Training Program for Implementation of Newly Developed Guidelines for Seismic Design and Retrofitting of Highway Bridges

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This paper describes the training program sponsored by the National Highway Institute (NHI) in cooperation with the Federal Highway Administration (FHWA) to implement the latest technology in seismic design and retrofitting of highway bridges on a national basis. This training program includes the development of training materials, presentation of two pilot workshops and the presentation of several 4 - 1/2 day workshops. The workshops are divided into lecture sessions and class assignments. The class assignments focus on practical applications. Although the workshop does not include computers the class assignments include input coding and output results from computer programs typically needed for seismic design and analysis.

The primary objectives of the workshops are to train bridge engineers to use the American Association of the State Highway and Transportation Officials (AASHTO) Guide Specifications for Seismic Design of Highway Bridges and to introduce bridge designers to the procedures for retrofitting bridges as described in the FHWA publication ***"Seismic Retrofitting Guidelines for Highway Bridges"***. The AASHTO Guide Specifications for Seismic Design are currently being incorporated into the AASHTO Standard Specifications for 1991.

Basic principals of seismology, structural dynamics and foundation modelling are presented. These basic principals are combined with current recommendations in the guidelines and the state-of-practice to give the practicing bridge engineer the knowledge required to design and retrofit bridges.

The procedures and methods available to engineers for the seismic design and retrofitting of bridges have increased markedly since the 1971 San Fernando earthquake in California. Knowledge and experience gained in research studies, post-earthquake field reconnaissance investigations, and the practical application of damage mitigation measures have contributed to this increase. In addition, the need for seismic design and retrofitting has subsequently increased nation wide due to the recent 1989 Loma Prieta earthquake. Several of these improvements in procedures and methods since 1971, however, have yet to find their way into many bridge design offices. Although some pilot courses have been presented in the past to help implement new seismic procedures, only a small percentage of practicing bridge engineers have been able to attend and many more training courses are needed. The courses now being taught utilize the state-of-practice consistent with the recently developed guide specifications *(1)* and the current available methodology.

One of the first efforts at training was the presentation of two one-week pilot workshops in 1981 designed to give working level bridge engineers hands-on experience in seismic analysis and design of bridges *(2)*. The development of these workshops was prompted by a successful Federal Highway Administration (FHWA)-sponsored Seismic Bridge Design Workshop held in Boise, Idaho in 1976 *(3)*. Both the Boise workshop and the two pilot workshops relied heavily on the methods developed by the California Department of Transportation (CALTRANS) following the San Fernando earthquake. In general, the two pilot workshops were enthusiastically received by the students, but they were handicapped at the time by the absence within the profession of the following three major elements:

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1. A nationally recognized seismic design specification for bridges that reflected the latest state-of-the-art.
2. Comprehensive, practical guidelines for seismic retrofitting of bridges.
3. User friendly computer programs readily available for the seismic analysis of bridges.

Recent research efforts and experience have made available the above three missing elements, and it is now possible to conduct much more effective training courses.

The first element was fulfilled in 1983 when the American Association of State Highway and Transportation Officials (AASHTO) adopted as a guide specification the report entitled "Seismic Design Guidelines for Highway Bridges" (ATC-6)*(1)*. These guidelines were prepared by Applied Technology Council (ATC) under FHWA contract with guidance from a panel of distinguished experts in the seismic design of bridges. The improvements in seismic design criteria contained in these guidelines have had a major impact on bridge seismic design practice.

A recognized weak point in the guide specifications was their treatment of foundations. In 1983, the Federal Highway Administration awarded a contract to the Earth Technology Corporation to develop a seismic design guide for bridge foundations*(4)*. This project is now complete, and the results, which complement the guide specifications, are useful in any training efforts relative to the seismic design and retrofitting of highway bridges.

