1980. Discussion centered on three major fields of concern for earthquake engineering research: soils, structures, and geology/seismology. Emphasis was given to ongoing research and development directly related to the earthquake analysis for evaluating dam safety. It was observed that there exists reasonable agreement between member agencies as to the methodology for evaluating seismic safety of earth/rock-fill and concrete dams. In general, no unnecessary duplication of research efforts was observed between member agencies.

As a result of discussions centered on strong-motion instrumentation and the mutual desire to improve the existing strong-motion data base, the following decisions were made:

(a) Request IRCC member agencies to expedite dissemination of strong-motion data.

(b) Contact USCOLD to determine the availability of a compilation of strong-motion data for dam installations worldwide and distribute these to IRCC member agencies. This task was assumed by Lucian G. Guthrie.

(c) Establish liaison to avoid redundancy of strong-motion instrumentation at dams in close proximity to one another.

It was suggested that this working group should be represented at the next NSF workshop on strong-motion instrumentation.

A subcommittee formed at the direction of the steering committee was established to determine the needs for research of earthquake-induced dynamic earth pressures on retaining walls. The subcommittee is to decide by January 1981 if further activities are justified.*

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* Recorder's Note: Prior to publication of this report, Paul F. Hadala at WES prepared a questionnaire to assess each member agency's needs for research of dynamic earth pressures on retaining structures. The questionnaire was mailed 10 March 1981 to each of the contact persons listed and is included as Appendix 7.

Finally, concern was expressed regarding a proliferation of committees organized for similar purposes, yet not being coordinated or in communication with each other.

SECOND INTERAGENCY GROUP MEETING FOR EARTHQUAKE ENGINEERING RESEARCH COORDINATION

SEPTEMBER 1980

Report of Meeting

Introduction

1. The second working group meeting for earthquake engineering research coordination for the Interagency Research Coordination Conference (IRCC) convened at 8:30 a.m. on 18 September 1980 at the Tennessee Valley Authority (TVA) headquarters in Knoxville, Tennessee. A letter of invitation, along with the originally proposed agenda and introduction of the topic statements, is included in Appendix 1. The opening remarks included a welcome presented by R. G. Domer of TVA and a brief overview of the history of the working group. The working group was created at the 10th IRCC and first met in Denver, Colorado, in September 1978. The parent organization, IRCC, meets biennially in odd years and this working group meets during even years to gather ongoing research and limit redundancy. Among the accomplishments of the first working group were: (a) developing recommendations for common terminology for earthquake response analyses, including earthquake ground motions and (b) determining areas of commonalty and differences in the agencies' procedures for defining earthquake ground motions. A report on this work was prepared and distributed to each agency involved.

2. At this second working group meeting, a question was raised by James Choromokos, Jr., of the Office, Chief of Engineers (OCE), concerning funding levels for earthquake engineering research in each of the attending agencies. The estimates of earthquake engineering research funding for the various agencies represented are as follows:

a. TVA - approximately $150,000.

b. Waterways Experiment Station (WES) - approximately $500,000.

c. Water and Power Resource Service (WPRS) - approximately $250,000 budgeted for FY 81.

d. Bonneville Power Administration (BPA) - most funding for electrical engineering, very little for earthquake.

e. U. S. Geological Survey (USGS) - approximately $1.27 million, considering all aspects such as dam safety, slides, instrumentation, etc.

f. National Science Foundation (NSF) - approximately $6 million.

g. National Bureau of Standards (NBS) - approximately $600,000, mostly toward development of building standards.

h. Federal Emergency Management Agency (FEMA) - approximately $100,000, mostly toward dam safety.

Attendees

3. Those in attendance were:

Name	Agency
T. J. Abraham	TVA
S. B. Ahmed	TVA
Chuck Babcock	NSF
Robert D. Bourn	BPA
George Buchanan	TVA
Dennis Carlin	TVA
James Choromokos, Jr.	OCE
Yung C. Chung	TVA
James Costello	NRC
Jim Coulson	TVA
D. R. Denton	TVA
Ronald G. Domer	TVA
G. D. Felpel	TVA
A. G. Franklin	WES
Lucian G. Guthrie	OCE
Frank Hand	TVA
Gus Harrell	TVA
Rich Hopkins	TVA
Joe Hunt	TVA
Kenneth King	USGS
Joe Koester	WES
S. T. Lin	TVA

Name	Agency
W. F. Marcuson III	WES
Paul Mlaker	WES
David M. Patrick	WES
Bill Seay	TVA
Samuel D. Stone	TVA
Bruce Tschantz	FEMA
Larry Von Thun	WPRS
F. Y. Yokel	NBS

General remarks

4. The topic statements (Appendix 1) were discussed on 18-19 September 1980. The presentations by the various agencies represented are divided into three major fields of concern for earthquake engineering research: soils, structures, and geology/seismology. Appendixes 2 and 3 contain related work topics submitted to the group from NSF and USGS, respectively, along with the covers and tables of contents of reports outlining the funding priorities of each organization for earthquake engineering related work. Appendixes 4-6 are statements of ongoing research and development related to earthquake analysis for evaluating dam safety from the Corps of Engineers (CE), TVA, and WPRS, respectively.

Topic Statements

Earthquake engineering research: soils

5. TVA, CE (WES), NBS, and WPRS all presented one or more topic statements describing ongoing research in the behavior of soils during earthquake loading. The methodologies involved literature review and a wide variety of laboratory and in situ techniques to evaluate dynamic properties of soil used for different engineering purposes.

a. Earthquake-induced dynamic pressures on retaining structures are being investigated by TVA through a program of literature review and computer finite element method (FEM) modeling. The final phase of this project will be to evaluate the current TVA policy which uses experimental data that may not be applicable for all present design situations. This dynamic soil-pressure research is geared primarily toward nuclear power plant basement walls.

b. The CE presented several research topics concerning the liquefaction susceptibility of soils during earthquake loadings. State-of-the-art laboratory techniques are used to construct repeatable, homogeneous sand specimens in one study to assess the strain and void ratio redistribution imparted by cyclic triaxial testing. The CE is trying to determine whether a redistribution of void ratio is caused by the laboratory-test conditions and cyclic loading. The CE does not believe that this redistribution of void ratio occurs in situ, and the use of cyclic triaxial test results in dynamic analyses of earth structures may be in question. Special freezing and cutting techniques are used to determine the ice-content redistribution in uniform homogeneous pre- and post-test specimens.

c. Other laboratory research by CE on soil liquefaction is aimed at determining the behavior of well-graded and gravelly materials. One finding of this study is that dams constructed of these materials have historically performed well under earthquake loading, and the conclusion should provide a vital additional empirical data base. TVA is currently evaluating gradation and density variations with sand and gravel mixtures, using a Drnevich free-free torsional resonant column device and 6-in.-diam specimens. WPRS is also conducting research in soil performance during seismic activity, comparing Drnevich free-free and Hardin free-fixed resonant column devices. Tests planned for the future include dynamic strength tests on silt-sand mixes and studies to examine the effects of "scalping" materials from triaxial test specimen gradations to match field gradations.

d. The CE is currently researching earthquake-induced settlements in cohesionless materials by correlating cyclic simple shear and cyclic triaxial test results for use in an effective stress analysis. Analytical solutions for seismically induced settlements in sands are being investigated and have yet to be field-verified. NBS is currently studying the evidence of a threshold shear strain for no volume change in cyclic triaxial test specimens.

e. Both CE and WPRS presented research topics related to in situ determinations of the behavior of soils under earthquake loading. CE (WES) has developed a penetrometer potentially capable of evaluating the in situ liquefaction susceptibility of soils. The device is essentially an electric friction cone with pore-pressure instrumentation which monitors the changes in groundwater pressure induced by penetrometer advance. WPRS is evaluating various geophysical techniques to determine the shear-wave velocity, and hence elastic moduli, of subsurface-soil strata. Both explosive and polarizable nonexplosive wave sources are used to provide in situ modulus information.

f. Researchers at NBS are investigating the Standard Penetration Test to study the effects of hammer geometry on energy transmission to the split spoon. The research is in cooperation with ASTM to overview United States' practices and achieve a stochastic model for energy input.

g. The CE is currently researching a wide variety of methodologies to delineate cavities and discontinuities in rock. To date, one of the most promising techniques to interrogate possible foundation materials is a crosshole radar procedure.

Earthquake engineering research: structures

6. The major portion of research outlined by CE, TVA, WPRS, and BPA concerned the stability of concrete dams during earthquake loading.

a. The overturning potential of high lock and dam sections was evaluated by TVA from an energy-balancing computation, equating maximum potential for overturning to the maximum kinetic energy imparted to the structure from ground motions. This technique has been evaluated and is now being used by the CE and WPRS.

b. The seismic response of concrete dams and appurtenant structures is being researched by WES to upgrade present methodology for determining the nonlinear response of dam-reservoir-foundation systems. Model tests for nonlinear response to strong ground motions have been conducted at WES on a nonoverflow monolith.

c. The hydrodynamic effects of earthquake motion on dams is being investigated by WPRS. Beginning with the simple model of a flat vertical plate in motion, a water-dam interface analytical model will be formulated. Depending on model success, arch dam curvature will be introduced, modeled, and investigated.

d. WPRS is also investigating the behavior of concrete dams following tectonic fault displacement by subjecting physical models to various fault movement configurations introduced at the base. Analytical models may be developed to represent dam performance under fault displacement, including such factors as construction joints and varied faulting modes.

e. TVA and WPRS presented research on the seismic stability of structural elements in other areas besides concrete dams. TVA is evaluating the shear properties of some structural components for nuclear plants by researching thin wall theory, the rigidity method, and FEM for open sections and high-aspect (height-to-width) ratio components. A literature search has produced little data on open sections. WPRS is studying the dynamic properties of instrumented large concrete specimens subjected to sinusoidal loading.

f. A unique study of buried pipe breaks is being conducted by TVA primarily for use in design of nuclear power facilities. The study is intended to assess the extent of washout caused by a sudden, complete break in a pressurized water line which could occur due to ground displacement.

g. The BPA's currently related work consists chiefly of upgrading switchyard components for seismic stability. One particular subject deals with busswork protection from displacement caused by ground motions, which consists of a flexible, conductive expansion joint at formerly brittle electrical connections.

Earthquake engineering research: geology and seismology

7. TVA, CE, and WPRS reported their respective research progress and needs as they pertained to the area of geology and seismology. These three agencies briefly outlined their current practice in utilizing geologic and seismologic input to assess the seismic safety of their dams.

a. TVA is in the process of documenting all faults and existing seismicity data for the TVA region of influence and the southeastern states, respectively. Both compilations will be computerized for data reference; the seismicity data for a quick zonal search (within the 200-mile radius required in current nuclear plant siting criteria) will be available.

b. Both CE and WPRS presented programs designed to upgrade existing strong-motion instrumentation of dams and lay groundwork for new installations to expand the network of stations. The drawbacks of digital strong-motion records were discussed; namely, instability and too much sophistication for serviceability. CE explained that it services and maintains its own network of installations throughout the eastern portion of the United States, while WPRS depends on USGS for instrument service. The CE program installs instruments at the crest, slope, and/or toe, and free-field rock in the dam vicinity where possible, while WPRS installs recorders at the crest, on the embankment slope or within galleries of concrete dams, and at the toe of its dams.

c. The CE is presently upgrading its methodology for selecting design earthquakes, largely through cooperation with private industry and other Government agencies. The probability of recurrence is being studied to assess the likelihood of a maximum event for Corps projects. A bibliography of published and partially completed reports by the Geotechnical Laboratory of WES on geological and seismological investigations of earthquake hazards is included in Appendix 1 with the topic statements (see page 1-43).

d. WPRS is evaluating risk analysis methods for dam design, utilizing a "balanced risk" approach for several possible failure methods. The paper entitled "Water Level Restrictions at Jackson Lake, Wyoming - 1978 Decision Basis" is included in Appendix 1 as an example of the WPRS approach (see page 1-59).

e. Induced seismicity is being investigated in a CE study of reservoir loading and fluid injection. This study consists mainly of a literature review, along with research into theoretical evaluation of local strain release and stress adjustment at reservoirs.

Discussions of Related Work Conducted and/or Sponsored by Others

NBS

8. A portion of the second working group meeting was devoted to discussion by five agencies not represented in IRCC. The contributions of NBS were previously mentioned. Not being a problem-oriented agency, the Bureau's earthquake engineering program originates from a mandate for Federal building needs and much of the geotechnical earthquake engineering funding is Congressionally appropriated through the FEMA disaster mitigation program.

NSF

9. The NSF presented a collection of its ongoing research topics (included in Appendix 2) in the earthquake engineering field. The NSF representative briefly detailed a breakdown of funding for research. The annual summary of awards is given in Appendix 2 for 1979.

NRC

10. The Nuclear Regulatory Commission (NRC) sponsors research in three primary areas of concern for earthquake engineering, particularly,

the safety assessment of critical nuclear power equipment under seismic loading:

a. Seismology and geology - $5 million anticipated for 1980-81.

b. Mechanical engineering - $2 million anticipated for 1980-81.

c. Structural engineering - $1 million anticipated for 1980-81.

USGS

11. The USGS presented two documents to the working group:

a. "Earthquake Hazard Reduction Program, 1978."

b. "Geological Survey Circular 816 - Program and Plans of the USGS for Producing Information Needed in National Seismic Hazards and Risk Assessment, FY 1980-84."

Both reports outline a schedule for various funding priorities in USGS for earthquake-related research and are given in Appendix 3.

FEMA

12. The FEMA representative introduced the Interagency Committee on Dam Safety (ICODS), created in June 1980 to provide overall coordination of dam safety analyses, and to achieve a forum of data and procedure. The first meeting of ICODS is planned for 16 October 1980 and a member from this working group, W. F. Marcuson III, was invited to attend.

Research and Development Related to Earthquake Analysis for Evaluating Dam Safety

13. In addition to the topic statements presented by the various agencies, CE, TVA, and WPRS, each presented their primary research objectives and methodologies directly related to assessing the behavior of dams subjected to earthquake motions.

CE

14. The CE (WES) described the current policy for evaluating seismic stability of dams at Corps installations, both earth/rock-fill and concrete. Two approaches are now taken for evaluating the seismic stability of earth and rock-fill structures: the Seed approach for

liquefaction of granular materials assesses embankment or foundation failure potential and a Newmark-type permanent displacement analysis calculates the deformation of the most critical sliding mass determined from static stability analysis.

15. The CE is investigating the inelastic response of concrete dams, as the maximum credible earthquake (MCE) required for some designs tends to invalidate linear elastic analysis. An example of the problem was illustrated using the Richard B. Russell Dam case history, where earth embankments are coupled with concrete sections. For the concrete section, Professor A. K. Chopra's EADHI code was used to combine hydrodynamics with the dam. The analysis was performed using 5 and 10 percent damping, assuming this would bracket the actual response of the system. The advent of tension cracks in a concrete section is considered to contribute a degree of inelasticity to the response, thus increasing the damping. An abstract of the presentation on Corps concrete dams is included in Appendix 4 with reference to published WES reports.

TVA

16. TVA presents its research and development program related to earthquake analyses of dams in Appendix 5. Included in the Appendix is an overview of TVA's responsibilities for existing dam maintenance and dam safety evaluations related to the nuclear power program.

WPRS

17. The WPRS outlines its research needs and procedures in Appendix 6, categorized into definition of seismic loads, analyses of earth and rock-fill dams, and analyses of concrete dams.

Discussion

18. WES pointed out that a traveling-wave study such as one desired by WPRS for concrete dams has been documented in a WES report on the earth embankment of Fort Peck Dam (WES Technical Report S-76-1, March 1976).

19. TVA concurred with the CE criteria for survivability of concrete dams with regard to cracking or earth dams with regard to deformation; i.e., the dam must retain impoundment safely until drawdown is complete.

20. Strong-motion instrumentation is in great demand for all concerns of the working group. More and better recording instruments need to be developed to enlarge the data base for characterizing ground motions.

Meeting of Steering Committee

21. The Steering Committee of IRCC met at 3:00 p.m., 19 September 1980, to discuss the progress of IRCC and the working group. Those in attendance were as follows:

Lucian G. Guthrie, Office, Chief of Engineers (CE)

R. G. Domer, Tennessee Valley Authority (TVA)

R. Joe Hunt, TVA

R. D. Bourn, Bonneville Power Administration (BPA)

W. F. Marcuson III, Waterways Experiment Station (WES)

J. P. Koester, WES

22. It was observed that there exists reasonable agreement between member agencies as to the methodology for evaluating the seismic safety of earth and concrete dams. The consensus was that more strong-motion instrumentation of new and existing structures was necessary. A lack of information on earthquake-induced dynamic earth pressures on retaining structures was noted as well as a need for improved verticality survey techniques in deep boreholes. Concern was expressed regarding a proliferation of committees organized for similar purposes, yet not being coordinated or in communication with each other. Overall, no unnecessary duplication of research efforts was observed between member agencies.

23. Specific decisions by the Steering Committee were formulated into the following recommendations and action items:

a. Much of the committee discussion centered on strong-motion instrumentation and the mutual desire to improve the existing strong-motion data base. The need was recognized to hasten the distribution of recorded seismic data to the agencies which rely on up-to-date ground motions for design and specification. To this end, the following decisions were made:

(1) Request IRCC member agencies to expedite dissemination of strong-motion data.

(2) Acquire a compilation of the location of strong-motion instruments installed at dams worldwide and distribute to member agencies.

(3) Establish liaison to avoid redundancy of strong-motion instrumentation at dams in proximity to one another; the example cited was Kentucky Dam (TVA) near Barkley Dam (CE).

b. The outcomes and conclusions of this working committee meeting should be reported to the upcoming IRCC at Vicksburg, Mississippi; specific topics to be addressed concern commonality in the areas of:

(1) Developing a terminology and exchanging information pertaining to the development of ground motions.

(2) Evaluation of new and existing facilities.

(3) Criteria for assessing stability of earth and concrete dams.

c. This working group should be represented at the next National Science Foundation workshop on strong-motion instrumentation.

d. Areas within or between member agencies where unnecessary repetition or duplication exists in research efforts should be identified; an example cited was TVA's ongoing research to investigate dynamic properties of cohesionless material previously documemted in the literature.

e. Each agency should determine its needs for research of earthquake-induced dynamic earth pressures on retaining structures. These findings will be communicated via telephone conference on or about 1 January 1981 by the following contact people who will also, at that time, decide whether further committee activities and/or workshops, etc., are justified:

P. F. Hadala, WES	FTS 542-3475
Frank Hand, TVA	FTS 852-2101
R. D. Bourn, BPA	FTS 429-4329
Karl Dreher, Water and Power Resources Service	FTS 234-3189

f. It should be decided at the Vicksburg IRCC biennial meeting what, if any, arrangements are to be made toward organizing the Third Interagency Working Group Meeting for Earthquake Engineering Research Coordination.

g. It was decided that the general form for topic statements will be modified to include a description of the funding level for each research item.

APPENDIX 1

INVITATION, PROPOSED AGENDA, AND TOPIC STATEMENTS,
INCLUDING REPORT MATERIAL AVAILABLE
TO MEETING ATTENDEES

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
P. O. BOX 631
VICKSBURG, MISSISSIPPI 39180

CIVIL ENGINEERING BRANCH
AUG 27 1980

IN Date	Time		OUT Date	Time
8/27	4	ROD	8/27	
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		CEF		
		FRH		
		NHLB		
		MGM		

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REFER TO:

WESGH

22 August 1980

TO: SEE DISTRIBUTION

Gentlemen:

The meeting of the Interagency Working Group for Earthquake Engineering Research Coordination will meet in the offices of the Tennessee Valley Authority (TVA) in Knoxville, TN, on 18-19 September 1980. Inclosure 1 is an agenda which I have prepared for this meeting. Please look this over and be prepared to discuss your topic statements. I believe these presentations should be limited to 7 to 10 minutes. This should allow about 5 minutes for questions.

Note that between 10:15 and 11:45 on 19 September, I have allowed each of the invited organizations about 15 minutes to discuss related work which they are either conducting or sponsoring.

On the afternoon of the 19th, I would like for TVA, the Corps of Engineers (CE), and the Water and Power Resources Service (WPRS) to prepare a 30-minute presentation on research and development related to earthquake analysis for evaluating dam safety (earth, rock-fill, and concrete dams). Additionally, I would like for you to document this in writing so that we can include it in our report covering the meeting. Note that I have allowed about 30 minutes from 2:30 to 3:00 for remarks from other government agencies which are concerned with dam safety.

Mr. Joe Hunt at TVA is in charge of local arrangements. He has a block of rooms reserved at the Holiday Inn on Chatman Highway for the evenings of 17-19 September. You may contact him on FTS 856-2190. His mailing address is:

Mr. Joe Hunt
Tennessee Valley Authority
WW11A6
Commercial Realty Management Building
400 Commerce Avenue
Knoxville, TN 37902

Please confirm with Mr. Hunt your plans for attending the meeting and when you plan to arrive in Knoxville.

WESGH
SEE DISTRIBUTION

22 August 1980

Inclosure 2 is a copy of all the topic statements which I have received to date.

During the time period 3:15 to 4:25 p.m. on 19 September, I would like to meet with members of the Steering Committee (indicated by an asterisk below) to discuss the significant conclusions reached during the meeting and also the content of the report which will document the meeting.

Should we have additional items which need to be discussed and for which we do not have time allotted, we can extend our meeting on Thursday afternoon beyond 4:30 p.m. I am asking each of you to look at the agenda and the topic statements; see if I have omitted something which you would like included. If so, bring this to my attention at the break the morning of 18 September. I will then inform everyone the additional agenda items.

If you have any questions regarding this meeting, please do not hesitate to call me at FTS 542-2217. Your cooperation and assistance is very much appreciated.

Sincerely,

Bill

W. F. MARCUSON, III
Research Civil Engineer
Acting Chief, Earthquake Engineering and Geophysics Division
Geotechnical Laboratory

2 Incl
As stated

DISTRIBUTION:
Bill Hakala, NSF
Fritz Matthiesen, USGS
Felix Yokel, NBS
Goutam Bagchi, NRC
*Bob Bourne, Bonneville Power Adm.
*Larry Von Thun, WPRS
*R. G. Domer, TVA
Joe Hunt, TVA
Chuck Thiel, FEMA
*Lucien Guthrie, OCE
Ernie Dodson, OCE
Mel Martin, OCE

8/26/80 - RGD:JL
cc (Enclosures):
R. O. Barnett, W9D224 C-K - Please handle.--RGD
MEDS, E4B37 C-K

MEETING OF THE INTERAGENCY WORKING GROUP
FOR EARTHQUAKE ENGINEERING RESEARCH
COORDINATION

To be held

18-19 September 1980

at the

Tennessee Valley Authority, Knoxville, Tennessee

TENTATIVE AGENDA

18 September

8:30 - 9:00	Welcome, Introductory Remarks, Etc.	W. F. Marcuson & R. G. Domer
9:00 -10:15	Earthquake Engineering - Soils	
	(1) Dynamic Soil Pressures	TVA
	(2) Earthquake-Induced Settlements in Soils	CE
	(3) Liquefaction of Dams and Foundations During Earthquakes	CE
	(4) Dynamic Properties of Well-Graded Materials	CE
10:15-10:30	Break	
10:30-11:45	Earthquake Engineering Research - Soils (Cont'd)	
	(5) Development of Technique and/or Device to Evaluate Liquefaction Potential of In Situ Cohesionless Material	CE
	(6) Remote Delineation of Cavities and Discontinuities in Rock	CE
	(7) Soil Performance During Seismic Activity	WPRS
	(8) In Situ Shear-Wave Velocity Measurement of Elastic Moduli Determinations	WPRS
11:45- 1:00	Lunch	
1:00- 2:45	Earthquake Engineering Research - Structures	
	(1) Shear Properties Used in Seismic Analysis Structures	TVA
	(2) Dam Stability via Energy Balance	TVA
	(3) Effects of Buried Pipe Breaks	TVA
	(4) Seismic Response of Concrete Dam and Appurtenant Structures	CE
2:45- 3:00	Break	
3:00- 4:30	Earthquake Engineering Research - Structures (Cont'd)	
	(5) Dynamic Properties of Concrete	WPRS
	(6) Structural Hydrodynamic Studies	WPRS
	(7) Behavior of Concrete Dams Following Tectonic Fault Displacement	WPRS

AGENDA (CONTINUED)

19 September

8:30 - 10:00	Earthquake Engineering Research - Geology, Seismology, etc.	
	(1) Locations and Descriptions of Fault in TVA Region	TVA
	(2) Seismicity of Southeastern United States	TVA
	(3) Strong-Motion Instrumentation Program	CE
	(4) Methodology for Selecting Design Earthquakes	CE
	(5) Seismic Effects of Reservoir Loading & Fluid Injection	CE
	(6) Strong-Motion Instrumentation Program	WPRS
	(7) Applicability of Risk Analyses Methods to Dam Design	WPRS
10:00 - 10:15	Break	
10:15 - 11:45	Discussions of Related Work Conducted and/or Sponsored by Others	
	(1) Bonneville Power Administration	
	(2) National Science Foundation	
	(3) Nuclear Regulatory Commission	
	(4) U. S. Geological Survey	
	(5) Federal Energy Management Agency	
	(6) National Bureau of Standards	
11:45 - 1:00	Lunch	
1:00 - 3:00	Research and Development Related to Earthquake Analysis for Evaluating Dam Safety	
1:00 - 1:30	TVA	
1:30 - 2:00	CE	
2:00 - 2:30	WPRS	
2:30 - 3:00	Remarks by FEMA, NRC, NSF, BPA	
3:00 - 3:15	Break	
3:15 - 4:25	Discussion	
4:25 - 4:30	Closing Remarks	Marcuson

EARTHQUAKE ENGINEERING RESEARCH

S O I L S

TOPIC STATEMENT

Agency TVA Priority ______ 1979 Session Number ______

Subject Area Earthquake Engineering

Project Title Dynamic Soil Pressures

Performing Organization Civil Engineering Branch

Principal Investigator H. R. Threlkeld, Dr. F. R. Hand

Starting Year CY 1979 Estimated Completion Year CY ~~1979~~ 1981

Technical Objectives:

The objective is to determine the dynamic soil pressures exerted on basement and retaining walls during an earthquake. The walls may be rigid or flexible and supported on rock or soil.

Technical Approach:

The study consists of (1) a review of current literature to compare the current dynamic soil pressures theories, (2) finite element analyses of various wall and soil configurations for both natural and artificial earthquake excitation, (3) comparison of various tests reported in the literature with each other and the results of our finite element analyses, and (4) evaluation of TVA's current practice based on experimental results from the 1930's.

General Progress:

We have completed our literature review and have started the finite element analyses.

Plans For Next Twelve Months:

Complete the finite element analyses and perform steps 3 and 4 as described above.

TOPIC STATEMENT

Agency NRC Priority ______ 1980 Session Number ______

Subject Area Earthquake Engineering

Project Title Earthquake-Induced Settlements in Soils

Performing Organization USAE Waterways Experiment Station

Principal Investigator R. H. Ledbetter (FTS 542-3380)

Starting Year FY 80 (Feb) Estimated Completion Year Continuing

Technical Objective: To study existing and develop new procedures using laboratory and analytical techniques to predict earthquake-induced settlements of soils.

Technical Approach: The approach is to review the literature and determine the current state of knowledge. A state-of-the-art report and recommendations for continued research directions will be prepared. This report will include recommendations concerning large and small scale testing for the purpose of verification of existing methodology.

General Progress: The literature is being reviewed. To date, one unified analytical solution for seismically induced settlements has been found. The solution is a computerized analysis for sands by Dr. W. D. Finn, University of British Columbia. Basic assumptions and concepts are as follows:

a. One dimensional

b. Free field conditions

c. Level ground surface with horizontal layers

d. Volumetric strain behavior is computed as a function of time due to the actual random input from an earthquake.

e. Pore pressure increase and dissipation is computed as a function of time due to the actual random input from an earthquake.

f. The time response of vertical settlement is computed.

g. Program inputs for the soil are dynamic shear stress-strain characteristics and volume-pore pressure characteristics.

