Technology Transfer Package on Seismic Base Isolation

Volume I

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Lawrence
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National
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Offices of
Risk Analysis and
Technology
and Nuclear Safety
Policy and Standards

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FOREWORD

This Technology Transfer Package provides some detailed information for the U.S. Department of Energy (DOE) and its contractors about seismic base isolation. Intended users of this package are DOE Design and Safety Engineers as well as DOE Facility Managers who are responsible for reducing the effects of natural phenomena hazards (NPH), specifically earthquakes, on their facilities. The package was developed as part of DOE's efforts to study and implement techniques for protecting lives and property from the effects of natural phenomena and to support the International Decade for Natural Disaster Reduction.

For over ten years, the DOE has researched the technology of seismic base isolation. The main purpose of seismic base isolation is to decouple a structure from the potentially damaging forces of an earthquake by placing a flexible isolation system between the structure and the ground. Ideally, the isolation system shifts the natural period of the isolated structure above the period range in which most of the earthquake energy is dissipated. With the shift, the effects of the seismic motions and forces on the structure can be substantially reduced.

In 1992, the DOE Office of Risk Analysis and Technology and the DOE Office of Nuclear Safety Policy and Standards sponsored two events which focused on seismic base isolation. Both events were organized by Lawrence Livermore National Laboratory (LLNL). The first event was the Workshop on Seismic Base Isolation for Department of Energy Facilities and it was held in Marina Del Rey, California on May 13th to 15th. Its goals were to introduce the concepts of base isolation and to illustrate that seismic isolation is a viable technology. Building on the information presented at the Workshop, the second event was the Department of Energy Short Course on Seismic Base Isolation. It was held in Berkeley, California on August 10th to 14th and it emphasized the engineering details of seismic isolation. This package contains course notes from the Workshop, course notes from the Short Course, and several references on base isolation. Copies of videotapes from the Short Course are available from LLNL upon request.

As the technical coordinator of the Workshop and Short Course, I appreciated all the support and assistance of several key members of the team. James Hill, EH-33, and V. Gopinath, NE-74, of the DOE were instrumental with their support of the technology transfer process. The experience of Robert Murray, Lilian Decman, and Dawn Matz at LLNL helped make both the Workshop and Short Course run smoothly. Success of both events was directly related to the excellent presentations of all the instructors. They had invaluable information to share and they all shared an enthusiasm about further developments with base isolation. I especially want to thank Dr. James Kelly, Dr. Charles Kircher, and Robert Bachman for their continued advice and efforts. Finally, my thanks are extended to the participants of both events, the companies who displayed information at the Workshop, the staff at the EERC, and all the tour guides for their efforts in contributing to the success of both events.

Stanley C. Sommer
Project Leader for Seismic Base Isolation
Fission Energy and Systems Safety Program

PERSPECTIVE

Seismic base isolation (SBI) has been identified as a potential concept for mitigating the effects of earthquakes on U.S. Department of Energy (DOE) facilities. UCRL-108242, *Technical Basis, Supporting Information, and Strategy for Development and Implementation of DOE Policy for Natural Phenomena Hazards*, stated that "there is a need to explore the feasibility of this concept for design of new DOE facilities as well as an approach for upgrading facilities". Base isolation is gaining acceptance within the U.S. structural engineering community and several new designs and retrofits of buildings have been successfully completed.

A main attribute of SBI is that it potentially meets the goals of national programs for mitigating the effects of earthquakes. In 1977, the National Earthquake Hazard Reduction Program (NEHRP) was initiated with the goal of reducing the risks to life and property of future earthquakes. While the Federal Emergency Management Agency (FEMA) and the National Institute of Standards and Technology (NIST) were the principal agencies, many Federal agencies like the DOE established plans and programs to meet the goal of the NEHRP. These efforts were increased with the passage of Executive Order 12699 in January 1990. The philosophy of that Order is "to reduce risks to the lives of occupants of buildings owned by the Federal Government", "to improve the capability of essential Federal buildings to function during or after an earthquake, and to reduce earthquake losses of public buildings, all in a cost-effective manner". Currently, the Interagency Committee on Seismic Safety in Construction (ICSSC) is working on an executive order that will require similar provisions as those in 12699 for existing Federal buildings. SBI is a technology that actively meets the philosophy of Executive Order 12699 and potentially satisfies the concerns of the forthcoming executive order on existing facilities.

To aid the exploration of SBI technology and its use within the Federal Government, a program for studying SBI concepts and their application to DOE and other Federal facilities was created. In 1992, the program consisted of four events at which personnel from private industry, the government, and universities presented detailed information about SBI.

The first event was the Symposium on Base Isolation for Federal Facilities and it was held in Washington, D.C. on March 25, 1992. Support for the symposium was provided by the Federal Construction Council and ICSSC. The goal of the symposium was to familiarize managers, architects, and engineers of Federal facilities with the technology and application of SBI for new and retrofit construction. Representatives from different government agencies and several structural engineering firms discussed applications of SBI, issues in implementing SBI in design practices, and SBI research by Federal agencies. Several examples demonstrated the utility of SBI. The announcement and agenda for the symposium are provided in this package and further information and materials are available from Riley Chung of NIST (phone number: 301-975-6062).

The second event was held in Port Hueneme, California on May 5, 1992 and it was sponsored by the Naval Civil Engineering Laboratory (NCEL) and NIST. Its purpose was to discuss issues of design and construction of Federally funded buildings incorporating SBI. The main issues discussed during this symposium were the use of a performance specification or a detailed design when procuring an isolation system and the different requirements and means of comparison between fixed base and isolated structures. An overall conclusion from the discussions was that fixed base and isolated structures are currently not compared on a "level playing field". The announcement and agenda for the symposium are provided in this package and further information and materials are available from John Ferritto of NCEL (phone number: 805-982-1243).

The third and fourth events were supported by the DOE Office of Risk Analysis and Technology and the DOE Office of Nuclear Safety Policy and Standards. Both events were organized by the Lawrence Livermore National Laboratory (LLNL). The third event was the Workshop on Seismic Base Isolation for Department of Energy Facilities and it was held in Marina Del Rey, California on May 13th to 15th. Its goals were to introduce the concepts of base isolation and to illustrate that seismic isolation is a viable technology. At the Workshop, DOE engineers and managers had a forum for investigating some technical aspects of SBI. The Workshop focused on the technology and use of SBI by discussing general concepts and examples, engineering details and characteristics of different isolation systems, and the design process involving SBI. Highlights of the Workshop were tours of two isolated buildings in Los Angeles, the Los Angeles County Fire Command and Control Facility and the University of Southern California Hospital. These tours provided working examples of the technology. Additionally, several companies with SBI products demonstrated their products in a display session on the second day of the Workshop. Course notes from the presentations as well as references which were referred to during the Workshop are included in this package.

Building on the information presented at the Workshop, the fourth event was the Department of Energy Short Course on Seismic Base Isolation. It was held in Berkeley, California on August 10th to 14th and it emphasized the engineering details of seismic isolation. While the Workshop discussed the general aspects of SBI, the Short Course emphasized the engineering details of seismic isolation. The Short Course provided an overview of SBI and its many applications, the theory or technical background of isolation, and the application of the theory to practical design using the provisions of the Uniform Building Code (UBC). To view equipment used in the testing of isolation systems, the participants toured the Earthquake Engineering Research Center (EERC), which is part of the University of California at Berkeley. The highlight of the Short Course was the student design problems which were used to bring together the topics being discussed. Participants not only did "hand" calculations to design isolation systems; they also used a nonlinear program, *3DBASIS*, to predict the response of their designed systems. Course notes from the presentations are included in this package and videotapes of the presentations are available from LLNL upon request.

The four events in 1992 provided much information about SBI. Many concepts and applications of SBI were illustrated. Within the DOE, Argonne National Laboratory (ANL) has been deeply involved since the early 1980s with testing and developing SBI. The effort at ANL, which is under the leadership of Ralph Seidensticker, is to develop seismic isolation for use in nuclear facilities. SBI was first considered for the Advanced Liquid Metal Reactor (ALMR) and this work was supported by the DOE Office of Nuclear Energy Programs. As compared to conventional nuclear power plants, the thin walls of an ALMR do not have inherent seismic resistance and are unable to withstand high seismic demand. Based on experience gained by France using SBI with their standardized plant designs, the "current ALMR concept in the US, the PRISM modular plant design by General Electric, uses seismic isolation for the nuclear reactor module to avoid excessive material thicknesses in the reactor vessel and piping, and to enhance the economical standardization of their plant design".

After their involvement with the ALMR design, ANL studied the use of SBI with the New Production Reactors (NPR). SBI was attractive for the DOE NPR because of its design requirement "that the facility be returned to full production following a major seismic event with minimum downtime and at a reasonable cost". An extensive amount of testing for the NPR project was done at EERC and at the DOE's Energy Technology Engineering Center. Additional work was done by ANL to study the response of isolated

buildings to actual earthquakes. ANL developed several computer codes for studying the responses of isolators and isolated structures to seismic input. For isolator testing, test programs were created, the effects of long period ground motions were studied, and the quality of elastomer compounds for bearings were examined. The effects of environmental factors like aging and temperature were also tested. Finally, nuclear-grade design and fabrication specifications for isolators were developed.

With the technical information developed at ANL and the technology transfer directed by LLNL in 1992, DOE is planning for its next phase of involvement with SBI. This phase will involve applying the technology to structures, systems, and components (SSCs) within the DOE. In order to determine which DOE SSCs are appropriate candidates for SBI, guidance and criteria are needed. Additionally, guidance and criteria are required for specifying the methods for implementing and designing with SBI. The two events organized by LLNL served as a mechanism for technology transfer about issues in implementation and design with SBI. Since many DOE personnel are becoming increasingly concerned about mitigating the effects of earthquakes on their facilities, available means for achieving that mitigation need to be studied.

While developing the guidance and criteria, further investigations of the many aspects of SBI are necessary. Since the use of SBI is relatively new in the U.S., an experience database, or "lessons learned", should be developed. This database could be supplemented by the vast experiences of some Japanese construction companies with SBI. Some information about the U.S. and Japanese uses of SBI is included in several presentations and references in this package. Most importantly, the response of isolated SSCs during actual earthquakes should be carefully studied. LLNL is currently exploring the establishment of cooperative efforts with Shimizu Corporation of Japan. With this agreement, data collected by Shimizu will be studied by LLNL. There are several other technical issues that may require more analyses and testing if SBI is to be considered for DOE facilities. Those issues include the response of isolated SSCs to low magnitude earthquakes, the lack of standardized material specifications for isolation systems, and the special requirements when using SBI in the retrofit of a SSC. With further development of the SBI technology specifically for DOE SSCs, guidance and criteria would be the tools for DOE managers and engineers to use when considering a new or retrofit design with SBI.

Development of the SBI guidance and set of criteria will be done within the framework of the Natural Phenomena Hazards (NPH) Program at LLNL. Under the leadership of Dr. Robert Murray, the NPH Program has written several DOE standards and guidance documents which address the effects of NPH on DOE SSCs. Future DOE involvement with SBI should reflect the policy of applicable DOE orders and there are several orders that reflect the demands of Executive Order 12699. DOE Order 5480.NPH deals with the design of new DOE facilities as well as the evaluation of existing facilities by adopting the philosophy of DOE-STD-1020-92 (UCRL-15910), *Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards*. As an integral part of DOE policy on NPH, specifically earthquakes, UCRL-15910 provides technical standards and criteria for NPH and their effects on SSCs. UCRL-15910 has a graded approach based on the importance and hazards associated with a particular SSC. SBI is a potential approach for satisfying the strict specifications for the higher category SSCs. These SSCs typically provide confinement of hazardous materials and have important mission requirements. In order to use SBI for the proper SSCs, guidance is needed.

An example of SBI guidance is a methodology to be used when determining which SSC at a DOE facility is an appropriate candidate for SBI. This package contains information on that type of guidance in papers on a screening process developed for the U.S. Navy and a decision methodology used at Fluor Daniel, Inc. As the notes in this package discuss,

SBI provides the maximum benefit for stiff, short, and regular structures on stiff soil. A potential disadvantage of SBI is that it typically costs between 3% and 15% more than fixed base designs based on UBC provisions. For that additional cost though, the building achieves much higher performance in terms of reducing the effects of seismic-induced damage. For SSCs that must remain operational or must sustain very little damage during an earthquake, this increased performance is highly desirable. The screening process must consider all the design parameters like cost, performance goal, and site conditions.

In order to use SBI in a design, the DOE additionally needs to develop design criteria. That criteria would most likely be based on the provisions of the UBC. Criteria developed for the U.S. Navy and other Federal agencies will also be studied. The criteria would be enhanced if it was applied to a DOE "demonstration" project which either is a new design or an existing design that needs seismic upgrading. Efforts are underway to identify a DOE SSC which could qualify as an appropriate "demonstration" project for SBI. All the efforts in the future phase of DOE involvement in SBI are dependent on continuing the technology transfer process that was begun with the Workshop and Short Course.

SBI is a promising technology within the U.S. and as with any "new" technology, care is required for implementing it. Concerns about the costs, structural requirements of the facility, performance and functionality requirements, and level of risk must be addressed. Since there is no current standard for the specifications of seismic isolation systems, the advantages and disadvantages of different systems must be carefully studied. Some of the systems are proprietary and there is not yet a structural engineering handbook for the systems as there is for other structural engineering components. Finally, the safety margins associated with the systems must be determined. Other countries have experience with the behavior of systems to actual earthquakes and this experience needs to be studied and applied to future designs. The DOE plans to continue to seek the latest advances in techniques for reducing the effects of NPH on its facilities.

Federal Construction Council
and
Interagency Committee on Seismic Safety in Construction

SYMPOSIUM ON BASE ISOLATION FOR FEDERAL FACILITIES

Wednesday, March 25, 1992

Lecture Room
National Academy of Sciences
2101 Constitution Avenue, NW
Washington, DC 20418

Base-isolation is a technique, when properly designed and installed, that can improve seismic performance of buildings and lifeline structures. The concept of disconnecting the building from the ground so that seismic forces are not transmitted was first proposed in the late 1880s. It was in the past several decades that this concept was more widely implemented in New Zealand and Japan for bridges and buildings, and in France and South Africa for nuclear power facilities. First applied in 1984 in the United States, base isolation has been used in--or is under consideration for use in--more than 30 bridges and 15 buildings.

The purpose of this symposium is to familiarize facilities managers, architects, and engineers with the technology and application of seismic base isolation for new and retrofit construction. Individuals from both governmental and nongovernment sectors will share with the attendees their experiences, including the decision-making process regarding issues in policy, technology, administration, and procurement through case studies. In addition, research efforts in Federal institutions will be presented and discussed.

SPONSORS: The symposium is jointly sponsored by the Interagency Committee on Seismic Safety in Construction (ICSSC) and the Federal Construction Council. ICSSC was established in 1980 under the National Earthquake Hazard Reduction program (NEHRP), pursuant to the Earthquake Hazard Reduction Act of 1977 as amended in 1980, and Executive Order 12380. ICSSC was formed to assist the Federal departments and agencies involved in construction to develop and incorporate earthquake hazards reduction measures in their ongoing programs.

The Federal Construction Council, established in 1953, is a continuing activity of the Building Research Board of the National Research Council. Its fundamental purpose is to help Federal agencies having an interest in construction identify and find solutions to common problems.

The symposium was organized by the National Institute of Standards and Technology, ICSSC's secretariat and the FCC Consulting Committee on Civil and Structural Engineering and is partially funded by the Department of Energy.

COST: There is no charge for the symposium. However, there is a \$10.00 per person fee to cover the cost of lunch and coffee. The fee must be paid prior to the symposium. (See attached registration slip).

TRANSPORTATION: Please note that there is no parking for symposium attendees at the National Academy of Sciences and that there are very few public parking lots in the immediate vicinity. Symposium attendees are urged to arrive by taxicab or other public transportation. (The nearest Metro stop is the Foggy Bottom/George Washington University station at 23 and I Streets, NW)

AGENDA

- 8:00 a.m. **REGISTRATION**
- 8:30 a.m. **Welcome**
 Andrew Lemer, Building Research Board, NRC
- 8:35 a.m. **Opening Remarks**
 Riley M. Chung, Building and Fire Research Laboratory, NIST
- 8:45 a.m. **NEHRP and the Role of ICSSC**
 Richard Wright, Building and Fire Research Laboratory, NIST
- 9:00 a.m. **Concepts of Base Isolation**
 Riley M. Chung, Building and Fire Research Laboratory, NIST
- 9:20 a.m. **Case Histories--Non-Federal Facility**
 - Fire Command and Control Center, Los Angeles, California
 Tom Anderson, Fluor Daniel Corp.
 - Mackay School of Mines, Reno, Nevada
 Doug Way, Base Isolation Consultants
- 10: 00 a.m. **BREAK**
- 10:25 a.m. **Case Histories--Federal Facilities**
 - U.S. Court of Appeals, San Francisco, California
 TBA, General Services Administration
 - Veterans Hospital, Long Beach, California
 Kharaiti Abrol, Department of Veterans Affairs
- 11:15 a.m. **Issues in Implementation**
 - Issue 1: Policy
 Robert A. Olson, VSP Associates
- 11:45 am
 - Issue 2: Technical
 Ian Buckle, National Center for Earthquake Engineering Research
- 12:15 p.m. **LUNCH**
- 1:15 p.m.
 - Issue 3: Administrative
 John Ferrito, Naval Civil Engineering Laboratory
- 1:45 p.m. **Research by Federal Agencies**
 - Department of Energy
 James Hill, Department of Energy
 - Department of the Navy
 John Ferrito, Naval Civil Engineering Laboratory
 - Army Corps of Engineers
 Jack Hayes, Construction Engineering Research Laboratory
 - National Institute of Standards and Technology
 H. W. Shenton III, Building and Fire Research Laboratory
- 3:00 p.m. **Discussions and Closure**
 H. S. Lew, Building and Fire Research Laboratory, NIST
- 3:30 p.m. **Adjournment**

Federal Construction Council
and
Interagency Committee on Seismic Safety in Construction
SYMPOSIUM ON BASE ISOLATION FOR FEDERAL FACILITIES

Wednesday, March 25, 1992

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 - National Institute of Standards and Technology
H. W. Shenton III, Building and Fire Research Laboratory
- 2:30 p.m. **Discussions and Closure**
H. S. Lew, Building and Fire Research Laboratory, NIST
- 3:00 p.m. **Adjournment**

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

BUILDING TECHNOLOGY SYMPOSIUM

USE OF SEISMIC BASE ISOLATION IN FEDERAL CONSTRUCTION

5 MAY 1992

NAVAL CIVIL ENGINEERING LABORATORY

PORT HUENEME, CALIFORNIA

OBJECTIVE

This symposium is intended to bring together representatives from industry, academia, and Government to discuss the issues of design and construction of Federally funded buildings incorporating seismic base isolation. The forum will consist of a series of presentations and panel discussions of the key issues by knowledgeable individuals.

Topics

Can base isolation be specified by a performance specification?

What design standards should be used for base isolation?

Can base isolation be specified in a competitive environment under provisions of the Federal Acquisition Regulations?

What testing is required and how does it fit into the Federal acquisition process and time schedules of acquisition programs such as the Military Construction Program.

Should the Government adopt a uniform seismic design standard for base isolation?

What research programs are in progress at the different Federal agencies?

What additional research is needed?

What are the different Federal agencies doing in preparing for base isolation.

There is no charge for this symposium.

Persons interested in attending should contact the session chairman:

John Ferritto, Structures Division Code L51
Naval Civil Engineering Laboratory
Port Hueneme, California 93043-5003

**AGENDA BASE ISOLATION WORKSHOP
5 MAY 1992 AT NCEL**

Morning Session 8:00 to 12:00

8:00 - 8:30	Registration	
8:30 - 8:40	J. M. Ferritto	Opening Remarks
8:40 - 9:10	Professor George Housner	
9:10 - 9:30	C. Kircher	"SEAOC/UBC Regulations for New Buildings and Guidelines for Retrofit of Existing Buildings."
9:30 - 9:50	R. L. Mayes	"The Need for design Criteria for Isolating Systems"
9:50 - 10:10	E. R. Fyfe	"A Performance Specification Including Testing For The Los Angeles Fire department 911 Building."
10:10 - 10:30	D. Way	"Performance Specifications vs. Detailed design in The Implementation of Base Isolation."
10:30 - 10:40		Break
10:40 - 11:00	L. R. Jones	"Performance Specification Issues."
11:00 - 12:00		Panel Discussion

Topic "In order to use base isolation on Federal construction, do we need design criteria? Should the Federal Government adopt a performance specification? How much control should the Government have in specifying the design of a isolated building which is in the category of an essential structure needed for critical government functions?"

Panel members: Mayes, Kircher, Fyfe, Jones, Bachman, Kemeny, Walters and Turner

Afternoon Session 1:00 to 5:00

1:00 - 1:20	G. C. Hart	Critical Issues In The Development of Design Criteria For Isolated Buildings.
1:20 - 1:40	V. Zayes	Design and Specification Of Friction Pendulum Seismic Isolators For Government Construction Projects.
1:40 - 2:00	D. Van Volkinburg	"The Benefits of Preselecting the Isolation System."
2:00 - 2:20	M. Caspe	"A Method For Competitively Bidding Seismic Isolation Projects.
2:20 - 2:40	J. Asher	"Application of Base Isolation to the San Bernadino County Medical Center Replacement Project."
2:40 - 3:00	H. Shenton	"Relative Performance of Fixed-Base and Base-Isolated Structures."
3:00 - 3:10		Break
3:10 - 3:30	R. Olson	"Base Isolation: Application of an Earthquake Engineering Investigation."
3:30 - 3:50	J. C. Miranda	"A Simplified Model For The Dynamic Behavior of Base Isolated Buildings."
4:00 - 5:00		Panel Discussion

Topic: How can the Federal Government use base isolation consistent with the requirements of the Federal Acquisition regulations (FAR). Can isolation devices be procured in a competitive manner or are they sole source private designs? Can base isolation be used on construction projects which have the unique time constraints. How does testing requirements impact on design and construction schedules?

Panel Members: Way, Weissberg, Zigant, Tarics, Olson, Asher, Essoglu

WORKSHOP ON SEISMIC BASE ISOLATION FOR DEPARTMENT OF ENERGY FACILITIES

**May 13-15, 1992
Marina Del Rey Marriott
Marina Del Rey, California**

**Hosted by:
Lawrence Livermore
National Laboratory**

**Sponsored by:
U.S. Department
of Energy**

Marina Del Ray Workshop

Marina Del Ray Workshop

WORKSHOP ON SEISMIC BASE ISOLATION FOR DEPARTMENT OF ENERGY FACILITIES

REVISED AGENDA

Day 1 - Wednesday, May 13, 1992

7:30 a.m.

Registration and Distribution of Materials

8:15 a.m.

Welcome-----Stanley Sommer

8:45 a.m.

The Development and Implementation of Base Isolation-----James Kelly

9:30 a.m.

Break

9:45 a.m.

Base Isolation in Japan-----James Kelly

Linear Theory of Base Isolation-----James Kelly

11:25 a.m.

Base Isolation of Rockwell Building-----Gary Hart

11:45 a.m.

Lunch

12:45 p.m.

Tours of Facilities with Seismic Base Isolation

Los Angeles County Fire Command and Control Facility-----Robert Bachman

University of Southern California Hospital-----Charles Kircher

4:45 p.m.

Break

6:00 p.m.

Reception

8:00 p.m.

Day 2 - Thursday, May 14, 1992

8:00 a.m.

Seismic Design Guidance for DOE Facilities - UCRL-15910-----Robert Murray

8:45 a.m.

Seismic Base Isolation Systems-----Ralph Seidensticker

9:45 a.m.

Break

10:15 a.m.

Selection Criteria for Base Isolation-----John Ferritto

11:00 a.m.

Current Building Code Provisions-SEAOC/UBC-----Charles Kircher

11:45 a.m.

Applications of Isolation Systems-----Charles Kircher

12:15 p.m.

Lunch

1:45 p.m.
 Testing of Laminated Elastomer Bearings-----Yao Chang
 2:45 p.m.
 Equipment Qualification for Base Isolation Systems-----John Eidinger
 3:30 p.m.
 Break
 4:00 p.m.
 Special Topics about Base Isolation Systems-----John Eidinger
 5:00 p.m.

Day 3 - Friday, May 15, 1992

8:00 a.m.
 D.O.E. Perspective on Seismic Base Isolation-----C. Chester Bigelow
 8:15 a.m.
 Design Decisions - Seismic Isolation Systems-----Thomas Anderson
 9:30 a.m.
 Break
 9:45 a.m.
 Construction with Base Isolation Systems-----C. Terry Dooley
 10:45 a.m.
 Quality Issues with Base Isolation Systems-----Gary Hart
 11:45 a.m.
 Lunch
 12:45 p.m.
 Design Example 1-----Robert Bachman
 2:15 p.m.
 Break
 2:30 p.m.
 Design Problem #2-----Douglas Way
 4:00 p.m.
 Concluding Remarks-----Stanley Sommer
 4:15 p.m.

Workshop on Seismic Base Isolation for Department of Energy Facilities

WELCOME

**Stanley C. Sommer
Lawrence Livermore National Laboratory
Nuclear Systems Safety Program**

**May 13, 1992
Marina Del Rey Marriott
Marina Del Rey, California**

LLNL/DOE Welcomes you to this Workshop.

- **Workshop Sponsor**

**U.S. Department of Energy
Office of Risk Analysis and Technology
Office of Nuclear Safety Policy and Standards**

- **Workshop Host**

**Lawrence Livermore National Laboratory
Nuclear Systems Safety Program**

This Workshop will Focus on the Technology and Use of Seismic Base Isolation.

- **Goals**

Educate audience about base isolation

Illustrate that base isolation is a viable technology

- **Main Topics**

General concepts and examples

Engineering details and characteristics of systems

Design process involving base isolation

The DOE is Focusing on Reducing the Effects of Natural Phenomena Hazards on its Facilities.

DOE Supports the International Decade for Natural Disaster Reduction

- **Natural Phenomena Hazards**

Earthquakes (Seismic)

Wind

Flood

Volcano

Lightning

Others

Many DOE Facilities are Located in Areas of High Seismic Risk.

- **Areas of High Seismic Risk**

**California: LLNL, SLAC, LBL, SNL, ETEC
Eastern U.S.: ORNL, Paducah, Savannah River**

- **DOE Facilities**

**Non-critical: office building, storage building
Critical: research laboratory, reactor**

- **Potential Uses of Base Isolation**

**Seismic retrofit of existing facility
Construction of new facility**

The Workshop Instructors are from the Government, Universities, and Industry.

Thomas L. Anderson - Fluor Daniel, Inc.
Robert E. Bachman - Fluor Daniel, Inc.
Yao W. Chang - Argonne National Laboratory
C. Terry Dooley - Morley Construction Company
John M. Eidinger - G & E Engineering Systems
John M. Ferritto - U.S. Department of the Navy
Gary C. Hart - University of California Los Angeles
James M. Kelly - University of California Berkeley
Charles A. Kircher - Charles Kircher & Associates
Robert C. Murray - Lawrence Livermore National Lab.
Ralph W. Seidensticker - Argonne National Laboratory
Douglas Way - Base Isolation Consultants, Inc.

Several People are Responsible for Organizing the Workshop.

- **Lawrence Livermore National Laboratory**

Stanley C. Sommer, Project Leader

Robert C. Murray, Associate Program Leader

Lilian S. Decman, Administrator

Dawn S. Matz, Administrative Assistant

- **U.S. Department of Energy**

James R. Hill, Project Manager

Gerald E. Meyers, Lead Engineer

V. Gopinath, Project Manager

There are Several Sources of Information for the Workshop.

- **Workshop Binder**

Workshop agenda

Copies of presentation materials (except photographs)

- **Reference Binder**

Copies of papers dealing with base isolation

Reference lists

We will Tour Several Buildings with Seismic Base Isolation on Wednesday.

- **Suggestions**

**Wear comfortable clothing for the bus trips and tours.
The isolation systems are not in directly accessible
areas so please be prepared for narrow quarters.**

- **Schedule**

**12:30 p.m. - Bus is in front of the hotel
12:45 p.m. - Bus leaves Marina Del Rey Marriott
1:30 p.m. - Tour L.A. County F.C.C.F.
3:00 p.m. - Tour U.S.C. Hospital
4:45 p.m. - Bus arrives at Marina Del Rey Marriott**

There will be a Display Room on Thursday.

