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U.S. - JAPAN COORDINATED PROGRAM
FOR
MASONRY BUILDING RESEARCH

REPORT NO. 11.1-2

PB93-214740

SUMMARY REPORT: U.S. COORDINATED PROGRAM FOR MASONRY BUILDING RESEARCH

submitted by

TECHNICAL COORDINATING COMMITTEE
FOR MASONRY RRESEARCH

NOVEMBER 1988

Conducted under the auspices of:
The UJNR Panel on Wind & Seismic Effects

Funded by The National Science Foundation

This report presents the results of a research project which was part of the U.S. Coordinated Program for Masonry Building Research. The program constitutes the United States part of the United States - Japan Coordinated Masonry Research Program conducted under the auspices of the Panel on Wind and Seismic Effects of the U.S.-Japan Natural Resources Development Program (UJNR).

This material is based on work supported by the National Science Foundation under the direction of Program Director, Dr. S.C. Liu.

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U.S. Coordinated Program for Masonry Building Research

Executive Summary

The U.S. Coordinated Program for Masonry Building Research is a comprehensive program of research into the structural aspects of reinforced masonry. It addresses the needs of the United States for improved technology applicable to the design and construction of reinforced masonry buildings. Improved masonry structural technology is expected to enable masonry buildings to become a more viable alternative to steel and concrete buildings, hence stimulate competition and foster reduced building costs. It is expected to stimulate engineering education in structural masonry because of the availability of a more cohesive and well-founded limit state design methodology. It is expected to contribute to the competitive position of the country in two ways: 1) by providing structurally adequate buildings at less cost, thus reducing overhead costs for other industries, and 2) by providing the U.S. construction industry with a superior product to market elsewhere.

Because materials are often locally available, extensive or sophisticated construction equipment is not mandatory, and forming is not required, masonry construction is possible in most parts of the world and constitutes a significant portion of world building inventories. However, masonry design and construction technology has not kept pace with that developed for buildings of other materials, e.g., steel and concrete. This is especially of concern for construction in seismically active locations.

Existing design codes and design methods are a mixture of empirical rules and linear-elastic working stress methods neither of which is satisfactory for designing reinforced masonry buildings with the proper level of ductility and strength for seismic and other conditions.

While reinforced masonry buildings have generally performed satisfactorily in previous earthquakes, the present state of reinforced masonry building design and analysis methods is not adequate to predict seismic response and safety. Much additional information and work is required to support the development of a limit state design methodology and analytical procedures which are necessary to bring masonry structural technology up to a level compatible with steel and concrete structural technology.

With NSF support, the Technical Coordinating Committee for Masonry Research (TCCMAR) was formed in February 1984 for the purpose of defining and performing both analytical and experimental research and development necessary to improve masonry structural technology. The research tasks are listed below:

Preliminary Material Studies
Material Models - Concrete Masonry
Material Models - Brick Masonry

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Dynamic Response Models of Masonry Systems
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Full Scale Test

Design Recommendations and Criteria Development

Coordination

TCCMAR was and is aware that the research tasks initially defined address critical issues and further that the need for task modification and the addition of other research tasks may be required in the future.

A systems approach is being taken to execute the research, i.e., the individual research tasks are time-phased and coordinated to avoid duplication of effort and to provide information when it is needed for continuing activities. The project has a strong interface with the masonry industry (producers, builders, and developers, code bodies). Its direction and procedures are reviewed by a panel of outside experts.

Work began on the initially scheduled research tasks in September - October of 1985 except for a special-purpose task "Preliminary Material Studies" which was completed in September 1985. The complete program is scheduled for completion by Jan 1993.

The masonry industry has agreed to supply, at no cost, the masonry units needed for experimental specimens. Industry has arranged for the fabrication of all two-story specimens under in-plane loadings and slender walls under out-of-plane loadings for several of the research tasks. Discussions have begun with the industry and will continue regarding fabrication, at no cost, of the larger experimental specimens which will be needed.

There have been and will continue to be a limited number of exchanges of U.S. and Japanese researchers as well as the annual joint meeting of the research teams from both countries.

1.0 INTRODUCTION

The U.S. Coordinated Program for Masonry Building Research is a comprehensive program of research into the structural aspects of reinforced masonry. It addresses the needs of the United States for improved technology applicable to the design and construction of reinforced masonry buildings of various sizes and in different regions of the U.S. Improved masonry structural technology is expected to make masonry buildings a more viable alternative to concrete and steel buildings, and thus stimulate competition and foster lower building costs.

The U.S. Coordinated Program for Masonry Building Research is the U.S. part of the third in a series of joint U.S.-Japan research programs conducted under the auspices of the UJNR Panel on Wind and Seismic Effects. The objectives of the panel are:

1) To encourage, develop, and implement the exchange of wind and seismic technology (including data, information, measurement and test facilities and equipment, and researchers) between appropriate United States and Japanese organizations.

2) To develop strong technical links between scientific and engineering researchers of the government, industrial and academic organizations from the two countries and encourage exchanges of guest researchers.

3) To conduct joint research in areas of strong winds, earthquakes and related phenomena. To publish findings from joint research efforts and distribute proceedings of annual joint meetings.

4) To conduct cooperative programs to improve engineering design and construction practices and other wind and earthquake hazard mitigation practices.

The U.S.-Japan Coordinated Program for Masonry Building Research was designed to meet these objectives with respect to the design and construction of reinforced masonry buildings for seismic conditions.

The U.S. part of the joint U.S.-Japan effort is a comprehensive program of masonry research designed to meet this country's needs and is based upon U.S. materials and construction practices. However, there are many fundamental issues which are common to both the U.S. and Japanese programs. Resolution of those common issues is the primary objective of the U.S.-Japan coordination. As is the case for the U.S., the Japanese program specifically addresses that country's needs and is based upon Japanese materials and construction practices.

2.0 BACKGROUND

2.1 Current Status of Masonry Structures Design in the U.S. -- Masonry buildings are essentially box structures in which the walls resist vertical and lateral loads, subdivide space and serve as the architectural surface. They are often economically competitive for low-rise buildings and for mid-rise buildings with repeated floor plans. Because materials are often locally available, extensive or sophisticated construction equipment is not mandatory, and forming is not required, masonry construction is possible in most parts of the world and constitutes a significant portion of world building inventories.

Masonry design and construction technology has not kept pace with that developed for buildings of other materials, e.g., steel and concrete. This is especially of concern for construction in seismically active locations.

Existing design codes (Ref. 1) and design methods (Ref. 2) are a mixture of empirical rules and linear-elastic working stress methods, neither of which is satisfactory for designing reinforced masonry buildings with the proper level of ductility and strength for seismic conditions. A new masonry building code developed by a joint committee of the ASCE and ACI is also a mixture of empirical rules and linear-elastic working stress methods. It should be noted that the UBC (Ref. 1) does contain a limited set of limit state provisions for reinforced masonry slender walls.

While reinforced masonry buildings have generally performed satisfactorily in previous earthquakes, the present state of reinforced masonry building design and analysis methods is not adequate to predict seismic response and safety. In the U.S. and elsewhere a significant amount of research has been done in the past decade or so (Ref. 3, 4, 5, 6, 7) with much of it supported by the National Science Foundation. While the research has produced much potentially useful information, much additional information and work is required. This is needed to support the development of a limit state design methodology and analytical procedures which are necessary to bring masonry structural technology up to a level compatible with steel and concrete structural technology and to provide for improved public safety. This need has been recognized by the UJNR Panel on Wind and Seismic Effects (Ref. 8).

2.2 **Technical Coordinating Committee for Masonry Research** -- With NSF support, TCCMAR was formed in February 1984. TCCMAR was and is comprised of researchers from academic and industrial organizations who have strong backgrounds in research into the properties and characteristics of reinforced masonry materials, structural components and systems, analytical techniques, structural dynamics, building codes, and earthquake engineering. TCCMAR was not intended to be a closed group; researchers may be added as needs develop. Current TCCMAR researchers are listed in Table 1.

TABLE 1

TCCMAR RESEARCHERS

Daniel Abrams 3148 Newmark Laboratory Dept. of Civil Eng. Univ. of IL 205 N. Mathews St. Urbana, IL 61801 217-333-0565	Samy Adham Agbabian Associates 250 N. Nash El Segundo, CA 90245 213-640-0576	Richard Atkinson Atkinson-Noland & Assoc. 2619 Spruce St. Boulder, CO 80302 303-444-3620
Russell Brown Civil Engineering Dept. Clemson University Clemson, SC 29631 803-656-3000 ex 3314	Robert Englekirk Englekirk & Hart 2116 Arlington Ave. Los Angeles, CA 90018-1397 213-733-2640	Robert Ewing Ewing & Assoc., Inc. 28907 Doverridge Dr. Rancho Palos Verdes, CA 90274 213-541-3795
Ahmad Hamid Department of Civil Eng. Drexel University Philadelphia, PA 19104 215-895-2342	Harry Harris Department of Civil Eng. Drexel University Philadelphia, PA 19104 215-895-2364	Gary Hart Englekirk & Hart 2116 Arlington Ave. Los Angeles, CA 90018-1397 UCLA-213-825-1377 E&H -213-733-2640
Gilbert Hegemier Dept. of AMES, R011 Univ. of Calif.-San Diego La Jolla, CA 92093 619-534-4280	Albin W. Johnson S. B. Barnes & Assoc. 2236 Beverly Blvd. Los Angeles, CA 90057 213-382-2385	John Kariotis Kariotis & Associates 711 Mission St. #D South Pasadena, CA 91030 213-682-2871
Richard Klingner Phil Ferguson Eng. Lab University of Texas-Austin 10100 Burnet Road Austin,TX 78758-4497 Lab-512-471-3062/4577 UT-512-471-7259	Ronald Mayes Computech Engin. Services 2855 Telegraph Ave. #410 Berkeley, CA 94705 415-843-3576	James L. Noland Atkinson-Noland & Assoc. 2619 Spruce St. Boulder, CO 80302 303-444-3620
Max Porter Dept. of Civil Engineering 416A Town Eng. Bldg.ISU Ames, IA 50011 515-294-7456	M.J.N. Priestley Dept. of AMES, Mail Code R011 Univ. of Calif.-San Diego La Jolla, CA 92093 619-534-5951	Frieder Seible Dept of Ames, R011 Eng. Bldg., Unit 1 Room 2808 Univ. of Calif.-San Diego La Jolla, CA 92093 619-534-4640
P.B. Shing University of Colorado Dept. of CEAE, Box 428 Boulder, CO 80309 303-492-8026	Bjorn Sveinsson Computech Engin. Service 2855 Telegraph Ave. #410 Berkeley, CA 94705 415-843-3576	Leonard Tulin University of Colorado Dept. CEAE, Box 428 Boulder, CO 80309 303-492-7994

The initial TCCMAR purposes were 1) to specifically define the research topics, both experimental and analytical, necessary to develop a consistent masonry structural technology for the U.S. and 2) to establish communication with its Japanese counterpart to enable Japanese and U.S. programs to be coordinated for the benefit of both.

TCCMAR-U.S. met in February 1984 and succeeded in identifying the research to be done and established the scope of an integrated program of many specific topics for the U.S. effort. It was recognized by the committee that such a program could not provide all the answers which ultimately should be provided, but would develop a basic body of knowledge and framework for future development.

Four members of TCCMAR-U.S. plus the U.S. chairmen of the UJNR Committee on Large-Scale Testing and Repair and Retrofit of Existing Structures met with the Japanese team in March 1984 to discuss masonry research and to conduct preliminary discussions on U.S.-Japan masonry research coordination. The results of the meeting are summarized in the resolutions (Ref 9). Both sides reaffirmed the need for masonry structural research and that benefits could be obtained through coordinated programs. Subsequently, at the meeting of the UJNR Committee on Large-Scale Testing held in May 1984 it was resolved that a coordinated masonry research program be carried out under the auspices of the UJNR Panel on Wind and Seismic Effects (Ref. 10). A TCCMAR member has attended each meeting of the UJNR Panel on Wind and Seismic Effects since May 1986 to keep the Panel informed of program progress, receive comments and participate in task group meetings.

Program evaluation and research needs assessment are continuing activities of TCCMAR. The original plan is not a static entity but rather one which can and has been modified as work has progressed and needs either revised or added. for example, since work began in Fall 1985, Tasks[1] 2.4(a), 2.4(b), 3.1(c), 4.1 and 7.1 have been added to the program and researchers R. Klingner (University of Texas-Austin), M.J.N. Priestley (University of California-San Diego) and Daniel Abrams (University of Illinois-Urbana) have become members of TCCMAR.

3.0 U.S. RESEARCH PLAN

3.1 **Research Approach** -- Although a great amount of masonry research information exists in the U.S. (Ref. 3, 4, 5, 6, 7) and elsewhere, much of it is difficult to compare because of differences in test procedures, instrumentation used, data recorded, analyses performed, presentations of results and so on. The research was usually initiated by individuals with varying interests and generally not coordinated in a formal manner with other research. Hence, research has tended to produce an uneven distribution of information with some areas having received more emphasis than others. Effective utilization of research results has been inhibited and comprehensive design method and code development rendered difficult because of this situation.

The U.S. plan, therefore, consists of a phased step-by-step program of separate, but coordinated research tasks. Emphasis is being placed upon intra-task information exchange, the effectiveness of which is enhanced by use of common materials and test procedures to the extent possible. It is expected that

1. Task descriptions are in Table 4 (Section 3.4)

this approach will improve the consistency of data collected and assure that all the data required for component and system modeling, and design method development is obtained. Transfer of data among the researchers thus allows results of separate tasks to be utilized in others, i.e., the U.S. plan is a "building block" procedure.

The research tasks which have been defined include experimental efforts to evaluate masonry materials behavior, reduced-scale building systems behavior, component behavior, and finally, full-scale masonry, i.e., building behavior. The mathematical modeling tasks address, in progressive levels of sophistication, material behavior, behavior of sample masonry test coupons, component behavior and full-scale masonry system behavior. Existing information and procedures, both analytical and experimental are being reviewed and utilized to the extent possible consistent with program objectives. The final tasks, development of design recommendations and building criteria, include development of masonry system analytical approaches suitable for use by practicing engineers and architects. The research program as defined, although extensive, will not provide all the information on all details regarding masonry building design and analysis. It is expected and intended, however, that program results will support substantial design code change as well as provide a consistent limit-state design methodology and basic cohesive design information.

The U.S. program is being conducted on a project basis to provide the task and schedule coordination required for efficient and orderly conduct of the program. The organization structure of the project is shown in Figure 1. The research tasks are described in the following section. Research tasks are and will be done by the TCCMAR members. Basic TCCMAR policies and objectives have been and will continue to be developed by an Executive Panel. The Consultants Panel, consisting of eminent individuals listed in Table 2, provied an objective overview of the program to assure program objectives are met.

TABLE 2 -- CONSULTANTS PANEL

Mete Sozen	Professor of Civil Engineering, University of Illinois, Champaign-Urbana
John Meehan	Research Director and Principal Structural Engineer, Structural Safety Section. Office of the State Architect, State of California. (Retired)
James Amrhein	Executive Director, Masonry Institute of America, Los Angeles, California
James Jirsa	Professor of Civil Engineering, University of Texas at Austin.

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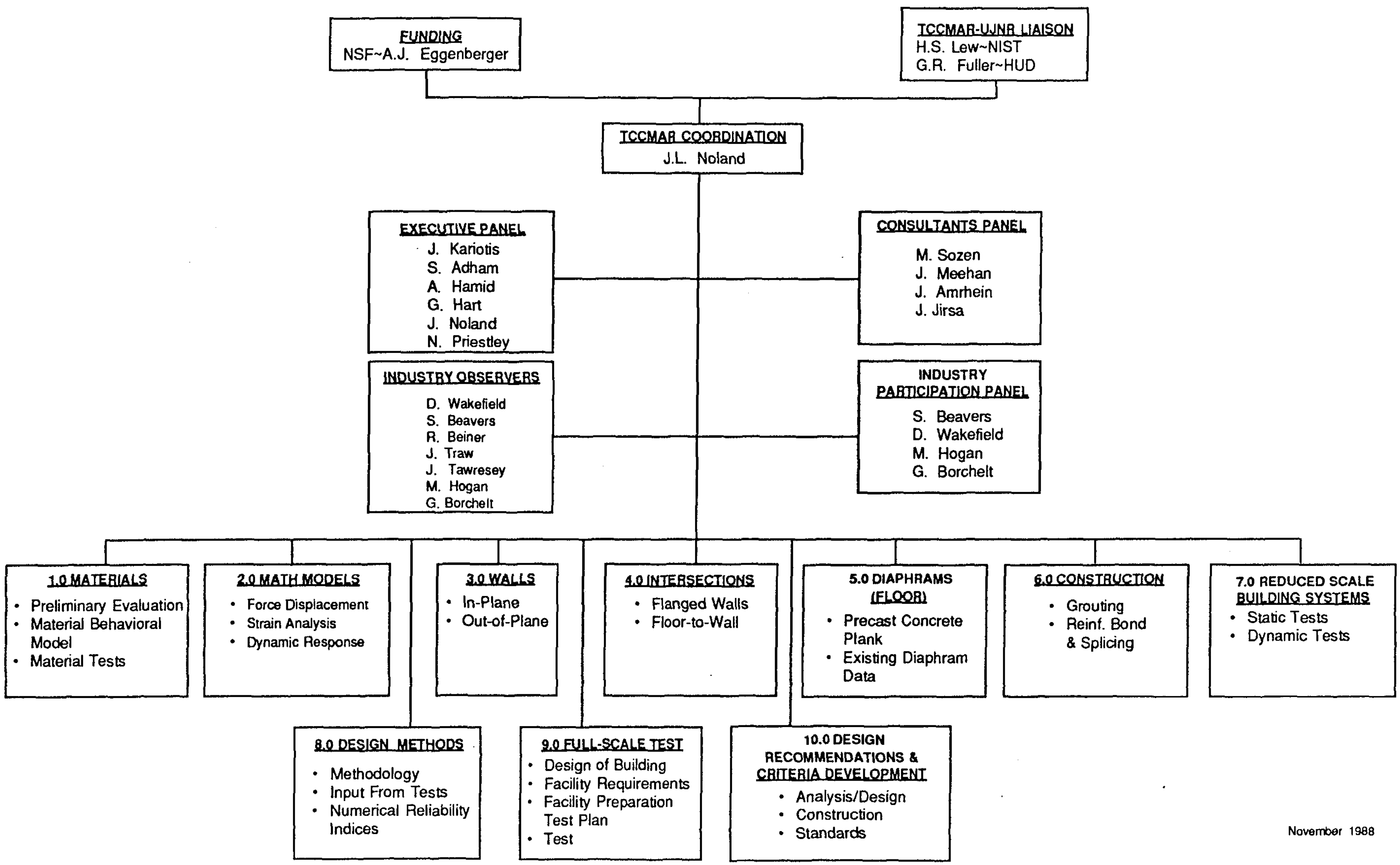


FIGURE 1 - TCCMAR ORGANIZATION (U.S.)