The second missing element listed above was addressed by a follow-up report to ATC-6 entitled "Seismic Retrofitting Guidelines for Highway Bridges" (ATC-6-2)*(5)*. This report, which was developed with a separate panel of experts, established a comprehensive approach to the problem of seismic retrofitting. The guidelines include methods for rapidly identifying those bridges that present the greatest seismic hazard, methods for quantitatively evaluating local and global weaknesses and identifying economical retrofitting techniques for individual bridges, and a description of specific retrofit measures that can be used to increase the seismic resistance of selected bridge components. The guidelines have been subsequently published by FHWA*(6)* and are used as a reference for the current training course being sponsored by FHWA.

CALTRANS has recently completed a 54 million dollar program (Phase 1) to seismically retrofit approximately 1260 bridges. This program focused on expansion joints and sought to reduce the vulnerability to collapse introduced by the discontinuity in the superstructure that occurs at these joints. Simplified analysis methods and many retrofitting details and construction procedures were the by-product of this program. The experience gained as a result of this program is invaluable and is included in the current FHWA course. In addition, CALTRANS is currently in the process of retrofitting bridges with single column bents for the Phase 2 retrofit program.

The third and final missing element is readily available computer programs which may be used in a production environment for bridge designers. A user-oriented computer code was written specifically for the Seismic Analysis of Bridges (SEISAB) *(7)*. This code, developed by Engineering Computer Corporation (currently Imbsen & Associates, Inc., (IAI)) with funding by the National Science Foundation, was specifically written to accommodate the provisions of the guide specifications. The elastic analysis portion of this computer code has been completed, and it is now possible for bridge designers, with minimum knowledge and training in theoretical structural dynamics and computer technology, to perform multi-modal response spectrum analyses of bridges. In addition, following the San Fernando earthquake CALTRANS implemented STRUDL, currently known as GTSTRUDL *(8)*, to conduct seismic analysis of bridges. A pre-processor has been developed specifically for this program to simplify the input coding.

Another factor related to implementation of seismic design procedures is the development of a "Seismic Design and Retrofit Manual for Highway Bridges" *(10)*. This document, which summarizes much of what is known about the seismic design and retrofitting of bridges, was written to update the original manual developed for the first two pilot workshops *(2)*. It therefore is an excellent reference document for the current workshop.

The recent development of design and retrofitting guidelines and the SEISAB computer code, plus experience gained from implementing improvements in seismic design and retrofitting practice have resulted in the conditions that made it timely to develop a comprehensive training course on the seismic design for highway bridges. This current course de-emphasizes hands-on computer use, but includes handout problem solutions using SEISAB. In addition, the course mentions other programs (i.e., GTSTRUDL, SAP, etc.) which can be used in the seismic analysis of bridges.

TRAINING COURSE DEVELOPMENT

The course outline that was prepared for this course reflected a balanced up-to-date approach to the seismic design and retrofitting of bridges and reflected as near as possible the consensus views of the project team. It included, where appropriate, items included in previous training courses as well as new, updated information. The course is organized into modular sessions to facilitate tailoring of the course to a specific audience (e.g. training and experience of attendees, seismic zone of interest, etc.). Each session contains certain components that can be deleted or emphasized as required. The contents of the course includes those sessions listed in the outline shown in Table 1. The workbook, instructor's guide, and visual aids were organized according to the course sessions. The workbook was designed to be useful before, during, and after the course presentation (see Figure 1). Before the presentation, the workbook is used to brief students on the material to be covered and orient them toward the objectives of each course session. During the presentation, the workbook facilitates note taking and helps students focus on the topics being discussed. After the presentation, the workbook will be a useful reference. The problem assignments that are included (12 total) can be referenced in the bridge engineers procedures for seismic design. Worked example problems included in the participant workbook utilize SEISAB and other computer programs. These examples emphasize the interpretation and use of output results. The problem assignments are presented by filling in selected calculations as shown in Figure 2. The following paragraphs discuss the content of each of the sessions presented as shown in Table 1.

Introduction to Seismic Design and Retrofitting of Bridges

Session 1 of the course provides the student with a conceptual understanding of the issues and goals of seismic design and retrofitting of bridges. This includes knowledge of the currently applicable design and retrofitting criteria, design and retrofitting strategies, the effect of siting, structural configuration, detailing on the seismic performance of bridges, and the performance of bridges during past earthquakes. The latest bridge damage from the 1989 Loma Prieta earthquake is presented in this session. In addition, a brief overview of the AASHTO Guide Specifications *(1)* is included. The preliminary seismic design concept which is introduced in shown in Figure 3.

