Issue No. 22

Spring 2000

The John A. Blume Earthquake Engineering Center

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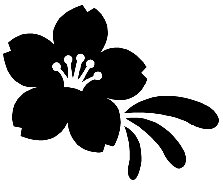

SPRING COMES TO THE BLUME CENTER

Spring is a busy time for The Blume Center, as our students prepare for the end of the school year and graduation.

There is much to report from the Winter Quarter, including information from 12WCEE in New Zealand, student resumes now available on our web site, and news from our Professors, students and alumni.

12WCEE IN NEW ZEALAND ATTENDED BY FACULTY, STUDENTS

The 12th World Conference on Earthquake Engineering was held January 30 through February 6, 2000 in Auckland, New Zealand.

Professors **Anne Kiremidjian**, **Gregory Deierlein**, **Chuck Memun, Eduardo Miranda**, and **Helmut Krawinkler** presented papers, as did Ph.D. candidates **Keith Porter** and **Sameh Mehanny**.

Professor **Laura Lowes** and several Blume Center alumni and affiliates were also present. A dinner for the Stanford group was hosted by Prof. Kiremidjian on February 4 at the Harbourside restaurant.

WINTER 2000 GRADUATES

Several Structual Engineering and Geomechanics students graduated at the end of the Winter 2000 Quarter. **Jorge Carballo** and **Hjortur Thrainsson** both received their Ph.D. degrees; Hjortur is doing Post-Doc research for The Blume Center and Jorge is currently working for RMS (Risk Management Solutions).

Brian Flaherty received his Engineering Degree and is working for Lockheed Martin in Sunnyvale.

Gavriel Charalambides, **Gwynn Masada**, **Eric Mastroianni** (Simpson Gumpertz & Heger, Inc., Arlington MA), **Jeffrey Milheizler** (Uzun & Case Engineers, Atlanta GA), **Francisco Parisi** (Rutherford & Chekene, San Francisco), **Chao Li**, and **Chao-Shiang Li** received their Master's Degrees.

BLUME CENTER NEWS

Maya Belabekian (Ph.D. '97) and her husband, Levon Kazarian, welcomed a baby girl, Eve, to their family on February 12, 2000.

Prof. Anne Kiremidjian presented a paper at the Joint Workshop on US-Japan Cooperative Research in Urban Earthquake Disaster Mitigation on January 6, 2000.

Prof. C. Allin Cornell gave an invited lecture in New Orleans at the Safety and Reliability Symposium of the annual OMAE meeting, February 14-15, 2000. The lecture "Seismic Reliability: Assessment and Design of Fixed Offshore Platforms" was co-authored by **Dimitris Vamvatsikos** and **Jorge Carballo**.

Profs. Gregory Deierlein and **Eduardo Miranda** presented papers at the 2000 North American Steel Construction Conference in Las Vegas, February 23-25.

On February 28-29, 2000 in San Francisco, **Profs. Helmut Krawinkler** and **Gregory Deierlein** presented papers at the US-Japan Workshop on Seismic Fracture Issues in Steel Structures.

Prof. Ronaldo Borja presented a paper at the Euroconference Geomath in Innsbruck, Austria, March 1-3. The conference discussed some pressing problems in geomechanics as well as the mathematical tools available for solving them.

On March 17, **Profs. Anne Kiremidjian** and **Frieder Seible** (UCSD) held a PEER supported workshop on Performance Based Bridge Engineering and Transportation Systems.

Prof. Anne Kiremidjian presented a paper on Risk Analysis of Transportation Systems at the US-Japan Workshop on "Effects of Near Field Earthquake Shaking", March 20-21 in San Francisco.

Prof. Gregory Deierlein presented a paper co-authored by **Sameh Mehanny** (Ph.D. '99) at the 6th ASCCS International Conference on Steel and Concrete Composite Structures held in Los Angeles from March 22-24, 2000.

NEW RESEARCH FUNDING

"Fiber Optic Sensors for Model-Based Simulation and Health Monitoring of Civil Structures," **Laura Lowes** and **Greg Deierlein**, awarded by Stanford's Office of Tech. Licensing.

"Micromechanical Simulation of Earthquake-Induced Fractures in Steel Structures," **Greg Deierlein**, awarded by NSF.