Industry Observers, listed in Table 3, provide the main interface between the project and the ultimate user group of the program results. The Observers were selected so that the main components of the user group, i.e., building codes bodies, masonry unit producers, trade organizations, and design professions, would be represented.

Funding for the U.S. program is being provided by the National Science Foundation and coordination with the UJNR panel is done through TCCMAR-UJNR Liaison personnel.

TABLE 3 -- INDUSTRY OBSERVERS

Donald Wakefield	Vice President-Marketing, Interstate Brick Co., West Jordan, Utah.
Stuart Beavers	Executive Director, Concrete Masonry Association of California and Nevada, Sacramento, CA.
Robert Beiner	Director of Engineering, International Masonry Institute, Washington, D.C.
Jon Traw	Vice President, Engineering, International Conference on Building Officials, Whittier, CA.
John Tawresey	Vice-President of Finance and Consulting Engineer, KPFF, Seattle, WA.
Mark Hogan	Director of Engineering, National Concrete Masonry Association, McLean, VA.
J. Gregg Borchelt	Director, Engineering & Research, Brick Institute of America, Reston, VA.

3.2 **Research Tasks** -- Table 4 presents a capsule description of the research tasks, identifies the principal investigator for each task and gives the task identification, i.e., research category number and task number. Additional tasks not yet listed may be proposed in the future.

TABLE 4 -- RESEARCH TASKS

Category	Task (Researcher)	Title-Purpose
1.0	1.1 (Atkinson)	**Preliminary Material Studies** -- To compare the behavior of clay and concrete unit masonry. To provide a basis for selection of the type or types of masonry to be used in subsequent tasks. To establish standardized materials test procedures for all the experimental tasks.
1.0	1.2 (Hamid) (Brown)	**Material Models** -- To measure the parameters required for development of the flexural compression stress-block. To determine uniaxial and biaxial material properties for analytical models (Tasks 2.1 and 2.2) including post-peak behavior. To evaluate non-isotropic behavior.
1.0	1.3 (Atkinson)	**Material Tests** -- To critically review and assess existing tests of masonry materials and assemblages to determine the usefulness of data produced with respect to the needs of analytical models and design methodology developed in the program. To revise existing tests as required and/or suggest new tests. The work will be done in coordination with Category 2 and 10 Tasks to establish accuracy requirements.
2.0	2.1 (Englekirk)	**Force-Displacement Models for Masonry Components** -- To develop force-displacement mathematical models which accurately characterize reinforced masonry components under cyclic loading to permit pretest predictions of experimental results. To develop models suitable for parameter studies and models suitable for design engineering.

TABLE 4 (Continued)

Category	Task (Researcher)	Title-Purpose
2.0	2.2 (Ewing)	**Strain Analysis Model for Masonry Components** -- To develop a strain model for reinforced masonry components in conjunction with Task 2.1. To identify regions of large strain thus assisting in experimental instrumentation planning. To develop a simplified model to be used to provide data for strength design rules and in-plane shear design procedures.
2.0	2.3 (Kariotis)	**Dynamic Response of Masonry Buildings** -- To develop a generalized dynamic response model to predict interstory displacements using specified time histories. To correlate force-displacement models and to investigate force-displacement characteristics of structural components in the near-elastic and inelastic displacement range. To provide data for building test planning.
2.0	2.4(a) (Porter)	**Dynamic Response of Diaphragms** -- To develop an analytical non-linear model of load displacement history of horizontal diaphragms. To provide associated displacements and stiffnesses for an integrated dynamic spring model. This Task will provide a computer model extension using a lumped-parameter mass parameter spring of the experimental data collected from Tasks 5.1 and 5.2. This work will provide input for Task 2.3.

TABLE 4 (Continued)

Category	Task (Researcher)	Title-Purpose
2.0	2.4(b) (Mayes) (Sveinsson)	**Dynamic Out-of-Plane Response of Reinforced Masonry Walls** -- To develop analytical models based upon the results of Task 3.2(b) which can be used to predict out-of-plane response of masonry walls of various shapes, sizes, and internal construction. To conduct response studies based on independent variation of parameters. The models will interface with the models of Tasks 2.3 and 2.4(a).
3.0	3.1(a) (Shing)	**Response of Reinforced Masonry Story-Height Walls to Fully Reversed In-Plane Lateral Loads** -- To experimentally establish the behavior of story-height walls subjected to small and large amplitude axial force, and bending moments considering various reinforcement ratios and patterns.
3.0	3.1(b) (Hegemier) (Seible)	**Development of a Sequential Displacement Analytical and Experimental Methodology for the Response of Multi-Story Walls to In-Plane Loads**--To develop a reliable test methodology for investigating structural response, through integrated analytical and experimental studies of three-story reinforced hollow unit masonry walls. The methodology will be the basis of studying the response of a full-scale masonry research building in Task 9.4. To develop analytic models in conjunction with Tasks 2.1, 2.2, and 2.3.

TABLE 4 (Continued)

Category	Task (Researcher)	Title-Purpose
3.0	3.1(c) (Klingner)	**Response of Reinforced Masonry Two-Story Walls to Fully Reversed In-Plane Lateral Loads** -- To establish the behavior of two-story walls subjected to small and large amplitude reversals of in-plane lateral deflections, axial force and bending moments considering the effect of openings, floor-wall joint details, reinforcement ratios and coupling between shear walls. To develop analytical models in conjunction with Tasks 2.1, 2.2, and 2.3.
3.0	3.2 (Hamid) (Mayes) (Harris)	**Response of Reinforced Masonry Walls to Out-of-Plane Static Loads** -- To verify the behavior of flexural models developed using material models, to evaluate the influence of unit properties, bond type and reinforcement ratios upon wall behavior. To provide stiffness data for correlation with dynamic wall test results (Task 3.2 (b)).
3.0	3.2 (Adham) (Mayes)	**Response of Reinforced Masonry Walls to Out-of-Plane Dynamic Excitation** --To experimentally determine effects of slenderness, reinforcement amounts and ratios, vertical load and grouting on dynamic response as needed for mathematical response models and the development design coefficients for equivalent static load methods.

TABLE 4 (Continued)

Category	Task (Researcher)	Title-Purpose
4.0	4.1 (Priestley)	**Response of Flanged Masonry Shear Walls to Dynamic Excitation** -- To experimentally investigate the dynamic behavior of flanged shear walls, in particular, the behavior of T-section walls and the significance of dynamic, as opposed to static or quasi-static testing, for in-plane loading. To develop analytical models to investigate the flange-web shear lag phenomena, and to identify the interaction between flange width, height, reinforcement content, and ductility level. (In conjunction with Tasks 2.1, 2.2, and 2.3)
4.0	4.2 (Hegemier)	**Floor-to-Wall Intersections of Masonry Buildings** -- To determine the effectiveness of intersection details to connect masonry wall components. To construct a nonphenomenological analytical model of intersection behavior for use in building system models.
5.0	5.1 (Porter)	**Concrete Plank Diaphragm Characteristics** -- To investigate experimentally concrete plank diaphragm floor diaphragms with stiff supports to determine modes of failure and stiffness characteristics including yielding capacity in terms of distortion as needed for masonry building models.
5.0	5.2 (Johnson) (Porter)	**Assembly of Existing Diaphragm Data**--To assemble extensive existing experimental data on various types of floor diaphragms, to reduce to a form required for static and dynamic analysis models.

TABLE 4 (Continued)

Category	Task (Researcher)	Title-Purpose
5.0	5.3 (Porter)	**Concrete Plank Diaphragm Characteristics Continuation** -- To investigate experimentally the behavior of concrete plank floor diaphragms with flexible supports to determine modes of failure and stiffness characteristics including yielding capacity in terms of distortion as needed for masonry building models.
6.0	6.1 (TBD)	**Grouting Procedures for Hollow Unit Masonry**-- To identify methods of grouting hollow unit masonry such that the cavity is solidly filled and reinforcement is completely bonded.
6.0	6.2 (Tulin)	**Reinforcement Bond and Splices in Grouted Hollow Unit Masonry** -- To develop data and behavioral models on the bond strength and slip characteristics of deformed bars and lap splices in grouted hollow unit masonry, as needed for building modeling.
7.0	7.1 (Abrams)	**Small Scale Models** -- To provide experimental test data on the dynamic behavior of three-story reinforced concrete masonry buildings built with 1/4 scale hollow concrete units. To demonstrate the viability of constructing and dynamically testing reduced scale building system models for basic behavior studies.
8.0	8.1 (Hart)	**Limit State Design Methodology for Reinforced Masonry** -- To select an appropriate limit state design methodology for masonry. To select and document a procedure to compute numerical values for strength reduction factors. To review program experimental research tasks to assure that statistical benefits are maximized and proper limit states are investigated.

TABLE 4 (Continued)

Category	Task (Researcher)	Title-Purpose
8.0	8.2 (Hart)	**Numerical Reliability Indices** -- To develop numerical values of statistically-based strength reduction factors using program experimentally developed data, other applicable data, and judgment. To complete development of the methodology.
9.0	9.1 (Kariotis)	**Design of Reinforced Masonry Research Building** -- **Phase 1** -- to develop the preliminary designs of the potential research buildings which reflect a significant portion of modern U.S. masonry construction. To select a single configuration in consultation with TCCMAR which will be used as a basis for defining equipment and other laboratory facilities using methods developed in Category 2 tasks and the associated load magnitudes and distributions. **Phase 2** - To prepare final drawings and specifications for construction of the five-story test specimen.
9.0	9.2 (Hegemier) (Seible)	**Facility Preparation** -- Define, acquire, install and check-out equipment required for experiments on a full-scale five-story reinforced masonry research building.
9.0	9.3 (Hegemier) (Seible) (Priestley)	**Full Scale Masonry Research Building Test Plan** -- To develop a detailed and comprehensive plan for conducting static load-reversal tests on a full-scale five-story reinforced masonry research building.

TABLE 4 (Continued)

Category	Task (Researcher)	Title-Purpose
9.0	9.4 (Hegemier) (Seible) (Priestley)	**Full Scale Test** -- To conduct experiments on a full-scale five-story reinforced masonry research building in accordance with the test plan and acquiring data indicated. To observe building response and adjust test procedures and data measurements as required to establish building behavior.
10.0	10.1 (Noland)	**Design Recommendations and Criteria Development** -- To develop and document recommendations for the design of reinforced masonry building subject to seismic excitation in a manner conducive to design office utilization. To develop and document corresponding recommendations for masonry structural code provisions.
11.0	11.1 (Noland)	**Coordination** -- To fully coordinate the U.S. research tasks. To enhance data transfer among researchers and timely completion of tasks. To schedule and organize TCCMAR and Executive Panel meetings. To establish additional program policies as the need arises. To stimulate release of progress reports and dissemination of results. To coordinate with industry for the purposes of informing industry and arranging industry support. To interface with NSF and UJNR on overall funding and policy matters.

3.3 SYSTEMS APPROACH AND TASK COORDINATION

3.3.1 Overall -- A systems approach is being taken to guide and control the program, i.e., The U.S. Coordinated Program for Masonry Building Research is a cohesive entity rather than a collection of separate projects. The individual research tasks which comprise the U.S. program are defined in a manner that they "fit together." Hence, the research tasks are interdependent, i.e, results from a given task may be required for the execution of others. Analytical tasks generally require interaction with experimental tasks on a fairly continuous basis so that analytical model development may incorporate data as they are obtained. The needs of the analytical tasks in turn serve to define, in part, the manner in which experimental tasks are designed and conducted and the data to be obtained.

The intra-task interaction is depicted generally in Figure 2. The circles represent task categories except where individual tasks within a category have different interaction relationships. The Coordination category and Design Methods category interact with all categories and tasks within the large boundary as well as with the Design Recommendations and Criteria Development category.

Coordination is accomplished by regular meetings of the entire TCCMAR twice a year. These meetings are augmented by more frequent meetings between researchers in a given Category, e.g., modeling or shear walls.

3.3.2 Modeling Coordination -- The primary responsibility for the development of analytical models lies with the core group of Category 2 researchers, i.e., EKEH (Ewing, Kariotis, Englekirk, and Hart). During the initial phase of the U.S. Coordinated Program for Masonry Building Research the Category 2 researchers spent a considerable amount of time investigating alternatives, reviewing literature, consulting with others, in addition to analyzing data coming from the experimental tasks, in order to refine the modeling approach to be taken. This type of activity is a normal part of any research effort and was especially important for this one because of the scope and importance of the final objectives. EKEH has regularly presented its work to others in TCCMAR for review. The group has met frequently with the researchers conducting experimental projects to define modeling data needs, acquire data and to coordinate modeling and experimental efforts as depicted in Figure 2.

It was recognized from the inception of the Coordinated Program that the modeling effort would be an evolutionary process. The models would develop and improve as experimental data became available for calibration and in turn, the models would become increasingly effective in predicting experimental results. It was also recognized that full integration of the TCCMAR experimental researchers and EKEH would be desirable and necessary to provide a broader base for evaluation of modeling approaches and modeling developments.

Proposals were therefore submitted in June 1987 (revised in January 1988) which resulted in support by NSF in the form of new grants and grant supplements to provide greater involvement by experimental researchers in the Category 2 (EKEH) modeling work. Grants and grant supplements awarded pertaining to modeling are:

TASK	RESEARCHER	TOPIC
2.4(a)	M. Porter	Dynamic Response of Diaphragms (new)
2.4(b)	R. Mayes	Dynamic Response of Walls Out-of-Plane (new)
3.1(a)	B. Shing	Behavior of Single Story Shear Walls (PYI)*

* Presidential Young Investigator Award

U.S.-JAPAN COORDINATED PROGRAM FOR MASONRY BUILDING RESEARCH

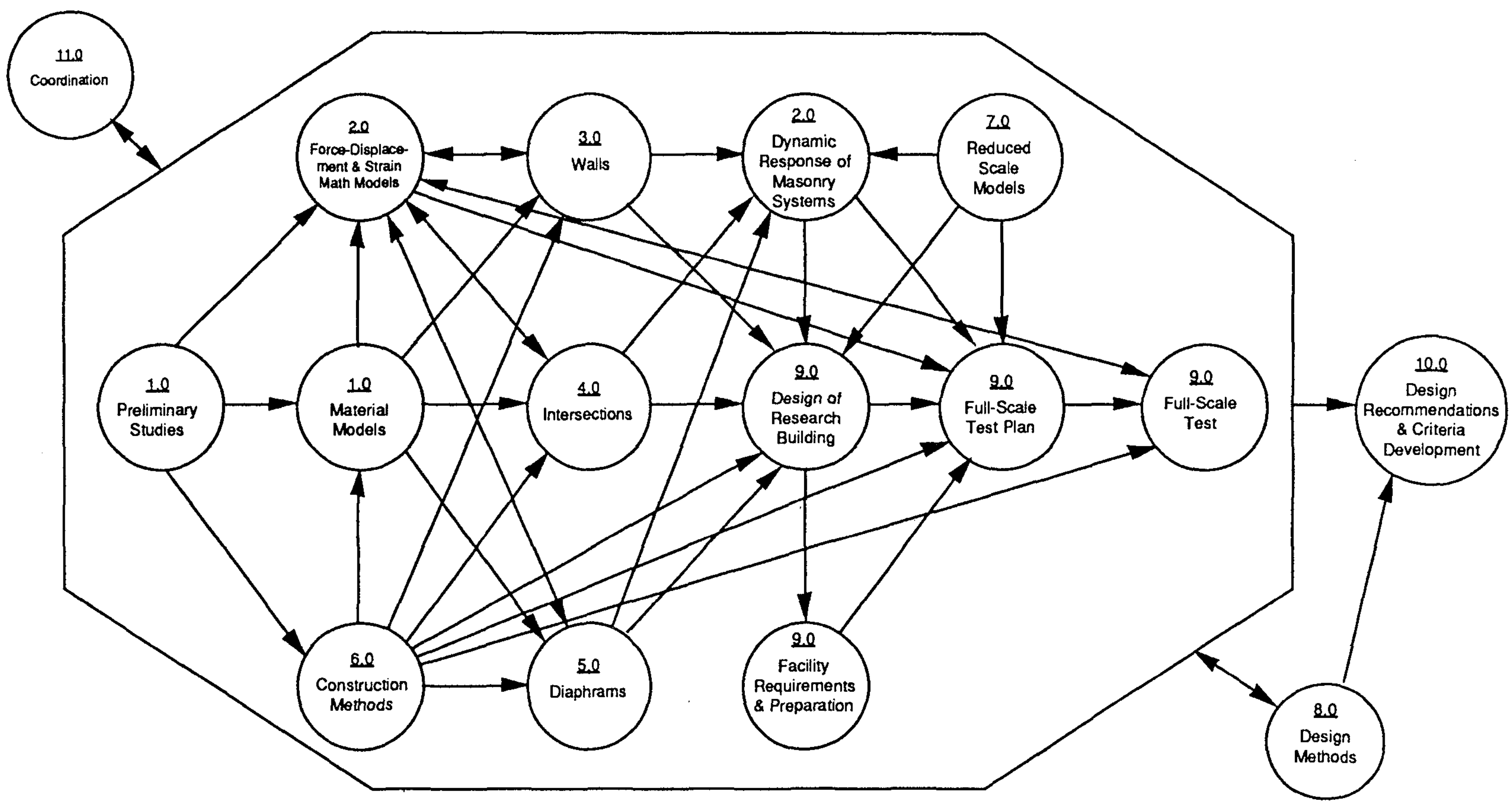


FIGURE 2 — TASK INGREDIENTS-DEPENDENCE CHART (U.S. PROGRAM)

November 1988

3.1(b)	G. Hegemier	Synthesis of Strain Analysis Models (supplement)
3.1(c)	R. Klingner	Models for Two-Story Shear Walls (supplement)
4.1(c)	M.J.N. Priestley	Flanged Walls (new)
7.1	D. Abrams	Non-linear Modeling of Masonry Systems (supplement)

The formal and direct involvement of the above will not only provide a valuable base of support for EKEH, but will also stimulate greater intellectual discussions than previously possible and lead toward a firm consensus within TCCMAR on modeling and ultimately, design recommendations.