Fundamental Concepts in Structural Dynamics

This session emphasizes physical concepts as opposed to mathematical derivations. Considerable attention is given to achieving this goal through the extensive use of graphical illustrations, models, and a VCR presentation that helps the students visualize basic concepts. A model of three single degree of freedom oscillators mounted on a common base is used for explaining the concept of natural period and the effect of earthquake ground motion on different types of structures. The concept of various modes of response is illustrated by a three degree of freedom model. Workshop assignments and example problems are included to help students become familiar with these critical concepts. It should be emphasized that this session uses bridge schematics in the text to teach the concepts of structural dynamics as shown in Figure 4.

Seismic Loading

This session covers the sources and characteristics of ground motion and other critical earthquake effects. The development of seismic zones is also discussed. The characterization of these phenomena for design loading is covered to introduce students to the concept of response spectrum, acceleration time history, the directionality of ground motion, etc. This information reflects the latest knowledge relative to the nature of earthquakes, including information from the 1989 Loma Prieta earthquake. The normalized response spectra sited in the AASHTO Guide Specifications *(1)* is shown in Figure 5. In addition, the new accceleration coefficient maps now adopted by AASHTO for the 1991 standard specification are shown in Figure 6.

Seismic Response Analysis

Session 4 includes a description and comparison of analysis methods. The material includes the ATC single mode spectral approach (procedure 1) as well as the multi-mode spectral approach (procedure 2). A brief overview of the example problem in Appendix A of the AASHTO Guide Specifications *(1)* is also included by projecting mode shapes of that bridge model on a screen to show participation factor contributions.

Structure modeling is a critical part of seismic response analysis. Correct idealization of the mass and stiffness characteristics of a structure can make the difference between reasonable or unreasonable analysis results. In addition a group assignment is given as shown in Figure 7 to introduce the participants to seismic structural form. A sample of the group assignment presentation from one of the courses is shown in Figure 8.

Design Concepts

This session is subdivided into lectures and workshop problems covering the various aspects of component design. The concept of ductility demand and the use of response modification factors are explained so that participants can get a true conceptual feeling for how a bridge is likely to perform during an earthquake. Recent knowledge gained from research on the ductile behavior of reinforced concrete columns is presented. This includes studies relative to the role of transverse confining steel, main longitudinal reinforcement, splices in reinforcement and the role of concrete in resisting compression and shear forces. A discussion of the behavior of wide piers is also included.

The actual design of a reinforced concrete column including both longitudinal and transverse steel design is covered in example and workshop problems. This includes an introduction to the concept of capacity design as it applies to multi-column bridge bents. Proper emphasis is also given to the importance of good detailing practice for seismic design.

Modeling of bridge abutments and foundations is a subject that has been clarified by the recent development of guidelines for foundation design. Because modelling of these elements has always been a problem for engineers in the past, special treatment is given to this subject. Workshop assignments are provided so that students can have first-hand experience in calculating the stiffness and damping characteristics of the most common types of abutment and foundation elements. The use of design charts are covered in the lectures and example problems. This part of the session reflects the findings of the recent FHWA-funded study conducted by the Earth Technology Corporation on the seismic design of bridge foundations *(4)*.

The design of conventional bearings, expansion joints, restrainers, and shear keys is a critical issue that is covered during session 5. The design of other types of bridge components is discussed briefly to introduce students to some of the latest thinking on this subject. The use of special motion restricting devices, energy dissipation devices and base isolation bearings is covered along with their related design philosophies and considerations.

The subject of ground stability is an important consideration during both the planning and design of bridges and their accompanying roadway approaches. A lecture is provided to give students knowledge in assessing probable ground stability during an earthquake.

Retrofitting

The seismic retrofitting guidelines developed by ATC *(5,6)* as well as the latest practical experience obtained from CALTRANS and others who have attempted to retrofit bridges is discussed.