- **Display Room**

Separate room from the presentation room

Workshop participants may visit it during second day

- **Companies with Displays**

Bridgestone Engineered Products Company

Dynamic Isolation Systems

Earthquake Protection Systems

Engdahl Enterprises

Seismic Risk Evaluation

Widmon Wein Cohen Architects

LINEAR THEORY OF BASE ISOLATION

J.M Kelly

University of California, Berkeley

Richmond, CA

13 May 1992

Seismic Base Isolation for DOE Facilities

Marina Del Rey, CA

$$m \ddot{u} = -c (\dot{u} - \dot{u}_b) - k (u - u_b) \quad (3.1)$$

$$m \ddot{u} + m_b \ddot{u}_b = -c_b (\dot{u}_b - \dot{u}_g) - k (u_b - u_g) \quad (3.2)$$

$$v_s = u - u_b \quad (3.3)$$

$$v_b = u_b - u_g \quad (3.4)$$

$$m \ddot{v}_b + m \ddot{v}_s + c \dot{v}_s + k v_s = -m \ddot{u}_g \quad (3.5)$$

$$(m + m_b) \ddot{v}_b + m \ddot{v}_s + c_b \dot{v}_b + k_b v_b = -(m + m_b) \ddot{u}_g \quad (3.6)$$

(i) $m_b < m$, but are of the same order of magnitude;

(ii) $\omega_s = \left[\frac{k}{m} \right]^{1/2} \gg \omega_b = \left[\frac{k_b}{M} \right]^{1/2}$ and define $\varepsilon = \left[\frac{\omega_b}{\omega_s} \right]^2$ and take ε to be of order of magnitude 10^{-2} ;

(iii) the damping factors for the structure and isolation system, β_s and β_b , respectively, where $\beta_s = \frac{c}{2m\omega_s}$ and $\beta_b = \frac{c_b}{2M\omega_b}$, are of the same order of magnitude as ε .

$$\phi^n = \{\phi_b^n, \phi_s^n\}^T ; \quad n = 1, 2$$

$$(-\omega_n^2 + \omega_b^2) \phi_b^n + (-\gamma \omega_n^2) \phi_s^n = 0 \quad (3.9a)$$

$$(-\omega_n^2) \phi_b^n + (-\omega_n^2 + \omega_s^2) \phi_s^n = 0 \quad (3.9b)$$

$$(1 - \gamma) \omega_n^4 - (\omega_b^2 + \omega_s^2) \omega_n^2 + \omega_b^2 \omega_s^2 = 0 \quad (3.10)$$

$$\frac{\omega_2^2}{\omega_1^2} = \frac{1}{2(1-\gamma)}$$

$$\left\{ (\omega_s^2 + \omega_b^2) \pm \left[(\omega_s^2 + \omega_b^2)^2 - 4(1-\gamma)\omega_s^2\omega_b^2 \right]^{1/2} \right\} \quad (3.11)$$

$$(\omega_s^2 - \omega_b^2)^2 \left[1 + 4\gamma \frac{\omega_b^2\omega_s^2}{(\omega_s^2 - \omega_b^2)^2} \right] \quad (3.12)$$

$$\omega_1^2 = \omega_b^{*2} = \omega_b^2 \left[1 - \gamma \frac{\omega_b^2}{\omega_s^2} \right] \quad (3.13)$$

$$\omega_2^2 = \omega_s^{*2} = \frac{\omega_s^2}{1-\gamma} \left[1 + \gamma \frac{\omega_b^2}{\omega_s^2} \right] \quad (3.14)$$

$$\omega_b^* = \omega_b \quad (3.15)$$

$$\omega_s^* = \frac{\omega_s}{(1-\gamma)^{1/2}} \quad (3.16)$$

$$(-\omega_b^{*2} + \omega_b^2) \phi_b^1 + (-\gamma \omega_b^{*2}) \phi_s^1 = 0 \quad (3.17a)$$

$$-\omega_b^{*2} \phi_b^1 + (\omega_s^2 - \omega_b^{*2}) \phi_s^1 = 0 \quad (3.17b)$$

$$\phi^1 = \left\{ \begin{array}{c} 1 \\ \omega_b^2/\omega_s^2 \end{array} \right\} \quad (3.18)$$

$$\phi^2 = \left\{ \begin{array}{c} 1 \\ -\frac{1}{\gamma} \left[1 - (1-\gamma) \frac{\omega_b^2}{\omega_s^2} \right] \end{array} \right\} \quad (3.19)$$

$$v_b = q_1 \phi_b^1 + q_2 \phi_b^2 \quad (3.20)$$

$$v_s = q_1 \phi_s^1 + q_2 \phi_s^2 \quad (3.21)$$

$$\ddot{q}_1 + 2\omega_b^* \beta_b^* \dot{q}_1 + \omega_b^{*2} q_1 = -L_1 \ddot{u}_g \quad (3.22)$$

$$\ddot{q}_2 + 2\omega_s^* \beta_s^* \dot{q}_2 + \omega_s^{*2} q_2 = -L_2 \ddot{u}_g \quad (3.23)$$

$$L_n = \frac{\phi^{n^T} \mathbf{M}^* \mathbf{r}^*}{\phi^{n^T} \mathbf{M}^* \phi^n} \quad (3.24)$$

$$L_1 M_1 = (1, \varepsilon) \begin{bmatrix} M & m \\ m & m \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix} = M + m \varepsilon \quad (3.25)$$

$$M_1 = (1, \varepsilon) \begin{bmatrix} M & m \\ m & m \end{bmatrix} \begin{bmatrix} 1 \\ \varepsilon \end{bmatrix} = M + 2m \varepsilon + m \varepsilon^2$$

$$L_1 = 1 - \gamma \varepsilon \quad (3.26)$$

$$L_2 M_2 = M + m a \quad (3.27)$$

where:

$$M_2 = M + 2 m a + a^2 m$$

and:

$$a = -\frac{1}{\gamma} [1 - (1 - \gamma) \varepsilon]$$

Since

$$\gamma = \frac{m}{M}, \quad L_2 M_2 = M (1 - \gamma) \varepsilon$$

and

$$M_2 = M \frac{(1 - \gamma) [1 - 2(1 - \gamma) \varepsilon]}{\gamma}$$

then

$$L_2 = \gamma \varepsilon \quad (3.28)$$

$$2 \omega_n^* \beta_n^* = \frac{\phi^{n^T} \mathbf{C}^* \phi^n}{\phi^{n^T} \mathbf{M}^* \phi^n} \quad (3.41)$$

$$2 \omega_b^* \beta_b^* = 2 \omega_b \beta_b (1 - 2 \gamma \epsilon) \quad (3.42)$$

$$2 \omega_s^* \beta_s^* = \frac{2 \omega_s \beta_s + \gamma 2 \omega_b \beta_b}{1 - \gamma} \quad (3.43)$$

$$\omega_b^* = \omega_b (1 - \gamma \epsilon)^{1/2} \quad (3.44)$$

$$\beta_b^* = \frac{\beta_b (1 - 2 \gamma \epsilon)}{(1 - \gamma \epsilon)^{1/2}} = \beta_b (1 - \frac{3}{2} \gamma \epsilon) \quad (3.45)$$

$$\omega_s^* = \omega_1 \frac{(1 + \gamma \epsilon)^{1/2}}{(-\gamma)^{1/2}} \quad (3.46)$$

$$\beta_s^* = \left[\frac{\beta_s}{(1-\gamma)^{1/2}} + \frac{\gamma\beta_b \varepsilon^{1/2}}{(1-\gamma)^{1/2}} \right] \left(1 - \frac{1}{2} \gamma \varepsilon\right) \quad (3.47)$$

Table 3-1			
ω	A Fixed-Base Structure	A_s Isolated Structure	A_b Isolated Base
ω_b^*	--	$0(1)$	$\frac{1}{2\beta_0} = 0\left(\frac{1}{\varepsilon}\right)$
ω_s	$\frac{1}{2\beta_1} = 0\left(\frac{1}{\varepsilon}\right)$	$0(\varepsilon)$	$0(1)$
ω_s^*	$0(\varepsilon)$	$0(1)$	$0(1)$

$$A_s = \left| \frac{v_s}{u_g} \right| = \left| \phi_s^1 \frac{L_1 \omega^2}{(\omega_b^{*2} - \omega^2) + i2\omega_b^* \omega \beta_b^*} + \frac{L_2 \omega^2}{(\omega_s^{*2} - \omega^2) + i2\omega_s^* \omega \beta_s^*} \right| \quad (3.48)$$

$$A_b = \left| \frac{v_b}{u_g} \right| = \left| \phi_b^1 \frac{L_1 \omega^2}{(\omega_b^{*2} - \omega^2) + i2\omega_b^* \omega \beta_b^*} + \phi_b^2 \frac{L_2 \omega^2}{(\omega_s^{*2} - \omega^2) + i2\omega_s^* \omega \beta_s^*} \right| \quad (3.49)$$

$$A_s = \left| \varepsilon \frac{(1-\gamma\varepsilon)\omega_b^{*2}}{i2\omega_b^{*2}\beta_b^*} - \frac{1}{\gamma} \frac{[1-(1-\gamma)\varepsilon]\gamma\varepsilon\omega_b^{*2}}{(\omega_s^{*2} - \omega_b^{*2}) + i2\omega_s^*\omega_b^*\beta_s^*} \right| \quad (3.50)$$

$$A_s = \frac{\varepsilon}{2\beta_b^*} \quad (3.51)$$

$$A_b = \left| \frac{1-\gamma\varepsilon}{2\beta_b^*} + \frac{\gamma\varepsilon^2}{(1-\varepsilon)+i\varepsilon} \right| \quad (3.52)$$

$$A_b = \frac{1-\gamma\varepsilon}{2\beta_b(1-\frac{3}{2}\gamma\varepsilon)} = \frac{1}{2\beta_b} \left(1 + \frac{1}{2}\gamma\varepsilon\right) \quad (3.53)$$

$$A_s = (1-(1-\gamma)\varepsilon) \frac{\varepsilon}{2\beta_s^*} \quad (3.54)$$

$$A_b = 1 + \frac{1}{2} \frac{\gamma^2 \varepsilon^2}{(2\beta_s^*)^2} \quad (3.55)$$

$$A_s = \omega^2 \varepsilon \left[\frac{(\omega_s^{*2} - \omega_b^{*2})^2 + \omega^2 (2\omega_s^* \beta_s^* - 2\omega_b^* \beta_b^*)^2}{[(\omega_b^{*2} - \omega^2)^2 + 4\omega_b^{*2} \omega^2 \beta_b^{*2}][(\omega_s^{*2} - \omega^2)^2 + 4\omega_s^{*2} \omega^2 \beta_s^{*2}]} \right]^{\frac{1}{2}} \quad (3.56)$$

$$A_b = \omega^2 \left[\frac{(\omega_s^{*2} - \omega_b^{*2})^2 + \gamma \varepsilon \omega^2 (2\omega_s^* \beta_s^* - 2\omega_b^* \beta_b^*)^2}{[(\omega_b^{*2} - \omega^2)^2 + 4\omega_b^{*2} \omega^2 \beta_b^{*2}][(\omega_s^{*2} - \omega^2)^2 + 4\omega_s^{*2} \omega^2 \beta_s^{*2}]} \right]^{\frac{1}{2}} \quad (3.57)$$

$$q_1 = -\frac{L_1}{\omega_b^*} \int_0^t \ddot{u}_g(t-\tau) e^{-\omega_b^* \beta_b^* \tau} \sin \omega_b^* \tau d\tau \quad (3.58)$$

$$q_2 = -\frac{L_2}{\omega_s^*} \int_0^t \ddot{u}_g(t-\tau) e^{-\omega_s^* \beta_s^* \tau} \sin \omega_s^* \tau d\tau \quad (3.59)$$

$$|q_1|_{\max} = L_1 S_D (\omega_b^*, \beta_b^*) \quad (3.60)$$

$$|q_2|_{\max} = L_2 S_D (\omega_s^*, \beta_s^*) \quad (3.61)$$

$$|v_s|_{\max} = \left\{ (\phi_s^1 q_{1\max})^2 + (\phi_s^2 q_{2\max})^2 \right\}^{1/2} \quad (3.62)$$

$$|v_b|_{\max} = \left\{ (\phi_b^1 q_{1\max})^2 + (\phi_b^2 q_{2\max})^2 \right\}^{1/2} \quad (3.63)$$

where now:

$$q_{1\max} = L_1 \frac{1}{\omega_b^{*2}} S_A (\omega_b^*, \beta_b^*)$$

and

$$q_{2\max} = L_2 \frac{1}{\omega_s^{*2}} S_A (\omega_s^*, \beta_s^*)$$

$$|v_s|_{\max} = \left\{ \varepsilon^2 (1 - \gamma \varepsilon)^2 \frac{S_A^2(\omega_b^*, \beta_b^*)}{\omega_b^{*4}} + \frac{1}{\gamma^2} (1 - (1 - \gamma) \varepsilon)^2 \gamma^2 \varepsilon^2 (1 - 2\gamma \varepsilon)^2 \frac{S_A^2(\omega_s^*, \beta_s^*)}{\omega_s^{*4}} \right\}^{1/2} \quad (3.64)$$

$$|v_b|_{\max} = \left\{ \frac{(1 - \gamma \varepsilon)^2 S_A^2(\omega_b^*, \beta_b^*)}{\omega_b^{*4}} + \frac{\gamma^2 \varepsilon^2 (1 - 2\gamma \varepsilon)^2 S_A^2(\omega_s^*, \beta_s^*)}{\omega_s^{*4}} \right\}^{1/2} \quad (3.65)$$

$$S_A(\omega, \beta) = \omega S_V \quad (3.66)$$

$$|v_s|_{\max} = \varepsilon \left\{ (1 - \gamma \varepsilon)^2 \frac{\omega_b^{*2}}{\omega_b^{*4}} + (1 - (1 - \gamma) \varepsilon)^2 \frac{\omega_s^{*2}}{\omega_s^{*4}} \right\}^{1/2} S_V = \varepsilon \frac{S_V}{\omega_b} = \varepsilon S_D(\omega_b, \beta_b) \quad (3.67)$$

$$|v_b|_{\max} = \left\{ \frac{(1-\gamma\varepsilon)^2 \omega_b^{*2}}{\omega_b^{*4}} + \frac{\gamma\varepsilon^2 \omega_s^{*2}}{\omega_s^{*4}} \right\}^{\frac{1}{2}} S_V = \frac{S_V}{\omega_b} = S_D(\omega_b, \beta_b) \quad (3.68)$$

$$C_s = \frac{k_s v_s}{m} = \omega_s^2 v_s \quad (3.69)$$

$$C_s = \omega_s^2 S_D(\omega_s, \beta_s) = S_A(\omega_s, \beta_s) \quad (3.70)$$

$$C_s = \omega_s^2 \left\{ \frac{\varepsilon^2 (1-\gamma\varepsilon)^2 S_A^2(\omega_b^*, \beta_b^*)}{\omega_b^{*4}} + \frac{\varepsilon^2 [1-(1-\gamma)\varepsilon]^2 S_A^2(\omega_s^*, \beta_s^*)}{\omega_s^{*4}} \right\}^{\frac{1}{2}} \quad (3.71)$$

Recalling that $\omega_b^{*2} = \omega_b^2 (1-\gamma\varepsilon)$ and $\omega_s^{*2} = \frac{\omega_s^2 (1+\gamma\varepsilon)}{1-\gamma}$, we obtain:

$$C_s = \varepsilon \left\{ \frac{(1 - \gamma \varepsilon)^2 S_A^2(\omega_b^*, \beta_b^*)}{(1 - \gamma \varepsilon)^2 \varepsilon^2} + \frac{[1 - (1 - \gamma) \varepsilon]^2 S_A^2(\omega_s^*, \beta_s^*)}{\frac{(1 + \gamma \varepsilon)^2}{(1 - \gamma)^2}} \right\}^{1/2}$$

$$= \left\{ S_A^2(\omega_b^*, \beta_b^*) + \varepsilon^2 (1 - \gamma)^2 (1 - 2\varepsilon) S_A^2(\omega_s^*, \beta_s^*) \right\}^{1/2} \quad (3.72)$$

$$C_s = \omega_b S_V (1 + \varepsilon^2 (1 - \gamma)^2 \frac{\omega_s^{*2}}{\omega_b^2})^{1/2}$$

$$= S_A(\omega_b, \beta_b) (1 + (1 - \gamma) \varepsilon)^{1/2}$$

$$\frac{S_A(\omega_b, \beta_b)}{S_A(\omega_s, \beta_s)}$$

**BASE ISOLATION
OF
ROCKWELL BUILDING**

by

**Gary C. Hart
Civil Engineering Department
University of California at Los Angeles**

THE ROCKWELL BUILDING

1. 1960'S CONCRETE FRAME
2. MID-RISE
3. SEISMIC ENVIRONMENT
4. BUSINESS INTERRUPTION

CRITICAL ISSUES

1. EXISTING BUILDING CAPACITY
FOR SELECTED LIMIT STATES
2. PERFORMANCE CRITERIA
FOR LIMIT STATE
3. STRUCTURAL ANALYSIS
4. QUALITY CONTROL

ROCKWELL PROJECT PLAN HART CONSULTANT GROUP, INC.

1. PROJECT PLANNING

- define tasks
- define responsibilities
- define time line

2. EXISTING PHYSICAL CONDITION OF BUILDING

- existing plan review
- measurement of as-built building dimension
- plan and observe material testing
- plan and observe structural member exposure
- review report

3. PAST EARTHQUAKE EXPERIENCE OF BUILDING

- past earthquake ground motion at building.
- SAP90 model of the building for largest past earthquake
- estimate past building responses (base shear, disp, etc)
- write and review report

4. DEFINE BUILDING DESIGN CRITERIA

- select design limit states
- select building component and system response limits
- write and review criteria
- wind study / max credible wind loads

5. DESIGN EARTHQUAKE

- select geotechnical
- review scope of work
- review report

6. ISOLATOR DESIGN

- select locations
- determine axial loads
- select isolator stiffness
- select isolator yield level

7. STRUCTURAL MODEL OF ISOLATED BUILDING

- developed SAP90 model for the building
- review input to SAP90 model
- make preliminary runs with design earthquakes
- develop nonlinear model (DRAIN 2DX, LPM)
- review nonlinear model
- run nonlinear model for the performance evaluation
- identify critical structural areas
- isolator fine tune for torsion, uplift, etc.
- final SAP90 runs
- final nonlinear model run
- write and review building model report

8. STRUCTURAL DETAILING

- structural component attachment
- isolator attachment
- other details

9. UTILITIES, ELEVATORS AND OTHER NONSTRUCTURAL ITEMS

- identify plane of isolation
- identify locations where the items across isolation plan
- flex the utility lines and restrain them above and below
- treatment of nonstructural items as the case stands

10. CONSTRUCTION SERVICES

LOS ANGELES COUNTY FIRE COMMAND AND CONTROL FACILITY

R.E. Bachman

Fluor Daniel, Inc.

Irvine, CA

13 May 1992

Seismic Base Isolation for DOE Facilities

Marina Del Rey, CA

FACTS SHEET
and
DESCRIPTION
of the
Los Angeles County
Fire Command and Control Facility

LOS ANGELES COUNTY FIRE COMMAND
AND
CONTROL FACILITY

DESIGN FACT SHEET

Owner: County of Los Angeles Fire Department

Location: City Terrace area of Los Angeles
Approximately 1 mile southwest of I-10 and I-710 interchange

Size: Two stories with a total of 32,675 sq. feet, 188 feet by 84 feet in plan

Soil Conditions: Stiff clay fill underlain by siltstone bedrock

Structural System: Steel inverted chevron braced frame with metal deck. A conventional concrete slab is used for 1st and 2nd floors. A very light weight insulating concrete is used for the roof the slab, Building supported on 32 isolators.

Seismic Weight:

1st Floor	=	1665 kips
2nd Floor	=	1775 kips
Roof	=	<u>790 kips</u>
Total	=	4230 kips

Design Code: 1987 L.A. County Building Code.

Tentative Recommendations of the Base Isolation Subcommittee of the Seismology Committee of Northern California.

Design Criteria: Site Specific Ground Motion

500 year event, $PGA = 0.42\text{ g}$
1000 year event, $PGA = 0.50\text{ g}$

1. Structural members above isolator designed not to exceed code allowables with 1/3 increase for 500 year event. An equivalent base shear coefficient of 0.16 g was used for design. (0.15 g c.g. + 0.01 g torsional)
2. Isolator must accommodate displacement of 1000 year event. Isolator member stress must be less than yield. Maximum corner displacement for 1000 year event taken at 9.6 inches.
3. Minimum Rattlespace/utility flexibility taken as 15.5 inches.

DYNAMIC PROPERTIES:

Fixed Base Period	Transverse	=	0.40 seconds
	Longitudinal	=	0.36 seconds
	Vertical	=	0.08 seconds
	Torsional	=	0.13 seconds
Isolated Period	Transverse	=	2.2 seconds
	Longitudinal	=	2.2 seconds
	Vertical	=	0.11 seconds
	Torsional	=	1.9 seconds

DYNAMIC RESPONSE:

Maximum calculated displacement for 500 year event at:

center of floor	=	5.6 inches
corner	=	8.6 inches

Maximum calculated displacement for 1000 year event at:

center of floor	=	6.1 inches
corner	=	9.6 inches

ISOLATORS:

SIMPLIFIED DESIGN MODEL

Supplied by:	Fyfe and Associates												
Type:	High damped natural rubber with ultimate restraint system or exterior bearings.												
Properties:	At displacement of 8.6 inches: <table><tr><td>Effective lateral stiffness</td><td>=</td><td>3 k/in.</td></tr><tr><td>Vertical stiffness (exterior)</td><td>=</td><td>1470 k/in</td></tr><tr><td>Vertical stiffness (interior)</td><td>=</td><td>2738kips/in.</td></tr><tr><td>Initial stiffness (approximate)</td><td>=</td><td>8.6 k/in.</td></tr></table>	Effective lateral stiffness	=	3 k/in.	Vertical stiffness (exterior)	=	1470 k/in	Vertical stiffness (interior)	=	2738kips/in.	Initial stiffness (approximate)	=	8.6 k/in.
Effective lateral stiffness	=	3 k/in.											
Vertical stiffness (exterior)	=	1470 k/in											
Vertical stiffness (interior)	=	2738kips/in.											
Initial stiffness (approximate)	=	8.6 k/in.											

Loads: Maximum Isolator Load:

$$\begin{aligned}D + L &= 255.9 \text{ kips} \\D + L + E_H &= 292.0 \text{ kips} \\D + L + E_H + E_V &= 470.2 \text{ kips}\end{aligned}$$

Figure 1.0 ANALYTICAL MODEL OF FCCF BUILDING ON FIXED BASE

FIGURE 4. Idealized base isolator force deflection properties.

FIGURE 3. Comparison of 500 year and 1000 year Design Response Spectra with elastic spectra obtained from the Design Ground Motion Time History, SEGM-2.

Project:
Fire Command and
Control System

Location:
Los Angeles County,
California

Client:
Los Angeles County Fire
Department

Scope:
System Design and
Installation,
Architectural/Engineering
Design,
Construction
Monitoring

The Los Angeles County Fire Department (LACFD) instituted a four-year program to expand and modernize the capabilities of its fire and emergency communications system. When completed, the new Fire Command Control System will provide computer-aided dispatch/digital mobile radio communications to LACFD units in a 4,000 square mile area and modernize communications for over 750 department vehicles, 150 fire stations and 16 field camps. Under subcontract to Planning Research Corporation, Fluor Daniel was selected to engineer, furnish and install a major portion of the system.

Responsibilities were divided into three areas of activity: design

and construction monitoring of the Fire Command and Control Facility; design, installation and testing of the UHF digital dispatch link; and modernization of command and control systems.

The 33,000 square foot Fire Command and Control Facility is the center for communications activity including 'E-911' emergency calls, voice recorders, dispatch consoles and administrative telephone services. Special design considerations included the facility's need to function during and after a natural disaster. It was designed to be fully self-contained with special features such as emergency backup power system, diverse routing for telephone feeds, and a state-of-the-art base

Over

FLUOR DANIEL

islator foundation system (see photo above) to allow the facility to withstand a magnitude 8.3 earthquake.

To increase the ability to handle more emergency calls over a shorter period of time and save time in the process, a new digital UHF mobile radio dispatch data link was designed and installed by Fluor Daniel. The system, controlled from the Fire Command and Control Facility's operations center, provides dispatch/data

communications with fire stations, remote fire camps, and LACFD vehicles equipped with new mobile digital terminals.

Approximately 23 major command and control subsystems were also upgraded, including VHF voice radio, various emergency radios, private branch exchange (PBX) switch, Enhanced 911, alarm and security, paging and a complete emergency standby power system.

for Command & Control Communications Facility

February 12, 1992

History and Future

On October 23, 1973, the Board of Supervisors, in response to serious overloading of the fire dispatching communication system, directed the Fire Chief to institute an engineering study to identify the Fire Department's communications needs. On June 18, 1974, the Board approved a contract with Public Safety Systems Inc. to design a 470 MHz Mobile Radio System and new Computer Aided Dispatch System.

With the passage of the property tax limit initiative in 1978, the project was placed on hold until new funding could be determined.

In 1984, Compass Consulting Group was retained to review the original plan and develop a revised program for implementing the Fire Command and Control System. Compass Consulting found that our current system was failing to meet the requests for emergency assistance from the public. They developed a request for proposals for a new system that included a turnkey contract to design a 32,000 square-foot facility consolidating the three existing dispatch centers into one seismically safe building, a Mobile Digital System, a state-of-the-art Computer Aided Dispatch System, and improved communications. Legal restrictions required that the actual building construction be a separate contract.

On December 15, 1987, the Board approved a contract with the PRC Public Management Services to design and implement the new Fire Command and Control System. The facility construction contract was awarded on March 14, 1988 to Shirley Bros., Inc. The total project budget was nearly 37 million dollars.

The design requirements call for a maximum dispatch time of less than one minute and 25 seconds 99 percent of the time, as compared to peak hour average of seven minutes for current dispatches. The completed 32,675 square-foot, two-story building is the first facility in the United States where base isolation seismic design for earthquake protection has been incorporated into the design and development of the structure. The building is designed to reduce seismic forces so that the building will remain functional after a severe major earthquake.

All emergency equipment has mobile digital terminals installed along with 150 administrative sites for a total of 750 terminals, making this one of the largest systems in the world. The new system is designed to meet the Department's communications needs well into the twenty-first century.

USC UNIVERSITY HOSPITAL

KPFF Consulting Engineers
2450 Broadway, Suite 570, Santa Monica, CA 90404

Phone (310) 828-1536
Fax (310) 828-9492

USC UNIVERSITY HOSPITAL

PROJECT SUMMARY

Project:	USC University Hospital
Location:	Los Angeles, CA
Owner:	National Medical Enterprises
Consulting Architect:	Sherwin E. Small, AIA
Architect:	Rees/Tyler, An Association
Structural Engineer:	KPFF Consulting Engineers
Geotechnical Engineer:	LeRoy Crandall & Associates
General Contractor:	J.A. Jones Construction Co.
Base Isolation Supplier:	Dynamic Isolation Systems, Inc.

This facility is serving as the primary teaching hospital for the USC Medical School. It is a 350,000 square foot, eight story structure which is the first base isolated hospital to be designed and constructed in the world.

Site constraints, architectural, and programming requirements dictated a highly irregular floor plan for this facility. The dynamic response of the conventional fixed base structure was characterized by significant coupling between the translational and torsional modes of vibration. In order to maximize the probability of maintaining the continuity of operations of the facility in the event of a major earthquake, and in order to improve the dynamic structural response of the facility, base isolation devices were incorporated into the design of the structure.

A project specific design criteria was developed by KPFF Consulting Engineers in collaboration with the California Office of the State Architect and their "Blue Ribbon" Peer Review Panel. This design criteria has served as the model for the current version of the California Hospital Base Isolation Design Guidelines.

Shown below are summaries of the major design issues which pertained to the project.

Base Isolation Feasibility Study

- A feasibility study was conducted in order to quantify the costs and benefits associated with the conventional fixed base building and the base isolated building.
- Analytical models were set up for each of the two structural alternatives, and the dynamic response of each of the two alternatives was quantified based on the application of the design basis earthquake.
- Cost comparisons were made for each of the two structural alternatives based on both initial construction cost and life cycle costs, including an estimate of potential earthquake damage.
- Feasibility Study Results:
 - The dynamic response of the base isolated structure was superior to that of the conventional fixed base structure; base isolation effectively de-coupled the translational and torsional modes of response.
 - Initial construction costs of the two structural alternatives were essentially equal.
 - The life cycle cost of the base isolated structural alternative was significantly less than the conventional fixed base alternative due to greatly reduced projected earthquake damage.

Site Characteristics

- The site is located approximately ten miles east of downtown Los Angeles.
- The site is characterized as a rock site (S1).
- The site is characterized as a "near-fault" site, being situated within approximately ten kilometers of the Newport-Inglewood fault
- Design Basis Earthquake:
 - 1.2 x ATC - 3, .4 g, S1 Spectrum
- Spectrum compatible time histories generated for building analyses.

L.A. Aerial Photography, Inc. Los Angeles

USC UNIVERSITY HOSPITAL UNDER CONSTRUCTION

TYPICAL FLOOR PLAN

Structural Performance

- Fundamental isolated period of vibration:..... 2.3 seconds.
- Base shear:..... .14 w
- Maximum analytical displacement at base level diaphragm:..... 7"
- Design Displacement:..... 10 - 1/2"
- Fundamental period of vibration of fixed base superstructure:..... 0.7 seconds

Structural Design

- Superstructure designed to provide essentially elastic response to application of design basis earthquake.
- Lateral force resisting system consists of concentric steel braced frames around perimeter of the structure.
- "Necked-down" region of diaphragms reinforced with redundant steel cross-bracing.
- Concrete basement level flat slab utilized as "table-top" for base isolation system below.
- Concrete perimeter beams, integral with concrete flat slab, at basement level directly below braced frame columns sized to resist overturning forces and redistribute uplift to "no-tension" bearing connections below.

Structural Analysis

- Complete member-by-member model of superstructure and isolator system formulated using computer program "ANSR".
- "ANSR" model served as the basis for non-linear time history analyses.
- Superstructure member stresses checked via the use of an equivalent linear model using the computer program "ETABS".
- Separate "SAP" models used to assess diaphragm stresses in "necked-down" region.

Base Isolation System

- Combination of lead-rubber and elastomeric bearings utilized.
- Lead-rubber bearings located directly below perimeter braced frames in order to maximize energy dissipation, minimize torsion, and minimize demand on basement level diaphragm.
- Typical bearing sizes: 22" and 26" square by 14" high
5" diameter lead core for bearings below braced frames
- Bearing connections to structure above and foundation below such that individual bearings can be removed, tested, and replaced at any time.

