GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[X] ORIGINAL [ ] REVISION NO. ______

Project No. E-20-638 (R5950-0A0) GTRC/~~GIT~~ DATE 6 / 24 / 85

Project Director: B. J. Goodno School/~~Lab~~ CE

Sponsor: National Science Foundation

Type Agreement: Grant ECE-8412140

Award Period: From 7/1/85 To ~~1/31/87*~~ 6-30-87 (Performance) 4/30/87 (Reports)

Sponsor Amount: This Change / Total to Date

Estimated: $ ______ $ 144,599

Funded: $ ______ $ 144,599**

Cost Sharing Amount: $ 3,615 Cost Sharing No: E-20-389

Title: Dynamic Behavior of Precase Cladding and Connections

ADMINISTRATIVE DATA OCA Contact John Schonk x4820

1) Sponsor Technical Contact:

Andrew J. Eggenberger
National Science Foundation
ENG/CEE
Washington, DC 20550

202/357-9500

2) Sponsor Admin/Contractual Matters:

Winston S. Sherman
National Science Foundation
DGC/ENG
Washington, DC 20550

202/357-9626

Defense Priority Rating: N/A Military Security Classification: N/A

(or) Company/Industrial Proprietary: N/A

RESTRICTIONS

See Attached NSF Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval — Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with GIT

COMMENTS:

No funds may be expended after 1/31/87.

*THIS Award includes a 6 month unfunded flexibility period.

**Total funds allocated as follows: E-20-638 - $63,434, E-16-A01 - $81,165.

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Project Director
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Reports Coordinator (OCA)

GTRC
Library
Project File

GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 1/27/88

Project No. E-20-638 School/Lab CE

Includes Subproject No.(s) E-16-A01 / Craig/ Goodno

Project Director(s) Goodno/Craig GTRC / GIT

Sponsor NSF

Title Structural Behavior of Precast Cladding & Connections Phase I

Effective Completion Date: 6/30/87 (Performance) 6/30/87 (Reports)

Grant/Contract Closeout Actions Remaining:

- [x] None
- [ ] Final Invoice or Final Fiscal Report
- [ ] Closing Documents
- [ ] Final Report of Inventions
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other

Continues Project No. Continued by Project No.

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Reports Coordinator (OCA)
Legal Services

Library
GTRC
Research Communications (2)
Project File
Other Duane Hutchison
Angela DuBose
Russ Embry

APPENDIX VI

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

FINAL PROJECT REPORT
NSF FORM 98A

PLEASE READ INSTRUCTIONS ON REVERSE BEFORE COMPLETING

PART I—PROJECT IDENTIFICATION INFORMATION

1. Institution and Address	2. NSF Program	3. NSF Award Number
School of Civil Engineering Georgia Institute of Technology Atlanta, Georgia 30332-0355	Earthquake Hazards Mitig. 4. Award Period From July'85 To June'87	ECE-8412140 5. Cumulative Award Amount $144,599

6. Project Title

Structural Behavior of Precast Cladding and Connections - Phase I

PART II—SUMMARY OF COMPLETED PROJECT *(FOR PUBLIC USE)*

The behavior of heavy precast concrete cladding panels and connections was investigated in a program of analytical and experimental studies. Several panel attachment systems representative of those actually used for the exterior facades of modern highrise buildings were considered in the research program. Past studies have shown that heavy cladding is not nonstructural as is typically assumed but rather provides lateral stiffness to the structure which should be accounted for in design of the overall structure for lateral forces and in the design of the cladding connections. The principal aim of the investigation was to determine the stiffness, energy dissipation and ductility properties of attachment systems for architectural panels on buildings.

In the experimental program, twenty four 4 ft x 4 ft x 6 inch concrete specimens containing the cladding connection inserts typical of Southeastern U.S. construction were fabricated by a local precast manufacturer and tested in the laboratory under varying combinations of pull-out, in plane shear and moment loadings. Both slotted wedge insert and weld plate connections were examined. Three additional test specimens were prepared using ductile rod connections typical of West Coast practice and all specimens were tested to failure. On the basis of these test results, previously developed analytical models for cladding were refined to include the observed behavior of the panel connections. In particular, superelement models of the panels and connections were assembled to study the force levels experienced by the connections under actual earthquake ground motion input and the lateral stiffness capabilities of the panel-connection system.

Principal findings of the study are: (1) actual performance data is now available for sample connections; (2) analytical models for cladding have been improved on the basis of laboratory test results; and (3) the groundwork has been laid for reevaluation of present design procedures for architectural cladding and connections.