The subject of seismic retrofitting is divided into three parts as presented in the seismic retrofitting guidelines *(5,6)* (see Figure 9). The first part is preliminary screening which is a planning function used during the implementation of an area-wide retrofitting program.

The detailed evaluation of an individual bridge to determine its capacity to resist earthquake loads is important when identifying the need for retrofitting and the most appropriate retrofitting strategy to be used. The method for calculating component capacity/demand ratios as proposed by the retrofitting guidelines is covered through lectures, example problems and workshop assignments.

Design of component retrofitting requires considerable innovation since no two structures are the same. Retrofitting techniques is discussed in terms of concepts. Several concepts are presented in the retrofitting guidelines. A considerable amount of standardization of these concepts as they relate to retrofitting of bearings and expansion joints was achieved by CALTRANS during their retrofitting program.

The retrofitting concepts for other components such as columns and footings is discussed briefly. Also included is a discussion of retrofitting of geotechnical components of the bridge.

Advanced Topics

Session 7 of the course will address advanced topics that may be of interest to certain groups. These topics include special bridge types and nonlinear analysis *(11)* for seismic analysis of bridges.

PILOT PRESENTATIONS AND COURSE PRESENTATIONS

Following two pilot presentations, the courses have been scheduled throughout the United States to state department of transportations or private agencies (over 20 courses have been given since January of 1990). Each course, which averages 40 students, is tailored to meet the needs and interests of the attendees and the particular seismic zone of interest. The principal instructor is Dr. Roy A. Imbsen, President of IAI. He is assisted by either Mr. Robert A. Schamber of IAI or Mr. James H. Gates of CALTRANS as one of his Co-Instructors and either Dr. Geoffrey R. Martin of the University of Southern California or Mr. Ignatius (Po) Lam of Earth Mechanics, Inc. as his other Co-Instructor. The FHWA Contracting Officer's Technical Representative (COTR) is Mr. Larry Jones.

REFERENCES

1. American Association of State Highway and Transportation Officials, "Guide Specifications for the Seismic Design of Highway Bridges," Washington, D.C. 1983.
2. Imbsen, R. A., Nutt, R. V., and Gates, J. H., "Seismic Design of Highway Bridges Workshop Manual," Federal Highway Administration, Washington, D.C., Report No. FHWA-IP-81-2, January 1981.
3. Imbsen, R. A., and Gates, J. H., "Seismic Bridge Design Workshop," September, 1976.
4. Lam, I. P., Martin, G. R., "Seismic Design of Highway Bridge Foundations," Vol. I, II and III, FHWA Report FHWA/RD-86/102, June, 1986.
5. Applied Technology Council, "Seismic Retrofitting Guidelines for Highway Bridges," Report No. ATC-6-2, 1983.
6. Applied Technology Council, "Seismic Retrofitting Guidelines for Highway Bridges," FHWA Report FHWA/RD-83/007, December, 1983.
7. Imbsen, R., Lea, J., Kaliakin, V., Perano, K., Gates, J., and Perano, S., "SEISAB-I User Manual," Engineering Computer Corporation, October 1982.
8. Georgia Institute of Technology, "GTSTRUDL User's Manual: Volume 1," GTICES Systems Laboratory, Atlanta, Georgia.
9. Imbsen, R. A., Nutt, R. V., Lea, J., and Gates, J. H., "SEISAB-I - Workshop Manual," November, 1984.
10. Buckle, I. G., Mayes, R. L. and Button, M. R., "Seismic Design and Retrofit Manual for Highway Bridges," Federal Highway Administration Report No. FHWA-IP-87-6, April 1986.
11. Imbsen, R. A., Penzien, J., "Evaluation of Energy Absorption Characteristics of Highway Bridges Under Seismic Conditions," Vol. 1 and 2, Report No. EERC 85/17, September, 1986.