The modeling effort has been organized on a control group basis as follows:

Topic	Group Leader	Group Members
FEM[1] (General)	Ewing	El-Mustapha, Hegemier, Atkinson, Brown, Seible
SCM[2] (General)	Hart	Mayes, Adham, Shing, Kelly
LPM[3] (General)	Kariotis	Klingner, Abrams, Porter, Sveinsson
Coupled Walls (FEM, SCM, LPM)	Klingner	Abrams, Kariotis, Seible, Ewing Porter, Adham, Kelly
Single Walls (FEM, SCM, LPM)	Shing	Mayes, Hart, Atkinson, Brown, El-Mustapha, Hegemier, Sveinsson

1. FEM = Finite Element Model
2. SCM = Structural Component Model
3. LPM = Lumped Parameter Model

Topic	Group Leader	Group Members
Tall Shear Walls (FEM, SCM, LPM)	Seible	Ewing, El-Mustapha, Atkinson, Shing, Hegemier
Slender Walls (FEM, SCM, LPM)	Mayes	Adham, Kariotis, Kelly, Sveinsson, Abrams, Brown, Porter
5-Story Building (Japan & U.S.)	Hegemier	Seible, Porter, Brown, Adham, Ewing
Task 10	Noland	Kariotis, Abrams, Klingner, Mayes, Hart, Atkinson, Kelly

It will be the responsibility of each group leader to utilize and integrate the talents and efforts of the group to develop the assigned model. Coordination between groups will be the responsibility of the group leaders and the TCCMAR Coordinator.

Among the goals established for the modeling efforts is to have reasonable correlation between the SCM, FEM and LPM models and the experimental results from the one, two and three story shear wall tests, the out-of-plane static and dynamic tests and especially with the results from the full-scale building tests. Other specific goals and parameter studies are outlined elsewhere [11].

A fundamental goal regarding utilization is that among the models developed, forms or versions of the models amenable to design office use will be provided. The criteria established for design office use include:

- the programs must be operational with reasonable "run time" on PC-type computers (286 or 386)
- the programs must be well documented including a description of underlying theory and assumptions in a manner understandable by design office personnel
- the degree of accuracy of modeling predictions should be consistent with accuracy of structural parameter data and earthquake ground motion estimation.

3.3.3 Design Methodology and Design Recommendations Coordination -- A limit state design methodology/philosophy based upon probabilistic methods has been developed in Task 8.1 and is described in TCCMAR Report 8.1-1. However, it is an entirely new form and approach for masonry structural design and will be the basis for the design recommendations to be developed in Task 10.1 later in the program.

The development of the analytical equations and data base necessary to implement and support the limit state design methodology has begun (Task 8.2). The data base will consist of all values from the experimental tasks on unit, grout, mortar, prism, and reinforcement strengths. The data base developed by TCCMAR will be coordinated with and augmented by a non-TCCMAR NSF-sponsored project to accumulate and normalize prism compressive characteristics data on a world-wide basis [12].

As originally and currently intended by TCCMAR, and depicted in Figure 2, work in Task 10.1 will be directed towards developing design recommendations and criteria for reinforced masonry buildings based upon the work done in Categories 2 and 8, supported by the results of the experimental tasks and other appropriate information. Task 10.1 has not yet been funded; the proposal will be submitted in early 1989 as shown in Figure 3. Several meetings and discussions have been held over the past year among TCCMAR researchers to define more specifically the philosophy, form and content of the design recommendations and criteria provided under Task 10.1 as well as overall program documentation. A fundamental concept of the Coordinated Program, and hence of the design and criteria recommendations produced, is that the work of Task 10.1 will be a synthesis of all previous program work to produce results directly applicable to the design process and code development. The basic end products of Tasks 10.1 will be:

A) Topical Reports synthesized from the Task Reports and archived data (experimental tasks produced in the individual tasks). Each topical report will be a formal treatise on the subject about 60 pages in length. The topical reports envisaged are:

No.	Topic	Pertinent Tasks
TR1	Material Properties & Tests	1.1, 1.2, 1.3*
TR2	Reinforced Masonry Walls: In-Plane Shear and Combined In-Plane Shear and Vertical Compression	2.1, 2.2, 3.1(a), 3.1(b), 3.1(c), 4.1, 9.4
TR3	Reinforced Masonry Walls: Out-of-Plane Forces Combined with Vertical Compression	2.4(a), 2.4(b), 3.2(a) 3.2(b1), 3.2(b2)
TR4	Diaphragms	2.3, 2.4(a), 2.4(b), Category 5 Tasks, 9.4
TR5	Bond and Splicing of Reinforcement in Masonry	Category 3 Tasks, 4.1, 6.2 Category 2 Tasks
TR6	Limit State Design Concepts for Reinforced Masonry	Categories 1-9
TR7	Modeling of Masonry Components and Building Systems	Category 2 Tasks, 3.1(b) 7.1, 9.4
TR8	Large Scale Testing of Masonry Building Systems	3.1(b), 3.1(c), Category 9 Tasks

* "A Critical Review of Masonry Tests and Recommendations for Improved Test Methods", proposed to NSF as Task 1.3.

TR9	Determination of Earthquake Induced Forces on Masonry Buildings	2.1, 2.3, 2.4(a), 2.4(b), 7.1, 8.1, 8.2, 9.4

B) Technical Summary Report - This document will be founded upon the topical reports and condense the information therein. The document will present the basic technical results in a cohesive manner. It is expected to be the most widely distributed technical document and be on the order of 120 pages in length. References to the appropriate topical and task reports will be made to direct a reader to further detail if desired.

C) Design and Criteria Recommendations - Recommendations pertaining to reinforced masonry building design and criteria will be made and presented in a manner such that findings of the Coordinated Program may be readily adapted by building code development bodies, e.g., ICBO and FEMA. The document will not be a building code, but will support code provisions.

3.3.4 Interface with Code/Standard Writing Organizations

Standards (Tests) -- Standard experiments (tests) to produce material properties information for design and research are an essential companion to structural modeling and design. Proposed Task 1.3 (see Table 4) will define the standard tests required to do so. ASTM committees C12 on Mortar and Grout, C15 on Masonry Units and E6 on assemblage tests have been briefed on TCCMAR plans in this area and lines of communication have been established for coordination between ASTM and TCCMAR in this area. It is expected that work done by TCCMAR with the cognizance and cooperation of ASTM will result in standard masonry tests consistent with the present and future needs of researchers and design according to limit state philosophy.

Standards (Design) -- As noted in Section 3.3.3 paragraph C herein, the Coordinated Program will not develop a reinforced masonry building code but rather recommendations. A standard is a consensus document the development of which involves the contributions and opinions of many people and some considerations beyond those addressed in the Coordinated Program. In order to "pave the way" for developing the design recommendations and standards in Task 10.1, the TCCMAR coordinator suggested at the May 1988 meeting of the Board of Directors of The Masonry Society (TMS) that an effort be made in the professional/code community to avoid a diffusion of effort on limit state standard development and to develop a common strategy to utilize the results of the Coordinated Program as a basis for a single consensus limit state based building standard for masonry structures. The Masonry Society called a meeting for 19 July 1988 to develop plans to do so. In attendance were:

NAME	REPRESENTING
James Amrhein	TMS President, Masonry Institute of America, and Western States Clay Products
Gary C. Hart	TMS Vice President, V. P. Englekirk & Hart (meeting chairman)
Leonard Hobbs	Lightweight Processing Company
Sam Henry	American Concrete Institute
Edwin Jones	American Society of Civil Engineers
Gregg Borchelt	Brick Institute of America
Mark Hogan	National Concrete Masonry Association
John Kariotis	Kariotis Associates, Board of Directors - TMS

Fred Willsen	Structural Engineers Association of California
Ron Mayes	Computech Engineering Services
James Noland	TCCMAR Coordinator
Stuart Beavers	Concrete Masonry Association of California and Nevada
Mike Merrigan	Masonry Institute of America
Nigel Priestley	ACI 531, University of California-San Diego
Samy Adham	Agbabian Associates

The attendees agreed that a single strength limit state design methodology was needed, but would not recommend removal of working stress or empirical methods in the immediate future. The attendees recommended the following course of action:

1) form a joint ACI 531/TMS Committee to develop a Resource Document documenting possible approaches to a limit state code for masonry and the state-of-the-art on strength limit state codes. Nigel Priestley would be the chair with members R. Klingner, G. Hart, and R. Mayes.

2) form a committee to prepare a skeleton of a strength limit state code for masonry to be "filled out" subsequently using results from the Coordinated Program (i.e., the design and criteria recommendations) and other information. R. Mayes was designated chair with members J. Noland, J. Kariotis, G. Hart, R. Brown, M. Hogan, and M. Porter.

Funding of $50,000 was estimated to be required for both of the above tasks and would be sought by TMS from industry sources. The Council for Masonry Research subsequently stated that it would consider providing $40,000 if the additional $10,000 were provided by others.

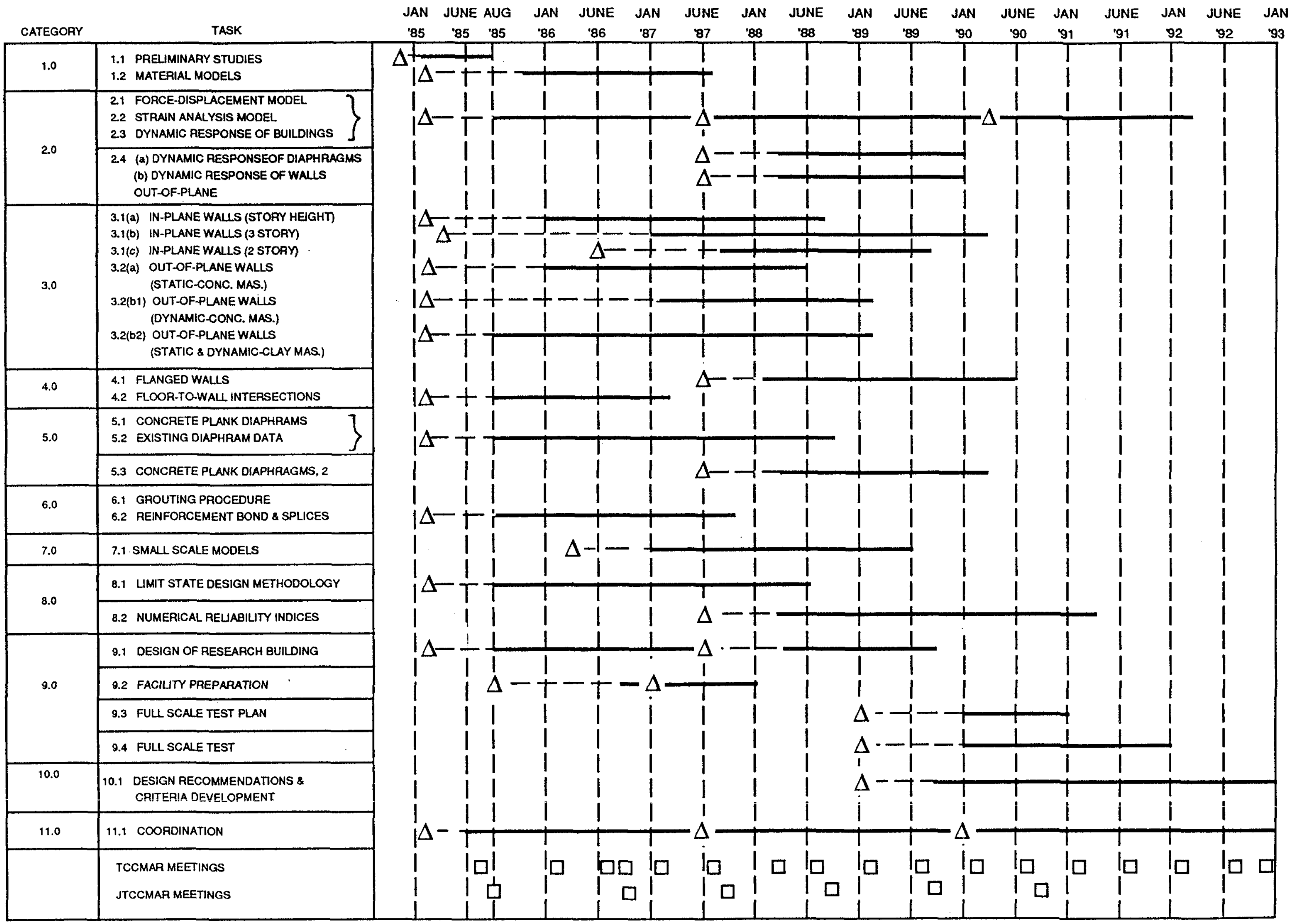
Therefore, pending financial support for the foregoing, the mechanism for translating Coordinated Program results into codes and standards will be in place in approximately one year.

3.4 **Schedule** -- The schedule for tasks comprising the U.S. program is shown in Figure 3. The total time required to complete the program is estimated to be approximately seven years from the time the majority of the tasks began, i.e. fall 1985. The tasks are time-phased so that results will be available in the proper sequence.

With the exception of the preliminary materials studies task, work began in the fall of 1985. The program as presently defined is expected to be complete by January 1993.

The schedule illustrates the parallel nature of experimental research and modeling. Modeling studies began in the fall of 1985 and will continue to February 1992. As data from the various experimental tasks becomes available, models will be progressively refined and calibrated.

U.S.-JAPAN COORDINATED PROGRAM FOR MASONRY BUILDING RESEARCH



Δ = PROPOSAL SUBMITTAL

FIGURE 3 — TASK SCHEDULE (U.S. PROGRAM)

MARCH1988

TABLE 5

BUDGET- U.S. COORDINATED PROGRAM FOR MASONRY BUILDING RESEARCH

Budget Request By Fiscal Year[2]

Category	Task	Task Title	Researcher	Institution	Total Granted, Proposed, & Estimated	Fiscal '85	Fiscal '86	Fiscal '87	Fiscal '88	Fiscal '89	Fiscal '90	Fiscal '91	Fiscal '92
1.0	1.1	Preliminary Studies	Atkinson	Atkinson-Noland	$56,286	$56,286	-	-	-	-	-	-	-
	1.2(a)	Materials Models-Concrete Masonry	Hamid	Drexel Univ.	71,712	39,839	$31,873	-	-	-	-	-	-
	1.2(b)	Materials Models-Brick Masonry	Brown	Clemson Univ.	83,875	42,560	41,315	-	-	-	-	-	-
2.0	2.1	Force Displacement Model	Englekirk }	EKEH Joint Venture	588,163	54,944	50,000	86,835	75,000	136,690	132,434	52,260	-
	2.2	Strain Analysis Model	Ewing }		569,836	58,009	42,410	78,477	93,000	129,397	126,481	42,062	-
	2.3	Dynamic Response Model	Kariotis }		629,720	53,590	41,740	77,201	112,029	144,225	150,935	50,000	-
	2.4(a)	Dynamic Response of Diaphragms	Porter	Iowa State University	20,138	-	-	-	-	20,138	-	-	-
	2.4(b)	Dynamic Parameter Study-Out of Plane Walls	Mayes	Computech	137,109	-	-	-	29,906	107,203	-	-	-
3.0	3.1(a)	In-Plane Walls (Story Height)	Noland/Shing	Univ. of Colorado	166,244	77,041	-	89,203	-	-	-	-	-
	3.1(b)	Sequential Displacement-Inplane Walls	Hegemier/Sieble	UCSD	419,344	-	194,356	199,988	25,000	-	-	-	-
	3.1(c)	In-Plane Walls (Two-Story)	Klingner	Univ. of Texas	173,462	-	-	173,462	-	-	-	-	-
	3.2(a)	Out-of-Plane Walls (Static-Conc. Masonry)	Hamid	Drexel Univ.	89,552	-	41,500	48,052	-	-	-	-	-
	3.2(b1)	Out-of-Plane Walls (Dynamic-Conc. Masonry)	Adham	USC	105,920	-	-	-	105,920	-	-	-	-
	3.2(b2)	Out-of-Plane Walls (Static & Dynamic-Clay Masonry)	Mayes	Computech	204,743	8,992	40,038	155,713	-	-	-	-	-
4.0	4.1	Flanged Wall Dynamic Study	Priestley	UCSD	304,345	-	-	-	93,068	119,044	92,233	-	-
	4.2	Floor-to-Wall Intersection	Hegemier	UCSD	62,400	-	62,400	-	-	-	-	-	-
5.0	5.1	Concrete Plank Diaphragms }	Porter/Johnson	Iowa State Univ.	119,980	15,000	52,490	52,490	-	-	-	-	-
	5.2	Existing Diaphragm Data }				-	-	-	-	-	-	-	-
	5.3	Concrete Plank Diaphragms-Continuation	Porter	Iowa State Univ.	75,485	-	-	-	-	75,485	-	-	-
6.0	6.1	Grouting Procedures	TBD	TBD	-	-	-	-	-	-	-	-	-
	6.2	Reinforcement Bond and Splices	Tulin	Univ. of Colorado	83,748	46,773	-	36,975	-	-	-	-	-
7.0	7.1	Small Scale Models	Abrams	Univ. of Illinois	206,852	-	-	92,992	86,299	27,561	-	-	-
8.0	8.1	Limit State Design Methodology	Hart	UCLA	80,668	36,088	21,798	22,782	-	-	-	-	-
	8.2	Numerical Reliability Indices	Hart	UCLA	216,666	-	-	-	54,000	64,642	68,615	29,409	-
9.0	9.1	Design of Research Building	Johnson, Kariotis	Barnes, Kariotis	74,893	21,920	-	-	-	24,937	28,036	-	-
	9.2	Facility Preparation	Hegemier	UCSD	1,205,700[3]	-	-	796,055	409,645	-	-	-	-
	9.3	Full Scale Test Plan	Hegemier, Priestley, Seible	-	(85,000)	-	-	-	-	(85,000)	-	-	-
	9.4	Full Scale Test	Hegemier, Priestley, Seible	-	(2,213,000)	-	-	-	-	(695,000)	(898,000)	(620,000)	-
10.0	10.1	Design Recommendations and Criteria Development	TCCMAR[1]		(780,000)	-	-	-	-	(150,000)	(250,000)	(380,000)	(200,000)
11.0	11.1	Coordination	Noland	Atkinson-Noland	454,863	42,275	44,540	37,540	90,120	114,935	125,453	-	-
			Totals	Grants & Proposals	6,201,704	553,317	664,460	1,947,765	1,173,987	964,257	724,187	173,731	-
			Totals	G+P+Est	9,419,704	553,317	664,460	1,947,765	1,173,987	1,894,257	1,872,187	1,173,731	200,000

[1] The entire TCCMAR or subgroup thereof to be formed
[2] Numbers in parentheses are estimates
[3] Additional 1/3 matching funds were received

JULY 1987
Rev. August 1987
Rev. August 1988

4.0 BUDGET

Funding awarded, pending and estimated for the U.S. Coordinated Program for Fiscal Years 1985 through 1991 is presented in Table 5.