PART III—TECHNICAL INFORMATION *(FOR PROGRAM MANAGEMENT USES)*

1. ITEM *(Check appropriate blocks)*	NONE	ATTACHED	PREVIOUSLY FURNISHED	TO BE FURNISHED SEPARATELY TO PROGRAM: Check (✓)	Approx. Date
a. Abstracts of Theses		X			
b. Publication Citations		X			
c. Data on Scientific Collaborators		X			
d. Information on Inventions		X			
e. Technical Description of Project and Results		X			
f. Other *(specify)*		X			

2. Principal Investigator/Project Director Name *(Typed)*	3. Principal Investigator/Project Director Signature	4. Date
Barry J. Goodno	[signature]	Dec. 23,'87

PART IV - SUMMARY DATA ON PROJECT PERSONNEL

NSF Division Engineering-Earthquake Hazard Mitigation

The data requested below will be used to develop a statistical profile on the personnel supported through NSF grants. The information on this part is solicited under the authority of the National Science Foundation Act of 1950, as amended. All information provided will be treated as confidential and will be safeguarded in accordance with the provisions of the Privacy Act of 1974. NSF requires that a single copy of this part be submitted with each Final Project Report (NSF Form 98A); however, submission of the requested information is not mandatory and is not a precondition of future awards. If you do not wish to submit this information, please check this box ☐

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

*U.S. Citizens/ Permanent Visa	PI's/PD's		Post-doctorals		Graduate Students		Under-graduates		Precollege Teachers		Others	
	Male	Fem.	Male	Fem.	Male	Fem.	Male	Fem.	Male	Fem.	Male	Fem.
American Indian or Alaskan Native												
Asian or Pacific Islander			1		1							
Black, Not of Hispanic Origin					1							
Hispanic												
White, Not of Hispanic Origin	2				1	1						
Total U.S. Citizens	2				1							
Non U.S. Citizens			1		2	1						
Total U.S. & Non-U.S. ..	2		1		3	1						
Number of individuals who have a handicap that limits a major life activity.												

*Use the category that best describes person's ethnic/racial status. (If more than one category applies, use the one category that most closely reflects the person's recognition in the community.)

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 OR PACIFIC ISLANDER: A person having origins in any of the original peoples of the Far East, Southeast Asia, the Indian subcontinent, or the Pacific Islands. This area includes, for example, China, India, Japan, Korea, the Philippine Islands and Samoa.

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.

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

THIS PART WILL BE PHYSICALLY SEPARATED FROM THE FINAL PROJECT REPORT AND USED AS A COMPUTER SOURCE DOCUMENT. DO NOT DUPLICATE IT ON THE REVERSE OF ANY OTHER PART OF THE FINAL REPORT.

FINAL PROJECT REPORT

NSF Award No. ECE-8412140
"Structural Behavior of Precast Cladding and Connections - Phase I"
July 1985 - June 1987

Professors Barry J. Goodno and James I. Craig
Co-Principal Investigators
Georgia Institute of Technology
Atlanta, Georgia 30332

PART III - TECHNICAL INFORMATION

a. <u>Abstracts of Theses</u>

The following MSCE Special Problem Reports describe research performed under this grant. Abstracts of reports 1-3 are attached; reports 4 and 5 are expected to be completed by March 1988 and report 6 by June 1988. Nos. 7 and 8 are Ph.D. research projects currently underway which have contributed to research activity on the grant, but which are not expected to be completed until Spring 1989.

\# 1) Mark C. Streit, Fall, 1985, "An Analytical Model for the Seismic Response Analysis of Low Rise Buildings Using Micro-computers" (MSCE)

\# 2) Luis R. Hasbun-Flamenco, Spring 1986, "The Effects of Soil-Structure Interaction in the Design of Low Rise Buildings" (MSCE)

\# 3) Jack A. Diamond, Fall 1987, "A Plane Frame Static and Dynamic Analysis Preprocessor Using AutoCAD" (MSCE)

4) Ralf Leistikow, (in progress), "Experimental Evaluation of Ductile Rod Connections for Heavy Cladding in Seismic Zones" (MSCE)

5) Satish Nagarajaiah, (in progress), "A Superelement Model for Precast Concrete Cladding" (MSCE)

6) George P. Wheatley, (in progress), "Use of Masonry and Stone Veneers for Heavy Claddings in Seismic Zones" (MSCE)

7) Shatha K. Naman, (Ph.D., in progress), "Analysis of Heavy Cladding on Buildings During Strong Ground Motion"

8) Clarence J. Fennell, (Ph.D., in progress), "Experimental Evaluation of Connections for Heavy Cladding Systems"

\# = publication relevant but only indirectly related to research project

b. **<u>Publication Citations</u>**

1. Goodno, B.J., and Craig, J.I., "Research Needs Related to Cladding and Nonstructural Components," Invited Presentation, presented by B. Goodno at the Structural Engineering Congress '85, ASCE Structural Division, held in Chicago, Illinois, on September 16-18, 1985.