BRACED FRAME ELEVATION

ISOLATOR IN PLACE

INTERIOR ISOLATOR BELOW

INTERIOR COLUMN ABOVE ISOLATOR

EXTERIOR ISOLATOR BELOW

EXTERIOR BRACED FRAME ABOVE ISOLATOR

ISOLATOR BEING TESTED

USC
UNIVERSITY
HOSPITAL

Richard K. Eamer Medical Plaza

Prepared by

J.A. JONES CONSTRUCTION COMPANY
Los Angeles, California

DOCUMENTATION
DATE 5-25-82

DOCUMENTATION
DATE 5-25-82

DOCUMENTATION
DATE 6-23-89

DOCUMENTATION
DATE 7-24-89

DOCUMENTATION

DATE 1/24/09

DOCUMENTATION
DATE 7-29-89

DOCUMENTATION
DATE 7-24-89

DOCUMENTATION
DATE 5-23-89

DOCUMENTATION

DATE 9-22-89

DOCUMENTATION

DATE 10-20-89

DOCUMENTATION
DATE 11-21-89

DOCUMENTATION

DATE 12-21-89

DOCUMENTATION

DATE 4-22-98

DOCUMENTATION

DATE 10.26.96

Seismic Design Guidance for DOE Facilities — UCRL-15910

Bob Murray
Lawrence Livermore National Laboratory

**Workshop on
Seismic Base Isolation
for
Department of Energy Facilities**

**Marina Del Rey Marriott
Marina Del Rey, California**

May 13-15, 1992

The Guidelines: UCRL-15910

- Provide the natural phenonema design and evaluation basis for DOE facilities
 - Performance based guidelines for earthquakes, winds, and floods such that specified levels of protection are achieved
- Applies to structures, systems and, components
 - 4 sets of deterministic procedures ranging:
 - from those provided by the UBC for normal facilities
 - to near those provided by nuclear power plant criteria

**Required by GDC 6430.1A for new facilities
DOE Developing Overall NPH Order**

The Guidelines fits into the overall DOE safety plan

Approach and philosophy for UCRL-15910

- **Graded Approach**
 - Different sets of criteria to apply depending on cost, importance, mission, level of safety
 - Range from low probability of damage/failure to very high confidence of extremely low probability of damage/failure
- **Performance Goal Philosophy**
 - Specification of NPH hazard probability to define loadings
 - Deterministic design/evaluation procedures with controlled conservatism to meet probabilistic performance goal
 - Means of achieving consistent criteria for all NPH at all locations across U.S.

Motivation for graded approach

- **Graded approach is common practice**
 - **UBC**
 - **NRC**
 - **DOD**

- **Graded approach enables facility design/evaluation consistent with cost, mission, and hazard**
 - **Few "reactor" facilities**
 - **Many facilities with wide variety of risk potential**

- **Graded approach enables cost-benefit studies and establishment of priorities for existing facilities**
 - **Few new designs**
 - **Evaluation of existing facilities requires:**
 - **cost benefit consideration**
 - **prioritize upgrading and retrofit**

Motivation for performance goals

- UBC approach (recent)
- Used for DOE NPRs
- New NRC approach (e.g. ALWR & 10 CFR 100 Appendix B)
- Quantifies graded approach
- Provides means for meeting DOE safety goals
- Enables development of consistent criteria
 - Across earthquakes, winds, and floods
 - Facilities across U.S.

Performance Goal == Annual probability of exceeding a specified level of facility damage due to Natural Phenomena Hazards

UCRL-15910 design and evaluation guidelines are based on these two concepts

**Consistent
Approach**

**Performance Goals,
Categories &
Probabilistic
Hazard Assessment**

**Simplified
Approach**

**Deterministic
Criteria for Design
& Evaluation**

The guidelines provide a consistent level of protection from natural phenomena

Earthquake

Wind

Flood

**Consistent methodology is used to assess
hazards for DOE sites throughout the U.S.**

**Most DOE facilities
are existing**

**Variable hazards
across the country**

We have developed a simplified approach for Natural Phenomena Hazards protection

Developed inventory of
existing critical facilities

Developed hazard models for each site

Return Period

Seismic

Wind

Flood

Evaluate each facility on a uniform basis

Select
category

Determine
hazard level

Evaluate
facility

Determine
acceptability

We have identified a wide variety of facilities

We established four categories

Category	Description	Hazard-response goal
General		Protect personnel from death and injury
Important or low hazard		Permit functioning during and immediately after event
Moderate hazard		Confine contents to protect employees, the public, and the environment.
High hazard		Confine contents to protect employees, the public, and the environment. <i>Very high confidence of confinement.</i>

Performance goals were assigned to each category by consensus

PERFORMANCE GOALS

CATEGORY	DESCRIPTION	PERFORMANCE GOALS
GENERAL USE	MAINTAIN OCCUPANT SAFETY	10^{-3} OF THE ONSET OF MAJOR STRUCTURAL DAMAGE → <i>UBC NORMAL</i>
IMPORTANT OR LOW HAZARD	OCCUPANT SAFETY, CONTINUED OPERATION, MINIMAL INTERRUPTION	5×10^{-4} OF COMPONENT DAMAGE (FUNCTION) → <i>UBC ESSENTIAL</i>
MODERATE HAZARD	OCCUPANT SAFETY, CONTINUED FUNCTION, HAZARD CONFINEMENT	10^{-4} OF COMPONENT DAMAGE (FUNCTION) → <i>INTERMEDIATE</i>
HIGH HAZARD	OCCUPANT SAFETY, CONTINUED FUNCTION, VERY HIGH CONFIDENCE OF HAZARD CONFINEMENT	10^{-5} OF COMPONENT DAMAGE (FUNCTION) → <i>~NRC</i>

UCRL-15910 categories are changing in the revision

- **Change Usage Categories to Performance Categories**
 - **Performance categories will have performance goals in terms of probability of SSC* damage**
 - not facility damage
 - not consequences of damage
 - **Project is underway on guidance for selecting performance categories for SSCs**
 - linkage between DOE safety goals and UCRL-15910 performance categories must be established
- **Add two new categories**
 - one below general use
 - one above high hazard

***SSC = Structure, System, or Components**

We have developed a simplified approach for Natural Phenomena Hazards protection

Developed inventory of existing
critical facilities

Develop hazard models for each site

Return Period

Seismic

Wind

Flood

Evaluate each facility on a uniform basis

Select
category

Determine
hazard level

Evaluate
facility

Determine
acceptability

**Simplified
Approach**

We developed hazard models for DOE sites

Earthquake

**Seismic Hazards
Defined**

(Tera Corp.)

**UCRL-53582,
Rev. 1**

Wind

**Wind/Tornado
Hazards
Defined**

**(McDonald &
Fujita)**

**UCRL-53526
Rev. 1**

Flood

**Flood Hazards
Defined
for
Some Sites**

**(J.R. Benjamin &
Associates)**

UCRL-5385

***PROBABILISTIC
BASED***

What are hazard models?

Seismic

Probability of Exceedance = 1/Return Period

Wind/tornado

Flood

DOE seismic hazard assessments should be updated

- **Assessments as summarized in Coats and Murray are based on 10 to 15 year old technology**
- **Reference to seismic input from the past studies will be removed from UCRL-15910**
- **Seismic hazard assessments will become the responsibility of individual sites following overall DOE guidelines and subject to DOE review**
- **Interim mean seismic hazard level will be established by the DOE approach**

We have developed a simplified approach for Natural Phenomena Hazards protection

Developed inventory of existing
critical facilities

Develop Hazard Models for each site

Return Period

a

Seismic

v

Wind

h

Flood

Evaluate each facility on a uniform basis

Select
category

Determine
hazard level

Evaluate
facility

Determine
acceptability

Facility Management selects a performance category based on SAR considerations

SAR Considerations

- Importance
- Cost
- Mission dependence
- Impact
 - personnel
 - public
 - environment

100

Category	Numerical Targets	Comparability
General Use	10^{-3}	UBC normal
Important Low Hazard	5×10^{-4}	UBC essential
Moderate Hazard	10^{-4}	Intermediate
High Hazard	10^{-5}	Near NRC

Determine the hazard loading for facilities being designed or evaluated

Procedures were developed to determine response and acceptability

NPH Design Criteria is a system!

UCRL-15910 provisions are based on Industry Codes and Standards

- **Uniform Building Code
(Consistent with NEHRP Provisions)**
- **ASCE 4-86**
- **ASCE 7-88**
- **ACI Code**
- **AISC Code**
- **DOD Seismic Design of Essential Buildings**
- **NUREG-0800 (Standard Review Plan)**

This approach has:

- Different categories of performance
 - 4 set of guidelines provided
 - Performance goals
UBC → near NRC

- *Probabilistic* hazard loading

- *Deterministic* evaluation methods

General areas where UCRL-15910 modifications or additions are planned

- **Categorization**
- **Treatment of Uncertainties**
- **Update of Seismic Hazard Assessment**
- **Existing Facilities**
- **Subsystems and Equipment**
- **Incorporate Review Comments**

**Workshop Planned for
September 1-4, 1992
in San Diego**

References

**Design and Evaluation Guidelines for Department of Energy
Facilities Subjected to Natural Phenomena Hazards**

*Robert P. Kennedy, et-al
UCRL-15910, June 1990*

Phenomenal News Volume 3, Number 2, January 1992

**Implementation of Executive Order 12699
Seismic Safety of Federal and Federally Assisted
or Regulated New Building Construction**

Richard Wright, NIST

Phenomenal News Volume 3, Number 3, April 1992

The World of Building Codes

Diana Todd, NIST

DOE Natural Phenomena Hazards Project update—1992

Bob Murray, LLNL

Description of seismic hazard for your site

- **Ground accelerations for DOE sites**
- **Response spectra shape**
- **Example: Ground motion description for a High Hazard Facility at LLNL**
- **Combination of earthquake response**

Maximum horizontal ground surface instrumental accelerations (in g) at DOE sites

DOE Site	Hazard Annual Probability of Exceedance		
	2x10 ⁻³	1x10 ⁻³	2x10 ⁻⁴
Kansas City Plant	.08	.10	.17
Los Alamos National Laboratory	.18	.22	.38
Mound Laboratory	.12	.15	.23
Pantex Plant	.08	.10	.17
Rocky Flats Plants **	.13	.15	.21
Sandia National Laboratories, Albuquerque	.17	.22	.38
Sandia National Laboratories, Livermore	.41	.48	.68
Pinellas Plant, Florida	.04	.05	.09
Argonne National Laboratory-East	.09	.12	.21
Argonne National Laboratory-West	.12	.14	.21
Brookhaven National Laboratory	.12	.15	.25
Princeton National Laboratory	.13	.16	.27
Idaho National Engineering Laboratory	.12	.14	.21
Feed Materials Production Center	.10	.13	.20
Oak Ridge National Laboratory, X-10, K-25, and Y-12	.15	.19	.32
Paducah Gaseous Diffusion Plant	.33	.45	*
Portsmouth Gaseous Diffusion Plant	.08	.11	.17
Nevada Test Site	.21	.27	.46
Hanford Project Site	.09	.12	.17
Lawrence Berkeley Laboratory	.55	.64	*
Lawrence Livermore National Laboratory (LLNL)	.41	.48	.68
LLNL, Site 300-854	.32	.38	.56
LLNL, Site 300-834 & 836	.28	.34	.51
Energy Technology and Engineering Center	.53	.59	*
Stanford Linear Accelerator Center	.45	.59	*
Savannah River Plant	.08	.11	.19

* Value not available and must be determined for High Hazard facilities at these sites

** Bedrock slopes at Rocky Flats. This value is surface acceleration at an average soil depth at this site.

There is conservatism in peak instrumental ground motion

- **Hazard curves from UCRL-15910 are in terms of the largest peak acceleration (PGA) from a 3-axis instrument on a small pad at the free ground surface**
- **This value may be an excessively conservative estimate of actual input to a stiff, massive structure or of earthquake damage potential**

Ground motion components

- Other components of earthquake ground motion will be less than the largest peak acceleration recorded from a 3-axis instrument

Ground motion components for General Use and Important or Low Hazard facilities

- Use peak instrumental acceleration in one horizontal direction
- Second orthogonal horizontal direction is handled by considering response to be 30 percent of maximum horizontal direction response
- Vertical motion is not generally considered

$$H_1 = 1.0 \times \text{Table Value}$$

$$H_2 = 0.3 \times \text{Table Value}$$

$$V = \text{usually not needed}$$

Ground motion components for Moderate and High Hazard facilities

- Use mean peak acceleration in both horizontal directions
- Vertical motion may be taken as 2/3 of mean peak acceleration
- Responses from three components combined statistically

$$H_1 = 1.0 \times \text{Table Value}$$

$$H_2 = 0.8 \times \text{Table Value}$$

$$V = 0.6 \times \text{Table Value}$$

Mean Peak Acceleration =

$$\left(\frac{1.0 + 0.8}{2} \right) \text{Table Value} = 0.9 \times \text{Table Value}$$

Vertical Acceleration =

$$\frac{2}{3} (0.9) \text{Table Value} = 0.6 \times \text{Table Value}$$

$$H_1 = H_2 = 0.9 \times \text{Table Value}$$

$$V = 0.6 \times \text{Table Value}$$

Newmark & Hall response spectra

1. Select soil type

Competent soil $V_s < 3500$ ft/sec

$$a_g = \text{PGA (g)}$$

$$v_g = 48 a_g \text{ (in/sec)}$$

$$d_g = 36 a_g \text{ (in)}$$

Rock $V_s > 3500$ ft/sec

$$a_g = \text{PGA (g)}$$

$$v_g = 36 a_g \text{ (in/sec)}$$

$$d_g = 20 a_g \text{ (in)}$$

2. Determine maximum values

50% spectra (Median Spectra)

$$a_{\max} = a_g (3.21 - 0.68 \ln \beta)$$

$$v_{\max} = v_g (2.31 - 0.41 \ln \beta)$$

$$d_{\max} = d_g (1.82 - 0.27 \ln \beta)$$

β = Damping (in %)

NUREG/CR-0098 response spectra shape

3. Control Points

Horizontal Spectra

For a_g Peak Ground Motion

Control Point	Frequency (Hz)	Period (sec)	Spectral Acceleration (g)
E	0.1	10	$\frac{0.395 d_{\max}}{g}$
D	$\frac{v_{\max}}{2\pi d_{\max}}$	$\frac{2\pi d_{\max}}{v_{\max}}$	$\frac{v_{\max}^2}{g d_{\max}}$
C	$\frac{g a_{\max}}{2\pi v_{\max}}$	$\frac{2\pi v_{\max}}{g a_{\max}}$	$a_{\max}$
B	8.0	0.125	$a_{\max}$
A	33.0	0.030	a_g
A'	100.0	0.010	a_g

Vertical spectra

S_a (vertical control point) = $2/3 S_a$ (horizontal control point), at same frequency

Example problem: Evaluation of earthquake components

- Consider ground motion at a facility at the Lawrence Livermore National Laboratory (LLNL) site
- Peak instrumental acceleration evaluated from the table
- Consider ground motion for a High Hazard facility

Category	Hazard Probability	Average Return Period	Peak Instrumental Acceleration
High Hazard	2×10^{-4}	5000 year	0.68g

Component	Mean Peak & Vertical	Largest Peak, 2nd Peak & Vertical
Largest Horizontal	$0.9(0.68) = 0.61g$	0.68g
Second Horizontal	$0.9(0.68) = 0.61g$	$0.8(0.68) = 0.54g$
Vertical	$0.6(0.68) = 0.41g$	$0.6(0.68) = 0.41g$

Example problem: Spectral shape

1. Use soil

$$a_g = 0.61g$$

$$v_g = 48 \times 0.61 = 29.3 \text{ in/sec}$$

$$d_g = 36 \times 0.61 = 22.0 \text{ in}$$

2. For 5% Damping

$$a_{\max} = 0.61 (3.21 - 0.68 \ln 5) = 1.29g$$

$$v_{\max} = 29.3 (2.31 - 0.41 \ln 5) = 48.35 \text{ in/sec}$$

$$d_{\max} = 22.0 (1.82 - 0.27 \ln 5) = 30.48 \text{ in}$$

3. Control Points

$$T_E = 10 \text{ sec}$$

$$A_E = \frac{0.395 \times 30.48}{386.4} = 0.03g$$

$$T_D = \frac{2\pi (30.48)}{48.35} = 3.96 \text{ sec}$$

$$A_D = \frac{(48.35)^2}{(386.4) (30.48)} = 0.20g$$

$$T_C = \frac{2\pi (48.35)}{(386.4) (1.29)} = 0.61 \text{ sec}$$

$$A_C = 1.29g$$

$$T_B = 0.125 \text{ sec}$$

$$A_B = 1.29g$$

$$T_A = 0.030 \text{ sec}$$

$$A_A = 0.61g$$

$$T_{A'} = 0.010 \text{ sec}$$

$$A_{A'} = 0.61g$$

Example: Spectral shape

Combination of earthquake response

- **Components are essentially statistically independent**
- **Small probability that peak responses from each direction will occur at the same time**
- **UBC provisions for General Use & Important or Low Hazard facilities**
 - **In general, responses from different directions are not combined**
 - **In those cases where combination is required:**
 - * **100% in one horizontal direction and 30% in the other horizontal direction**
 - * **SRSS is an acceptable alternative**
 - * **Vertical component not combined**
- **Moderate & High Hazard facilities**
 - **when maximum in one direction occurs, responses of other two components are 40% of the maximum**
 - **or SRSS of three components**

Example: Earthquake response combination

- Column axial forces from dynamic analyses in each direction

$$P (DL + LL) = 25 \text{ kips}$$

$$P (EQ - NS) = 50 \text{ kips}$$

$$P (EQ - EW) = 40 \text{ kips}$$

$$P (EQ - V) = 10 \text{ kips}$$

- 100-40-40 rule

$$\begin{aligned} P_{\max} &= P(DL+LL) + P(EQ-NS) + 0.4 (P(EQ-EW)) + 0.4 (P(EQ-V)) \\ &= 25 + 50 + 0.4 (40) + 0.4 (10) = 95 \text{ kips} \end{aligned}$$

- SRSS

$$P_{\max} = P(DL + LL)$$

$$+ \sqrt{P (EQ - NS)^2 + P(EQ - EW)^2 + P (EQ - V)^2}$$

$$= 25 + \sqrt{50^2 + 40^2 + 10^2} = 90 \text{ kips}$$

**WORKSHOP ON SEISMIC BASE ISOLATION
FOR DEPARTMENT OF ENERGY FACILITIES**

SEISMIC BASE ISOLATION SYSTEMS

Ralph W. Seidensticker

Argonne National Laboratory

**Marina Del Rey Marriott
Marina Del Rey, California
May 13-15, 1992**

SEISMIC BASE ISOLATION SYSTEMS

- **Overview of Isolator Design Concepts**
- **Description of Various Types of Isolation Systems**
- **Description of Isolator System Characteristics**

INTRODUCTION AND SCOPE

- **There are many ways to provide seismic isolation**
- **Several different devices have been proposed for the various isolation system concepts**
- **This presentation discusses several isolation systems, selected as representative of the variety of approaches used to achieve seismic isolation**
- **The isolation systems may be used for either new work or retrofit projects; they may also be used to isolate individual pieces of critical equipment**
- **General design considerations for the main components of each system are addressed**
- **Not included are costs and questions related to design of the isolated structure**

TOPICS INCLUDED FOR EACH ISOLATION SYSTEM

- **General description of the isolation system**
- **Description of special features of the system**
- **Description of how the isolation system works and the functions of major components of the isolators**
- **Discussion of significant response characteristics of the system to earthquake motions**
- **Discussion of failure modes and safety margins**
- **Comments on aging and environmental effects, e.g., temperature, water, chemical, etc.**

GENERAL REQUIREMENTS FOR ANY SEISMIC ISOLATION SYSTEM

- **Remains stable for required design loads and displacements**
- **Provides adequate margins of safety against failure**
- **Does not degrade under repeated cyclic loading**
- **Has clearly defined operating characteristics**
- **Has reliable and predictable performance under normal service loads and under design earthquake motions**
- **Has well certified fabrication process and quality control procedures**
- **Performance certified by adequate laboratory testing**
- **Isolators can be inspected, maintained, and replaced (if necessary)**

DOEWKSH.P.005

BASIC ELEMENTS OF SEISMIC ISOLATION SYSTEMS

- **A flexible mounting device which shifts the response of the structural system to very low frequencies; or**
- **A sliding mechanism which limits the forces which can be transmitted to the supported structure**
- **A damping device (or mechanism) to dissipate the ground motion energy and to control displacements of the isolators to acceptable limits**
- **A means (or mechanism) to provide rigidity under low lateral load demands (e.g., wind loads)**

- A - Sliding System (no restoring force)
- B - Bilinear System
- C - Linear System

IDEALIZED FORCE-DISPLACEMENT RELATIONSHIPS FOR VARIOUS ISOLATION SYSTEMS*

* ADAPTED FROM THE SEISMIC DESIGN HANDBOOK, EDITED BY FARZAD NAEIM, 1989.

TYPES OF ISOLATION CONCEPTS

- Flexible Mounting Systems
 - Elastomeric bearings (laminated steel-rubber bearings)
 - Sliding plates
 - Rollers and/or ball bearings
 - Helical steel coil springs
 - Sleeved piles
 - Rocking systems
 - Suspended floors
- Damping Devices/Mechanisms
 - High-damping rubber
 - Plastic deformation of a metal
 - Friction
 - Viscous fluid damping

SELECTED SEISMIC ISOLATION SYSTEMS FOR DISCUSSION

- **Elastomeric Bearings**
 - **Laminated steel-high damping rubber bearings**
 - **Laminated steel-rubber bearings with lead plug**
- **Sliding Systems**
 - **Friction Pendulum System (FPS)**
 - **Alexisismon System**
- **GERB System (helical steel coils with visco-elastic dampers)**

LAMINATED HIGH DAMPING RUBBER-STEEL ISOLATOR BEARINGS

LAMINATED HIGH DAMPING RUBBER-STEEL ISOLATOR

**Bolted Rubber
Bearing**

**Dowel Type
Rubber Bearing**

LAMINATED HIGH-DAMPING RUBBER-STEEL ISOLATORS GENERAL DESCRIPTION

- **The bearings are an integral unit - the flexibility and damping functions are contained within the bearing**
- **The bearings may be of dowelled or bolted design**
- **The rubber compound may be varied to achieve design requirements**
- **Provides isolation in horizontal direction only**
- **Bearings generally are very stiff in the vertical direction**
- **Outer protective (cover) layer can be of different compounds to enhance resistance to environmental effects**

LAMINATED HIGH DAMPING RUBBER-STEEL ISOLATORS

SHEAR STIFFNESS K_H AS A FUNCTION OF SHEAR STRAIN

LAMINATED HIGH DAMPING RUBBER-STEEL ISOLATORS

EQUIVALENT DAMPING COEFFICIENT, h_{eq} AS A FUNCTION OF SHEAR STRAIN

LAMINATED HIGH DAMPING RUBBER-STEEL ISOLATORS

TYPICAL HYSTERETIC LOADING CURVES

LAMINATED HIGH DAMPING RUBBER-STEEL ISOLATORS SPECIAL FEATURES/CONSIDERATIONS

- **Bearing response is non-linear**
- **Stiffness varies with horizontal displacement (shear strain)**
 - **For low displacements, stiffness is high and provides resistance to wind loads**
 - **At higher displacement, stiffness reduces significantly, resulting in lower frequency response of the isolated structure**
 - **For displacements two or three times design shear strain, the horizontal stiffness increases, thus increasing the frequency of the isolated structure**
- **Effective damping varies with horizontal displacement, but is generally 10% or greater in the design displacement region**
- **Tests show adequate factors of safety on failure for displacements beyond design displacement**
- **Bolted, or fixed, type of design can take some tension, thus accommodating uplift forces**
- **Has good fatigue resistance**
- **Requires care in fabrication to assure adequate bonding of steel shims and rubber**

LEAD-RUBBER ISOLATOR BEARINGS

LEAD-RUBBER ISOLATOR BEARINGS GENERAL DESCRIPTION

- **The bearings are an integral unit - flexibility and damping functions are contained within the bearing**
- **The bearings are generally designed as dowelled bearings**
- **The lead core is cylindrical in shape and composed of commercially pure lead to ensure predictable mechanical properties**
- **The lead core is elastic under low horizontal loads (e.g., wind) and becomes plastic under earthquake ground motions**
- **Provides isolation in the horizontal direction only**
- **Vertical stiffness is very high**
- **Outer protective (cover) layer can be of different compounds to enhance resistance to environmental effects**
- **The design is patented**

LEAD-RUBBER ISOLATOR BEARINGS

- Q_d = Characteristic strength (klps)
- F_1 = Yield force (klps)
- F_{max} = Maximum force (klps)
- K_d = Post-elastic stiffness (klp/inch)
- K_u = Elastic (unloading) stiffness (klp/inch) ($=6.5 K_d$)
- Δ_m = Maximum bearing displacement

LOAD DISPLACEMENT CHARACTERISTICS*

* FIGURE FROM HANDBOOK BY DYNAMIC ISOLATION SYSTEMS, INC., "DESIGN OF LEAD-RUBBER ISOLATION BEARINGS FOR BRIDGES"

LEAD-RUBBER ISOLATION BEARINGS

VARIATION OF DAMPING AND STIFFNESS

LEAD-RUBBER ISOLATOR BEARING

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TYPICAL HYSTERETIC LOADING CURVES

LEAD-RUBBER ISOLATOR BEARINGS SPECIAL FEATURES/CONSIDERATIONS

- Bearing response is non-linear
- Stiffness varies with horizontal displacement (shear strain)
 - For low displacement, stiffness is high and controlled by elastic response of rubber and lead, providing for resistance to wind loads
 - For large displacements the lead core will yield and behave plastically, resulting in lower frequency response of the isolated structure
- Effective damping is estimated to be from 20% to 40%, depending on the specific nature of the earthquake and the supported structure
- Tests show adequate factors of safety on failure for displacements beyond the design displacement
- Requires care in fabrication to assure adequate bonding of steel and rubber and tight fit of the central lead plug

SLIDING ISOLATION SYSTEMS THE ALEXISIMON SYSTEM

ALEXISIMON POT BEARINGS AND RUBBER SPRINGS

THE ALEXISMON SYSTEM GENERAL DESCRIPTION

- **The system separates the function of flexibility and restoring force; Teflon sliding bearings carry the vertical load, while rubber (or steel) springs provide horizontal restoring forces**
- **The horizontal rubber springs carry no vertical load; thus no concern for buckling**
- **The sliding bearing can accommodate some rotation at the vertical loads**
- **Connecting elements (i.e., seismic fuses) are used to prevent movement during low horizontal loads (e.g., wind loads)**
- **Provides isolation in the horizontal direction only**
- **The system is patented**

THE ALEXISISMON SYSTEM

LINEAR FORCE-DISPLACEMENT CHARACTERISTIC

THE ALEXISIMON SYSTEM SPECIAL FEATURES/CONSIDERATIONS

- **Separation of functions (i.e., separate vertical load bearings and horizontal springs) eliminates concerns over bearing buckling**
- **The fundamental response of the system to earthquake motions is generally a linear response (after seismic fuses break); the horizontal restoring force increases with increasing displacement**
- **Tests on systems using flat Teflon sliding bearings have shown a "stick-slip" behavior whenever reversals of motion of the supported mass occurs; this leads to a high frequency input to the isolated structure**

SLIDING ISOLATION SYSTEMS THE FRICTION PENDULUM SYSTEM (FPS)

THIS FIGURE FROM REPORT NO. UCB/EERC-87/01, "THE FPS EARTHQUAKE RESISTING SYSTEM, EXPERIMENTAL REPORT," BERKELEY, CALIFORNIA, JUNE, 1987.

THE FRICTION PENDULUM SYSTEM

a) Closed

b) Open

THESE FIGURES FROM REPORT NO. UCB/EERC-87/01, "THE FPS EARTHQUAKE RESISTING SYSTEM, EXPERIMENTAL REPORT," BERKELEY, CALIFORNIA, JUNE, 1987.

THE FRICTION PENDULUM SYSTEM (FPS) GENERAL DESCRIPTION

- **The FPS uses steel connections which feature an articulated friction slider on a spherical concave surface**
- **The FPS components have self-lubricating bearing materials and mating surfaces**
- **Some of the specific materials used and manufacturing specifications of the FPS components are proprietary; the concave surface is a hard-dense chrome over steel**
- **The connection is protected from the atmosphere by use of a gasketed joint**
- **Provides horizontal isolation only**
- **The system is patented**

THE FRICTION PENDULUM SYSTEM (FPS) PRINCIPLES OF OPERATION

PENDULUM MOTION

SLIDING PENDULUM MOTION

EQUATIONS: PERIOD $T = 2\pi\sqrt{r/g}$

STIFFNESS $k = W/r$

CENTERED POSITION

DISPLACED POSITION

THIS FIGURE FROM REPORT NO. UCB/EERC-87/01, "THE FPS EARTHQUAKE RESISTING SYSTEM, EXPERIMENTAL REPORT," BERKELEY, CALIFORNIA, JUNE, 1987.

THE FRICTION PENDULUM SYSTEM (FPS) HYSTERETIC LOOPS OF THE FPS

THESE FIGURES FROM REPORT NO. UCB/EERC-87/01, "THE FPS EARTHQUAKE RESISTING SYSTEM, EXPERIMENTAL REPORT," BERKELEY, CALIFORNIA, JUNE, 1987.