Table 5 does not include funds or fund-equivalents from industry (see Section 5).

5.0 INDUSTRY PARTICIPATION

5.1 Current

California Nevada Concrete Masonry Association completed and projected supply and delivery of concrete masonry units to researchers:	
20,300 CMU at $2.25 each + miscellaneous	$65,800
Western States Clay Products Completed and projected supply and delivery of hollow clay units to researchers:	
9300 at $2.00 each	$18,600
Construction & Misc. for Task 3.2(b2)	25,000
Masonry Institute of America	
wall panels for Task 3.2(b1)	$11,900
cash for Task 3.2(b2)	2,000
mortar and grout cylinder molds	300
	$14,200
National Concrete Masonry Association	$ 5,000
Delaware Valley Masonry Institute (Task 3.2a)	$ 5,000
Sabins and Company (Task 3.2a)	5,000
S. Grossi and Sons (Task 3.2a)	20,000
Prestressed Concrete Operations (Task 5.1)	13,200
Central Premix Concrete Co. (Task 5.1)	1,200
Council for Masonry Research (general materials and materials testing)	20,000
SIKA Corp. (Grout aid for all specimens)	$500 (est)
Masonry Institute of Texas (Task 3.1c)	$1,200
Colorado Masonry Industry (Tasks 3.1a and 6.2)	$ 2,000
TOTAL	$184,700

5.2 Anticipated

The Masonry Institute of America is prepared to commit $20,000 toward construction of the five story research building (Task 9.4). The Industry Participation Panel under Ch. Stuart Beavers is working on the balance needed for Task 9.4 and to support construction of specimens for Tasks 3.1(b) and 4.1. Masonry units will be provided.

6.0 CURRENT STATUS OF RESEARCH TASKS

6.1 Summary -- The overall progress and status of the U.S. program may be determined generally from the schedule (Figure 3). The status of the research tasks is summarized in Table 6. More detailed status and summary reports of each task are in Appendix 1.

7.0 TCCMAR (U.S.) MEETINGS

Meetings of the entire U.S. team including consultants and industry observers have been held for the purpose of direct communication of planning, review of results and discussion of problems and coordination of efforts. Because of distances and costs involved, the meetings have been and will be scheduled at approximately 6 month intervals. TCCMAR meetings which have been held are listed in Table 7.

In addition several meetings of TCCMAR subgroups have been held to focus upon specific issues. Some are listed in Table 7. Several others, mainly concerned with analytical modeling, have also been held.

8.0 JOINT U.S.-JAPAN TCCMAR (JTCCMAR) MEETINGS

Joint meetings have been held with the Japanese research team (TCCMAR/Japan) to develop lines of communication, discuss research plans, and review results. The meetings reflect the spirit of UJNR objectives and have been mutually beneficial. Papers and reports presented are in proceedings of the meetings.

To date four meetings have been held as listed in Table 8. Plans and arrangements have been made for the fifth on the date and at the place given in the Table. Meeting agendas for and resolutions made are in Appendix 5.

The main portion of the Japanese program will finish in March 1989. However, a small effort by the Japanese will maintain continuity with the U.S. program.

TABLE 6
SUMMARY OF FUNDED TASK STATUS AS OF 31 AUGUST 1988

TASK	TITLE	PERCENT COMPLETE	COMMENTS
1.1	Preliminary Material Studies	100	Complete. Report 1.1-1 published, Sept. 1985.
1.2(a)	Materials Models -- Concrete Masonry	95	Test machine stiffness problem fixed. All experimental procedures developed. Report 1.2(a)-1 published, Aug. 1988.
1.2(b)	Materials Models -- Clay Masonry	95	Testing completed. Report 1.2(b)-1 published, May 1988.
2.1	Force Displacement Models	60	Research and evaluation indicated that "Structural Component Models" (SCM) are the best approach. Correlation studies using results of Task 3.1(a) begun. Results promising. Reports 2.1-1, 2.1-2 and 2.1-3 published.
2.2	Strain Analysis Models	65	Basic technical approach developed based upon extensive evaluation of alternatives. FEM will be used to understand in-plane response of reinforced masonry walls. Analytical model will replicate degrading force-displacement. Predictive models made for Task 3.1(c) shear walls.

2.3	Dynamic Response of Masonry Building Systems	65	Integrated approach developed to formulate lump parameter models for building response analyses. Builds upon Task 2.1 and 2.2. Families of ground motion-time-history records selected for use in building system studies. LPM with foundation flexibility studies begun. Reports 2.3-1 and 2.3-2 published in 1987 and 1988.
2.4(a)		-0-	Not yet funded.
2.4(b)		15	The focus of the work to date has been the reduction of the experimental data from Task 3.2(b2). Also to assist in subsequent modeling, a number of response quantities are being completed.
3.1(a)	In-Plane Walls -- Story Height	90	22 of 26 walls tested. Fixture and procedure satisfactory. Photos taken for photogrammetric analysis. Supplement received to add clay unit walls. Donation received to test one wall with joint reinforcement as shear steel. Analyses in progress. Report 3.1(a)-1 published 1986.
3.1(b)	In-Plane Walls -- Three-Story and GSD Method	10	Methodology for tests defined to develop Generated Sequential Displacement test method. Specimens defined. No further progress possible until Task 9.2 complete. Report 3.1(b)-1 published 1987.

3.1(c)	In-Plane Walls -- Two-Story	40	Design and construction of test set-up completed. Specimen construction began June 1988 and testing began Sept. 1988.
3.2(a)	Out-of-Plane Walls -- Static Tests (Concrete Masonry)	95	Testing completed Sept. 1988. Analyses underway.
3.2(b1)	Out-of-Plane Walls -- Dynamic Tests (Concrete Masonry)	90	Tests completed. Labor for wall construction was provided by industry. Results being analyzed.
3.2(b2)	Out-of-Plane Walls -- Static and Dynamic Tests (Clay Masonry)	100	Tests completed. Labor for wall construction was provided by industry. Results being analyzed.
4.1	Flanged Shear Walls -- Dynamic Tests	20	Preliminary analytical studies and static tests in progress. Report 4.1-1 published 1988.
4.2	Wall-to-Floor Intersections	80	Last part of analysis to be completed. Report expected in Feb. 1989.
5.1	Concrete Plank Diaphragms	85	Tests completed. Analyses nearly complete.
5.2	Review of Existing Data on Diaphragms	85	Open literature acquired. Seeking proprietary data.
6.2	Reinforcement Bond and Splices	100	Completed. Reports 6.2-1 and 6.2-2 published.
7.1	Small Scale Models - Dynamic Tests	80	Model material studies completed. Dynamic testing completed. Static tests of twin structure completed in Fall 1988. Data reduction and interpretation underway.
8.1	Limit State Methodology	95	Draft of final report prepared.

8.2	Numerical Reliability Indices	15	Development and acquisition of data for the materials data base computer program began. Efforts initiated to identify factors affected by the development of a probable-value-based limit state design methodology.
9.1	Preliminary Design of Research Building	100	Complete. Report 9.1-1 published.
9.2	Test Facility Preparation (Equipment)	75	Equipment defined, selected, and ordered. Most equipment delivered. Expected to be operational by Nov. `88. Check-out will be done using Task 3.1(b) specimens. Reports 9.2-1, 9.2-2 published.
11.1	Coordination	60	On-going activity. Report 11.1-1 published.

TABLE 7

TCCMAR MEETINGS HELD

Date	Location	Main Topics
February 1984	Pasadena, CA	Research needs of reinforced masonry. Specific tasks identified.
July 1985	Boulder, CO	Research program reviewed. Budgets reduced by an average of 45%.
October 1985	Boulder, CO	Revised program reviewed and presented to consultants and visitors. Electronic mail for TCCMAR communications suggested.
February 1986	Los Angeles, CA	Review of research tasks. Changes suggested. Modeling concepts & philosophy discussed.
July 1986	Boulder, CO	Review of research tasks with comments and suggestions on each. Decision made to postpone if not delete Task 7.1 on small scale model static tests.
September 1986	Keystone, CO	Overview slides for project PR reviewed. Standard displacement history for cyclic tests adopted. Grant supplements discussed.
February 1987	Torrey Pines, CA	Tasks reviewed and discussed. Emphasis placed on Cat. 2 modeling tasks. Final set of overview slides presented. Task 7.1 redefined as shake table tests of reduced-scale 3-story masonry building structures.
February 1987 (subgroup)	San Diego, CA	Planning meeting with NSF program manager to discuss coordination of modeling and future funding needs.
August 1987	La Jolla, CA	Research Task progress reviewed. Plans for 3rd JTCCMAR made. Final report for Task 6.2 reviewed. Need for special meeting on shear walls recognized.
September 1987 (subgroup)	Boulder, CO	Reviewed and modified one-story shear wall test matrix. Defined terms. Discussed two-story shear wall configuration.

January 1988	Salt Lake City, UT	Review of research tasks with comments and suggestions on each. Disciplinary subgroups formed and meetings held for more detailed discussions.
March 1988 (subgroup)	Ames, IA	Review of floor diaphragm test results. Interface with Category 2 work established. Type II specimens for Task 3.1(c) reviewed.
March-April 1988 (subgroup)	San Diego, CA	Meeting of modeling and full-scale test groups held to resolve purposes, objectives and configuration of 5-story research building. Modeling group coordination plans developed.
July 1988	Napa, CA	Tasks reviewed and discussed. Use of standard displacement history reaffirmed. Industry participation reviewed. JTCCMAR-4 plans presented and call for papers issued. Subgroup meetings held.

TABLE 8

JOINT U.S. - JAPAN MEETINGS

Date	Location	Title of Proceedings
March 1984	Tsukuba, Japan	First Workshop of U.S.-Japan Cooperative Research on Masonry Structures
August 1985	Tokyo, Japan	The First Joint Technical Coordinating Committee on Masonry Research: U.S.-Japan Cooperative Research Program
September 1986	Keystone, CO	The Second Meeting of the Joint Technical Coordinating Committee on Masonry Research: U.S.-Japan Cooperative Research Programs.
October 1987	Tomamu, Japan	The Third Meeting of the Joint Technical Coordinating Committee on Masonry Research: U.S. Japan Cooperative Research Programs.
October 1988	San Diego, CA	The Fourth Meeting of the Joint Technical Coordinating Committee on Masonry Research: U.S.-Japan Cooperative Research Programs.
(Planned) October 1989	Tsukuba, Japan	The Fifth Meeting of the Joint Technical Coordinating Committee on Masonry Research: U.S.-Japan Cooperative Research Programs.

9.0 FOREIGN (NON-JAPANESE) RESEARCHER VISITS

The U.S. Coordinated Program for Masonry Building Research has attracted international attention through papers published and presentations made at international conferences. Several researchers from countries other than Japan have visited to learn of and comment on the U.S. Program. These are listed below.

Dr. John Scrivener of the University of Melbourne, Australia spent a six month sabbatical at the University of Colorado and at Atkinson-Noland and Associates. He was supported by the University of Colorado, the University of Melbourne and the National Science Foundation. Dr. Scrivener met frequently with the Principal Investigators of Tasks 3.1(a) and 6.2 to offer comments on the research at the University of Colorado and upon the overall U.S. research program. He prepared reports pertinent to Tasks 3.1(a) and 6.2 which have been published and distributed (12, 13).

Dr. M.J. N. Priestley of the University of Cantebury in New Zealand spent approximately two weeks in the U.S. for the purpose of consulting on the research plans for Tasks 2.1(a), 3.2(b), and 6.1. His time was spent equally between Boulder and San Diego. Meetings with Dr. Priestley were attended by Tulin, Shing, Atkinson, Hegemier, Seible, Woodward, Ewing and Noland. The results of the meetings are reflected in the research plans for Tasks 3.1 (a), 3.1 (b), and 6.2.

Dr. Priestley subsequently joined the faculty at the University of California-San Diego. He is now a member of TCCMAR and is the P.I. for Task 4.1.

Alf Waldum of the Norwegian Building Research Institute visited Boulder, CO for approximately two weeks in late summer 1986 to become acquainted with the TCCMAR program and masonry research at the University of Colorado. Mr. Waldum has been instrumental on the recent introduction of reinforced masonry in Norway.

Tamas Balogh of the Hungarian Institute for Building Science was visiting at the University of Illinois in 1987 with attention to the masonry research under Dr. Abrams. He attended the TCCMAR meeting at Salt Lake City in January 1988.

Alkut Aytun, Head of the Structural Systems Research Department, Scientific and Technical Research Council of Turkey stopped briefly in Boulder during June 1988 to review the U.S. Program.

Professor Georgio Macchi and Michele Calvi of the University of Pavia, Italy visited the University of California-San Diego in August 1987 to review the TCCMAR research there and the Powell Laboratory. Dr. Calvi attended the TCCMAR meeting in La Jolla and presented a review of a new shear wall testing apparatus at the University of Pavia. An agreement was reached to set up a cooperative program between University of California-San Diego and the University of Pavia to study masonry and concrete shear wall behavior and to exchange personnel.

10.0 U.S.-JAPAN RESEARCHER EXCHANGE

Direct contact other than at formal joint meetings with Japanese counterparts has been a valuable component of the U.S. program. Among the exchanges made are the following:

Dr. Masaomi Teshigawara (BRI-Tsukuba, Japan) spent the fall of 1985 in the U.S. primarily at the University of Colorado. He involved himself in both Tasks 3.1(a) and 6.2 and was helpful in relating the Japanese experiences on the subjects of these Tasks.

Arrangements were made for Dr. Teshigawara to visit several U.S. organizations concerned with masonry, i.e., NCMA, BIA, NBS, University of Illinois-Urbana, PCA as well as the University of California in San Diego and Berkeley.

Dr. Frieder Seible spent an extra week in Japan immediately prior to the joint U.S.-Japan meeting in August 1985 to review the large-scale test facilities. This was done to discover any information which could affect the design of the large-scale test laboratory which has been built at UCSD.

Dr. Osamu Senbu visited the U.S. in August-September 1986. Arrangements were made for him to stay in Boulder and to subsequently attend the joint meeting in September in Keystone, Colorado.

Hart, Kariotis, Ewing and Noland visited BRI for two days in May 1986 as a stop-over on the way to a NSF-sponsored U.S.-China masonry structures meeting in Harbin, China. It was an opportunity to review Japanese test results and to continue with arrangements for the next joint U.S.-Japan meeting to be held in September 1986.

Dr. Kyle Woodward visited BRI for two weeks in June-July 1986 to investigate, in detail, the experimental equipment, instrumentation, data acquisition, etc., in use there for large scale testing. This was done to support planning of the experimental equipment acquisition for the laboratory at UCSD and planning of the large-scale masonry tests to be done there.

Dr. Frieder Seible was the recipient of a Japanese government research award and of additional support by the Japanese industry to support a four-month residency at the Building Research Institute, Tsukuba, Japan from mid-August 1987 to mid-December 1987. This enabled him to observe and participate in the Japanese tests of a full-sized masonry building. His experience will greatly benefit the U.S. in its tests of a full-sized five story building specimen in 1990.

11.0 TECHNOLOGY TRANSFER

The technology developed, data, and other findings which result from a research program must be made available to the public for use in an active manner to have the greatest utilization possible. For a program such as this, which extends over a substantial period of time, it is appropriate that the results be documented and released as an on-going activity in addition to the documentation and dissemination which will occur at the completion of the work.