\# 2. Goodno, B.J., "Structural Analysis Applications on Microcomputers," <u>Proceedings</u>, The 3rd National Conference on Microcomputers in Civil Engineering, held in Orlando, Florida, on November 4-6, 1985, pp. 1-6.

3. Goodno, B.J., "Cladding-Structure Interaction," Invited Presentation, Workshop on Cladding, Committee No. 12A, at the Third International Conference on Tall Buildings, held in Chicago, Ill., on January 6-10, 1986.

4. Goodno, B.J., "Earthquake Engineering Research at Georgia Tech," presentation at the Workshop of the Technology Transfer and Development Council, Southeastern U.S. Seismic Safety Consortium, held at The Citadel on January 16-17, 1986.

\# 5. Naman, S.K., and Goodno, B.J., "Seismic Evaluation of a Low Rise Steel Building," <u>Engineering Structures</u>, Vol. 8, No. 1, January 1986, pp. 9-16.

6. Goodno, B.J., and Naman, S., "Drift Criteria: Influence of Nonstructural Elements," <u>High-Rise Buildings: Recent Progress</u>, Council on Tall Buildings and Urban Habitat, IABSE-ASCE-AIA-APA-IUA, Lehigh University, Bethlehem, Pa., 1986, pp. 131-138.

7. Craig, J.I., Goodno, B.J., Keister, M.J., and Fennell, C.J., "Hysteretic Behavior of Precast Cladding Connections," <u>Proceedings</u>, Third ASCE Engineering Mechanics Specialty Conference on Dynamic Response of Structures, held at UCLA on March 31-April 2, 1986, pp. 817-826.

8. Goodno, B.J., and Palsson, H., "Analytical Studies of Building Cladding," <u>Journal of Structural Engineering</u>, ASCE, Vol. 112, No. 4, Paper 20498, April 1986, pp. 665-676.

9. Goodno, B.J., and Pinelli, J.P., "The Role of Cladding in Seismic Response of Lowrise Buildings in the Southeastern U.S.," <u>Proceedings</u>, The Third U.S. National Conference on Earthquake Engineering, held in Charleston, S.C., on August 24-28, 1986, Vol. II, pp. 883-894.

\# 10. Goodno, B.J., and Naman, S.K., "Earthquake Analysis of Lowrise Buildings in Zones of Moderate Seismicity," <u>Proceedings</u>, Eighth European Conference on Earthquake Engineering, held in Lisbon, Portugal, on September 7-12, 1986, Vol. 8, pp. 79-86.

11. Goodno, B.J., "Cladding-Structure Interaction: The State of the Art,"

Invited Presentation, 1986 ASCE Structures Congress, held in New Orleans, La., Sept. 15-18, 1986 (see Structures Congress '86 Abstracts, ASCE, p. 271).

\# 12. Goodno, B.J., "Static and Dynamic Analysis of Highrise Buildings on Microcomputers," Proceedings, Fourth Conference on Computing in Civil Engineering, ASCE, held in Boston, MA, October 27-31, 1986, pp. 300-315.

\# 13. Goodno, B. J., and Streit, M. C., "Seismic Response Analysis of Low Rise Buildings Using Microcomputers," Proceedings, The 4th National Conference on Microcomputers in Civil Engineering, held in Orlando, Florida, on November 5-7, 1986, pp. 262-266.

14. Goodno, B.J., "Static and Dynamic Analysis of Highrise Buildings on Microcomputers," ICES Journal, ICES User's Group, Cranston, Rhode Island, Vol. XVIII, Issue No. 2, November 1986, pp. 50-66.

\# 15. Goodno, B.J., and Streit, M. C., "Dynamic Analysis of Low Rise Buildings on Microcomputers," Microcomputers in Civil Engineering, Elsevier Science Publishing Co., New York, Vol. 2, Number 1, March 1987, pp. 39-46.

16. Goodno, B. J., "Effect of Non-Structural Elements on Earthquake Response of Buildings - Theoretical Aspects," to be presented at the Conference on Tall Buildings in Seismic Regions sponsored by the Council on Tall Buildings and Urban Habitat, in Los Angeles, California, on February 25-26, 1988.