RESEARCH SPOTLIGHT

NONLINEAR SITE RESPONSE ANALYSIS OF LSST16 EVENT FROM 1986 LOTUNG EARTHQUAKE

By Chao-Hua (Eric) Lin and Ronaldo I. Borja

Introduction

Lotung is a seismically active region in northeastern Taiwan, and was the site of two scaled-down nuclear plant containment structures constructed by the Electric Power Research Institute (EPRI) in cooperation with Taiwan Power Company, for soil-structure interaction research. Three surface and two downhole (DHA and DHB) arrays were installed to monitor both ground surface and deeper layer motions. More than 20 pore-pressure transducers have been installed in clusters along the accelerometer arrays. Considering that potentially liquefiable layers are located approximately between 2 and 20 m below the ground surface throughout the site, pore pressure sensors were embedded at depths between 3 and 16 m from the ground surface. On November 15, 1986, a strong earthquake, denoted as the LSST16 event, with magnitude 7.0 and epicentral distance of 80 km, shook the test site. Downhole acceleration and pore-pressure time history data were recorded simultaneously during the earthquake. The objective of the present study is to analyze the free-field downhole motion and the earthquake-induced pore pressure buildup by using a fully nonlinear finite element (FE) model.

The constitutive model used for the soil is a bounding surface plasticity model with ellipsoidal loading function capable of accounting for stress-induced anisotropy. The model is coupled with a nonlinear hyperelastic model to ensure an energy-conserving elastic response. The combined model is cast within the framework of return mapping algorithm that allows fully implicit integration and consistent linearization of the elastoplastic constitutive equations. The FE model used in the present study is coded into a FORTRAN program SPECTRA-UWP, which is based on a multiphase continuum formulation (Biot 1956), and incorporates the effect of transient fluid flow through porous media. Since the formulation is based on effective stresses, the model is capable of predicting excess pore pressure buildup due to cyclic loading.

Constitutive model

Bounding surface plasticity theory is based on the notion that there exists a surface that encloses all possible states in stress space, and that plastic yielding inside this surface is possible through some form of mapping of the stress point onto its image on the bounding surface. The most widely used mapping rule for soils is radial mapping (Dafalias and Herrmann 1982). This feature was used by Borja et al. (2000) to develop relationships between the bounding surface and the oading surface.

The idea is based on homologous relationships between a surface $F = 0$ representing the bounding surface, and a surface ¦ = 0 representing the loading surface. Both surfaces have the projection center as their centers of homology, which has the physical significance of being the point of last unloading. In the formulation, $F = 0$ implies ¦ = 0, and $dF/dt = 0$ implies d¦/dt = 0. Thus, the consistency condition on ¦ follows naturally from the consistency condition on F, and so the loading function ¦ may be treated essentially as a yield function.

With the bounding surface formulation, we have enhanced the model presented by Borja and Tamagnini (1998) and cast a Cam-Clay type plasticity model within the framework of bounding surface plasticity. The complete formulation is presented in Borja et al. (2000). The formulation involves the following ingredients of the constitutive model: (a) ellipsoidal bounding and loading functions; (b) bilogarithmic compressibility law for the bounding surface; (c) exponential hardening law for the loading surface; and (d) nonlinear hyperelastic constitutive law for the recoverable component of deformation. A key feature of the numerical implementation involves the use of return mapping algorithm in strain space and has the following features: (a) fully implicit stress-point integration in strain space; (b) consistent linearization of the local evolution equations; and (c) consistent linearization of the global equations leading to an exact tangent operator. The latter two features guarantee that the Newton iterations in the local and global levels exhibit asymptotic rate of quadratic convergence.

As a numerical example, we consider an element test consisting of a volume-preserving stress-controlled cyclic simple shearing from an initially isotropic state of stress. The result is presented in Fig. 1 in the form of stress path on the deviatoric stress q-mean normal stress p plane.

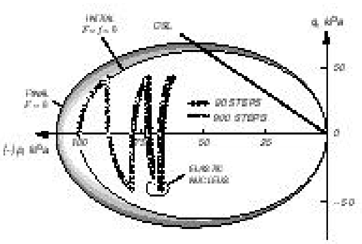

Fig. 1. Stress path for cyclic simple shearing example.

