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THE JOHN A. Blume EARTHQUAKE ENGINEERING CENTER

DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING, STANFORD UNIVERSITY

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CORDOVA RECEIVES EERI/FEMA GRADUATE FELLOWSHIP AWARD

Paul Cordova, PhD Candidate, has been selected as the 2003-2004 NEHRP Graduate Fellow in Earthquake Hazard Reduction. The Earthquake Engineering Research Institute awards this fellowship each year in a cooperative program with FEMA's National Earthquake Hazards Reduction Program. The award is given to foster the participation of capable individuals in furthering the goals and practice of earthquake hazard mitigation. The Fellowship provides $12,000 for a nine-month stipend and $8,000 for tuition, fees and research expenses.

The focal point of Cordova's research is an innovative composite frame system that incorporates composite steel beams with reinforced concrete columns. The goal is to develop an understanding of the seismic behavior and performance criteria of these systems and apply this to the seismic design. His advisor at Stanford is **Prof. Greg Deierlein**.

SPRING 2003 GRADUATES

The following students graduated with a Master's Degree in Civil and Environmental Engineering. From the Structural Engineering and Geomechanics Program: **Jose Andrade**, **Suzanne King**, **Duk Jin Joo**, **Tom Messervey** (USMA, West Point), **Matthew Verti**, **Allison Johnson-Moore**, **Bora Kutruza** (Weidlinger Associates, Inc.), **Curtis Haselton** (PhD Program, Stanford), **Jennifer Ellis**, **David Lam**, **Wesley Morgan**, **Can Berk Bingol**, **Kevin Morton**, **Josh Gebelein** (Nabih Youssef & Assoc.), and **Kwok-Wai Yu**. From the Design/Construction Integration Program: **Ines Lam** (Skidmore, Owings & Merrill LLP), **Noreen Chan**, **Gerassimos Trezos** (Greek Air Force), **Melissa Hardy** (Holder Construction Co.), **Jeffrey Threet**, **Chigoziem Uzoigwe**, and **Lena Bississo**.

Receiving their Ph.D. in Civil and Environmental Engineering (Structural Engineering and Geomechanics) were **Fatemeh Jalayer** (CalTech) and **T.L. Murlidharan**.

MEHANNY ANDDEIERLEIN SELECTED AS 2003 REESE WINNERS

Sameh S.F. Mehanny (PhD '99) and **Prof. Greg Deierlein** are the recipients of the ASCE 2003 Raymond C. Reese Research Prize, for the paper "Seismic Damage and Collapse Assessment of Composite Moment Frames", Journal of Structural Engineering, September 2001. The Reese Prize is given in recognition of a paper published by ASCE that describes a notable achievement in research related to structural engineering and how it can be used. Deierlein and Mehanny accepted their award during the Structural Engineering Institute Award Luncheon on May 30 at the 2003 Structures Congress in Seattle.

Alumni, Affiliates and Friends are encouraged to send news items about yourselves to earthquake@ce.stanford.edu for inclusion in the next newsletter.

BLUME CENTER NEWS

On March 17-20, **Prof. Sarah Billington** attended and presented a paper at the Euro-C conference (Computational Modeling of Concrete and Concrete Structures), Salzburger Land, Austria.

Prof. Eduardo Miranda was invited to give presentations on *Seismic Design Criteria for Steel-Reinforced Concrete Composite Structures* at the 2003 North American Steel Construction Conference in Baltimore on April 2-5, 2003.

On April 7, **Prof. Anne Kiremidjian** gave a four hour lecture on seismic hazard modeling at the "Seminario Sobre Innovaciones Enasegurabilidad Yevaluatcion De Riesgo Por Terremoto" at Javeriana University, Bogota Colombia.

On April 9, **Prof. Anne Kiremidjian** gave the commemorative lecture for the 20th anniversary of the Popayan earthquake in Popayan, Colombia. The title of the lecture was *"Recent development in earthquake hazard and risk evaluation"*.