17. Craig, J. I., "Effect of Non-Structural Elements on Earthquake Response of Buildings - Experimental Aspects," to be presented at the Conference on Tall Buildings in Seismic Regions sponsored by the Council on Tall Buildings and Urban Habitat, in Los Angeles, California, on February 25-26, 1988.

18. Craig, J. I., and Goodno, B. J., "Cladding-Structure Interaction: Modeling and Performance of Connections," to be presented by J. I. Craig at the ACI Annual Convention, Session on Design, Fabrication and Erection of Precast Wall Panels, Committee 533 (Precast Panels), in Orlando, Florida, on March 25, 1988.

19. Meyyappa, M., Goodno, B. J., and Fennell, C. J., "Modeling and Performance of Precast Cladding Connections," to appear in the Proceedings of The ASCE Specialty Conference on Computing in Civil Engineering, to be held in Washington, D. C. on March 29-31, 1988 (10 pages).

20. Goodno, B. J., Meyyappa, M., Nagarajaiah, S., and Naman, S., "A Refined Model for Precast Cladding and Connections," abstract submitted for review in June 1987 for the 9th World Conference on Earthquake Engineering, to be held in Tokyo, Japan on August 2-9, 1988.

21. Palsson, H., and Goodno, B. J., "Influence of Interstory Drift on Cladding Panels and Connections," abstract submitted for review in June 1987 for the 9th World Conference on Earthquake Engineering, to be held in Tokyo, Japan on August 2-9, 1988.

22. Craig, J. I., Fennell, C. J., and Leistikow, R., "Experimental Studies of the Performance of Precast Cladding Connections," abstract submitted for review in June 1987 for the 9th World Conference on Earthquake Engineering, to be held in Tokyo, Japan on August 2-9, 1988.

23. Palsson, H., and Goodno, B. J., "Localized Response of Cladding to Interstory Drift," submitted for review for possible publication in Journal of Structural Engineering, ASCE.

= publication relevant but only indirectly related to research project

c. Data on Scientific Collaborators

1. Dr. Barry J. Goodno, Professor, School of Civil Engineering, Georgia Institute of Technology, Co-Principal Investigator, Project Director

2. Dr. James I. Craig, Professor, School of Aerospace Engineering, Georgia Institute of Technology, Co-Principal Investigator

3. Dr. Murugappan Meyyappa, Research Engineer, School of Aerospace Engineering

4. Ms. Shatha K. Naman, Graduate Research Assistant, School of Civil Engineering (Ph.D. candidate)

5. Mr. Clarence J. Fennell, Graduate Research Assistant, School of Civil Engineering (Ph.D. candidate)

6. Mr. Ralf Leistikow, Graduate Research Assistant, School of Civil Engineering

7. Mr. Satish Nagarajaiah, Graduate Research Assistant, School of Civil Engineering

8. Mr. George P. Wheatley, Graduate Research Assistant, School of Civil Engineering

9. Mr. Ralph L. Shaw, Graduate Research Assistant, School of Civil Engineering

d. <u>Information on Inventions</u>

None

e. <u>Technical Description of Project and Results</u>

A technical description of the research project and results to date is presented in the above publications (see Section b. above) and in two proposals for follow-on and related research:

1. "Behavior of Architectural Nonstructural Components in the Mexico Earthquake," National Science Foundation, Earthquake Hazards Mitigation, Grant ECE-8610929, June 1986 to May 1988.

2. "Performance of Heavy Cladding Systems in the Whittier Narrows Earthquake," National Science Foundation, Earthquake Hazards Mitigation, submitted November 25, 1987 (currently under review)

f. <u>Other</u>

None

AN ANALYTICAL MODEL FOR THE SEISMIC RESPONSE ANALYSIS OF LOW RISE BUILDINGS USING MICROCOMPUTERS

A SPECIAL RESEARCH PROBLEM
Presented to

The Faculty of the School of Civil Engineering

by

Mark C. Streit

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Civil Engineering

Georgia Institute of Technology

December 1985

ABSTRACT

As the efficiency and capability of the microcomputer increases, so does the scope of its application in structural engineering computation. One particular application, structural dynamic analysis, has inherently required efficient memory usage and computational algortihms due to the large arrays and tedious numerical computation involved. A coarse breakdown illustrating some of the computations involved would consist of: dynamic matrix formulation, solution of an algebraic eigenvalue problem, coordinate transformations and numerical solution for time history dynamic response which may include displacements, velocities, accelerations, and force resultants.