The Technology Transfer component which has been defined for the program consists of the following (see also Section 3.3.3):

A. Task Reports - One or more reports are prepared for each Research Task comprising the Coordinated Program. Task Reports are complete technical research reports. Each Task Report is a "stand-alone" document and fully describes the subject of the report. In the case of reports on experimental research, all pertinent data is included in a clear and understandable form. Copies of Task Reports are distributed initially to about 75 concerned individuals. Arrangements have been made to furnish the Earthquake Engineering Research Library at UC-Berkeley with copies of all Task Reports which have been and will be released.

B. Papers - Papers published in technical journals and conference proceedings are an important part of technology transfer because they focus on individual issues and are more widely read than larger documents. TCCMAR researchers have and will continue to prepare such papers.

Arrangements have been made to provide complete copies of proceedings of all the meetings of the Joint U.S.-Japan Technical Coordinating Committee on Masonry Research to the Earthquake Engineering Research Library at UC-Berkeley.

C. Presentations - Presentations on various aspects of the Coordinated Program to professional, code, industry, and other concerned groups are encouraged and many have been and will continue to be, made. Typically, no papers are associated with presentations, but some material may be distributed.

D. Seminars & Workshops - Participation in seminars and workshops is another form of Technology Transfer which is encouraged because of the more in-depth communication which can occur. Some participation has occurred, and more is anticipated.

E. Topical Reports - Reports will be prepared on each basic topic addressed in the Program and will be a treatise on the subject. Topical Reports are discussed more fully in Section 3.3.3.

F. Technical Summary Report - The Technical Summary Report, to be prepared late in the program, will present basic technical findings and conclusions and sufficient supporting data to substantiate them. Topical Reports will be the primary references, but Task Reports will be listed if additional detail is required.

G. Design and Criteria Recommendations - Recommendations for reinforced masonry building design and criteria will be formulated documented in a manner suitable for review and adoption by code bodies. Recommendations will also be made for standard tests which provide masonry material properties.

11.1 Papers (Published and Presented)

Following is a list of papers, published in technical journals or conference proceedings, that have resulted from the Coordinated Program. The proceedings from the four JTCCMAR meetings are available through the Earthquake Engineering Research Library, Berkeley, California.

Title/Publication	Author/s	Related Task
"A Study and Comparison of the Compressive Stress-Strain Behavior of Concrete and Clay Masonry", Proc. - 1st meeting of JTCCMAR, Tokyo, Aug. 1985	R.H. Atkinson G.R. Kingsley	1.1
"Stress-Strain Behavior of Grouted Hollow-Unit Masonry", Proc. - Third ASCE Engineering Specialty Conference on Dynamic Response of Structures, UCLA, April 1986	R.H. Atkinson G.R. Kingsley	1.1
"Comparison of the Behavior of Clay and Concrete Masonry in Compression", Proc. - Fourth Canadian Masonry Symposium, Fredericton, N.B., June 1986	R.H. Atkinson G.R. Kingsley	1.1
"Material Properties of Grouted Block Masonry in Compression", Proc. - Third Meeting of JTCCMAR, Tomamu, Oct. 1987	A. Hamid G. Assis H. Harris	1.2(a)
"Comparison Behavior of Grouted Block Masonry - Preliminary Results", Proc. - Fourth NAMC, UCLA, August 1987	A. Hamid G. Assis H. Harris	1.2(a)
"Compressive Stress Distribution of Grouted Hollow Brick Masonry", Proc. - 8th IBMAC, Dublin, Sept. 1988, also Proc. - Fourth Meeting JTCCMAR, San Diego, Oct. 1988	R. Brown J. Young	1.2(b)
"Properties of the Compressive Stress Distributions of Grouted Hollow Clay Masonry", Proc. - Fourth NAMC, UCLA, Aug. 1987, also Proc. - Second Meeting of JTCCMAR, Keystone, CO, Sept. 1986	R. Brown	1.2(b)
"A Finite Element Computer Program for the Nonlinear Static Analysis of Reinforced Masonry Walls", Proc. - 8th IBMAC, Dublin, Sept. 1988	R. Ewing A. El-Mustapha J. Kariotis	2.2

Title/Publication	Author/s	Related Task
"Correlation of Finite Element Analysis and Experiments on Reinforced Masonry Walls", Proc. - 8th IBMAC, Dublin, Sept. 1988, also Proc. - Fourth Meeting of JTCCMAR, San Diego, Oct. 1988	R. Ewing A. El-Mustapha J. Kariotis	2.2
"Force-Deformation Models for Reinforced Masonry Buildings: Preliminary Plan", Proc. - Second Meeting of JTCCMAR, Keystone, CO. Sept. 1987	R. Ewing	2.2
"A Nonlinear Dynamic Lumped Parameter Model for Reinforced Masonry Structures", Proc. - 8th IBMAC, Dublin, Sept. 1988	J. Kariotis A. El-Mustapha R. Ewing	2.3
"Dynamic Response of Building Systems with Reinforced Masonry Shear Walls", Proc. - 8th IBMAC, Dublin, Sept. 1988	J. Kariotis A. El-Mustapha R. Ewing	2.3
"Analytical Modeling for Reinforced Masonry Buildings and Components--TCCMAR Category 2 Program", Proc. - Fourth NAMC, UCLA, Aug. 1987, also Proc. - Third Meeting of JTCCMAR, Tomamu, Oct. 1987	R. Ewing J. Kariotis R. Englekirk G. Hart	2.1 2.2 2.3
"Generation of Sequenced Displacements for Experimental Testing of Reinforced Masonry by a Nonlinear Dynamic Model", Proc. - Fourth Meeting of JTCCMAR, San Diego, Oct. 1988	J. Kariotis A. El-Mustapha R. Ewing	2.2 2.3
"Response of Reinforced Masonry Story-Height Walls to Fully Reversed In-Plane Loads", Proc. - Fourth Meeting of JTCCMAR, San Diego, Oct. 1988	P. Shing J. Noland H. Speah E. Klamerus	3.1(a)
"Inelastic Behavior of Masonry Wall Panels Under In-Plan Cyclic Loads", Proc. - Fourth NAMC, UCLA, Aug. 1987	P. Shing J. Noland H. Speah E. Klamerus	3.1(a)
"Tests of Reinforced Masonry Wall Panels Under In-Plane Cyclic Loads", Proc. - Third Meeting of JTCCMAR, Tomamu, Oct. 1987	P. Shing J. Noland H. Speah E. Klamerus	3.1(a)
"Inelastic Behavior of Reinforced Masonry Shear Walls Under In-Plan Cyclic Loads", M.S. Thesis, University of Colorado-Boulder, Dec. 1987	H. Speah	3.1(a)
"Seismic Performance of Reinforced Masonry Shear Walls", Proc. - Ninth WCEE, Tokyo-Kyoto, Aug. 1988.	P. Shing H. Speah E. Klamerus J. Noland	3.1(a)

Title/Publication	Author/s	Related Task
"Experimental and Analytical Evaluation of the Inelastic Behavior of Reinforced Masonry Shear Walls", MS Thesis, University of Colorado-Boulder, July 1988	E. Klamerus	3.1(a)
"Behavior of Single-Story Reinforced Masonry Shear Walls Under In-Plane Cyclic Lateral Loads", Proc. - Fourth Meeting of JTCCMAR, San Diego, Oct. 1988	P. Shing E. Klamerus M. Schuller J. Noland	3.1(a)
"Inelastic Behavior of Concrete Masonry Shear Walls", Journal of Structural Engineering, ASCE (accepted for publication)	P. Shing E. Klamerus H. Speah J. Noland	3.1(a)
"Full-Scale Structural Testing", Concrete International, ACI, July 1986	F. Seible G. Hegemier	3.1(b) 9.3/9.4
"Analytical Models for the Evaluation of Shear Walls with Openings", Proc. - Second Meeting of JTCCMAR, Keystone, Sept. 1986	F. Seible H. LaRovere	3.1(b)
"From Materials and Components to Masonry Prototype Structures; The TCCMAR-U.S. Experimental Program", Proc. - Fourth NAMC, UCLA, Aug. 1987, also Third Meeting of JTCCMAR, Tomamu, Oct. 1987	F. Seible G. Hegemier	Categories 1,3,4,5,6, 7, & 9 Tasks
"Modeling of Reinforced Masonry Components and Subassemblages", Proc. - Fourth Meeting of JTCCMAR, San Diego, Oct. 1988	F. Seible H. LaRovere Z. Friedman	3.1(b) 2.1 2.2
"Preliminary Report on Testing of Specimen 2a, TCCMAR Task 3.1(c): In-Plane Seismic Resistance of Two-Story Concrete Masonry Walls with Openings", Proc. - Fourth Meeting of JTCCMAR, San Diego, Oct. 1988.	A. Antrobus G. Leiva H. Merryman R. Klingner	3.1(c)
"Nonlinear Response of Reinforced Block Masonry Walls Under Out-of-Plane Cyclic Loading", Proc. - Fourth Meeting of JTCCMAR, San Diego, Oct. 1988	A. Hamid M. Hatern H. Harris B. Abboud	3.2(a)
"Some Potential Problems Associated with Dynamic Testing of Slender Walls", Proc. - Second Meeting of JTCCMAR, Keystone, CO, Sept. 1986	S. Adham	3.2(b1)
"The Transverse Dynamic Response of Clay Masonry Walls - Progress Report", Proc. - Fourth Meeting of JTCCMAR, San Diego, Oct. 1988	B. Sveinsson R. Mayes M. Bondet	3.2(b2)

Title/Publication	Author/s	Related Task
"Out-of-Plane Dynamic Response of Clay Masonry Walls", Proc. - SEAOC Conference, Hawaii, Oct. 1988, also Fourth Meeting of JTCCMAR, San Diego, Oct. 1988	B. Sveinsson M. Blondet R. Mayes	3.2(b2)
"The Transverse Response of Clay Masonry Walls Subjected to Strong Motion Earthquakes - Preliminary Results from Static Tests", Proc. - Third Meeting of JTCCMAR, Tomamu, Oct. 1987	B. Sveinsson R. Mayes M. Blondet	3.2(b2)
"Out-of-Plane Response of Masonry Walls to Seismic Loads", Proc. - Fourth NAMC, UCLA, Aug. 1987	B. Sveinsson T. Kelly R. Mayes L. Jones	3.2(b2)
"The Transverse Response of Clay Masonry Walls Subjected to Strong Motion Earthquakes - Research Plan", Proc. - Second Meeting of JTCCMAR, Keystone, CO, Sept. 1986	B. Sveinsson T. Kelly R. Mayes	3.2(b2)
"Diaphragm Floor Slabs for TCCMAR Study", Proc. - Third Meeting of JTCCMAR, Tomamu, Oct. 1987, also Proc. - Fourth Meeting of JTCCMAR, San Diego, Oct. 1988	M. Porter C. Ekberg R. Meyer P. Temel	5.1
"Sequential Phased Displacement (SPD) Procedure for TCCMAR Testing" Proc. - Third Meeting of JTCCMAR, Tomamu, Oct. 1987	M. Porter	3.1(a & c) 3.2(a, b2) 5.1 5.3 9.3/9.4
"Length of Lap Spliced Reinforcement in Masonry Structures", Proc. - 8th IBMAC, Dublin, Sept. 1988	Z. Soric L. Tulin	6.2
"Analytical Study of Bond Stress/Slip in Masonry Reinforced with Spliced Reinforcement", Proc. - Third Meeting JTCCMAR, Tomamu, Oct. 1987	Z. Soric L. Tulin	6.2
"Bond Stress and Slip in Masonry Reinforced with Spliced Reinforcement", The Masonry Society Journal, Jan.-June 1987	Z. Soric L. Tulin	6.2
"Bond and Splices in Reinforced Masonry", Proc. - Fourth NAMC, UCLA, Aug. 1987	Z. Soric L. Tulin	6.2
"Comparison Between Predicted and Observed Responses for Bond Stress and Relative Displacement in Reinforced Concrete Masonry", Proc. - Fourth NAMC, UCLA, Aug. 1987	Z. Soric L. Tulin	6.2

Title/Publication	Author/s	Related Task
"Analytical Bond Stress/Slip Model for Reinforced Masonry", Proc. - Fourth NAMC, UCLA, Aug. 1987	Z. Soric L. Tulin	6.2
"Measured Hysteresis in a Masonry Building System", Proc. - Third U.S. Conference on Earthquake Engineering, Charleston, Aug. 1986	D. Abrams	7.1
"Lateral Resistance of a Two-Story Reinforced Concrete Block Building", Proc. - Session on Advances in Analysis of Structural Masonry, ASCE Structures Congress, Sept. 1986	D. Abrams	7.1
"Dynamic and Static Testing of Reinforced Concrete Masonry Structures", Proc. - Ninth WCEE, Tokyo-Kyoto, Aug. 1988	D. Abrams	7.1
"Dynamic Testing of One Quarter Scale Reinforced Concrete Masonry Building Structures", Proc. - Fourth Meeting of JTCCMAR, San Diego, Oct. 1988	D. Abrams T. Paulson	7.1
"Dynamic and Static Testing of Reinforced Concrete Masonry Structures", Journal of The Masonry Society, Dec. 1988	D. Abrams	7.1
"Technology Transfer, Limit State Design and the Critical Need for a New Direction in Masonry Code Design Criteria", Proc. - Fourth NAMC, UCLA, Aug. 1987	G. Hart	8.1
"Limit State Design Criteria for Minimum Flexural Steel", Proc. - Fourth NAMC, UCLA, Aug. 1987	G. Hart A. Basharkhah G. Zorapapel	8.1
"Design of The Research Building", Proc. - Second Meeting of JTCCMAR, Keystone, CO, Sept. 1986	J. Kariotis A. Johnson	9.1
"Evaluation of the Loading System of the Japanese 5-Story Full-Scale Masonry Research Building", Proc. - Third Meeting of JTCCMAR, Tomamu, Oct. 1987	F. Seible Y. Yamazaki M. Teshigawara	9.3/9.4
"The Japanese 5-Story Full-Scale Reinforced Concrete Masonry Test--Design and Construction of the Test Building", The Masonry Society Journal, July-Dec. 1987	F. Seible T. Okada Y. Yamazaki M. Teshigawara	9.3/9.4
"The Japanese 5-Story Full-Scale Reinforced Concrete Masonry Test--Loading and Instrumentation of the Test Building", The Masonry Society Journal, July-Dec. 1987	F. Seible Y. Yamazaki T. Kaminosono M. Teshigawara	9.3/9.4

Title/Publication	Author/s	Related Task
"U.S.-Japan Coordinated Program on Masonry Research", Proc. - Third Conference on Dynamic Response of Structures, ASCE, March 31-April 2, 1986, also Proc. - Fourth Canadian Masonry Symposium, University of New Brunswick, June 1986	S. Okamoto J. Noland	11.1
"A Review of the U.S. Coordinated Program for Masonry Building Research", Proc. - Fourth NAMC, UCLA, August 1987, also Proc. - Third Meeting of JTCCMAR, Tomamu, Oct. 1987	J. Noland	11.1
"U.S. Coordinated Program for Masonry Building Research-1986/1987", Proc. - 19th Joint Meeting UJNR Panel on Wind and Seismic Effects (May 1987), Center for Building Technology, NBS, published January 1988	J. Noland	11.1
"Status of the U.S. Coordinated Program for Masonry Building Research", Proc. - Fourth Meeting of JTCCMAR, San Diego, Oct. 1988	J. Noland	11.1
"Current Status of the U.S. Coordinated Program for Masonry Building Research", Proc. - 20th Joint Meeting UJNR Panel on Wind and Seismic Effects (May 1988), Center for Building Technology, NIST, (to be published)	J. Noland	11.1

11.2 TASK REPORTS

Following is a list of Task Reports that have been generated to date. All are available through the Earthquake Engineering Research Library, Berkeley, California.

Task No. Author/s - Title

1.1-1: Atkinson, R.H. and Kingsley, G.R., Comparison of the Behavior of Clay & Concrete Masonry in Compression, September 1985.

1.2(a)-1: Hamid, A., Assis, G., Harris, H., Material Models for Grouted Block Masonry, August 1988

1.2(b)-1: Young, J.M., Brown, R.H., Compressive Stress Distribution of Grouted Hollow Clay Masonry Under Strain Gradient, May 1988

2.1-1: Hart, G. and Basharkhah, M., Slender Wall Structural Engineering Analysis Computer Program (Shwall, Version 1.01), September 1987.

2.1-2: Hart, G. and Basharkhah, M., Shear Wall Structural Engineering Analysis Computer Program (Shwall, Version 1.01). September 1987.

2.1-3: Nakaki, D. & Hart, G., Uplifting Response of Structures Subjected to Earthquake Motions, August 1987.

2.3-1: Ewing, R.; Kariotis, J.; El-Mustapha, A., LPM/I, A Computer Program for the Nonlinear, Dynamic Analysis of Lumped Parameter Models, August, 1987.

2.3-2: Ewing, R., El-Mustapha, A., Kariotis, J., Influence of Foundation Model on the Uplifting of Structures, July 1988

3.1a-1: Scrivener, J., Summary of Findings of Cyclic Tests on Masonry Piers, June 1986.

3.1b-1: Seible, F. and LaRovere, H., Summary of Pseudo Dynamic Testing, February 1987.

4.1-1: Limin, H., Preistley, N., Seismic Behavior of Flanged Masonry Shear Walls, May 1988

4.2-1: Hegemier, G. Murakami, H., On the Behavior of Floor-to-Wall Intersections in Concrete Masonry Construction: Part I: Experimental

4.2-2: Hegemier, G., Murakami, H., On the Behavior of Floor-to-Wall Intersections in Concrete Masonry Construction: Part II: Theoretical

6.2-1: Scrivener, J., Bond of Reinforcement in Grouted Hollow-Unit Masonry: A State-of-the-Art, June 1986.