No field-verification of the approach has been made. A copy of the computerized analysis (DESRA II) has been obtained and adapted to the WES computer.

During FY 80 the following work is planned:

a. Prepare a state-of-the-art report with recommendations for continued research.

b. Investigate Professor Finn's analytical solution.

c. Conduct a small number (three to six) of laboratory cyclic triaxial tests on saturated sand in order to tentatively evaluate laboratory settlement behavior.

d. Search for well documented case histories to verify DESRA II and other methodologies which can be identified and/or developed.

Plans for Next 12 Months: Depending on our recommendations, our current plans are as follows:

a. Relate cyclic triaxial test to cyclic simple shear test data. Cyclic simple shear data are used as input parameters for DESRA II; however, cyclic triaxial testing is more routinely used, is more economical and is easier to conduct; therefore, we hope to modify these cyclic triaxial test data and use them as input parameters instead of cyclic simple shear data.

b. Verify DESRA II and any other methodology with either case histories and/or large scale tests.

c. Investigate the feasibility of in situ testing techniques for evaluating the characteristics and potential for seismically induced settlements of soils.

TOPIC STATEMENT

Agency CE Priority 1 1980 Session Number

Subject Area Geotechnical Earthquake Engineering

Project Title Liquefaction of Dams and Foundations During Earthquakes

Performing Organization Earthquake Engineering and Geophysics Division, WES

Principal Investigator W. F. Marcuson, III (FTS 542-2217)

Starting Year 1973 Estimated Completion Year 1981

Technical Objectives: To develop and evaluate laboratory and/or analytical methods to determine pore water pressures and strains within saturated cohesionless embankments and foundations subjected to seismic loads. Develop correlations of field performance during earthquakes with soil properties.

Technical Approach: This program is presently primarily dedicated to the evaluation of the degree of nonuniformity of strain and void ratio distribution at various stages in the cyclic triaxial test. Our approach is to first build repeatable homogeneous specimens, then subject these specimens to various degrees of pore pressure response in the cyclic triaxial test. Once this predetermined pore pressure response has been achieved, the specimen is frozen in such a way as not to impede drainage and is cut into 108 segments. The ice content (void ratio) of each segment is then determined. Analysis of these data should indicate the degree of void ratio redistribution that takes place during cyclic triaxial testing.

General Progress: Since the 1978 meeting we have published two more research reports entitled "Liquefaction Potential of Dams and Foundations," WES Research Report S-76-2. These reports are Report 3 "Elastic-Plastic Work-Hardening Constitutive Model for Fluid-Saturated Granular Material" dated August 1978 and Report 6 "Laboratory Strength of Sands Under Static and Cyclic Loadings" dated March 1979. Report 7 "Geotechnical Earthquake Engineering: State-of-the-Art, 1980" will be published this fall. A report by Professor V. P. Drnevich entitled "Evaluation of Sample Disturbance on Soils Using the Concept of 'Reference Strain'" was published as WES Technical Report GL-79-13 in September 1979. Professor Marshall Silver is presently under contract to conduct a feasibility study on large scale cyclie shear tests including shake tables, centrifuges, and the like.

Plans for the Next 12 Months: The evaluation of the degree of nonuniformity of strain and void ratio distribution at various stages in the cyclic triaxial test will be continued. We are currently building specimens at a relative density of approximately 65 percent with a standard deviation of about 3.2 percent. Our consultants believe this variation is still too large. We are trying to reduce the standard deviation by approximately 50 percent and to build homogeneous specimens at various relative densities.

TOPIC STATEMENT

Agency CE Priority 1 1980 Session Number

Subject Area Earthquake Engineering

Project Title Dynamic Properties of Well-Graded Materials

Performing Organization USAE Waterways Experiment Station

Principal Investigator M. E. Hynes-Griffin (FTS 542-2280)

Starting Year FY 80 Estimated Completion Year FY 82

Technical Objectives: To evaluate the susceptibility of well-graded earth-rock mixtures to liquefaction as a result of earthquake shaking and determine the controlling material properties.

Technical Approach:

a. Obtain data on dams constructed with saturated zones of widely graded soils that have been subjected to large earthquakes in the past, and correlate measured material properties with field performance.

b. Investigate the feasibility and possible development of a large-scale cyclic test device designed to monitor well-graded specimens.

c. Perform cyclic triaxial tests on compacted well-graded specimens to determine the effects of changes in density, gradation, and stress history on the pore pressure response and deformation of the material during the test.

d. Perform a series of strain-controlled $\bar{R}$ tests on similar specimens to provide correlations between cyclic test performance and static test performance.

General Progress:

a. Information on the past performance of dams in California constructed of well-graded materials that have been subjected to significant earthquakes is being processed.

b. A feasibility study of the development of a large-scale testing device and sample preparation has been completed and the decision has been made that development of such a device at this time is not advisable.

c. A material has been chosen for a series of cyclic triaxial tests and $\bar{R}$ tests. The decision has been made that the emphasis of the parameter study should focus on stress history effects on cyclic and $\bar{R}$ performance of samples.

d. Additional researchers have been contacted. Geotechnical Engineers, Inc., and Professor H. B. Seed have contributed suggestions as to the stress path to use for preconsolidation and rebound and shared past experience with such tests.

e. A procedure for compacting 6-inch diameter specimens for the cyclic triaxial and $\bar{R}$ test series has been developed that will provide specimens that display uniform strain characteristics over the height of the specimen during cycling. Earlier procedures led to necking of the specimen due to non-uniformity of gradation within a layer and of density between layers. A total of five layers are used in preparing the specimens.

f. The cyclic triaxial testing program has been initiated for two gravel contents, 34 percent and 50 percent by weight, with the minus No. 4 sieve fraction held constant. The fines contents for these two mixtures are 23 percent and 19 percent, respectively.

g. A pore pressure transducer that can be compacted into the specimen is being developed.

Plans For Next Twelve Months: Continue development of the pore pressure transducer, commence $\bar{R}$ testing series, and continue stress history (i.e., overconsolidation) investigation.

TOPIC STATEMENT

Agency Corps of Engineers	Priority	1980 Session Number

Subject Area: Earthquake Engineering

Project Title: Development of Technique and/or Device to Evaluate the Liquefaction Potential of In Situ Cohesionless Material

Performing Organization: Waterways Experiment Station

Principal Investigator: A. G. Franklin

Starting Year: FY 1979 Estimated Completion Year: FY 1982

Technical Objectives:

To develop methods and procedures for the evaluation of the liquefaction potential of soils by means of in situ tests, either through empirical correlations between liquefaction potential and data from conventional tests or by the development of new devices to measure liquefaction-related soil characteristics.

Technical Approach:

The study includes field and laboratory evaluation of in situ test devices or methods, such as the Standard Penetration Test (SPT), the Dutch cone, and the Wissa piezometer probe, to calibrate their response to liquefaction-related soil characteristics, including contraction-dilation behavior, shear strength, and density.

General Progress:

Two types of piezometer probes have been designed and fabricated: a piezometer probe and a probe of the Dutch cone type, incorporating sensors to measure simultaneously the end-bearing load, side friction load, and pore pressure generated by the advance of the probe. This has been called the PQS probe. Both have interchangeable points to study the distribution of pore pressures around the tip. The PQS probe has been field tested and procedures for routine field use have been established.

Plans for Next Twelve Months:

The PQS probe will be field tested at one or more sites containing cohesionless soils that have been subjected to earthquake shaking to compare the response of soils that did and did not liquefy. Laboratory tests in sand placed with controlled relative density are contemplated.

TOPIC STATEMENT

Agency WES Priority ________ 1980 Session Number ________

Subject Area Earthquake Engineering

Project Title Remote Delineation of Cavities and Discontinuities in Rock (CWIS 31150)

Performing Organization WES

Principal Investigator Robert F. Ballard, Jr. (FTS 542-2201)

Starting Year FY 76 Estimated Completion Year FY 81

Technical Objectives: To improve existing or develop new test systems, techniques, and analysis procedures for detecting and delineating anomalous conditions in rock and/or soils.

Technical Approach: The study is being conducted by choosing two well-documented test sites. Both sites, located in the state of Florida, are cave systems. Medford Cave is a mapped air-filled labyrinth which was created by solutioning activity in limestone. The second site is located at Manatee Springs and as the name implies is a wet site which has been mapped by cave divers. Numerous borings have been placed at both test sites in an effort to describe subsurface conditions in as accurate a manner as possible. Up to 25 geophysical techniques will be used, both on the ground surface and in borings in an effort to determine which techniques are most applicable to the specific problem, their degree of resolution, relative economic conditions, advantages, and limitations. Seven different agencies are being used to conduct tests at both test sites so that virtually every field of expertise directly related to the cavity/anomaly detection problem will have been covered. Many of the techniques which are presently being used can be improved, thus resulting in a more uniform measurement of in situ soil properties used for earthquake stability analyses and structure performance criteria.

General Progress: To date, drilling is finished and approximately 20 geophysical methods have been used at the Medford test site. Drilling has been completed at Manatee Springs and crosshole electromagnetic surveys are in the process of being completed. Conventional downhole logging has also been done. Preliminary results of tests conducted at Medford Cave indicate that certain seismic methods, microgravity, surface electrical resistivity, certain borehole and surface ground probing radar and acoustic resonance techniques show a great deal of promise in the detection and delineation of anomalous conditions. Conceivably, some of the geophysical methods can be used to detect areas where potential sinkholes are likely to develop under earthquake-type loadings.

Plans for the next twelve months: Field testing will be completed at both test sites and complete documentation in the form of preliminary reports will be done. Technology transfer is being accomplished onsite by coordination with various agencies who have a desire to watch tests in progress which are relevant to specific problem areas.

TOPIC STATEMENT

Agency WPRS Priority 1 1980 Session Number ______

Subject Area Material Properties

Project Title Soil Performance During Seismic Activity (E-6)

Performing Organization WPRS

Principal Investigator L. P. Kaufman

Starting Year - Estimated Completion Year FY82

Technical Objectives:

To improve capabilities in determining dynamic properties and cyclic strength for various soil conditions for earth and earth-supported structures. These capabilities are needed in the investigation of the safety of existing structures and in the design of safe and economical new structures.

Technical Approach:

Various soil types and conditions will be tested in the laboratory using a variety of dynamic testing equipment. The results of these tests will be used to determine how differences in soil properties and cyclic strengths affect the stability of structures and foundations. As appropriate test apparatus, procedures, and methods of analysis will be developed and improved.

General Progress:

The effects various methods of test and test apparatus have on measured dynamic properties and cyclic strengths are being investigated. Work has continued for determining the effects of soil type, gradation, and specimen type and size on measured dynamic response properties.

Plans for Next Twelve Months:

Work will continue toward investigating the effects of gradation and specimen size on both dynamic properties and strength. A program will be conducted to research the effects methods of scalping for modeling field gradations have on dynamic response parameters. Another program will investigate the comparative dynamic strengths of a series of standard sand specimens reconstituted with increasing percentages of silt as tested in the cyclic triaxial apparatus.

TOPIC STATEMENT

Agency WPRS Priority ____________ 1980 Session Number ____________

Subject Area Soils - Earthquake

Project Title In Situ Shear Wave Velocity Measurements for Elastic Moduli Determinations

Performing Organization WPRS

Principal Investigator A. Viksne

Starting Year FY74 Estimated Completion Year Continuing

Technical Objectives:

The objective of this program is to evaluate various geophysical exploration methods for obtaining the shear wave velocity of materials which is used as a means for determining the in situ and en masse elastic properties of earth structures and materials as well as the foundation and constituent soils. The elastic moduli are required as input parameters in advanced finite element programs for dynamic analysis of earth dams and in the evaluation of liquefaction potential of engineering works sites.

Technical Approach:

A number of geophysical exploration methods for obtaining shear wave velocity such as the borehole methods (primarily down hole, and cross hole) as well as geophysical borehole logging have been tested under a variety of field conditions. Field tests included the use of cased and uncased boreholes and the use of explosive and nonexplosive energy sources.

General Progress:

To date, shear wave velocity measurements have been performed on more than ten different sites using a variety of techniques. The results of some of these tests have been summarized in a report REC-ERC 76-6, April 1976. Additional tests were performed by contract and the results will be available sometime in 1980.

Plans for Next Twelve Months:

Future work will include design and testing of different systems for using nonexplosive and reversible impact energy sources in the borehole methods as well as further research on utilizing geophysical borehole logging techniques for obtaining continuous in situ shear wave velocity values and subsequently shear modulus.

EARTHQUAKE ENGINEERING RESEARCH

S T R U C T U R E S

TOPIC STATEMENT

Agency TVA Priority I 1978 Session Number

Subject Area Earthquake Engineering

Project Title Shear Properties Used in Seismic Analysis of Structures

Performing Organization TVA

Principal Investigator Dennis Carlin, Jr.

Starting Year FY80 Estimated Completion Year FY81

Technical Objectives: To evaluate the three methods (1) thin wall theory, (2) rigidity method, and (3) finite elements method for calculating shear properties (area, shear center, shape factors) for use in seismic analysis of nuclear power plant structures. The study will consider primarily structures with small height to width (aspect) ratios and open sections.

Technical Approach: First, a literature search will be conducted. Next, a comparison of the results of analysis using the three methods found in the literation search will be made. Finally, additional analyses of structures will be performed as required to complete the evaluation of the three methods.

General Progress: The library search is presently in progress. In particular, material which pertains directly to seismic analysis of power plant structures is being collected and evaluated.

Plans for Next Twelve Months: The project, as outlined under Technical Objectives, will be completed by December 1980.

Agency TVA Priority ______ 1978 Session Number ______

Subject Area Earthquake Engineering

Project Title Dam Stability via Energy Balance

Performing Organization TVA - EN DES - CEB

Principal Investigator Norman E. Stone

Starting Year FY79 Estimated Completion Year FY81

Technical Objectives: To develop a simplified technique to determine the structural stability of dam and lock section when excited by an earthquake. Method will be developed to adequately represent surrounding media.

Technical Approach: To further develop simplified method now being used and to correlate results with a more complex nonlinear computer analysis.

General Progress: Considerable technical library research has been made on this method. The stability of some typical lock sections has been evaluated to show them to be stable.

Plans for Next Twelve Months: If possible, the computer correlation will be initiated.

TOPIC STATEMENT

Agency TVA Priority ______ 1979 Session Number ______

Subject Area Earthquake Engineering

Project Title Effects of Buried Pipe Breaks

Performing Organization Civil Engineering Branch

Principal Investigator Dr. F. R. Hand, ~~R. A. Banks~~ C. N. Sun

Starting Year CY 1979 Estimated Completion Year CY ~~1979~~ 1980

Technical Objectives:

To determine the effects of a break in a buried pipe and the ensuing washout on any adjacent structures or features.

Technical Approach:

The general approach is to determine the limiting size of the washout for a given pipe size, flow rate, and burial depth. This limiting size is determined by calculating how large the diffusion of the jet of water must be so the velocity of the water at the edge of the washout is less than the critical velocity required for soil particle transport.

General Progress:

One specific set of conditions has been considered.

Plans For Next Twelve Months:

Two more specific cases will be considered. Then a general procedure will be developed for determining the limiting washout size.

TOPIC STATEMENT

Agency CE Priority ______ 1980 Session Number ______

Subject Area Earthquake Engineering

Project Title Seismic Response of Concrete Dams and Appurtenant Structures

Performing Organization WES

Principal Investigator Paul Hlakar (FTS 542-3365)

Starting Year FY81 Estimated Completion Date FY84

Technical Objectives: To determine the coupled nonlinear response of the concrete dam-reservoir-foundation system to earthquake ground shaking and to practically revise the Corps criteria for the seismic analysis of concrete dams and appurtenant structures in accordance with this determination.

General Approach: This work simultaneously involves studies to define the effects of the least understood variables on seismic response as well as the usable modification of design criteria consistent with knowledge already gained about the effects of other variables on seismic response. Thus, the criteria are now being modified to reflect an increased understanding of the locally expected earthquake motion and the dynamic response of the structure-reservoir system. Parametric studies are now planned to similarly reduce the results of recently developed foundation effects models to a field usable form. At the same time, nonlinear analyses, dynamic material property experiments, controlled model tests and necessarily limited prototype experiences are being exploited to gain an understanding of the structure's nonlinear response to strong ground motion. A probabilistic study is also proposed to derive design criteria consistent with a desired level of reliability for these structures. The transfer of this technology is further aided by numerous consultations by the investigators to District offices having unique seismic problems. This process is also assisted by the investigators teaching separately funded short courses "Fundamentals of Dynamic Analysis for Earthquake Engineering" and "Earthquake Analysis of Gravity Dams and Appurtenant Structures."

Plans for Next Twelve Months: The design criteria for intake towers will be revised to reflect an increased understanding of the locally expected earthquake motion and the dynamic response of the structure-reservoir system. Parametric analytical studies will be made of the interaction among the dam-reservoir-foundation system during a seismic excitation. A theoretical model will be developed to describe the recently obtained experimental data for the dynamic, biaxial behavior of concrete. This model will then be used in parametric, analytical studies of the nonlinear behavior of a concrete gravity dam during extreme ground shaking.

TOPIC STATEMENT

Agency WPRS Priority 1 1980 Session Number ______

Subject Area Material Properties

Project Title Dynamic Properties of Concrete (DE-12)

Performing Organization WPRS

Principal Investigator F. J. Jackmauh

Starting Year FY75 Estimated Completion Year FY84

Technical Objectives:

Tests on large concrete specimens subjected to sinusoidal vibrations of various frequencies, cycling in tension and compression, are performed to give stress, strain, and time relationships. Designers are now using a dynamic analysis computer program to predict strain-time values on structures subjected to vibrations. At present, only static uniaxial modulus information is available for the computer program and dynamic biaxial test results on mass concrete are required.

Technical Approach:

Test specimens are epoxied into a vertical test frame with a reactor and load cell providing force and feedback. A horizontal force will also be applied to the specimen. Strain gages will be cast into the concrete to measure strains in the orthogonal stress fields, and monitored during testing, recording each gage's output. A minicomputer will be used for load control.

General Progress:

Uniaxial tests have been performed on several series of concrete specimens. The report is being prepared. A load frame for biaxial tests has been procured, assembled and checked for dimensional tolerances. Six test specimens with embedded strain gages are ready for testing. Report No. GR-80-3 on the design of the biaxial test system is being printed.

Plans for Next Twelve Months:

Data acquisition and load control programs using an HP9825 computer will be developed, and initial dynamic tests will be conducted.

TOPIC STATEMENT

Agency WPRS Priority 1 1980 Session Number ________

Subject Area Structural Behavior

Project Title Structural Hydrodynamic Studies (DB-15)

Performing Organization WPRS - E&R Center

Principal Investigator F. J. Jackmauh

Starting Year FY76 Estimated Completion Year FY84

Technical Objectives:

To provide answers to the following questions: (1) How is the effective mass of water attached to a dam determined when a dam is subjected to vibratory motion, and how does it affect the dynamic characteristics of the dam at various modes of vibration? (2) How applicable are analytical techniques used to design arch dams for hydrodynamic effects? (3) What method of investigating hydrodynamic effects might be the most suitable for future consideration and study?

Technical Approach:

The program has several phases as follows: (1) Parameters to be investigated for analytical techniques in designing dams will be established. (2) A simple dam model, such as a vertical plate, will be constructed and tested. Experimental results from these tests will be compared with results from analytical techniques. (3) When analytical solutions satisfactorily describe the behavior of the experimental model, another model with a vertical face, but curved horizontally, will be built and tested. Again, analytical solutions will be compared with model test results. Depending on the outcome of the work at this stage, further testing and analytical evaluation may be performed to determine effects of foundation shape. An analytical and experimental model of an actual dam may be used for this phase. Experimental and analytical work will be closely coordinated.

General Progress:

Parameters to be investigated have been established. A computer program incorporating hydrodynamic pressure procedures into the Service's Arch Dam Analysis program has been procured and partially modified. Vibration test equipment has been checked out and the fixture to couple the actuator to the model has been manufactured and expect delivery August 1980.

Plans for Next Twelve Months:

The equipment components will be assembled and the dynamic response of the fixture determined under frequencies up to 300 Hz. The performance will be compared to the dynamic response analyses performed on the fixture design. If satisfactory, tests on the simple dam model will be started.

TOPIC STATEMENT

Agency WPRS Priority 1 1980 Session Number ______

Subject Area Structural Behavior

Project Title Behavior of Concrete Dams Following Tectonic Fault Displacement (DF-1)

Performing Organization WPRS - University Contractor

Principal Investigator K. J. Dreher

Starting Year FY81 Estimated Completion Year FY82

Technical Objectives:

To determine the ability of concrete gravity and arch dams to withstand significant fault displacements in their foundations. Components of normal, reverse, and strike-slip faulting will be considered, and the effects of contraction joints evaluated. Performance of concrete dams following fault displacements for static loading conditions in combination with earthquake ground accelerations will also be assessed.

Technical Approach:

A simple two-dimensional model of a gravity dam section including its reservoir an foundation will be constructed on a large shaking table. Idealized fault displacement will be simulated by providing a foundation block which can be displaced relative to the rest of the model. Structural response to fault displacement and earthquake ground acceleration including hydrodynamic effects will be investigated separately and in combination. The modeling techniques developed will be extended to three dimensions and a gravity-arch or arch dam modeled including several contraction joints and various modes of fault displacement. The response to fault displacement and ground acceleration will again be studied separately and in combination. Along with these physical model studies, analytical techniques to mathematically model fault displacements and subsequent structural behavior will also be developed.

General Progress:

The physical modeling portion of this work will be performed under contract by a structural mechanics laboratory having a large shaking table (at least 6 m square) capable to excitation frequencies on the order of 50 Hz.

Plans for Next Twelve Months:

The contract for the model studies will be awarded and the dimensional studies completed. Techniques for constructing the three-dimensional models including contraction joints will also be developed.

EARTHQUAKE ENGINEERING RESEARCH

GEOLOGY-SEISMOLOGY-ETC.

TOPIC STATEMENT

Agency TVA Priority ______ 1980 Session Number ______

Subject Area ______

Project Title Location and Description of Faults in the TVA Region

Performing Organization Geologic Services Group - Civil Engineering and Design Branch

Principal Investigator Robert J. Floyd

Starting Year 1975 Estimated Completion Year 1981

Technical Objectives: The objective is to assemble and coordinate all available information on faults in an area that includes all or parts of 11 states in and around the Tennessee Valley region.

Technical Approach: All available published and open-file data have been researched and used to plot faults on standard 1:500,000 USGS base maps for each state. Each fault on the maps has been assigned an identification number, which is keyed to a fault data card which summarizes information on type of fault, length, strike and dip, displacement, age, and pertinent references. References cited are compiled as lists for individual states.

General Progress: All faults have been plotted on manuscript maps and are now being scribed in final form. Fault data cards and reference lists have been prepared and have undergone preliminary edit.

Plans For Next Twelve Months: Scribed fault maps will be reviewed for accuracy, and identification numbers will be added. Fault data cards and reference lists will be computerized. State geological surveys will be consulted where necessary to assist in resolving questions on fault data, and will be given the opportunity to review the final map and data for their state.

LOCATION AND DESCRIPTION OF FAULTS IN THE TVA REGION

INTRODUCTION

In 1975 the Geologic Services Branch of the Division of Water Management (now Geologic Services Group of the Civil Engineering and Design Branch, Division of Engineering Design) began compilation of fault maps of individual states in the TVA region. The principal objective was to have readily available documentation for all faults within a 200-mile radius of any existing or potential TVA nuclear power plant site. Because of staff limitations and the pressure of deadlines for the completion of high-priority projects, the fault study was destined to be an intermittent investigation, with compilation done mostly by scientific cooperative students under the supervision of staff geologists.

TECHNICAL APPROACH

All available published and open-file data were evaluated and used as sources to plot faults at 1:500,000 scale. Negatives of USGS state base maps were obtained and used to prepare stable blueline mylars on which the faults were plotted in pencil.

Each fault was assigned a key identification number, beginning with number 1 in each state. Documentation for each fault was recorded on fault data cards, which begin with the name of the fault (if any) and the key identification number (each number is preceded by state abbreviation letters, such as AL 14). Other parameters on the fault data cards are reference (text material), map reference, location, type (of fault), local length (length within the state), total length (includes extent outside the state), strike, dip, displacement, age, and remarks.

Compilation of data was based on state and federal published maps and reports, open-file materials, theses and dissertations, and journal articles. Some of the research required conferences with state geological survey and university personnel.

GENERAL PROGRESS

Compilation copies of all state maps have been refined by professional scribing of fault traces. Number identification overlays for all states are almost complete. The scribed fault traces and corresponding number identification overlays will soon be composited with screened base maps to provide proofs for review.

PLANS FOR NEXT 12 MONTHS

Information on fault data cards and bibliographic reference lists will be entered into a computer. Printouts and map proofs will be provided to state geological surveys for review and consultation on resolving questions for final presentation. Concurrently, TVA geologists will perform their final review and editing.

This series of maps and the accompanying documentation data, when completed, will represent a unique set of detailed fault information not available from any other source. Plans for reproduction, distribution, and availability to the general public have not been finalized.

SUMMARY BY STATES

The following paragraphs indicate the extent of the study area for each state, number of faults documented, and principal sources and reliability of data. Large areas that contain few if any faults are discussed and evaluated, and correlation of faults across state lines is summarized.

Alabama

Because the limits of the study area were not established at the time of compilation, information was gathered for essentially the entire state. Two hundred sixty-one faults were catalogued, 69 of which remain unverified. Information was acquired mostly from state and federal geological publications, and to a lesser degree from theses and dissertations. Most of the unverified listings were acquired from an unpublished map (1:250,000) and report compiled by the Geological Survey of Alabama (Self and others). Personal communication accounts for a lesser but still significant amount of information, especially for details unavailable from publications.

A decision was made to show faults outside the southern boundary of the study area, most of which are younger faults and some of which reportedly are still active. The apparently unfaulted belt which trends northwestward across the central part of the state coincides with the outcrop of Cretaceous formations which overlie the Paleozoic rocks in which most Alabama faults have been mapped. Faults undoubtedly are present beneath Cretaceous formations of the Coastal Plain, but their location and extent have not been documented in publications. Lack of source information also accounts for apparently unfaulted areas, especially in the east-central part of the state.

Faults that cross the state lines into Tennessee, Georgia, and Mississippi show fair to good correlation with corresponding faults in the adjoining states.

Georgia

Approximately the north half of Georgia is included in the study area. Eighty-five faults or groups of faults have been catalogued. For map locations, the 1976 Geologic Map of Georgia (scale 1:500,000) was relied on almost entirely. Text references were derived from state and federal publications, some from adjoining states.

Large apparently unfaulted areas within the Piedmont reflect the difficulty in determining characteristics of faults here, as in the Piedmont of Alabama, the Carolinas, and Virginia.

Matching of faults across state lines indicates fair to good agreement along the Alabama and Tennessee borders, and poor to very poor along the North Carolina and South Carolina borders.

Illinois

Within the study area, which extends 125 miles northward from the southern tip of the state, 78 faults have been documented. The principal map reference was the Preliminary Seismotectonic Map of the Central Mississippi Valley and Environs (1978), at the convenient scale of 1:500,000, by Heyl and McKeown. Where similar information from other sources showed minor differences in the location of a trace, a compromise location was necessary. If the variation in location was t[illegible] for a compromise, the Heyl and McKeown map was used as the primary map refere[illegible] and the other source as the secondary reference. Sources which show smaller areas in greater detail are referenced under "Remarks" on the fault data cards.

Illinois faults that extend into Kentucky and Indiana generally match satisfactorily with the corresponding faults in the adjoining states.

Indiana

The study area includes that portion of the state south of the latitude of Bloomington. Eight faults have been catalogued, all along the state lines adjoining Illinois and Kentucky. Most of the study area appears to be devoid of faults, which may be a true representation or may be the result of incomplete mapping. It is likely that more faults exist here, especially in the southwestern portion of the area.

Because very little detailed geologic mapping has been done here, compilation data were obtained mainly from geologic publications for the adjoining states. No personal communications about faults in this area were received during the compilation, and there have been no further attempts to acquire unpublished data.