The primary focus of this special research was to develop a computer program to be implemented on a microcomputer to effectively model low-rise steel-framed buildings and calculate their seismic response to earthquake excitation. This class of buildings, one to five stories in height, was modelled considering both rigid and flexible floor diaphragm action. An assemblage of two dimensional frames and/or trusses was employed to develop the stiffness properties of a building model. Inertia properties were user- specified and were processed within the program to account for any required translation of axes. A dynamic analysis was performed to compute the response time history of the system subjected to seismic excitation in the form of applied ground accelerations. Using the resulting displacement response, the forces at the dynamic degrees of freedom were determined and a vector of maximum lateral forces computed for each frame. The computed results were compared against those obtained using a program based on the response spectrum method (RSPECB). The response spectrum method is a more approximate, although more widely used method of analysis.

To provide a realistic test model, a low-rise steel framed office building in the Atlanta area was selected for evaluation. The selected building was used in a response spectrum analysis conducted by a previous researcher. A comparison was made between the two analytical methods, namely modal analysis and response spectrum analysis. The modelling procedures, assumptions, and program implementation are discussed in this report. Information on microcomputer compilation and execution along with a discussion of the limitations of the program are also included.

THE EFFECTS OF SOIL-STRUCTURE INTERACTION IN THE DESIGN OF LOW-RISE BUILDINGS

A Special Research Problem

Presented to

The Faculty of the School of Civil Engineering

By

Luis R. Hasbun Flamenco

In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Civil Engineering

Georgia Institute of Technology

March 1986

Approved:

____
Dr. Barry Goodno, Faculty Advisor

____
Dr. Richard Barksdale
Member of Reading Committee

Abstract

The majority of structures designed for earthquake resistance are analyzed under the assumption that they rest on a nonyielding base such as bedrock. In reality only a small percentage of structures rest on bedrock. Past research has shown that for a given earthquake, ground accelerations on flexible soil are different from those recorded on bedrock. An increase or decrease in response will result due to the influence of the dynamic properties of the flexible ground. By considering the dynamic characteristics of soil, a more realistic model of the entire system can be developed for analysis and design.

The objective of this research was to study the effects of soil-structure interaction in seismic regions. Currently various building codes consider such effects. The main code in use in seismic regions of the U.S. is UBC-85. The tentative provisions of ATC-3-06 also address flexible foundation effects and may form the basis of future seismic provisions in U.S. codes. One of the methods presented by these codes is the equivalent static load approach to seismic loading. A more exact method is response spectrum analysis. This pseudo-dynamic analysis method allows rocking and horizontal translation of the foundation to be considered. The equivalent static load methods of UBC-85 and ATC-3-06 will be compared in this report with response spectrum analysis using a low rise steel frame building as a case study. The sensitivity of the structure behavior to different soil conditions will be evaluated. Recommendations will be made on the use of soil-structure interaction in seismic response investigations and will conclude the research.

A PLANE FRAME STATIC AND DYNAMIC ANALYSIS PREPROCESSOR USING AUTOCAD

A Special Research Problem

Presented to

The Faculty of The School of Civil Engineering

by

Jack Alan Diamond

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Civil Engineering

Georgia Institute of Technology

December 1987

Approved:

29 Oct. 87

Dr. Barry J. Goodno, Faculty Advisor

26 Oct. 87

Dr. Lawrence F. Kahn, Member of Reading Committee

A PLANE FRAME STATIC AND DYNAMIC ANALYSIS
PREPROCESSOR USING AutoCAD

ABSTRACT

The proper use of graphical pre and postprocessing software for structural analysis applications on microcomputers can save a significant amount of engineering time. The focus of this research was to develop an improved graphical preprocessor for plane frame analysis using AutoCAD and to add the option of preparing data for dynamic analysis, as well. The resulting preprocessor creates a structural model subjected to either static or dynamic loads with the capability of handling a variety of different load cases.

First, the needs of a structural engineer to create a plane frame structural analysis input file graphically are described. Then, the current graphical preprocessors for plane frame analysis as reported in literature are reviewed. Next, the reasons for using AutoCAD, along with the information on how data is extracted from an AutoCAD drawing file are explained, followed by a discussion on creating the final input file for the analysis program. The procedure for using the preprocessor is illustrated with a simple static analysis example. Finally, several more complex examples, including a dynamics problem, are presented for verification of the preprocessor software.

Several suggestions are made to guide potential follow-on developers of the software, particularly those concerned with options for postprocessing of the analysis and design results. Finally, principal conclusions of this research are presented,

along with several recommendations for further study.