Prof. Ronnie Borja gave a plenary lecture on the computational and algorithmic aspects of strain localization in geomaterials for the Seventh Computational Plasticity Congress (COMPLAS VII) held in Barcelona on April 7-10.

Prof. Eduardo Miranda was invited to present a general overview of PEER's research related to Performance Based Earthquake Engineering at the 2003 Applied Insurance Research (AIR) Spring Conference in Orlando Florida on April 15-16. The conference was attended by more than 120 professionals from insurance, reinsurance and broker companies.

Prof. Sarah Billington attended and made a presentation at a Symposium, May 1-3, in honor of her father, **David P. Billington** at Princeton University (in honor of him turning 75 and for teaching at Princeton for 45 years). This was not a retirement event! She gave a presentation on teaching CEE 80N at Stanford.

The Project Based Learning Laboratory (PBL), directed by **Dr. Renate Fruchter**, hosted the 10th Anniversary of the Architecture/Engineer/Construction Global Teamwork course, on May 9, with worldwide partners from Europe, Japan and the US.

Prof. Sarah Billington gave a presentation at the PTI (Post-tensioning Institute) Convention in Huntington Beach on recent experimental research on precast post-tensioned bridge piers for seismic regions, on May 18. The research was sponsored in part by PTI.

On May 19, **Profs. Helmut Krawinkler**, **Greg Deierlein** and **Eduardo Miranda** participated in the annual NSF site visit of the PEER Center. Krawinkler and Deierlein represented the PEER Research Management Committee and Miranda gave a presentation on earthquake loss modeling for buildings.

At the invitation of **Prof. Masayoshi Nakashima**, **Prof. Allin Cornell** gave a keynote lecture in a workshop at Kyoto University on the probabilistic aspects of Performance Based Earthquake Engineering, and provided information to an AIJ (Architectural Inst. of Japan) steel building code subcommittee meeting on the basis of the new FEMA 350 (SAC) seismic guidelines for steel frames, from March 19-31.

Profs. Helmut Krawinkler, **Greg Deierlein**, **Chuck Menun** and **Sarah Billington** attended the 1st annual NEES Consortium Meeting in Park City Utah, May 21-22.

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RESEARCH SPOTLIGHT

SIMULATION OF EARTHQUAKE LIQUEFACTION RESPONSE ON PARALLEL COMPUTERS

JUN PENG, JINCHI LU, KINCHO H. LAW AND AHMED ELGAMAL

INTRODUCTION

Simulations of earthquake responses and liquefaction effects generally involve coupling solid and fluid phases, and often require the incorporation of soil plasticity models. Large-scale earthquake simulations are not feasible on most current single processor computers. Utilization of parallel computers, which combine the resources of multiple processing and memory units, can potentially reduce the solution time significantly. Furthermore, parallel computing allows analysis of large and complex models that may not fit into a single processing unit. Application software, such as finite element programs, must be re-designed in order to take full advantage of parallel computing.

This joint research effort between Stanford University and University of California at San Diego explores the implementation of a geomechanics nonlinear finite element program on distributed memory parallel computers. The research focuses on the development of a parallel version of a nonlinear finite element program, CYCLIC, for the simulation of earthquake ground response and liquefaction effects. The objective is to extend the computational capabilities of the finite element program to simulate large-scale systems, and to broaden the scope of its applications to seismic ground-foundation interaction problems.

PARCYCLIC

The parallel finite element program, ParCYCLIC, is implemented based on a sequential geomechanics nonlinear finite element program, CYCLIC, which has been developed to analyze cyclic mobility and liquefaction problems (Parra 1996; Yang et al. 2003). CYCLIC is based on small-deformation theory, which does not account for nonlinearity effects due to finite deformation or rotation. Extensive calibration of CYCLIC has been conducted with results from experiments and full-scale response of earthquake simulations involving ground liquefaction. For the liquefaction model currently employed, emphasis is placed on controlling the magnitude of cycle-by-cycle permanent shear strain accumulation in clean medium-dense sands. Following the classical plasticity formulation, it is assumed that material elasticity is linear and isotropic, and that nonlinearity and anisotropy are the results of plasticity. The selected yield function forms a conical surface in stress space with its apex along the hydrostatic axis, as shown in Figure 1. During shear loading, the soil contractive/dilative behavior is handled by a non-associative flow rule (Parra 1996) so as to achieve appropriate interaction between shear and volumetric response.