THE FRICTION PENDULUM SYSTEM (FPS) SPECIAL FEATURES/CONSIDERATIONS

- **The FPS connection is an integral unit; sliding surfaces, damping and restoring force are all located within the connection bearing**
- **The shifted natural period of vibration of the system is determined using the pendulum equation $(T = 2\pi\sqrt{r/g})$; it is independent of the mass of the supported structure**
- **The FPS system response is bi-linear**
- **The lateral stiffness of the system is directly proportional to the supported weight ($K = W/r$)**
- **The semi-spherical design of the articulated slider results in uniform pressure on mating surfaces; this results in smooth sliding motion and avoids problems such as stick-slip which may occur with flat sliding supports**
- **The center of internal stiffness coincides with the center of the supported mass; this virtually eliminates torsional effects due to structural eccentricities**

THE GERB SYSTEM

THE GERB SYSTEM

THIS FIGURE COURTESY OF GERB VIBRATION CONTROL SYSTEMS, INC., WESTMONT, ILLINOIS

DOEWSHP.033

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- DOEWKSHP.034

THE GERB SYSTEM LATERAL STIFFNESS

Lateral Stiffness

THIS FIGURE COURTESY OF GERB VIBRATION CONTROL SYSTEMS, INC., WESTMONT, ILLINOIS

DOEWKSH.P.035

THE GERB SYSTEM DAMPING RESISTANCE

Damping
Resistance

THIS FIGURE COURTESY OF GERB VIBRATION CONTROL SYSTEMS, INC., WESTMONT, ILLINOIS

THE GERB SYSTEM SPECIAL FEATURES/CONSIDERATIONS

- **The coil springs provide a flexible support (both horizontally and vertically) and the supported mass behaves as a rigid body**
- **The GERB support system results in translational and rotational displacements which may be coupled**
- **The rocking mode is generally governed by horizontal translation; the rocking amplitudes are usually small, and even negligible if the GERB unit is placed on the same level as the center of gravity of isolated heavy equipment (e.g., turbines)**
- **The viscoelastic dampers can provide damping of 20% to 30%**
- **The system provides isolation in both horizontal and vertical directions**
- **The system has been used for seismic/vibration protection of heavy critical equipment (e.g., main steam turbines)**

REF. PLICHON, 1975

REINFORCED ELASTOMER BEARING WITH FRICTION SURFACE

DOEWKSH.P.038

AT REST

ELASTOMER DISTORTION ONLY

ELASTOMER DISTORTION
+
PLATE SLIPPAGE

BEHAVIOR OF COMBINED ELASTOMERIC BEARING AND FRICTION PLATES

SEISMIC ISOLATION SYSTEMS SUMMARY

- Many types of seismic isolation systems have been used or proposed
- We have examined the overall behavior of several selected isolation systems to gain a perspective on the variety of choices available to the design engineer
- We have covered some of the special features of the selected isolation systems, but we have not included many important details needed to use these systems
- The final selection of an isolator system depends on many factors not covered in this session

Selection Criteria for Base Isolation

**John Ferritto
Naval Civil Engineering Laboratory**

Navy Exposure

- **102 Installations**

- **\$25-30 Billion**

The Navy has \$25 billion of facilities in seismically active regions. Each year \$200 million of new facilities are added to those areas. There are over 100 Naval activities in seismic Zones 3 and 4. There presently exists a critical threat to the fleet if major fleet support facilities are destroyed. The threat is especially great for West Coast activities where a single earthquake could cause serious damage to several bases. Many of the buildings at these installations were built without adherence to current seismic standards. The Navy, because of its waterfront mission, must site its facilities on low-lying coastal areas where fine-grained soil conditions are ordinarily marginal and extremely susceptible to large deformation under earthquake loads. High seismicity combined with marginal bearing and saturated soil conditions in areas susceptible to flooding make the Navy especially vulnerable to major damage. The combinations of location and large-size, high-mass structures require specialized technology which is not available from the civilian sector.

Earthquake Hazard Reduction Act (1977)

- **Hazard Reduction Program**
- **Identity Risk**
- **Federal Agencies Take Lead**
- **Contingency Plans**
- **R&D to Reduce Risk**

The Earthquake Hazards Reduction Act of 1977, and subsequent acts, intended to reduce the risks to life and property from earthquakes, directs Federal agencies to develop technical standards for critical facilities and to implement earthquake safety practices. The Naval Facilities Engineering Command (NAVFAC) tasked the Office of Naval Research (ONR) to form a panel of recognized experts to advise the Navy on techniques for providing protection against earthquake hazards. The panel believes that a carefully planned program of upgrading of the seismic resistance of selected facilities located in areas of high seismic activity is required to reduce the threat of loss of operational readiness. There presently exists a critical threat to the fleet if major West Coast fleet support facilities are destroyed. The threat is especially great for West Coast activities where a single event could cause serious damage to several bases.

SITE SEISMICITY ANALYSIS

Navy Standardized Procedures

Evaluate Geology and Tectonics

Define Faulting

Create Epicenter Data Base

Compute Fault and/or Regional Recurrence

Compute Probability Distribution Ground Motion

Evaluate Site Soil Conditions

Develop Site Specific Response Spectra

HISTORICAL EPICENTER DATA BASE

EARTHQUAKE RECURRENCE

Recurrence San Gabriel fault.

PROBABILITY OF SITE GROUND MOTION

Total probability of not exceeding acceleration at the site,
all faults contributing.

GROUND MOTION

The specification of loading may be either an earthquake acceleration time history or a response spectra. Local site conditions can influence the response of facility significantly. The magnitude of an earthquake and the distance the site is away from the energy source influence the frequency content of the motion reaching the site.

SITE EFFECTS

ROCK SITE

Magnitude 6.6

Distance 20 miles

0.15 g

ALLUVIUM SITE

SOURCE EFFECTS

MAGNITUDE 5

DISTANCE 14 MILES

0.15 g MOTION

MAGNITUDE **7**

DISTANCE 30 MILES

0.15 g MOTION

Screening

Inventory of Existing Buildings

Rapid Analysis

Detailed Analysis

Screening Criteria

Building Age
Size (> 3000 sq ft)
Category Code
High Occupancy

RAPID STRUCTURAL ANALYSIS

First Mode of a Multi-Mass System

Equivalent Single-Mass System

DETAILED STRUCTURAL ANALYSIS

Selection Criteria for Base Isolation

Building Selection Criteria

Agency Plan and Needs

- Need for Isolation?
- Building Importance
- Suitable site
- Suitable building
- Area of high seismicity
.2 g 20 yrs .4 g during life
- Special needs- utilities

Issues Related to the Selection of U.S. Navy Buildings for Base Isolation

ABSTRACT This report presents research conducted at UCLA. It recommends the base isolation systems that are fully satisfactory for Navy buildings. The report contains a discussion of the building selection process, quality control and design issues. A technical discussion of ground motion, torsion and uncertainty is also presented. 1

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Building Selection Criteria

Feasibility

Need for Isolation

Suitability of site and building

Cost effectiveness

Building Selection Criteria

Building Use

**Increased Safety
Contents
Mission Essential**

Building Selection Criteria

Building Type

**Relatively stiff
Squat**

Low to medium rise buildings

2 to 5 stories

Fixed base periods 0.7 to 1.0 sec

Building Selection Criteria

Seismic Motion

**Areas of high seismicity
moderate event 0.2 g or higher
0.4 g during design life**

Building Selection Criteria

Suitability Of Site

**Moderately stiff to stiff
subsurface soil**

SITE EFFECTS

ROCK SITE

Magnitude 6.6

Distance 20 miles

0.15 g

ALLUVIUM SITE

Design Requirements

Performance Specification

VS.

Design Procedure

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Criteria for NAVFAC P355.1
Isolation for Essential Buildings

Criteria Compatible with Design
Analysis Procedures for Essential
Buildings - EQ-I & EQ -II

CR 89.016

August 1989

NCEL

Contract Report

**An Investigation Conducted by: University of
California, Los Angeles**

**Sponsored by Naval Facilities Engineering
Command
Alexandria, VA 22332**

SEISMIC DESIGN CRITERIA FOR BASE ISOLATED U.S. NAVY ESSENTIAL BUILDINGS

ABSTRACT This report presents design criteria for laminated rubber seismic isolation systems for use in construction of Navy essential buildings. Base isolation has been shown to limit seismic motions transmitted to structures and is effective in reducing damage. The design criteria, applicable only to structures having structural detailing as required in Seismic Zones 3 and 4, utilizes two structural load levels and has levels of performance associated with each. A structure designed according to these provisions will withstand the most probable maximum earthquake with inelastic demand ratios of 2.0 in beams and 1.25 in columns.

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**PRELIMINARY
UNOFFICIAL NAVY DESIGN PROCEDURE**

DYNAMIC ANALYSIS

ANALYSIS 1

ELASTIC RESPONSE SPECTRA INCLUDING K_{EFF}

EQ I 50% IN 50 YEARS DRIFT .005

LESS THAN 20 % BEAMS IDR > 1.25 *

LESS THAN 10% COLUMNS IDR > 1.25 *

EQ II 10% IN 100 YEARS DRIFT 0.010

BEAMS IDR < 2.0 *

COLUMNS IDR < 1.25 *

*** DUCTILE MOMENT RESISTANT FRAME**

SEE NAVFAC P355.1 TABLE 4.2

TIME HISTORY ACCEPTABLE 6 RECORDS

CHECK DISPLACEMENTS

NONLINEAR SDOF TIME HISTORY CHECK

ANALYSIS 2

SAME STRUCTURE FIXED ABOVE ISOLATOR

RESPONSE SPECTRA EQ I

IDR < 3 FOR ALL BEAMS & COLUMNS

TESTING REQUIREMENTS

DISPLACEMENT RESPONSE OF OSCILATOR IN INCHES

SINGLE DEGREE HYSTERETIC MODEL
 AVERAGE OF MAXIMUM ACCELERATION = 0.087
 FIRST YIELD POINT = 0.021

RATIO OF K2 TO K1 (REDUCTION) = 0.074
 DAMPING RATIO = 0.000

NATURAL PERIOD = 1.144
 TIME INCREMENT = 0.008
 1ST YP DISPLACEMENT = 0.267 IN

MAXIMUM DISPLACEMENT = 1.211 IN

10

Use of Single Degree Of Freedom Model

**Charles Kircher & Associates
Consulting Engineers**

CURRENT BUILDING CODE PROVISIONS - SEAOC/UBC

presented by

**Charles A. Kircher, Ph.D, P.E.
Charles Kircher & Associates, Mountain View, California**

May 14, 1992

PRESENTATION AGENDA

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OVERVIEW OF SEISMIC ISOLATION CODES

STATE AND LOCAL CODES

- Seismology Committee, Structural Engineers Association of California (SEAOC), *Recommended Lateral Force Requirements and Commentary*, ("Blue Book"), "Tentative General Requirements for the Design and Construction of Seismic-Isolated Structures," Appendix 1L, Fifth Edition, 1990
- Building Safety Board (BSB), California Office of Statewide Health Planning and Development, "An Acceptable Method for Design and Review of Hospital Buildings Utilizing Base Isolation," April 1989 (revised January 1992) - based on guidelines developed by SEAOC
- State of California, *California Administrative Code, Title 24, Building Standards, Part 2, Basic Regulations*, "Regulation for Seismic-Isolated Structures," - proposed changes incorporating BSB guidelines for hospitals into Title 24 (1994)

OVERVIEW OF SEISMIC ISOLATION CODES

FEDERAL AND NATIONAL CODES

- International Conference of Building Officials, *Uniform Building Code*, "Earthquake Regulations for Seismic-Isolated Structures," Division III of Chapter 23, 1991 Edition - based on Appendix 1L of the SEAOC Blue Book
- Building Seismic Safety Council (BSSC) of the National Institute of Building Sciences, *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings* - Technical Subcommittee 12: Base Isolation/Energy Dissipation tasked with developing requirements for the 1994 NEHRP provisions update
- United States General Services Administration, *Facilities Standards for the Public Buildings Service*, PBS P 3430.1A , "Base Isolated Structures," (Appendix 12-D of Chapter 12, "Seismic Design Guidelines") - references 1986 SEAONC "Yellow Book"
- American Association of State Highway and Transportation Officials, *Guide Specifications for Seismic Isolation Design*, June 1991 - based on static analysis formulas of SEAOC/UBC

BACKGROUND AND PHILOSOPHY OF SEAOC/UBC

**WHY?
(NEED FOR SEAOC/UBC PROVISIONS)**

- **Building codes and regulations provide seismic requirements for fixed-base buildings that are not directly applicable to isolated structures**
- **Isolated buildings and structures are being designed and constructed in California and other states (e.g., first isolated building: Foothill County Law and Justice Center was designed and constructed in the mid-1980's)**

BACKGROUND AND PHILOSOPHY OF CODE

SEAOC ISOLATED-STRUCTURE CODE EFFORTS

- Base isolation committees have been active in the northern and southern sections of the Structural Engineers Association of California (SEAOC) since mid-1980's
- Northern section of SEAOC published isolated structure design requirements (SEAONC "Yellow Book") in September 1986
- State Seismology Committee formed Ad Hoc Base Isolation Subcommittee in 1988 to develop "consensus" document (Appendix 1L of the 1990 SEAOC "Blue Book")
- International Conference of Building Officials (ICBO) adopted SEAOC provisions as non-mandatory appendix of the Uniform Building Code (Division III of Chapter 23 of the 1991 UBC)

BACKGROUND AND PHILOSOPHY OF SEAOC/UBC

SCOPE AND LIMITATIONS

- SEAOC/UBC provisions are intended primarily for design of new buildings and other ground-supported structures
- SEAOC/UBC provisions do not preclude, but may not fully prescribe design requirements for:
 - (1) vertical isolation of buildings and structures
 - (2) isolation retrofit of existing buildings and structures
 - (3) isolation of equipment and other secondary systems located in a building or structure
- SEAOC/UBC provisions may not allow certain isolation systems

BACKGROUND AND PHILOSOPHY OF SEAOC/UBC

ACCEPTABLE ISOLATION SYSTEMS

- In general, the SEAOC/UBC provisions will permit the use of an isolation system that can be shown to:
 - (1) remain stable for the required design displacements
 - (2) provide increasing resistance with increasing displacement
 - (3) not degrade under repeated cyclic load
 - (4) have quantifiable engineering parameters (e.g., stiffness and damping)

BACKGROUND AND PHILOSOPHY OF SEAOC/UBC

DESIGN STRATEGY

- **Trade-off:** Use isolation to improve the seismic performance of the building and contents above that of a fixed-base building (comparable superstructure and cost)

or

Use isolation to achieve the same performance as a fixed-base building (less superstructure and cost)

- SEAOC/UBC provisions are intended primarily to improve the seismic performance of an isolated building and its contents over that of a comparable fixed-base building, rather than to effect design economy of the superstructure

BACKGROUND AND PHILOSOPHY OF SEAOC/UBC

SEISMIC CRITERIA

- **SEAOC/UBC provisions define two levels of earthquake ground motion:**

DESIGN-BASIS EARTHQUAKE (DBE) - the level of ground shaking that has a 10 percent probability of being exceeded in a 50-year period (same earthquake definition as that specified by the SEAOC/UBC provisions fixed-base building design)

MAXIMUM CREDIBLE EARTHQUAKE (MCE) - the maximum level of ground shaking that may ever be expected at the building site within the known geological framework, may be taken as the level of ground motion that has a 10 percent probability of being exceeded in 250 years

BACKGROUND AND PHILOSOPHY OF SEAOC/UBC

BASIC DESIGN APPROACH

- SEAOC/UBC provisions require the structure above the isolation system to remain "essentially elastic" for the design basis earthquake (DBE)
- SEAOC/UBC provisions require the isolation system to be designed and tested for the full effects of the maximum credible earthquake (MCE)

BACKGROUND AND PHILOSOPHY OF SEAOC/UBC

PROTECTION PROVIDED BY FIXED-BASE BUILDINGS

RISK CATEGORY	EARTHQUAKE GROUND SHAKING LEVEL		
	Minor	Moderate	Major
Life-Safety	✓	✓	✓
Structural Damage	✓	✓	
Nonstructural and Contents Damage	✓		

BACKGROUND AND PHILOSOPHY OF SEAOC/UBC

PROTECTION PROVIDED BY ISOLATED BUILDINGS

RISK CATEGORY	EARTHQUAKE GROUND SHAKING LEVEL		
	Minor	Moderate	Major
Life-Safety	✓	✓	✓
Structural Damage	✓	✓	(✓)
Nonstructural and Contents Damage	✓	✓	(✓)

BACKGROUND AND PHILOSOPHY OF SEAOC/UBC

**SOURCES OF UNCERTAINTY IN THE RESPONSE OF
SEISMICALLY ISOLATED BUILDINGS**

- **SEISMIC LOAD** (i.e., level, frequency content and duration of ground motion)
- **ISOLATION SYSTEM** (i.e., design properties and long-term reliability of isolators)
- **DESIGN METHOD** (i.e., equivalent static, response spectrum or time history analysis)

CRITERIA SELECTION

DESIGN METHODS

- **STATIC ANALYSIS**
 - (1) Establishes minimum design displacements and forces
 - (2) Useful for preliminary design and design review
- **DYNAMIC ANALYSIS**
 - (1) Establishes site-specific ground motion criteria
 - (2) Specifies response spectrum analysis methods
 - (3) Specifies time history analysis methods

CRITERIA SELECTION

SITE-SPECIFIC SPECTRA REQUIRED

- Isolated structure is located on a soft soil (i.e., Soil Type S_3 , or S_4)
- Isolated structure is located near an active fault (i.e., within 15 km)
- Isolated structure period is very long (i.e., greater than 3 seconds)
- Isolated structure is located in zones of low or moderate seismicity (i.e., Seismic Zone 1, 2a or 2b)

CRITERIA SELECTION

RESPONSE SPECTRUM ANALYSIS REQUIRED

- When site-specific spectra are required
- Superstructure is "irregular" (e.g., structure above the isolation system has a "soft" or "weak" story)
- Superstructure is tall (i.e., structure above the isolation system exceeds 4 stories or 65 feet, in height)
- Isolation system is, or may be "coupled" dynamically with the superstructure (i.e., the isolated-structure period is less than or equal to 3 times the elastic, fixed-base period of the structure above the isolation system)

CRITERIA SELECTION

TIME HISTORY ANALYSIS REQUIRED*

- Isolated structure has a "nonlinear" isolation system (e.g., sliding systems, highly-damped systems)
- Isolated structure has a "nonlinear" superstructure (i.e., superstructure response exceeds elastic analysis limits)
- Isolated structure is located on very soft soil and may be subjected to long-period, long-duration shaking (i.e., Soil Type S_4)

* Time history analysis may be used in lieu of response spectrum analysis

STATIC ANALYSIS

PRESCRIPTIVE FORMULAS

- **Formulas directly applicable to design of isolated buildings with "stiff" and "regular" superstructures, and "linear" isolation systems**
- **Formulas also applicable to preliminary design of other types of isolated buildings**
- **Formulas appropriate for design adequacy checking by peer reviewers and building officials**

STATIC ANALYSIS

DISPLACEMENT TERMINOLOGY

STATIC ANALYSIS

**LONG-PERIOD SPECTRAL ACCELERATION
(5%-DAMPED RESPONSE)**

STATIC ANALYSIS

**LONG-PERIOD SPECTRAL VELOCITY
(5%-DAMPED RESPONSE)**

STATIC ANALYSIS

**LONG-PERIOD SPECTRAL DISPLACEMENT
(5%-DAMPED RESPONSE)**

STATIC ANALYSIS

DESIGN DISPLACEMENT, FORMULA (E-1)*

The isolation system shall be designed to withstand a peak lateral design displacement, D , in inches, as follows:

$$D = \frac{10(ZNS_I)T_I}{B}$$

where: Z = seismic zone coefficient
 N = near-field coefficient
 S_I = site-soil coefficient
 T_I = effective period of the isolated building (seconds)
 B = damping coefficient

* Formula numbers refer to the SEAOC provisions, UBC formulas are identical but have a different numbering scheme

STATIC ANALYSIS

EFFECTIVE PERIOD, FORMULA (E-2)

The effective period, T_I , of the isolated building shall be determined using the deformational characteristics of the isolation system as follows:

$$T_I = 2\pi \sqrt{\frac{W g}{k_{\min}}}$$

where: W = total seismic dead load above the isolation interface
 g = gravity constant
 $k_{\min}$ = minimum effective stiffness of the isolation system at design displacement, D , as determined by prototype testing

STATIC ANALYSIS

EFFECTIVE STIFFNESS (k_{eff}) AND DAMPING (β)

STATIC ANALYSIS

TOTAL DESIGN DISPLACEMENT (INCLUDING TORSION)

- Calculation to be based on actual plus 5% accidental eccentricity
- If the stiffness of the isolation system is uniformly distributed, the total design displacement, D_T , is specified by Formula (E-3), as follows:

$$D_T = D \left[1 + y \frac{12e}{b^2 + d^2} \right]$$

$$\approx 1.15D - 1.3D$$

- The minimum value of the total design displacement is specified as follows:

$$D_T \geq 1.1D$$

STATIC ANALYSIS

TOTAL MAXIMUM DISPLACEMENT, FORMULA (E-4)

The minimum value of the total maximum displacement, D_{TM} , required for verification of isolation system stability is prescribed as follows:

$$D_{TM} = 1.5D_T$$

STATIC ANALYSIS

ISOLATION SYSTEM TERMINOLOGY

STATIC ANALYSIS

ISOLATION SYSTEM AND SUBSTRUCTURE DESIGN, FORMULA (E-5)

The lateral force or shear, V_B , required for working-stress design of the isolation system, and structural elements below the isolation system, is prescribed as follows:

$$V_B = \frac{k_{\max} D}{1.5}$$

where: $k_{\max}$ = maximum effective stiffness of isolation system at the design displacement, D , as determined by prototype testing

STATIC ANALYSIS

SUPERSTRUCTURE DESIGN, FORMULA (E-6)

The lateral force or shear, V_s , required for working-stress design of the structure above the isolation system is prescribed as follows:

$$V_s = \frac{k_{\max} D}{R_{wI}}$$

where: R_{wI} = design-force reduction coefficient, as specified for various types of lateral-force-resisting systems

STATIC ANALYSIS

COMPARISON OF LATERAL DESIGN FORCE FORMULAS: FIXED-BASE AND ISOLATED BUILDINGS

- Fixed-Base Buildings:
- Isolated Buildings:

$$V = \frac{ZICW}{R_w} \quad (1-1)$$

where:

$$C = \frac{1.25S}{T^{2/3}} \quad (1-2)$$

where:

$$D = \frac{10ZNS_I T_I}{B} \quad (E-1)$$

$$k_{\max} = \frac{4\pi^2 W}{gT_I^2} \quad (k_{\max} = k_{\min})$$

$$V = \frac{ZI(1.25)SW}{T^{2/3} R_w}$$

$$V_s = \frac{ZNS_I W}{T_I B R_{wI}}$$

$$V_s = \frac{k_{\max} D}{R_{wI}} \quad (E-6)$$

STATIC ANALYSIS

**COMPARISON OF LATERAL DESIGN FORCE FORMULA TERMS:
FIXED-BASE AND ISOLATED BUILDINGS**

Lateral Design Force Formula Term	Fixed-Base Buildings	Isolated Buildings
Seismic Zone Factor	Z	Z
Importance Factor	I	(1.0)
Near-Fault Coefficient	(1.0)	N
Building Weight	W	W ¹
Lateral Force Coefficient (Spectral Shape Factor)	$1.25S/T^{2/3}$	S_i/T_i
Response Reduction Coefficient(s) (Knock-Down Factor)	$1/R_w$	$1/BR_{wi}$

¹ Above the Isolation Interface

STATIC ANALYSIS

**COMPARISON OF DESIGN LATERAL FORCE COEFFICIENTS:
FIXED-BASE AND ISOLATED BUILDINGS**

STATIC ANALYSIS

**COMPARISON OF RESPONSE REDUCTION COEFFICIENTS:
FIXED-BASE AND ISOLATED BUILDINGS**

STRUCTURAL SYSTEM	R_{wi} ISOLATED BUILDINGS	R_w FIXED-BASE BUILDINGS
Special Moment-Resisting Frame	3.0	12
Shear Wall	2.6	6
Braced Frame (Concentric)	2.2	8
Ordinary Moment-Resisting Frame	1.8	6

STATIC ANALYSIS

SUPERSTRUCTURE DESIGN LIMITS

- In all cases, the value of V_s shall not be less than any one of the following:
 1. The lateral seismic force required by the SEAOC/UBC provisions for a fixed-base structure of period, T_f
 2. The base shear corresponding to the design wind load
 3. The lateral force required to fully activate the isolation system

STATIC ANALYSIS

DISTRIBUTION OF FORCE, FORMULA (E-7)

The total force shall be distributed over the height of the structure above the isolation interface in accordance with the following formula:

$$F_x = V_s \left[\frac{w_x}{\sum w_i} \right]$$

where: F_x = lateral force applied to level x

w_x, w_i = that portion of the total seismic dead load, W , assigned to level x or i, respectively

STATIC ANALYSIS

COMPARISON OF DESIGN LATERAL FORCE DISTRIBUTIONS: FIXED-BASE AND ISOLATED BUILDINGS

$$F_t = 0.07TV$$

$$F_x = (V - F_t)w_x h_x / \sum_{i=1}^n w_i h_i$$

$$V = ZI(1.25)SW/T^{2/3}R_w$$

$$F_x = V_s w_x / \sum_{i=1}^n w_i$$

$$V_s = ZNS_1 W/BT_1 R_{wi}$$

STATIC ANALYSIS

DESIGN EXAMPLE: MINIMUM LATERAL FORCE AND DISPLACEMENT

Notes:

- (1) Building assumed to be located in Seismic Zone 4, on Soil Type S_2 , 15 km from active faults ($ZNS = 0.6$).
- (2) Lateral force resisting system assumed to be a steel, concentric-braced frame.

DYNAMIC ANALYSIS

DESIGN SPECTRA

DESIGN LEVEL	WITH SITE-SPECIFIC HAZARD ANALYSIS	WITHOUT SITE-SPECIFIC HAZARD ANALYSIS
Design-Basis Earthquake (DBE)	$\geq 0.8E$	$\geq 1.0E$
Maximum Credible Earthquake	$\geq 1.25DBE$	$\geq 1.25DBE$

where: E is the normalized response spectrum of the SEAONC/UBC provisions, scaled by the appropriate soil type coefficient, S_i , and seismic zone coefficient, Z

DYNAMIC ANALYSIS

DESIGN TIME HISTORIES

- At least three (3) pairs of horizontal components to be selected from recorded events
- Each pair of time history components to be scaled to match the design spectrum
- Time histories to be consistent with the duration of the design earthquake
- Time histories to incorporate near-fault phenomena for sites within 15 km of a major active fault

DYNAMIC ANALYSIS

COMPARISON OF PEAK DISPLACEMENT: STATIC FORMULA (E-1) AND TIME HISTORY ANALYSIS

Notes:

- (1) Building assumed to be located in Seismic Zone 4, on Soil Type S₂, 15 km from active faults (ZNS = 0.6).
- (2) Nine (9) pairs of recorded time history components were time domain scaled such that the average value of their 5%-damped response spectra was approximately equal to assumed site conditions at long periods (i.e., 0.6/T).
- (3) Isolation systems were modeled as bi-linear, hysteretic elements, 10% - 20% effective damping.

DYNAMIC ANALYSIS

**COMPARISON OF PEAK DISPLACEMENT:
STATIC AND TIME HISTORY ANALYSIS**

DYNAMIC ANALYSIS

COMPARISON OF PEAK STORY SHEAR: STATIC (ESA), RESPONSE SPECTRUM (RSA) AND TIME HISTORY ANALYSIS (THA)

◇ ESA - Formula (E-7)
 ◆ ESA - Formula (1-8)
 ○ RSA - 10% Damping
 ■ THA - Mean (3)
 □ THA - Maximum (3)

Notes

- (1) Building assumed to be located in Seismic Zone 4, on Soil Type S_2 , 15 km from active faults ($ZNS = 0.6$).
- (2) Three (3) time histories were used for THA, each time-domain scaled to match $ZNS/T = 0.6/T$ at long periods.
- (3) Superstructure is an 11-story, reinforced-concrete shear wall system, approximately 25,000 kips total weight, with a fixed-base period of about 0.6 seconds.
- (4) Effective period and damping of the isolated building are about 2.0 seconds and 10%, respectively.