Kentucky

The entire state of Kentucky is included in the study area. Three hundred fifty-seven faults and portions of faults were catalogued. Most of these faults were acquired from Kentucky Geological Survey 1:250,000 fault maps, which had been compiled by reduction of fault traces shown on modern 7-1/2 minute geologic quadrangle maps (scale 1:24,000). Recent Kentucky Geological Survey 1:250,000 oil and gas maps were used as a source of some faults not shown on 7-1/2 minute geologic quadrangle maps, but many of these faults are questionable and are so indicated on the fault data cards.

Large areas of Kentucky that contain few if any faults are realistic, having been adequately covered by detailed mapping, and are continuous with similar adjoining areas in Tennessee to the south.

Faults that cross state lines generally show satisfactory correlation with corresponding faults in Tennessee and Illinois.

Mississippi

The study area included only the north half of Mississippi. Eighty-five faults were plotted and documented. The 1969 Geologic Map of Mississippi (scale 1:500,000) was too generalized to be of much help in this study. State geological survey reports, especially county reports and bulletins, were the source for most fault traces shown, but lack of a consistent map scale in these reports made compilation difficult.

The map shows several apparently unfaulted areas, especially in the southern and western parts of the study area. Some of these areas are in counties for which information either does not exist, or is unpublished and not readily available. Other areas are underlain by very recent sediments in which faults are very difficult to find, and in these areas the situation is also complicated by the difficulty in distinguishing between faults and slumps. Dr. E. E. Russell of Mississippi State University was especially helpful in clarifying the status of questionable faults.

Oil and gas exploration has led to a general knowledge of subsurface geologic structure in Mississippi, and many subsurface faults identified during exploration may or may not have a surface expression. No attempt has been made to differentiate on the map between traces of mapped surface faults and known subsurface faults. Such distinctions are made on the fault data cards.

Several faults were found to be partly in Mississippi and partly in Alabama, and for these faults it was necessary to reference data from both states. No faults were noted that crossed the state line between Mississippi and Tennessee.

North Carolina

Eighty-eight faults or groups of faults have been plotted and catalogued within the area of this study, which covers the west half of the state. Some were taken from the 1958 Geologic Map of North Carolina (scale 1:500,000), but other state and federal publications and maps have provided most of the information.

Many relatively large, apparently unfaulted areas can be seen on the map, and this is undoubtedly the result of inadequate information. The Piedmont province, because of the nature of the geologic structures involved, obviously contains numerous faults which have not been recognized and/or mapped.

Faults that crossed state lines generally did not correlate satisfactorily into South Carolina, Virginia, or Georgia but in most places matched satisfactorily with adjoining faults in Tennessee.

South Carolina

Forty-six faults have been documented in the study area, which covers the northwest half of the state. Most of the faults were referenced to readily available state and federal publications and journal articles. Some were obtained from M.S. theses at the University of South Carolina and from discussions with state geological survey personnel.

Faults that crossed state lines into Georgia and North Carolina generally did not match the corresponding faults in those states.

Tennessee

The entire state of Tennessee is included in the study area. Three hundred eighty faults or groups of faults have been plotted and documented. Most of the faults shown have been compiled from the Geologic Map of Tennessee (1966), scale 1:250,000, modified where necessary by more recent or more detailed mapping. Other state and federal publications were also consulted, especially for the eastern part of the state along the North Carolina border. Theses and dissertations were also used as sources.

Large, apparently unfaulted areas can be seen on the map in the Mississippi Embayment of west Tennessee, where Cretaceous and younger sediments which contain very few known faults overlie Paleozoic rocks which are believed to be extensively faulted. Central and east-central Tennessee contain large, apparently unfaulted areas which extend to the western Cumberland escarpment. Because this part of Tennessee has the best detailed map coverage, the scarcity of faults is real and not just apparent.

Edge matching along state lines showed good correlation with Kentucky, Virginia and Georgia, and moderate to good correlation with North Carolina and Alabama. No faults are shown that cross the Tennessee-Mississippi line.

Virginia

The study area extends for approximately 300 miles northeastward from the southwest tip of the state. One hundred ninety-five fault traces and portions of traces were plotted and catalogued. Some of the long, complex faults that have different names and characteristics along various segments of their length have been assigned more than one identification number.

Sources used included the 1963 Geologic Map of Virginia (scale 1:500,000), state and federal publications, county reports, and theses and dissertations. Personal communication was also a source of numerous references.

Faults that cross the state line generally do not match well with corresponding faults in North Carolina. This no doubt is the result of incomplete mapping, which probably also accounts for the apparent lack of faulting in Franklin and Bedford Counties. Virginia faults closely match most corresponding faults across the state line in Tennessee.

FAULT NAME: *Goat Rock Fault Zone*

MAP NUMBER: AL 42

REFERENCE: Crickmay, 1933, 1952
Bentley, 1964
Bentley and Neathery, 1970
Rodgers, 1970

MAP REFERENCE: Bentley and Neathery, 1970, Fig. 2

LOCATION: Lee, Russell, and Macon Counties

TYPE: Thrust

LOCAL LENGTH: 12 miles

TOTAL LENGTH: 112 miles

STRIKE: ENE

DIP: 20^{o} to 50^{o} SSE

DISPLACEMENT: NW side down

AGE: Pre-Cretaceous

REMARKS: Crickmay states that "the existence of the Goat Rock thrust is based entir ly on the presence of a mylonitized zone extending from Goat Rock Dam to Flint River. The zone is remarkable for its width (two to three miles) and the presence of a horizon of black ultramylonite in its central part."

The Goat Rock Fault Zone is bounded on the southeast by the Goat Rock Fault and on the northwest by the Bartletts Ferry Fault (AL 6). The Goat Rock Fault corresponds to GA 38, and the Bartletts Ferry Fault to GA 40.

TOPIC STATEMENT

Agency TVA Priority ______ 1980 Session Number ______

Subject Area ______

Project Title Seismicity of the Southeastern U. S.

Performing Organization Geologic Services - Civil Design Branch

Principal Investigator Donald J. Reinbold

Starting Year 1977 Estimated Completion Year 1981

Technical Objectives: To compile a complete and consistent historical earthquake data base for the southeast U. S. (south of 39 degrees north latitude) to be used in seismic hazard evaluations.

Technical Approach: N/A

General Progress: A completed earthquake listing, including reference material, is available for the southeast U. S. east of 87 degrees west longitude exclusive of the Charleston-Summerville, South Carolina area.

Plans For Next Twelve Months: Addition of data between 87 degrees and 92 degrees west longitude which includes the New Madrid earthquake zone; add data for Charleston-Summerville.

TOPIC STATEMENT

Agency WES Priority ______ 1980 Session Number ______

Subject Area Earthquake

Project Title Strong-Motion Instrumentation Program

Performing Organization USAE WES

Principal Investigator R. F. Ballard, Jr., & F. K. Chang

Starting Year FY 73 Estimated Completion Year Continuing

Technical Objectives:

To obtain data on the nature of strong ground motion resulting from earthquakes and the performance of structures (dams) subjected to earthquake loading.

Technical Approach:

The CE is continually upgrading its strong-motion instrumentation program by replacing existing old instrumentation with new units, modifying instrumentation systems and shelters to utilize solar cells for battery charging and time code generators. Emphasis is currently being placed on deletion of interconnection of instruments for common starts. Numerous malfunctions resulting in battery and/or film depletion in all instruments or a common circuit suggest that time code, in lieu of WWVB or interconnection, will present a better alternative.

General Progress:

The CE has installed 325 accelerographs, 25 peak recording accelerographs, and 74 seismoscopes. The total number of projects instrumented as of 31 August 1980, is 101. These structures are located in 33 states and Puerto Rico.

Plans for Next Twelve Months:

Eighty-two accelerographs and 18 peak recording accelerographs will be added to the CE strong-motion instrumentation system.

TOPIC STATEMENT

Agency WES Priority ________ 1980 Session Number ________

Subject Area Earthquake Engineering

Project Title Methodology for Selecting Design Earthquakes (CWIS 31038)

Performing Organization WES

Principal Investigator E. L. Krinitzsky (FTS 542-3329)

Starting Year FY 76 Estimated Completion Year FY 81

Technical Objectives: To provide up-to-date methodologies that use the full state of the art for assessing earthquake hazards in the various geologic and tectonic regions of the United States. To relate areas of seismic risk and local geotechnics with characteristic bedrock ground motions, attenuations with distance, effects of topography and rock types in modifying ground motions. To assess probability factors in the recurrence of maximum events. To determine surface effects of ground motion including circumstances favoring soil liquefaction. The methodologies will be designed to provide maximum usefulness for assessments of Corps projects.

Technical Approach:

a. Maintain cognizance and liaisons with other Government agencies, engineering firms, and individual researchers who are developing information in this field.

b. Collect seismic histories and data on important seismic events and their effects from which to develop new information on centers of recurrence, characteristics of bedrock motion, local attenuations, and other characteristics.

c. Relate seismic events to structural deformations and determine how characteristics of earthquake ground motions are relatable to given geotectonic situations.

d. Undertake reviews of the effects of specific rock and soil types on earthquake ground motions.

e. Relate earthquake characteristics to regional or subregional geologic and tectonic areas. Synthesize the experience in these areas to develop capabilities for predicting earthquake risks, including time histories of ground motions in bedrock.

f. Evaluate these approaches and synthesize elements of the best of them into methodologies for use in Corps projects.

General Progress: Continued activities of previous years. Updated and systematized already established methodologies. Developed improved means of assessing earthquake ground motions in areas that are peripheral but close to areas of high seismic risk but with low rates of recurrence, notably the New Madrid and Charleston areas. Assessed effects of major seismic events on river behavior and on riverbank stability and channel maintenance as on the Lower Mississippi River. Assembled case histories on the evaluation of seismic risk for engineering.

Plans for Next Twelve Months: Continue cognizance, collection of data, assessment of practices, and special studies at earthquake sites, in seismically active areas and in the vicinities of major Corps engineering works. Continue evaluation of European, Chinese, and Japanese practices. Prepare critical selections for predicting earthquake risks, recurrence rates for earthquakes, and time histories of earthquake ground motions in bedrock. Develop site specific techniques for assigning root mean square values for seismic energy. Continue the world-wide catalogue of strong motion earthquake records. Continue to update and improve practices for the evaluation of earthquake hazards and the selection of earthquake ground motions for Corps problems. Report: "Review of Industry Practices in the Specifying of Earthquake Motions," begun October 1979, complete September 1981.

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TOPIC STATEMENT

Agency WES Priority ______ 1980 Session Number ______

Subject Area Earthquake Engineering

Project Title Seismic Effects of Reservoir Loading and Fluid Injection (CWIS 3103)

Performing Organization WES

Principal Investigator E. L. Krinitzsky (FTS 542-[illegible])

Starting Year FY 76 Estimated Completion Year FY 81

Technical Objectives: To enhance Corps evaluations of seismic effects that result from water loading in reservoirs and from injection of fluids into wells and to provide optimum methods for conducting Corps evaluations of susceptibility of sites to possible induced seismic events.

Technical Approach:

a. Develop and maintain cognizance of worldwide experience in relating hydrologic conditions and hydraulic effects to earthquake events.

b. Describe Corps experience at new and old dams.

c. Assemble data from microearthquake monitoring at dams and at fluid injection sites. Develop new monitoring programs. Relate data to ambient seismicity prior to loading and to regional tectonics and buildup of strain unrelated to water loading.

d. Investigate cyclical history of buildup and recession of events directly related to water loading and to events in adjacent areas where water loading is not a factor. Determine net effects of water loading. Indicate effects of water loading on probabilistic analyses of earthquake recurrence.

e. Undertake theoretical studies of the effects of reservoirs on local strain release and stress adjustment.

f. Maintain liaison with geological surveys, engineering organizations, and individual experts to maintain an up-to-date knowledge of practices and evaluation in this field.

g. Develop data and reports for maximum relevance in application for Corps problems.

General Progress: Continued previous studies. Updated review of induced seismicity at Corps projects. Updated assessment of microearthquake studies at Corps sites. Developed liaisons and mutual associations with organizations studying seismicity and the effects of water impoundment. Developed data from such sources for relevance to Corps dams and reservoirs. Related reservoir-associated seismicity to regional tectonics. Initiated a state-of-the-art review of probabilities of recurrence of earthquakes.

Plans for the Next Twelve Months:

a. Standards of data appraisal for assessing induced seismicity. Standards will be established for variables of size, time and three-dimensional location for critical assessment of reservoir related earthquake events. Criteria will be generated for determining the sufficiency of data and for judging induced seismicity in a uniform system of analysis.

b. Interpretation of mechanics of induced seismicity. The roles of water load and pore water pressure will be examined using a selection of elastic continuum models. The applicability of the models will be evaluated through a comparison with laboratory tests and predictions of in situ values.

c. Interpreted case histories of reservoir-induced earthquakes. Well known cases of reservoir-induced seismicity will be critically evaluated through a rigorous examination of the mechanical properties of the rocks at the sites, the seismic histories of the sites, the changes in the rock systems caused by impoundments, and the patterns of post-impoundment seismicity.

TOPIC STATEMENT

Agency WPRS Priority ____ 1980 Session Number ____

Subject Area Earthquake

Project Title Strong Motion Instrumentation Program

Performing Organization WPRS

Principal Investigator A. Viksne

Starting Year FY72 Estimated Completion Year Continuing

Technical Objectives:

To obtain data on the nature of strong ground motion resulting from earthquakes and the performance of structures (dams) subjected to earthquake loading.

Technical Approach:

The WPRS is continually upgrading its strong-motion instrumentation program, by replacing existing old instrumentation with new units, modifying instrumentation systems to utilize solar cells for power and WWVB (time code) receivers for common time base, obtaining and installing wherever possible remote recording downhole instrumentation systems.

General Progress:

Generally the instrumentation programs have followed the schedule of (dynamic) seismic analysis for the structures (dams) under evaluations. The evaluations and related instrumentation programs to date have been primarily for structures located in Seismic Zones 3 and 4.

Plans for Next Twelve Months:

To continue to investigate means for improving strong-motion instrumentation systems, to make the whole system more reliable and dependable, especially remote recording downhole systems. Also, continue improving the design of surface instrument housing.

TOPIC STATEMENT

Agency WPRS Priority 1 1980 Session Number ____________

Subject Area Probabilistic Methods

Project Title Applicability of Risk Analyses Methods to Dam Design (RA-1)

Performing Organization WPRS and Contractor

Principal Investigator L. J. Von Thun

Starting Year FY81 Estimated Completion Year FY83

Technical Objectives:

To investigate the opportunities for use of risk-based analysis in dam safety and just how such method may be used. Based upon existing studies, mathematical methods are available to make such analysis; however, it needs to be determined what application, and the scope of application, including reliability, in dam safety evaluations there is for these methods. In other words, how reliably can the level of risk for dam failure be predicted?

Technical Approach:

Investigators will perform a comprehensive study of various risk analyses methods and techniques, and correlate them with performance records on existing dams. It is recommended that Federal programs be developed and funded to research the applicability of probabilistic techniques to hydrologic and seismologic predictions in dam design; identification and acceptability of residual risk in high hazard dams; use of risk-based analysis in material selection, design, and operation; structural consequences of exceeding design assumptions; use of decision analysis, as it relates to risk, in dam siting, design, construction, and operation.

General Progress:

Have begun development of a historical data base that provides failure probability as a function of type of dam, year of construction, area of the country, height of dam, etc. Also have begun calculated approach to determine risk of failure.

Plans for Next Twelve Months:

Complete historical approach to estimate probability of failure. Complete calculated approach to estimate of probability of failure for two existing dams.

Water Level Restrictions at Jackson Lake, Wyoming - 1978 Decision Basis

SUMMARY REPORT

U.S. Department of the Interior
Bureau of Reclamation
Engineering and Research Center

April 1978

Water Level Restrictions at Jackson
Lake, Wyoming - 1978 Decision Basis

SUMMARY REPORT

Contents

Appendixes

Water Level Restrictions at Jackson Lake, Wyoming - 1978 Decision Basis

I. Executive Summary

During the USBR review of its existing structures for adequacy of performance under current earthquake criteria, Jackson Lake Dam was identified as being located in an area with the potential for strong earthquake shaking. The fine-grained soils on which the embankment portion of the dam was founded and the hydraulic fill methods which were used to place a portion of the earth embankment presented the potential for liquefaction at the site under strong earthquake loading. A drilling, sampling, and laboratory testing program was initiated in order to define the location and physical properties of the various materials in the embankment and foundation. Once this information was obtained, a dynamic analysis of the dam and of the dam with any proposed modifications or treatments could be carried out.

Because it was anticipated that it would be several years before any permanent remedial measures could be completed, temporary restrictions on the water level at Jackson Lake were considered. In order to receive an independent evaluation on the severity of the situation and thus the need to consider further any immediate remedial action, two experts in the field of liquefaction, Professor Harry Seed and Professor Ken Lee, were asked to examine the dam, foundation, and pertinent data. Their reports (see appendix A) indicated that the dam and foundation were indeed subject to liquefaction and its potential for occurring was great enough to warrant investigating what temporary restrictions would be appropriate.

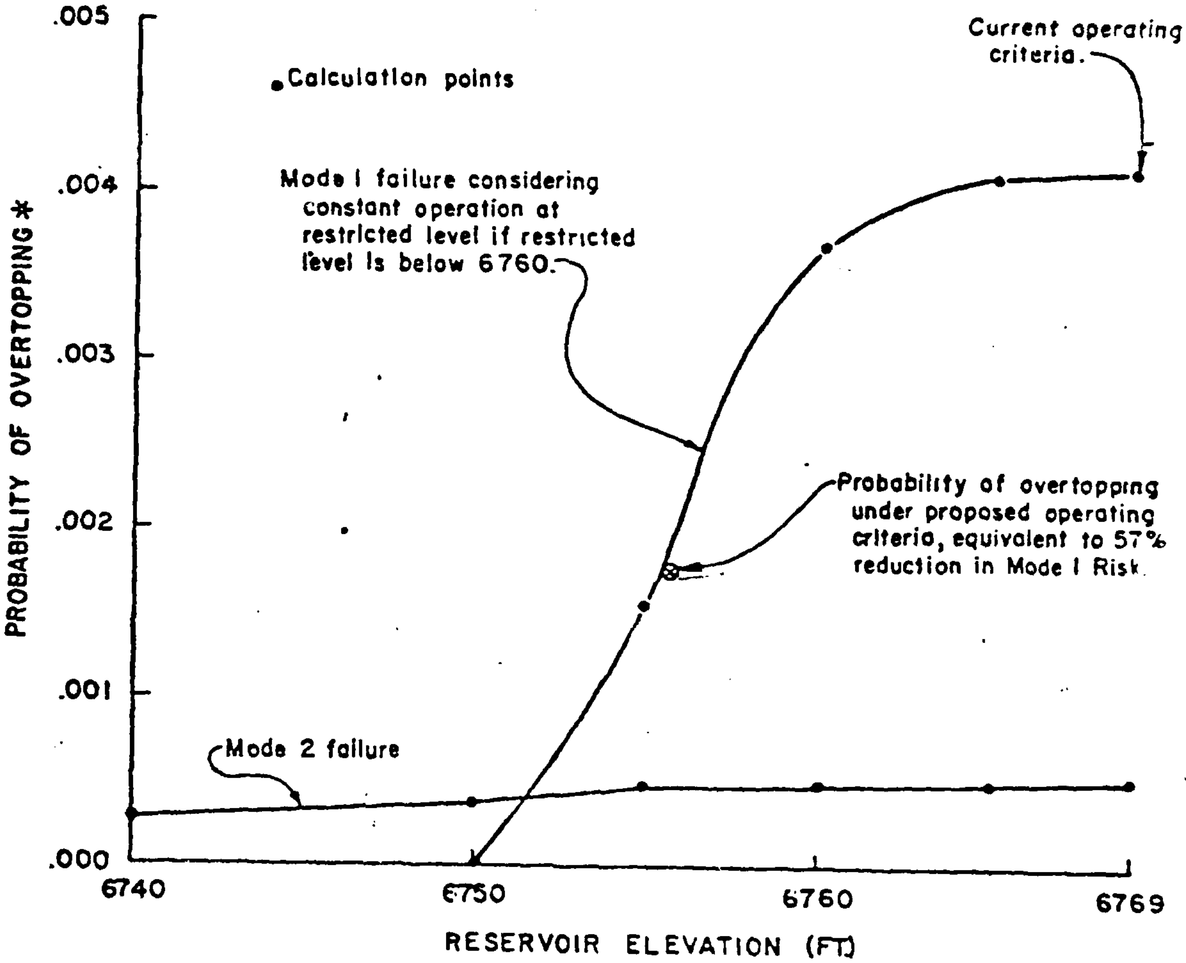
An estimate of a restriction level which would not allow overtopping of the embankment even under "reasonable worst case" conditions was performed. The "reasonable worst case" conditions were established considering (a) material properties, (b) embankment geometry and construction methods, (c) reports of the independent consultants on the condition of the dam and the seismic potential of the area, (d) case histories of embankment liquefaction, (e) the possibility of an earthquake-generated wave, and (f) topography of the reservoir bottom. This "reasonable worst case" analysis established an elevation restriction of 6754 which provided for 2 feet of freeboard. To assess the probability of an overtopping condition as a function of the restriction level and to assess the level of downstream damage as a function of various modes of failure and restriction levels, a risk analysis was performed. The risk of overtopping was computed as a function of the probability of occurrence of various levels of earthquakes, the probability of various structural responses due to these earthquakes and the probability that the reservoir would be at an elevation which would produce overtopping both with and without an earthquake-generated wave. The analysis showed that at elevation 6756.5 the risk of overtopping due to the primary mode of failure under consideration was reduced by 50 percent (see figure 1). Further, it was seen by analysis of the outflow hydrograph that even in the event of overtopping (from the primary mode of failure hypothesized) the flood produced with the water level restricted to this level would be greatly reduced (see figure 2). This level of reduction in risk appeared appropriate but the impact on benefits still needed to be incorporated into the decision analysis.

Risk of overtopping studies for restricted elevations below 6760 considered the reservoir to be maintained at the restricted elevation on a year-round basis. Actual operations could produce a variable reservoir elevation which would maintain the absolute risk of overtopping at about the same level and yet minimize impact on recreational interests which are affected by the actual lake level as well as the timing and amount of releases. An operational plan which satisfied these objectives was developed by regional and project personnel. This plan called for water levels at elevation 6760 for 1 month out of the year but were below elevation 6755 for about 9 months. These criteria provide a lower risk of overtopping than a constant restriction level of 6756.5 but do present the potential for larger floods during the 1-month period when elevations reach elevation 6760 if overtopping were to occur during this period; however, the total benefits of this operating plan appeared to outweigh this short-term increased hazard. The proposed operation plan (figure 3) was adopted by the E&R Center design and operations personnel, Pacific-Northwest regional personnel, and Minidoka Project personnel on March 3, 1978, as an appropriate plan for recommendation to the Commissioner.

II. Water Level Restriction Investigation

A dynamic stability investigation of the embankment portion of Jackson Lake Dam is in progress. At this time the investigation indicates the embankment is likely to fail if a strong earthquake occurs on the nearby Teton-Hoback fault system. Therefore, a restriction in the maximum reservoir water surface to reduce the risk of a catastrophic failure was evaluated. This evaluation considered the following five factors:

1. Earthquake activity of the area
2. Potential location of embankment instability
3. Potential instability of embankment section
4. Potential seiche wave from earthquakes
5. Embankment freeboard for seiche wave



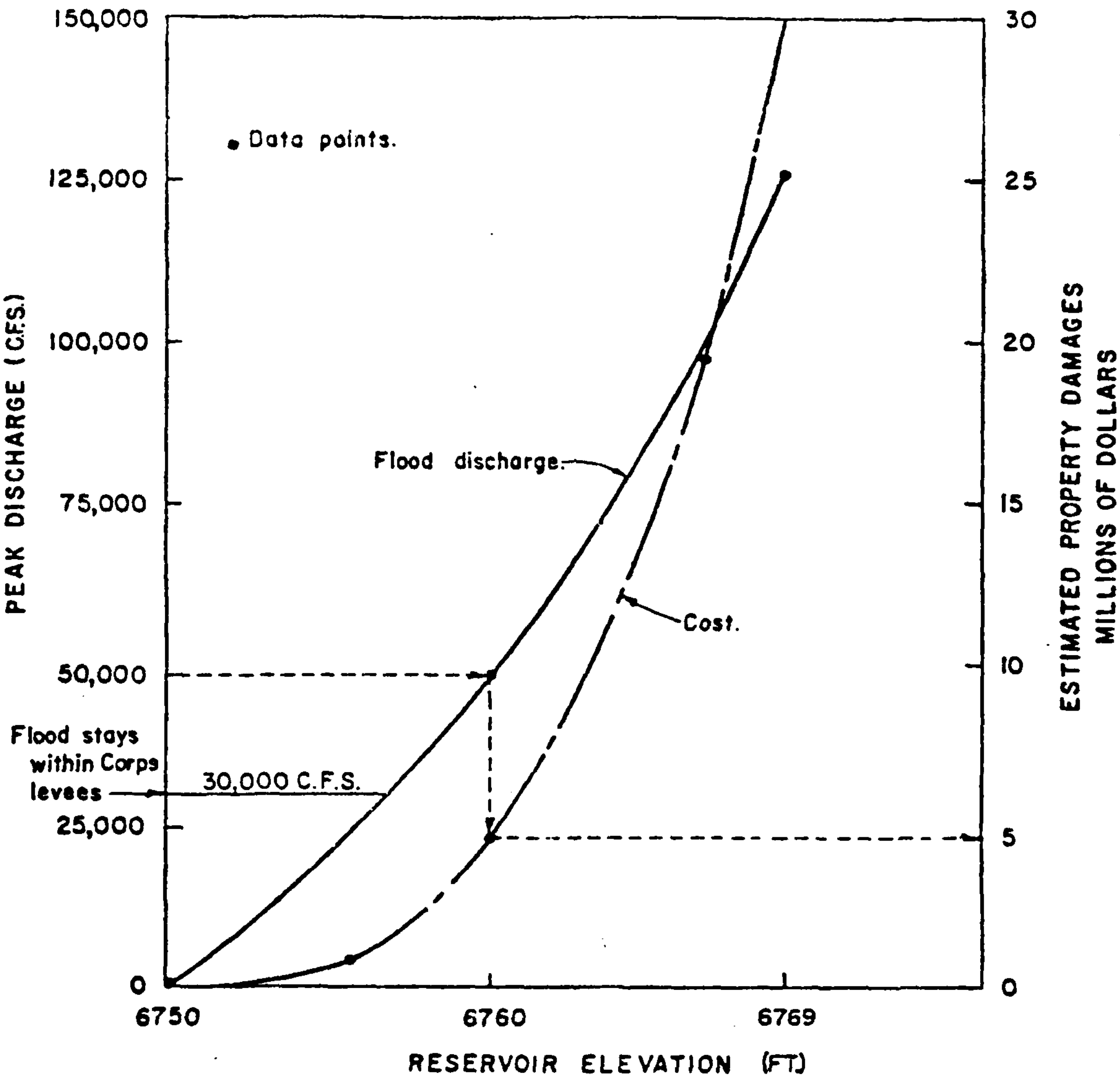
RISK OF OVERTOPPING
VS
RESERVOIR ELEVATION OF
JACKSON LAKE

* FROM LIQUEFACTION FAILURE DUE TO EARTHQUAKE PLUS EFFECT OF A SEICHE.

MODE I - LIQUEFACTION AT BASE LEVEL OF 6750.

MODE 2 - LIQUEFACTION AT BASE LEVEL OF 6730.