6.2-2: Soric, Z. and Tulin, L., Bond Splices in Reinforced Masonry, August 1987.

8.1-1: Hart, G., A Limit State Design Method for Reinforced Masonry

9.1-1: Kariotis, J.C., Johnson, A.W., Design of Reinforced Masonry Research Building, September, 1987

9.2-1: Seible, F., Report on Large Structures Testing Facilities in Japan, September 1985.

9.2.2: Seible, F., Design and Construction of the Charles Lee Powell Structural Systems Laboratory, November 1986.

9.2.3: Seible, F., The Japanese Five-Story Full Scale Reinforced Masonry Building Test, January 1988.

11.1-1: TCCMAR, Summary Report: U.S. Coordinated Program for Masonry Building Research, September 1985 to August 1986.

11.3 PRESENTATIONS

Presentations have been made at several industry and professional meetings to describe the nature and content of the U.S. Coordinated Program for Masonry Building Research as well as of specific research topics which are part of the program. Presentations were made at the following meetings:

Abrams: Poster Session, Fourth NAMC, UCLA, August 1987.

University of Illinois CE Dept. Seminar, September 1987

Annual Convention of the International Masonry Institute, St. Louis, November 1987.

Kardelja University, Ljubljana, Yugoslavia, December 1988.

ZRMK Institute, Ljubljana, Yugoslavia, December, 1988.

Gradevinski Institute, University of Zagreb, Yugoslavia, December 1988.

Brown: Meeting of the Upper South Carolina Mason Contractors Association, Greenville, SC, Oct. 1985.

University Professors Masonry Workshop, sponsored by TMS, BIA, & NCMA, Boulder, CO, April 1988.

University Professors Masonry Workshop, sponsored by TMS, BIA, & NCMA, North Carolina State University, Raleigh, NC, Oct. 1988.

Hart: Ninth WCEE, Kyoto, August 1988.

National Science Foundation Seminar, May 1988 (with Noland).

Structural Engineers Association of San Deigo Student Night, San Diego, May 1988.

U.S./Japan Cooperative Research Seminar, Haikaido, Sept. 1987.

U.S./China Masonry Workshop, Harbin, May 1987.

Engineers Week, California State University, Los Angeles, April, 1987.

Concrete Masonry Association of California-Nevada, Annual Meeting, May 1986 and May 1988.

Klingner: Poster Session, Fourth NAMC, UCLA, Aug. 1987.

Associated Masonry Contractors of Houston, Sept. 1987.

International Council for Building Research (CIB), Stockholm, Sept. 1987.

Soviet Delegation/project working Group 10.04 Construction in Seismic Areas, May 1988.

Board of Directors, Brick Institute of Texas, July 1988.

Gradevinski Institute, Zagreb, Yugoslavia, Sept. 1988.

International Council for Building Research (CIB) Austin, TX, Oct. 1988.

Mayes: Annual Meeting, Western States Clay Products Association, 1987, 1988.

Annual Convention, Structural Engineers of California, Hawaii, 1988.

Noland: First Joint U.S.-Japan Masonry Workshop - Tsukuba, Japan, March, 1984.

Concrete Masonry Association of California and Nevada, Lake Tahoe, September, 1984.

Western States Clay Products Association, Seattle, October 1984.

Masonry Research Foundation, July 1985.

First Joint Technical Coordinating Committee on Masonry Research, Tokyo, Japan, August 1985.

ASCE Structures Congress, Chicago, September 1985.

ASCE Conference on Dynamic Response of Structures, UCLA, March 1986.

Concrete Masonry Association of California and Nevada, Monterey, September 1986.

Second Meeting of the Joint Technical Coordinating Committee on Masonry Research, Keystone, CO, USA, October, 1986.

Fourth North American Masonry Conference, UCLA, August, 1987.

Structural Engineers Association of California, San Diego, CA, October, 1987.

Third Meeting of the Joint Technical Coordinating Committee on Masonry Research, Tomamu, Japan, October, 1987.

Masonry Structures Design Course, U.S. Army Engineers
Savannah, GA, April 1987
Fort Worth, TX, July 1987
Huntsville, AL, May 1988.

National Science Foundation, Washington D.C. (with Hart), April 1987.

20th Meeting of UJNR Panel on Wind and Seismic Effects, Gaithersburg, MD, May 1988.

TMS - Masonry Industry Meeting on Strength Design of Masonry, Los Angeles, July 1988.

Technical Session of ASTM Committee E6, Toronto, October 1988.

Porter: Seminar in Structural Engineering, Iowa State University, March 1986.

UJNR meeting, May 1986.

Masonry Institute of Iowa, 1986.

Priestley: Seismic Design Seminar on Concrete and Masonry Structures, UCSD, June 1988.

Seible: Academic Honors Program, UCSD, Nov. 1985.

Seminar sponsored by the County of Riverside Dept. of Health, Sept. 1986.

MTS Corporation Seminar, Minneapolis, Sept. 1986.

Structural Engineers of San Diego meeting at UCSD, Oct. 1986.

EERI Annual Meeting, San Diego, Feb. 1987.

California Building Officials Annual Meeting, San Diego, Feb. 1987 (with G. Hegemier).

Building Inspector Program, San Diego State University, Feb. 1987.

General Membership Meeting, ASCE, May 1987.

North San Diego County Section AIA and North County Civil Engineers and Land Surveyors Association, Joint Meeting, San Diego, May 1987.

Second Japan Masonry Forum, Sapporo, Oct. 1987.

Association of Independent Insurance Agents and Brokers of San Diego, San Diego, Jan. 1988

American Society of Mechanical Engineers, April 1988.

Seismic Design Seminar, UCSD, April 1988.

Structural Engineering and Solid Mechanics Seminar, UCSD, October 1988.

Shing: Structural Group - ASCE, Colorado Section, Feb. 1987.

Seminar, Dept. of Civil Engineering, University of Wyoming, July 1986.

Western States Clay Products Association annual meeting, Sept. 1988.

12.0 REFERENCES

1. Uniform Building Code, International Conference of Building Officials, Whittier, CA 1985.

2. Schneider, R., and Dickey, W., "Reinforced Masonry Design," second ed., Prentice Hall, 1987.

3. Proceedings of the North American Masonry Conference, Noland and Amrhein, ed., Boulder, Colorado, August 1978.

4. Proceedings -- Conference on Masonry Research in Progress, Noland and Amrhein, ed., Boulder, Colorado, May 1980.

5. Proceedings of the Second North American Masonry Conference, Colville and Vannoy, ed., College Park, MD August 1982.

6. Proceedings of the Third North American Masonry Conference, Matthys and Borchelt, ed., Arlington TX, June 1985.

7. Proceedings of the Fourth North American Masonry Conference, Kariotis and Hart, ed., Los Angeles, CA, 1987.

8. Resolution of the Fifteenth Joint Meeting, U.S.-Japan Panel on Wind and Seismic Effects -- UJNR, March 17-20, 1983.

9. Resolutions of the first Workshop on the U.S.-Japan Masonry Program -- UJNR, March 17, 1984.

10. Report of the Task Committee on Large Scale Testing Program -- UJNR, May 17, 1984.

11. Ewing, R.D. Kariotis, J,C., Englekirk, R.E., and Hart, G.C. "Analytical Modeling for Reinforced Masonry Buildings and Components - TCCMAR Category 2 Program", Proc. Fourth North American Masonry Conference, UCLA 1987 Paper #39. Published by The Masonry Society.

12. "Development of a Data Base for Compressive Stress-Strain Behavior of Masonry" NSF Project/Grant #CES-8806180 in progress. R.H. Atkinson, P.I.

APPENDIX 1

RESEARCH TASK SUMMARY
AND
STATUS REPORTS

APPENDIX 1. RESEARCH TASK SUMMARY AND STATUS REPORTS

INTRODUCTION

The following sections describe, in some detail, the current status of each task in the U.S. Coordinated Program for Masonry Building Research. Each section contains a short project summary, and a description of its contribution to the Coordinated Program and to the design and construction industry as a whole. The project status is then outlined in terms of work completed to date, work remaining, technical problem areas, dissemination of results, and budget status. Finally, the contribution of the research to the funding of students and the completion of their degrees is described in a section titled "Academic Component".

Much of the information in these sections has been summarized in Tables 4 and 6 of this document.

TCCMAR/US

Task Status Report

Date: November 1988

Category: 1

Task No.: 1.1

Task Title: Preliminary Studies

Principal Investigator: R.H. Atkinson

1.0 Project Summary

In the United States both hollow clay and concrete block units are used in reinforced masonry construction. Present working stress design codes make no distinction between the two types of masonry, thus implicitly assuming that they have identical properties. Most masonry research studies, however, have limited their efforts to only one type of masonry with only a very few studies investigating both materials simultaneously under similar conditions. Thus the degree to which clay unit and concrete block masonry have common engineering behavior characteristics has not been established.

The principal objectives of the research study were: 1) to conduct parallel compression tests on clay and concrete masonry prisms under identical conditions of manufacture and testing, and to determine the degree to which these two materials exhibit common engineering behavior characteristics, and 2) to obtain the complete stress-strain curves for masonry in compression. Secondary objectives of this study were to provide data on materials to be used and to establish standardized test procedures to be followed by all U.S. investigators in the joint U.S.-Japanese Coordinated Masonry Research Program.

The experimental program consisted of ten series of tests, each including five clay and five concrete prisms, in which one parameter was changed for each series. The prisms were tested in uniaxial compression in a stiff, servo-controlled test machine to strains well beyond the strain at ultimate strength.

2.0 Research Justification

The prism test constitutes the principal means to characterize the structural load carrying properties of masonry. This test is currently used for design, quality control and for research purposes. In spite of the wide use of this test method, understanding to what extent test results reflect the true material behavior of masonry is limited and subject to differing opinions. The composite nature of masonry which is composed of mortar, units, grout and steel produces a deformation and failure phenomenology far more complex than reinforced concrete, for example.

In particular the strain behavior of masonry as it is loaded in compression to peak load resistance and into the post-peak stress range was virtually unknown at the time this program began. The only available data on the complete stress-strain curve was on masonry tested in New Zealand and the applicability of this to the U.S. was questionable due to differences in constitutive materials.

So long as the U.S. used the working stress design approach, the lack of reliable stress-strain data was perhaps tolerable. With the proposed advancement of U.S. masonry design procedures into the limit state method, the need for understanding the complete stress-strain curve becomes critical. The strain at peak load and the characteristics of the post-peak descending branch are required to set reliable limiting strain levels in any proposed design code.

The experiments in this program were carefully designed and conducted to determine the influence of a number of material and construction variables on the complete stress-strain curve for both clay and concrete masonry. Advanced instrumentation and test control techniques were required to measure needed material behavior. The results provided the needed understanding of masonry behavior for planning TCCMAR experimental and analytical tasks.

The results also provide the only comprehensive set of data with which to evaluate the fundamental deformational behavior of modern masonry. The data provides the means to identify crack initiation, crack growth and formation of failure macro structures in terms of modern fracture mechanics theory.

3.0 Project Status

A. Work to Date:

This task is complete with the task report, "A Comparison of the Behavior of Clay and Concrete Masonry in Compression" published in September, 1985.

Test variables included: unit width, grouted or ungrouted prisms, two levels of mortar strength, loading direction and platen restraint. Complete axial stress-strain curves were obtained for each test as well as lateral strain measurements at selected locations.

The most important conclusion reached was that although clay and concrete masonry prisms loaded in compression may exhibit different failure mechanisms, the shape of the complete stress-strain curves of these two materials were essentially identical. This implies that clay and concrete hollow unit masonry may be regarded as one material for purposes of both working stress and ultimate strength design.

Additional data was obtained and conclusions presented regarding the similarities and differences of clay and concrete masonry in areas of failure mode and effects of bond pattern, mortar strength, unit size and loading direction on measured strength and stiffness.

B. Work Remaining:

None

C. Technical Problem Areas:

At the time of this project the only available servo-controlled test machine having the required 1,000,000 lbs. load capacity limited overall prism height to approximately 16 inches. Use of clay and concrete units with a height of 4" provided three bed joints in the prism and a height/minimum thickness ratio of 2.0 or greater.

Subsequent prism tests conducted for a different project on another servo-controlled testing machine allowing greater prism heights have shown that prisms having h/t ratios between 2.0 and 3.0 are affected by end restraint conditions. These later results show that strain at peak load and the post-peak response are more sensitive to the h/t ratio than peak strength levels.

4.0 Technology Transfer

4.1 TCCMAR Reports:

1. "A Comparison of the Behavior of Clay and Concrete Masonry in Compression," R. H. Atkinson and G.R.Kingsley, Report No. 1.1-1, U.S.-Japan Coordinated Program for Masonry Building Research, September 1985.

2. "A Study and Comparison of the Compressive Stress-Strain Behavior of Concrete and Clay Masonry," R.H. Atkinson and G.R. Kingsley, presented to First Joint Technical Coordinating Committee on Masonry Research, U.S.-Japan Coordinated Earthquake Research Program, Tokyo, Japan, August 26, 1985.

4.2 Conference or Journal Papers:

1. Atkinson, R.H. and Kingsley, G.R., "Stress-Strain Behavior of Grouted Hollow Unit Masonry," Proc. Third ASCE Engineering Specialty Conference on dynamic Response of Structures, UCLA, April 1986.

2. Atkinson, R.H. and Kingsley, G.R., "Comparison of the Behavior of Clay and Concrete Masonry in Compression," Proc. Fourth Canadian Masonry Symposium, Fredericton, N.B., Canada, June 1986.

4.3 Workshops and Seminars:

None

5.0 Budget Status

Award Start Date	Award End Date	Award Amount	From. F.Y.	Unspent Amount
6/1/85	7/31/88	$56,286	1985	-0-

6.0 Academic Component

One undergraduate civil engineering student at the University of Colorado was employed as a laboratory assistant on this project. Upon completion of this project the student was employed by the University on another non-TCCMAR NSF funded masonry research project. While on this second project the student was awarded a NSF Undergraduate Research Grant. This student should graduate in 1989 and has expressed interest in Graduate School studies.

TCCMAR/US

Task Status Report

Date: November 1988

Category: 1.0

Task No.: 1.2(a)

Task Title: Material Models

Principal Investigators: Drs. A.A. Hamid and H.G. Harris

1.0 Project Summary

Current American masonry codes are based on the working stress design method. In order to implement the more appropriate ultimate strength design methodology it is necessary to determine the stress-strain parameters for the compression stress block under eccentric compression loading. It is the objective of this research to establish these parameters for grouted block masonry. A unique test setup has been designed to test fully grouted block masonry prisms under compressive stress gradients. The shape of the full stress-strain curves under concentric and eccentric loadings are established. Values of the stress parameters $k_1 k_3$ and k_2 are presented in terms of extreme fiber compressive strain. The results indicate that a strength design methodology similar to that for reinforced concrete may be feasible for reinforced grouted block masonry.

2.0 Research Justification

For block masonry, no documented data on the full stress-strain relationship under eccentric compression loading is currently available in the literature. This information is critical for the development of an ultimate strength design methodology for block masonry which is urgently needed for more cost efficient masonry buildings. This development has far more reaching implications for the masonry industry in that it places reinforced masonry on the same economic advantages as other structural materials such as structural steel and reinforced concrete. During the course of this study, a unique test setup, and data acquisition system have been developed to provide a reliable data base on the compression behavior of masonry under a displacement control environment.

3.0 Project Status

A. Work to Date:

Design and verification of the test setup have been completed. Concrete prisms with a height to thickness ratio equal to that of the masonry prisms were tested under eccentric compression and the stress parameters $k_1 k_3$ and k_2 were compared to those available in the concrete literature. A good agreement was obtained which provides confidence in the test setup used in this program. A number of the masonry prisms were tested under in-plane eccentric compression. Preliminary analysis of the test results has been carried out. The values analysis of the test results has been carried out. The values of the stress parameters in terms of extreme fiber compressive strain were obtained. The results obtained so far indicate that an ultimate strength design methodology similar to that for reinforced concrete may be feasible for reinforced grouted masonry.

B. Work Remaining:

The results of the tests conducted so far indicate that the values of the stress parameters are highly sensitive to the test setup, the loading scheme and type and position of the instrumentation. Further work will be conducted to refine the testing procedure in order to minimize system dependence and to achieve a more reliable data base. Testing of the rest of the masonry prisms will be conducted. Complete data analysis will be conducted to arrive at the most probable values for the stress parameters to be used in the development of an ultimate strength design methodology for reinforced block masonry.

C. Technical Problem Areas:

Grout strength of the two phases of construction is not compatible because of the use of two deliveries of the ready mix grout which were ordered from the same plant with the same request of mix proportions. To solve this problem, it was decided to conduct more tests where a prism is cut into halves; one half to be tested under eccentric load whereas the other half will be tested under concentric load to determine appropriate f'm values. This approach will provide more accurate values of $k_1 k_3$.

4.0 Technology Transfer

4.1 TCCMAR Reports:

1. "Material Models for Grouted Block Masonry", Ahmad A. Hamid, George F. Assis, Harry G. Harris, Drexel University, August 1988.

4.2 Conference or Journal Papers:

1. Hamid, A.A., Assis, G. and Harris, H.G., "Material Properties of Grouted Block Masonry in Compression," Proceedings of the Third Meeting of the Joint Technical Coordinating Committee on Masonry Research, Tomamu, Japan, October 1987.

2. Hamid, A.A., Assis, G. and Harris, H.G. "Comparison Behavior of Grouted Block Masonry-Preliminary Results," Proceedings of the Fourth North American Masonry Conference, University of California, Los Angeles, August 1987.