DYNAMIC ANALYSIS

DESIGN LIMITS

Design Parameter	Static Analysis	Dynamic Analysis	
		Response Spectrum	Time History
Design Displacement	$D = 10ZNST/B$	-	-
Total Design Displacement	$D_T \geq 1.1 D$	$\geq 0.9 D_T$	$\geq 0.9 D_T$
Total Maximum Displacement	$D_{TM} = 1.5 D$	$\geq 0.8 D_{TM}$	$\geq 0.8 D_{TM}$
Design Shear (At or Below Isolation System)	$V_B = K_{MAX}D/1.5$	$\geq 0.9 V_B$	$\geq 0.9 V_B$
Design Shear ("Regular" Superstructure)	$V_S = K_{MAX}D/R_{WI}$	$\geq 0.8 V_S$	$\geq 0.6 V_S$
Design Shear ("Irregular" Superstructure)	$V_S = K_{MAX}D/R_{WI}$	$\geq 1.0 V_S$	$\geq 0.8 V_S$
Drift	$0.010/R_{WI}$	$0.015/R_{WI}$	$0.020/R_{WI}$

NONSTRUCTURAL COMPONENTS

NONSTRUCTURAL DESIGN REQUIREMENTS

- **ABOVE THE ISOLATION INTERFACE** - Design for calculated peak response reduced by 1.5 (or design using SEAOC/UBC requirements for fixed-base building components)
- **ACROSS THE ISOLATION INTERFACE** - Design for the total maximum displacement, D_{TM}
- **BELOW THE INTERFACE** - Design using SEAOC/UBC requirements for fixed-base building components

DETAILED SYSTEM REQUIREMENTS

DETAILED ISOLATION SYSTEM REQUIREMENTS

- **ENVIRONMENTAL** - Isolation system is to be designed considering the effects of aging, creep, fatigue, operating temperature, moisture and damaging substances
- **WIND FORCES** - Isolation system drift due to wind is limited to that permitted between floors of the superstructure
- **FIRE RESISTANCE** - Isolation system is to meet fire resistance requirements of the building's structure
- **LATERAL RESTORING FORCE** - Isolation system is to have a specified level of restoring force or to be designed for the greater of either 3.0 times the total design displacement, D_T , or 36ZNS

DETAILED SYSTEM REQUIREMENTS

**DETAILED ISOLATION SYSTEM REQUIREMENTS
(CONTINUED)**

- **DISPLACEMENT RESTRAINT** - If displacement of the isolation system is "restrained" to less than 1.5 times the total design displacement, then the isolation system and superstructure are to be evaluated for loads corresponding to the maximum credible earthquake (MCE)
- **INSPECTION AND REPLACEMENT** - Access is to be provided for inspection and replacement of all isolation system components
- **QUALITY CONTROL** - A quality control testing program is required for fabrication of isolator units

DETAILED SYSTEM REQUIREMENTS

ISOLATION SYSTEM DISPLACEMENT RESTRAINT CONCEPT

DETAILED SYSTEM REQUIREMENTS

DETAILED STRUCTURAL SYSTEM REQUIREMENTS

- **HORIZONTAL DISTRIBUTION OF FORCE** - A diaphragm (or other structural elements) is required above the isolation interface to connect vertical-load-carrying elements and to provide rigidity at the base of the superstructure
- **BUILDING SEPARATIONS** - the minimum separation between an isolated building and other structures is to be not less than the total maximum displacement

DESIGN AND CONSTRUCTION REVIEW

PEER REVIEW

- Design review of the isolation system and related test programs is required for all isolation projects
- The review team is to include persons licensed in the appropriate disciplines and experienced in isolation theory and application
- Isolation system review topics include:
 - (1) Site-specific seismic criteria
 - (2) Preliminary design
 - (3) Prototype testing
 - (4) Final design and supporting analyses
 - (5) Quality-control testing

ISOLATION SYSTEM TESTS

PROTOTYPE TESTS

- **Prototype tests are required to confirm the force-deflection properties used for design and to verify the overall adequacy of the isolation system**
- **Prototype tests are to include two, full-size specimens of each type and size of isolator unit, as well as specimens of the wind restraint system, if such is used in the design**

ISOLATION SYSTEM TESTS

PROTOTYPE TESTS (CONTINUED)

- **Cyclic-Load tests are to be performed (with vertical load equal to typical DL) as follows:**
 - (1) 20 full cycles at the wind design force,
 - (2) 3 full cycles at each increment: 0.25, 0.50, 0.75, and 1.0 times the total design displacement (D_T),
 - (3) $15S_i/B$, but not less than 10, full cycles at 1.0 times the total design displacement (D_T)
- **If isolator units support vertical load, the cyclic-load tests of Item (2) above are to be repeated for two additional load cases:**
 - (1) $1.2 \text{ DL} + 0.5 \text{ LL} + |E|$
 - (2) $0.8 \text{ DL} - |E|$

ISOLATION SYSTEM TESTS

PROTOTYPE TESTS (CONTINUED)

- Additional cyclic-load tests may be required to quantify effects of rate of loading, direction of load, etc., on isolator properties
- Static-load tests are to be performed at the total maximum displacement (D_{TM}) of isolators for the following two load cases:

(1) $1.2 DL + 1.0 LL + |E|$

(2) $0.8 DL - |E|$

TESTS OF THE ISOLATION SYSTEM

ISOLATION SYSTEM ACCEPTANCE CRITERIA

- Force-deflection plots show a positive incremental force-carrying capacity for all prototype tests
- Effective stiffness does not vary appreciably for isolator units of a common type and size
- Effective stiffness does not degrade appreciable during the 10 + cycles of load at 1.0 times the total design displacement (D_T)
- All specimens remain stable at the total maximum displacement (D_{TM}) under full vertical load

DESIGNING WITH BASE ISOLATION SYSTEMS

Presented by

**Charles A. Kircher, Ph.D, P.E.
Charles Kircher & Associates, Mountain View, California**

May 15, 1992

PRESENTATION AGENDA

A. Assembling the Design Team	3
B. Evaluating Isolation System Alternatives	5
C. Developing Preliminary Designs	8
D. Specifying Isolation System Performance	10

ASSEMBLING THE DESIGN TEAM

OVERALL PROJECT ORGANIZATION

ASSEMBLING THE DESIGN TEAM

KEY DESIGN TEAM MEMBERS

EVALUATING ISOLATION SYSTEM ALTERNATIVES

ISOLATION SYSTEM BEARING SUPPLIERS/FABRICATORS¹

ISOLATOR TYPE	SUPPLIER/FABRICATOR
High Damping Rubber (HDR) Isolators	<p>LTV Energy Products Company Oil States Industries Division Arlington, Texas</p> <p>FURON - Structural Bearing Division Athens, Texas</p> <p>Dynamic Rubber, Inc. Athens, Texas</p> <p>Bridgestone Engineered Products, Inc. Huntington Beach, California</p>
Lead Rubber (LR) Isolators	Dynamic Isolation Systems, Inc. Berkeley, California
Friction Pendulum System (FPS) Isolators	<p>Earthquake Protection Systems, Inc. San Francisco, California/ VSL Corporation, San Jose, California</p>

1. Experienced isolator suppliers/fabricators with offices in the United States.

EVALUATING ISOLATION SYSTEM ALTERNATIVES

ISOLATOR SUPPLIER/FABRICATOR QUALIFICATION TOPICS

AREA	TOPIC
Technical	Isolated Structure Performance
	Isolator Properties - Design Basis
	Isolator Properties - Long Term
Project Personnel	Isolator Designer/Consultant
	Isolator Fabricator
Company (Fabricator)	Overall Manufacturing Capability
	Isolator Production Capacity
	Quality Control/Product Warranty

EVALUATING ISOLATION SYSTEM ALTERNATIVES

TECHNICAL PERFORMANCE ISSUES

ISSUE	HDR Isolators	LR Isolators	FPS Isolators
Design-Basis Period (seconds)	1.5 - 3.5	1.5 - 2.5	1.5 - 3.5
Design-Basis Damping (% of critical)	10% - 15%	10% - 25%	15% - 30%
Higher-Mode Effects	Best ¹	OK ¹	OK ¹
Torsional Effects (additional response at edge of structure)	10% - 30%	10% - 30%	0% - 10%
Stability (factor of safety)	≥ 3.0 (D = 0) ≈ 1.0 (D _{TM})	≥ 3.0 (D = 0) ≈ 1.0 (D _{TM})	≈ 2.0
Isolator Clearance (height, h, inches)	8 - 24	12 - 24	6 - 12
Local Loads on Structure (moment on superstructure/foundation)	$M = V/2 \times h$	$M = V/2 \times h$	$M = V \times h$ or $M = 0$

1. Higher-mode effects can significantly increase story shears and floor spectra.

DEVELOPING PRELIMINARY DESIGNS

KEY DESIGN PARAMETERS

- **Rubber Isolators (e.g., HDR or LR):**
 - (1) Effective stiffness, expressed as a function of lateral displacement (or rubber strain)
 - (2) Effective damping, expressed as a function of lateral displacement (or rubber strain)
 - (3) Vertical-load capacity, expressed as a function of lateral displacement
- **Sliding Isolators (e.g., FPS):**
 - (1) Dynamic (sliding) coefficient of friction, expressed as a function of vertical load
 - (2) Static (breakaway) coefficient of friction, expressed as a function of vertical load
 - (3) Restoring force stiffness (i.e., radius of curvature of FPS sliding surface).

DEVELOPING PRELIMINARY DESIGNS

BI-LINEAR CHARACTERIZATION OF FORCE-DEFLECTION CURVE

$$a = \frac{F_{\max} g}{W}$$

$$T = 0.32 \sqrt{\frac{d}{a}}$$

$$\beta = \frac{0.637 (a_y d - d_y a)}{ad}$$

SPECIFYING ISOLATION SYSTEM PERFORMANCE

ISOLATOR SPECIFICATION

- **Performance vs. Material/Fabrication Requirements**
- **Minimum Performance Requirements:**
 - (1) **Basic Configuration and Dimensions**
 - (2) **Minimum Vertical-Load Capacity (at Design Displacement)**
 - (3) **Acceptable Range of Effective Stiffness**
 - (4) **Acceptable Range of Effective Damping**
- **Prototype Testing Requirements**

**WORKSHOP ON SEISMIC BASE ISOLATION
FOR DEPARTMENT OF ENERGY FACILITIES**

TESTING OF LAMINATED ELASTOMER BEARINGS

Y. W. Chang

Argonne National Laboratory

**Marina Del Rey Marriott
Marina Del Rey, California
May 13-15, 1992**

**Dowel Type
Rubber Bearing**

**Bolted Rubber
Bearing**

DOWELLED AND BOLTED RUBBER BEARINGS

COMPARISON OF DOWEL- AND BOLTED-TYPE CONNECTIONS

- **Dowel-Type Connection**
 - **No tension in elastomer**
 - **Possibility of roll over under large displacement**
- **Bolted-Type Connection**
 - **Tensile stresses can develop in elastomer**
 - **Bearing cannot roll out**
 - **Under large horizontal displacement, bearing may exhibit buckling type of instabilities**

Shape Factor S

$$S = \frac{\text{Loaded Area}}{\text{Force Free Area}}$$

Square Bearing

$$S = \frac{a}{4t}$$

Circular Bearing

$$S = \frac{\phi}{4t}$$

Low Shape Factor 3 - 6

Medium Shape Factor 9 - 18

High Shape Factor 20 - 30

A TYPICAL HYSTERESIS LOOP OF A ELASTOMER BEARING, $\gamma < 100\%$

ARGONNE - LTV BEARING TEST
 FATIGUE - 150% SHEAR STRAIN - 0.5 HZ

FILENAME: 901108.03
 BEARING TYPE: 1
 BEARING ID.: ED4866-S/N 07
 VERT PRESSURE: 695 PSI
 TEST No.: 1

Cycle	Stiffness	Shear Modulus	Damping
1	4.13 Kips/in	101 psi	8.28 %
40	3.24 Kips/in	79 psi	6.31 %

VARIATIONS IN HYSTERESIS LOOPS

DOEWKSH.P108

SENDAX-BEARING TEST
SHEAR DIAGNOSTIC TEST 5% - 100% STRAIN

	Strain	Stiffness	Shear Modulus	Damping
FILENAME: 910325.13	5%	5.39 Kips/in	171 psi	17.81
	10%	3.02	121	23.03
	25%	2.29	72	27.77
VERT PRESSURE: 1000 PSI	50%	1.56	49	27.49
FREQUENCY: 0.5 HERTZ	75%	1.20	41	26.68
	100%	1.16	37	25.54

Horizontal Load vs Displacement

HYSTERESIS LOOPS OF A HIGH DAMPING RUBBER BEARING

HYSTERESIS LOOP OF A NATURAL RUBBER BEARING

Horizontal stiffness of the bearing is given by

$$K_H = \frac{GA}{t_r}$$

G = Shear modulus of elastomer

A = Area of bearing

t_r = Total rubber thickness

$$f_H = \frac{1}{2\pi} \sqrt{\frac{K_H}{m}} \text{ or}$$

$$K_H = \frac{W}{g} (2\pi f_H)^2 = \frac{GA}{t_r}$$

Dividing both sides by A gives

$$\frac{G}{t_r} = \frac{p}{g} (2\pi f_H)^2$$

A guide for initial design is that p should normally be about 1000 psi

The vertical stiffness of the entire bearing is

$$K_v = \frac{E_c A}{t_r}$$

where E_c = Compression Modulus = 5.6 GS²

A = Area of bearing

t_r = Total rubber thickness

$$\frac{K_v}{K_H} = \left(\frac{f_v}{f_H} \right)^2$$

and

$$\frac{K_v}{K_H} = \frac{E_c}{G}$$

**SHEAR MODULI: EFFECTIVE MODULUS SHOWN AS SOLID LINE,
STORAGE MODULUS SHOWN AS DOTTED LINE**

SHEAR MODULUS

- Effective Modulus, G_{eff}

$$G_{\text{eff}} = \frac{\Delta \tau}{\Delta \gamma} = \frac{\tau_{\text{max}}^+ - \tau_{\text{max}}^-}{\gamma_{\text{max}}^+ - \gamma_{\text{max}}^-} \quad (1)$$

- Storage Modulus, G'

$$G' = \frac{\tau(\gamma_{\text{max}}^+) - \tau(\gamma_{\text{max}}^-)}{\gamma_{\text{max}}^+ - \gamma_{\text{max}}^-} \quad (2)$$

Note: For rounded loops, typical at lower strain levels, Eqs. 1 and 2 can differ by about 12 percent; for pointed tip loops, which occur at higher strains, the values are nearly the same.

DAMPING

- Effective damping ratio, $\bar{\zeta}$ is defined as

$$\bar{\zeta} = \frac{U_D}{2\pi U_S}$$

where U_D = energy dissipated during a loading and unloading cycle

U_S = energy stored during a loading and unloading cycle

DAMPING (Cont'd)

- Damping ratio, ζ is defined as

$$\zeta = \frac{U_D}{4\pi G' \gamma_{\max}^2}$$

where U_D = energy dissipated during a loading and unloading cycle
(i.e. the area within the hysteresis loop)

G' = storage modulus

$\gamma_{\max}$ = the maximum shear strain

Note: The storage modulus is defined to be the stress at the maximum strain.

ANL-SENDAI BEARING TESTS

SHEAR MODULUS vs. SHEAR STRAIN
Bearing (3rd Cycle) and Coupon Tests

SHEAR MODULUS VS. SHEAR STRAIN FOR BEARING AND COUPON TESTS

ANL-SENDAL BEARING TESTS

DAMPING FACTOR vs. SHEAR STRAIN

Bearing and Coupon Tests

DAMPING FACTOR vs. SHEAR STRAIN FOR BEARING AND COUPON TESTS

DOEWKSH.P.120

UNIVERSITY OF CALIFORNIA, BERKELEY TESTS

- **EERC has two (2) testing machines**
- **One for testing of a single isolator bearing**
 - **Operates at 3 Hz**
 - **Vertical load capacity 300 tons; horizontal load capacity 150 tons**
 - **Horizontal displacement ± 6 inches or 0 to 12 inches**
- **One for testing of a set of four isolator bearings**
 - **Vertical load 500 tons per bearing**
 - **Horizontal displacement ± 18 inches or 0 to 36 inches**

SINGLE BEARING SHEAR TEST RIG

LARGE-SCALE BEARING TEST RIG

ETEC SEISMIC BEARING TEST RIG

DOEWKSH.P.124

TESTING OF BEARINGS

- **To determine the performance characteristics of the bearings under a wide range of loadings**
- **To establish a data base for development of design formulas**
- **To validate the analytical models and method of analysis**
- **To assure that the bearings manufactured met the design specifications**

TYPES OF TESTS

- **Horizontal Stiffness Tests**
- **Vertical Stiffness Tests**
- **Failure Tests**
 - **Vertical Tension**
 - **Vertical Compression**
 - **Combined Tension-Shear and Compression-Shear**
- **Fire Tests**
- **Manufacturing Quality Assurance Tests**

HYSTERESIS LOOPS: MODERATE SHEAR STRAIN REGION, 1ST CYCLE

DOEWKSHR.128

HYSTERESIS LOOPS: MODERATE SHEAR STRAIN REGION, 2ND CYCLE

HYSTERESIS LOOPS: LARGE STRAIN REGION

DOEWKSH.P.130

EQUIVALENT STIFFNESS AND VISCOUS DAMPING OF LOW SHEAR MODULUS BEARING FOR TESTS PERFORMED AT 0.5 HZ FREQUENCY

HORIZONTAL SHEAR TEST FREQUENCY: 0.5 Hz								
PRESSURE ¹ PSI	FILENAME (5-100%)	DYNAMIC PROPERTIES	SHEAR STRAIN					
			5%	10%	25%	50%	75%	100%
0	910325.10	K _{em} (Kips/in) β (%) G (psi)	3.64 13.69 115	3.14 11.72 100	2.61 9.66 83	2.21 8.82 70	1.97 8.27 62	1.83 8.02 58
500	910325.11	K _{em} (Kips/in) β (%) G (psi)	4.39 18.35 139	3.37 17.84 107	2.45 16.29 78	1.93 14.57 61	1.66 13.75 53	1.53 13.25 48
621	910325.12	K _{em} (Kips/in) β (%) G (psi)	4.69 18.31 149	3.47 20.71 110	2.41 19.27 76	1.85 17.39 59	1.58 16.17 50	1.46 15.23 46
1000	910325.13	K _{em} (Kips/in) β (%) G (psi)	5.39 17.81 171	3.82 23.03 121	2.29 27.77 72	1.56 27.49 49	1.28 26.68 41	1.16 25.54 37
1500	910325.14	K _{em} (Kips/in) β (%) G (psi)	6.35 15.51 201	4.44 21.65 141	2.49 31.04 79	1.52 36.96 48	1.1 42.39 35	0.92 42.52 29

¹These pressures are the target pressures, actual values are indicated in the plots.

STIFFNESS OF LOW SHEAR MODULUS BEARING AT VARIOUS PRESSURE LOADINGS

SENDAI - BEARING TEST COMPRESSION TEST					
FILENAME	PRESSURE ¹ PSI	ΔP PSI	STIFFNESS (Kips in)		f_v HERTZ
			1ST CYCLE	5TH CYCLE	
910325.15	500	± 100	1114.11	1114.12	12.10
910404.04	500	± 100	916.88	914.16	10.99
910325.16	621	± 100	1151.32	1149.26	10.84
910404.05	621	± 100	1059.80	1054.51	10.56
910325.17	1000	± 100	1697.81	1657.7	10.47
910404.06	1000	± 100	1621.35	1588.43	10.21
910325.18	1500	± 100	3878.29	3820.09	13.03
910404.07	1500	± 100	2545.18	2635.64	10.56

¹These pressures are the target pressures, actual values are indicated in the plots.

SENDAI-BEARING TEST
SHEAR DIAGNOSTIC TEST 5% - 100% STRAIN

	Strain	Stiffness	Shear Modulus	Damping
FILENAME: 910325.13	5%	5.39 Kips/in	171 psi	17.81
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FREQUENCY: 0.5 HERTZ	50%	1.56	49	27.49
	75%	1.20	41	26.68
	100%	1.16	37	25.54

Horizontal Load vs Displacement

FORCE DISPLACEMENT PLOTS: VERTICAL PRESSURE 1000 PSI; FREQUENCY 0.5

SEISMIC ISOLATION R&D

- **ANL's program in seismic isolation was funded by the U.S. Department of Energy (DOE) and the National Science Foundation (NSF)**
- **The program includes work in LMR, NPR, and a joint U.S./Japanese program**
- **During the last three years, a large number of elastomeric bearings have been tested**
- **The goals of the tests were to determine performance characteristics and failure modes of the bearings**
- **Most tests were performed at EERC, University of California, Berkeley**
- **Some tests were performed at ETEC and Shimizu Corporation**

VIDEO PRESENTATION

TIME: 16 MIN.

ANL BEARING TEST PROGRAM

- Combined Compression and Shear Test
- Tension Test
- Fatigue Test
- Compression Test
- Buckling Test

COMBINED COMPRESSION AND SHEAR TEST

- Vertical Load
0, 500, 1000, 1500 psi
- Shear Strain
5, 10, 25, 50, 75, 100
150, 200, 250, 300, 350%

BRIDGESTONE BEARING HD-30

Diameter	24.5 cm
Rubber	22 layers @ 2 mm = 4.4 cm
Steel	21 plates @ 0.8 mm = 1.68 cm
Vertical Load	30 metric tons

SAFETY MARGIN TEST FOR BEYOND DESIGN BASIS EARTHQUAKES

- **Tension Test**

LTV Bearing	Type 1
Diameter	16"
Total Height	7-1/16"
Rubber	10 layers @ 3/8"
Steel	9 layers @ 1/16"
Maximum Load	90 Kips

- **Fatigue Test**

Vertical Load	12,500 lbs.
Shear Strain	150%
Cycle/Sequence	40
LTV Bearing	16" diameter
Themocouples	10

- **Compression Test**

LTV Bearing	Type 6
Diameter	14"
Rubber	24 layers @ 5/32"
Steel	23 layers @ 1/16"
Maximum Load	2060 Kips

LTV Bearing	Type 5
Diameter	14"
Rubber	12 layers @ 5/16"
Steel	11 layers @ 1/16"
Maximum Load	1200 Kips

- **Buckling Test**
Critical Load 1672 Kips

BRIDGESTONE-BEARING TEST SHEAR STRESS-STRAIN DIAGRAMS

BEARING ID:	HR030-4	HR030-3	HR030-2	HR030-5
VERT PRESSURE:	0 psi	500 psi	1000 psi	1500 psi
STRAIN RANGE :	561 %	550 %	507 %	473 %

Shear Stress/Shear Strain

STRESS-STRAIN CURVES FOR BEARINGS IN FAILURE TESTS

BRIDGESTONE-BEARING TEST SHEAR FAILURE

BEARING ID: HR030-4 HR030-3 HR030-2 HR030-5
 VERT PRESSURE: 0 psi 500 psi 1000 psi 1500 psi
 STRAIN RANGE : 561 % 550 % 507 % 473 %
 Horizontal load/deflection

FORCE DISPLACEMENT CURVES FOR BEARINGS IN FAILURE TESTS

DOEWKSH.P.140

FORCE DISPLACEMENT CURVE FOR BEARINGS IN TENSION

DOEWKSH.P.141

ARGONNE - LTV -BEARING TEST
TENSION FAILURE TRIAL NO. 1

FILENAME: 901022.03
BEARING TYPE: 1
BEARING ID: ED4866-S/N 06
TEST No.: 17
MAX TENSILE STRESS: 512 PSI

Vertical Load vs Vertical Deflection

DOEWKSH.P142

LOAD KIPS

ARGONNE-LTV BEARING TEST
COMPRESSION TEST

Filename: 910403.04
Bearing Type: 2
Bearing ID: ED-4867 S/N-10
Max Pressure: 17.45213 Ksi
Max.Vert.Load: 2686.553 Kips
Test No.: 23

Vertical load/deflection

ARGONNE - LTV -BEARING TEST
FAILURE IN TENSION

FILENAME: 901105.Q3
BEARING TYPE: 1
BEARING ID: ED4866-S/N 02
TEST No.: 15
MAX TENSILE STRESS: 230 PSI

Vertical Load vs Vertical Deflection

DOEWKSH.P144

Load KIPS

BEARING APPEARANCE AT 200% STRAIN

BEARING APPEARANCE AT 300% STRAIN

BEARING TYPE 1. FATIGUE TEST AT 150% SHEAR STRAIN

BEARING TYPE 5. FATIGUE TEST AT 150% SHEAR STRAIN

SUMMARY

- **Test program confirms the high performance characteristics and reliability of elastomer bearings under various loading conditions**
- **The bolted bearings, if designed properly, can undergo very large horizontal displacement with no buckling type of instabilities. Tensile stress developed in elastomer is small and has no effects on the response of elastomer bearings.**
- **The shape of the hysteresis loops change with magnitude of vertical pressure loads**
- **Bearings are able to withstand very large shear strains (several times design value)**
- **Compression tests revealed that failure mechanism is yielding and tearing of the steel shim plates**

SUMMARY (Cont'd)

- **Tension tests have demonstrated that bearings are able to sustain very large tensile forces before failure**
- **Performance characteristics and failure mechanisms of bearings are strongly influenced by quality of bond between rubber and steel shim plates**
- **Need for improved acceptance tests to detect poor bond between steel and rubber**
- **Shear failure test should be performed with zero axial compression or even slight axial tension**
- **Fatigue failure of one LTV bearing occurred at 1120 cycle of $\pm 150\%$ shear strains, equivalent to about 30 minutes of extremely strong ground shaking**

ENVIRONMENTAL EQUIPMENT QUALIFICATION CONCERNS FOR BASE ISOLATION SYSTEMS

**WORKSHOP ON SEISMIC BASE ISOLATION FOR DEPARTMENT OF
ENERGY FACILITIES**

PRESENTED BY JOHN EIDINGER

G&E ENGINEERING SYSTEMS, INC.

MAY 14, 1992

WHY DO ENVIRONMENTAL EQUIPMENT QUALIFICATION

- BASE ISOLATION SYSTEMS INCLUDE ELASTOMERS (NATURAL RUBBER, NEOPRENE, ETC.), AND POSSIBLY HYDRAULIC DAMPERS (FLUIDS), FRICTION PLATES (TEFLON)
- MANY OF THESE MATERIALS FARE POORLY UNDER HARSH ENVIRONMENTS
- BASE ISOLATION SYSTEMS MUST PERFORM THEIR FUNCTION UNDER NORMAL AND ACCIDENT CONDITIONS - NOT JUST UNDER EARTHQUAKE LOADS
- THEREFORE, BASE ISOLATION SYSTEMS MUST BE QUALIFIED FOR SUITABLE PERFORMANCE UNDER NORMAL AND HARSH ENVIRONMENTS
- IDEALLY, THE EEQ PROCESS WILL SHOW A QUALIFIED LIFETIME OVER 40 YEARS.
- MANY NUCLEAR PLANT PARTS, HOWEVER, ARE QUALIFIED FOR ONLY 5 TO 10 YEARS, AND THEREFORE REQUIRE REPLACEMENT DURING THE PLANTS LIFETIME

REVIEW OF COMMERCIAL NUCLEAR INDUSTRY EEQ HISTORY

- GENERAL DESIGN CRITERION 4 (APPENDIX A 10 CFR 50):
 - ◆ STRUCTURES, SYSTEMS AND COMPONENTS 'IMPORTANT TO SAFETY' SHALL BE DESIGNED TO ACCOMMODATE THE EFFECTS OF ... POSTULATED ACCIDENTS, INCLUDING LOSS OF COOLANT ACCIDENTS"
- ASME CODE SECTION III
 - ◆ REQUIRES DYNAMIC QUALIFICATION OF MECHANICAL EQUIPMENT
 - ◆ OPERABILITY NOT DIRECTLY ADDRESSED
- IEEE 323 (1971 AND 1974)
 - ◆ COVERS ENVIRONMENTAL QUALIFICATION OF ELECTRICAL EQUIPMENT
- NRC IE BULLETIN 79-01B
 - ◆ ENVIRONMENTAL EQUIPMENT QUALIFICATION REQUIREMENTS FOR OPERATING PLANTS
- NUREG 0588
 - ◆ ENVIRONMENTAL EQUIPMENT QUALIFICATION REQUIREMENTS FOR NEW PLANTS PLANTS
- 10CFR50.49 EQ FINAL RULE
 - ◆ ENVIRONMENTAL EQUIPMENT QUALIFICATION REQUIREMENTS FOR ALL PLANTS

THE ENVIRONMENT

- WHAT ARE THE CONDITIONS THAT CAN CHANGE THE ISOLATION SYSTEM'S STRUCTURAL PROPERTIES? (STIFFNESS AND DAMPING)

- NORMAL CONDITIONS

- ◆ OZONE AND ULTRAVIOLET ATTACK

- ◆ COLD AND HOT WEATHER

- ◆ AGE EFFECTS

- ◆ CREEP

- ◆ MILD RADIATION ENVIRONMENT

- ACCIDENT CONDITIONS

- ◆ HIGH TEMPERATURE ENVIRONMENT

- ◆ HIGH RADIATION ENVIRONMENT

- ◆ CHEMICAL ATTACK

- ◆ AGING EFFECTS

EVENTS LEADING TO ACCIDENT CONDITIONS

- HIGH HAZARD DOE FACILITIES GENERALLY HAVE FEWER SEVERE ACCIDENT CONDITIONS THAN COMMERCIAL NUCLEAR PLANTS.
- SOME DOE REACTORS (N, L, K, etc.) CAN HAVE SIMILAR ACCIDENT SCENARIOS
- MOST OTHER DOE FACILITIES HAVE ACCIDENT CONDITIONS LEADING TO "SOMEWHAT" HARSH ENVIRONMENTS
- THE BASE ISOLATION SYSTEM DESIGNER MUST REVIEW THE ACCIDENT ANALYSES BASED (TYPICALLY) ON CHAPTER 15 OF THE SAFETY ANALYSIS REPORT.
- TYPICAL ACCIDENTS INCLUDE:
 - ◆ LOSS OF COOLANT AND SECONDARY PIPE BREAKS
 - ▶ CAN AFFECT ISOLATORS SUPPORTING EQUIPMENT WITHIN BUILDINGS
 - ▶ CAUSES HIGH TEMPERATURES, PRESSURES, HUMIDITY, RADIATION. CAN CAUSE CHEMICAL SPRAY, FLOODING
 - ◆ LOSS OF HVAC
 - ▶ LEADS TO HIGHER TEMPERATURES
 - ◆ OTHERS

ACCIDENT SERVICE CONDITIONS

- ISOLATION SYSTEM OPERATING TIME

- ◆ THIS COULD BE 40 YEARS AFTER THE ACCIDENT OR IT COULD BE A FEW DAYS AFTER THE ACCIDENT, WITH THE PROVISION FOR REPLACEMENTS DUE TO DAMAGE
- ◆ ISOLATION SYSTEM MUST HAVE ADEQUATE STRUCTURAL PROPERTIES, GIVEN THE DAMAGE DUE TO ENVIRONMENTAL EFFECTS

- TEMPERATURE AND DURATION

- ◆ MAXIMUM TEMPERATURE AND TEMPERATURE VERSUS TIME PROFILES DEVELOPED FOR POSTULATED ACCIDENTS. THIS IS IMPORTANT FOR ELASTOMERS USED WITHIN STRUCTURES.

- CHEMICAL SPRAY

- ◆ CHEMICAL SPRAYS (BORIC ACID, ETC.) ARE SOMETIMES USED TO MITIGATE ACCIDENTS. THE CHEMICAL SPRAY CONTENT AND PH SHOULD BE DETERMINED AND ISOLATOR MATERIALS EVALUATED FOR DETRIMENTAL EFFECTS

- RADIATION

- ◆ ACCIDENT RADIATION LEVELS ARE CALCULATED FOR FULL SPECTRUM OF ACCIDENT SCENARIOS FOR ALL AFFECTED LOCATIONS.
- ◆ THIN BARRIERS CAN BE USED TO REDUCE BETA. CONCRETE SHIELDING CAN BE USED TO REDUCE GAMMA.

