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The John A. Blume Earthquake Engineering Center

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LETTER FROM THE DIRECTOR

Performance Based Design II - This is the second of my letters discussing issues relating to performance based design. In the current and subsequent issues I will address the various components of the problem.

In general, a performance based design code requires the following: (a) definition of performance for different types and uses of structures, (b) development of analytical formulations at the structural system level for each performance definition, (c) development of load requirements, (d) formulation of design concepts leading to resistance requirements, (d) calibration of acceptable performance levels for generic structural types, (e) development of simplified guidelines for implementing these procedures in practice, and (f) verification of the design procedure. Let us first concentrate on the definitions of performance.

Seismic performance criteria should be postulated with the owner, architect, designer, and contractor in mind. Because performance based design is intended to provide greater flexibility through more choices, the legal issues that may arise need to be carefully thought through. The objective of the owners is to select the structure that will have the optimal performance under limited resources. Thus, seismic performance levels will have to take into consideration safety, functionality, and economy.

In general, owners would like to be able to select from several possible alternatives with the cost and a safety measure attached to each alternative. An important requirement, then, for performance definitions is the development of a semantic description of the performance level that an average owner can understand. Preferably, these definitions can be translated to some quantitative measure that reflects the safety (or reliability) of the design and the cost of achieving that safety level. Such an approach can facilitate the difficult problem that owners would face when having to select from many different performance levels. Decision theory can provide the framework for selecting the optimal design under limited resources. With this approach, multiple objectives arising from the owner, architect, designer, and contractor can be quantified, taking uncertainties and costs into consideration. The ultimate goal is to develop measures that reflect the utility of each performance level on a relative scale. Thus, owners will need to understand the interpretation of the scale rather than face a complex decision problem.

CENTER NEWS

Professor Helmut Krawinkler has received the Distinguished Alumni Award from his alma mater, San Jose State University [M.S., 1967], for his contributions to education, research, and seismic code developments.

Several Blume Center researchers participated in the recent ASCE Structures Congress XIV held in Chicago April 15-18, including **Professors Helmut Krawinkler**, **Kincho Law**, and **H. Allison Smith** and **UPS Visiting Professor Greg Deierlein**.

Professor Haresh Shah continued his participation in the World Seismic Safety Initiative (WSSI) and gave presentations on seismic risk management at WSSI meetings in Singapore, Myanmar, and Vietnam.

Dr. Stephanie King was awarded one of fifteen fellowships for U.S. participants in the 1996 International Young Scholars Summer Institute in Geographic Information to be held in Berlin, Germany in July, 1996. This program is sponsored by the NSF-funded National Center for Geographic Information and Analysis.

In March, **Professor Anne Kiremidjian** participated in the NSF sponsored US-Japan Workshop on Structural Control and Health Monitoring in Kyoto, Japan.

In May, **Dr. Renate Fruchter** organized a workshop for educators on "Computer Integrated A/E/C", for the Computer Integrated Civil & Environmental Engineering (CICEE) Synthesis Coalition sponsored by NSF.

Professor Anne Kiremidjian made a presentation at the Catastrophe Risk Management Conference in Phoenix, Arizona in May, where she spoke on "Performance of Buildings in Earthquakes: Implication to Portfolio Loss Assessment."

For the next three years, **Professor Helmut Krawinkler** will serve as Team Leader for System Performance of the FEMA/SAC Steel Project. This $8.5million project will focus on improvements of the seismic performance of steel frame structures with welded connections.

Professor H. Allison Smith has accepted a position as a Visiting Scholar at Columbia University's Department of Civil Engineering and Engineering Mechanics, effective July 1, 1996 through June 30, 1997.