4.3 Workshops and Seminars:

1. Overall U.S./TCCMAR program presented during the Fourth Canadian Masonry Symposium, Fredericton, New Brunzwick, June 1986.

2. Overall U.S./TCCMAR program presented to architects, engineers, contractors and manufacturers, 1/2-day seminar sponsored by the Delaware Valley Masonry Institute and Pennsylvania Concrete Masonry Association, Philadelphia, April 7, 1987.

5.0 Budget Status

	Award Start Date	Award End Date	Award Amount	From. F.Y.	Unspent Amount
1.	9/1/85	8/31/86	$39,939	1985	-0-
2.	9/1/86	3/31/87	$31,873	1986	-0-

6.0 Academic Component

None

TCCMAR/US

Task Status Report

Date: November 1988

Category: 1

Task No.: 1.2(b)

Task Title: Compressive Stress Distribution of Grouted Clay Masonry Under Strain Gradient

Principal Investigator: Russell H. Brown

1.0 Project Summary

The objectives of this research were to determine the properties of the compressive stress block under strain gradient of grouted hollow brick masonry for both in-plane and out-of-plane bending, and to determine load deformation relationship for compression and combined bending and compression loadings. This information was determined experimentally using prisms 16 in. wide and 24 in. high, with thicknesses varying from 4, 6, and 8 in. Determination of flexural compressive stress block properties were accomplished using a compression testing machine combined with a closed-loop actuator to produce a neutral axis in the desired location. The compressive stress block was determined for both in-plane and out-of-plane loading by positioning the actuator relative to the prism in the appropriate manner. Displacement control closed-loop feedback technology was used to control the location of the neutral axis. Monotonic tests were conducted for the compression stress block experiments. Deformation characteristics were obtained by mounting deflection transducers on all test specimens. A total of 39 test specimens were tested. An additional 16 prisms are being shipped to Dr. Hamid at Drexel University for testing using his servo-controlled apparatus which permits determination of the descending branch of the stress-strain curves.

The results will be included in mathematical models for the prediction of in-plane and out-of-plane loading for reinforced grouted and partially grouted hollow brick masonry walls.

2.0 Research Justification

Several decisions based on economic exigency will require the TCCMAR program to predict the effects of certain variables without actually testing their full-scale effects. One of these variables will be multi-story testing of structures of grouted hollow clay masonry. In order to predict the response of such structures, it is necessary to conduct tests on smaller specimens and components of both clay and concrete masonry, and to use the results of material behavior to predict the overall structural response. Only concrete masonry will be tested as a multi-story full-scale structure, hence the need to determine smaller scale material and component properties of clay masonry.

This project will establish the compressive stress-strain relationship of grouted hollow clay masonry subjected to a strain gradient. Results will be compared to those of similar tests on concrete masonry units. Essential information needed for mathematical modeling and design, such as properties of the compressive stress curve, will be established. These properties will be compared for clay masonry and concrete masonry, and will also be compared to a substantial amount of previous testing for reinforced concrete.

3.0 Project Status

A. Work to Date:

The task has been completed and a report issued. A total of 39 tests were performed: 15 consisting of in-plane loading, nine in out-of-plane loading, and 15 of concentric loading for determination of standard prism compressive strength. The test apparatus which was designed for the project was a modified Forney 600^k testing machine with servo controlled hydraulic actuators attached to provide a supplementary eccentric axial compressive load. The apparatus worked well for in-plane tests. I requested and received a six month no-cost extension in an attempt to rectify the sensitivity problem. After spending the additional time, I concluded with the assistance of our electronics staff that the out-of-plane tests could not be conducted with acceptable control accuracy. The remaining 16 prisms intended for out-of-plane testing are being shipped to Dr. Ahmad Hamid at Drexel University for testing using his servo-controlled test apparatus.

The following are the primary observations and conclusions from the research:

1. An extreme fiber compressive strain of .0025 may safely be used for hollow clay masonry. Were it not for four inch walls, this maximum, compressive strain could be increased to .003. A value of .003 has been used for many years in reinforced concrete design, and use of the same number for clay masonry could be significant in justifying other analogies to reinforced concrete.

2. Values of $k_1 k_3$ and k_2 were determined to be 0.74 and 0.37 respectively. Those values are very close to 0.7225 and 0.425 used in reinforced concrete.

3. The shape of the stress strain curve under a strain gradient is similar to that of the same material under axial compression. The axially loaded specimen has greater stiffness probably because of the Poisson effect. This relationship will permit material properties determined by uniaxial tests to be used to predict behavior under strain gradient.

4. Design of hollow grouted clay masonry may be accomplished using an equivalent rectangular stress block similar to that used in reinforced concrete design. Adjustments should be made in capacity reduction factors and/or load factors to account for differences in material property variations.

5. Failure modes of grouted hollow clay prisms under strain gradient include splitting of the face shell near the zone of extreme compression strain followed by face shell spalling. Often a column of grout remains intact after the specimen loses most of its load carrying capacity.

6. A lower value of extreme compressive strain at failure for the thinner specimens tested in-plane should be expected owing to the higher height to thickness ratio.

7. Preliminary evaluation of data obtained from similar testing of concrete masonry prisms reveals that both clay and concrete masonry are sufficiently similar in properties that a common analysis and design technique, including ultimate limit states, is likely to be possible.

B. Work Remaining:

A total of 16 prisms have been crated for shipment to Drexel University to be tested by Dr. Ahmad Hamid. Three cubes of masonry units will also be shipped. It is hoped that Dr. Hamid can test these prisms using his servo-control apparatus and obtain descending branch of the stress-strain curve.

C. Technical Problem Areas:

Out-of-plane testing could not be accomplished using the set-up originally planned. A servo-controlled primary load source and greater feedback sensitivity are required. The specimens constructed for this purpose will be tested at Drexel University either concentrically or in-plane. This will provide additional data in support of the in-plane test program.

4.0 Technology Transfer

4.1 TCCMAR Reports:

1. "Compressive Stress Distribution of Grouted Hollow Clay Masonry Under Strain Gradient", Jeffrey M. Young and Russell H. Brown, Clemson University, Civil Engineering Department, May, 1988.

4.2 Conference or Journal Papers:

1. Young, J.M. and Brown, R.H., "Compressive Stress Distribution of Grouted Hollow Brick Masonry", proceedings of the 8th International Brick/Block Masonry Conference, Dublin, Ireland, Elsevier Applied Science Publishers, Ltd., September 18-21, 1988. Also printed in the Proceedings of the 4th meeting of the Joint TCCMAR U.S.-Japan Coordinated Research Program, San Diego, California, October 17-19, 1988.

2. Brown, R.H., "Properties of the Compressive Stress Distribution of Grouted Hollow Clay Masonry", Proceedings, 4th North American Masonry Conference, University of California at Los Angeles, August, 1987. Also printed in the proceedings of the 2nd meeting of the Joint Technical Coordinating Committee on Masonry Research, September 8-10, 1986, Keystone, Colorado.

4.3 Workshop and Seminars:

1. An overview of the Technical Coordinating Committee on Masonry Research

    a) Upper South Carolina Mason Contractors Association meeting, October 21, 1985, Greenville, SC.

    b) University Professors Masonry Workshop, April 24-26, 1988, Boulder, CO.

    c) University Professors Masonry Workshop, October 3-5, 1988, North Carolina State University, Raleigh, NC.

5.0 Budget Status

The expiration date for the budget is November 30, 1988. At the time of this writing, approximately $1,000 remains in the budget. It is anticipated that this will be used for shipping costs and publication costs.

6.0 Academic Component

Jeffrey M. Young received his Master of Science degree while writing his thesis entitled, "Compressive Stress Distribution of Grouted Hollow Clay Masonry Under Strain Gradient".

Bala Socklingham worked assisting Mr. Young on this project while pursuing a Master of Science degree.

Theo Ulmer and John Allen were undergraduate civil engineering students who were supported during the summer on this project.

TCCMAR/US

Task Status Report

Date: November 1988

Category: 2

Task No.: 2.1

Task Title: Force Displacement Model

Principal Investigator: Robert E. Englekirk

1.0 Project Summary

This task of TCCMAR involves the development of pre-test and post-test analytical models. The models will be structural engineering models that are experimentally verified and capable of accurately estimating the force displacement characteristics at critical limit states. The analytical models of component members will be expanded into a multi-component system model called an SCM (Structural Component Model). This model will enable force displacement calculations to be made for structural systems using a static and/or time history dynamic analysis.

The objectives of the research are severalfold. One objective is to provide assistance to each experimental researcher in developing an independent check that the size, steel, etc. of their specimen optimizes its impact on the structural engineering community. A factor such as the minimum code steel is not always as clear cut an issue as it seems. Also, by working with the experimentalist and looking forward to Task 10, this analytical research in many cases anticipates changes in future design recommendations. For example, the 180° horizontal bending of shear steel in shear walls. Another objective of this research is the independent pre-test estimation of the loads required to achieve different limit states. As with the previous objective the intent is one of cooperative interface with the experimentalist so that together they can maximize the lessons to be learned from the test and to maximize the impact of the research on the structural engineering community. A third objective is the development of analytical equations to predict response and computer programs to calculate response that are understandable to structural engineers and that will be used by structural engineers.

2.0 Research Justification

The force displacement performance of single masonry components must be accurately predictable if the structural engineer is to have any confidence in his or her design/analysis capabilities. these models must be verified by experimental tests. Also, they must be compatible with the overall performance expectations of the seismic/building design/building construction process.

The challenge of Task 2.1 is to produce analytical models of components and systems that are accurate and at the same time meaningful to structural engineers involved in the design of masonry structures. Approximately 95% of all masonry construction is in one to three story buildings where the uncertainties associated with soil conditions, construction, seismic loading and design accuracy are much greater than for highrise buildings. The challenge is to redirect the current design related analytical models into ones that include explicit consideration of force and displacement calculation and capacity. At the same time these structural engineering analytical models must be on a firm scientific foundation and must be supported by Task 2.2's finite element studies.

3.0 Project Status

A. Work to Date:

Test planning and test data interpretation has been successfully carried out in support of the University of Colorado, in-plane wall tests. Over 16 walls have been analyzed to estimate their first cracking, first yield and maximum load limit states. In all cases where the vertical steel yielded prior to masonry crushing the order of limit states was correctly identified and the type of wall (e.g. Flexure) performance correctly defined.

A very accurate force displacement model has been developed for flexural walls subject to in-plane loads. The load at first yield and the maximum load were estimated to be within approximately 10 percent of test values. Relationships were developed for effective wall moment of inertia at first yield and also for the reduction in stiffness with increased drift ratio.

Input was provided for the design of the University of Texas coupled wall specimen. Pre-test estimation of the coupled wall tests was performed as independent input to the experimental effort.

Tall New Zealand in-plane wall tests results were reviewed and analyzed for supplemental information to TCCMAR. The test results for a masonry frame that was conducted in New Zealand were similarly analyzed. These two test reports have provided valuable supplemental material to TCCMAR and will be beneficial in the Task 10 research.

Research into the development of the system structural component model (SSCM) has begun. The reading and reviewing of the Wilson and Safferini elastic system analysis approach proposed to us by Dr. Seible is very promising as to its basic philosophy and will play an important role.

B. Work Remaining:

The final single component in-plane flexural analytical model is being completed. Shear type walls are next to be analyzed in detail.

In a companion task Dr. Priestley has prepared a pre-test report for the flanged walls. This report will be reviewed and the tests will be observed.

A major effort is anticipated for the SSCM model. Decisions will be made as to the detailed form of the model and the analysis details.

C. Technical Problem Areas:

None

4.0 Technology Transfers

4.1 TCCMAR Reports:

1. "Slender Wall Structural Engineering Analysis Computer Program" (Shwall, Version 1.01), G. Hart and M. Basharkhah, Report No. 2.1-1, September 1987.

2. "Shear Wall Structural Engineering Analysis Computer Program" (Shwall, Version 1.01), G. Hart and M. Basharkhah, September 1987.

3. "Uplifting Response of Structures Subjected to Earthquake Motions," D. Nakaki, and G. Hart, August 1987.

4.2 Conference or Journal Papers:

None

4.3 Workshops and Seminars:

1. Concrete Masonry Association of California and Nevada Annual Convention, May 1986 and May 1988.

2. US/China International Masonry Symposium, Harbin, China, May 1987.

3. Fourth North American Masonry Conference, August 1987.

4. International Brick/Block Masonry Conference, Dublin, Ireland, September 1988.

5.0 Budget Status

	Award Start Date	Award End Date	Award Amount	From. F.Y.	Unspent Amount
1.	2/1/86	1/31/87	$48,910	1986	-0-
2.	7/9/87	5/31/88	$45,830	1987	-0-
3.	--	--	$84,767	1988	-0-
4.	5/31/88	5/31/89	($139,260)	1988	$120,500
5.	--	--	($131,690)	(1989)	($131,690)
6.	--	--	($127,434)	(1990)	($127,434)

6.0 Academic Component

This task is not conducted at a university. However, two of the engineers who worked on this research effort had their MS degrees in structural engineering prior to employment. As a result of their interest in this funded research, both have decided to enroll in the UCLA Ph.D. program and will do their thesis on material related in part to this funded research.

TCCMAR/US

Task Status Report

Date: November 1988

Category: 2

Task No.: 2.2

Task Title: Analytical Models for Reinforced Masonry Components

Principal Investigator: Robert D. Ewing

1.0 Project Summary

The TCCMAR analytical research is being conducted in three integrated and coordinated tasks in Category 2, where three structural engineering modeling approaches are being developed: Structural Component Models (SCMs) in Task 2.1, Finite Element Models (FEMs) in Task 2.2, and Lumped Parameter Models (LPMs) in Task 2.3. Each of the tasks provide different, but complimentary, analytical modeling approaches that are needed to effectively investigate and evaluate the nonlinear response of typical reinforced masonry buildings. The Category 2 research will lead to experimentally validated analytical models, procedures, and guidelines for the analysis of the probable response of typical reinforced masonry buildings. The overall objective of these three coordinated tasks is to provide improved design and analysis procedures for reinforced masonry structures, as well as contribute to a better understanding of their performance.

The Task 2.2 research on FEMs has two main objectives. One main objective is to develop a nonlinear, finite element computer program for the static analysis of reinforced masonry building components subjected to in-plane loading. After being validated by experiments, the computer program will be used to provide characteristics of reinforced masonry components that have not been tested, since it is not feasible to conduct a sufficient number of tests to provide data for all modeling needs. These calculations will extend the base of available data of component characteristics needed for the development of the SCMs and LPMs. The other main objective is to participate in the development of the SCMs and LPMs through collaboration and coordination with the principal investigators in tasks 2.1 and 2.3, respectively.

2.0 Research Justification

A search of the literature for prior research findings has confirmed that the use of nonlinear finite element models is the most comprehensive analytical approach for the investigation of the limit state behavior of reinforced masonry. The current state-of-the-art on finite element analysis of reinforced concrete structures is documented in two ASCE publications; one gives the findings of an ASCE task committee and the other gives the proceedings of a joint US/Japan symposium. The research on nonlinear finite element models for reinforced concrete panels demonstrates that the models can reasonably reproduce the degrading force-displacement envelopes up to the peak strength, as well as the relative degrees of associated damage. However, the researchers reported difficulties in reproducing the post peak strength behavior. The deficiencies that were noted by some of the researchers include: objectivity, difficulty in passing over the limit points, convergence, problems associated with non-positive definite stiffness matrices, and compression behavior past peak strength.

The development of the FEM/I computer program is technically challenging, since it has to overcome many of the deficiencies that have been noted by previous researchers, as well as incorporate modeling capabilities that specifically represent the behavior observed for reinforced masonry. Therefore, the main intellectual content of the research in Task 2.2 will involve the development of a state-of-the-art nonlinear model for reinforced masonry. This will be accomplished by investigating several capabilities for the models: displacement control as the primary excitation, an initial stiffness formulation, material models that are explicitly formulated and controlled by strain (i.e., secant material moduli), preservation of Gauss point integrity, tension crack orientation adjustment after initial cracking, compression strength reduction after tensile cracking normal to the compressive strains, and degrading unloading rules. Some of these investigations are supported by research on reinforced concrete. Vecchio and Collins have shown that a compression strength reduction occurs in reinforced concrete after tensile cracking normal to the compressive stresses. Also, Peter's tests show that the final tensile cracks do not necessarily coincide with the initial cracks. When completed this modeling capability will significantly extend the state-of-the-art for modeling reinforced masonry.

The computer program will be operational on modern personal computers. This capability will make the developed technology available to a large group of interested engineers and researchers, since a large main frame computer will not necessarily be required to operate the program.

3.0 Project Status

A. Work to Date:

The work to date is described in the following paragraphs and follows the numbered phases given in Section 5.0, Budget Status.

During the first funded phase of the research, coordination with the other TCCMAR researchers was established and analytical methods and models were identified for the strain and force-deformation analysis of reinforced masonry components. Development and/or adaptation of software packages to meet these needs was initiated. This software will be distributed to the other TCCMAR researchers. Where possible, all of the software will be designed for use on the new generation of scientific personal computer (i.e., COMPAQ, Deskpro 286/386 and IBM-PC-AT compatible). With the approval of NSF, part of the approved computer budget was used to purchase a COMPAQ Deskpro 286 personal computer for these analyses. Existing computer programs were selected as the basis for the development of two of the software needs; namely,

1. A three dimensional, nonlinear, lumped parameter dynamic analysis program for use in the dynamic response studies. This program is needed to determine probable loads, as well as typical building system response to seismic loads.

2. A two-dimensional, nonlinear, static finite element program for the analysis of one-, two-, and three-story reinforced masonry piers, in-plane.