- SUBMERGENCE

- ◆ THE POTENTIAL FOR FLOODING, DUE TO BROKEN PIPES SHOULD BE INVESTIGATED. IF CAUSTIC MATERIALS ARE USED, THESE SHOULD ALSO BE CHECKED, ESPECIALLY IN AREAS WITH PLASTIC PIPE.

- THERMAL LAG

- ◆ THE ACTUAL ISOLATOR SURFACE AND INTERNAL TEMPERATURES MAY LAG BEHIND THE INCREASE IN BULK VAPOR TEMPERATURES. THESE EFFECTS CAN BE CONSIDERED IN CALCULATING THE ISOLATION SYSTEMS QUALIFIED LIFE.

PROPERTIES OF ELASTOMERS

- ELASTOMERS ARE COMPOSED OF POLYMERS, FILLERS, OILS, ACCELERATORS, ANTIOZONANTS AND RETARDERS THAT ARE BLENDED AND VULCANIZED
- VULCANIZATION TRANSFORMS THESE MATERIALS INTO A STRONG, ELASTIC, TOUGH MATERIAL BY CREATING A 3D NETWORK OF CROSSLINKS BETWEEN THE MOLECULAR CHAINS.
- AT LOW SHEAR STRAINS, UNCOILING OF THE MOLECULES PROVIDES LINEAR ELASTICITY
- AT HIGH SHEAR STRAINS, CRYSTALLIZATION OF THE MOLECULES OCCURS: THIS LEADS TO INCREASED STIFFNESS, BUT REDUCED DUCTILITY. UNLOADING REVERSES THIS PROCESS.
- ENVIRONMENTAL CONDITIONS AFFECT THE MOLECULAR STRUCTURE. THIS LEADS TO CHANGES IN MECHANICAL PROPERTIES (TEAR STRENGTH, FATIGUE RESISTANCE, CREEP RESISTANCE). THESE CHANGES IN MECHANICAL PROPERTIES AFFECT THE LOAD DEFLECTION AND DAMPING CHARACTERISTICS.
- THE QUESTION TO BE ANSWERED: HOW MUCH CHANGE CAN THE ISOLATOR TAKE, AND STILL BE WITHIN ACCEPTABLE STRUCTURAL PERFORMANCE LIMITS?

FABRICATION PROCESS

- TWO METHODS: COLD BONDING, OR FULLY-VULCANIZED
- COLD BONDING PROCESS: SHEETS OF FULLY VULCANIZED ELASTOMER ARE BONDED TO INTERLEAVING STEEL PLATES, WITH ADHESIVE, AND CURED AT ROOM OR ELEVATED TEMPERATURES.
- ADVANTAGES:
 - ◆ RELATIVELY CHEAP TO PERFORM
 - ◆ EACH LAYER CAN BE INSPECTED PRIOR TO THE APPLICATION OF THE NEXT LAMINATION
- DISADVANTAGES:
 - ◆ LONG CURE TIMES
 - ◆ DIFFICULT TO MONITOR THE QUALITY OF ADHESIVE BONDS BETWEEN THE STEEL AND ELASTOMER SHEETS
 - ◆ DEBONDMENTS EXPERIENCED IN SERVICE
- FULLY VULCANIZED PROCESS: UNVULCANIZED ELASTOMER IS MOLDED ONTO THE LAMINATION PLATES. THE ASSEMBLY IS THEN HEATED AND PRESSED IN A MOLD, TO VULCANIZE THE ELASTOMER AND CURE THE ADHESIVE.
- ADVANTAGES:
 - ◆ ONE STEP PROCESS WITH SHORT CURING TIME
- DISADVANTAGES
 - ◆ DIFFICULT TO MONITOR THE VULCANIZATION PROCESS
 - IN EITHER CASE, THE END USER OFTEN CAN ONLY PERFORM QA INSPECTIONS ON THE COMPLETED UNIT, SUCH AS LOAD-DEFLECTION CHECKS. SUCH TESTS CAN MISS INTERNAL DEFECTS, SUCH AS IMPROPER BONDS.

LONG TERM PERFORMANCE

- TO DETERMINE DAMAGE THRESHOLDS (FOR TEMPERATURE, OR RADIATION EFFECTS), WE NEED TO KNOW THE FAILURE MECHANISMS OF THE BEARINGS
- PAST BEARING FAILURES (NON-ISOLATION BEARINGS) ARE FEW, AND THE DATA IS DIFFICULT TO COLLECT. HOWEVER, TRENDS INCLUDE:
 - ◆ EXCESSIVE CREEP
 - ◆ ELASTOMER SPLITTING
 - ◆ DEBONDING (MOST COMMON).
- DEBONDING CAN LEAD TO INITIATION OF CRACK PROPAGATION WHEN THE BEARING IS SUBJECTED TO LARGE EARTHQUAKE-INDUCED SHEAR STRAINS.
- ELASTOMERS WHICH HAVE STRAIN CRYSTALLIZATION (LIKE NATURAL RUBBER AND NEOPRENE) TEND TO HAVE BETTER DEBONDING CAPABILITY
- ELASTOMERS IN THE PRESENCE OF OZONE HAVE REDUCED FATIGUE LIFE, POSSIBLE BECAUSE SMALL OZONE-INDUCED CRACKS PROVIDE INITIATION SITES FOR LARGER FATIGUE CRACKS.
- CREEP TENDS TO INCREASE WITH THE HARDNESS OF RUBBER, AND THE PRESENCE OF LARGE LATERAL SHEAR STRAINS.
- AS MORE CREEP DEVELOPS, THE ELASTOMERS TEND TO STRAIN CRYSTALLIZE. THIS INCREASED CRYSTALLIZATION LEADS TO INCREASED SHEAR STIFFNESS.

AGING EFFECTS

- THE ARRHENIUS MODEL OF ACCELERATED AGING IS OFTEN EMPLOYED TO DEVELOP A CORRELATION BETWEEN THE AGING OF A COMPONENT AT A RELATIVELY LOW TEMPERATURE FOR A LONG TIME (LIKE 40 YEARS FOR A BEARING AT 80 DEGREES F) AND ACCELERATED AGING AT A HIGH TEMPERATURE FOR A SHORT TIME (AS IN A TEST).
- THE ARRHENIUS MODEL IS BASED ON EXPERIMENTALLY DETERMINED DEGRADATION OF MATERIAL PROPERTIES
- MODEL: $t = B \exp(E_a / kT)$
 - ◆ t = qualified time before damage threshold reached
 - ◆ B = experimentally determined constant, dependent on material and the definition of failure
 - ◆ E_a = activation energy (eV)
 - ◆ k = Boltzman's constant
 - ◆ T = temperature (degrees Kelvin)
- DEFINITION OF DAMAGE THRESHOLD THIS DEPENDS UPON THE APPLICATION. SHOULD BE EXPRESSED AS THE RETENTION OF ELONGATION AT BREAK, CREEP, MAXIMUM SHEAR STRAIN, ETC. IF WE TEST THE ENTIRE ISOLATION UNIT (VERY EXPENSIVE), CAN BE EXPRESSED AS CHANGE IN STRUCTURAL PROPERTIES (STIFFNESS, DAMPING)
- B IS DEVELOPED BY PERFORMING OVEN TESTS AT VARIOUS TEMPERATURES UNTIL THE DEFINED DAMAGE THRESHOLD IS REACHED

REACTOR BUILDING

600 VOLT 8TN INSTRUMENT CABLE

THERMAL LAG TIME PROFILE

TEMPERATURE EFFECTS

- AT TEMPERATURES ABOVE 160 DEGREES F, MOLECULAR CHANGES IN THE ELASTOMER LEAD TO HIGHER STIFFNESS AND INCREASED EMBRITTLEMENT.
- FOR EXAMPLE: 80% REDUCTION IN ELONGATION AT BREAK WAS OBSERVED AFTER 170 DAYS AT 160 DEGREES F, OR AFTER 7 DAYS AT 212 DEGREES F.
- FOR EXAMPLE: 100% INCREASE IN MODULUS WAS OBSERVED AFTER 50 DAYS AT 160 DEGREES F, OR AFTER 7 DAYS AT 212 DEGREES F.
- THE ARRHENIUS TECHNIQUE OFTEN USED FOR NUCLEAR PLANT APPLICATION (GASKETS, ETC.) MAY NOT HOLD FOR LARGE BULK ELASTOMERIC BEARINGS. THUS, SHORT TESTS AT ELEVATED TEMPERATURES MAY NOT BE EASILY CONVERTED TO LONGER DURATIONS AT MORE MODEST TEMPERATURES.
- AT TEMPERATURES BELOW ABOUT 10 DEGREES F, COLD CRYSTALLIZATION BEGINS. THIS PROCESS IS QUICKENED IF THE ELASTOMER IS STRESSED. THIS LEADS TO HIGHER STIFFNESS AND INCREASED EMBRITTLEMENT.
- FIFTEEN FOLD INCREASES IN SHEAR STIFFNESS HAVE BEEN OBSERVED IN BRIDGE BEARINGS TESTED IN THE COLD CRYSTALLIZATION TEMPERATURE RANGE.
- AT TEMPERATURES BELOW MINUS 40 DEGREES F, THE GLASS TRANSITION TEMPERATURE IS REACHED. THIS PROCESS IS RAPID, AND RESULTS IN A BRITTLE, VERY STIFF MATERIAL.

OZONE EFFECTS

- OZONE: ATTACKS MOLECULAR CHAINS, CAUSING INCREASE IN CROSS LINK DENSITY, EMBRITTLEMENT AND CRACKING. THESE EFFECTS ARE ACCELERATED IN TENSION FIELDS. TENSION FIELDS ARE PRESENT UNDER STATIC COMPRESSION LOADS AT THE BULGES IN THE ELASTOMERS AT THE FREE SURFACE (BETWEEN THE LAMINATED PLATES).
- OZONE IS SOLVED MOSTLY BY PROVIDING EXTRA MATERIAL SURROUNDING THE ENTIRE BEARING. THIS STOPS THE OZONE ATTACK TO THE OUTER EDGES, AND ALSO PROVIDES CORROSION PROTECTION FOR THE STEEL PLATES.
- STILL, OZONE ATTACK CAN LEAD TO REDUCED FATIGUE LIFE AT HIGH CYCLIC SHEARS. SMALL CRACKS AT THE OUTSIDE CAN INITIATE LARGER FATIGUE CRACKS. CRACKS THAT EXTEND INTO THE INTERLAMINAR REGIONS OF A BEARING CAN ACCELERATE DEBONDING OF THE ADHESIVE.

FIRE EFFECTS

- ACCOMMODATE BY ADDING SACRIFICIAL LAYER OF RUBBER ON THE EXPOSED SIDES OF THE BEARING
- CAN PASS 2 TO 4 HOUR FIRE RATING TESTS
- SOME INVESTIGATION NEEDED ABOUT POST-FIRE STRUCTURAL PROPERTIES, DUE TO THERMAL AGING EFFECTS

RADIATION EFFECTS

- THE BASE ISOLATION DEVICE MUST BE QUALIFIED FOR BETA AND GAMMA RADIATION
 - ◆ BETA RADIATION: LOW VELOCITY, HIGH MASS PARTICLES. LOW PENETRATING POWER. A SEALED METAL HOUSING WILL SHIELD THE INTERNALS OF AN ISOLATION DEVICE FROM MOST OF THE BETA DOSE
 - ◆ GAMMA RADIATION: HIGH VELOCITY, LOW MASS PARTICLES. HIGH PENETRATING POWER. IT IS NORMALLY REASONABLE TO ASSUME THAT ALL PARTS OF A COMPONENT WILL BE EXPOSED TO THE SAME GAMMA DOSE.
- THE DAMAGE THRESHOLD IS THE RADIATION DOSE THAT CAUSES THE FIRST CHANGE IN ANY PROPERTY OF A MATERIAL
- THE FUNCTIONAL THRESHOLD IS THE MAXIMUM RADIATION DOSE AT WHICH A COMPONENT PART CAN STILL PERFORM ITS FUNCTION. THIS THRESHOLD CONSIDERS CHANGES IN THE APPLICABLE MATERIAL PROPERTIES, THE FUNCTION OF THAT MATERIAL IN THE OVERALL ISOLATOR FUNCTION.

RADIATION EFFECTS

- RADIATION HAS A NEGATIVE EFFECT ON ELASTOMERS. RADIATION RUPTURES THE MOLECULAR CHAINS AND INCREASES CROSSLINKING. THE RESULT IS INCREASED STIFFNESS AND DECREASED MAXIMUM ELONGATION AT BREAK.
- BEARINGS CAN EASILY BE PROTECTED FROM BETA RADIATION DOSES.
- THICK MASSES OF CONCRETE ARE NEEDED TO REDUCE GAMMA RADIATION DOSES.
- THRESHOLD DAMAGE (NO OBSERVED CHANGES IN GLOBAL STIFFNESS PARAMETERS) OCCURS AT ABOUT 4×10^7 RADS FOR NATURAL RUBBER. SEVERE DAMAGE (LITTLE REMAINING ELONGATION) OCCURS AT ABOUT 4×10^8 RADS.
- TYPICAL DOSES IN A PWR CONTAINMENT DUE TO A LOCA ARE ABOUT 1×10^7 RADS GAMMA, AND 2×10^8 RADS BETA.

RADIATION EXAMPLES

- THE LAYERS OF NATURAL RUBBER IN A ISOLATOR, WITHIN THE LAYERED PLATES SHOULD NOT BECOME EMBRITTLED DUE TO RADIATION. THIS MATERIAL HAS A LOWER FUNCTIONAL THRESHOLD THAN THE RUBBER MATERIAL WHICH ENCASES THE RUBBER
- RUBBER MAY BE ABLE TO PERFORM ITS STATIC FUNCTION (COMPRESSION) AT A HIGHER DOSE THAN ITS DYNAMIC FUNCTION (LARGE SHEAR STRAINS)
- SHIELDING: BETA RADIATION (SOMETIMES AS HIGH AS $2E8$ RADS IN A PWR) IS PRESENT, BUT TEST SHOWS FUNCTIONAL THRESHOLD AT $1E7$ RADS, THEN PROVIDE SHIELDING. REQUIRED SHIELDING THICKNESS IS THIN:
 - ◆ Unshielded Dose / Shielded Dose = $\text{EXP}(14.68 u t)$ [EVANS]
 - ◆ u = linear absorption coefficient (cm)
 - ◆ t = thickness of shielding
 - ◆ say shielding material has density 10 gm / cm^3
 - ◆ $t_{\text{required}} = (\ln(2e8/1e7) / (14.2 * 10)) = 2 \text{ mm THIN !!!!!}$

OWNER: WPPSS
FACILITY: WNP 2
SPEC: ZH08-18

MPL:
PPD:

PAGE NO:
REVISION: 5
DATE: September, 1983

EQUIPMENT DESCRIPTION	ENVIRONMENT			DOCUMENT REF.		QUALIFICATION METHOD	OUTSTANDING ITEMS
	PARAMETER	FSAR	QUALIFICATION	FSAR	QUAL		
SYSTEM Standby Gas Treatment TAG NUMBER SGT-SPV-F1, F2, F3, F4, F5, F6 MANUFACTURER Automatic Switch (ASCO) MODEL NUMBER 0211 D2MO COMPONENT Solenoid Pilot Valve FUNCTION/SERVICE 1/2" S. O. Deluge Valve Assy SGT-DV-18 LOCATION: BLDG R ELEVATION See Note 2 COLUMN See Note 2	OPERATING TIME	6 months	> 6 months	1	4	Materials Test, and Engineering Analysis	None
	TEMPERATURE (F)	90 max. normal 104 max. abnormal Profile 4	185	2	4	Materials Test, and Engineering Analysis	None
	PRESSURE (PSIA)	14.7	14.7	2	4	Engineering Analysis	None
	RELATIVE HUMIDITY (%)	40 max. normal 90 max. normal Profile 4.22X	95	2	4	Engineering Analysis	None
	CHEMICAL SPRAY	N/A	N/A	2	N/A	N/A	None
	RADIATION (RAD)	6.8 x 10 ⁴	4 x 10 ⁵	3	4	Materials Test and Engineering Analysis	None
	AGING	40 years	7 years	2	4	Operating Experience and Engineering Analysis	None Note 1
	ACCURACY	N/A	N/A	N/A	N/A	N/A	None
FLOOD LEVEL SLEV: ABOVE FLOOD LEVEL? YES X NO (Ref. 5)	Prepared by: _____ Reviewed by: _____ 3						
DOCUMENTATION REFERENCES				NOTES			
1. BRI CIR list, REV 8, 6/1/83 2. FSAR Para 3.11 and WPPSS Calculation NC-02-82-14-0 3. 4. 5. BRI Calculation #5.51.055				Qualified 1. The solenoid valves will be rebuilt on a schedule based on the 7 year qualified life and coils will be changed to Class II prior to plant operation.			

TYPICAL ENVIRONMENTAL QUALIFICATION SUMMARY

RESOLUTION OF ENVIRONMENTAL QUALIFICATION ISSUES

- PROVIDE SHIELDING
 - ◆ USE THIS WHEN THE ISOLATION DEVICE COMPONENT IS IN A HIGH RADIATION ENVIRONMENT
- PROVIDE SINGLE FAILURE REDUNDANCY
 - ◆ USE THIS WHEN A SINGLE COMPONENT FAILS DUE TO HIGH LOCAL TEMPERATURES, CHEMICAL SPRAY, ETC.
 - ◆ COULD BE JUST THAT THE ADJACENT ISOLATORS PICK UP THE VERTICAL LOAD DUE TO SINGLE ISOLATOR'S "FAILURE (EXCESSIVE CREEP, LOWERED COMPRESSIVE STIFFNESS, ETC.)
- RE-DESIGN RUBBER / ISOLATOR COMPOUNDS
- RELOCATE ISOLATION DEVICES TO MORE BENIGN ENVIRONMENT

PRACTICAL APPLICATION

- **IN-SERVICE INSPECTION PROGRAM IN USE FOR 6 NUCLEAR UNITS (KOEBS, CRUAS)**
 - ◆ VISUAL CHECKS FOR CRACKS AND TEARS, BULGES
 - ◆ HARDNESS CHECKS (INDICATOR OF SHEAR STIFFNESS)
 - ◆ MEASUREMENT OF VERTICAL DISPLACEMENT (CREEP)
 - ◆ INSPECTION DONE ONCE PER YEAR
 - ◆ LOAD DEFLECTION TESTS PERFORMED ON SAMPLE PADS STORED IN SIMILAR ENVIRONMENT
- **PERFORM THE EEQ AT THE PROJECT DESIGN STAGE, NOT AFTER YOU BOUGHT THE BEARINGS. BEST PLACE TO CONTROL THE QUALITY OF THE MATERIALS IS IN THE MANUFACTURING PROCESS. POOR QUALITY CONTROL HERE LEADS TO POOR PERFORMANCE OVER TIME**
- **THE IDEAL WORLD: TEST THE COMPLETED ASSEMBLIES, CONSIDERING ALL THE ENVIRONMENTAL VARIABLES**
- **THE REAL WORLD: QUALIFY THE BEARINGS BASED UPON AVAILABLE QUALIFICATION TESTS OF SUBCOMPONENTS. PERFORM A FEW PLANT-SPECIFIC TESTS**

LEVEL OF EFFORT

- IF EXPERIENCE IS ANYTHING TO GO BY:
 - ◆ EARLY (PRE 1980) EEQ EFFORTS IN THE NUCLEAR INDUSTRY WERE LIMITED IN SCOPE. THE OLDER PLANTS GOT BY "CHEAP"
 - ◆ TODAY, THE OLD PLANTS HAVE INVESTED SUBSTANTIALLY IN EEQ UPGRADES. NEW PLANTS HAVE PERFORMED IN DEPTH ORIGINAL DESIGN EFFORTS
 - ◆ TODAY, ALL PLANTS MAINTAIN AN ACTIVE REPLACEMENT PARTS PROGRAM, CONSTANTLY UPDATING EEQ BINDERS
- WHAT HAS BEEN DONE UP TO NOW?
 - ◆ "ABOUT" 99%+ OF ALL ISOLATION SYSTEM TESTS HAVE BEEN TO IDENTIFY STRUCTURAL PROPERTIES (STIFFNESS, DAMPING)
 - ◆ MATERIAL BEHAVIOR EFFORTS PERFORMED MOSTLY BY THE RUBBER MANUFACTURERS (DUPONT, MRPRA, ETC.)
 - ◆ FEW OVEN TESTS OF COMPLETED ASSEMBLIES
 - ◆ FEW POST AGING TESTS OF COMPLETED UNITS

SPECIAL TOPICS FOR BASE ISOLATION SYSTEMS

**WORKSHOP ON SEISMIC BASE ISOLATION FOR DEPARTMENT OF
ENERGY FACILITIES**

PRESENTED BY JOHN EIDINGER

G&E ENGINEERING SYSTEMS, INC.

MAY 14, 1992

TOPICS

- EARTHQUAKE SELECTION AND FACTOR OF SAFETY
- RELATIVE MOTION EFFECTS
- EARTHQUAKE MAGNITUDE AND SOIL AMPLIFICATION EFFECTS
- LATERAL TORSIONAL RESPONSE

EARTHQUAKE SELECTION AND FACTORS OF SAFETY

- SELECTION OF INPUT MOTIONS DIRECTLY AFFECT THE DESIGN OF THE ISOLATION SYSTEM
- THE LEVEL OF THE "SSE" GIVES US THE DESIGN DISPLACEMENT OF THE ISOLATION SYSTEM
- THE UNCERTAINTY OF THE "SSE" GIVES US THE FACTOR OF SAFETY NEEDED AT THE DESIGN DISPLACEMENT

UNCERTAINTY IN THE EARTHQUAKE

- IF WE RELY UPON STATISTICAL ANALYSIS OF PAST EARTHQUAKE EVENTS, THEN, AT ROCK SITES, FOR A MAGNITUDE 8 EVENT, WE GET AN "AVERAGE" GROUND DISPLACEMENT OF PERHAPS 10 INCHES (10 KM FROM FAULT), BUT A "MEAN PLUS ONE STANDARD DEVIATION" GROUND DISPLACEMENT OF PERHAPS 22 INCHES
- STATISTICAL ANALYSIS OF LONG PERIOD MOTIONS SUGGEST THAT THERE IS ABOUT A 2 - 3 FOLD INCREASE IN GROUND DISPLACEMENTS, BETWEEN MEAN 10,000 YEAR AND 100,000 YEAR EVENTS
- FOR NEW COMMERCIAL REACTORS FACILITIES, TODAY'S SAFETY GOALS SUGGEST FREQUENCY OF CORE DAMAGE $< 1 \text{ E-5}$, FREQUENCY OF LARGE RELEASE $< 1 \text{ E-6}$ PER YEAR
- FOR DOE, USE PERFORMANCE GOALS BASED ON HIGH, MODERATE OR LOW HAZARD USAGE

FACTORS OF SAFETY

- BASED UPON THE UNCERTAINTY IN THE EARTHQUAKE, AND THE SAFETY GOALS, THE REQUIRED FACTOR OF SAFETY FOR DISPLACEMENT ON THE ISOLATOR IS ESTABLISHED
 - ◆ FOR COMMERCIAL REACTORS, SUGGEST $FS = 3$, USING 10,000 YEAR MEAN SSE, AT VERY HIGH ISOLATOR RELIABILITY
 - ◆ FOR DOE HIGH HAZARD FACILITIES, SUGGEST $FS = 1$, USING [TBD] YEAR MEAN SSE, AT VERY HIGH ISOLATOR RELIABILITY
 - ◆ FOR DOE MODERATE HAZARD FACILITIES, SUGGEST $FS = 1$, USING [TBD] YEAR MEAN SSE, AT HIGH ISOLATOR RELIABILITY
 - ◆ FOR DOE LOW HAZARD FACILITIES, USE UBC
- OTHER WAYS TO CALCULATE THE FACTOR OF SAFETY ON ISOLATOR DISPLACEMENT CAN USE MEAN PLUS ONE STANDARD DEVIATION MOTIONS
 - ◆ THIS SHOULD LEAD TO SHORTER RETURN PERIOD EVENTS, OR HIGHER FS REQUIREMENTS, ETC.
- KEY: ENSURE THAT A SOMEWHAT LARGER EARTHQUAKE WILL NOT FAILURE THE ISOLATION SYSTEM IN A "NON-DUCTILE" MANNER

RELATIVE MOTION EFFECTS

- TRADITIONAL DYNAMIC ANALYSIS INPUTS A SINGLE MOTION FOR THE ENTIRE FOUNDATION
- REAL EARTHQUAKES DO NOT PUT IN THE SAME MOTION AT ALL POINTS IN THE FOUNDATION
- THIS IS NOT A BIG PROBLEM FOR BASE ISOLATED STRUCTURES, UNLESS VERY LONG (LIKE BRIDGES)
- EXAMPLE
 - ◆ WAVE PASSAGE EFFECT
 - ◆ ATTENUATION EFFECT
 - ◆ RATH PAY INCOHERENCEY EFFECT
 - ◆ EXTENDED SOURCE EFFECT

WAVE PASSAGE EFFECT

ATTENUATION EFFECT

RAY PATH INCOHERENCY EFFECT

EXAMPLE OF RELATIVE MOTION EFFECTS

- ASSUME MAGNITUDE 7 EVENT
- CLOSEST DISTANCE TO FAULT IS 10 KM
- INCLUDE ALL 4 EFFECTS
- RESULTS
 - ◆ MAXIMUM DISPLACEMENT AT ONE POINT IS + 8, - 6 INCHES
 - ◆ AT SEPARATION DISTANCE OF 330 FEET, MAXIMUM OUT-OF-PHASE MOTION IS ABOUT ± 0.6 INCHES
 - ◆ AT SEPARATION DISTANCE OF 4900 FEET, MAXIMUM OUT-OF-PHASE MOTION IS ABOUT + 8, -3 INCHES
 - ◆ LONG PERIOD MOTION (UNDER 1 HERTZ) ABOUT 90% IN PHASE
 - ◆ HIGH FREQUENCY MOTION (OVER 10 HERTZ) RANDOM

STATION
0 STATION
330 FEET STATION
4900 FEET **Acceleration Time Histories**

Displacement Time Histories

Relative Displacement Time Histories

**NOTE: DISPLACEMENTS WILL INCREASE DUE TO
MAGNITUDE EFFECTS AND SOIL SITE EFFECTS**

FREE FIELD SPECTRA

- FOR THE SAME PEAK GROUND ACCELERATION, A MAGNITUDE 7 EVENT WILL PRODUCE ABOUT 50% MORE GROUND DISPLACEMENT THAN A MAGNITUDE 6 EVENT
- FIRM SOIL SITES WILL GENERALLY HAVE SOMEWHAT LOWER PEAK GROUND ACCELERATIONS, FOR THE SAME DISTANCE FROM THE FAULT, AS COMPARED TO ROCK SITES
- SOFT SOIL SITES (ARTIFICIAL FILLS, ETC) WILL AMPLIFY ACCELERATIONS BY A FACTOR OF 2 -3 AT LOW G LEVELS, AND DEAMPLIFY AT HIGH G LEVELS.
- FOR THE SAME MAGNITUDE AND G LEVEL, FIRM SOIL SITES HAVE ABOUT 2 TIMES THE DISPLACEMENT AS ROCK SITES
- FOR THE SAME MAGNITUDE AND G LEVEL, SOFT SOIL SITES HAVE ABOUT 3 - 4 TIMES THE DISPLACEMENT AS ROCK SITES

FREE FIELD RESPONSE S

Workshop
On
Seismic
Base
Isolation
for
Depart
of
Energy
Facilities

Rock Sites
5% Damping

MAGNITUDE EFFECTS

ROCK - FIRM - SOFT SOIL ACCELERATION RELATIONSHIP

Workshop
On
Seismic
Base
Isolation
for
Department
of
Energy
Facilities

Rock, Firm
and Soft Soil
Sites

SITE AMPLIFICATION - DEAMPLIFICATION EFFECTS

FREE FIELD RESPONSE SPECTRA

Workshop
On
Seismic
Base
Isolation
for
Department
of
Energy
Facilities

Rock, Firm,
and Soft Soil
Sites
5% Damping

ROCK, FIRM AND SOFT SOIL SITE EFFECTS

LATERAL - TORSIONAL RESPONSE

- ANALYTICAL TREATMENT
- EXPERIMENTAL OBSERVATION
- CODE ISSUES

ANALYTICAL TREATMENT

- LATERAL, LONGITUDINAL AND TORSIONAL FREQUENCIES CAN BE THE SAME
- LATERAL AND LONGITUDINAL FREQUENCIES THE SAME AS LONG AS ISOLATORS HAVE SAME X AND Y STIFFNESS PROPERTIES (THIS IS COMMON CASE)
- TORSIONAL FREQUENCY WILL MATCH TRANSLATIONAL FREQUENCY IF EACH ISOLATOR'S STIFFNESS IS MATCHED TO CARRY THE DEAD WEIGHT ATOP OF IT (THIS IS COMMON CASE)
- COUPLING WILL ARISE IN THESE THREE MODES IF ANY INBALANCE OCCURS BETWEEN CENTER OF MASS AND CENTER OF RIGIDITY.
- PRACTICAL CONCERN: PURE NORTH-SOUTH INPUT MOTION WILL MANIFEST ITSELF, AFTER A LITTLE TIME, INTO SUBSTANTIAL EAST-WEST DISPLACEMENT OF THE STRUCTURE. HENCE, ISOLATOR DISPLACEMENTS WILL BE LARGER THAN THAT PREDICTED FROM SIMPLE UNI-DIRECTIONAL RESPONSE SPECTRA EVALUATIONS.