RESEARCH SPOTLIGHT

Nonlinear Dynamic Soil-Structure Interaction - Application to Lotung Array

by Heng-Yih Chao, Ph.D. Candidate
Research Advisor: Professor Ronaldo I. Borja

Accurate representation of soil-structure interaction (SSI) effects is a crucial part of earthquake engineering analysis. A number of sophisticated mathematical techniques, elaborate computer codes, and simpler engineering approximations have been developed through the years, and continue to be developed today. Among the large number of soil-structure models that exist, linear models are understandably more visible owing to their simplicity. However, linear models do not provide a means for understanding the influence of other, perhaps more important, factors that could dominate the SSI response, such as the hysteretic material behavior, the Masing phenomenon, nonproportional damping, and material stiffness degradation. Most of the nonlinear models treat nonlinear behavior via equivalent linear methods, which determine the values of soil properties based on the level of strains predicted from the previous iteration. These methods work best for studies of free-field motion assuming vertically propagating waves, but are questionable and difficult to implement in a three-dimensional setting. Furthermore, nonlinear wave propagation problems are essentially three-dimensional since all three components of motion are coupled even if all waves propagate in the same direction, which could lead to further difficulties with the equivalent linear methods.

A full 3D bounding surface constitutive model with a vanishing elastic region, which models plastic deformation right at the onset of loading and is able to resolve most of the fundamental difficulties associated with problems exhibiting significant nonlinear behavior, is incorporated in a nonlinear finite element (FE) code called SPECTRA. The FE model used in this study is based on a fully nonlinear solution algorithm capable of capturing the simultaneous propagation of multidirectional components of wave motion through an inelastic soil medium.

Of particular importance to the SSI analysis is the issue of radiation boundary condition which insures that the free-field motion is properly generated in the nonlinear regime. The 1D model presented by Borja and Chao (1996) allows the prediction of the free-field motion which accounts for coupled three-directional kinematical response, even if all waves are assumed to propagate only in the vertical direction. These coupled responses, which are not accounted for in many 1D site response analysis codes, emanate from plastic deformation and cause the stresses in the soil mass to depend not only on the vertical strain but also on the two non-zero components of shearing strain. Because the 1D site response model used in this study accounts for such coupled kinematical response, it can be used directly to generate the input free-field motion for 3D nonlinear SSI analysis.

The 3D nonlinear SSI code developed in this study is used to interpret the ground motion data recorded by seismic arrays installed in Lotung, a seismically active region in northeastern Taiwan, and is site of two scaled-down nuclear plant containment structures (1/4-scale and 1/12-scale models) constructed

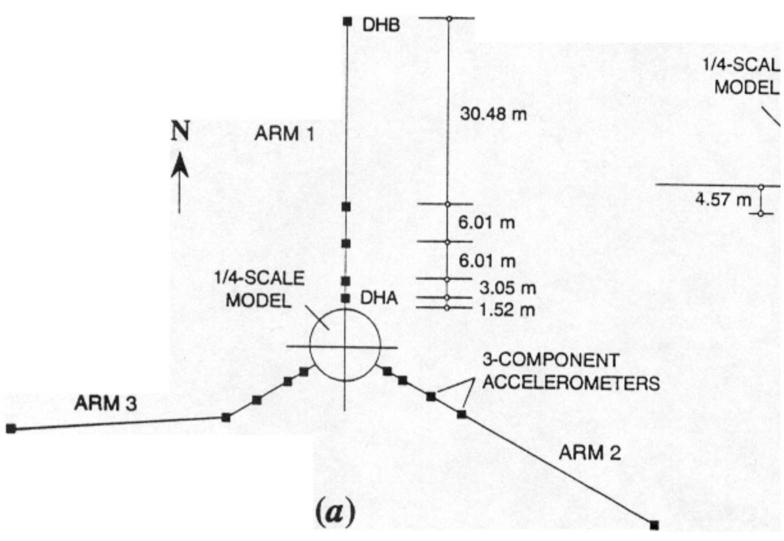

Figure 1. Location of Surface and Downhole Instrumentation, LSST Site
(a) Plan; (b) Elevation