Initially, the bounding and loading surfaces coincide, but as the shear stress oscillates the bounding surface expands with plastic compaction, while the stress path approaches the critical state line. Solutions obtained with 90 and 900 load increments give an indication of the relative accuracy of the implicit integration algorithm. The re-

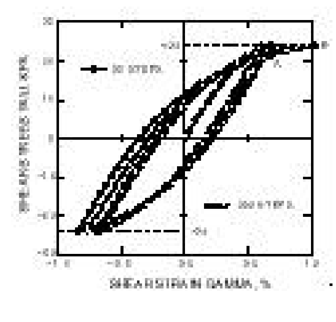

Fig. 2. Stress-strain curve for cyclic simple shearing example.

sulting cyclic stress-strain curves, shown in Fig. 2, clearly illustrate hysteretic effects beneath the bounding surface as well as an overall degradation of stiffness with cyclic loading.

Preliminary analysis of LSST16 earthquake data

Investigation of the transient response of fluid-saturated porous media subjected to external loading is of particular importance in a number of practical engineering problems. The problem involves transient interaction between the fluid and solid soil skeleton. In order to analyze the soil behavior under such condition, a u-w-p coupled formulation based on Biot's theory of mixtures was developed to incorporate the effect of transient flow of fluid in a dynamic setting. The finite element dynamic equation of motion is then coded into a Fortran program called SPECTRA-UWP.

Nine material parameters are required by the FE model to describe the constitutive response of the soil. According to the soil profile, the potentially liquefiable soil layers are located approximately between 3 and 9 meters below the ground surface. Thus, the analyses of free-field motion were limited to the top 17 m of the soil and the acceleration time history records of DHB array at 17-m depth were used as input motions. In the limit of vertically propagating waves, "mixed" stick elements were used to account for solid displacement (u), relative displacement (w), and pore pressure (p). Locally, each stick element has 8 nodes, 3 nodes for u, 3 nodes for w, and 2 nodes for p. The solid and relative displacement fields were interpolated quadratically, while the pore pressure displacement field was interpolated bilinearly. The FE mesh used in the present study contains a total of 17 stick elements.

We now simultaneously apply the three components of the input ground motion, east-west (EW), north-south (NS), and up-down (UD), at the bottom of the FE mesh and perform a nonlinear time-domain analysis. The water table is assumed at the ground surface and the hydrostatic pressures were distributed linearly along the depth. Fig. 3 compares the downhole acceleration-time histories predicted by the FE code SPECTRA-UWP to the motions recorded by the downhole array DHB. The label FA1-5 was used in the original digitized recording and pertains to the station at the ground surface. Fig. 4 shows the comparison of the predicted values of excess pore pressure at 6-m below the ground surface to the recorded data at similar depth.

Results of Fig. 3 show that peak accelerations predicted by the nonlinear model are within 10% error in both directions; zero crossings are predicted quite well. On the other hand, result of Fig. 4 shows that the model overpredicted the buildup of excess pore pressure by 20%. The discrepancy could be due to the large variations of soil properties. As was discovered at the Lotung site, the permeability of soil layers is not truly isotropic and homogeneous; as a result, one or two field records may not be representative of the general response at the site. Since the calculated pore pressure response is higher than the field records, it indicates that the coefficients of permeability estimated for top layers might be lower than the actual ones.

Summary

A nonlinear site response analysis of the LSST16 event in Lotung, Taiwan has been presented. The analysis was performed using a fully coupled inelastic dynamic FE code SPECTRA-UWP. The procedure was formulated for level ground subjected to vertically propagating waves. The constitutive relation is based on a fully implicit stress-point integration algorithm for a class of anisotropic bounding surface plasticity models with ellipsoidal loading function.

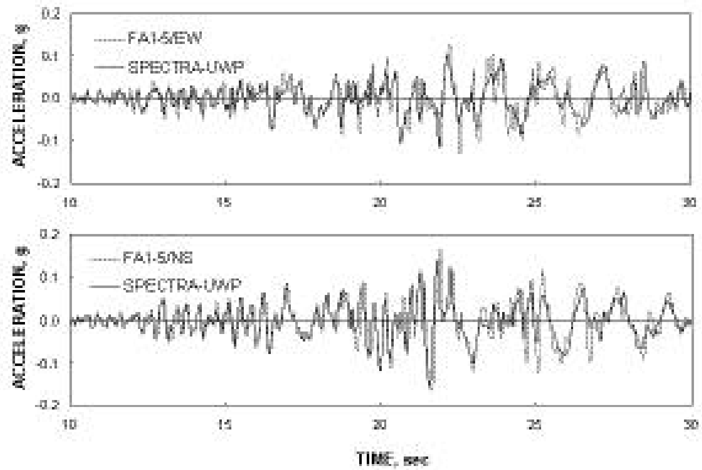

Fig. 3. EW & NS Acceleration versus Time Histories of Downhole Motion for Array DHB