FIGURE I



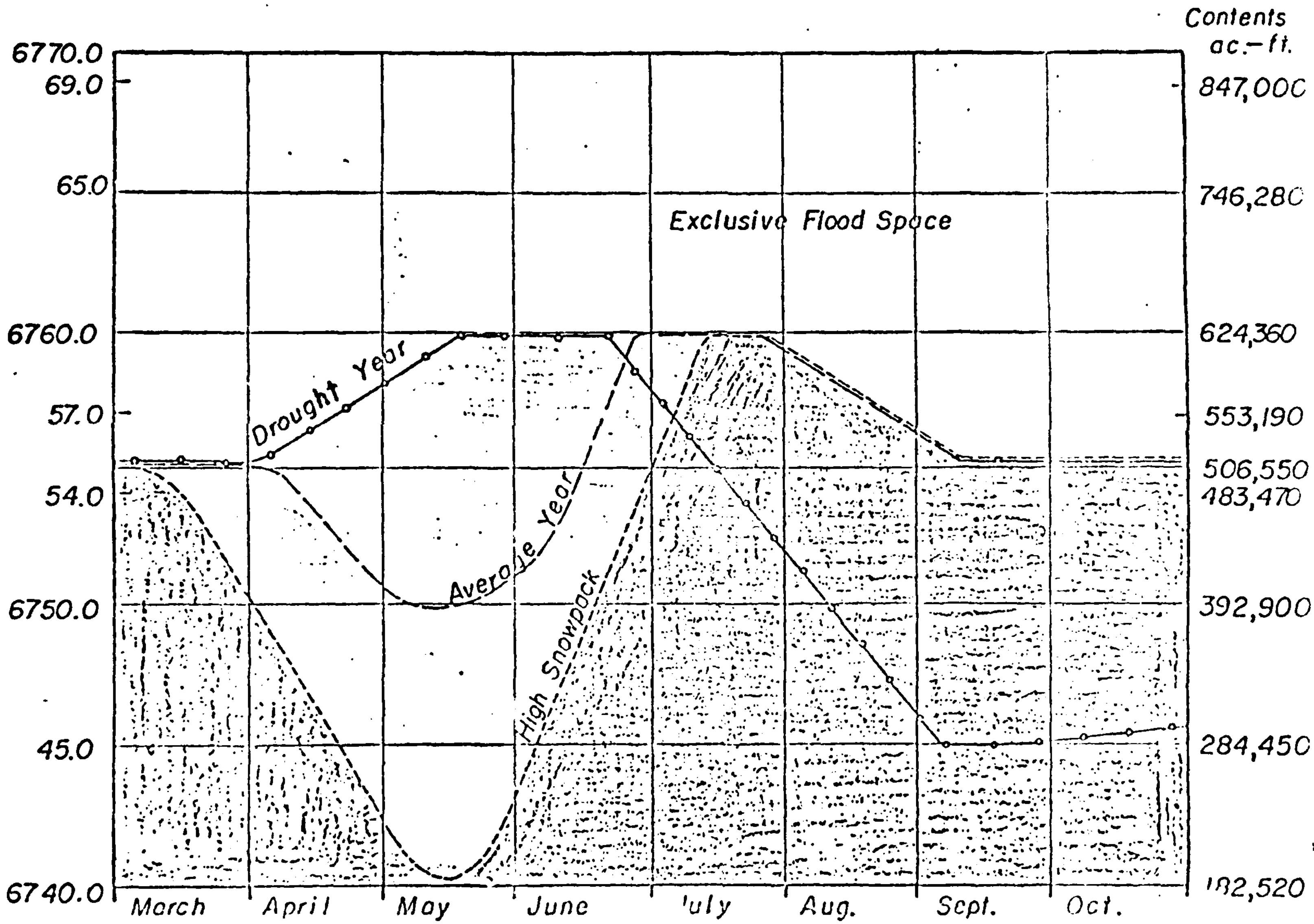
JACKSON LAKE

FLOOD AND FLOOD EFFECTS *
VS
RESERVOIR RESTRICTION LEVEL

* GIVEN THAT OVERTOPPING OCCURS AND FAILURE MODE IS MODE I WITH A 400 FT. BREACH.

FIGURE 2

JACKSON LAKE PROPOSED OPERATIONS



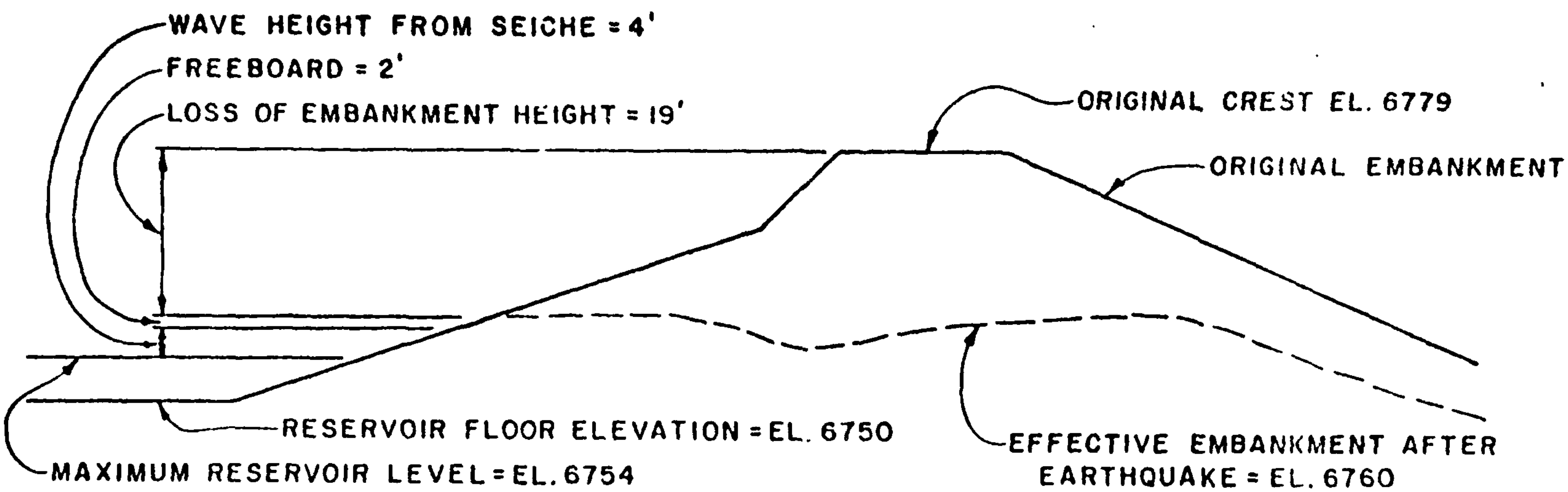
Each of these five factors is considered in greater detail in the following paragraphs.

1. Earthquake activity of area. - Jackson Lake Dam is located near an active earthquake area. The nearby Teton-Hoback faults are believed to have moved through over 10,000 feet of displacement. Geologically speaking, part of these displacements is relatively recent because they cut through glacial moraines deposited some time between 8,500 and 25,000 years ago. The Teton-Hoback faults are considered capable of producing a maximum credible earthquake of magnitude 7-1/4.

2. Potential location of embankment instability. - The embankment section that extends from the north end of the concrete dam to a point 700 feet farther north is considered less susceptible to failure because of its internal construction and the downstream buttressing effects of the highway fill. The embankment section immediately north of where the highway fill leaves the embankment is considered more susceptible to failure because: (1) the embankment itself is mainly a loose gravelly sand to silty sand which is susceptible to liquefaction, (2) the foundation directly beneath the embankment is a loose sandy silt which is also susceptible to liquefaction, and (3) the downstream embankment slope is relatively steep and unbuttressed. At this section the crest elevation is 6779 and the reservoir floor elevation is 6750 (see figure 4).

3. Potential instability of embankment section. - The field investigations performed on the embankment and foundation indicated both were susceptible to liquefaction under significant earthquake shaking. To obtain an independent opinion on the embankment stability under earthquake loading, two well-known experts in this field were hired as consultants. The opinion of H. B. Seed of the University of California at Berkeley and K. L. Lee of UCLA was that both the embankment and foundation would be susceptible to liquefaction from strong earthquake shaking (magnitude 6.0 or greater).

To aid in predicting the embankment failure displacements at Jackson Lake Dam, it is instructive to examine the behavior of similar dams that have failed from liquefaction due to earthquake shaking. After earthquakes had triggered their embankment failures, Sheffield Dam had about 20 percent and Lower San Fernando Dam had 70 percent of their original height remaining. The Jackson Lake embankment and foundation conditions are considered more similar to the Sheffield Dam conditions. Therefore, the assumption was made that after strong earthquake shaking one-third of the original embankment height would be effective in



MAXIMUM RESERVOIR ELEVATION =
ORIGINAL CREST ELEVATION
− LOSS OF EMBANKMENT HEIGHT
− WAVE HEIGHT FROM SEICHE
− FREEBOARD DESIRED

JACKSON LAKE DAM
CRITICAL SECTION

FIGURE 4

retaining the reservoir. For the critical embankment section located previously (see factor 2), the remaining effective embankment elevation would be 6760 (see figure 4).

4. Potential seiche wave from earthquake. - A major seiche wave could be expected at Jackson Lake Dam following an earthquake because the Teton fault system cuts across the western margin of the reservoir. If the western portion of the reservoir rose relative to the eastern portion, as would be expected geologically, a wave would be generated which if not provided for could erode the failed embankment section. At Hebgen Dam it was reported that seiche waves overtopped the more erosion-resistant embankment for four extended time periods following a 1959 earthquake. For Jackson Lake the seiche wave assumed at the embankment was 4 feet high.

5. Embankment freeboard for seiche wave. - To keep the seiche wave below the top of the effective remaining embankment section (elevation 6760), an additional 2 feet of freeboard were proposed. The calculated initial water surface subtracting a 4-foot wave height and 2 feet of additional freeboard from 6760 is 6754.

From considering the preceding five factors, a reservoir elevation of 6754 was considered reasonable to greatly reduce the risk of catastrophic failure at Jackson Lake Dam.

III. Risk - Benefit Decision Analysis Study

The decision analysis for determination of the optimum reservoir restriction level for Jackson Lake essentially consisted of (1) identifying all the relevant factors involved in establishing the hazards, risks, and benefits as a function of reservoir level; (2) quantifying these data and engineering judgments where possible; and (3) presenting the information in a useful format for decision-making. The decision analysis model used for Jackson Lake is shown in figures 5A and 5B as a six-step process. The results from carrying out each of those steps for Jackson Lake are discussed below.

Step 1 - Hazard Evaluation

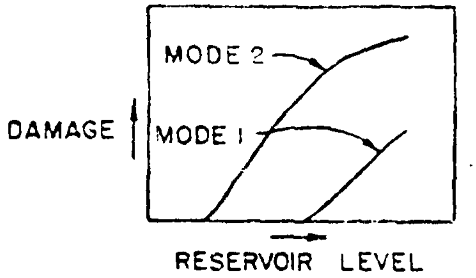
Two modes of liquefaction failure were hypothesized for the embankment portion of Jackson Lake Dam based on the construction history and dam and reservoir geometry. These modes were:

Mode 1. - Liquefaction of the embankment and/or foundation at or above elevation 6750 over widths of 400 and 800 feet.

Mode 2. - Liquefaction of the embankment and foundation at elevation 6730 over widths of 200, 400, and 800 feet.

DECISION ANALYSIS MODEL TO DETERMINE RESERVOIR RESTRICTION LEVEL AT JACKSON LAKE

1. EVALUATE HAZARD AS A FUNCTION OF RESERVOIR LEVEL FOR EACH POTENTIAL FAILURE MODE



2. ESTIMATE PROBABILITY OF VARIOUS LEVELS OF EARTHQUAKES CAUSING LIQUEFACTION AT THE DAM

EARTHQUAKE –		PROBABILITY OF –			
SOURCE	MAG	EARTHQUAKE		DAM LIQUEFYING FROM THIS E.Q.	LIQUEFACTION
A	6 0 6 5 7.0	.003 .002 .001	X	5 .75 1.00	.0015 .0015 .0010
B	6.5 7.0	.002 001	X	.1 .3	.0002 .0003
C	7.0 7.5	.02 .01	X	.1 .2	.002 002

(NUMBERS ARE HYPOTHETICAL)

3. EVALUATE PROBABILITY OF STRUCTURAL DAMAGE CONDITION FOR EACH MODE UNDER EACH SEISMIC LOADING LEVEL

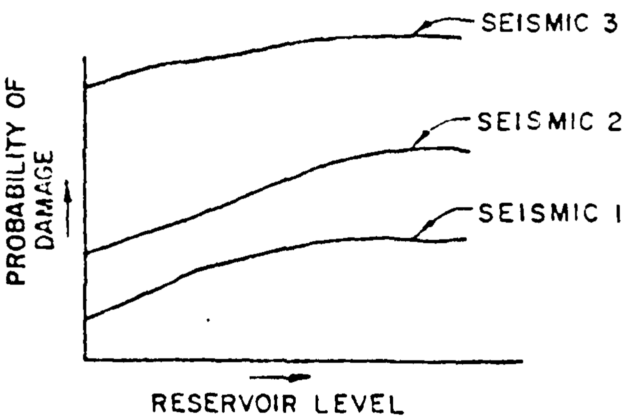
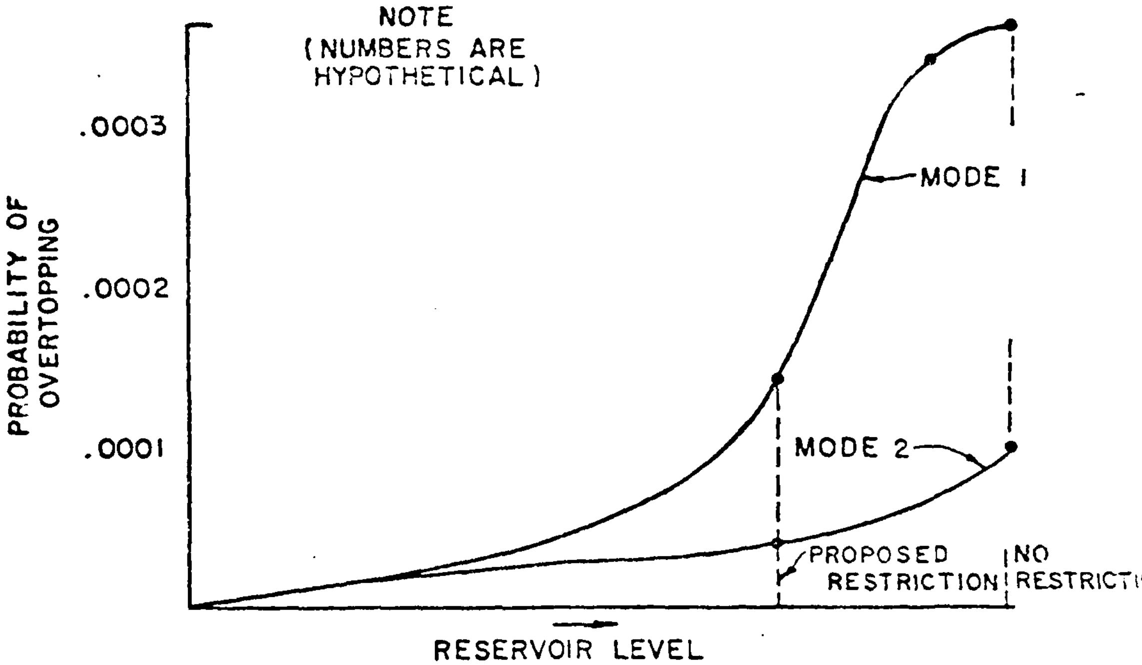


FIGURE 5A

4. COMPUTE PROBABILITY OF OVERTOPPING AS A FUNCTION OF RESERVOIR RESTRICTION LEVEL FOR EACH FAILURE MODE



5. EXAMINE LIKELYHOOD OF OVERTOPPING AND DOWNSTREAM HAZARD POTENTIAL FOR CURREN VS ANY PROPOSED OPERATING CRITERIA.

6. EVALUATE
   REDUCTION IN RISK IN EACH MODE.
   ACCEPTIBILITY OF RISK FOR EACH MODE.
   CONSIDER BENEFITS VS RESERVOIR ELEVATION.
   OPERATING PROCEDURES FOR MAXIMUM BENEFITS WITHIN RANGE OF ACCEPTABLE RISK.

FIGURE 5B

The major portion of the dam founded at elevation 6750 and above was placed with hydraulic fill methods and the foundation of this portion of the dam is a silty sand (see Part II above). On the other hand, most of the portion of the dam founded below elevation 6750, is less susceptible to liquefaction because of the methods or materials used in construction. For purposes of the risk analysis study, it was assumed that, given that a failure took place, the probability that it would be Mode 1 is 0.9, and the probability it would be Mode 2 is 0.1.

Once the modes are identified, the next task is to determine the floods associated with each mode as a function of reservoir elevation and the downstream damage associated with the level of flooding. This information was supplied in the reports provided in appendix C. Examination of these data shows:

a. Large damage for flows exceeding 50,000 ft^3/s.

b. Flows exceeded 50,000 ft^3/s for Mode 2 failures even with drawdowns exceeding 20 feet.

c. Considerable reduction in flows and damage potential for Mode 1 type failures for restricted levels below elevation 6760.

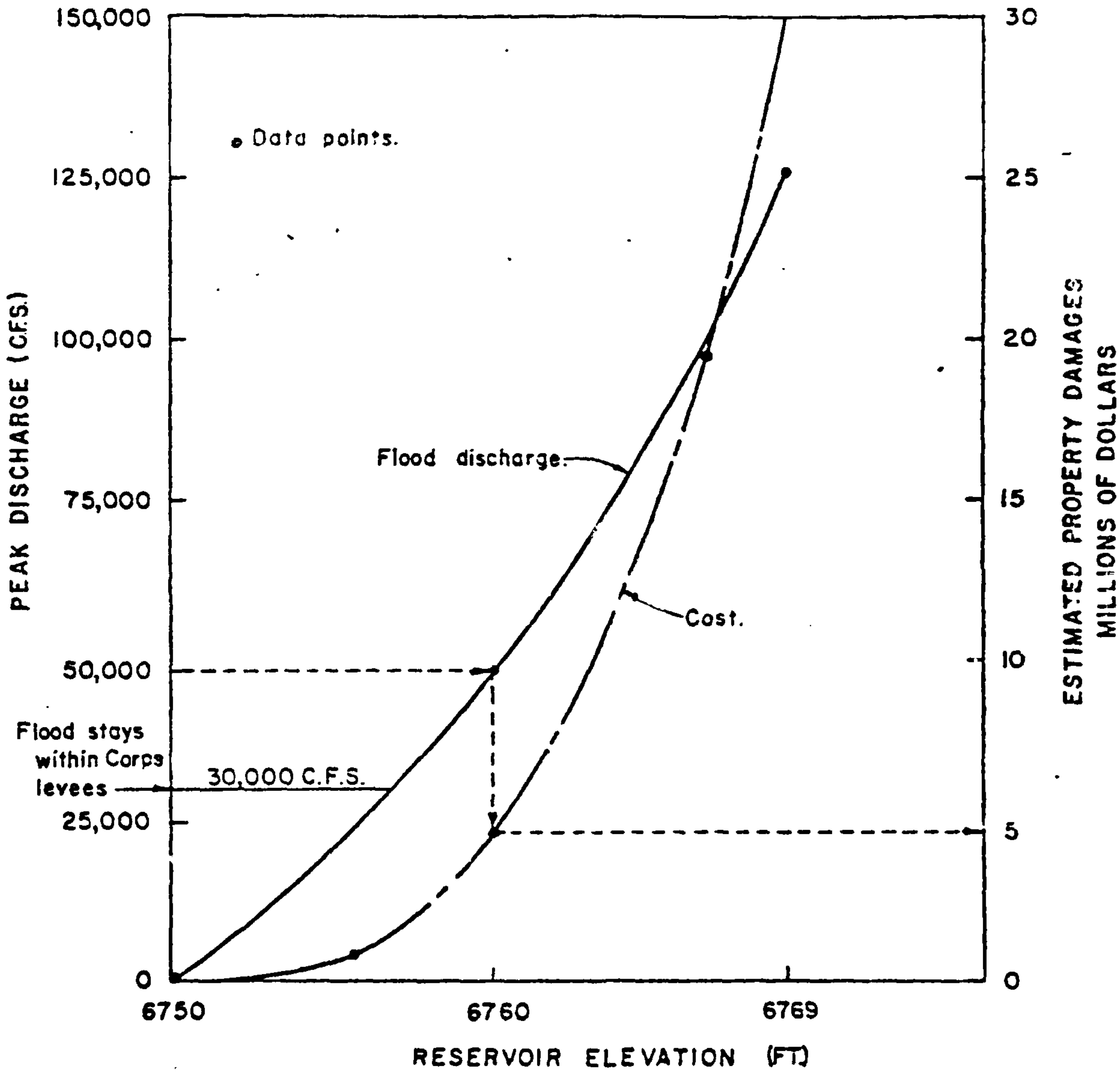
d. Floods stay within U.S. Corps of Engineer levels for Mode 1 overtopping failures with reservoir below elevation 6757.

The more likely Mode 1 failure is sensitive to reservoir level variations and the analysis demonstrated significant improvements could be achieved by restricting reservoir levels as opposed to the less likely Mode 2 effects which are somewhat insensitive to reservoir restrictions. Thus it was evident that the major influence of any restriction would be in decreasing the risk of a Mode 1 failure and at the same time reducing the potential hazard if Mode 1 overtopping were to occur.

Figure 6 (identical to figure 2) shows the rate of increase of flood levels and flood damages as a function of reservoir restriction level for Mode 1 and thus portrays the potential downstream hazard at any given reservoir level. This information will be used later in the decision analysis as it is combined with the risk of overtopping analysis.

Step 2 - Evaluation of the Seismicity Affecting the Site and the Consequent Potential for Liquefaction

Earthquakes to be considered in the risk analysis can come from several sources at varying distances from the site. The likelihood



JACKSON LAKE

FLOOD AND FLOOD EFFECTS *
VS
RESERVOIR RESTRICTION LEVEL

* GIVEN THAT OVERTOPPING OCCURS AND FAILURE MODE IS MODE I WITH A 400 FT. BREACH.

FIGURE 6

of liquefaction is a function of an earthquake's distance from the site and its strength. The probability of occurrence of earthquakes of a given level from each source must therefore be evaluated along with the probability of that level of earthquake causing liquefaction of the dam or foundation.1/

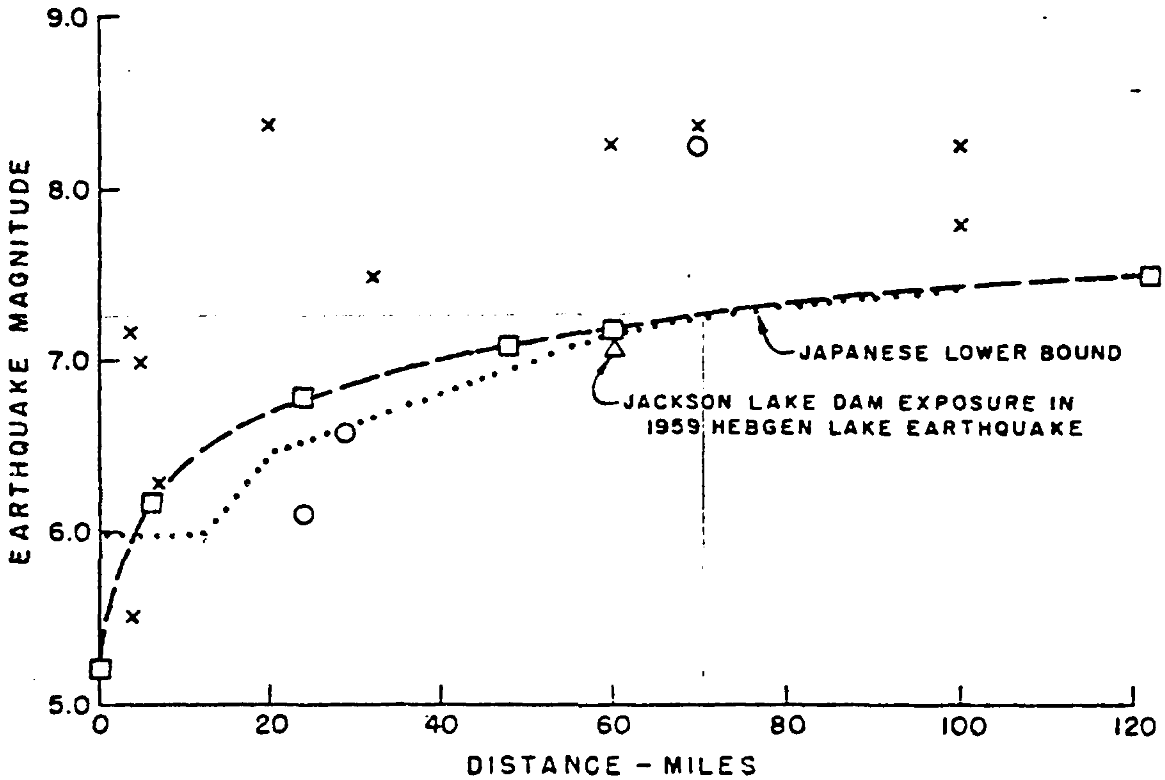
To begin this evaluation, a threshold level of seismicity which is strong enough and close enough to produce liquefaction needs to be established. The lower bound was established using (1) the guidelines given by Seed and Lee after their review of the susceptibility of the dam and foundation to liquefaction, and (2) historic records of earthquakes which have been strong enough to produce liquefaction (see figure 7). Next, all sources of earthquakes near Jackson Lake Dam which are capable of producing earthquakes above this threshold need to be identified and the probability of the occurrence of these earthquakes established. To take into account the higher probability of occurrence of lower level earthquakes and allow for quantifying the higher probability of liquefaction at the damsite due to larger level earthquakes, the calculations are performed considering the earthquakes from the various sources in half-magnitude intervals.

The source areas defined for Jackson Lake Dam are shown on figure 8 and described below.

Source 1. - This is the seismically active area near Yellowstone National Park at the Wyoming-Montana border. The Hebgen Lake, Montana earthquake (mag. 7.1) of 1959 was included in this area. The maximum credible earthquake from this area is considered to be magnitude 7.5. Because of the distance of this area from Jackson Lake, only earthquakes of magnitude level 7.5 are considered to have the potential for causing liquefaction at the site. From a plot of the historic seismicity of the area (figure 9), the estimated recurrence interval of earthquakes of magnitude 7.5 is 100 years. The probability of such an earthquake actually producing liquefaction at Jackson Lake Dam is estimated to be 1 in 10 on the basis of (1) Seed's comments in his report and (2) the lack of liquefaction due to the 1959 event. Thus, the annual probability of liquefaction due to source area 1 is the probability of the earthquake times the probability that the earthquake will cause liquefaction = 0.01 x 0.1 = 0.001.

Source 2. - This area is the intermountain seismic belt within 100 miles of the site but excluding the Teton-Hoback faults near

1/ All earthquake magnitudes in this report are considered Richter Magnitude.

