17:03:54 OCA PAD AMENDMENT - PROJECT HEADER INFORMATION 09/13/93

Active

Project #: E-20-G12 Cost share #: E-20-325 Rev #: 4
Center # : 10/24-6-R7276-0A0 Center shr #: 10/22-1-F7276-0A0 OCA file #:
Work type : RES
Contract#: BCS-9110173 Mod #: LTR OF 9-10-93 Document : GRANT
Prime #: Contract entity: GTRC

Subprojects ? : N CFDA: 47.041
Main project #: PE #: N/A

Project unit: CIVIL ENGR Unit code: 02.010.116
Project director(s):
RIX G J CIVIL ENGR (404)894-2292

Sponsor/division names: NATL SCIENCE FOUNDATION / GENERAL
Sponsor/division codes: 107 / 000

Award period: 910815 to 940131 (performance) 940430 (reports)

Sponsor amount	New this change	Total to date
Contract value	0.00	53,482.00
Funded	0.00	53,482.00
Cost sharing amount		5,001.00

Does subcontracting plan apply ?: N

Title: SITE CHARACTERIZATION FOR LIQUEFACTION SUSCEPTIBILITY USING GEOTOMOGRAPHY

PROJECT ADMINISTRATION DATA

OCA contact: Jacquelyn L. Tyndall 894-4820

Sponsor technical contact	Sponsor issuing office
CLIFFORD J. ASTILL	ANDREA R. KLINE
(202)357-9500	(202)357-9626
NATIONAL SCIENCE FOUNDATION	NATIONAL SCIENCE FOUNDATION
1800 G STREET, NW	1800 G STREET, N.W.
WASHINGTON, DC 20550	WASHINGTON, D.C. 20550

Security class (U,C,S,TS) : U ONR resident rep. is ACO (Y/N): N
Defense priority rating : N/A NSF supplemental sheet
Equipment title vests with: Sponsor GIT X

Administrative comments -
ISSUED TO EXTEND PROJECT TERMINATION DATE THROUGH JANUARY 31, 1994 WITH NO ADDITIONAL FUNDS. FINAL REPORT NOW DUE APRIL 30, 1994.

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 05/20/94

Project No. E-20-G12 | Center No. 10/24-6-R7276-0A0

Project Director RIX G J | School/Lab CIVIL ENGR

Sponsor NATL SCIENCE FOUNDATION/GENERAL

Contract/Grant No. BCS-9110173 | Contract Entity GTRC

Prime Contract No. ______

Title SITE CHARACTERIZATION FOR LIQUEFACTION SUSCEPTIBILITY USING GEOTOMOGRAPHY

Effective Completion Date 940131 (Performance) 940430 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	N	
Final Report of Inventions and/or Subcontracts	N	
Government Property Inventory & Related Certificate	N	
Classified Material Certificate	N	
Release and Assignment	N	
Other	N	

CommentsLETTER OF CREDIT APPLIES. 98A SATISFIES PATENT REQUIREMENT.

Subproject Under Main Project No. ______

Continues Project No. ______

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Managment	Y
Research Security Services	N
Reports Coordinator (OCA)	Y
GTRC	Y
Project File	Y
Other	N
	N

E20-612

To NSF Program: Earthquake Hazard Mitigation Program

Annual NSF Grant Progress Report

PI Name: Glenn J. Rix

NSF Award Number: BCS-9110173

PI Institution: Georgia Institute of Technology

PI Address: School of Civil Engineering
Atlanta, GA 30332-0355

Date: December 1, 1992

I certify that to the best of my knowledge (1) the statements herein (excluding scientific hypotheses and scientific opinions) are true and complete, and (2) the text and graphics in this report as well as any accompanying publications or other documents, unless otherwise indicated, are the original work of the signatories or individuals working under their supervision. I understand that the willful provision of false information or concealing a material fact in this report or any other communication submitted to NSF is a criminal offense (U.S. Code, Title 18, Section 1001.)

Signature: ______________________________

Please include the following information:
1. A brief summary of overall progress, including results obtained to date, their relationship to the general goals of the award and their significance to science;
2. an indication of any current problems or favorable or unusual developments;
3. a brief summary of work to be performed during the next year of support if changed from the original proposal; and
4. any other information pertinent to the type of project supported by NSF or as specified by the terms and conditions of the grant.

During the first year of the project, progress has been made on the following tasks that were outlined in the proposal.