The computational procedure of the developed ParCYCLIC program is illustrated in Figure 2. The procedure can be divided into three distinct phases, namely: preprocessing and input phase, nonlinear solution phase, and output and postprocessing phase. In the nonlinear solution phase, modified Newton-Raphson algorithm is employed, that the stiffness matrix at each iteration step uses the same tangential stiffness from the initial step of the increment. Although this modified iterative approach will typically require more steps per load increment compared with full Newton-Raphson scheme, substantial savings can be realized as a result of not having to assemble and factorize a new global stiffness matrix during each iteration step. As shown in Figure 2, if the solution is not converged after a certain number of iterations (e.g., 10 iterations) within a particular time step, the time step will be split into two to expedite convergence.

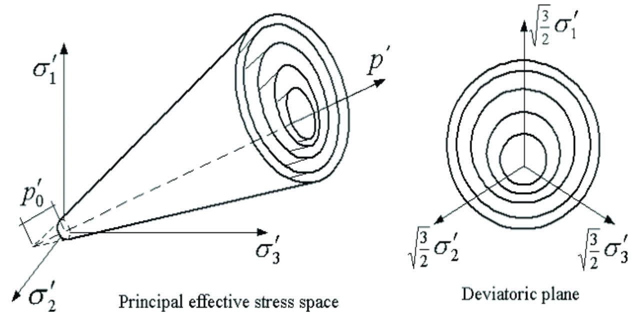

Figure 1 - Conical yield surface in principal stress space and deviatoric plane

PARALLEL PROCESSING

Programming models required to take advantage of parallel programming are significantly different from the traditional paradigm for a serial program (Mackay 1992). To achieve high efficiency for parallel applications, it is important to keep all participating processors busy performing useful computations and to minimize communications among the processors.

One common approach in developing application software for distributed memory parallel computers is to use the single-program-multiple-data (SPMD) paradigm. In this parallel programming paradigm, all processors are assigned the same program code but run with different data sets comprising the problem. Each processor of the parallel machine solves a partitioned domain, and data communications among sub-domains are performed through message passing. In the implementation of ParCYCLIC, METIS (Karypis and Kumar 1998) routines are applied to decompose the finite element domain. The algorithms in METIS are based on multilevel graph partitioning (Karypis and Kumar 1998), which is an efficient and popular domain decomposition approach.

After the domain partitioning, symbolic factorization is performed to set up the data structure for storing global stiffness matrix. The assembly of the global matrix from the element stiffness matrices is one of the most natural tasks for parallel implementation. Since each element stiffness matrix can be generated independently of the other element stiffness matrices, each

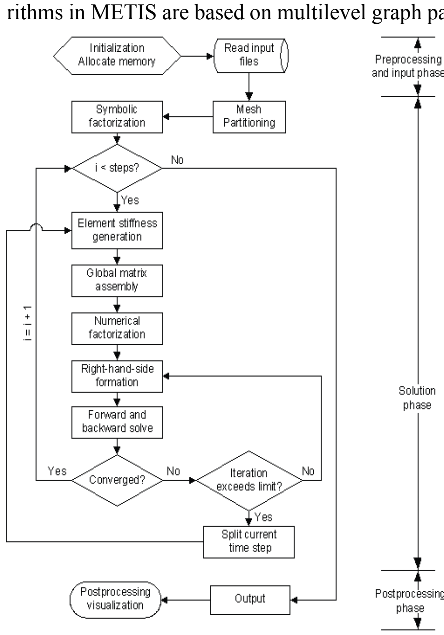

Figure 2 - Flowchart of ParCYCLIC computational procedures

processor can work independently on the elements assigned to it. Once the processor assignment and the assembly of the global stiffness matrix are completed, numerical solution of the global system of linear equations can proceed. A parallel row-oriented sparse solver (Mackay and Law 1993) is adopted in ParCYCLIC for performing the numerical calculation. The parallel numerical factorization procedure is divided into two phases. In the first phase, each processor independently factorizes certain portions of the matrix that assigned to a single processor. In the second phase, other portions of the matrix shared by more than one processor are factored. Following the parallel factorization, the parallel forward and backward solution phases proceed to compute the solution to the global system of equations.