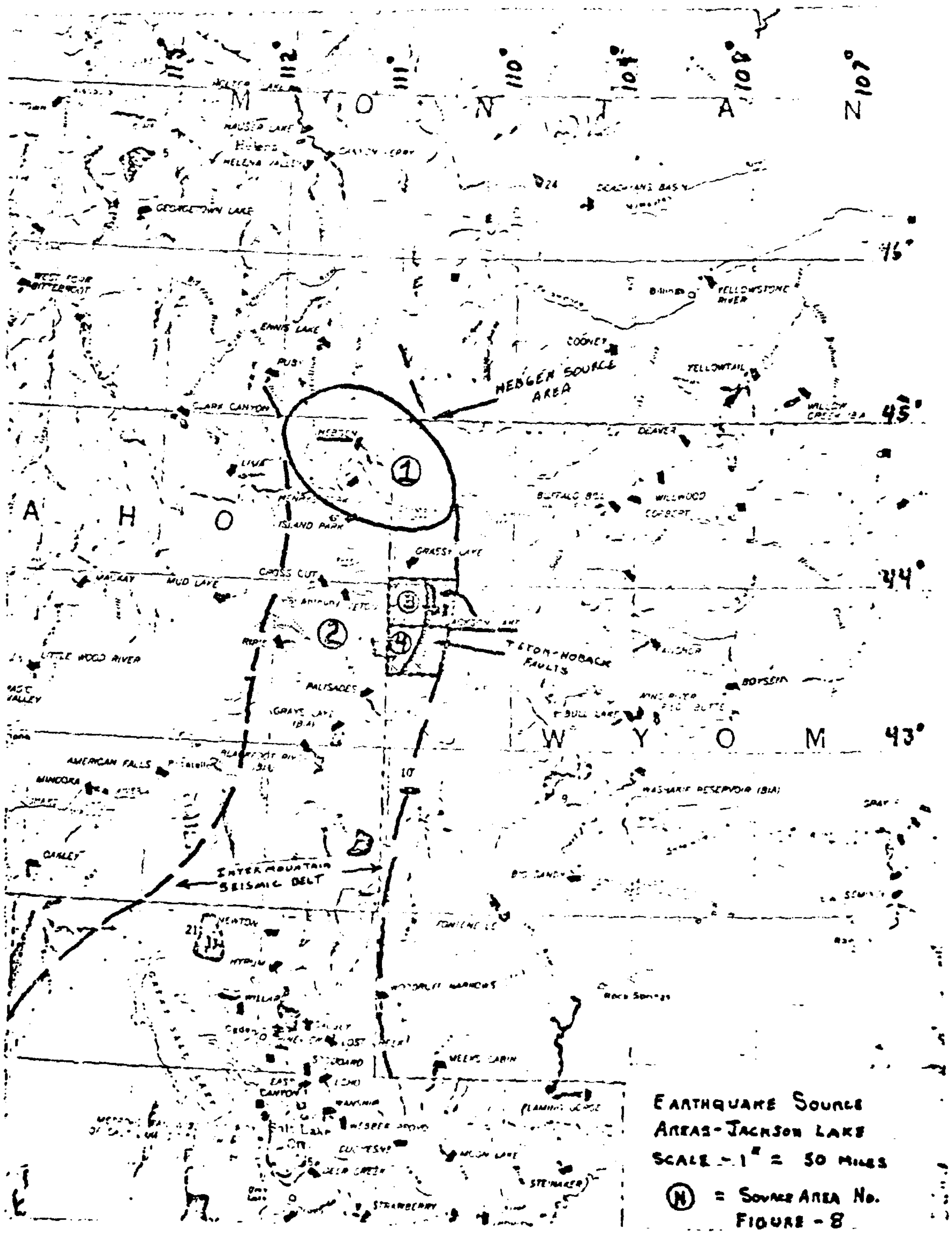


LIQUEFACTION POTENTIAL
VS
MAGNITUDE AND DISTANCE

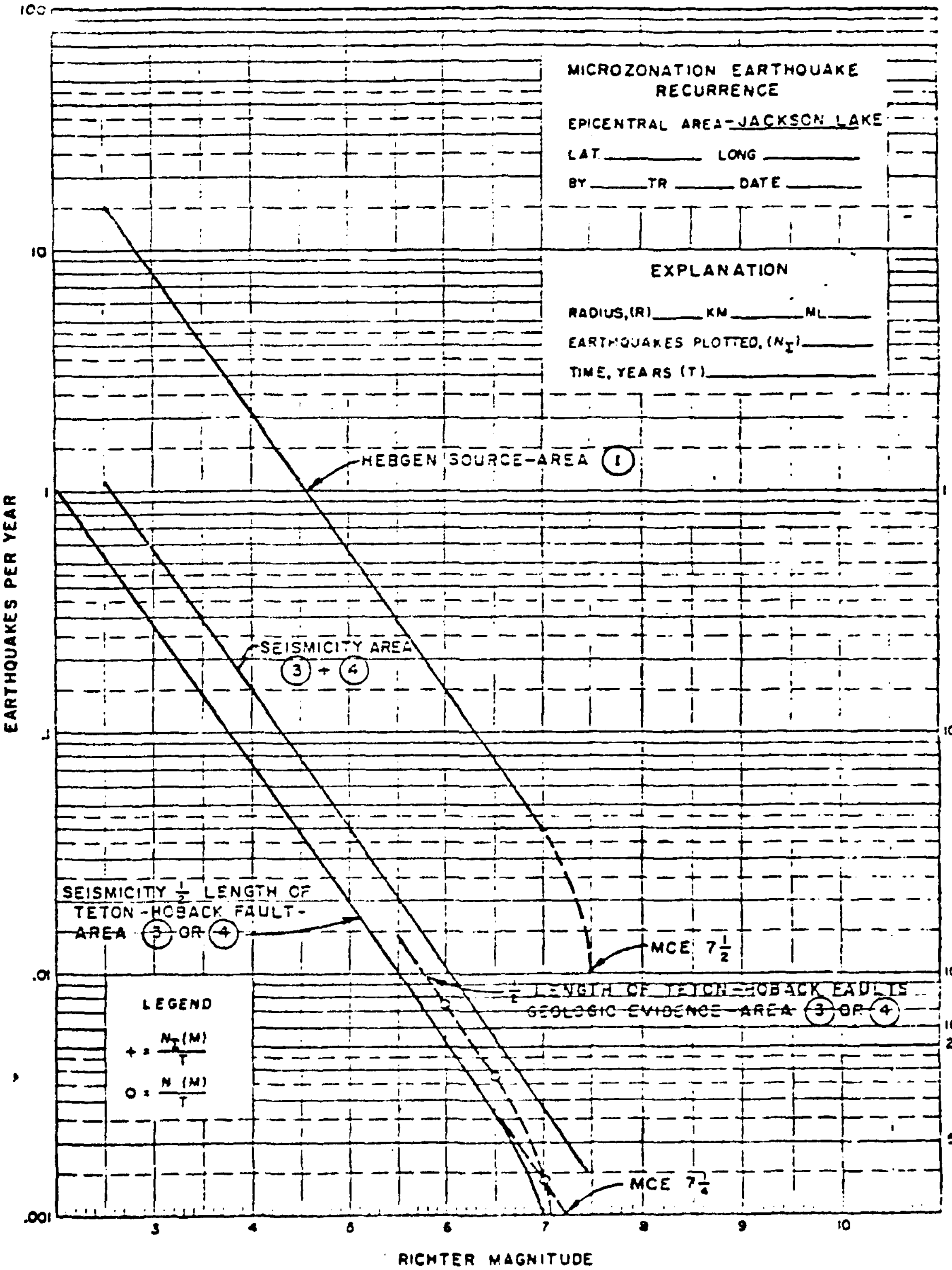
KEY

× = LIQUEFACTION
○ = NO LIQUEFACTION } DATA FROM SEED AND IDRISS (1971)
□ = JAPANESE LOWER BOUND LIQUEFACTION DATA
••• = LOWER BOUND USED FOR JACKSON LAKE DAM

FIGURE 7



MONTANA
IDAHO
WYOM
110°
109°
108°
107°
46°
45°
44°
43°
Helena
HAUSER LAKE
HELENA VALLEY
CANYON FERRY
GEORGETOWN LAKE
ENNIS LAKE
CLARK CANYON
HEBGEN
HEBGEN SOURCE AREA
ISLAND PARK
GRASSY LAKE
CROSS CUT
MUD LAKE
MACKAY
TETON-HOBACK FAULTS
PALISADES
AMERICAN FALLS
MINIDOKA
OAKLEY
INTERMOUNTAIN SEISMIC BELT
NEWTON
HYRUM
BIG SANDY
YELLOWSTONE RIVER
YELLOWTAIL
BOYSEN
MEEKS CABIN
STRAWBERRY
STEINAKER
Rock Springs
EARTHQUAKE SOURCE AREAS-JACKSON LAKE
SCALE - 1" = 50 MILES
(N) = SOURCE AREA NO.
FIGURE - 8



MICROZONATION EARTHQUAKE RECURRENCE
EPICENTRAL AREA-JACKSON LAKE
LAT. LONG
BY TR DATE
EXPLANATION
RADIUS,(R) KM ML
EARTHQUAKES PLOTTED, (N)
TIME, YEARS (T)
HEBGEN SOURCE-AREA (1)
SEISMICITY AREA (3) + (4)
SEISMICITY ½ LENGTH OF TETON-HOBACK FAULT-AREA (3) OR (4)
MCE 7½
½ LENGTH OF TETON-HOBACK FAULTS GEOLOGIC EVIDENCE-AREA (3) OR (4)
MCE 7¼
LEGEND
+ = N(M)/T
O = N (M)/T
EARTHQUAKES PER YEAR
RICHTER MAGNITUDE
100
10
1
.1
.01
.001
3
4
5
6
7
8
9
10
100
167
200
500

FIGURE 9

Jackson Lake (source areas 3 and 4) and also excluding the Hebgen source area (source area 1). Only earthquakes of the magnitude 7.5 level from this area are considered capable of producing liquefaction at the dam. The recurrence interval of magnitude 7.5 earthquakes from this area is estimated to be 500 years. The probability of such an earthquake producing liquefaction at the site is again considered to be 1 in 10. Thus the annual probability of liquefaction at the site from area 2 is 0.002 x 0.1 = 0.0002.

Source 3. - This area encompasses the Teton fault which runs through Jackson Lake. Earthquakes from this area of magnitude 6 to 7-1/4 are considered capable of producing liquefaction at the site. Estimates of recurrence intervals for earthquakes between these levels were made on the basis of geologic evidence and historic seismicity. The results are shown on table 1. Estimates of the likelihood of liquefaction due to the various levels of earthquakes as given on table 1 were based strictly on judgment.

Source 4. - This area encompasses the Hoback fault which lies to the southeast of the site. The Hoback fault was considered to have the same seismic capability as the Teton fault, but because it lies at a greater distance from the dam its potential for causing liquefaction at the dam was reduced. The estimates used for source area 4 are also given in table 1.

The sum of the probabilities of liquefaction at the site for each area and level of earthquakes yield the total probability of some type of liquefaction failure at the site in a 1-year period. This value is shown on table 1 as 0.0069.

Table 1. - Probability of liquefaction at Jackson Lake Dam

Earthquake -		Probability of -				
Source area	Magnitude range	Earthquake occurring	x	Dam liquefying from this E.Q.	=	Liquefaction at the site
1	7.5	0.01	x	0.1	=	0.001
2	7.5	0.002	x	0.1	=	0.0002
3	6.0-6.5	0.0031	x	0.5	=	0.00155
	6.5-7.0	0.0020	x	0.75	=	0.00150
	7.0-7.25	0.0012	x	0.95	=	0.00114
4	6.0-6.5	0.0031	x	0.1	=	0.00031
	6.5-7.0	0.0020	x	0.3	=	0.0006
	7.0-7.25	0.0012	x	0.5	=	0.0006
				Sum	=	0.0069

In addition to the effects of the earthquake shaking, certain of the earthquake can produce a wave on the reservoir (seiche). The possibility and influence of the seiche are taken into account later in the analysis in the determination of whether or not overtopping of the reservoir will occur.

Step 3 - Evaluation of the Structural Condition of the Dam Following Liquefaction

The preceeding step estimated the probability of liquefaction occurring but did not evaluate the degree of severity of the liquefaction. In fact, liquefaction could occur at the site and the effects could range from almost no loss in embankment height to nearly complete failure. In order to make a judgmental quantification of this fact the earthquakes have been divided into three strength levels and the dam has been assumed to take on one of three possible failure conditions with varying probability for each of the earthquake levels given that liquefaction has occurred. Ideally, the structural response conditions should be determined by using dynamic analysis studies appropriately evaluated considering historic prototype experience. In this case since no dynamic analyses have been performed, the estimates of failure condition are judged only on the small amount of available historic information. For that reason the evaluation is strongly influenced by the experience at Sheffield and Lower San Fernando Dams.

The earthquake levels and their relative probability of occurrence given that a liquefaction-producing earthquake occurs (probability = 1.0) were categorized according to strength levels with the following relative probabilities:

Level 1 = L1 = 0.25
Level 2 = L2 = 0.50
Level 3 = L3 = 0.25

Level 3 were the strongest earthquakes (e.g., 7 to 7-1/4 near the site) and Level 1 the weakest.

The structural conditions which the dam could assume were described by the percent of dam height remaining between the assumed bottom elevation of liquefaction (Mode 1 = 6750, Mode 2 = 6730) and the top of the dam (elevation 6779). They are given as:

Condition 1 = C1 = 90 percent
Condition 2 = C2 = 50 percent
Condition 3 = C3 = 20 percent

The probability that the dam will take on a particular condition given that a liquefaction-producing earthquake occurs is equal to the product of the probability that the dam assumes the condition at that level times the relative probability of an earthquake of that level occurring. Tables 2A and 2B show these estimates for assumed Mode 1 and Mode 2 type failure condition.

Table 2A. - Mode 1 postfailure structural condition

Given earthquake load level	Probability of structural condition C1	C2	C3		Relative probability of E.Q. level		Structural condition probability given liquefaction occurs C1	C2	C3
L1	0.4	0.4	0.2		0.25		0.1	0.1	0.05
L2	0.2	0.4	0.4	x	0.5	=	0.1	0.2	0.2
L3	0.05	0.35	0.6		0.25		0.0125	0.0875	0.15

Adding the last column for condition 3 shows that if liquefaction takes place it is considered there is a 0.4 probability that only 20 percent of the embankment above elevation 6750 will remain.

Table 2B. - Mode 2 postfailure structural condition

Given earthquake load level	Probability of structural condition C1	C2	C3		Relative probability of E.Q. level		Structural condition probability given liquefaction occurs C1	C2	C3
L1	0.5	0.4	0.1		0.25		0.125	0.1	0.025
L2	0.3	0.4	0.3	x	0.5	=	0.15	0.2	0.15
L3	0.1	0.4	0.5		0.25		0.025	0.1	0.125

These structural condition estimates, which rely on engineering judgment, provide a means of assessing the relative probability of various possible postfailure conditions which are necessary for completing the risk analysis.

Step 4 - Compute probability of overtopping as a function of reservoir restriction level

With the information from the previous step, the number of feet of freeboard or the height of the water above the failed embankment can be computed for each of the structural conditions and each reservoir level. These data are shown in table 3 for Modes 1 and 2.

Table 3. - Post assumed failure condition
Embankment level vs. reservoir restriction level

Given condition	Mode 1 Reservoir level +6700 69	65	60	55	50	40	Mode 2 Reservoir level +6700 69	65	60	55	50	40
C1	7	11	16	21	26	36	5	9	14	19	24	34
C2	-4.5	-0.5	4.5	9.5	14	24	-14.5	-10.5	-5.5	-0.5	4.5	14.5
C3	-13	-9	-4	1	5	14	-29	-25	-20	-15	-10	0

- = embankment below reservoir level.

To determine whether or not overtopping occurs requires consideration of the reservoir operating criteria and the height of the earthquake-generated wave. For the purposes of this analysis, the criteria applied were:

a. Current operation - Reservoir at 6769 - 1/6 of the year
Reservoir at 6765 - 1/6 of the year
Reservoir at 6760 - 2/3 of the year

b. Restriction at 6765 - Reservoir at 6765 - 1/3 of the year
Reservoir at 6760 - 2/3 of the year

c. Restriction at 6760 or below - Reservoir at restricted level for the full year

With respect to the sieche it was assumed that:

a. Level 3 earthquakes could produce a seiche up to 17 feet.

b. Level 2 earthquakes would produce a seiche up to 6 feet 50 percent of the time.

c. Level 1 earthquakes would not produce a seiche.

d. The wave height could not exceed the depth of water.

To calculate the absolute probability of overtopping for each reservoir level required the following operations (elevation 6769 for Mode 1 will be used as an example):

a. From table 3, determine under what conditions the dam was overtopped. (For elevation 6769 reservoir level the dam is overtopped for structural conditions 2 and 3 at all levels of earthquake loading and for condition 1 at level 3 loading since a level 3 seiche of 17 feet would overtop the 7 feet of freeboard available.)

b. From table 2A or 2B sum the probabilities of the structural conditions which were determined to allow overtopping. (For elevation 6769 reservoir level Mode 1 use table 2A. Since all structural conditions and earthquake levels produce overtopping except structural condition 1, earthquake levels 1 and 2, the probability of overtopping condition is 1.0 - (0.1 + 0.1) = 0.8.)

c. The absolute probability of overtopping is obtained by multiplying

the probability of having overtopping conditions
x
the probability of the failure mode
x
the probability that liquefaction producing earthquake occurs
x
the probability that the reservoir will be at that elevation

and, if the latter is less than 1.0 you must sum the absolute probability of overtopping for all other elevations at which the reservoir will remain during the year.

For the current operation (in effect restriction at 6769) elevations 6765 and 6760 must also be considered. Thus, probability of overtopping under current restriction at elevation 6769 is:

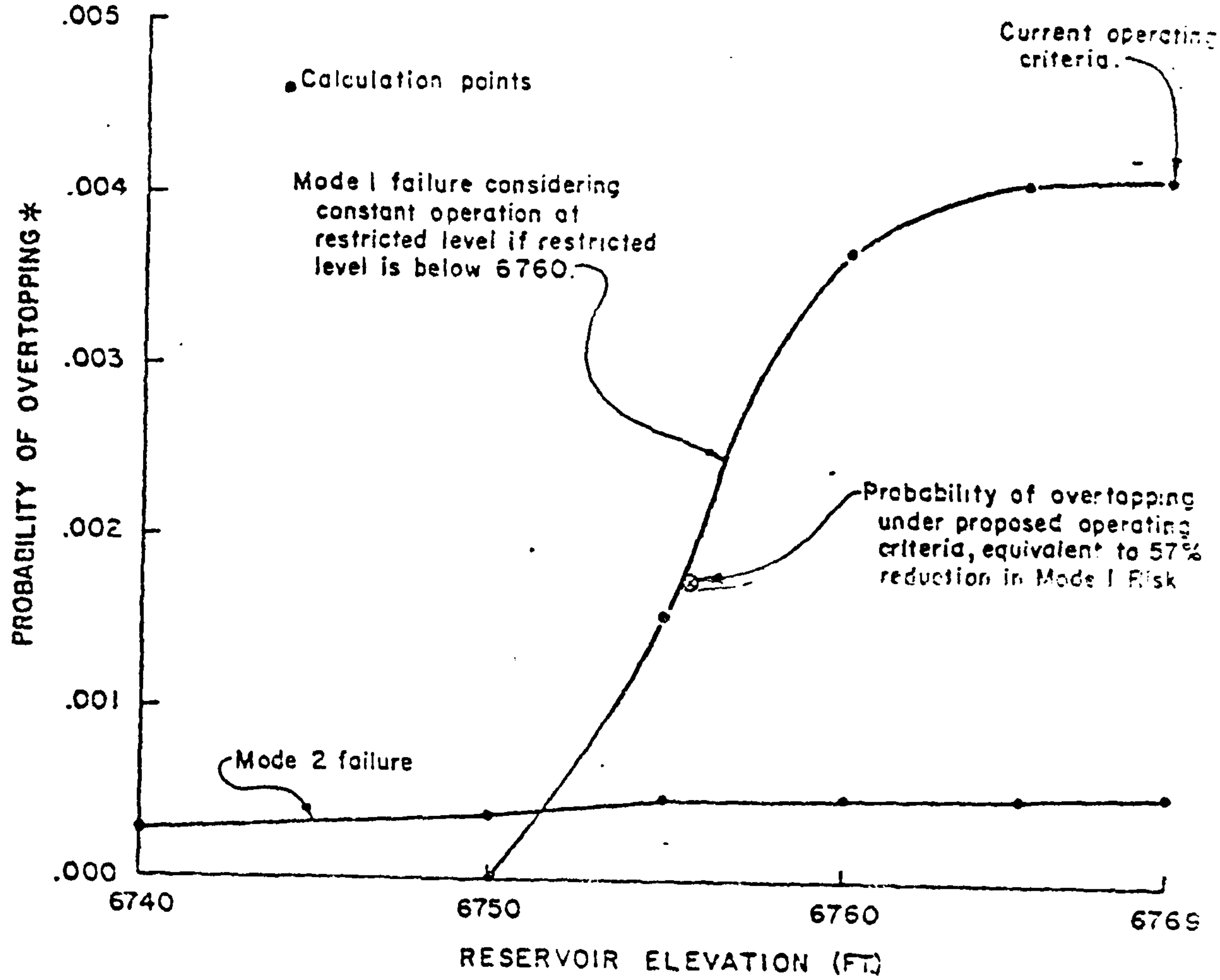
Overtopping probability		Mode probability		Liquefaction probability		Time probability
= 0.8	x	0.9	x	0.0069	x	1/6 (time at 6769)
+ 0.8	x	0.9	x	0.0069	x	1/6 (time at 6765)
+ 0.59	x	0.9	x	0.0069	x	2/3 (time at or below 6760)

= .0041

The risk of overtopping values was calculated for 5-foot increments of reservoir elevation (appendix B) and is plotted on figure 10.

Step 5 - Examine overtopping and hazard relationships to select acceptable restriction level

Review of the absolute risk of overtopping versus reservoir elevation given in figure 10 shows that the risk of overtopping from Mode 1 decreases rapidly with drop in reservoir elevation. Likewise, figure 6 shows that the peak discharge and flood damage potential also decrease rapidly with drop in reservoir elevation in the event overtopping took place. Recreational use of the area below the dam is heavy during certain periods of the year. Estimates of potential loss of life versus flood level were not developed; however, the regional study (appendix C) concluded that boaters would be able to clear the stream prior to the flood wave. Despite the lack of definitive figures it is reasonable to expect that the potential loss of life would decrease rapidly with drop in reservoir elevation in a similar manner to the drop in damage level.



RISK OF OVERTOPPING VS RESERVOIR ELEVATION OF JACKSON LAKE

* FROM LIQUEFACTION FAILURE DUE TO EARTHQUAKE PLUS EFFECT OF A SEICHE.

MODE 1 - LIQUEFACTION AT BASE LEVEL OF 6750.

MODE 2 - LIQUEFACTION AT BASE LEVEL OF 6730.

FIGURE 1

Examination of figures 6 and 10 show that if a reservoir restriction level of 6756 is specified, the peak discharge is approximately 25,000 ft^3/s and the risk of overtopping has decreased by more than 50 percent. At a reservoir restriction level of 6757, the peak discharge would be approximately 30,000 ft^3/s and the risk of overtopping would be reduced over 40 percent. Since a flood of 30,000 ft^3/s is contained within the downstream levees built by the Corps of Engineers and since the risk of overtopping at all is cut by significant amount, a restriction level between 6756 and 6757 (6756.5) appears to be a restriction level which would be meaningful in reducing the potential hazard.

Step 6 - Consideration of impact of restriction and establishment of a reservoir operation plan to maximize benefits under restricted condition

Restriction of the reservoir level decreases the amount of available storage for irrigation purposes. In addition, the Jackson Lake area is a major scenic and recreation area of the nation and reduction in the reservoir level impacts this use in several ways including:

1. Boating on the lake is curtailed and boat ramp access is made difficult.

2. Water releases for rafting and for fishing are not able to be controlled at optimum levels.

3. Large areas of reservoir bottom area are left exposed which detracts from the beauty of the lake and the area.

In order to minimize the adverse impact of the imposition of restrictions on Jackson Lake an operation plan was developed (figure 3) which coordinated water storage and water release maxima with periods of peak public need. The operation plan devised kept the risk of overtopping below the level considered appropriate (a 57-percent reduction in risk of overtopping) by maintaining the reservoir at or below elevation 6755 for over 9 months of the year even though it was allowed to reach elevation 6760 for 1 month.

Although the risk of overtopping is not increased by the operation plan the level of hazard from a Mode 1 type failure is increased above the level considered as an appropriate cutoff point (30,000 ft^3/s) which was discussed above. However, this increased potential hazard exists for only about a 1-month period or 1/12 of the year. This period of peak public need unfortunately coincides with the period of peak public use. Although this 1-month period presents a higher potential hazard than that from a constant 6756.5 restriction level, having an effective operation plan which maintains usability of the recreational aspects of the lake's waters is reasonable

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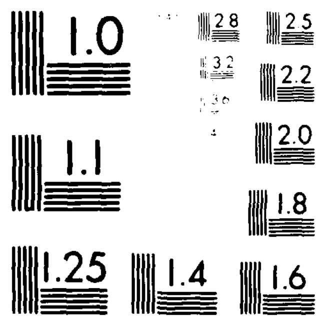

MICROCOPY RESOLUTION TEST CHART
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and justifiable. Considering the planned restriction in total, it is considered that a meaningful reduction in risk and hazard will be achieved and although the impact on recreation and irrigation is significant the plan recommended is both responsible with respect to public safety and responsive to public needs.

IV. Conclusions

The question of a level of acceptable risk is brought to bear at Jackson Lake as the twin goals of maintaining dam safety and providing maximum benefits from the project are brought together. Responsible management of a public facility in such a case requires that an objective assessment is made of the hazard, the risk of failure, and the loss in benefits due to any restriction imposed.

To determine an appropriate restriction level a "reasonable worst case" analysis was made and in addition, a decision analysis model was used to provide a convenient format for presentation of all the available information and to permit an objective evaluation of these data. Similar conclusions were reached by both methods. Although the data were limited, the risk analysis clearly showed a marked decrease in the risk of overtopping with decreasing reservoir elevation.

Analysis of the flood hydrograph for the most likely hypothetical failure mode likewise showed a significant decrease in potential hazard with decreasing reservoir elevation. Examination of these relationships, and determination of a reservoir operation procedure which minimizes adverse impact from a restricted reservoir level permitted establishing a reservoir operation plan which provides for a meaningful reduction in risk to the public and yet maintains the usefulness of the reservoir.

Larry Von Thun

UNITED STATES DEPARTMENT OF COMMERCE
National Bureau of Standards
Washington, D.C. 20234

August 8, 1980

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Vicksburg, MS 39180

Dear Bill:

Attached are my topic statements pertaining to the Knoxville meeting.

<u>Topic of on-going research at NBS in geotechnical earthquake engineering</u>.

1. In the area of soil liquefaction, NBS is exploring the effect of cyclic strain on pore water pressure build-up and the existence of a threshold shear strain below which no volume change will occur. A design approach has been suggested by which information on G_{max} as measured by geophysical methods can be used to determine whether liquefaction at a site is possible.

2. In a study of the Standard Penetration Test NBS measured simultaneously the potential energy of the hammer before its downward motion, the kinetic energy at impact and the energy which reaches the sample by the stress-wave propagated through the drill stem. By comparing these energies it has been determined that the geometry of the hammer has a significant effect on the energy transmitted when the drill stem is short. NBS will also study available blow count data from Japan to determine whether they need to be reinterpreted because of differences in delivered energy.

Sincerely yours,

Felix Y. Yokel, Ph.D., P.E.
Leader, Geotechnical Engineering Group

TOPIC STATEMENT

Agency TVA Priority ________ 1980 Session Number ________

Subject Area Soil Dynamics

Project Title Dynamic Properties of Gravelly Soils

Performing Organization Materials Engineering Laboratory

Principal Investigator Y. C. Chung

Starting Year FY 80 Estimated Completion Year FY 80

TECHNICAL OBJECTIVES:

Information in the literature on this subject is sparse, studies to investigate both shear moduli and damping factors of granular soils will be conducted to provide vital information for the dynamic stability analysis.

TECHNICAL APPROACH:

A number of different gradations will be considered representing gravel sizes only and blends of gravel and sand with a maximum size of 1-1/2 inch down to the fine sand fraction. Tests will be conducted in a torsional resonant column apparatus with free-free boundary conditions for 6-in.-diameter specimens.

GENERAL PROGRESS:

Computer program for 6-in.-diameter specimen has been verified.

PLANS FOR NEXT TWELVE MONTHS:

1. Establish vibratory compaction technique to prepare 6-in.-diameter specimens.
2. Establish and perform standard resonant column test procedures.
3. Evaluate test results.

