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CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: Short course on "Fundamentals of Seismic Design" (20.01402.158)

DATE/PLACE: May 14-16, 2001
University of Wisconsin-Madison
Madison, WI

AUTHOR: B. Dasgupta

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PERSONS PRESENT:

The short course was attended by about 56 engineers from engineering firms, federal and state government, the military, universities and research institutions, and foreign countries. The instructors for this course were Jose Pincheira, Assistant Professor from University of Wisconsin-Madison; Michel Oliva, Associate Professor from University of Wisconsin-Madison; S.K. Ghosh, President, S.K. Ghosh Associates, Inc.; and David Mar, Tipping, Mar and Associates.

BACKGROUND AND PURPOSE OF TRIP:

The purpose of this trip was to attend a short course on Fundamentals of Seismic Design. The objective of the course was to teach the basic principles and current practices of earthquake resistant design of building structures, and help understand the relations of these principles to the codes and standards. The subject of this short course is relevant to the design of waste handling building and the surface facilities that will be used in the High-Level Waste Repository Program and will greatly enhance our abilities for the review of surface facility design.

SUMMARY OF PERTINENT POINTS:

1. Impact of Earthquakes on Structural Systems Engineering
(Jose Pincheira)

This session primarily dealt with the fundamentals of engineering seismology. The instructor provided an overview of seismology and its impact on the structural systems. The topics covered were sources of earthquake, earthquake recording, measures of earthquake size/ magnitude, selection of design earthquake, and time histories and spectra. The instructor provided basic understanding of plate tectonics, elastic rebound theory, local and long distance effects of earthquake, and elastic wave theory. Other topics discussed were: earthquake recording instruments (strong motion accelerograph and seismograph), characteristics of typical strong-motion records (near-filed, medium-field and far-field records), strength of earthquakes, ground motion parameters for earthquake engineering design (peak ground motion/effective peak motion, frequency content, duration, and response spectrum), selection of design earthquake based on deterministic or probabilistic approach. Several slides were shown on the earthquake damages to buildings, bridges, multistoried parking lots, etc.

2. Single-Degree-of Freedom (SDOF) Systems
(Jose Pincheira)

Dynamic response of a single-degree-of freedom (SDOF) system to ground motion and development of response spectra was discussed in this session. The response spectra are plots of maximum response of a damped single degree of freedom system as a function of natural frequency or period of vibration of the structure. Usually the system response in terms of displacement, velocity and acceleration, of a single mass and spring system relative to the base ground motions, are plotted in a four-way logarithmic plot. The natural period of vibration (inversely proportional to the square-root of ratio of stiffness to mass), defines the characteristic of a structure idealized as single mass and spring system for example, a short and stiff structure will have a low period of vibration and a tall and slender structure will have a long natural period of vibration. A response spectra forms the basis for elastic and inelastic design of an earthquake resistant structures.

Response spectra of actual ground motion are irregular, and a smoothed spectra is used for seismic design of a structure. The basic shape of the design spectra is trapezoidal consisting of constant acceleration, constant velocity and constant displacement. For linear elastic response of structure the general shape of design response spectra is simply an amplification of maximum ground motion parameters.In practice, however, it is generally uneconomical to design a structure to respond in the elastic range during an extreme event. As a result, the structure will generally be expected to respond in the inelastic range and thus suffer some structural damage. Exceptions to this general situation are nuclear power plants where a linear design is used. The general shape of the inelastic design spectrum is the same as the linear elastic design spectrum except that the spectral quantities are reduced based on an assumed ductility ratio (maximum displacement developed by the system to the yield displacement of the system).

3. Multi-Degree-of-Freedom (MDOF) Systems
(Michael Oliva)

In this session analysis of MDOF systems and behavior of MDOF systems were discussed in detail. Starting from development of equation of dynamic motion for MDOF in matrix form, the instructor discussed the solution of the equations of motion (undamped with no load, undamped but loaded system, and damped loaded system), formation of mass matrix, and damping matrix, natural frequencies and mode shapes of vibrations, loading on the MDOF system when support movement occurs, use of response spectrum curves with MDOF systems, and nonlinear/inelastic dynamic analysis with MDOF systems.