TABLE 1 OUTLINE FOR FHWA TRAINING COURSE ON SEISMIC DESIGN OF HIGHWAY BRIDGES

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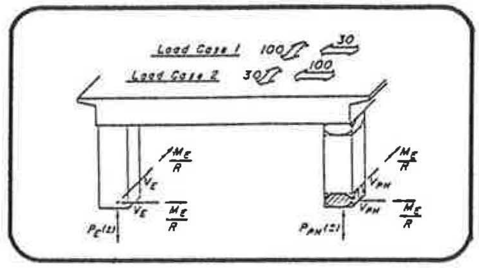
SEISMIC DESIGN OF

HIGHWAY BRIDGES



TRAINING COURSE

PARTICIPANT WORKBOOK

Prepared for the
U.S. Department of Transportation
Federal Highway Administration

by

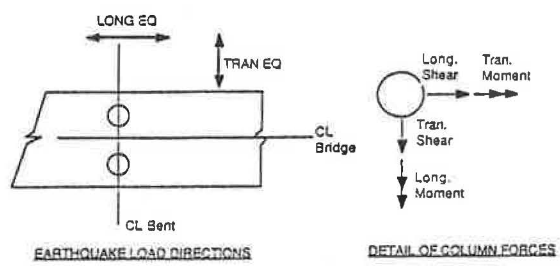
Imbsen & Associates, Inc.

June, 1989

FIGURE 1 Cover on Participant Workbook

EXAMPLE PROBLEM ASSIGNMENT 6A

COLUMN DESIGN (SPC B)

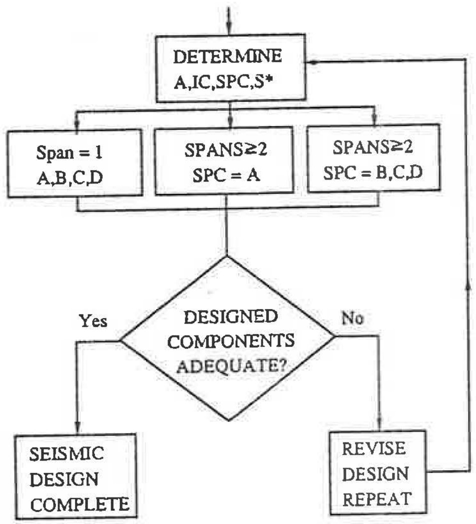


STEP 1. DETERMINE THE LOAD COMBINATIONS 1 AND 2

	Longitudinal		Transverse		Axial
	Shear (kip)	Moment (k-ft)	Shear (kip)	Moment (k-ft)	Force (kip)
DEAD LOAD	0	97	0	114	658
LONG EQ	179	2300	255	3517	291
TRAN EQ	150	2025	471	6512	521
LC 1					
LC 2					

LC1 = 1.0 * LONG EQ + 0.3 * TRAN EQ
LC2 = 0.3 * LONG EQ + 1.0 * TRAN EQ

FIGURE 2 Example Problem Assignment



*A = Acceleration Coefficient
IC = Importance Classification
SPC = Seismic Performance Category
S = Site Coefficient