APPENDIX 2

FUNDING PRIORITIES OF THE NATIONAL SCIENCE FOUNDATION FOR EARTHQUAKE-RELATED RESEARCH

NATIONAL SCIENCE FOUNDATION
WASHINGTON D C 20550

September 5, 1980

W.F. Marcuson, III
Research Civil Engineer
U.S. Waterways Experiment Station
Vicksburg, MS 39180

RE: Interagency Working Group for Earthquake
Engineering Research Coordination

Dear Bill:

Enclosed are summaries of NSF-funded research projects related to "Earthquake Analysis for Evaluating Dam Safety". These projects have been funded in the last several years under the Earthquake Hazards Mitigation Program.

I look forward to seeing you in Knoxville.

Best wishes,

Bill

William W. Hakala
Program Manager
Problem Focused Research

Attachments

Induced Seismicity at Nurek, Tadjikistan, USSR

David W. Simpson

Lamont-Doherty Geological Observatory, Columbia University

Palisades, NY 10027

Award # 77-25324 (Continuation of 77-01092)

$207,125 for 21 months beginning January 31, 1978

(Total award: $314,025)

The seismic regime can be severely modified by the impounding of large reservoirs. Earthquakes with Richter magnitudes near 6 have occurred near five large reservoirs, resulting in millions of dollars of property damage, structural damage to dams, the loss of more than 200 lives and injuries to thousands of persons. Throughout the world, over 100 large dams are now under construction or in the planning stage, at least some of which are likely to cause induced activity. The potential for a major disaster is obvious, yet scientists are just beginning to understand this type of seismic activity.

A joint US-USSR study of seismicity at Nurek Reservoir, Tadjikistan, USSR has been underway since 1975. An existing network of ten Soviet Seismograph Stations within 50 km of the reservoir is being augmented with a ten station network of American radio-telemetered seismographs located within 10 km of the reservoir. A model has been developed to explain many of the observed features of the temporal and spatial characteristics of the induced seismicity at Nurek. This model, based on the interaction between stresses created by the reservoir load and increased pore pressure, show that the times of greatest potential for increased seismicity are following rapid increases and during rapid decreases in reservoir water levels.

This project is continuing this seismicity study and is investigating the earthquake spectra, and the causes of induced seismicity. The objective is to further the understanding of the process by which reservoir induced seismicity occurs, to identify the characteristics of the induced activity and to develop a framework for the assessment of the potential for induced seismicity at a given reservoir site.

This project is a continuation of Grant ENV77-01092

Induced Seismicity at Nurek Reservoir, Tadjikistan, USSR

David W. Simpson

Lamont-Doherty Geological Observatory, Columbia University

Palisades, NY 10027

Award # 77-01092

$106,125 ($81,900AEN, $25,000 EAR) for 12 months beginning Dec. 15, 1976

The seismic regime can be severely modified by the impounding of large reservoirs. Earthquake with magnitudes of 6 have occurred near five large reservoirs, resulting in millions of dollars of property damage, structural damage to dams, the loss of more than 200 lives and injuries to thousands of persons. Throughout the world, over 100 large dams are now under construction or in the planning stage, at least some of which are likely to cause induced activity. The potential for a major disaster is obvious, yet some scientists are just beginning to understand this type of seismic activity.

This project is to continue a joint US-USSR study, begun in 1975, of seismicity at Nurek Reservoir, Tadjikistan, USSR. An existing network of ten Soviet Seismograph Stations within 50 km of the reservoir is being augmented with a ten station network of American radio-telemetered seismographs located within 10 km of the reservoir. A model has been developed to explain many of the observed features of the temporal and spatial characteristics of the induced seismicity at Nurek. This model, based on the interaction between stresses created by the reservoir load and increased pore pressure, shows that the times of greatest potential for increased seismicity are following rapid increases and during the rapid decreases in water load. Tests of this model and further refinements to it will be made as the reservoir continues to fill.

Risk-Based Assessment of the Saferty of Dams

Erik H. VanMarcke

Massachusetts Institute of Technology

Cambridge, MA 02139

Award # 78-15898

$230,995 for 18 months beginning March 1, 1979

Major constructed facilities, such as dams, pose potential hazards to life and property, and to the environment. To date, the profession has, largely by trial and error, developed design prodedures which do not require explicit, quantitative treatment of risk and uncertainty. The objective of this project is to develop a methodology for quantitative assessment of the risk of dam failure and risk-benefit for alternative measures for dam hazard mitigation, and to establish scientific basis for risk-based dam safety design provisions and criteria.

Research will be carried out to develop a general framework for risk and decision analysis of dams, to develop risk analysis methodology for specific dam failure causes and mechanism such as hydrology, earthquake, stability and landslide, foundation defects and uneven settlement, and load combinations. Effort will also be made to apply the methods developed to specific dam engineering problems in order to test methodoliges, to uncover needed improvements and gaps in procedures.

Seismic Response of Three-Dimensional Dam-Reservoir Systems

Theodore Y. Wu

California Institute of Techonology

Pasadena, CA

Award # 77-16085

$222,518 for 36 months beginning March 15, 1978

The objective of this project is to determine, by theoretical and numerical analysis, the seismic response of a dynamically coupled, three-dimensional dam-reservoir system including the hydrodynamic interaction effect, the flexibility effect, the effect of phase variation and spatial attenuation of seismic waves, and the side confinement of the dam.

The failure of a dam during strong earthquakes can cause catastrophic property damage and loss of human lives to a densely populated community on the downstream side of the dam. Since the cost of constructing a major dam is very large, it is important to carry out research to ascertain adequate design criteria for constructing future dams and to develop and improve methods for monitoring the safety performance of existing dams during earthquakes.

Hydrodynamic loading functions have been determined for various reservoir configurations. In this project, efforts will be directed to studies of the the hydroelasticity response of the dam-reservoir as a system during a typical strong earthquake, the effect of water compressibility, the elastic property of the dam, the effect of wave propagation, etc. will be considered.

Earthquake Response of Dams Including Hydrodynamic and Foundation Reactions

Anil K. Chopra

University of California

Berkeley, CA 94720

Award # 76-80073

$138,300 for 2 years beginning November 15, 1976
($67,600 in FY 77 - $70,700 in FY 78)

The basic purpose of this research investigation is to develop (i) reliable and effective techniques for earthquake analysis of dams including effects of hydrodynamic and foundation interaction, and (ii) a fundamental understanding of the effects of interaction and their significance in the response of dams to earthquake ground motion. Dams of three types: conctete gravity, concrete arch and earth, are included.

Procedures for including hydrodynamic and foundation interaction effects in analysis of response of dams to earthquake ground motion will be formulated. Computer programs will be developed to implement these procedures for numerical evaluation of earthquake significance of interaction effects in earthquake response of dams.

The developments and results expected from the proposed investigation will enable better evaluation of the response of dams to earthquake ground motion, thus improving the capability to assess the safety of existing dams and of designs proposed for dams to be constructed.

Earthquake Behavior of Techi Dam

Ray W. Clougn

University of California

Berkeley, CA 94720

Award # 78-19333

$151,728 for 24 months beginning January 15, 1979

Numerical methods, particularly the finite element procedures, for seismic response analysis of arch dams have been well developed. However, many assumptions inherent in the analyses have not been verified by experiments and many uncertainties remain in the results even after the most refined analyses. The objective of the project is to conduct U.S. - Republic of China cooperative research to obtain seismic response information from the Techi Dam in Taiwan. The Techi Dam is a modern, thin shell concrete structure located in a region of significant seismic behavior of arch dams. The project will install additional instrumentation in the dam, calculate and measure the dam vibration properties, refine the mathematical model through numerical analysis, observation and correlation study, evaluate the seismic response and perform table tests of scaled dam models.

The project will demonstrate the effectiveness of current response analysis procedures, and will provide inproved techniques for treating reservoir and foundation interaction, as well as better understanding of expected faiure mechanism.

Support of USCOLD Committee - Evaluation of the Incremental Seismic Risk Due to Reservoir Filling

George W. Housner

California Institute of Technology

Pasadena, CA 91104

Award # 76-01545

$12,400 for 24 months beginning September 1, 1976

This grant will provide continued support for the USCOLD Committee or Earthquake Effects on Dams. Members of the committee represent industry, academic institutions, and Government. All of the committe members have a particular interest in the earthquake safety of dams and the development of the best procedures for planning and desingni: dams in seismic regions.

The committee has in progress the following projects:

1. Effects of reservoir filling on occurrence of earthquakes near dams.

2. Seismic instrumentation for dams. This project has been completed and a report has been published. The report has bee submitted for publication in the Geotechnical Journal of the American Society of Engineers.

3. Earthquakes near dams. This project is collecting information on recorded strong earthquake motions on or near dams.

4. Dams damaged by earthquakes. This project is collecting information on all dams that have experienced strong ground shaking with or without damage.

<u>Earthquake Stability of Reinforced Earth Structures</u>

Kenneth L. Lee

University of California

Los Angeles, CA 90024

Award # 75-15417

$276,900 for 24 months beginning January 1, 1976

This project is for continued research on the topic of seismic design of reinforced earth structures retaining walls, dikes and dams, etc. The previous studies have led to a suggested seismic design method for s special type of reinforced earth retaining wall. In addition, it has also demonstrated the validity of using small scale models for studying the static and dynamic response of reinforced walls. The findings form the basis for the additional continued studies proposed herein to extend the scope of the research to cover a variety of possible wall designs for special conditions.

It is proposed to perform (1) more model tests with small walls up to 15 in. high on the horizontal sinusoidal motion shaking table at UCLA, (2) large scale model tests with walls up to 5 ft. high on the large shaking table at Berkeley to verify and extend the small scale model tests, (3) forced vibration tests to obtain the modal frequencies of existing walls at different excitation levels, (4) additional soil-tie friction studies, and (5) analytical and semi-empirical studies to refine the stress distribution analysis, and especially to study the problem of wall deformations which develop during sustained strong shaking.

It is intended that the work proposed herein will lead to a logical final conclusion which will enable engineers to proceed confidently with seismic designs for particular projects involving the reinforced earth techniques.

Analysis of the Seismic Stability of Earth Dams

H. Bolton Seed

University of California

Berkeley, CA 94720

Award # 75-21875

$173,500 for 24 months starting February 15, 1976

The near failure of the San Fernando Dams in the earthquake of Feb. 9, 1971 has led to increased concern regarding the seismic stability of embankment dams and the usefulness of older methods of evaluating seismic stability. On the other hand, many older earth dams, built before any seismic design techniques were in use at all, are known to have survived extremely strong earthquake shaking without any detrimental effects. A study will be made of the significant differences between earth dams known to have performed well and dams known to have performed poorly during strong earthquake shaking to determine the signifincant factors responsible for these difference in behavior. In addition recently developed dynamic analysis methods for evaluating the seismic response and performance of dams will be investigated for their adequacy and effectiveness in predicting the observed performance with sufficient reliability to ensure public safety without being unduly overconservative.

The specific objective of this research is to develop simplified procedures for evaluating the probable performance of earth dams subjected to strong earthquake shaking. The results of this research would contribute significantly to both improved safety and economy in the design of these critical structures.

Dynamic Testing and Acoustic Analysis of Concrete Dams

G. Bruce Taylor

Anco Engineers, Inc.

Santa Monica, CA 90404

Award # 79-00004

$165,496 for 18 months beginning June 1, 1979

A dynamic test procedure for concrete dams will be developed to acoustically detect defects in dams which could cause failure under extreme conditions. A gas expansion device will be submerged in the reservoir near the face of the dam. The shock wave which is produced in the water will interact with the concrete interface and excite motion in the dam. Any defects which exist in the structure will emit acoustic signals which will be located through triangulation. The testing program will be augmented with a detailed analytical study of the structure utilizing finite element analysis techniques. Approximately eight concrete dams located in the United States will be examined. This non-destructive test method should be of great value in helping to evaluate the safety of dams subjected to seismic and other loadings.

Seismic Response of Three-Dimensional Dam Reservoir Systems

Allen T. Chwang

California Institute of Technology

Pasadena, CA 91125

Award # 77-16985

$221,547 for 36 months beginning March 15, 1978

The potential failure of a dam during strong earthquakes can cause catastrophic property damage and loss of human lives to a densely populated community of the downstream side of the dam. Since the cost of constructing a major dam is very large, it is important to carry out research to ascertain adequate design criteria for constructing future dams and to develop and improve methods for monitoring the safety performance of existing dams during earthquakes.

The objective of this projects is to determine, by theoretical and numerical analysis, the seismic response of a dynamically coupled, three-dimensional damreservoir system including the hydrodynamic interaction effect, the flexibility effect, the effect of phase variation and spatial attenuation of seismic waves, and the effects of the side confinement of the dam. Preliminary experimental verification of theoretical results on full-scale dams will also be conducted.

A Symbol Processor for Earth Dam Seismic Response With A Nonlinear-Inelastic Soil Model

John O. Dow

University of Colorado

Boulder, CO 80302

Award #78-23073

$28,160 for 12 months beginning January 1, 1978

The research objectives are to improve the nonlinear, inelastic soil model in the seismic response analysis of earth dams and to incorporate this development into LUSH, a currently used finite element earth dam seismic response program. The developments will include the significant nonlinear effects cause by large shear deformations by modeling the soil with a step-wise linear representation. Recently developed symbol processing techniques will be utilized in the development of finite element and overall system matrices to: (1) Replace approximate numerical algorithms with exact operations. (2) Formulate expressions which are too complex or time consuming to be performed by hand. (3) Generate closed form solutions by executing numerical algorithms in symbolic form.

The research will provide: (1) An analysis procedure for seismic stability and liquefaction potential in embankment dams, (2) Static analysis of nonlinear, inelastic systems, (3) Dynamic analysis of other large systems such as buildings and bridges, (4) Computer aided design by allowing parametric definition of system properties.

Earthquake-Induced Longitudinal Vibration of Earth Dams

Ahmed M. Abdel-Ghaffar

University of Illinois at Chicago Circle (initial award)

Princeton University, Princeton, NJ 08540 (current)

(transferred Award # 80-05615 from Chicago Circle)

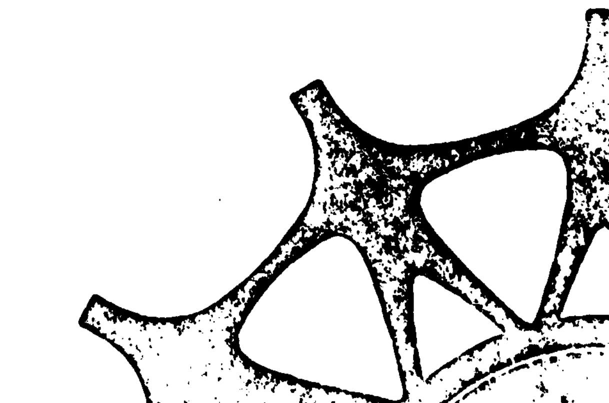
Award # 78-22865

$29,929 for 12 months beginning January 1, 1979 ($22,410 transferr to Princeton)

The research analyzes the longitudinal vibrational behavior of ear dams during earthquakes. The principal objectives of the investigation are: first, development of a simplified method, using an analytical elastic model, for evaluation of dynamic characteristic earth dams in a direction parallel to the dam axis and for estimat earthquake-induced strains and stresses in that direction. Both s and compressional (axial) deformation will be considered. In addi results of full-scale dynamic tests, both ambient and forced (conducted by the investigator) and real earthquake observations c some existing dams will be utilized to confirm and improve the met of analysis. Secondly, a rational procedure will be developed to estimate dynamic strains and corresponding elastic moduli and damp factors for hysteresis loops from the crest as well as the base records of earth dams. This will lead to a study of the nonlinea behavior in terms of the variation of stiffness and damping prope with the strain levels of different loops. Finally, the data so obtained will be compared with those previously available from laboratory investigations.

DIVISION OF PROBLEM-FOCUSED RESEARCH

SUMMARY OF AWARDS FISCAL YEAR 1979



NATIONAL SCIENCE FOUNDATION
Directorate for Engineering and
Applied Science
Washington, D.C. 20550

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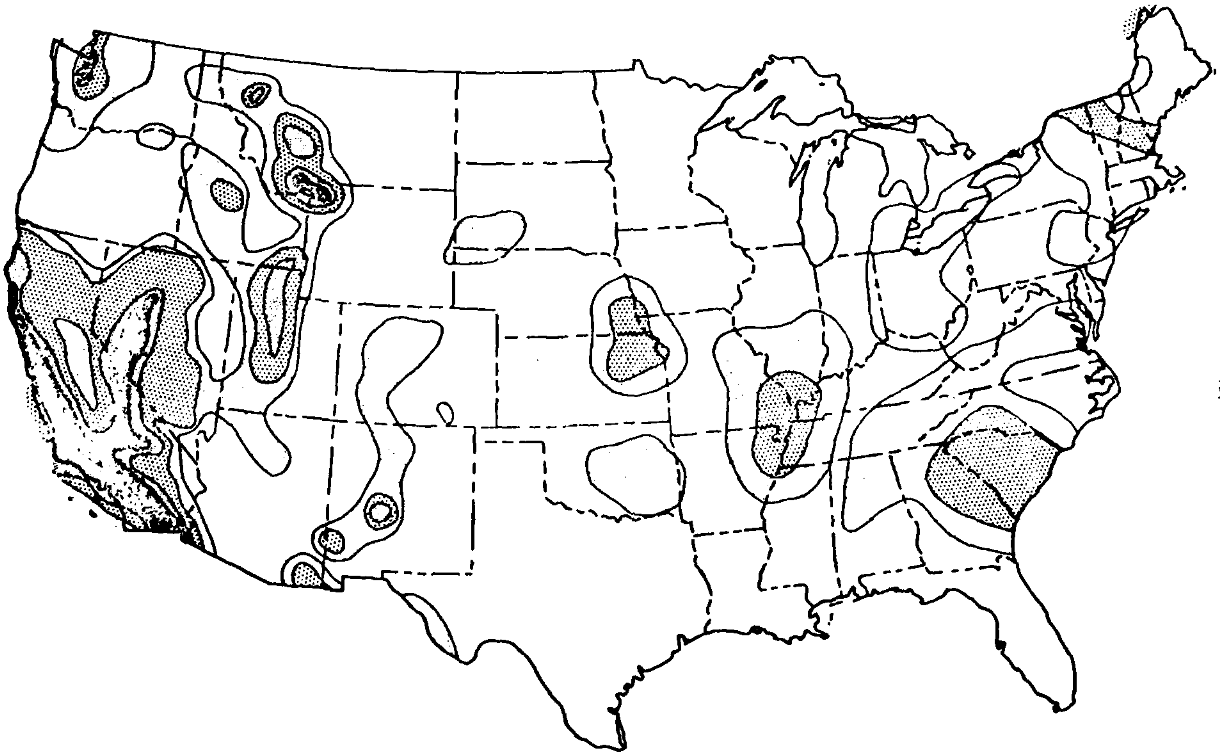
APPENDIX 3

FUNDING PRIORITIES OF THE U. S. GEOLOGICAL SURVEY FOR EARTHQUAKE-RELATED RESEARCH

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

EARTHQUAKE HAZARDS REDUCTION PROGRAM 1978



Open-File Report 79-387

3-1

This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards and nomenclature.

EARTHQUAKE HAZARDS REDUCTION PROGRAM

PROJECT SUMMARIES — FISCAL YEAR 1978

by

Marilyn P. MacCabe

with a List of Publications for 1977
compiled by Patricia J. Meader and Wanda H. Seiders

U.S. Geological Survey
345 Middlefield Road
Menlo Park, California 94025

Open-File Report 79-387

United States Department of the Interior

CECIL D. ANDRUS, *Secretary*

Geological Survey

H. William Menard, *Director*

Cover: A schematic representation of relative earthquake risk in the United States simplified from "A Probabilistic Estimate of Maximum Acceleration in Rock in the Contiguous Unitied States" by S. T. Algermissen and D. M. Perkins (U.S. Geological Survey Open File Report 76-416, 45p., 1976). The shaded areas represent the horizontal acceleration in rock that with 90 percent probability is not likely to be exeeeded in 50 years. The light stippled area is 4 to 10% of the acceleration due to gravity; the darker stippled area is 10 to 20%; the darkest stippled area is 20 to 40% and the black area is greater than 40%.

CONTENTS

Program and Plans of the U.S. Geological Survey for Producing Information Needed in National Seismic Hazards and Risk Assessment, Fiscal Years 1980–84

By Walter W. Hays

GEOLOGICAL SURVEY CIRCULAR 816

1979

United States Department of the Interior
CECIL D. ANDRUS, *Secretary*

Geological Survey
H. William Menard, *Director*

Free on application to Branch of Distribution, U.S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202

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ILLUSTRATIONS

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APPENDIX 4

RESEARCH AND DEVELOPMENT AT THE U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION RELATED TO EARTHQUAKE ANALYSIS OF DAM SAFETY

Seismic Analyses to Evaluate the Safety of Corps' Concrete Dams

Paul Mlakar
Structures Laboratory
USAE Waterways Experiment Station

The Corps' current criterion[1] requires that concrete dams sustain the appropriate operating basis earthquake without loss of operating or extensive repair and that these structures withstand the site's maximum credible earthquake without a failure involving loss of life or extensive property damage. The present state of the art can address only the most significant factors involved in the implied linearly elastic response to the operating basis earthquake. The inelastic response of concrete dams, which must sometimes be considered for the maximum credible earthquake, is the subject of ongoing research. Until the results of this work are available, the seismic safety of new and existing concrete dams is being assured by performing state-of-the-art linear elastic analyses and interpreting their results with the best possible engineering judgment.

This state of the practice is illustrated by the seismic safety analysis of the concrete portion of the Richard B. Russell Dam performed by the Waterways Experiment Station for the Savannah District.[2,3] The maximum credible earthquake for this structure was specified as a scaled set of recorded time histories and as a smoothed elastic response spectrum. Maximum stresses in the nonoverflow monoliths were computed from the scaled time histories and from a synthetic time history consistent with the smoothed response spectrum using a two-dimensional linear elastic finite element analysis that modeled the interaction between structure and reservoir. Values for these stresses were also computed from the smoothed response spectrum using the first mode of a one-dimensional linear elastic analysis and approximately including the effects of structure-reservoir interaction. The safety of the design was judged by comparing the results of a similar analysis of the Koyna Dam to the performance of this structure in the 1967 earthquake. Maximum stresses in the intake and overflow monoliths were computed from the smoothed response spectrum using three-dimensional, linear, elastic finite element analyses in which the inertial effects of hydrodynamic interaction were approximated. The safety of these monoliths was judged by considering the influence of foundation flexibility on base stresses and the presence of reinforcing steel in areas highly stressed by operational loading conditions.

REFERENCES

[1] U. S. Army Corps of Engineers. 1977. "Earthquake Design and Analysis for Corps of Engineers Dams," Engineer Regulation No. 1110-2-1806, Office, Chief of Engineers, Washington, D. C.

[2] Norman, C. D. and Stone, H. E. 1979. "Earthquake Analysis of the Gravity Monoliths of the Richard B. Russell Dam," Technical Report No. SL-79-8, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, MS.

[3] Norman, C. D. 1979. "Earthquake Analysis of the Modified Geometry of the Concrete Nonoverflow Section Richard B. Russell Dam," Technical Report No. SL-79-14, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, MS.

APPENDIX 5

RESEARCH AND DEVELOPMENT AT THE TENNESSEE VALLEY AUTHORITY RELATED TO EARTHQUAKE ANALYSIS OF DAM SAFETY

TVA Research and Development Related to Earthquake Analysis for Evaluating Dam Safety

Samuel D. Stone
Principal Civil Engineer

INTRODUCTION

TVA has responsibility for the operation, maintenance, and safety of 47 existing dams. These dams are quite variable in type, size, age, and function. TVA has dams on the main river with navigation and power generating facilities; multi-purpose dams for flood control, recreation, and power generation; a dam for pumped-storage power generation; and detention (dry) dams. Roughly half of the dams are concrete and half are earth and/or rockfill. The concrete dams are gravity dams, and many of them have flanks of earthfill. TVA does not have any concrete arch dams. The dams made of earth material consist of compacted earthfills, hydraulic fills, dumped rockfills, compacted rockfills, and rock-filled timber crib. The dams vary in age from 1911 to Tellico Dam which was closed last December (1979). Six dams were acquired from previous owners. These purchased dams were constructed around 1911 to 1913 and 1930 and are older than TVA which was created in 1933. The first two TVA dams, Norris and Wheeler, were designed by the Bureau of Reclamation. Most of the dams were designed and constructed by TVA using state-of-the-art techniques that were accepted by the profession at the time. Relative to earthquakes, most of the earlier dams had no earthquake analyses during design except Norris, Kentucky, Pickwick, and Wheeler. Later, pseudo-static earthquake analyses were routinely investigated during design.

TVA has not engaged in "pure" research and development in its dam safety program. Research and development endeavors have been project oriented to relate to specific needs identified during an evaluation.

DAM SAFETY EVALUATIONS RELATED TO NUCLEAR POWER PLANT PROGRAM

During the mid to late 1970's TVA evaluated three of its existing dams as a result of its nuclear power plant construction program.

The most sophisticated investigation was at Watauga Dam which is a 318-foot-high dumped rockfill dam with a compacted central core of earth. Standard penetration test and undisturbed sample borings were made. In-situ geophysical measurements were made from the bore holes. Laboratory static and cyclic triaxial shear tests were conducted. Woodward-Clyde Consultants performed a nonlinear dynamic finite element analysis of the dam. This analysis was of the type used on the San Fernando dams. In addition, TVA obtained the opinion of Dr. H. Bolton Seed on the earthquake stability of this dam.

Chatuge and Nottely Dams were evaluated for seismic stability by Dr. A. J. Hendron of the University of Illinois. Standard penetration test and undisturbed sample borings were made at both sites. Piezometers were intalled at Nottely Dam. Static and cyclic triaxial shear tests were made on the undisturbed samples. The cyclic tests were not entirely conventional. Consolidated-undrained test specimens were strained to 62 to 68 percent of their static strength, then given 10 loading cycles that were 15 percent of the static strength, and then strained to failure statically. Dr. Hendron made a dynamic analysis to evaluate each dam using the Newmark Displacement Analysis.

DAM SAFETY REVIEW

Like other Federal agencies responsible for dam safety, TVA has instituted a dam safety evaluation during the past couple years. TVA has had a strong inspection and maintenance program in operation for many years.

I will only discuss the areas of the dam safety evaluation that are of interest to this group--the seismic and structural evaluation. I will not discuss TVA's hydrologic evaluation, emergency preparedness plans, security, etc., that are a part of the overall evaluation.

TVA has used a step-by-step process in its dam safety evaluation. This philosophy permits advancement to a higher and more refined level of study if warranted or termination of an evaluation depending upon individual project needs. This procedure can be summarized as follows:

1. Evaluate existing available data.

2. Obtain additional data where existing data is inadequate, e.g., new borings, additional laboratory tests.

3. Evaluate data using empirical parameters.

4. Initiate simplified and conservative analyses, e.g., pseudo-static or Newmark stability analyses.

5. If above evaluations appear to be unfavorable, do more refined analysis, e.g., energy balance or finite element.

Blue Ridge Dam has been evaluated by TVA in our dam safety review program. This 167-foot-high dam is a semi-hydraulic fill dam built in 1930 and purchased by TVA in 1939. Standard penetration test and undisturbed sample borings were made and piezometers installed in the dam. Liquefaction potential was initially investigated by evaluating the data by the empirical parameters reported by D'Appolonia in 1970 in the ASCE Geotechnical Journal. Laboratory static and cyclic consolidated-undrained triaxial shear tests were subsequently made. The cyclic tests were similar in nature to the type used at Chatuge and Nottely, but the strain pattern and loads were different. A dynamic analysis was made by the use of the Newmark method.

SEISMIC EVALUATION

Seismic studies have been made to determine the maximum creditable earthquake (MCE) at each dam site. Three seismo-tectonic provinces have been defined in the TVA area. These are the East Tennessee (Southern Appalachian), the mid-Tennessee (Central Stable Region), and the West (New Madrid Faulted Zone). Two techniques were used to determine the MCE. On one method, it was assumed that the maximum historical earthquake within the province could occur at the dam site. The second approach considered the largest historical earthquake that had occurred outside the province. This earthquake was assumed to occur on the province boundary at the nearest point to the site, and the earthquake was attenuated to the dam site. The theoretical maximum-ground acceleration for the MCE was found to be 0.15g for all dam sites except the Beech River dams which were 0.20g and Kentucky Dam which was 0.35g. Subsequently, a comparison was made of the acceleration for the MCE with the acceleration which the dam was originally designed.