4. Modeling Buildings for Dynamic Response Analysis
(Michael Oliva)

Modeling approaches and modeling assumptions were discussed in this session. Various techniques for modeling structures are applied to satisfy particular seismic requirements of the building codes. One of the most basic applications of structural analytical modeling for dynamic response is in obtaining an accurate estimate of a structure's natural periods of vibration. The design seismic forces to be resisted by the structure are evaluated using the NEHRP Equivalent Lateral Force Procedure as well as procedures in other codes. The codes provide procedures to calculate the design lateral force at the base of the structure, and proportion the base shear to obtain the story shear. Structural analysis is completed to obtain design forces on individual resisting elements. This can be a relatively simple process for simple structure, or extremely complex for structures with multiple redundancy and/or significant unsymmetry. Tall buildings and buildings with structural irregularities must be designed to meet high seismic performance standards and may require special dynamic analysis that involves consideration of actual dynamic vibration of the building. The uses of various procedures for system analysis for multistoried structures were demonstrated using available software analysis tools such as SAP2000, STAD-III, and ETABS and focused on the dynamic response of a six-story precast concrete parking structure.

5. Code Provisions for Earthquake-Resistant Design (New Construction)
(Michael Oliva)

For designing earthquake resistant structures in the United States three major codes are used depending on the geographical locations. The model codes have variations in approach to seismic design. The Federal Emergency Management Agency (FEMA) received a mandate in the form of National Earthquake Hazards Reduction Program (NEHRP) to develop a national approach to seismic design. The current 1997 NEHRP recommended provisions has been adopted by IBC2000, while the older 1991 version of NEHRP provided the basis for the current SBC and NBC provisions.

The design ground motions have been traditionally based on a constant probability of exceedance for the entire US. The previous editions of NEHRP seismic hazards around the nation were defined at a uniform 10% probability of exceedance in 50 years and the design requirements were based on assigning a structure to a Seismic Hazard Exposure Group and a Seismic Performance Category. While this approach provided for a uniform likelihood throughout the nation that the design ground motion would not be exceeded, it did not provide for a uniform margin of safety for structures designed for that ground motion. The reason for this is that the rate of change of earthquake ground motion versus likelihood is not constant in different regions of the United States. As a result, the ground motions specified in the latest design provisions have been revised to provide nearly an equal margin of safety against the failure across the country.

The 1997 NEHRP provisions are based on ground motions with a return period of about 2500 years or a 2% probability of exceedance in 50 years. The maximum considered earthquake ground motions are presented in seismic hazard maps that accompany the provisions. The maps show the spectral acceleration for 5% damping at two periods, 0.2 and 1.0 seconds, to represent short-period and long -period range response, respectively. The new provisions are intended to have nearly equal margin of safety against failure across the country. Still in regions of high seismicity with shorter return periods, such as California, these probabilistic values may not adequately represent the motions expected at a given site. In those regions the motions have been based on deterministic hazard maps.

6. Seismic Details for Reinforced Concrete Buildings
(S.K. Ghosh)

In this session seismic design of reinforced concrete based provisions of the codes were covered. The subject matter of the reinforced concrete design under seismic loading is vast and it was not possible to cover all aspects in allotted time. The instructor, a leading expert in the seismic design, provided concepts and procedures of seismic design contained in IBC2000 which is based on the NEHRP 1997 and pointed out key aspects of reinforced concrete detailing requirements. Following topics were discussed: ground motion maps, seismic design category based on short period and 1 sec period response acceleration, design base shear and its distribution over the story height, story drift, load combinations (LFRD, UBC, ASD), ACI-318 (Chapter 21) reinforcement detailing requirements, design requirement for structural systems (moment frames, shear walls, braced frames, and dual systems). The seismic design of a 12- story reinforced concrete building located in Site class D (Los Angeles) was demonstrated through a worked out example. The static lateral force procedure was used as the basis of design for the dual system consisting of moment frames and shears walls following the requirements of IBC 2000.