FIGURE 3 Preliminary Seismic Design Concept

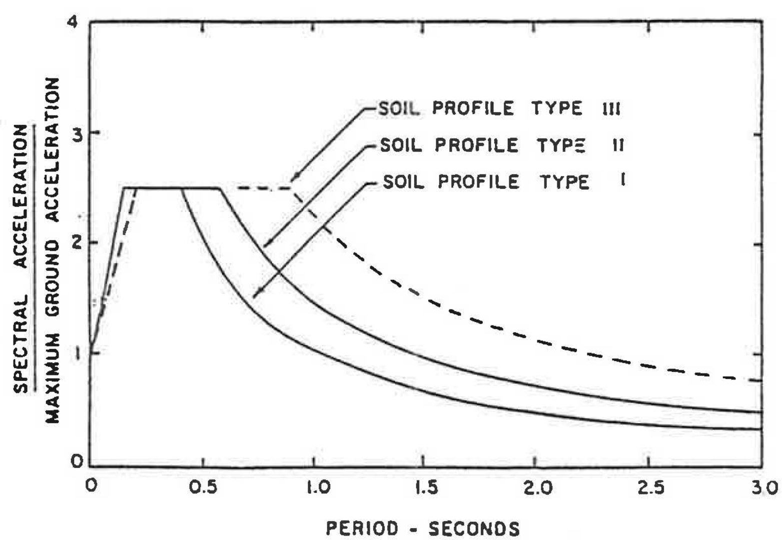


FIGURE 5 Normalized Response Spectra

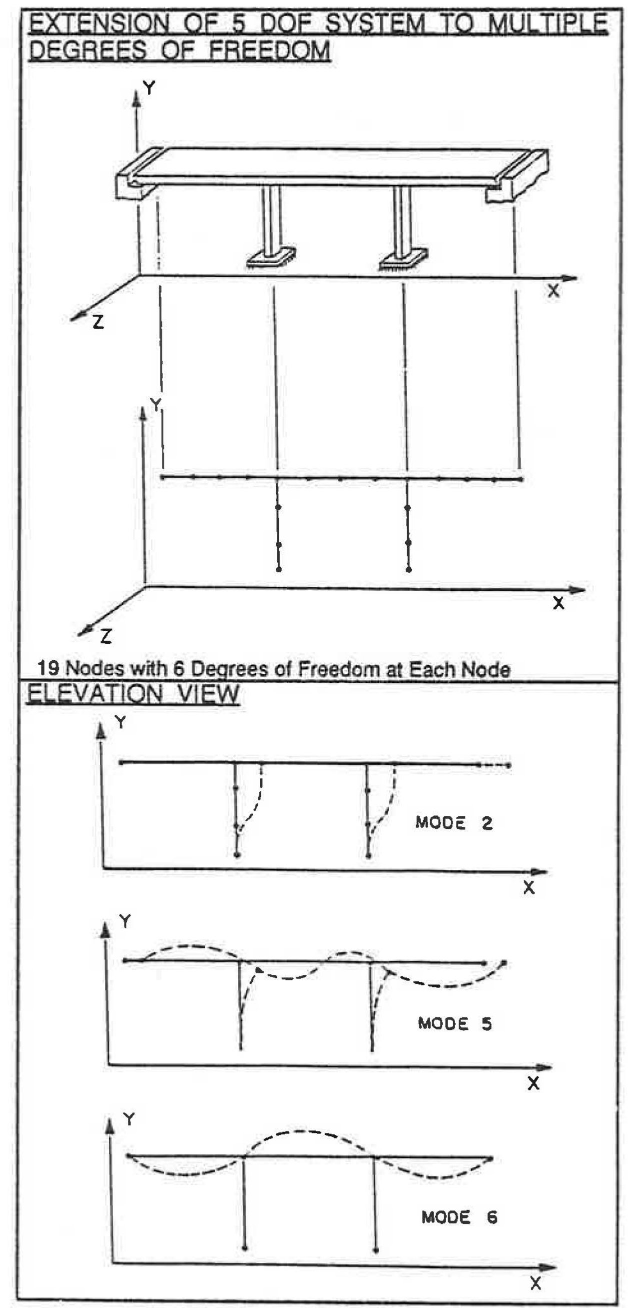


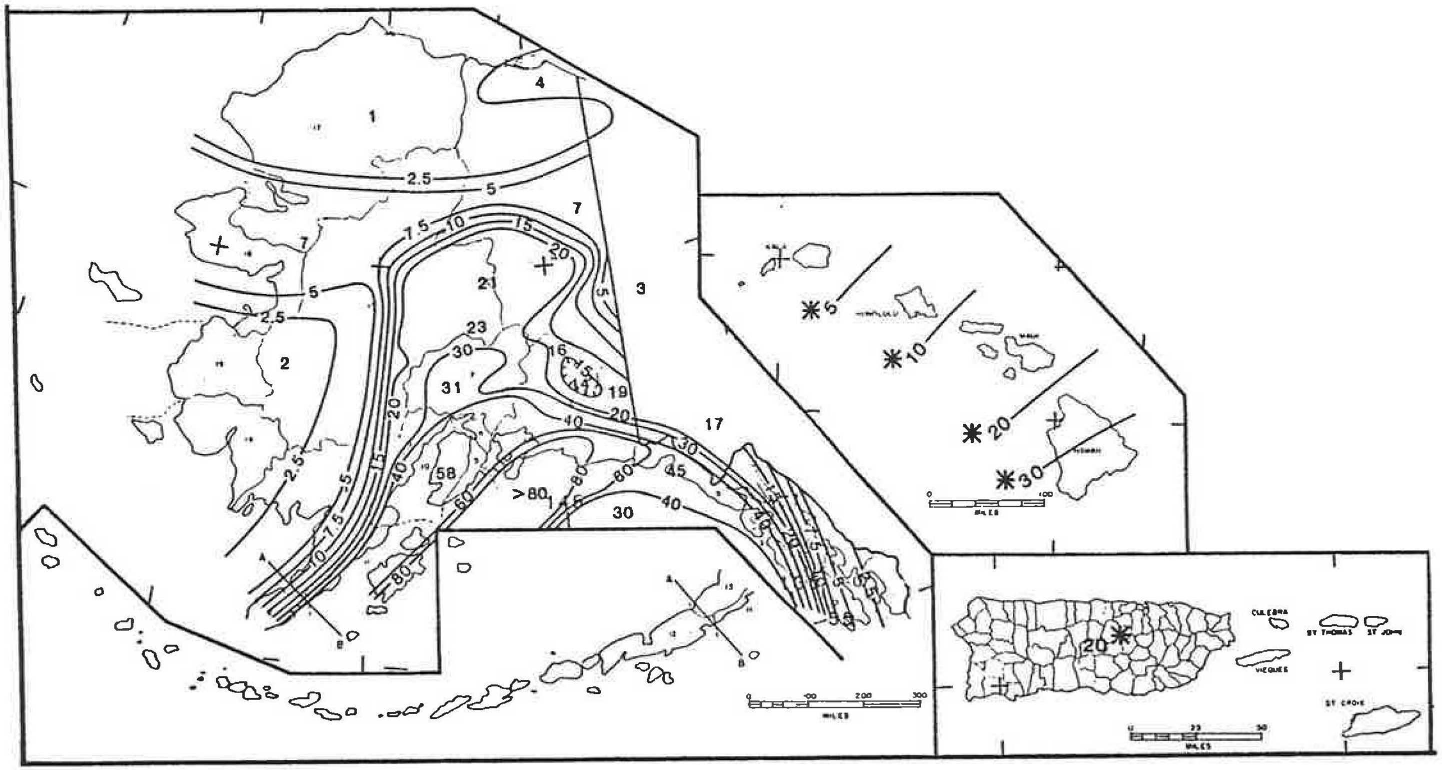
FIGURE 4 Typical Bridge Schematic to Illustrate Dynamic Concepts

<u>**Western Part of the United States**</u>

FIGURE 6a Acceleration Coefficient (expressed as percent of gravity) Using the Adopted AASHTO Standard Specification Map for 1991 in Rock with 90 Percent Probability of Not Being Exceeded in 50 years.

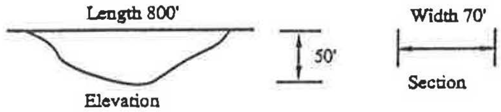
Eastern Part of the United States

FIGURE 6b Acceleration Coefficient (expressed as percent of gravity) Using the Adopted AASHTO Standard Specification Map for 1991 in Rock with 90 Percent Probability of Not Being Exceeded in 50 years.



Alaska, Hawaii and Puerto Rico

FIGURE 6c Acceleration Coefficient (expressed as percent of gravity) Using the Adopted AASHTO Standard Specification Map for 1991 in Rock with 90 Percent Probability of Not Being Exceeded in 50 years.



Assume AASHTO Guide Specifications Apply
High Seismic Area, Type III Soils

Superstructure Type to be Selected By Group
Span Range: 70' to 160'

In Small Groups (45 min.)