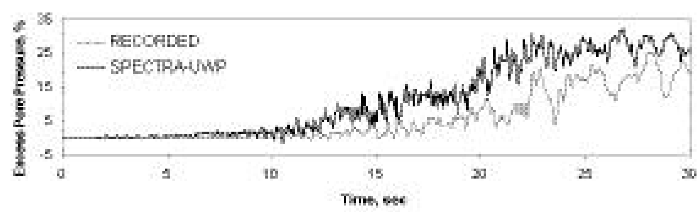

Fig. 4. Predicted and Recorded Pore-Pressure Response at 6 m Depth

Acknowledgments

Financial support for this research was provided by National Science Foundation Contract No. CMS-9613906, through the program of Dr. C. J. Astill.

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Dafalias, Y.F., and Herrmann, L.R. 1982, "Bounding surface formulation of soil plasticity," In: Ch.10: Soil Mechanics-Transient and Cyclic Loads, G.N. Pande and O.C. Zienkiewicz, eds., pp. 253-282, John Wiley & Sons, New York.

STUDENT RESUMES NOW AVAILABLE

The Blume Center is pleased to announce that resumes from our recent and upcoming graduates in the Master's and Ph.D. programs are now available through The Blume Center web site: http://blume.stanford.edu/. The resumes are in Adobe Acrobat format and can easily be printed out. If you would like to access them, click on the Student Resumes link at the bottom of our home page.

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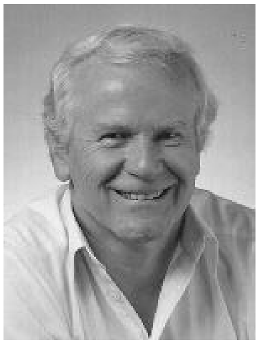

Professor Helmut Krawinkler will be spending the Spring Quarter on sabbatical in Europe. He will be visiting colleagues, discussing research, and giving seminars at universities and research institutes in Innsbruck, Ljubljiana, Istanbul, Naples, Milan, San Sebastian, Ispra, and Zurich. We look forward to his return this summer.

AWARDS

Outstanding Paper Award 1998, EERI, "Earthquakes, Records, and Nonlinear Responses" by **Nilesh Shome**, **C. Allin Cornell, Paolo Bazzurro**, and **Jorge Carballo**.

RECENTLY PUBLISHED PAPERS

"Strength and Ductility of Concrete Encased Composite Columns," **El-Tawil, S**.; **Deierlein, G.G.** (1999), Jnl. of Structural Engineering, ASCE, Vol. 125(no. 9), pp. 1009-1019.

"Finite-Element Fracture Analyses of Welded Beam-Column Connections," **Chi, W-M.**; **Deierlein, G.G**.; **Ingraffea, A.R**. (1999), *Fatigue and Fracture Mechanics: 30th Volume*, ASTM STP 1360, American Society of Testing and Materials, 1999.

"Provisions for the Seismic Design of Steel Structures with Eccentrically Braced Frames in Mexico," **Miranda, E.,** *Proc. 2000 North American Steel Construction Conference*, Las Vegas, Nevada, February 23-26, 2000, pp. 21.1-21.21

12WCEE - Auckland, NZ, February 2000

"Strength Reduction Factors for Multi-Degree-of-Freedom Systems," **Santa-Ana, P.** and **Miranda, E.**, *Paper 1446*.

"Amplification Factors to Estimate Inelastic Displacement Demands for the Design of Structures in the Near Field," **Baez, J.I.** and **Miranda, E.,** *Paper 1561*.

"Inelastic Displacement Ratios for Displacement-Based Earthquake Resistant Design," **Miranda, E**., *Paper 1096*.

"Seismic Loss Estimation Model for Mexico City," **Ordaz, M., Miranda, E., Reinoso, E.** and **Perez-Rocha, L.E**., *Paper 1902*.

"Seismic Behaviour of Structures With Energy Dissipating Systems in Mexico," **Jara, J.M., Ayala, A.G**. and **Miranda E.**, *Paper 0175*.

"A Building Damage Estimation Method for Business Recovery," **Porter, K.A., Kiremidjian, A.S., LeGrue, J.**, and **King, S.A**., *Paper 2821*.

"Seismic Risk Analysis of Port Facilities," **Kiremidjian, A.S.**, **Audigier, M.**, **Chiu, S.** and **King, S.**, *Paper 2811*.

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