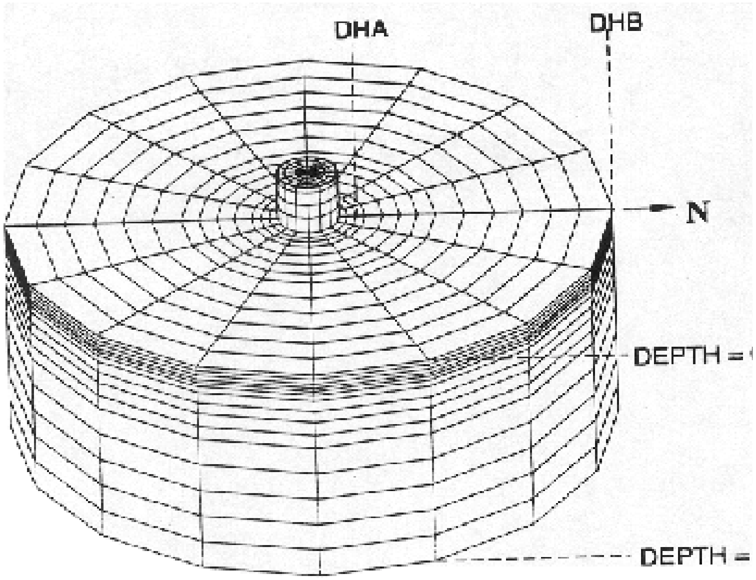

Figure 2.

Full Scale Finite Element Mesh for Nonlinear SSI Analysis

by Electric Power Research Institute, in cooperation with Taiwan Power Company, for soil-structure interaction research. Figure 1 shows the location of the surface accelerometers and two downhole instrumentation arrays in the vicinity of the l/4-scale nuclear containment model at the Large-Scale Seismic Test (LSST) site in Lotung. The two downhole arrays, designated DHA and DHB, are located approximately at 3 m and 49 m from the edge of the l/4-scale model, and contain three-component accelerometers oriented in the east-west (EW), north-south (NS), and up-down (UD) directions installed at depths of 6, 11, 17, and 47 m. Because of its distance from the containment model, array DHB is expected to record essentially free-field downhole motions; however, because of its proximity to the structure, array DHA is expected to record downhole motions that contain SSI effects as well. The local geology at the test site has been established from shear wave velocity and field boring tests. Soil samples from boreholes up to 150 m deep have also been tested in the laboratory. Test results suggest that the soil at the site could undergo strong nonlinear response even during moderate to strong earthquakes.

On May 20, 1996, an earthquake of magnitude 6.5, epicentral distance of 66 km, and focal depth of 15.8 km shook the test site. Ground motions recorded at the free-field downhole array DHB have been analyzed using the 1D model developed. The results indicate that the recorded downhole motions for DHB array were dominated by nonlinear response, and that both hysteretic and viscous soil behavior contribute significantly in producing such a response. The close agreement between the predicted and recorded acceleration time histories, not reported in this article, is worthy of note considering that the numerical model assumed coupled responses of the three components of motion. The results also confirmed many crucial assumptions, including the hypotheses that waves travel essentially in the vertical direction, and that there exists a unified constitutive theory that couples the motions.

A full scale, 3D finite element mesh (shown in Fig. 2) is generated and intended to model the influence of the SSI effects on the motions recorded by the downhole array DHA. The partial results in Fig. 3 show that the two downhole motions are nearly identical at greater depth, but differ quite noticeably near the ground surface during the period of peak response. Since the soil profiles in the vicinity of the two arrays were assumed to be the same, this discrepancy could very well be attributed to SSI effects. Once calibrated against more recorded data from strong motion arrays at various locations, the model developed in this study can be used as a tool to analyze the effects of SSI on a variety of engineering applications.

<u>Reference</u>

Borja, R. I. and Chao, H. Y. (1996). "Nonlinear Ground Response Model for Lotung LSST Site, " *Journal of Geotechnical Engineering*, ASCE (In review).