The inter-process communication of ParCYCLIC is implemented using MPI (Snir and Gropp 1998). MPI (Message Passing Interface) is a specification of a standard library for message passing that was defined by the MPI Forum, a broadly based group of parallel computer vendors, library developers, and applications specialists. The strength of MPI is its portability, which makes it suitable to write programs to run on a wide range of parallel computers and workstation clusters. For ParCYCLIC, during the global matrix assembly and matrix factorization phases, most of the communications are point-to-point messages; while in the forward and backward solution phase, most of the communications are broadcast messages.

PARALLEL PERFORMANCE

The performance of ParCYCLIC is tested on the Blue Horizon machine at San Diego Supercomputer Center. Blue Horizon is an IBM Scalable POWERparallel (SP) machine, which has 144 compute nodes, each with eight POWER3 RISC-based processors and with 4 GBytes of memory. Each processor on the node has equal shared access to the memory. The performance of ParCYCLIC is evaluated by using a three-dimensional soil-pile interaction model, as shown in Figure 3. In this model, a 3x3 pile group, embedded in a fully saturated soil foundation with three stratums (liquefiable soil as middle layer), is subjected to earthquake excitation along the X direction at the base. As shown in Figure 3, only half of the model is used due to its geometrical symmetry.

Table 1 summarizes the timing results of the nonlinear analysis for one time step. The results for the solution phase and the total execution

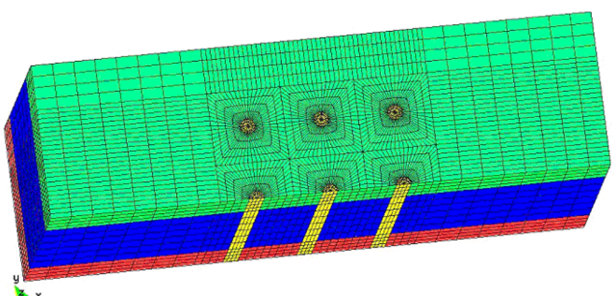

Figure 3 - A soil-pile interaction finite element model

Table 1 – Solution times for the soil-pile interaction model (time in seconds)

(130,020 equations; 29,120 elements; 96,845,738 non-zeros in factor *L*)

Number of processors	LDL^T factorization	Forward and backward solve	Solution phase	Total execution time
2	332.67	1.41	370.42	455.91
4	166.81	0.78	187.72	286.97
8	85.20	0.45	97.71	186.67
16	50.73	0.29	59.39	147.55
32	27.80	0.23	34.61	124.30
64	18.41	0.26	24.40	116.21

time (which includes the sequential phases such as input, domain decomposition, output and postprocessing steps) are also illustrated in Figure 4. Note that the results for one processor are not available because the model is too large to fit into the memory of a single processor. The performance results demonstrate excellent parallel speedup on the solution phase for the model. The results also show that

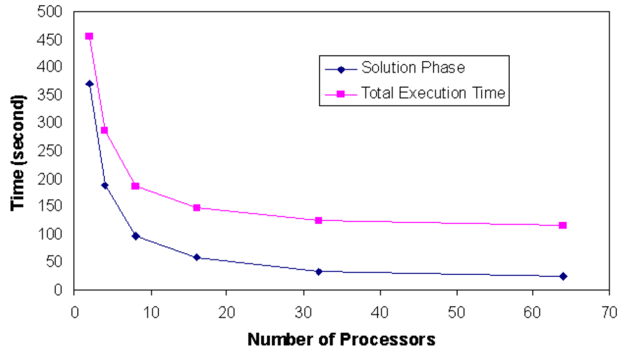

Figure 4 - Solution times for the soil-pile interaction method

the ParCYCLIC program is scalable to a large number of processors, e.g., 64 or more.