Task 1 - Literature Review

The literature review is complete. Attention was focused on three aspects of tomography: (1) available algorithms for ray tracing in arbitrarily heterogeneous media, (2) algorithms available for backcalculation of velocity structure from travel time observations, and (3) applications of geotomography to geotechnical engineering including a review of strain-based approaches to liquefaction susceptibility analyses.

Task 2 - Algorithm Development and Equipment Fabrication

Following the literature review, two ray tracing algorithms were implemented, tested for accuracy, and compared for efficiency. The first algorithm is an algorithm developed by Langan et al., (1985). The soil mass is divided into cells that are characterized by a seismic velocity at the center of the cell and velocity gradients in the x and y directions. The use of gradients allows the soil mass to be accurately modeled by fewer cells than if constant velocity cells were used. Ray tracing begins by assigning a starting direction to a ray at the source. Within individual cells, the raypath becomes curved because of the velocity gradients. At cell boundaries, the ray is refracted according to Snell's law. Once the ray exits on the boundary of the grid, its position is compared with the location of the receiver. The starting direction of the ray is adjusted to improve the agreement between the exit position and the receiver location.

The algorithm produced accurate ray traces, but at high computational costs.

- There are numerous checks as the algorithm proceeds to assure accuracy. These checks reduce the algorithm's efficiency.
- Rays are traced individually. For a large number of source and receiver positions, the algorithm was inefficient.
- The algorithm failed to converge for several complex, heterogeneous soil profiles.

Because of these shortcomings, a second algorithm developed by Schneider et al (1992) was implemented. The algorithm is similar to a finite-difference scheme in that the arrival time of the wave at a particular node is calculated using the arrival times at surrounding nodes. In addition to producing accurate ray traces, the algorithm has several important advantages compared to others that were considered:

- For a given source location, arrival times at all of the receiver positions are simultaneously calculated
- The algorithm easily handles arbitrarily complex distributions of velocity.

A limitation of the algorithm is that it does not explicitly produce the ray path between the source and receiver.

Work is presently near completion on developing an tomographic inversion program using the Schneider et al (1992) ray tracing method as a basis. Several alternative solutions are being developed including algebraic reconstruction techniques (ART) and conjugate gradient methods.

Design and fabrication of source and receiver equipment is underway but is not complete.

Task 3 - Field Trials

A site on the Georgia Tech campus has been selected for field trials.

Task 4 - Testing at Charleston, SC area sites

Reconnaissance tests have been performed at six Charleston-area sites to locate one suitable for using seismic geotomography for liquefaction susceptibility site characterization. Surface wave tests were performed at the sites to complement the conventional SPT, CPT, and index tests performed by Martin and Clough (1991). Synthetic seismograms were obtained to allow site-specific responses to be calculated.

Summary

Progress on developing and implementing the algorithms for curved ray tracing in heterogeneous media and for inversion is proceeding as expected. With, the exception of performing a parametric study to assess the influence of cell size, velocity contrasts, etc., this phase of the project is nearly complete. Design and fabrication of the source and receivers is progressing more slowly than first envisioned. Because of delays encountered in this phase, I anticipate requesting a no-cost extension to allow work to proceed past the January 31. 1993 project termination date. Once the equipment is constructed, I expect that field testing at Georgia Tech and in Charleston, SC will proceed smoothly because of preliminary work already performed at those two sites.

References

Langan, R.T., Lerche, I., and Cutler, R.T., (1985), "Tracing of Rays Through Heterogeneous Media: An Accurate and Efficient Procedure," *Geophysics*, Vol. 50, pp. 1456-1465.

Martin,J.R.,II & Clough,G.W. (1990). Implications from a Geotechnical Investigation of Liquefaction Phenomena Associated with Seismic Events in the Charleston, SC Area. US Geological Survey Report, 414 pp.

Schneider, Jr., W.A., Razinger, K.A., Balch, A.H., and Kruse, C., (1992), "A Dynamic Programming Approach to First Arrival Traveltime Computation in Media with Arbitrarily Distributed Velocities," *Geophysics*, Vol. 57, No. 1, pp. 39-50.

Students Supported

A Master of Science student, Elizabeth Leipski, recently completed her thesis on the selection, implementation, and comparison of several ray tracing algorithms.

Papers Acknowledging NSF Support

Leipski, E.A., (1992), *Analytical Investigation of In Situ Seismic Methods*, Master of Science Thesis, Georgia Institute of Technology, 124 pp.