ANALYTICAL EXAMPLE

- ASSUMPTIONS

- ◆ STIFFNESS OF EACH ISOLATOR IS DIRECTLY PROPORTIONAL TO THE MASS IT SUPPORTS
- ◆ THERE IS AN ECCENTRICITY, e , BETWEEN THE CENTER OF STIFFNESS AND THE CENTER OF MASS
- ◆ THE SUPERSTRUCTURE BEHAVES AS A RIGID BLOCK ATOP THE ISOLATORS

**SIMPLIFIED THREE DEGREE OF
FREEDOM SYSTEM**

ANALYTICAL DETAILS

X (North-South),	Y (East-West),	θ (Torsional about ZZ axis)
$K_x = \sum_{i=1}^N k_x^i$	$K_y = \sum_{i=1}^N k_y^i$	$K_\theta = \sum_{i=1}^N k_x^{i2} + \sum_{i=1}^N k_y^{i2}$
$M_x = \sum_{i=1}^N m_x^i$	$M_y = \sum_{i=1}^N m_y^i$	$M_{zz} = \sum_{i=1}^N m_i \left(x_i^2 + y_i^2 \right)$

Theoretical uncoupled frequencies, when the center of mass and rigidity coincide:

$$f_x = \frac{1}{2\pi} \sqrt{\frac{K_x}{M_x}} \qquad f_y = \frac{1}{2\pi} \sqrt{\frac{K_y}{M_y}} \qquad f_\theta = \frac{1}{2\pi} \sqrt{\frac{K_\theta}{M_{zz}}}$$

If isolator stiffness is proportional to supported mass, then:

$$f_x = f_y = f_\theta = f_0 = \text{the base isolation target frequency}$$

Theoretical coupled frequencies, when the center of mass and rigidity do not coincide:

$$e_x \neq 0 \quad e_y \neq 0 \quad e = \sqrt{e_x^2 + e_y^2} \quad r = \sqrt{\frac{M_{zz}}{M}}$$

For small ratio of $\frac{e}{r}$, then the three coupled frequencies are:

$$f_1 = f_0 \left(1 - \frac{e}{2r} \right) \quad f_2 = f_0 \quad f_3 = f_0 \left(1 + \frac{e}{2r} \right)$$

Closed Form Solution: The motion is undamped, the eccentricity is the same in both directions, and a unit velocity pulse is applied in the x direction $e_x = e_y = \frac{1}{\sqrt{2}}e$

Solution:

$$u_x = -\frac{1}{2\omega_0} \sin \omega_0 t \left(1 + \cos \omega_0 \frac{e}{2r} t \right)$$

$$u_\theta = -\frac{1}{\sqrt{2}\omega_0} \cos \omega_0 t \sin \omega_0 \frac{e}{2r} t$$

$$u_y = -\frac{1}{2\omega_0} \sin \omega_0 t \left(1 - \cos \omega_0 \frac{e}{2r} t \right)$$

u_x Displacement due to unit X velocity pulse

u θ Displacement due to unit X velocity pulse

uy Displacement due to unit X velocity pulse

U_x (Corner Displacement), X direction due to unit X
velocity pulse

PRACTICAL EXAMPLE

- SUBJECT FCLJC BUILDING TO 1940 EL CENTRO RECORD
- ANALYTICALLY PUT IN ECCENTRICITY OF 5% OF LONG DIRECTION OF THE BUILDING
- RESULTS
 - ◆ X DIRECTION DISPLACEMENT, CENTER OF MASS = 6.7 INCHES
 - ◆ Y DIRECTION DISPLACEMENT, CENTER OF MASS = 2.3 INCHES
 - ◆ CORNER DISPLACEMENT, X DIRECTION = 8.8 INCHES

u_x Displacement due to El Centro 1940

u_{θ} Displacement due to El Centro 1940

uy Displacement due to El Centro 1940

U_x (Corner Displacement), X direction due to El
Centro 1940

VERTICAL AND TORSIONAL RESPONSE

● VERTICAL RESPONSE

- ◆ ADDING THE VERTICAL EARTHQUAKE COMPONENT ADDS OR SUBTRACTS ABOUT 5% TO HORIZONTAL DISPLACEMENT OF ISOLATORS
- ◆ ADDING THE VERTICAL EARTHQUAKE COMPONENT ADDS OR SUBTRACTS ABOUT 25% TO HORIZONTAL ACCELERATIONS, BUT AT THE SECOND HORIZONTAL MODE FREQUENCY (ABOUT 4 HZ) OF THE ISOLATED STRUCTURE
- ◆ ALTHOUGH THE VERTICAL RESPONSE OF THE STRUCTURE IS MOSTLY A DIRECT REFLECTION OF THE VERTICAL INPUT MOTION, THERE IS SOME EXCITATION AT THE FIRST VERTICAL FREQUENCY OF THE STRUCTURE

● TORSIONAL RESPONSE

- ◆ AFTER FIFTEEN SECONDS, THE OUT-OF-PLANE MOTION WAS ABOUT 3% OF PEAK IN-PLANE MOTION, WITH CORNER MOTION ABOUT 6% OF PEAK IN-PLANE MOTION.

EXPERIMENTAL OBSERVATIONS

- 40 KIP FRAME ON EERC SHAKE TABLE
- SIMPLE RUBBER BEARING ISOLATION SYSTEM
- HORIZONTAL FREQUENCY = 0.6 HZ
- VERTICAL FREQUENCY = 11 HZ
- EL CENTRO 1940 HORIZONTAL AND VERTICAL COMPONENTS

Figure 4.2. Dimensions of Structure

Horizontal Stiffness Characteristics of Low
and High Damping Rubber Bearings

Figure 3.3. Vertical Stiffness Characteristics of Low Damping Rubber Bearings

Shear Deflection of Rubber Bearings

RL Base, Displacements with (—) and without (---)

Vertical Motion, El Centro 400 Horizontal, 350 Vertical

RL Base, Accelerations with (—) and without (---)

Vertical Motion, El Centro 400 Horizontal, 350 Vertical

Figure 7.5. RL Base, Displacements, El Centro 450

Figure 7.6. RL Base, Accelerations, El Centro 450

. RL Base, Absolute Vertical Accelerations,
El Centro 400 Horizontal, 350 Vertical

. RL + RH Bases, Relative Vertical Accelerations,
El Centro 400 Horizontal, 350 Vertical

Figure 7.9. RL Base, Transverse Motions, El Centro 450

POUNDING - WHAT HAPPENS IF THE GAPS ARE TOO SMALL?

- RECENT EARTHQUAKE EXPERIENCE (LOMA PRIETA, ETC.) HAS SHOWN THAT IF BUILDINGS POUND INTO EACH OTHER, SUBSTANTIAL DAMAGE OCCURS
- WHAT HAPPENS IF A BASE ISOLATED STRUCTURE POUNDS?
- BY PROVIDING A FACTOR OF SAFETY FOR EXTRA DISPLACEMENT PAST THE "SSE", POUNDING SHOULD NOT OCCUR
- HOWEVER, THE DESIGNER SHOULD BE COGNIZANT OF POSSIBLE PERFORMANCE BEYOND THE DESIGN BASIS EVENT

ANALYTICAL STUDY

- SAN BERNARDINO COUNTY BUILDING
- FOUR EARTHQUAKES
 - ◆ MEXICO CITY (LOW FREQUENCY)
 - ◆ CALTECH (HIGH FREQUENCY)
- AVAILABLE GAP SET TO 50% OR 80% OF "DEMANDED" DISPLACEMENT
- CONTACT STIFFNESS VARIED

° TO BE PUBLISHED BY BRUCE MALSON

MEXICO CITY EARTHQUAKE RECORD (0.17 PGA)

CALTECH EARTHQUAKE RECORD A4 (0.41 PGA)

**CALTECH EARTHQUAKE RECORD A4 (0.41 PGA)
VARIATION OF CONTACT SPRING STIFFNESS
BY $\pm 500\%$**

Pounding: Gap = 80 %

No Pounding

Pounding: Gap = 80 %

No Pounding

DESIGN DECISIONS

SEISMIC ISOLATION SYSTEMS

T. L. Anderson
Fluor Daniel, Inc.
Irvine, CA

15 May 1992
Seismic Base Isolation for DOE Facilities
Marina Del Rey, CA

FLUOR DANIEL

Design Decisions about Isolation Systems

- Trade Studies
- Cost/Benefit Analysis
- Procurement

Reference: T. L. Anderson, "Seismic Isolation for the Los Angeles County Fire Command and Control Facility," Workshop Reference Binder

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DESIGN DECISION

- How do you make it?
- Retrofit or new construction?
- Equal performance or code minimums?
- DOE or commercial facility?
- What's involved in an honest selection?

DESIGN DECISION

- Building height, configuration
- Performance requirements
 - Function
 - Containment
 - Investment
 - Code limitations
- Options
 - Framing
 - Hardening
 - Isolation
 - Acceptable Damage

DESIGN DECISION

- Design Conditions
 - Seismic exposure
 - Site geology
 - Contents fragility
 - Functional requirements
 - Risk avoidance
- Performance measurement
 - Building
 - Contents
 - Personnel
 - Cost
 - * Construction
 - * Life cycle
- Suppliers
- Decision making

DESIGN DECISIONS - TRADE STUDIES

1. Establish performance requirements
2. Set seismic design criteria
 - Applicable code
 - Hazard
 - * Zone/fault proximity
 - * Spectra
 - * Time histories
 - * Allowable stresses/deflections
 - * Inelasticity
 - * 1 or 2 level event

TRADE STUDIES

3. Select isolation system types
 - Technical merit
 - Cost influence (secondary)
 - Musts
 - Wants
 - Decision Analysis methodology*

* Kepner Tregoe, Reference Binder

EXAMPLE

- a. MUSTS:
1. Reduce base shear
 2. Attenuate accelerations
 3. Shake table tested
- b. WANTS:
1. Simplicity
 2. Displacement control
 3. Wind drift
 4. Temporal stability
 5. Previous building use
 6. High frequency attenuation
 7. Stick slip
 8. Dwell
 9. Vendor support
 10. Cost

Example (continued)

KT Scoring Matrix for
Seismic Isolation Solution

CANDIDATE SYSTEMS

WANTS	Wt	EHLR	DC	EWLC	FP	SLIDER
Simplicity	7					
Ultimate Restraint	5					
Wind Drift	8	7	7	9	10	10
Temporal Stability	9					
Previous Bldg. Use	6					
High Frequency Attenuation	10	10	10	9	3	3
Stick-Slip	6					
Dwell	7	10	10	10	8	2
Vendor Support	4					
Cost	0					
WEIGHTED TOTALS		XXX	XXX	XXX	XXX	XXX

EHLR = Elastomeric high loss rubber
 DC = EHLR w/Displacement Control
 EWLC = Elastomeric with lead core
 FP = Friction pendulum
 SLIDER = Low friction slide plates

ACCELERATION FOURIER TRANSFORMS

MRPRA SET 1 (861021.06)

SLIDER 4x4 IN (861117.01)

EL CENTRO HORIZONTAL SPAN 150

Example (continued)

- c. Use weighted table to short list (select) systems for adverse consequence analysis

Adverse consequences (for each alternative)

			*	**
1.	AAA			
2.	BBB			
3.	CCC			

* Probability of occurrence

** Seriousness if it should happen

- H,M,L Scale
- H/H is unsatisfactory
- Seek to minimize risk

For example, if wind deflection is higher than calculated, human discomfort under the design wind may be possible

P = L; S = M

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TRADE STUDIES

4. Preliminary Analyses and Design (*)

- Linear analysis
- SDOF models
- Solution bounds
- Base shear/accelerations
- Isolator sizes and capacity
- Displacement and rattle space
- Superstructure type/sizing
- Foundation requirements
- Structural deformations
- Instructure accelerations

* T. L. Anderson, "Seismic Isolation Design and Construction Practice," 4NCEE, May 1990, Palm Springs, CA, Reference Binder

DESIGN DECISIONS - COST/BENEFIT ANALYSIS

Construction Cost for Alternatives

- Fixed-base design(s)
- Seismic hardening multipliers

Ex:

Seismic Hardening Multipliers*

-	Computer Room HVAC unit	=	1.2
-	Chillers	=	3.0
-	Air Handling Units	=	1.5
-	Cooling Tower	=	1.5
-	Boiler	=	3.0
-	Electrical Equipment	=	1.15

* Experience and manufacturer's recommendations

Normal equipment cost (used in isolated case) x hardening factor = equipment cost in fixed-base case

COST/BENEFIT ANALYSIS

Construction cost for alternatives

- Isolated design(s)
- Isolators
 - Prototype
 - Testing
 - Installation
 - Typical costs
- Foundation modifications
 - Additional floor(?)
 - Rattle space
 - Retaining walls
 - Utilities

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COST/BENEFIT ANALYSIS

- Feedback construction costs into K-T analysis (?)
- Comparative construction cost evaluation
 - Experience to date
 - Comparative performance (?)

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COST/BENEFIT ANALYSIS

Life Cycle Costs & Benefits

1. Building Performance
 - Drift
2. Equipment
 - Acceleration
3. Contents
 - Acceleration
 - Administrative measures
4. Intangibles
 - Subjective
 - Hardening concerns
 - Human response/skill level
 - Visibility

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COST/BENEFIT ANALYSIS

Life Cycle Costs (LCC)
Seismic Loss Estimate

LCC = Construction cost + present value of future seismic losses (PVL)*

$$PVL = AEL (P) \sum_{i=1}^t \frac{1}{(1+RR)^i} \quad (1)$$

where: AEL = Annual expected loss = loss/design life
in years

P = Probability of damage in t years

t = Design life in years

RR = Expected rate of return

* T. L. Anderson, "Pipeline Fault-Crossing Design Strategy," 8WCEE, San Francisco, CA, July 1984, Reference Binder

COST/BENEFIT ANALYSIS

$$\text{and } P = P_E \cdot P_{D/E} \quad (2)$$

where P_E = probability of a specified level of shaking occurring during design life = probability of exceedance

$P_{D/E}$ = conditional damage probability = probability of damage given a specified level of shaking

$P \approx$ damage ratio*

Element Damage Cost = Original cost x repair multiplier x damage ratio

* Reference J. M. Ferritto, "Economics of Seismic Design for New Buildings," ASCE J. Str. Div., V.110, No. 12, Dec. 1984, pp 2925 - 2938, Reference Binder

Damage Ratios-Drift, Steel Structure

Element (1)	Cost, in dollars (2)	Repair multi- plier (3)	INTERSTORY DRIFT								
			0.001 (4)	0.005 (5)	0.010 (6)	0.020 (7)	0.030 (8)	0.040 (9)	0.070 (10)	0.100 (11)	0.140 (12)
1a. Rigid frames	117,500 (Varies with design)	2.0	0	0.01	0.02	0.05	0.10	0.25	0.35	0.50	1.00
b. Braced frames		2.0	0	0.03	0.14	0.22	0.40	0.85	1.00	1.0	1.0
c. Shear walls		2.0	0	0.05	0.30	0.30	0.60	0.85	1.00	1.0	1.0
2. Non-seismic structural frame	625,500	1.5	0	0.005	0.01	0.02	0.10	0.30	1.00	1.0	1.0
3. Masonry	417,600	2.0	0	0.10	0.20	0.50	1.00	1.0			
4. Windows and frames	120,600	1.5	0	0.30	0.80	1.00					
5. Partitions, architectural elements	276,200	1.25	0	0.10	0.30	1.00					
6. Floor	301,200	1.5	0	0.01	0.04	0.12	0.20	0.35	0.80	1.00	1.0
7. Foundation	412,100	1.5	0	0.01	0.04	0.10	0.25	0.30	0.50	1.0	1.0
8. Building equipment and plumbing	731,600	1.25	0	0.02	0.07	0.15	0.35	0.45	0.80	1.0	1.0
9. Contents	500,000	1.00	0	0.02	0.07	0.15	0.35	0.45	0.80	1.0	1.0

(After Ferritto, 1984)

Damage Ratios (P_D/E) as a Function of Acceleration for Steel Structures

Element	Dollars	Repair multi- plier	Floor Acceleration in g's				
			0.08	0.18	0.50	1.2	1.4
1. Floor and roof system		1.5	0.01	0.02	0.10	0.50	1.0
2. Ceilings and lights		1.25	0.01	0.10	0.60	0.95	1.0
3. Building equipment and plumbing		1.25	0.01	0.10	0.45	0.60	1.0
4. Elevators		1.5	0.01	0.10	0.50	0.70	1.0
5. Foundations (slab on grade, sitework)		1.5	0.01	0.02	0.10	0.50	1.0
6. Contents		1.05	0.05	0.20	0.60	0.90	1.0

(After Ferritto, 1984)

COST/BENEFIT ANALYSIS

Example: LACFD FCCF Project
Seismic Damage Loss for Fixed-Base FCCF

Element	Level			\$(K) Cost X	Repair Mult. X	Damage Ratio =	Damage Cost \$(K)
	Gd	2nd	Rf				
Floor/Roof System	X			97	1.5	0.07	18.2
		X		97	1.5	0.3	43.7
			X	97	1.5	0.4	58.2
Ceilings and Lights		X		100	1.25	0.7	87.5
			X	100	1.25	0.9	112.5
Building Equipment and Plumbing	X			833	1.25	0.3	312.4
		X		311	1.25	0.5	194.4
			X	156	1.25	0.6	117.0
Foundations	X			90	1.5	0.07	9.5
Contents	X			125	1	0.4	50.0
		X		125	1	0.7	87.0
			X	—	1	0.8	

Total Loss = \$1090K

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COST/BENEFIT ANALYSIS

Example: (continued)

Seismic Damage Loss for Base-Isolated FCCF

Element	\$(K) Cost X	Repair Mult. X	Damage Ratio =	Damage Cost \$(K)
Floor/Roof System	290	1.5	0.01	4.4
Ceilings & Lights	200	1.25	0.01	2.5
Building Equipment & Plumbing	1,300	1.25	0.01	16.3
Foundations	250	1.5	0.01	3.8
Contents	250	1.0	0.05	12.5

Total Loss = \$39.5K

COST/BENEFIT ANALYSIS

Example: (continued)

SEISMIC RISK - FCCF

- Fixed Base
 1. LAC Building Code - 75 Year Return Period
 2. Project Imposed - 1,400 Year (1.8%)
- Base-Isolated
 1. SEAOC - 2,000 Year (1.2%)

COST/BENEFIT ANALYSIS

Example: (continued)

PRESENT VALUE OF FUTURE SEISMIC LOSSES

Fixed Base:

$$PVL = \frac{\$1,090,000}{25} (0.018) \sum_{i=1}^{25} (1+0.08)^{-i}$$

$$= \$8,720 \leftarrow$$

Base Isolated:

$$PVL = \frac{\$39,500}{25} (0.012) \sum_{i=1}^{25} (1+0.08)^{-i}$$

$$= \$200 \leftarrow$$

- Sensitivity
- 40 to 1

DESIGN DECISION - PROCUREMENT

- Sources
- Performance specification versus design specification
- Commodity approach
- "Or equal" clause (with suitable backup)
- State-of-the-practice
 - Off the shelf design
 - Custom design

Performance Table (Standard Type)

HHD: Bearing with High Elasticity & High Damping

(Other types are available on request)

Product No.	Application Load Range W_0	Performance						Dimensions				Weight	
		Horizontal Direction			Vertical Direction			Dr	hr	Df	H	W	W
		$K_{hx}=10\text{cm}$ (ton/cm)	$K_{hx}=20\text{cm}$ (ton/cm)	Hoq. (cm)	Δx (cm)	Kv (ton/cm)							
HHD-060	150 ~ 200	1.70	1.20	0.15	35	1,400		60	29	88	34	500	1,100
HHD-065	180 ~ 240	2.00	1.40	0.15	35	1,700		65	28	93	33	500	1,100
HHD-070	210 ~ 290	2.30	1.70	0.15	35	2,000		70	27	98	32	600	1,300
HHD-075	240 ~ 320	2.70	1.90	0.15	40	2,300		75	27	107	32	700	1,500
HHD-080	270 ~ 350	3.00	2.10	0.15	40	2,500		80	27	112	33	800	1,800
HHD-085	300 ~ 400	3.40	2.40	0.15	40	2,800		85	26	117	33	900	2,000
HHD-090	340 ~ 450	3.80	2.70	0.15	40	3,200		90	26	122	32	1,000	2,200
HHD-100	410 ~ 560	4.60	3.30	0.15	40	4,000		100	27	137	35	1,400	3,000
HHD-110	500 ~ 680	5.70	4.00	0.15	40	4,900		110	26	152	34	1,600	3,500
HHD-120	580 ~ 790	6.50	4.60	0.15	40	5,700		119	26	159	34	1,900	4,200

Dr : Rubber Diameter (interior plate diameter)
Df : Flange Outer Diameter
hr : Total Thickness of Rubber
(1 layer of rubber x number of layers)
H : Total Height of Rubber Bearing

$K_h(x=10)$: Horizontal direction spring constant.
(Equivalent horizontal spring constant at horizontal displacement $x=10\text{cm}$)
 $K_h(x=20)$: Horizontal direction spring constant.
(Equivalent horizontal spring constant at horizontal displacement $x=20\text{cm}$)
Hoq : Equivalent viscous damping ratio
 Δx : Designed Horizontal Displacement (max. load is to be 2 times as much as designed load)
Kv : Vertical Direction Spring Constant
(min. assured value)

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Performance Table (Standard Type)

LHD: Bearing with Low Elasticity & High Damping

(Other types are available on request)

Product No.	Application Load Range Wo	Performance					Dimensions				Weight	
		Horizontal Direction				Vertical Direction	Dr	hr	Df	H	W	W
		$K_{HX}=10\text{cm}$	$K_{HX}=20\text{cm}$	Hep	Δx	Kv						
	(M. ton)	(ton/cm)	(ton/cm)		(cm)	(ton/cm)	(cm)	(cm)	(cm)	(cm)	(kg)	(lb)
LHD-050	70 ~ 90	0.83	0.55	0.15	35	1,200	52	19	71	23	400	900
LHD-060	100 ~ 120	1.10	0.72	0.15	35	1,400	60	17	85	22	500	1,100
LHD-070	130 ~ 170	1.50	1.00	0.15	35	2,200	70	17	99	22	600	1,300
LHD-080	170 ~ 210	1.90	1.30	0.15	40	2,800	79	16	116	22	800	1,800
LHD-090	220 ~ 280	2.50	1.70	0.15	40	3,600	92	19	126	24	900	2,000
LHD-100	270 ~ 330	3.00	2.00	0.15	40	4,400	101	19	141	24	1,200	2,600

Dr : Rubber Diameter (interior plate diameter)
Df : Flange Outer Diameter
hr : Total Thickness of Rubber
(1 layer of rubber x number of layers)
H : Total Height of Rubber Bearing

$K_h(X=10)$: Horizontal direction spring constant.
(Equivalent horizontal spring constant at horizontal displacement $X=10\text{cm}$.)
 $K_h(X=20)$: Horizontal direction spring constant.
(Equivalent horizontal spring constant at horizontal displacement $X=20\text{cm}$.)
Heq : Equivalent viscous damping ratio
 Δx : Designed Horizontal Displacement (max. load is to be 2 times as much as designed load)
Kv : Vertical Direction Spring Constant
(min. assured value)

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Seismic Base Isolation System Suppliers

1. Andre
Division of BTR Silvertown Ltd.
PO Box 4
Horningslow Road
Burton-on-Trent
Staffs DE130QN
England
Attn: Mr. W. Brake, Sales Manager
(283) 510 510
Telex 34419
2. Base Isolation Consultants, Inc.
246 First Street, Ste. 304
San Francisco, CA 94102
Attn: Mr. D. Way, Vice President
(415) 495-0515
FAX (415) 777-2858
3. Bridgestone Engineered
Products Company
PO Box 6147
Huntington Beach, CA 92615-6147
Attn: Mr. R. Busch
(714) 962-1666
FAX (714) 968-3441
4. Dynamic Isolation Systems, Inc.
2855 Telegraph Avenue, Suite 410
Berkeley, CA 94705
Attn: Mr. R. Mayes, President
(415) 843-7233
FAX (415) 843-0366
5. Fyfe Associates, Inc.
1341 Ocean Avenue
Del Mar, CA 92014
Attn: Mr. E. Fyfe, President
(619) 792-1501
FAX (619) 259-3872
6. Kajima Corporation
2-7, Motoakasaka 1-chome
Minato-ku, Tokyo 107
Japan
(03) 404-3311
FAX (03) 345-6049

FLUOR DANIEL

Seismic Base Isolation System Suppliers (Cont.)

7. Shimizu Construction Company
Ohsaki Research Institute
Fukoku Seimei Bldg., 27th floor
2-2-2, Uchisaiwai-cho
Chiyoda-ku, Tokyo 100
Japan
Attn: Mr. Hiroshi Yamahara,
General Manager
(03) 508-8101
8. Skellerup Polymer Products Ltd.
PO Box 19-555
Woolston
Christchurch, New Zealand
89 91 89
9. Societe E. R. A.
Residence "La Bruyere," Batiment B2
2, Rue de l' Horticulture
13009 Marseille
France
Attn: Mr. P. Delfosse,
Technical Director
33 91 75 17 74
FAX 33 91 26 55 56
Telex 420322F
10. Telesis International
4605 Lankershim, Suite 710
No. Hollywood, CA 91602
Attn: Mr. J. Brennen, President
(818) 769-8894
FAX (818) 769-4822

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PROCUREMENT

- Performance specification

- Period Range
- Damping Range
- Displacement Specified
- Base Shear Limit
- Displacement Margin
- Ultimate Restraint System (?)
- Testing
- Confirmation Analyses

- Example - FCCF*

* Seismic Base Isolation System Requirements Specification, Reference Binder

FLUOR DANIEL

CONSTRUCTION
WITH
BASE ISOLATION SYSTEMS

From the Contractor's Point of View
Lessons From Experience

C. Terry Dooley
Senior Vice President
Morley Construction Company
Santa Monica, California

NEW BUILDINGS WITH BASE ISOLATION

Before Construction

Get contractor advice on design details

Pre-qualify a limited number of GC bidders

Special Care Needed During Construction

Flexible connections and joints

A new subtrade (the isolators) is on the critical path

What if there is a major quake during construction?

Structural behavior?

Insurance?

EXISTING BUILDINGS: RETROFIT WITH BASE ISOLATION

Best to interview contractors
and to negotiate the general contract:

- Decision can be based on quality, personnel, experience
- Contractor can help to uncover existing conditions
- Contractor can propose details & solutions
- Changes can be accommodated easily

IF THE JOB MUST BE BID:

- Pre-qualify General Contractors
- Provide complete drawings and specifications
- Hold several pre-bid conferences & job walks
- Analyze bids carefully
Questions? Exceptions? Thoroughness?
- Require a schedule & staging plan

THE STRUCTURE ITSELF

- Original drawings are needed
- Record changes during intervening years
- Strength & condition of materials
- Access to structural elements
 - may dictate hours of work
 - may require movement of utilities
- Response to external loads during construction

OTHER SYSTEMS TO BE MODERNIZED

- Seismic anchorage of non-structural elements
- Fire & life safety
- Handicapped access
- Electrical & backup power systems
- HVAC systems
- Asbestos
- Architectural finishes
- Landscaping

PROJECT MANAGEMENT

■ Active contact persons needed daily for decisions during construction:

- Owner
- Structural Engineer
- Architect / Electrical / Mechanical

■ Quality of Contractor's Forces

- Management with Engineering background
- Project Manager & Engineers
- Superintendents & Foremen
- Subcontractors

HUMAN RELATIONS

- Depend on the extent & nature of occupancy
- Choice of work schedule
- Communication: Personal, Written, Audio, Video
- Involvement of tenants in the process
- Identification of workers
- Response to complaints

COSTS, BUDGETS

- On negotiated contracts, a series of iterations
- Tradeoffs; Decisions on design, methods & schedules
- Changes are certain
- Cost has ranged widely on seismic retrofit work:
(\$2.50 to 45.00 /sf)
- Sample is too small to give range on base isolation

4 Corner Columns	x 1 isolator	= 4
24 Exterior Wall Columns	x 2 isolators	= 48
26 Interior Columns	x 1 isolator	= 26
54 Columns Total		= 78 isolators

SCHEMATIC PLAN

Rockwell International Corporation
Building 80, Seal Beach, California
Seismic Upgrade, 1990

MORLEY

- Existing Structure Above Plane Of Isolation
- Existing Structure, Below Plane
- New Structure (Attached To Existing)
- Isolation Hardware

SCHEMATIC SECTION
North-South Thru Elevation Core And Stair #2

Rockwell International Corporation
Building 80, Seal Beach, California
Seismic Upgrade, 1990

MORLEY

QUALITY ISSUES
WITH
BASE ISOLATION SYSTEMS

by

Gary C. Hart
Civil Engineering Department
University of California at Los Angeles

DOE WORKSHOP ON BASE ISOLATION
MAY 13-15, 1992

QUALITY ISSUES

- PEER REVIEW
- ISOLATOR RELIABILITY
- QUALITY CONTROL

DESIGN AND PEER REVIEW

UBC Sec. 2308. (a) General. A design review of the isolation system and related test programs shall be performed by an independent engineering team including persons licensed in the appropriate disciplines, experienced in seismic analysis methods and the theory and application of seismic isolation.

DESIGN AND PEER REVIEW

(b) Isolation System. Isolation system design review shall include, but not be limited to, the following:

1. Review of the site-specific seismic criteria, including the development of site-specific spectra and ground motion time histories, and all other design criteria developed specifically for the project.
2. Review of the preliminary design, including the determination of the total design displacement of the isolation system design displacement and lateral force design level.

DESIGN AND PEER REVIEW

3. Overview and observation of prototype testing (Section 2381).
4. Review of the final design of the entire structural system and all supporting analyses.
5. Review of the isolation system quality control testing program [Section 2377(b)9].