CONCLUSIONS

This article presents the analysis and solution strategies employed in ParCYCLIC, a parallel nonlinear finite element program for the simulations of earthquake site response and liquefaction. In ParCYCLIC, finite elements are employed within an incremental plasticity coupled solid-fluid formulation. A constitutive model developed for the simulation of liquefaction-induced deformations is a main component of this analysis framework. Large-scale experimental results for 3-D geotechnical simulations are presented to demonstrate the performance of ParCYCLIC. It is shown that ParCYCLIC can be used to simulate large-scale problems, which would otherwise be infeasible using single-processor computers due to the limited memory sizes. Furthermore, the results show that the ParCYCLIC program is scalable to a large number of processors. Research continues to optimize the program to further reduce the total solution time and to apply the finite element program for large-scale simulation of ground-foundation interaction problems.

ACKNOWLEDGEMENTS

This research was supported by the National Science Foundation Grant Number CMS-0084530, and an equipment grant from Intel Corporation. Thanks to Dr. Zhaohui Yang for his assistance with the development of the original CYCLIC code. The authors also would like to acknowledge the San Diego Supercomputer Center (SDSC) for providing computing facilities employed in this research.

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Published Papers

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Kwan, WP, and **Billington, SL**, (2003) *"Unbonded Post-tensioned Bridge Piers: Part I - Monotonic and Cyclic Analyses,"* ASCE J. Bridge Engineering, 8(2): 92-101.

Kwan, WP, and **Billington, SL**, (2003) *"Unbonded Post-tensioned Bridge Piers: Part II - Seismic Analyses,"* ASCE J. Bridge Engineering, 8(2): 102-111.

Blume Center Hiking Trip

On April 19, about 40 Blume Center students, staff and faculty (and guests) bussed up to Point Reyes National Seashore and enjoyed a 10 mile hike to the beach and back. After several weeks of cold and rainy weather, the day was perfect, clear and sunny and, despite one or two blisters and a little sunburn everyone had a great time! After the hike the group had dinner at The Cantina in Mill Valley. The Blume Center helps sponsor the Annual Hike so that our students can enjoy the Bay Area and get to know their professors and fellow students.

Blume Center News continued from page 1

Prof. Anne Kiremidjian gave a Keynote Lecture on Developments in Seismic Damage to Newtorks in the USA and Europe at the GNDT-MAE-SAFERR Conference on Seismic Risk in Urban Areas, Erice, Italy, May 25-29, 2003.

A joint paper on Wireless Communication for Structural Damage Detection Systems by **Anne Kiremidjian**, **Jerry Lynch**, **Kincho Law**, **Tom Kenny**, **Edward Carrier**, **Tom Lee**, and **Anil Kottapalli** was presented by Lynch at the ASCE Structure Congress in Seattle, WA on May 30.

Ph.D. Candidate **Arash Altoontash** presented a paper at the ASCE Structure's Congress in Seattle, May 30, entitled, "A Versatile Model for Beam-Column Joints", co-authored by **Prof. Greg Deierlein**.

Congratulations to **Profs. Helmut Krawinkler** and **Greg Deierlein** for their recent elections to the Board of Directors of the NEES (Network for Earthquake Engineering Simulations).

On June 16-18, **Prof. Sarah Billington** attended and delivered a lead paper at the HPFRCC-4 International Workshop (High Performance Fiber-Reinforced Cementitious Composites) in Ann Arbor, MI. The paper was titled "Reverse Cyclic Load Response of Highly Ductile Fiber-reinforced Cement-based Composites."

Dr. Renate Fruchter received an equipment donation from Microsoft in response to the "WILD Interactions" proposal.

Shah Family Innovation Prize

EERI is currently accepting nominations for the Shah Family Innovation Prize given to individuals less than 35 years old who have demonstrated the potential to make major contributions to the field of earthquake risk mitigation and management. For more information, please see their web page: www.eeri.org/eeri/Committees/Honors/shah1.html. Deadline for nominations is October 15.

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