Rix, G.J., (1994), "*Site Characterization Using Seismic Geotomography,*" Abstract accepted for the Symposium on Dynamic Geotechnical Testing II, ASTM, Reno.

Rix, G.J., and Indridason, J., (1994), "*Liquefaction During the 1886 Charleston Earthquake*," Accepted for the XIII International Conference on Soil Mechanics and Foundation Engineering, New Delhi.

OMB Number 345-0058

NATIONAL SCIENCE FOUNDATION
1800 G STREET, NW
WASHINGTON, DC 20550

BULK RATE
POSTAGE & FEES PAID
National Science Foundation
Permit No. G-69

PI/PD Name and Address

Glenn J. Rix
School of Civil Engineering
GA Tech Res Corp - GIT
Atlanta GA 30332-0420

NATIONAL SCIENCE FOUNDATION FINAL PROJECT REPORT

PART I - PROJECT IDENTIFICATION INFORMATION

1. Program Official/Org. Clifford J. Astill - BCS
2. Program Name EARTHQUAKE HAZARD MITIGATION PROGRAM
3. Award Dates (MM/YY) From: 08/91 To: 01/94
4. Institution and Address

   GA Tech Res Corp - GIT
   Administration Building
   Atlanta GA 30332
5. Award Number 9110173
6. Project Title

   Site Characterization for Soil Liquefaction Susceptibility Using Geotomography

This Packet Contains
NSF Form 98A
And 1 Return Envelope

' Grant Conditions (Article 17, GC-1, and Article 9, FDP-11) require submission of a Final Project ort (NSF Form 98A) to the NSF program officer no later than 90 days alter the expiration of the rd. Final Project Reports for expired awards must be received before new awards can be made : Grants Policy Manual Section 677).

v, or on a separate page attached to this form, provide a summary of the completed projects and technical information. Be to include your name and award number on each separate page. See below for more instructions.

PART II - SUMMARY OF COMPLETED PROJECT (for public use)

ummary (about 200 words) must be self-contained and intelligible to a scientifically literate reader. Without restating the ct title, it should begin with a topic sentence stating the project's major thesis. The summary should include, if pertinent project being described, the following items:

primary objectives and scope of the project
techniques or approaches used only to the degree necessary for comprehension
findings and implications stated as concisely and informatively as possible

Please refer to the attached summary

PART III - TECHNICAL INFORMATION (for program management use)

eferences to publications resulting from this award and briefly describe primary data, samples, physical collections, tions, software, etc. created or gathered in the course of the research and, if appropriate, how they are being made available research community. Provide the NSF Invention Disclosure number for any invention.

Please refer to the attached information

y to the best of my knowledge (1) the statements herein (excluding scientific hypotheses and scientific opinion) are true and complete, and text and graphics in this report as well as any accompanying publications or other documents, unless otherwise indicated, are the original of the signatories or of individuals working under their supervision. I understand that willfully making a false statement or concealing a al fact in this report or any other communication submitted to NSF is a criminal offense (U.S. Code, Title 18, Section 1001).

	5/12/94
Principal Investigator/Project Director Signature	**Date**

IMPORTANT: MAILING INSTRUCTIONS
Return this *entire* packet plus all attachments ... envelope attached to the back of this form. Please copy the ... mation from Part I, Block I to the *Attention block* on the ...

NSF Form 98A (Rev. 2/92)

Principal Investigator:	Dr. Glenn J. Rix
NSF Award:	BCS-9110173
Period of Support:	August 15, 1991 to January 31, 1994
Title:	Research Initiation Award - Site Characterization for Liquefaction Susceptibility Using Seismic Geotomography
Amount:	$53,482

Part II - Summary of Completed Project

The specific objective of this project was to implement tomographic inversion algorithms based on curved (refracted) ray tracing for near-surface site characterization. The use of algorithms based on curved rays is particularly important for sites where large seismic velocity contrasts result in significant ray bending. A node-based scheme was selected to calculate travel times through an arbitrarily complex medium efficiently. This scheme was used as the basis of a conventional nonlinear least-squares inversion program. Obtaining solutions using the least-squares approach required significant computational effort because of the iterative nature of the calculations.