STRUCTURAL EVALUATION OF EARTH AND ROCKFILL DAMS

This evaluation consisted of studying reports, photos, as-built drawings, lab test data, construction records, performance histories, etc. This evaluation was oriented toward discovering any deficiencies or questionable items related to construction methods, foundation materials, embankment materials, embankment zonation, design, etc. Projects were placed in a "high, moderate, low, or none" priority category for future recommended action. As a result of these studies, TVA has made some new borings, conducted lab testing and made limited analytical studies. More work is planned in the near future.

STRUCTURAL EVALUATION OF CONCRETE DAMS

TVA has done some simplified dynamic analyses to determine the amplification throughout the dam of horizontal and vertical accelerations at the bedrock surface. Dynamic forces are obtained using a lump mass stick model. These dynamic forces are then applied as equivalent static forces in overturning and sliding analyses. If overturning appears to be a problem with this simplified analysis, an energy balance study is made. This analysis involves the determination of the energy required to raise and move the center of mass of the structure to reach an overturning position. The maximum kinetic energy of the structure as it rocks due to the combined effect of the earthquake ground motion and structural response is determined. A factor of safety against overturning can be obtained from the ratio of energy required to overturn the structure to maximum kinetic energy.

RESULTS OF DAM SAFETY EVALUATION

As a result of the seismic, hydrologic, and structural evaluations made to date, the following has been revealed:

1. Some hydrologic concerns relative to spillway capacities.

2. Some concerns about Kentucky Dam mainly due to its location relative to the New Madrid area and some sand in part of its foundation.

3. Some concerns relative to TVA's two hydraulic fill dams and a few others with sands in their foundation.

In general, TVA feels good about the safety aspects of its dams. TVA has developed a tentative schedule for further studies and evaluation on a priority sequence relative to the magnitude of our concerns.

OTHER DAM SAFETY IMPROVEMENTS AT TVA

At this time, TVA has no plans to upgrade any of its dams due to seismic considerations. TVA has recently upgraded some dams, is currently upgrading a dam, and has future plans to upgrade dams for structural or hydrologic reasons. All upgradings to date and those presently planned are on old dams purchased by TVA. TVA plans to study other dams designed and built by the agency to determine if upgrading is required.

Mass concrete was added to the spillway, intake blocks, and nonoverflow blocks at Nolichucky Dam in 1972-73 to improve its stability.

The structural stability of Ocoee No. 1 was upgraded in 1973-75. The non-overflow and intake blocks were posttensioned with tendons into bedrock, and additional face concrete was added to these blocks for aesthetic reasons. Mass concrete was added to the spillway blocks.

At this time roller compacted concrete is being added to the downstream face of Ocoee No. 2 Dam to improve its stability. This 67 year old low hazard structure is a rock-filled timber crib dam.

Plans are being finalized to add three new spillway bays at Blue Ridge Dam. This will upgrade the dam to handle the maximum probable flood. This addition is awaiting approval of the TVA Board of Directors.

APPENDIX 6

RESEARCH AND DEVELOPMENT AT THE WATER AND POWER RESOURCE SERVICE RELATED TO EARTHQUAKE ANALYSIS OF DAM SAFETY

Research and Development Related to
Earthquake Analysis for Evaluating
Dam Safety

Water and Power Resources Service
Larry Von Thun
September 19, 1980

I. Definition of Seismic Loads

A. Contracting to a greater degree for selection of earthquake magnitudes and location affecting site. Requiring MCE and recurrence data for each source. Asking for MCE recurrence. Encouraging contractors to develop rationale other than magnitude to rupture length = 1/2 fault length relation.

B. Ground motions retained in house. Developing standard base procedure based on scaling normalized near field spectra according to spectral intensity. Modification of standard spectra would be made for specific site or source conditions.

C. Recurrence interval or probability level being used is still 100,000 year or 1 x 10^{-5}. Looking toward balanced risk approach decision in 1 year. Still awaiting joint decision among Federal agencies on active fault criteria.

II. Analysis of Earth Dams - Rockfill Dams

A. Developing criteria and procedures to avoid hydraulic fracturing during sampling.

B. Improvement of soil testing techniques. (Discussed in research statement.)

C. Shear wave velocity measurements improvement. (Discussed in research statement.)

D. Use of both rotational shear and repeated direct shear to obtain residual strengths.

E . Strong motion instrumentation. (Discussed in research statement.)

F. Development of computer program for displacement calculation using time history of motion and Newmark type displacement calculations. Incorporate effects of time history of pore pressure change, strength change, hydrodynamic effects, vertical acceleration, and momentum.

G. Model in laboratory to verify above analytical technique.

H. Laboratory model to examine fault displacement response of filter materials.

III. Analysis of Concrete Dams

A. Fault displacement analysis using analytical tools of dam-foundation interaction.

B. Behavior of dams following tectonic fault displacement. (Discussed in research statement.)

C. Hydrodynamic interaction. (Discussed in research statement.)

D. Dynamic properties of concrete. (Discussed in research statement.)

E. Dynamic performance of a jointed rock mass strength and deformational response. (Proposal stage)

F. Improved instrumentation to obtain dynamic response. (Need)

G. Effect of traveling waves on dynamic performance. (Need)

APPENDIX 7

QUESTIONNAIRE: ASSESSMENT OF CURRENT PRACTICES AND RESEARCH NEEDS FOR DYNAMIC EARTH PRESSURES ON RETAINING STRUCTURES, FROM PAUL F. HADALA, U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
P. O BOX 631
VICKSBURG, MISSISSIPPI 39180

IN REPLY REFER TO WESGA

8 March 1981

Mr. Frank [illegible], Tennessee Valley Authority, Knoxville, TN 37902
Mr. [illegible], Bonneville Power Administration, Portland, OR [illegible]
Mr. Karl [illegible], Water Power Resources Service, Denver, CO [illegible]

Gentlemen:

At the September 1980 meeting, the Earthquake Engineering Working Group established by the Steering Committee of the Interagency Research Coordination Conference requested you gentlemen and me to serve as points of contact for coordination on the subject of seismic loadings on retaining walls. Because the Corps of Engineers is revising EM 1110-2-2502, "Retaining Walls" (May 1961), at this time and would like to include the best available guidance on seismic design of earth retaining structures, I would like to solicit your assistance on a quid-pro-quo basis.

I have formulated several questions and provided answers to these same questions based on the present status of the subject area as I know it. I request that each of you answer the same questions and furnish copies of your answers to the other three members. This will accomplish my personal objective and will certainly satisfy the request of the working group for coordination in the area.

The questions are as follows:

(a) Does your agency have any published guidance documents that deal with seismic loadings on retaining walls? In addition to the backfill induced loadings for the level surface case, is there any guidance for seismic loadings on the "passive" side and in backfill induced seismic loads in the [illegible] of sloping or surcharged backfills? Please furnish [illegible].

(b) [illegible] safety factors for [illegible], sliding, and [illegible] which your agency uses for the seismic loading [illegible] compare with those [illegible] static [illegible]?

[illegible]

WESGA
Mr. Frank Hand
Mr. Robert Bourn
Mr. Karl Dreher

8 March 1981

(d) Is new guidance currently under development? When is it presently scheduled to be released?

(e) Are you presently conducting any research, analysis, or testing in the subject area? If so, please describe and tell when the results will be available.

(f) Are you aware of any references on the subject in addition to those in Incl 1? If so, please furnish title, author, date, and source for each.

(g) How are groundwater-induced loadings treated when a portion of the backfill is below the groundwater table? Is the pore water assumed to move with the soil and the mass of the moving wedge increased to account for the presence of the water? Is the pore-water pressure calculated separately? If it is, is there any inertially-induced component in this pressure and how is it calculated? What distribution, with elevation, is used for inertial groundwater loadings?

(h) Has any consideration been given by your agency to the adoption of (1) "allowable rigid body movement" and "allowable rigid body tilt" criteria and (2) seismic-design procedures for retaining walls, which would involve the calculation of such movements in some manner analogous to the sliding block model proposed by Newmark in his 1965 Rankine Lecture?

(i) Does your agency have any published guidance documents that deal with the structural design of retaining walls for seismic loadings? If so, please provide references.

(j) Does your agency use any special design details in the reinforcing steel, the construction, contraction or expansion joints, the backfill drains, or toe drains for walls which are in areas of high seismic risk?

(k) How do allowable stresses for the concrete and reinforcing steel used in the seismic loading case compare with those used for the static-loading cases?

(l) How are inertial water loads calculated for those walls where the wall actually functions to retain impounded water as in the case of a floodwall or a wing wall for an intake structure or pumping plant?

Questions (i), (j), (k), and (l) are not really within the province of our charter. Mr. Lucian Guthrie of the Structures Branch in OCE suggested they be included in order to save time in collecting information needed for other purposes.

[illegible]

8 March 1981

Mr. Frank Hand
Mr. Robert Bourn
Mr. Karl Dreher

My answers to all of the above questions except (f) are contained in Incl 2. Inclosure 1 is my response to question (f). Your response to this letter by 31 March 1981 would be greatly appreciated. If you wish clarification of any of my questions, please call me at FTS 542-3475 or commercial number 601/634-3475.

Sincerely,

PAUL F. HADALA
Assistant Chief
Geotechnical Laboratory

2 Incl
As stated

CF w/incl:
HQDA (DAEN-CWE-SS/Ralph Beene)
HQDA (DAEN-CWE-DS/Lucian Guthrie)
Dist. Engr. (SWFED-F-T/Scott Gleason)
Div. Engr. (LMVED-TS/Victor Agostinelli)
Dr. W. F. Marcuson, WES
Dr. P. F. Mlaker, WES
Div. Engr. (SPDED-G/Mr. F. G. McLean)

27 February 1981

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ANSWERS TO QUESTIONS POSED IN MY MULTIPLE
ADDRESS LETTER OF 2 MARCH

(a) Does your agency have any published guidance documents that deal with seismic loads on retaining walls? In addition to the backfill-induced loading for the level surface case, is there any guidance for seismic loadings on the "passive" side and in backfill-induced seismic loads for the cases of sloping or surcharged backfills? Please furnish copies or references.

Paragraph 5 of EM 1110-2-2502, "Retaining Walls," dated 29 May 1961, is our only published guidance on the subject. The entire paragraph is reproduced in Incl 1. It gives no guidance concerning the items mentioned in the second sentence of question (a) except for the last sentence in Incl 1.

ER 1110-2-1806, "Earthquake Design and Analysis For Corps of Engineers Dams," (incl 2) makes no specific mention of retaining walls of any type. If the wall were an appurtenant structure whose loss would somehow cause the loss of the reservoir, this regulation would also apply. While the regulation provides guidance on the choice of parameters to describe the earthquake, no analysis or design procedures applicable to reinforced concrete walls are mentioned.

Department of the Army TM 5-809-10, "Seismic Design for Buildings," gives no guidance on seismically-induced earth-pressure loadings on the exterior basement walls of buildings.

(b) How do safety factors for overturning sliding and foundation-bearing pressure, which your agency uses for the seismic loading case, compare with those used for static loads?

EM 1110-2-2502 does not differentiate between the two cases with respect to the above-mentioned safety factors.

(c) What distribution, with elevation, of earth-pressure loading or what point of application of concentrated force is used for inertial loadings from backfill soils?

Paragraph 5 of EM 1110-2-2502 suggests the use of an inertial force on the wall at a distance above the base of 2/3 of the height of the wall.

(d) Is new guidance presently under development? When is it presently scheduled to be released?

As mentioned in the basic letter, EM 1110-2-2502 is currently under revision. A firm date for the release of the revision is currently unavailable.

(e) Are you presently conducting any research, analysis, or testing in the subject area? Please describe it and tell when the results will be available.

No research, testing, or analysis is in progress. Mission Problem No. 11-033-9, "Earthquake Loadings on High Retaining Walls," (Incl 3) was submitted for rating by the Corps of Engineers field-operating agencies in December 1980. It was ranked 281 out of 470. Because the ranking is below the median, it is unlikely that any financial support for research in this area will be forthcoming in the near future.

The LMVD Computer Aided Structural Engineering (CASE) Committee has had a subcommittee at work on a computer program for the design of T-walls. This program includes a provision for calculation of seismic loadings via the Mononobe-Okabe method as suggested in the May 1961 edition of EM 1110-2-2502. The question concerning the treatment of pore-water loadings during earthquake excitation raised in the basic letter arose during the preparation and review of this program and its draft documentation.

(f) Are you aware of any reference on the subject in addition to those in Incl 1?

No.

(g) How are groundwater-induced loadings treated when a portion of the backfill is below the groundwater table? Is the pore water assumed to move with the soil and the mass of the moving wedge increased to account for the presence of the water? Is the pore-water pressure calculated separately? If it is, is there any inertially-induced component in this pressure and how is it calculated? What distribution, with elevation, is used for inertial groundwater loadings?

EM 1110-2-2502 gives no guidance on this question. References 5, 11, and 20 in Incl 1 to the basic letter give conflicting advice on the subject. There appear to be no data from shaking tests on walls where water pressures were measured. All the laboratory tests have been performed using dry sand.

Surveys of field performance of walls in earthquakes indicate that many more seismically-induced failures have occurred in walls used as waterfront structures than in walls which had unsaturated backfills or foundations. See for example References 2, 6, and 31 of Incl 1 to the basic letter which, when considered together, illustrate this point. Whether the failures of the waterfront structures are due to loss of bearing capacity (i.e., liquefaction) or excess loading on the wall cannot be determined from the information available.

(h) Has consideration been given by your agency to the adoption of (1) "allowable rigid body movement" and "allowable rigid body tilt" criteria and (2) seismic design procedures for retaining walls which involve the calculation of such movements in some manner analogous to the sliding block model prepared by Newmark in his 1965 Rankine Lecture?

No. We are aware of Reference 29 of Incl 1 to the basic letter which proposes such a method and of the fact that the National Science Foundation has given Professor Whitman at MIT a grant for additional research in this area.

(i) Does your agency have any published guidance documents that deal with the structural design of retaining walls for seismic loadings?

Yes. EM 1110-2-2502, Paragraph 5b and 9 provides such guidance.

(j) Does your agency use any special design details in the reinforcing steel, the construction, contraction or expansion of joints, the backfill drains, or toe drains for walls which are in areas of high seismic risk?

No.

(k) How do allowable stresses for concrete and reinforcing steel used in the seismic loading case compare with those used for the static loading case?

See Paragraph 5b of the current edition of EM 1110-2-2502, which says that, "increased working stresses are permissible," and refers the reader to EM 1110-1-2101 for details. Paragraph 4 of that manual permits a 33 percent increase.

(l) How are inertial water loads calculated for those walls where the wall actually functions to retain impounded water as in the case of a floodwall, or wingwall for an intake or pumping plant?

The procedure to be used is specified in EM 1110-2-2502 and is given in EM 1110-2-2200, "Gravity Dam Design." The procedure is based on Westergaard's Method. See also Reference 26 of Incl 1 to the basic letter.

SUPPLEMENTAL LOADS. A retaining wall may be required to resist other loads, alone, or ...bination with the lateral earth pressures produced by the backfill and surcharge loadings.

a Wind Loads. When walls are constructed in an exposed location, wind loads may be a factor ... construction and prior to backfilling. Where such a condition exists, a horizontal loading of ... should be applied.

b Earthquake Loads. When a wall performing an important function is to be built in an area of ...ismic activity, earthquake forces should be provided for in the design. Such forces are a Group II ... for which increased working stresses are permissible (EM 1110 1-2101, Working Stresses for ...ural Design). "Uniform Building Code" of International Conference of Building Officials (Los ...geles, Calif.) contains a United States map outlining seismic damage zones. Earthquake accelera-

tions of .05g and .10g should be used in Zones 2 and 3, respectively. Seismic forces acting on a wa... are as follows:

(1) The inertia force of the wall mass is applied at the center of gravity.

(2) Dynamic water loads are determined by Westergaard's parabola. (EM 1110 2-220..., Gravity Dam Design.) The structure is designed for simultaneous increases and decreases on opposit... sides of the wall when such can occur.

(3) Although there is uncertainty concerning behavior of backfill during earthquakes, th... *dynamic earth pressure* magnitude can be approximated by the method of Mononobe and Okabe in Japan (Summarized in "Bearing Capacity of Sandy Soil and Lateral Earth Pressure During Earth... quakes", by Shunzo Okamoto, Proceedings of World Conference on Earthquake Engineering, Berkele... Calif., 1956). In this method, the horizontal earthquake acceleration is combined with gravity actin... on the Coulomb sliding wedge in either positive or negative direction to produce the resultant earth pressure on the wall. Experiments by Matsuo in Japan gave fair agreement with the total magnitude of the resultant force, but gave an entirely different pressure distribution. (See P. 32 1, "Aseismic Design of Quay Walls in Japan," by Amano et al., Proceedings of World Conference on Earthquak... Engineering, Berkeley, Calif., 1956.) Professor Jacobsen's shaking-table experiments at Stanford University (made for TVA Kentucky Project) also verified the magnitude of the total dynamic for... determined by the Mononobe-Okabe method (within the earthquake acceleration range applicable i... the U.S.), and found that this component acts at about two-thirds the fill height above the base. Th... value of the dynamic effect is affected somewhat by the type of backfill. With a typical backfill materi... the dynamic earth pressure increase for an acceleration of 0.05g is approximately 10% of the static pressu... and for 0.10g acceleration, it is about 20%. Decreases for negative accelerations are slightly but n... significantly less. A vertical wall face is assumed in this method. When a wall has a setback or slop... face, the portion of backfill between the wall and a vertical plane through the heel can be assumed t... exert an inertia force added to that of the wall mass.

DEPARTMENT OF THE ARMY
DAEN-CWE-D Office of the Chief of Engineers ER 1110-2-1806
DAEN-CWE-S Washington, D. C. 20314

Regulation
No. 1110-2-1806 30 April 1977

Engineering and Design
EARTHQUAKE DESIGN AND ANALYSIS FOR
CORPS OF ENGINEERS DAMS

1. Purpose. The purposes of this ER are to discuss seismic design concepts and to provide general guidance and direction for (a) the seismic design of new dam structures and (b) the initiation of a program to evaluate the seismic stability of existing dams.

2. Applicability. This regulation is applicable to all Divisions and Districts having Civil Works responsibilities.

3. References. Selected references are listed in Table 1, Appendix A.

4. Policy. Designs for seismic stability of new dams and seismic stability investigations of existing dams should be in accord with these instructions. Departures may be proposed where there are, in the judgment of the District Engineer, justifying circumstances.

5. General.

a. Technology in earthquake engineering is changing rapidly. Procedures for selecting design earthquakes and dynamic response techniques are now available to help in assessing the resistance of dams and appurtenant structures to earthquakes. Such techniques and procedures involve an evaluation of the effects on structures of estimated earthquake ground motions, and range from simplified concepts to comprehensive dynamic analyses of the finite element type. Although Corps of Engineers designs will continue to employ the seismic coefficient method of analysis, a supplemental dynamic response investigation, representative of the "state-of-the-art", should be performed for critical structures in locations of strong seismicity.

b. Regardless of the method of analysis, the final evaluation of the seismic safety of the structure should be based on all pertinent factors involved in the investigation, and not just on the numerical results of the analysis. Factors that should be considered in the final evaluation include reliability of input data to the analysis (seismicity, foundation conditions, material behavior) as well as other items such as consequences of failure, frequency and duration of pool levels, and site geometry.

This regulation cancels ETL 1110-2-109 dated 21 Oct 70.

c. Investigations and analyses for the earthquake engineering of dams and appurtenant structures are listed in Table 2 of Appendix A. Some of the procedures involved in these activities are still in a developmental stage, and are not considered as routine at this time.

6. Definitions.

a. Types of Earthquake Analyses.

(1) Seismic Coefficient Method. Using this procedure a seismic coefficient, which represents the ratio of an assumed acceleration of structure to the acceleration of gravity, is multiplied by the weight of the structure or element thereof to obtain the horizontal inertial force. The forces resulting from the reaction of reservoir water on vertical or near-vertical surfaces of the structure are usually determined by the Westergaard formula (Reference 8) using the selected seismic coefficient. The derived inertial and hydrodynamic forces are incorporated into a static analysis as described in References 6 and 8.

(2) Dynamic Methods. Dynamic response analyses are based upon the structure's dynamic characteristics and the expected ground motions for the particular location and employ one or more of the following methods:

(a) Response Spectrum Method. This method is used to estimate the maximum dynamic response of concrete dams and appurtenant structures due to a design earthquake. The design response spectrum must be known for systems with natural frequencies similar to the natural frequencies of the structure being investigated. Ground motion values for determining design response spectra curves are derived from geological and seismological studies. These parameters, when properly modified to account for the dynamic characteristics of the structure, define the maximum dynamic response of an equivalent system. This method provides the magnitudes and distribution of the seismically induced forces on the structure. The dynamic stresses are computed by an equivalent static stress analysis and then are compared with the dynamic material strengths to evaluate seismic stability. Inputs to this method of dynamic analysis include natural frequencies, mode shapes and damping of the structure. The structure can be modeled as a one-, two-, or three dimensional system.

(b) Time History Method. This method is used to analyze the dynamic response with respect to time of concrete and embankment dams and appurtenant structures. A time history of rock motion from a design earthquake and the geometric and dynamic properties of the structure and/or foundation are the inputs to a computer aided analysis, usually using a finite element method of solution. However, closed solutions are available for one-dimensional analyses. The output includes stress distribution and magnitudes of motions in the structure and/or foundation as functions of time. These results are then compared with the dynamic strengths and corresponding deformations to evaluate seismic stability. The structure and/or foundation can be modeled as a one-, two-, or three-dimensional system.

(c) Newmark Method. The Newmark method is used to estimate deformations which might be seismically-induced in an embankment dam. The acceleration required to overcome the dynamic resistance of the trial sliding portion of an embankment is determined from slope stability analyses and dynamic shear strengths. This yield acceleration is used in the equations of motion for the sliding mass to compute permanent displacements. The computed displacements are then compared with the allowable displacements to determine the adequacy of the structure. This method is based on the assumption that the whole moving mass is a single rigid body with resistance mobilized along the sliding surface.

(3) Dynamic Method References. Table 2 of Appendix A lists reference numbers under "remarks" for the methods of dynamic analysis described above.

b. Design Earthquakes. Design earthquakes define the ground motion at the site of the structure and form the bases for dynamic response analyses. Usually, several design earthquakes for both the maximum earthquake and the operating basis earthquake, as applicable, are investigated.

(1) Maximum Earthquake. The maximum earthquake is defined as the severest earthquake that is believed to be possible at the site on the basis of geological and seismological evidence. It is determined by regional and local studies which include a complete review of all historic earthquake data of events sufficiently nearby to influence the project, all faults in the area, and attenuations between causative faults and the site.

(2) Operating Basis Earthquake. The "operational" earthquake is generally more moderate than the maximum earthquake and is selected on a probabilistic basis from regional and local geology and seismology studies as being likely to occur during the life of the project. It is generally as large as earthquakes that have occurred in the seismotectonic province in which the site is located.

c. Capable Fault. A capable fault is one that is considered to have the potential for generating an earthquake. It is defined as a fault that can be shown to exhibit one or more of the following characteristics:

(1) Movement at or near the ground surface at least once within the past 35,000 years.

(2) Macro-seismicity (3.5 magnitude or greater) instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault.

(3) A structural relationship to a capable fault such that movement on one fault could be reasonably expected to cause movement on the other.

d. Design Response Spectra. A design response spectrum is a plot of the maximum values of acceleration, velocity, and/or displacement experienced by a family of single-degree-of-freedom systems subjected to a time history of the design earthquake ground motion. Maximum values of the parameters are expressed as a function of the natural periods and damping of the structure. The response of a multi-degree-of-freedom structure can be estimated by taking the square root of the sum of the squares of the single-degree-of-freedom responses.

e. Liquefaction. Liquefaction is the sudden large decrease of the shearing resistance of a cohesionless soil. It is caused by the collapse of the soil structure due to strain and is associated with a temporary increase of the pore water pressure. It involves a temporary transformation of the material into a fluid mass.

7. Guidance for New Designs.

a. Analyses and Procedures.

(1) Analyses by the seismic coefficient method will continue to be used for all new designs utilizing seismic coefficients at least as large as shown on the attached Figures 1 through 4 of Appendix B. In case of a location close to a boundary line, the higher seismic coefficient should be considered. For seismic zones for areas not shown on the figures in Appendix B, see the seismic zone tabulation in Section 1 of Reference 20.

(2) In addition to a seismic coefficient analysis, the seismic design of all major dams in Seismic Zone 4, and in Zone 3 where foundation liquefaction potential exists, should include dynamic methods.

This would involve a geological and seismological evaluation to establish the design earthquake(s) and a dynamic analysis of the dam. For all other major dams in Seismic Zones 0 through 3, a geological and seismological review should be conducted to locate faults and ascertain the seismic history of the region around the dam. Where capable faults or recent earthquake epicenters are discovered within a distance to the dam where an earthquake could cause structural damage, a dynamic analysis should be performed. For these instructions a dam is considered to be a major one if its failure would endanger lives or vital installations.

(3) To determine if a foundation liquefaction potential exists, the in-situ void ratio should be determined. The steady-state or critical void-ratio should also be determined for several confining pressures by R tests on undisturbed samples with dead load increments as described in Reference 5. A comparison of these values will indicate whether the soil in-situ is dilative or contractive (liquefiable) under existing and anticipated loads. A piezometer probe (Reference 15) may be used in saturated sands and silts to determine if the soil is dilative or contractive in-situ under the existing pressures.

(4) In the immediate vicinity of capable faults, defensive design against both physical dislocation of the structure and against strong vibrational energy should be employed.

b. Defensive Design Measures.

(1) Embankments. Defensive design features for embankment structures should be used regardless of the method of seismic analysis. Defensive design features may include: (a) ample freeboard to allow for the loss of crest elevation due to subsidence, slumping or fault displacement; (b) wide transition sections of filter materials which are least vulnerable to cracking; (c) vertical or near-vertical drainage zones in the central portion of the embankment; (d) filter materials of rounded to subrounded gravels and sands; (e) increased hydraulic conductivity of filter layers and vertical drainage zones or the inclusion of additional properly designed filter zones of higher conductivity; (f) wide impervious cores of plastic clay materials or of suitable well graded materials to help insure self-healing in the event cracking should occur; (g) stabilization of reservoir rim slopes to provide for dam safety against effects caused by slides into the reservoir; (h) [illegible] details that will minimize erosion in the event of overtopping; (i) removal of foundation material that may be adversely affected by ground motion; (j) flaring embankment sections at abutment contacts; and (k) zoning of embankments to minimize saturation of materials. In some cases stockpiling of filter material may be desirable for use in emergency repairs.

(2) Concrete Structures. Defensive design features for concrete structures include provisions for increasing strength and ductility. The possible occurrence of high dynamic tensile stresses in the upper portion of gravity dams indicates that the past practice of using lower strength concrete in the upper portions of high gravity structures should be discontinued. Also, the break in slope on the downstream face of gravity dams should be gradual or eliminated to avoid undesirable stress concentrations. Reinforced elements subjected to high dynamic compressive stresses, such as the lower portion of intake towers, should be detailed to provide confinement of the concrete and prevent buckling of the principal reinforcement. Mass at the crest or near the top of structures should be held to a minimum, consistent with design requirements. In locations of high seismicity, where project requirements permit, controls for cut-and-cover conduit outlets should be housed in a hemispherical gate structure buried beneath the embankment in lieu of in a tower. Embedment of outlet conduits in bedrock when feasible will improve seismic stability. For outlet tunnels, control shafts in abutment bedrock are preferable to tall, free-standing intake control towers in areas of high seismicity.