(1) Select two different structural configurations which the group feels would be adequate for this site. Do not get too bogged down at this point, just pick two reasonable bridges based on your experience.
(2) Evaluate each of the bridges on the basis of seismic performance. List positive and negative aspects of each bridge. Select one bridge to present and discuss to the total group.

Discussion (15 min.)

(3) Each group to present and discuss the positive and negative seismic aspects of their selected design. Discussion of total group should focus on advantages and disadvantages of each design, if possible, determine a single design which appears reasonable.

FIGURE 7 Group Assignment for Structural Form Example Problem

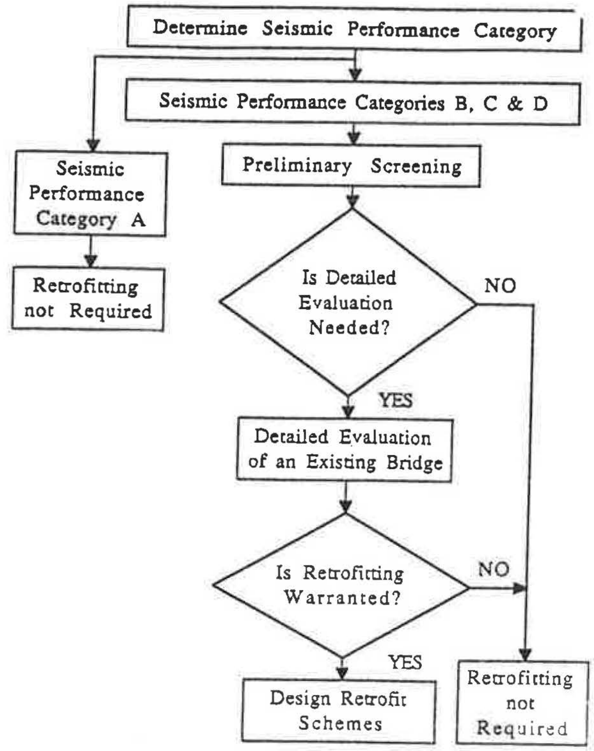


FIGURE 9 Seismic Retrofitting Process

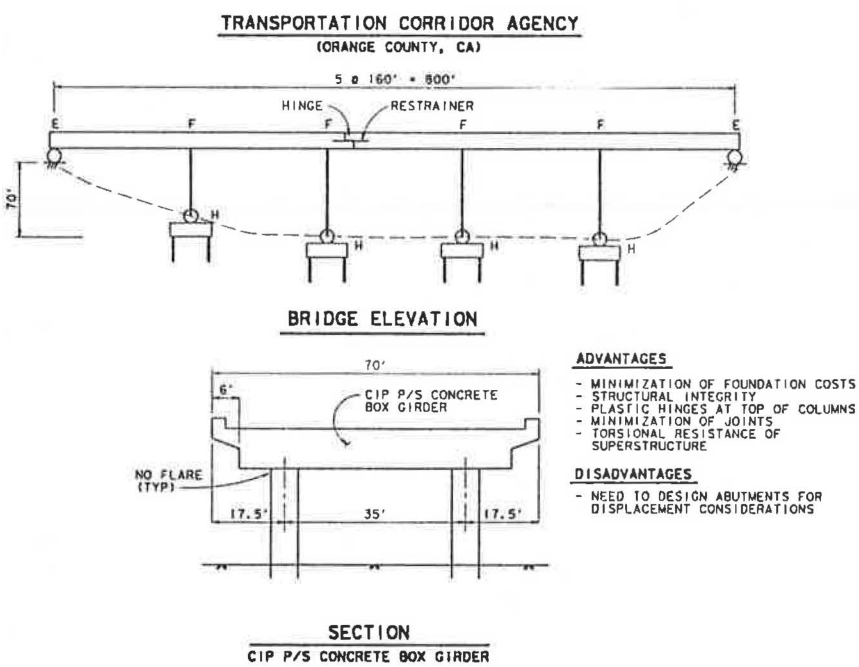


FIGURE 8 Sample of Group Assignment Presentation for Structural Form Example