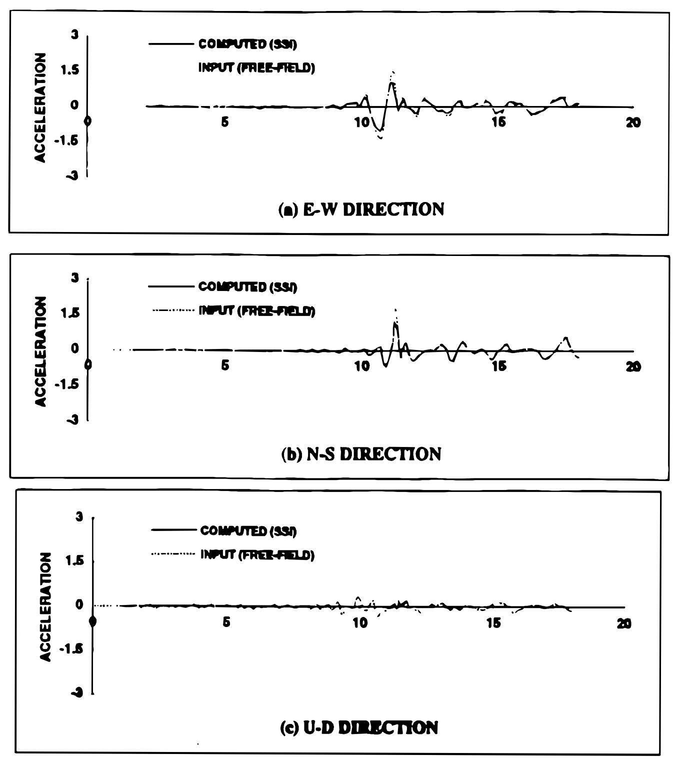

Figure 3. Acceleration-Time History at DHA

ALUMNI NEWS

Dr. Piotr Moncarz [Ph.D., 1981], Vice President of Failure Analysis Associates, continues to teach the spring quarter course, CE 287- Structural Performances and Failures. He has taught this popular course for many years, and we thank him for this outstanding volunteer service to our educational program**.**

Edward J. Thometz [M.S., 1991] has taken position with Stanford Management Group in Mountain View. He and his wife, Asami, are expecting their first child this summer.

After successfully defending her doctoral research in April, **Vicki Vance [M.S., 1992; Ph.D., 1996]** is taking a position at Melvyn Green and Associates in Torrance where she will be research seismic retrofit of historical structures.

Pasan Seneviratna [Ph.D., 1995] has accepted employment with the engineering consulting firm Krawinkler, Luth, and Associates in Menlo Park.

Nesrin Basoz [Ph.D., 1996] and **Ajay Singhal [Ph.D., 1996]**, who successfully defended their doctoral research in May, will be staying at Stanford and working as a post-doctoral fellows with Professor Anne Kiremidjian.

NEWLY SPONSORED RESEARCH PROJECTS

Analysis of Bridge Damage Data from the Northridge Earthquake, sponsored by the National Center for Earthquake Engineering Research (NCEER). Principal Investigator: Professor Anne S. Kiremidjian. 6/1/96 - 12/31/96.

Integrated Approach to Seismic Hazard Analysis , sponsored by the National Science Foundation (NSF). Principal Investigator: Professor Anne S. Kiremidjian. 6/1/96 - 5/31/97.

Rehabilitation and Upgrading of the John A. Blume Earthquake Engineering Center Shaking Table Facilities, sponsored by the National Science Foundation (NSF). Principal Investigator: Professor Anne S. Kiremidjian; Co-Principal Investigator: Professor Helmut Krawinkler. 6/1/96 - 12/31/96.

*Integrating Computer Model with Field Monitoring Program for Underground Structure Construction***,** sponsored by Stanford's Center for Integrated Facility Engineering (CIFE). Principal Investigator: Professor Ronaldo I. Borja. 10/1/96 - 9/30/97.

GIS Course Notes: There are a few remaining copies of the course notes from the Blume Center's Short Course on *Seismic Hazard and Risk Analysis with Geographic Information Systems*, given in April by Professor Anne Kiremidjian and Dr. Stephanie King. The course notes are available, while supplies last, for $50.00. Please contact the Blume Center for more information.

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