PEER REVIEW

- CONCEPTUAL DESIGN
- EXISTING STRUCTURE?
 - Experimental Testing
 - Deformation Capacity
 - Past Earthquake Performance
- EARTHQUAKE GROUND MOTION
- PROTOTYPE TEST PROGRAM
- STRUCTURAL DESIGN INTENT
- STRUCTURAL ANALYSIS DETAILS
- BUILDING DEPARTMENT REVIEW
- ISOLATOR RANDOM REVIEW
- CONSTRUCTION CHANGE ORDERS

ISOLATOR RELIABILITY

- LONG TERM ISSUES
- PERFORMANCE SPECIFICATION
- COMPONENT TEST DATA
- SYSTEM TEST DATA
- STRUCTURAL SYSTEM ANALYTICAL MODELING
- PERFORMANCE DEPENDENCE ON AXIAL LOAD

ISOLATOR SYSTEMS

- 1 HIGH - DAMPING RUBBER
- 2 COMPOSITE RUBBER/LEAD CORE
3. FRICTION

ISOLATOR RELIABILITY

- 1 INITIAL STIFFNESS
- 2 YIELD OR SLIP FORCE
- 3 POST YIELD/SLIP FORCE
DEFLECTION CURVE

ISOLATOR RELIABILITY

SYSTEM	INITIAL STIFFNESS	YIELD/SLIP FACE	POST YIELD/FACE DEFLECTION
HIGH DAMPING	EXCELLENT	GOOD	EXCELLENT
LED CORE	EXCELLENT	EXCELLENT	EXCELLENT
FRICTION	EXCELLENT	POOR	POOR

COEFFICIENT OF DYNAMIC FRICTION VS. PRESSURE

QUALITY CONTROL

- NUMBERS IN THE ANALYTICAL MODEL
- PROTOTYPE TESTING
- BUILDING ISOLATOR TESTING
- STRONG MOTION EARTHQUAKE INSTRUMENTATION

WIND RESTRAINT SYSTEM

- DESIGN WIND FORCE
 - UBC (50 Year Return period)
 - Design Basis (19% in 50 years)
 - Maximum Credible (10% in 250 years)

- LIMIT STATE
 - Yield of Isolator
 - Slip of Isolator

- ACCEPTABLE SAFETY LEVEL
 - Serviceability Limit State ($\beta = 1$ to 1.5)
 - Ultimate Limit State ($\beta = 1.5$ to 4.5)

DESIGN EXAMPLE 1

R.E. Bachman

Fluor Daniel, Inc.

Irvine, CA

15 May 1992

Seismic Base Isolation for DOE Facilities

Marina Del Rey, CA

DESIGN EXAMPLE 1

A Base Isolated Emergency Communications Center

located in Southern California

DESIGN EXAMPLE #1

AN EMERGENCY COMMUNICATIONS CENTER
BASE ISOLATED IN SOUTHERN CALIFORNIA

PROBLEM: DEVELOP BASIC DESIGN PARAMETERS:
AND FORCES FOR ISOLATION SYSTEM AND BUILDING.

GIVEN: RECTANGULAR TWO STORY BUILDING.

PLAN DIMENSIONS, 188 FT BY 84 FT

HEIGHT = 36.5 FT

STRUCTURAL SYSTEM = STEEL BRACED FRAME WITH
INVERTED CHEVRON BRACING

NUMBER OF COLUMNS = 32

ASSUME ISOLATORS UNDER EVERY COLUMN

BUILDING SITE AND LOCATION:

LOCATION: SOUTHERN CALIFORNIA

NEAREST ACTIVE FAULT SITE = 15.0 KM

SOIL CONDITION, SANDSTONE = SOIL TYPE S1

BASIC WIND SPEED = 70.0 MPH, EXPOSURE C
ANSI CLASSIFICATION III

BASIC STRUCTURAL PROPERTIES:

<u>SEISMIC MASS</u>	<u>PSF</u>
ROOF = 790. KIPS	50.
2ND FLOOR = 1775. KIPS	112.
1ST FLOOR = 1665. KIPS	105.

TOTAL = 4230. KIPS

GROSS ECCENTRICITY = 3.4% BY CALCULATION

ESTABLISH BASIC DYNAMIC PARAMETERS AND FORCES:

STEP 1: DETERMINE LIMITING PARAMETERS OF THE ISOLATION SYSTEM

- BASE ISOLATION PERIOD, T_I
- DAMPING, β
- LIMITING DISPLACEMENT OF ISOLATOR, D

USUALLY PERIOD T_I RANGES BETWEEN 2 AND 2.5 SEC.
AND DAMPING β RANGES BETWEEN 10% AND 20%.
DISPLACEMENT IS GENERALLY WHATEVER IS CALCULATED.

ASSUME — $T_I = 2.2$ SEC. } THIS WILL GENERALLY BE
 $\beta = 15\%$ } DEPENDENT ON TYPE
OF ISOLATOR.

STEP 2: DETERMINE THE DESIGN DISPLACEMENT, D

USING EQUATION E-1, PAGE 189-C OF APPENDIX II

$$D = 10 Z N S_I T_I / B \quad (\text{INCHES})$$

$$Z = 0.4 \quad (\text{FROM TABLE 1-A, PAGE 30})$$

$$N = 1.0 \quad (\text{FROM TABLE B, PAGE 202-C})$$

$$S_I = 1.0 \quad (\text{FROM TABLE A, PAGE 202-C})$$

$$T_I = 2.2 \text{ SEC.} \quad (\text{ASSUMED})$$

$$B = \left[(1.2 + 1.5) / 2 \right] = 1.35 \quad (\text{FROM TABLE C, PAGE 202-C})$$

$$D = \left[\frac{10 (0.4) (1.0) (1.0) (2.2)}{1.35} \right] = 6.5 \text{ INCHES}$$

STEP 3: DETERMINE ISOLATOR EFFECTIVE STIFFNESS, K, AT DISPLACEMENT D

FOR EXAMPLE, ASSUME $K_{\min} = K_{\max} = K$
 (FOR MANY ISOLATORS, THE RANGE OF EFFECTIVE STIFFNESS VALUES IS SMALL)

USING EQUATION E-2, PAGE 189-C OF APPENDIX 1L

$$T_I = 2\pi \sqrt{\frac{W}{Kg}}$$

$$K = \left(\frac{2\pi}{T_I} \right)^2 \frac{W}{g}$$

$$K = \left(\frac{2\pi}{2.2} \right)^2 \times \frac{4230.}{386.4} = 89.3 \frac{\text{KIPS}}{\text{IN}} \text{ FOR 32 ISOLATORS}$$

$$K_{\text{INDIVIDUAL}} = \left(\frac{89.4}{32} \right) = 2.79 \frac{\text{KIPS}}{\text{IN}}$$

STEP 4: DETERMINE TOTAL DISPLACEMENT D_T OF ISOLATOR.

USING EQUATION E-3, PAGE 189-C OF APPENDIX 1L

$$D_T = D \left[1 + \frac{12ye}{(b^2 + d^2)} \right]$$

$$y = 92. \text{ FT}$$

$$e = 3.4\% + 5.0\% = \frac{(8.4)(188)}{100} = 15.8 \text{ FT}$$

$$b = 84. \text{ FT}$$

$$d = 188. \text{ FT}$$

$$D_T = (6.5) \left[1 + \frac{12(92)(15.8)}{(84)^2 + (188)^2} \right] = 9.2 \text{ INCHES}$$

STEP 5: CALCULATE THE TOTAL MAXIMUM DISPLACEMENT D_{TM}

USING EQUATION E-4, PAGE 189-C OF APPENDIX 1L

$$D_{TM} = 1.5 D_T = (1.5)(9.2) = 13.8 \text{ INCHES}$$

STEP 6: CALCULATE THE MINIMUM LATERAL FORCE, V_b , FOR ALL STRUCTURAL ELEMENTS BELOW ISOLATOR INTERFACE.

USING EQUATION E-5, PAGE 189-C OF APPENDIX 1L

$$V_b = \frac{K_{MAX} D}{1.5}$$

IN THIS CASE FOR ONE ISOLATOR USE $K_{MAX} = K_{INDIVIDUAL}$

$$V_b = \frac{(2.79)(6.5)}{1.5} = 12.1 \text{ KIPS}$$

FOOTING AND ISOLATOR ANCHORAGE SHOULD BE DESIGNED FOR THESE FORCES.

STEP 7: COMPUTE THE MINIMUM LATERAL FORCE, V_s , FOR ALL STRUCTURAL ELEMENTS ABOVE ISOLATOR INTERFACE.

USING EQUATION E-6, PAGE 190-C OF APPENDIX 1L

$$V_s = \frac{K_{MAX} D}{R_{WI}}$$

$R_{WI} = 1.8$ IF BRACE CARRIES GRAVITY LOADS.

$R_{WI} = 2.2$ IF BRACE DOES NOT CARRY GRAVITY LOADS.

ALTHOUGH CODE REQUIRES BEAM TO BE DESIGNED AS IF BRACE DOES NOT EXIST, DESIGN AS IF BRACE CARRIES GRAVITY LOAD. (SINCE THE BRACING WILL CARRY SOME GRAVITY LOAD.)

$K_{MAX} = K$ OF 32 ISOLATORS

$$V_s = \left[(89.3)(6.5) / 1.8 \right] = 322.5 \text{ KIPS}$$

COMPUTE FOR INTEREST, EQUIVALENT ACCELERATION COEFFICIENT, a :

$$a = (322.5 / 4230) = 0.076 g$$

STEP 8: COMPUTE LIMITS OF V_s

V_s SHALL BE GREATER THAN OR EQUAL TO:

- (1) THE LATERAL SEISMIC FORCE FOR A FIXED BASE STRUCTURE OF SAME WEIGHT AND PERIOD T_I

$$V = \frac{ZIC}{R_w} W$$

$$I = 1.0$$

$$Z = 0.4$$

$$S = 1.0$$

$$C = \frac{1.25 S}{T^{2/3}} = \left[\frac{(1.25)(1.0)}{(2.2)^{2/3}} \right] = 0.74$$

$$R_w = 6.0$$

$$V = \left[\frac{(0.4)(1.0)(0.74)}{(6.0)} \right] (4230) = 208.7 \text{ KIPS}$$

COMPUTE FOR INTEREST, EQUIVALENT ACCELERATION COEFFICIENT, a :

$$a = (208.7 / 4230) = 0.049 g$$

(2) THE BASE SHEAR CORRESPONDING TO THE DESIGN WIND LOAD

$$V_{WIND} = P A$$

$$P = [q G_h C_p - \cancel{q_h (G C_{pi})}] \quad \text{DOESN'T CONTRIBUTE TO OVERALL BASE SHEAR.}$$

$$V = 70.0 \text{ MPH}$$

$$C_p = 0.8 \text{ WINDWARD WALL}$$

$$I = 1.07$$

$$C_p = -0.5 \text{ LEEWARD WALL}$$

$$G_h = 1.23$$

HEIGHT ZONE	K_z	q	P
0-15	0.80	11.49	11.3
15-20	0.87	12.49	12.3
20-25	0.93	13.36	13.1
25-30	0.98	14.67	13.8
30-36.5	1.06	15.22	15.0
LEEWARD WALL	1.06	15.22	-9.4

$$\begin{aligned}
 V_{WIND} &= [(188)(15.)(P_1) + (188)(5.)(P_2 + P_3 + P_4) \\
 &\quad + (188)(6.5)(P_5) + (188)(36.5) P_{\text{PLEEWARD}}] \\
 &= [(188)(15)(11.3) + (188)(5.)(12.3 + 13.1 + 13.8) \\
 &\quad + (188)(6.5)(15.0) + (188)(36.5)(-9.4)] \\
 &= (31866 + 36848 + 18330 + 64502) \text{ lbs}
 \end{aligned}$$

$$V_{WIND} = 151.5 \text{ KIPS}$$

STEP 9: VERIFY THE DESIGN OF ISOLATOR TO ACHIEVE DESIGN PROPERTIES

ASSUME THE FOLLOWING ISOLATOR PROPERTIES PROVIDED BY SUPPLIER.

USING KIRCHEN SIMPLIFIED EQUATIONS,

(1) CHECK DAMPING AT DISPLACEMENT OF 6.5 INCHES

$$\beta = \frac{0.637 (a_y d - d_y a)}{a d}$$

OR

$$\beta = \frac{0.637 (F_y d - d_y F)}{F d}$$

@ $d = 6.5$ INCHES

$$F = 6.3 + 2.2 (6.5 - 0.7325) = 19.0 \text{ K}$$

$$\beta = \frac{0.637 [(6.3)(6.5) - (0.7325)(19.0)]}{(19.0)(6.5)}$$

$$\beta = 0.139 \text{ OR } 13.9\%$$

$\therefore$ DAMPING ASSUMPTION OF 15.0% O.K.

$$\beta = \frac{0.637 [F_y d - d_y F]}{F d}$$

$$F_y = 6.3 \text{ K}$$

$$d_y = 0.7325 \text{ in}$$

$$F = 8.6 d \quad (\text{for } 0 < d < 0.7325)$$

$$F = [6.3 + (d - 0.7325) 2.2] \quad \text{for } (0.7325 < d)$$

d	F	β
0.1	0.9	0.0
0.7325	6.3	0.0
1.0	6.9	0.12
1.5	8.0	0.19
2.0	9.1	0.208
2.2	9.5	0.209
3.0	11.3	0.20
4.0	13.5	0.18
5.0	15.7	0.16
6.0	17.9	0.15
8.0	22.3	0.12
10.0	26.7	0.10
12.0	31.1	0.09
14.0	35.5	0.08
16.0	39.9	0.07

← MAXIMUM

(2) CHECK ISOLATION PERIOD AT 6.5 INCHES

$$K = \frac{F}{d} = \left(\frac{19.0}{6.5} \right) = 2.92 \text{ K/IN}$$

$$K_{\text{TOTAL}} = 32 (2.92) = 93.5 \text{ K/IN}$$

$$T = 2\pi \sqrt{\frac{W}{Kg}} = 2\pi \sqrt{\frac{4230.}{(93.5)(386.4)}} = 2.15 \text{ SECONDS}$$

∴ PERIOD ASSUMPTION OF 2.2 SECONDS O.K.

(3) CHECK WIND YIELD FORCE

$$\text{WIND YIELD} = (6.3)(32) = 201.6 \text{ KIPS}$$

$$\text{WIND FORCE} = 151.5 \text{ KIPS}$$

∴ SINCE WIND FORCE IS LESS THAN WIND YIELD,
ISOLATOR O.K.

(4) TESTING LOADS AND DISPLACEMENT REQUIREMENTS
TO CHECK ISOLATOR STABILITY BY TEST.

PER SECTION L : -

CYCLIC LOAD TESTS

$$\text{TEST DISPLACEMENT} = D_T = 9.2 \text{ INCHES}$$

$$1) \text{ VERTICAL TEST LOAD} = 1.2 DL + 0.5 LL + |E|$$

$$2) \text{ VERTICAL TEST LOAD} = 0.8 DL - |E|$$

MAXIMUM LOAD TESTS FOR STABILITY

$$\text{TEST DISPLACEMENT} = D_{TM} = 13.8 \text{ INCHES}$$

$$1) \text{ VERTICAL LOAD TEST} = 1.2 DL + 0.5 LL + |E|$$

$$2) \text{ VERTICAL LOAD TEST} = 0.8 DL - |E|$$

STEP 10:

DISTRIBUTE FORCES TO LATERAL FORCE RESISTING SYSTEM.

USING EQUATION E-7, PAGE 190-C FROM APPENDIX 1L

$$F_x = \frac{V_s W_x}{\sum_{i=1}^n W_i}$$

$$\sum_{i=1}^n W_i = (790 + 1775 + 1665) = 4230 \text{ KIPS}$$

$$\text{ROOF SHEAR} = \left[\frac{(322.5)(790)}{4230} \right] = 60.2^{\text{K}}$$

$$\text{2ND FLOOR SHEAR} = \left[\frac{(322.5)(1775)}{4230} \right] = 135.3^{\text{K}}$$

$$\text{1ST FLOOR SHEAR} = \left[\frac{(322.5)(1665)}{4230} \right] = 127.0^{\text{K}}$$

DISTRIBUTE ROOF SHEAR (ASSUME 8.4% ECCENTRICITY)

$$F_R = \left[\frac{V_R}{z} + \frac{V_R e}{d} \right]$$
$$= \left[\frac{60.2}{z} + \frac{60.2(15.8)}{188} \right] = 35.2^{\text{KIPS}}$$

DISTRIBUTE 2ND FLOOR SHEAR (ASSUME 8.4% ECCENTRICITY)

$$F_2 = \left[\frac{135.3}{2} + \frac{135.3 (15.8)}{188} \right] = (67.7 + 11.4) = 79.1 \text{ KIPS}$$

DISTRIBUTE 1ST FLOOR SHEAR (ASSUME 8.4% ECCENTRICITY)

$$F_1 = \left[\frac{127.0}{2} + \frac{127.0 (15.8)}{188} \right] = (63.5 + 10.7) = 74.2 \text{ KIPS}$$

SUMMARY OF END FRAME SHEARS

(SIMILAR FOR LONGITUDINAL DIRECTION)

STEP 11: DESIGN ISOLATOR COMPONENT AND FOOTING

ASSUME SPREAD FOOTING

ALLOWABLE SOIL BEARING = 5.0 KSF

FOR EARTHQUAKE, ALLOW $\frac{1}{3}$ INCREASE = 6.65 KSF

HORIZONTAL DESIGN SHEAR

$$V_b = \frac{KD}{1.5} = \left[\frac{(2.79)(6.5)}{1.5} \right] = 12.1 \text{ KIPS}$$

$$P = 255.9 K + 18.0 K = 273.9 \text{ KIPS}$$

$$V = 12.1 \text{ KIPS}$$

$$M = \left[(12.1)(27.) + (273.9) \left(\frac{6.5}{2} \right) \right]$$

$$= (326.7 + 890.2) = 1217. \text{ KIP} \cdot \text{IN}$$

STEP 12: BRACING DESIGN

ASSUME FROM ANALYSIS IN STEP 11

$$D+L = 29.7 \text{ KIPS (LONGITUDINAL)}$$

$$D+L = 10.9 \text{ KIPS (TRANSVERSE)}$$

$$E = 24.0 \text{ KIPS (LONGITUDINAL & TRANSVERSE)}$$

DESIGN LONGITUDINAL BRACE FOR,

$$F = [29.7 + 1.5(24)] = 65.7 \text{ KIPS}$$

DESIGN CONNECTIONS FOR,

$$F = 29.7 + \frac{3}{8} R_w (24)$$

$$= [29.7 + (\frac{3}{8})(1.8)(24)]$$

$$= (29.7 + 16.2)$$

$$= 45.9 \text{ KIPS} \longrightarrow \text{USE } \underline{65.7 \text{ KIPS}}$$

IN ADDITION,

$$(L/r) \leq \frac{720}{\sqrt{F_y}}$$

$$\text{AND } F_{as} = \lambda F_a ; \lambda = \text{STRESS REDUCTION FACTOR (FROM SECTION 4F, pg. 51)}$$

STEP 13: CHECK STORY DRIFT IN FRAME FOR STEP 11 ANALYSIS.

$$\delta = \frac{0.010}{R_{WI}} = \left(\frac{0.010}{1.8} \right) = 0.00555$$

ASSUME FROM ANALYSIS (FROM STEPS 11-12),
MAXIMUM INTERSTORY DRIFT = 0.2 INCH

STORY HEIGHT = 15.5 FT.

$$\text{ALLOWABLE DRIFT} = (15.5)(12)(0.00555) = 1.03 \text{ INCH}$$

∴ SINCE ACTUAL DRIFT = 0.2 INCH, DESIGN O.K.

STEP 14: CHECK ISOLATION DRIFT FOR WIND LOADS

$$\delta_{\text{WIND}} = \left(\frac{V_{\text{WIND}}}{K} \right) = \left[\frac{151.5^K}{(8.6)(32)} \right] = 0.55 \text{ INCH}$$

∴ SINCE WIND LOAD DRIFT IS LESS THAN ALLOWABLE DRIFT, DESIGN O.K.

STEP 15: CHECK BUILDING FIXED BASE PERIOD VERSUS ISOLATION PERIOD.

BUILDING FIXED BASE PERIOD BY ANALYSIS,

$$T_{\text{(LONGITUDINAL)}} = 0.36 \text{ SECONDS}$$

$$T_{\text{(TRANSVERSE)}} = 0.40 \text{ SECONDS}$$

RATIO OF ISOLATED PERIOD TO FIXED BASE PERIOD,

$$\frac{T_I}{T_{\text{(LONG.)}}} = \left(\frac{2.2}{0.36} \right) = 6.1$$

$$\frac{T_I}{T_{\text{(TRANS.)}}} = \left(\frac{2.2}{0.40} \right) = 5.5$$

SINCE RATIO IS GREATER THAN 3, SIMPLIFIED STATIC ASSUMPTION IS O.K.

STEP 16: RATTLESPACE AND UTILITY CONNECTIONS

PROVIDE FLEXIBILITY IN UTILITY CONNECTION AND
RATTLESPACE AT LEAST EQUAL TO $D_{TM} = 13.8$ INCHES

STEP 17: ELEMENTS OF STRUCTURES AND NON-STRUCTURAL COMPONENTS.

DESIGN USING SECTION 2312(g) APPROACH WITH
 $I = 1.0$

$$F_p = Z I C_p W_p$$

STEP 18: OPTIMIZATION AND DYNAMIC ANALYSIS

BY PERFORMING NON-LINEAR TIME HISTORY ANALYSIS
TO VERIFY RESULTS THE DESIGN REQUIREMENTS
PRESENTED EARLIER CAN BE REDUCED.

BELOW THE INTERFACE :

THE TOTAL DESIGN DISPLACEMENT,

$$= 0.9 D_T = 0.9 (9.2) = 8.3 \text{ INCHES}$$

THE TOTAL MAXIMUM DISPLACEMENT,

$$= 0.8 D_{TM} = 0.8 (13.8) = 11.0 \text{ INCHES}$$

ABOVE THE INTERFACE :

THE DESIGN SHEAR ,

REGULAR CONFIGURATION

$$= 0.60 V_s = (0.60)(322.5) = 193.5 \text{ KIPS}$$

IRREGULAR CONFIGURATION

$$= 0.80 V_s = (0.80)(322.5) = 258.0 \text{ KIPS}$$

STEP 19: CONSIDERATIONS IN PERFORMING DYNAMIC ANALYSIS:

TWO TYPES OF ANALYSIS,

- 1) RESPONSE SPECTRA
- 2) TIME HISTORY

RESPONSE SPECTRA,

- a) 1ST MODE $\rightarrow$ HIGH DAMPING
- b) OTHER MODES $\rightarrow$ LOW DAMPING

TIME HISTORY,

- a) USE BETWEEN 3 AND 7 TIME HISTORIES.
- b) TIME HISTORIES SHOULD BE REPRESENTATIVE OF ACTUAL EARTHQUAKES AND SCALED SO THAT THE SRSS OF THE 5% DAMPED SPECTRA FOR THE HORIZONTAL COMPONENTS DOES NOT FALL BELOW 1.3 TIMES THE DESIGN BASIS EARTHQUAKE SPECTRA BY MORE THAN 10% IN THE PERIOD RANGE OF T_1 MINUS ONE SECOND TO T_1 PLUS TWO SECONDS.
- c) WITHIN 15. KM OF AN ACTIVE FAULT, TIME HISTORIES SHALL INCORPORATE NEAR FAULT EFFECTS.

DYNAMIC ANALYSIS MODEL - TYPICAL ASSUMPTIONS

- 1) HORIZONTAL DIAPHRAM MODEL - VERTICAL GROUND MOTION IGNORED.
- 2) BOTH HORIZONTAL DIRECTIONS OF GROUND MOTION CONSIDERED AND RESULTS ARE COMBINED BY SRSS FOR RESPONSE SPECTRA ANALYSIS.
- 3) EQUIVALENT STIFFNESS USED FOR ISOLATORS FOR RESPONSE SPECTRA ANALYSIS.
- 4) MODEL SHOULD INCLUDE EFFECTS OF ACTUAL AND ACCIDENTAL ECCENTRIC MASS.

COMPUTER CODES - TIME HISTORY

- 1) N-PAD
- 2) 3D-BASIS (NCEER)
- 3) DRAIN-2D (TWO DIMENSIONAL ANALYSIS)

COMPUTER CODES - RESPONSE SPECTRA

- 1) E-TABS
- 2) SK-COMBAT
- 3) SAP-90

SPECIAL ITEMS OF CONCERN

- 1) P-DELTA EFFECTS ACROSS ISOLATOR MUST BE CONSIDERED IN DESIGN AND ANALYSIS OF COLUMNS, ISOLATORS, AND FOUNDATIONS.
- 2) VERTICAL ACCELERATION EFFECTS MUST BE CONSIDERED IF EQUIPMENT FUNCTIONALITY IS IMPORTANT AND EQUIPMENT IS SENSATIVE TO VERTICAL VIBRATIONS IN THE 8 TO 15 CYCLES PER SECOND FREQUENCY RANGE.

Workshop on Seismic Base Isolation for Department of Energy Facilities

Hosted by LLNL

Design Problem #2

Martin Luther King Jr./Charles R. Drew Medical Center
A Case History in Design

Presentation by:

Douglas Way

Base Isolation Consultants, Inc.

San Francisco, CA

Martin Luther King Jr./Charles R. Drew Medical Center

Design Team

Owner - County of Los Angeles

Architects - Langdon/Wilson

Structural Engineers - John A. Martin Associates

**Seismic Isolation Consultants - Base Isolation
Consultants Inc.**

Feasibility Study

issues:

Earthquake Risks

Initial Construction Costs assoc. w/ Base Isolation

Earthquake assoc. Damage

Functionality of Facility

Summary of Earthquake Risks

Fault	Dist. (mi.)	Maximum Probable	Maximum Credible	Maximum Acc. Probable	Maximum Acc. Credible
Newport/ Inglewood	2.0	6.8	7.0	.48g	.49g
San Andreas	45.0	-	8.3	-	.16g

Dynamic Analysis Results Based on .48g Ground Motion

Struct.	Period	Displ.		Base Shear	Accel.
Type		@ Roof	@ Base		@ Roof
	(sec.)	(in)	(in)	(g)	(g)
<hr/>					
FB Code Frame (5% damp.)	1.04	11.4	0.0	0.62	1.21
ISO Code Frame (10% damp.)	2.37	13.8	10.6	0.23	0.27
ISO Stiff. Frame (10% damp.)	2.30	12.6	10.6	0.22	0.25

Basis of Building Costs for Hospital Construction

Architectural	\$78/s.f.	26%
Mechanical & Electrical	\$87/s.f.	29%
Structural	\$54/s.f.	18%
Contents	\$81/s.f.	27%
<hr/>		
Total	\$300/s.f.	100%

Additional Construction Costs assoc. w/ Base Isolation

Costs assoc. w/ Earthquake Damage

Element Damage =

Cost X Repair Multiplier X Damage Ratio

Ferritto

Damage Estimate Calculations

Building Comp.	Drift D.R.	Accel. Ratio	Sum of D.R.	Damage
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FB Mom. Frame

Arch	.49	.30	.79	\$62/s.f.
M&E	.09	.26	.35	\$30/s.f.
Struct.	.03	.15	.18	\$10/s.f.
Contents	.09	.37	.46	\$37/s.f.

\$139/s.f. (46%)

ISO Stiff. Frame

Arch.	.00	.37	.10	\$ 8/s.f.
M&E	.00	.10	.10	\$ 7/s.f.
Struct.	.00	.05	.05	\$ 3/s.f.
Contents	.00	.12	.12	\$ 10/s.f.

\$ 28/s.f. (9%)

Damage Estimate Comparison

Fixed-base Moment Frame vs Base-Isolated Stiffened Frame

\$28 vs \$139/s.f.

N-PAD - A Non-Linear Program for the Analysis of Base-Isolated Structures

Bi-linear Elastic Element

Bi-linear Plastic Element

Elastic Element

N-PAD Model of Martin Luther King Medical Center

High-Damping Rubber Hysteresis

HDR Compound
Martin Luther King Medical Center

N-PAD Analytical Results

Hysteresis of HDR Bearing

Martin Luther King Medical Center
N-PAD Hysteresis of Corner Pad, BC140

N-PAD Analytical Results

X and Y Displacement Plot

N-PAD Analytical Results

Base Acc. and Roof Acc.

Workshop on Seismic Base Isolation for Department of Energy Facilities

CONCLUDING REMARKS

**Stanley C. Sommer
Lawrence Livermore National Laboratory
Nuclear Systems Safety Program**

**May 15, 1992
Marina Del Rey Marriott
Marina Del Rey, California**

LLNL/DOE Appreciates your Participation in the Workshop.

- **Feedback for LLNL**
Workshop evaluation form
Short Course interest form
- **Workshop Materials**
Workshop binder
Reference binder

This Workshop Focused on the Technology and Use of Seismic Base Isolation.

- **Goals**

Educate audience about base isolation

Illustrate that base isolation is a viable technology

- **Main Topics**

General concepts

Engineering details and characteristics of systems

Design process involving base isolation

DOE is Studying Role of Seismic Base Isolation for its Many Facilities.

Workshop on Seismic Base Isolation for Department of Energy Facilities

Department of Energy Short Course on Seismic Base Isolation

Survey commercial/government facilities that currently use or are considering base isolation

Apply base isolation to appropriate DOE facilities

Department of Energy Short Course on Seismic Base Isolation is Being Organized.

- **Purpose**

Present in-depth lectures which cover technical and design issues of base isolation systems.

- **Instructors**

Dr. James M. Kelly, U.C. Berkeley

Dr. Charles A. Kircher, C. Kircher & Associates

- **Dates and Locations**

August 10 - 14, 1992

Berkeley Marina Marriott

Earthquake Engineering Research Center