7.Seismic Design of Steel Buildings
(Michael Oliva and David Mar)

The main implications of the design philosophy in the current code rely on the deformation capacity of the system. The current design codes implicitly assume that the structure will deform well into the inelastic range during a maximum credible earthquake. Therefore, the structural system must be designed and detailed to provide the required ductility and deformation capacity anticipated to occur during the earthquake. In this session basic requirement to achieve ductile behavior in steel construction without inducing member instability and fracture was primarily discussed. The structural steel systems discussed were: moment resistant frames, special moment resistant frames, ordinary moment resistant frames, concentrically braced frames, special consideration on V-braced frames, K-braced frames and eccentrically braced frame. Three case studies were presented during this session demonstrating the design strategy and structural detailing for seismic strengthening of two existing buildings, and design of one four-story braced frame structure in the high seismic area in California. Background material covered during this session was informative, however, code provisions on seismic steel design was not discussed in detail.

8. Seismic Vulnerability of Existing Structures & Main Issues in Seismic Evaluation and Rehabilitation
(Jose Pincheira)

In this session seismic evaluation and rehabilitation of existing structures have been discussed. Seismic rehabilitation problems involve those structures which have inadequate strength and/or ductility because of suffered damage during an earthquake, changed of occupancy, or deteriorated structural system. The main considerations for seismic rehabilitation are estimation of available strength and deformation capacity of the structure, evaluation if the building can be retrofitted and how can it be retrofitted, and evaluation of economic feasibility. The seismic evaluation process is provided in the procedures FEMA 310-1998 and FEMA 273-1997. FEMA 310 is a three tire approach which involves screening phase, evaluation phase and detailed evaluation phase. FEMA 310 provides rough estimates of building performance, however, if the building is found deficient no guidance on rehabilitation procedure is provided. The approach in FEMA 273 is more detailed and provides guidance for rehabilitation. The FEMA 273 is a displacement-based procedure in which the engineer selects the desired earthquake ground motion and performance level. The performance levels are defined in terms of imposed deformation demands for rehabilitation objectives of the structure such as, "operational," "immediate occupancy," "life safety," and "collapse prevention." To support the performance objective for the retrofitted design the analysis procedure required by FEMA 273 may vary from simpler Linear elastic and Linear Dynamic, to sophisticated Nonlinear Static ("pushover") and Nonlinear Dynamic (time history) analysis techniques.

9. Evaluation Procedures & NEHRP Rehabilitation Guidelines and Design Strategies for Seismic Rehabilitation (David Mar)

In this session the state-of-the-art analysis and design strategies developed for seismic retrofit solutions for two unique structures were discussed. In the first example an overview was provided on the analysis methodologies used for the seismic rehabilitation of a historic high rise building located in San Francisco. The focus of the presentation was on the use of sub-structured modeling techniques to capture the seismic response of the retrofit strategy that incorporates a pair of cantilever towers on deep foundations to brace the structure. The second example deals with the seismic rehabilitation of a multistoried building structure which unlike traditional building structures utilizes a twin reinforced concrete towers to support the weight of the floors, which are suspended on hangers. Due to the building's unusual construction seismic rehabilitation was required for potential strong ground shaking anticipated at its near fault site. Sophisticated analyses were used to estimate the seismic demand of the structure and to predict the response. These include pushover analysis using 3D nonlinear finite element modeling, dynamic time-history analysis, and nonlinear soil-structure interaction analysis.

CONCLUSIONS:

The course covered wide range of issues related to seismic design of the structures. The course provided basic understanding, and current information on the subject citing the latest codes and standards, and NEHRP provisions. The instructors, well experienced and experts in this field, were very enthusiastic and almost all of them had more material to cover than the time allotted. The course had been very valuable and will be extremely useful for our review activities. For additional information, lecture notes and handout materials are available with the author.

PROBLEMS ENCOUNTERED:

None

PENDING ACTIONS:

None

SIGNATURES:

Biswajit Dasgupta
Senior Research Engineer

7/15/01
Date

CONCURRENCE:

for A. H. Chowdhury, Manager
Mining, Geotechnical, and Facility Engineering Element

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Date

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Technical Director

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