The use of artificial neural networks was explored as an alternative to conventional least-squares algorithms. An artificial neural network is a highly-interconnected collection of simple processing elements that can be trained to approximate a complex, nonlinear function through repeated exposure to examples of the function. In the context of tomographic inversion, a neural network can be trained to approximate the inverse function by repeatedly showing it forward problem solutions calculated using the node-based scheme mentioned earlier. The single most important advantage of using neural networks for backcalculation is speed. The neural networks trained in this study were several orders of magnitude faster than the conventional least-squares algorithm. A limitation of the neural network approach is that the borehole geometry and source-receiver positions must be selected prior to training the network. That same geometry and source-receiver positions must then be used in acquire experimental data if the network is to successfully invert the travel time data.

In a broader context, this study is an effort to make tomographic methods more "accessible" to engineers by reducing the complexity and increasing the robustness of the inversion step. Although this study was able to make progress in this area, tomographic methods still require significant experimental and computational effort.

Part III - Technical Information

The results of this study have been and will be disseminated through the following publications:

Leipski, E.A., (1992), Analytical Investigation of In Situ Seismic Methods, Master of Science Thesis, Georgia Institute of Technology, 124 pp.

Rix, G.J., (1994), "Tomographic Inversion Using Artificial Neural Networks," *Dynamic Geotechnical Testing II*, ASTM Special Technical Publication, Philadelphia.

Rix, G.J., (1994), "Tomographic Inversion Techniques for Near-Surface Site Characterization," Planned submission to the Journal of Geotechnical Engineering, ASCE.

PART IV -- FINAL PROJECT REPORT -- SUMMARY DATA ON PROJECT PERSONNEL

(To be submitted to cognizant Program Officer upon completion of project)

The data requested below are important for the development of a statistical profile on the personnel supported by Federal grants. The information on this part is solicited in resonse to Public Law 99-383 and 42 USC 1885C. All information provided will be treated as confidential and will be safeguarded in accordance with the provisions of the Privacy Act of 1974. You should submit a single copy of this part with each final project report. However, submission of the requested information is not mandatory and is not a precondition of future award(s). Check the "Decline to Provide Information" box below if you do not wish to provide the nformation.

Please enter the numbers of individuals supported under this grant.
Do not enter information for individuals working less than 40 hours in any calendar year.

	Senior Staff		Post-Doctorals		Graduate Students		Under-Graduates		Other Participants[1]	
	Male	Fem.	Male	Fem.	Male	Fem.	Male	Fem.	Male	Fem.
A. Total, U.S. Citizens	1				1	1				
B. Total, Permanent Residents										
U.S. Citizens or Permanent Residents[2]:										
American Indian or Alaskan Native										
Asian.										
Black, Not of Hispanic Origin.										
Hispanic										
Pacific Islander										
White, Not of Hispanic Origin										
C. Total, Other Non-U.S. Citizens										
Specify Country 1.										
2.										
3.										
D. Total, All participants (A + B + C)	1				1	1				
Disabled[3]										

☐ Decline to Provide Information: Check box if you do not wish to provide this information (you are still required to return this page along with Parts I-III).

[1] Category includes, for example, college and precollege teachers, conference and workshop participants.

[2] Use the category that best describes the ethnic/racial status fo all U.S. Citizens and Non-citizens with Permanent Residency. *(If more than one category applies, use the one category that most closely reflects the person's recognition in the community.)*

[3] A person having a physical or mental impairment that substantially limits one or more major life activities; who has a record of such impairment; or who is regarded as having such impairment. *(Disabled individuals also should be counted under the appropriate ethnic/racial group unless they are classified as "Other Non-U.S. Citizens.")*

AMERICAN INDIAN OR ALASKAN NATIVE: A person having origins in any of the original peoples of North America and who maintains cultural identification through tribal affiliation or community recognition.

ASIAN: A person having origins in any of the original peoples of East Asia, Southeast Asia or the Indian subcontinent. This area includes, for example, China, India, Indonesia, Japan, Korea and Vietnam.

BLACK, NOT OF HISPANIC ORIGIN: A person having origins in any of the black racial groups of Africa.

HISPANIC: A person of Mexican, Puerto Rican, Cuban, Central or South American or other Spanish culture or origin, regardless of race.

PACIFIC ISLANDER: A person having origins in any of the original peoples of Hawaii; the U.S. Pacific territories of Guam, American Samoa, and the Northern Marinas; the U.S. Trust Territory of Palau; the islands of Micronesia and Melanesia; or the Philippines.

WHITE, NOT OF HISPANIC ORIGIN: A person having origins in any of the original peoples of Europe, North Africa, or the Middle East.