8. Investigative Program for Existing Dams. The following investigations should be accomplished at all existing dam projects, including projects under construction, where failure would endanger lives or vital installations:

a. A seismic stability investigation of existing dams in Seismic Zone 4 by dynamic methods.

b. Where appropriate, and in addition to Seismic Zone 4 projects, a liquefaction potential determination for all existing dams in Seismic Zone 3. See paragraph 7a(3).

c. A geological and seismological review of existing dam projects in Seismic Zones 2 and 3, to locate faults and ascertain the seismic history of the region around the dam and reservoir.

d. A seismic stability investigation of existing dams by dynamic methods regardless of the seismic zone in which the dam is located where capable faults or recent earthquake epicenters are discovered within a distance where an earthquake could cause structural damage.

9. Criteria.

a. Seismic Coefficient Method of Analysis. The results of seismic stability analyses by the seismic coefficient method shall continue to meet requirements outlined in References 6, 8, 12 and 13.

b. Dynamic Analyses.

(1) Embankment Dams. Embankments should be capable of retaining the reservoir under conditions induced by the maximum earthquake. Deformation is acceptable provided such deformation would not result in failure leading to loss of life or excessive downstream property loss.

(2) Concrete Dams. The seismic design for concrete dams and appurtenant structures should be based on the "operational" earthquake. The structure should resist this loading essentially within the elastic range, remain operational and not require extensive repair work. Mechanical and control systems should remain functional through an "operational" earthquake. (The elastic response spectrum provides a convenient and economical method for deriving earthquake forces for this condition). In addition, concrete structures should be capable of surviving a maximum earthquake without a failure of a type that would result in loss of life or significant damage to downstream property. Inelastic behavior with associated damage is permissible under the maximum earthquake.

10. Action.

a. New Designs. New designs for seismic stability will be based on this regulation and should be reported in the appropriate design memoranda.

b. Program for Existing Dams.

(1) Each Division shall submit for approval a recommended schedule for accomplishing the investigations required in paragraph 8 of this regulation within a four-year period. This schedule should include the scope of the investigation recommended for each dam. For completeness, the schedule should also include projects where a seismic investigation is complete or in progress. Projects for which exclusion from the requirements of this regulation is desired should be identified and supporting reasons furnished. Priority should be given to embankment dams having cohesionless foundation strata whose densities were not evaluated during design and to concrete gravity dams on soil, shale, and sandstone foundations, or on any foundation with questionable sliding stability. The schedule should be submitted to HQDA (DAEN-CWE) WASH DC 20314 within six months from the date of this regulation. Before submission the schedule must be coordinated fully with appropriate elements to determine the adequacy of available funds to support the proposed schedule. (RCS DAEN-CWE(OT)1063).

(2) For each seismic investigation conducted, a report will be prepared for permanent record and reference purposes. The report will contain a descripion of the dam project and the seismic investigation made, the results of the investigation, and, where a dynamic analysis is performed, the evaluation of the seismic stability and recommendations and cost estimates for remedial work where appropriate.

(3) The reports shall be submitted to the Division Engineer for review. The reports may be approved by the Division Engineer except for the following situations in which case the reports shall be submitted to HQDA (DAEN-CWE-BB) WASH DC 20314 for review and approval:

(a) Those reports prepared in Division offices.

(b) Those reports of investigations and subsequent evaluations which indicate that the seismic stability is questionable.

(c) Those reports of investigations and subsequent evaluations which recommend remedial work.

One information copy of each report approved by Division Engineers will be furnished DAEN-CWE-BB, including submittal and approval correspondence. (Exempt report paragraph 7-2t, AR 335-15).

(4) One copy of each approved report will be furnished by the originating District or Division directly to the Waterways Experiment Station, ATTN: Technical Information Center (WESTV), P. O. Box 631, Vicksburg, Mississippi 39180. Each report furnished to the center will contain a copy of all correspondence pertaining to its submission, review, and approval, bound under the front cover. The reports will be used as sources of data to help integrate ongoing seismic research with current design practice and will be available for loan to other Corps of Engineers installations. The center will announce periodically the reports available for loan. (Exempt report paragraph 7-2t, AR 335-15).

11. Funding. Normal construction and/or operations and maintenance programming and funding should recognize the requirements of this regulation and provide for accomplishment of the needed investigations within the time indicated. To assure that the requirements of this program are funded, it is essential that the scheduled operations be fully coordinated with the appropriate elements and are fully justified in the budget submissions.

FOR THE CHIEF OF ENGINEERS:

2 Appendixes
APP A - Tables 1 and 2
APP B - Figures 1 thru 4

RUSSELL J. LAMP
Colonel, Corps of Engineers
Executive

APPENDIX A

Table 1

REFERENCES

Reference No.	Description
1	Ambraseys, N. N. and Sarma, S. K., "The Response of Earth Dams to Strong Earthquakes," Geotechnique, Vol XIVV, 1967 (Source A).*
2	Krinitzsky, Ellis L., Misc. Paper S-73-1, Report 2, "Fault Assessment in Earthquake Engineering," May 1974, WES (Source B).
3	Hofman, R. B., Misc. Paper S-73-1, Report 3, "Factors in the Specification of Ground Motions for Design Earthquakes in California," June 1974, WES (Source B).
4	Newmark, N. M., "Effects of Earthquakes on Dams and Embankments," Geotechnique, Vol XV, 1965 (Source A).
5	Castro, Gonzalo, "Liquefaction of Sands," Harvard Soil Mechanics Series No. 81, January 1969 (Source A).
6	EM 1110-2-1902, Stability of Earth and Rock-Fill Dams
7	EM 1110-2-1907, Soil Sampling Manual
8	EM 1110-2-2200, Gravity Dam Design
9	EM 1110-2-2300, Earth and Rock-Fill Dams General Design and Construction Considerations
10	Chopra, A. K., and Liaw, C-Y, "Earthquake Resistant Design of Intake-Outlet Towers," Journal of the Structural Division, ASCE, Vol. 101 No. ST7, July 1975 (Source C).
11	Krinitzsky, Ellis L. and Chang, Frank K., Paper, MP-S-73-1, Report 4, "Earthquake Intensity and Selection of Ground Motions for Seismic Design," Sep 1975, WES (Source B).
12	EM 1110-2-2400, Structural Design of Spillways and Outlet Works

*For 'sources', see A-3.

Table 1 Cont'd

Reference No.	Description
13	EM 1110-2-2502, Retaining Walls
14	Newmark, N. M. and Hall, W. J., "A Rational Approach to Seismic Design Standards for Structures." Proceedings of the Fifth World Conference on Earthquake Engineering, Rome, Italy, June 1973 (Source A).*
15	Wissa, Anwar E. Z., Martin, R. Torrance, and Garlanger, John E., "The piezometer Probe." Proc. ASCE Conference on Insitu Measurement of Soil Properties, Vol 1, June 1-4, 1975 (Source A).
16	Casagrande, Arthur, "Liquefaction and Cyclic Deformation of Sands-A Critical Review," Presented at the Fifth Pan-American Conference on Soil Mechanics and Foundation Engineering, Buenos Aires, Argentia, November 1975. Also printed as No. 88, Harvard Soil Mechanics Series, July 1976 (Source A).
17	Ballard, R. F., Jr., and McLean, F. G., MP S-75-10, "Seismic Field Methods for In-Situ Moduli, April 1975, WES (Source B).
18	Stockdale, William K., "Modal Analysis Methods in Seismic Design for Buildings", Technical Report M-132, June 1975, CERL, Accession No. AD A012732 (Source D).
19	Chakrabarti, P., and Chopra, Anil K., "Hydrodynamic Effects in Earthquake Response of Gravity Dams", Journal of the Structural Division, ASCE, June 1974 (Source C).
20	TM 5-809-10, Seismic Design for Buildings
21	Idriss, I. M. and Seed, H. B., "Seismic Response of Horizontal Soil Layers", Journal of the Soil Mechanics Division, ASCE, July 1968 (Source A).
22	Schnabel, P. B., Lysmer, J. and Seed, H. Bolton, "SHAKE: A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites", EERC Report 72-12, Dec. 1972 (Source E)

*For 'sources', see A-3.

Table 1 Cont'd

REFERENCE SOURCES

Source A:

Engineering Societies Library
Photo Duplication Department
345 East 47th Street
New York, N.Y. 10017

Source B:

U. S. Army Engr. Waterways Experiment Station
ATTN: WESTS
P. O. Box 631
Vicksburg, MS 39180

Source C:

ASCE Publication Sales
345 East 47th Street
New York, N.Y. 10017

Source D:

National Technical Information Service (NTIS)
P. O. Box 1553
Springfield, VA 22151

Source E:

NISEE/Computer Applications
729 Davis Hall
University of California
Berkeley, CA 94720

Table 2

EARTHQUAKE ENGINEERING ACTIVITIES

ACTIVITIES	REMARKS
1. Geological and Seismological	
a. Fault Detection, Dating and Assessment	a. Required for all projects in seismic and non-seismic areas. Should be emphasized where seismic design is important, especially determinations of fault activity. Assess potential for earthquakes in seismic zones where capable faults cannot be located. See Ref. 2.
b. Design Earthquakes and associated Ground Motion Parameters	b. Required for dynamic analyses. Where capable faults can be identified, relate magnitude to length of fault and determine attenuation of ground motion from fault to site. Resulting design earthquakes will be selected considering all evidence available including tectonic and seismological history as well as fault activity. See Refs. 2, 9 and 11.
c. Time Histories and Spectra	c. For dynamic analyses. Refs. 3, 11, 14 and 18.
2. Foundation Investigation and Testing	
a. Foundation Investigation	a. In-situ and relative densities should be determined. See Ref. 7 for undisturbed sampling in sands. Where dynamic analyses are to be made, make downhole, cross hole and surface geophysical investigations to determine in-situ compression and shear moduli. Ref. 17. Determine critical void ratio by methods given in Ref. 5. Piezometer probe may be used in saturated materials to assess dilative or contractive state in-situ. (Ref. 15).

Table 2 Cont'd

ACTIVITIES	REMARKS
b. Dynamic and Static Testing	b. Required for evaluation of intermediate and large-strain moduli, dynamic stability, liquefaction and permanent deformation of embankments or foundations. Refs. 1, 4, 5 and 16.
3. Analyses for Earthquake Effects	
a. Seismic Coefficient Method	a. Follow procedures now described in appropriate engineering manuals using seismic coefficients of Figures 1 through 4 of Appendix B. Required for all new projects. Refs. 6 and 8.
b. Dynamic Analyses	b. Use to be compatible with instructions of this regulation.
(1) Response Spectrum Method	(1) Use for concrete dams and appurtenant structures. Refs. 4, 10, 14, and 18.
(2) Time History Method	(2) Use for all types of dams and appurtenant structures for special investigations and analyses where circumstances warrant. Refs. 10, 18, 19, 21 and 22.
(3) Newmark Method	(3) Use for embankment dams. Refs. 1 and 4.
c. Mathematical Modeling	
(1) One-Dimensional System	(1) Defined as a system in which the motion of the system at any time can be specified completely by displacements in a single direction. This system can be used to model both a concrete dam when cantilever beam action only is assumed and a

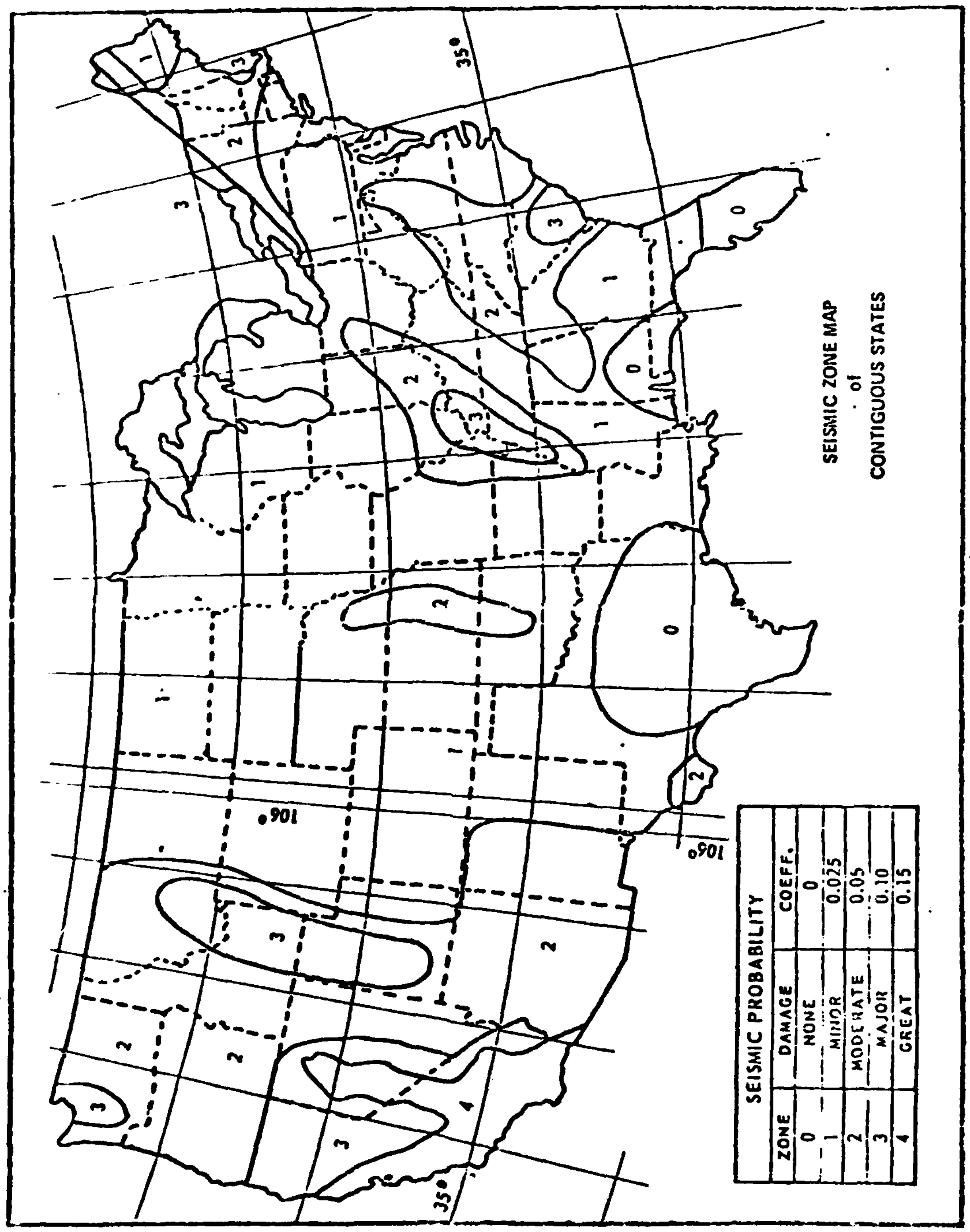
Table 2 Cont'd

ACTIVITIES	REMARKS
	level soil foundation with horizontal layering. The level ground response determined by using a one-dimensional system for a foundation with horizontal layering can be used as a first approximation to the response of the embankment (Refs 21 and 22).
(2) Two- or Three-Dimensional System	(2) Defined as a system in which the motion of the system at any time can be specified completely by displacements in two or three directions for a two-dimensional or three-dimensional system, respectively. These systems can be used to model all types of structures by using the finite element method of analysis.

APPENDIX B

SEISMIC ZONE MAPS

NOTE: Seismic zones for areas not shown in this appendix can be found in the seismic zone tabulation in section 1 of reference 20.



Map from TM 5-809-10, April 1973

Figure 1

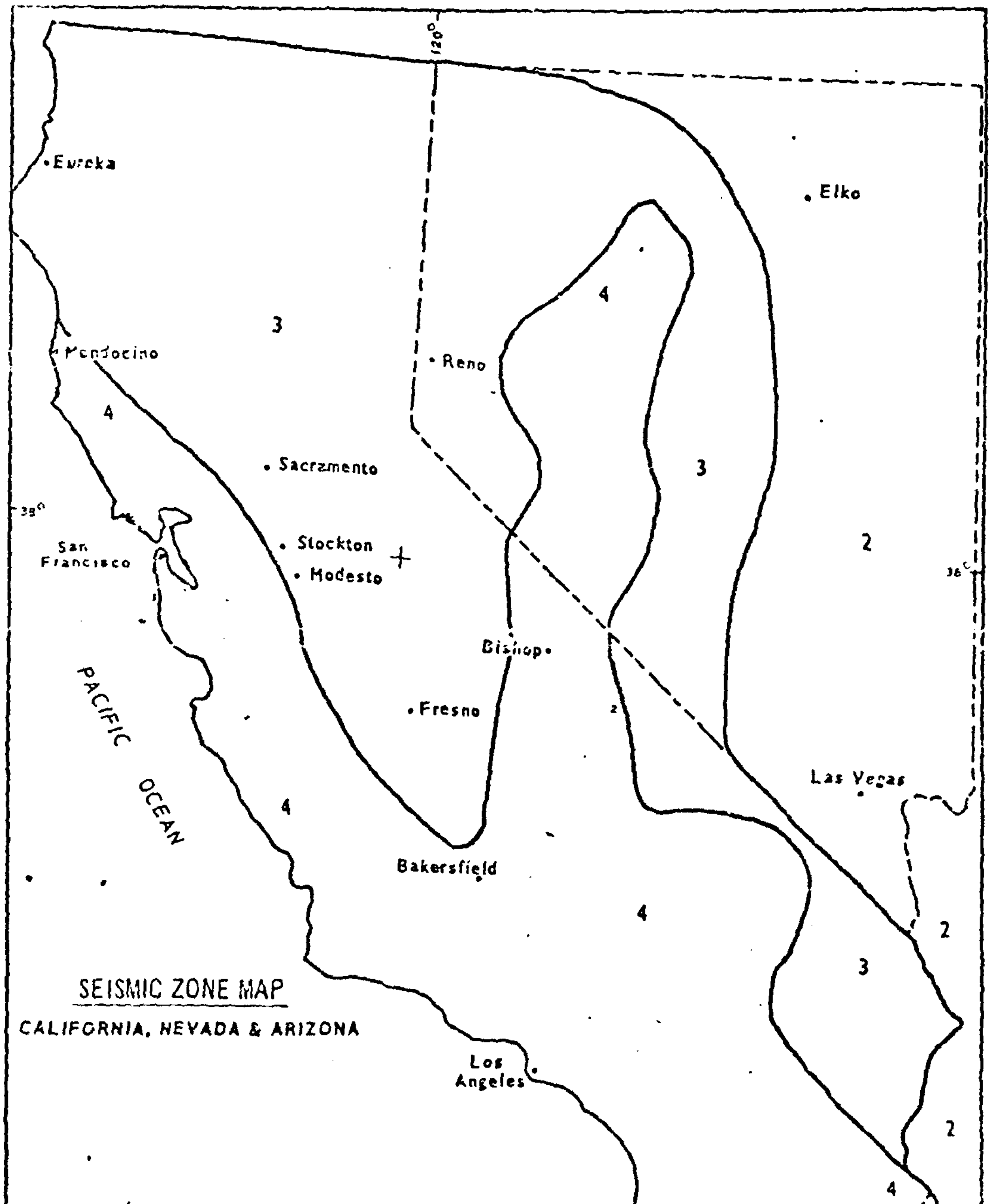
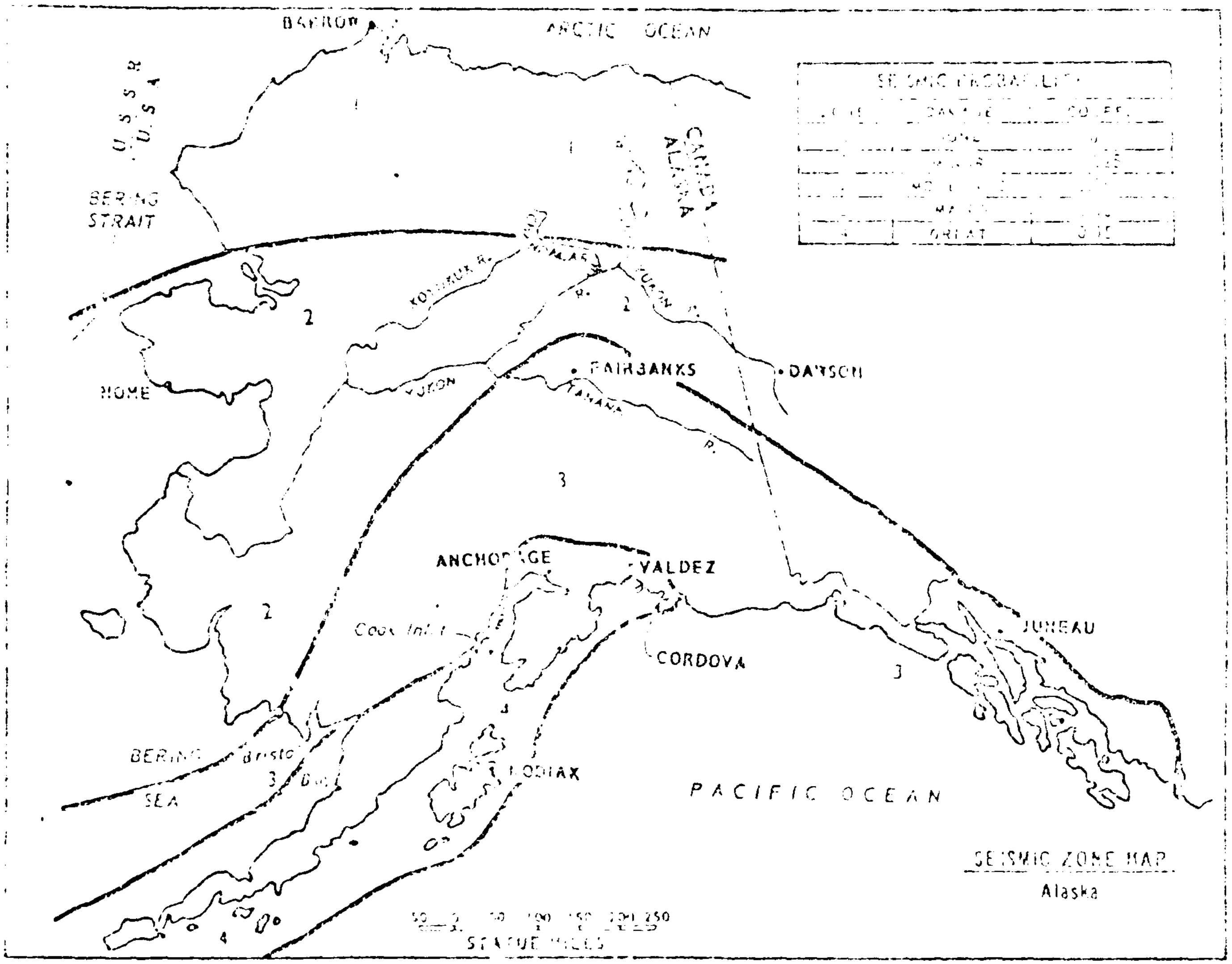
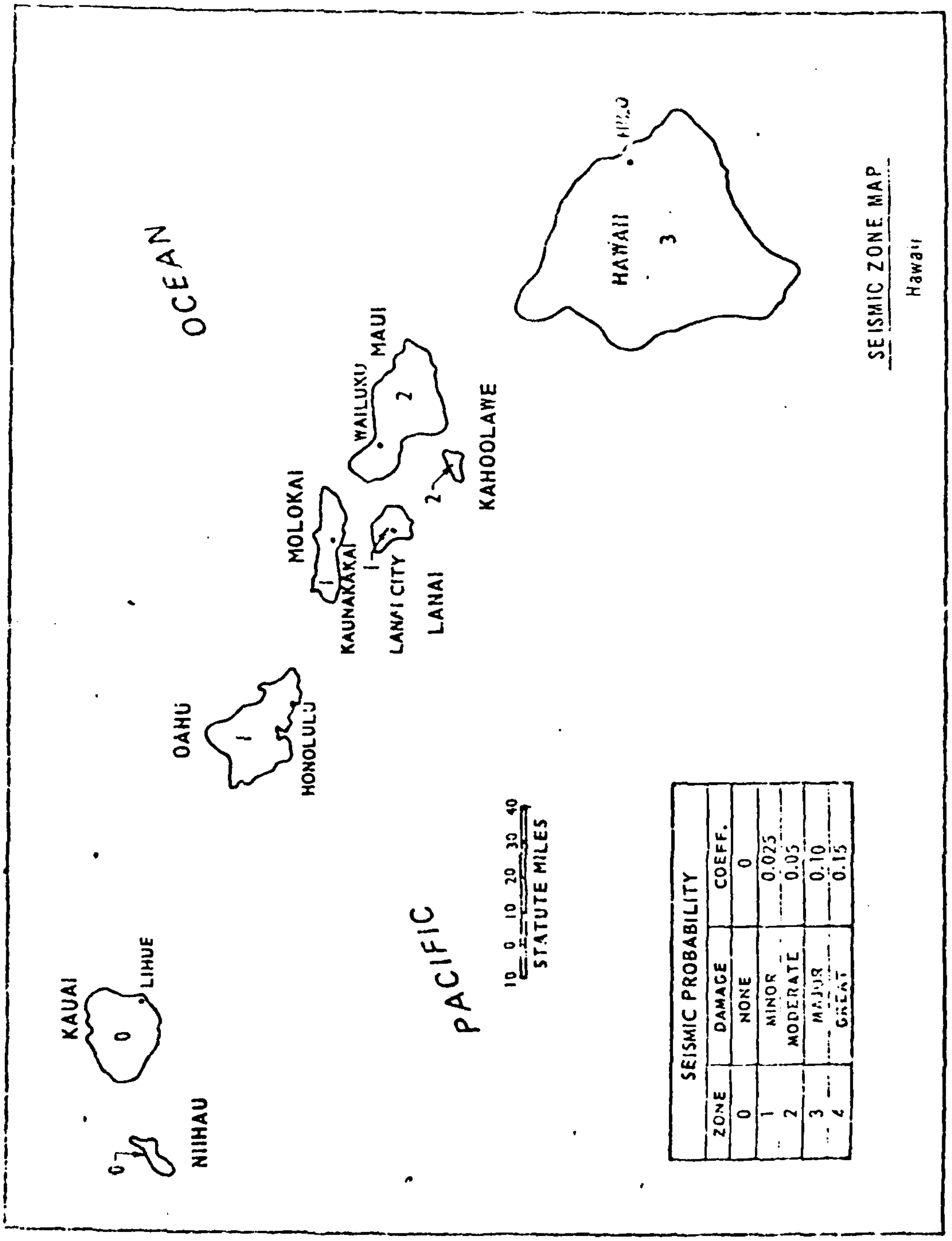

SEISMIC ZONE MAP
CALIFORNIA, NEVADA & ARIZONA
Eureka
Elko
Mendocino
Reno
Sacramento
San Francisco
Stockton
Modesto
Bishop
Fresno
Las Vegas
Bakersfield
Los Angeles
San Diego
Yuma
PACIFIC OCEAN
120°
38°
36°
1
2
3
4
40 0 40 80 MILES
SCALE

Figure 2



SEISMIC ZONE MAP

Alaska



SEISMIC PROBABILITY		
ZONE	DAMAGE	COEFF.
0	NONE	0
1	MINOR	0.025
2	MODERATE	0.05
3	MAJOR	0.10
4	GREAT	0.15

Figure 4

MISSION PROBLEM

NO 11 - 033 - 9

1. TITLE: Earthquake Loadings on High Retaining Walls

2. PROBLEM: The design of Corps projects embodies the use of retaining walls in earthquake areas. Little guidance exists and very little information is available pertaining to the dynamic loadings applied to these walls by the soil behind them during an earthquake.

3. DESCRIPTION: The use of current analytical procedure, as well as controlled laboratory and field testing, can be used to investigate the various parameters which participate in the loadings on these walls during earthquake shaking. Soil-structure interaction, soil pressures and pertinent design parameter factors can be determined and criteria established for rational design for earthquake considerations.

4. APPLICATION: Design of retaining walls in high seismic hazard areas. Results of the study would be incorporated into an ETL or EM, as appropriate.

Paul F. Hadala
Geotechnical Laboratory, WES
FTS 542-2217

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DATE
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