During the second funded phase of the research, a program plan for the development of the analytical models was completed, and the plan is given in the TCCMAR paper presented at the Fourth North American Masonry Conference (see Section 4.2). In addition to the overall planning of the analytical research and the coordination and collaboration with the other Category 2 research, six specific tasks were defined for Task 2.2, and they are listed below:

Task 2.2(a) - Develop Finite Element Computer Program.
Task 2.2(b) - FEM Correlation, One-Story Wall Tests.
Task 2.2(c) - FEM Correlation, Two-Story Wall Tests.
Task 2.2(d) - FEM Correlation, Three-Story Wall Tests.
Task 2.2(e) - FEM Correlation, Five-Story Building.
Task 2.2(f) - Dynamic Ductility Demands.

in the dynamic response studies was started in Task 2.3. This program is based on force-deformation properties that are being developed from experimental and analytical correlations. In addition to an existing library of linear and nonlinear elements, nonlinear elements that represent the in-plane, hysteretic response of reinforced masonry piers are needed. These elements may have flexural and shear components with separate force-deformation properties. The analytical formulation, FORTRAN programming, and PC adaptation of the three-dimensional, nonlinear lumped parameter dynamic analysis program (LPM/I) was completed and the user's guide was written (see Section 4.1). A seven parameter, hysteretic, degrading strength element was incorporated into the program using the add-on capability. This computer program has been used for the analysis of typical reinforced masonry building systems (see Sections 4.1 and 4.2). Additional nonlinear force-deformation models will be incorporated into this computer program as they are developed. Checkout of this program was accomplished using one- and two-dimensional problems with varying degrees of complexity. The checkout was made using problems with known solutions (closed-form or from other computer programs), when they were available.

Also, during the seconded funded phase of the research, the analytical basis for the two-dimensional, nonlinear, static finite element program was researched and expanded. The analytical formulation, FORTRAN programming, and PC adaptation of the two-dimensional, nonlinear, static finite element program (FEM/I) was completed (Task 2.2(a)) and the user's guide was written (see Section 4.1). An overlay or layered model is being used to represent the in-plane characteristics of the reinforced masonry and is described in the User's guide (Section 4.1) and in technical papers (Section 4.2). The masonry is represented by a model that has bimodular orthotropy, and allows tension crack orientation adjustment after initial tension cracking. The model includes tension stiffening, compression softening, and strain softening, as well as unloading. The masonry model also includes a compressive strength reduction due to tensile strains that are normal to the principal compressive strains. The reinforcement is represented by a bilinear model and includes unloading. The material models are formulated in terms of element strains. Also, the models can be displacement or force controlled. Checkout of this program was accomplished using one- and two-dimensional problems with varying degrees of complexity, and were made using problems with known solutions (closed-form or from other computer programs), when they were available. This computer program was used for the analysis of the one-story reinforced masonry piers that have been tested at the University of Colorado (Task 2.2(b)).

During the third funded phase of the research, the correlation of the nonlinear finite element analyses with the one-story walls was continued (Task 2.2(b)). Correlation calculations were accomplished using monotonic displacement controlled numerical simulations. Initial correlations with experiments on one-story reinforced masonry shear walls tested at the University of Colorado show good agreement with the overall force-displacement envelopes (i.e., not only peak force, but displacement at peak force and post peak response) measured in the tests, as well as the sequence of events leading to the final limit state. Flexural cracking, yielding of the reinforcement, and compression toe crushing was calculated and observed for the flexural type specimens. For the shear type specimens, diagonal shear cracking and yielding of the horizontal reinforcement was calculated and observed. Prediction and correlation calculations for the two-story coupled shear walls being tested at the University of Texas-Austin have been started (Task 2.2(c)), and no difficulties were encountered with the calculations. The correlation is awaiting the completion of the individual tests and receipt of the test data. The computer program is operational on modern personal computers, and the correlation and prediction calculations were made on Compaq 286/386 computers. This capability makes the developed technology available to a large group of interested engineers and researchers, since a large main frame computer is not required to operate the program.

Although the FEM/I computer program will undergo changes and improvements as the overall TCCMAR program progresses, the computer program is almost complete. We estimate that Task 2.2(a) is 85% complete, Task 2.2(b) is 30% complete, and Task 2.2(c) is 10% complete.

Coordination with the Japanese researchers was accomplished at two meetings; one in Tsukuba City, Japan (May 14-16, 1986, travel funded by another project) and one at the "Second Meeting of The Joint Technical Coordinating Committee on Masonry Research" in Keystone, Colorado (September 7-10, 1986). Coordination with the other TCCMAR researchers has continued on both analytical and experimental tasks, and analysis model needs have been revised and updated based on the developing research.

B. Work Remaining:

The correlations and predictions for the wall and building test programs need to be completed; namely,

Task 2.2(b) - One-story wall tests being conducted at the University of Colorado. This work is currently underway.

Task 2.2(c) - Two-story wall tests being conducted at the University of Texas, Austin. This work is currently underway.

Task 2.2(d) - Three-story wall tests being conducted at the University of California, San Diego.

Task 2.2(e) - Five-story building test to be conducted at the University of California, San Diego.

The FEM/I Computer program (Task 2.2(a)) will need additional capabilities for the two-and three-story wall analyses. These capabilities include a diaphragm type element, a coupling beam type element, and a representation for flanged walls. These models will be developed in conjunction with the test programs at the University of Texas, Austin, and the University of California, San Diego. Separate reports will be written for each of the wall test programs, and the user's guide will be updated as required by the new models. Following these calculations, the computer program will be used to develop response modes and limit states for a series of masonry walls subjected to bi-axial, in-plane loadings. These analyses will lead to the development of force-deformation models for the masonry components.

Additional elements for the LPM/I and the SCM programs need to be developed and incorporated into these programs. The major areas of development include improved unloading paths and strength envelopes. The element characteristics will be based on nonlinear finite element analyses.

Finally, Task 2.2(f) needs to interface with Task 2.3(g) where component distortions due to dynamic displacements will be interpreted.

Coordination with the other TCCMAR researchers will continue on both analytical and experimental tasks, and analysis models will be developed and revised as the research continues.

C. Technical Problem Areas:

The overall program plan for this analytical research, including companion Tasks 2.1 and 2.3 and the experimental tasks, has taken some time to finalize. This has delayed some of the analytical research, and the schedule has been slipped. Also, this has made interfacing with the other tasks more difficult. The main technical problem area that remains concerns the interfacing with the requirements and technical needs of the SCMs. Although there are many technical challenges remaining, we do not see any other special technical problem areas at this time other than limitations imposed by the budget.

4.0 Technology Transfer

4.1 TCCMAR Reports:

1. "Influence of Foundation Model On The Uplifting of Structures," J.C. Kariotis, A.M. El-Mustapha, and R.D. Ewing, Report 2.3-2. Ewing/Kariotis/Englekirk & Hart, So. Pasadena, CA, July 1988.

2. "FEM/I, A Finite Element Computer Program For The Nonlinear Static Analysis of Reinforced Masonry Building Components," R.D. Ewing, A.M. El-Mustapha, and J.C. Kariotis, Report 2.2-1. Ewing/Kariotis/Englekirk and Hart, Rancho Palos Verdes, CA, December 1987.

3. "LPM/I, A Computer Program For The Nonlinear Dynamic Analysis of Lumped Parameter Models," R.D. Ewing, J.C. Kariotis, and A.M. El-Mustapha, Report 2.3-1. Ewing/Kariotis/Englekirk and Hart, So. Pasadena, CA, August 1987.

4. "Analytical Modeling For Reinforced Masonry Building Components, TCCMAR Category 2 Program," J.C. Kariotis, A.M. El-Mustapha, and R.D. Ewing. Kariotis and Associates, So. Pasadena, CA, August 1987.

5. "Response Predictions For A Five-Story Reinforced Concrete Masonry Test Building," R.D. Ewing. Informal Meeting Report, U.S.-Japan Coordinated Earthquake Research Program, Tsukuba City, Japan, May 14-16, 1986.

4.2 Conference or Journal Papers:

1. Ewing, R.D., El-Mustapha, A.M., and Kariotis, J.C., "A Finite Element Computer Program For The Nonlinear Static Analysis of Reinforced Masonry Walls." 8th International Brick/Block Masonry Conference, Elsevier Applied Science Publisher, Ltd., Dublin, Ireland, September 1988.

2. Ewing, R.D., Kariotis, J.C., and El-Mustapha, A.M., "Correlation of Finite Element Analysis and Experiments on Reinforced Masonry Walls." 8th International Brick/Block Masonry Conference, Elsevier Applied Science Publishers, Ltd., Dublin, Ireland, September 1988.

3. Kariotis, J.C., El-Mustapha, A.M., and Ewing, R.D., "A Nonlinear Dynamic Lumped Parameter Model For Reinforced Masonry Structures." 8th International Brick/Block Masonry Conference, Elsevier Applied Science Publishers, Ltd., Dublin, Ireland, September 1988.

4. Kariotis, J.C., El-Mustapha, A.M., and Ewing, R.D., "Dynamic Response of Building Systems With Reinforced Masonry Shear Walls." 8th International Brick/Block Masonry Conference, Elsevier Applied Science Publishers, Ltd., Dublin, Ireland, September 1988.

5. Ewing, R.D., Kariotis, J.C., Englekirk, R.E., and Hart, G.G., "Analytical Modeling for Reinforced Masonry Buildings and Components - TCCMAR Category 2 Program." Proceedings of the Fourth North American Masonry Conference, ed. G.C. Hart and J.C. Kariotis, The Masonry Society, Los Angeles, August 1987.

6. Ewing, R.D., "Force-Deformation Models for Reinforced Masonry Buildings: Preliminary Plan." Second Meeting of The Joint Technical Coordinating Committee on Masonry Research, U.S.-Japan Cooperative Research Program, Keystone, Colorado, September 8-10, 1986.

4.3 Workshops and Seminars:

No workshops, seminars, or presentations are involved, other than the presentations associated with the technical papers listed in Section 4.2.

5.0 Budget Status

The budget status is provided in the following table:

	Award Start Date	Award End Date	From. Amount	Unspent F.Y.	Amount
1.	9/1/85	3/01/86	$58,009	1985	-0-
2.	3/1/86	8/31/87	$42,410	1986	-0-
	3/1/86	10/1/86	$78,477	1987	-0-
3.	3/1/88	3/01/88	$93,000	1988	$54,824
	--	--	($129,397)	(1989)	($129,397)
	--	--	(126,481)	(1990)	($126,481)

Note:

1. The original grant from NSF (ECE-8517021) was awarded to Agbabian Associates (AA) under the direction of Robert D. Ewing, and $58,009 was awarded to AA for the first phase of research.

2. Effective March 1, 1986, the grant was transferred to Ewing and Associates (EA) under the direction of Robert D. Ewing (ECE-8696076), and $42,410 was awarded to EA for the second phase of research.

3. Grant No. ECE-8517021 - Phase 1.
   Grant No. ECE-8696076 - Phase 2. (changed to CES-8696076)
   Grant No. CES-8722868 - Phase 3.

4. Grant No. CES-8722868 is a continuing grant which has been approved on scientific/technical merit for approximately three years. Pending awards for this grant are shown in parenthesis.

5. Unfunded flexibility periods are not included in the award dates.

6.0 Academic Component

Since this research task is being conducted by a small business, this section is not applicable to Ewing and Associates.

TCCMAR/US

Task Status Report

Date: November 1988

Category: 2.0

Task No.: 2.3

Task Title: Dynamic Response of Masonry Building Systems

Principal Investigator: John C. Kariotis

1.0 Project Summary

Task 2.3 is a part of the analytical models of reinforced masonry and is performed in close collaboration with Tasks 2.1 and 2.2 of Category 2 research. The specific research topic is the development of a series of dynamic models of masonry building systems that can estimate the nonlinear relative displacements of parts of building systems. This Task includes correlation with researchers outside of TCCMAR that are developing descriptive mapping of seismic hazards throughout the United States. The research defines the earthquake loading of reinforced masonry components by development of response models that include all construction materials that are commonly combined with reinforced masonry walls.

The objective is to define the response of masonry building systems to the earthquake hazards of the United States. The research will provide a method for correlation of the required strength of masonry components with current and proposed seismic hazard mapping. Task 2.1 and 2.2 will provide methods for determination of the nonlinear materials properties of masonry components. Task 2.3 develops this component data into dynamic response models of systems. Task 2.3 will provide the analytical tool to validate the recommendations of Task 10 and develop analytical techniques that can be used in design offices. The computational models are designed to operate on the current generation of scientific personal computers such as Compaq 286 and 386 machines. The research method is to utilize the nonlinear models developed in Task 2.1 and 2.2 Category 2 to predict the strength of nonlinear models used in Task 2.3. Task 2.3 combines the behavior of the reinforced masonry elements with the linear or nonlinear behavior of the remainder of the building system to determine system response. The research incorporates the probable earthquake motions of the seismic regions into the system response. The seismic hazard is defined by research reported in Open Files of the United States Geological Survey.

2.0 Research Justification

The research effort to quantify the seismic loading of masonry buildings has indicated that the current design of masonry buildings can be either non-conservative or over-conservative. The basic reasons for non-conservatism of current design requirements are:

1. Masonry buildings generally use floor and roof diaphragms that are flexible in comparison to the masonry shear walls. However, this relative flexibility is ignored by current design provisions and the earthquake response is assumed as that of a single-degree-of-freedom (SDOR) model in lieu of a multi-degree-of-freedom (MDOF) model.

2. The strength degradation in the post peak strength range that is common to masonry shear walls is not recognized as affecting the code required strength.

3. The influence of the seismic zoning parameters, acceleration and velocity, has not been considered in the determination of design requirements for the seismic zones of the United States.

4. Current design that are based on a single probability of annual occurrence of an earthquake ground motion and do not adequately address the frequency of occurrence of possible earthquake damage and the prediction of structural stability.

The basic reasons for over-conservatism in current design requirements are as follows:

1. Possible earthquake damage to masonry shear walls is commonly limited by foundation flexibility. The influence of this limitation of the earthquake response of masonry shear walls can be inserted into current design requirements with minor rewriting. The net result is that many masonry buildings may be properly designed for the same strength requirements as similar reinforced concrete buildings.

2. The design of masonry buildings as MDOF response models can result in a lesser required strength of the shear wall. The use of a MDOF model for this class of building will give significant improvement in the design concept for diaphragms and wall anchorages. The resultant design requirements will provide limitation of commonly observed earthquake

damage to wall anchorages and provide cost-savings in the construction of flexible diaphragms.

In addition to these benefits of the research on future seismic design requirements, the improved analyses can be readily used for the analysis of existing buildings for earthquake damage potential. Improved analyses for estimation of possible earthquake damage in existing buildings has been proven to be highly cost-effective for a program of earthquake damage reduction.

3.0 Project Status

A. Work to Date:

The research has included a study of nonlinear equivalent damping of typical foundation soils. Studies of soils modeling used by prior researchers have been completed and conclusions have been made as to the most probable soils behavior. A computational model has been developed that includes impact damping as part of the energy dissipation of the combined foundation-structure model. A paper reporting this research was presented at the July 1988 TCCMAR meeting. This paper has also been submitted for publication in the Structural Journal of the ASCE.

The studies of masonry shear wall buildings designed by national recommendations (NEHRP) indicate that foundation/structure interaction governs the response of many masonry structures with foundations of minimum embedment. The seismic design requirements were written specifically to allow such interaction. The specified strength of the structural elements above grade is required to exceed the required stability moment at the soils level. The top displacement of the soils-structure model has been investigated and the preliminary results indicate that the total top displacement of the response model is equal to or less than the top displacement of a nonlinear structural element on a flexible foundation without uplifting. This data indicates that simple design techniques can be developed that will approximate the nonlinear analyses of foundation/structure response.

The bar chart in Figure 3 of Section 3 has been revised to indicate progress to date and coordinated tasks. Task 2.3(a) has been extended to include new studies of the available data on recorded ground motions. A paper that expands on the preliminary paper presented at the July 1988 TCCMAR meeting is in preparation. Task 2.3(c) is essentially complete and parametric studies are underway to determine the sensitivity of the model to the range of material properties of bearing soils. Task 2.3(e) has been advanced in priority and is being correlated with the data developed in Task 2.3(a).

Task 2.4(a) is underway. The research performed by ABK under an NSF contract and grant is being utilized to validate the analysis model. In addition, a fully instrumented warehouse building will be used as a case study for validation of a full building model.

B. Work Remaining:

The work remaining is that shown in Figure 1, post July 1, 1988. In conjunction with the Task 2.3 research tasks, the Principal Investigator of Task 2.3 has collaborated with Task 2.2 to validate the nonlinear FEM model and has assisted in utilization of that model to make pre-experimental predictions of Category 3 Task 3.1(c) research.

C. Technical Problem Areas:

The materials behavior of reinforced masonry components tested by cyclic loading differs from monotonic test results. The dynamic model used for research must include such effects as sliding when unloading and reloading and strength degradation due to flexure and shear independently. A behavioral model that includes displacement due to all effects is being developed by correlation with the Task 3.1(a) experiments. As the nonlinear model becomes increasingly sophisticated, correlation with real components will require judgmental decisions as to the materials properties that affect the behavior. Parametric studies will have to be made to determine when more complex models do not provide comparable benefits.

4.0 Technology Transfer

4.1 TCCMAR Reports:

1. "LPM/1 A Computer Program for the Nonlinear, Dynamic Analysis of Lumped Parameter Models," Ewing, Kariotis, and El-Mustapha, TCCMAR Report 2.3.1, National Science Foundation, July 1988.

2. "Influence of Foundation Model on Uplifting of Structures," Kariotis, El-Mustapha and Ewing, TCCMAR Report 2.3.2 National Science Foundation, July 1988.

4.2 Conference or Journal Papers:

1. Kariotis, El-Mustapha, and Ewing, "Influence of Foundation Model on Uplifting of Structures," Presented at TCCMAR Napa Valley, CA, July 1988.

2. Kariotis and El-Mustapha, "Correlation of Seismic Input Utilized for Research with National Seismic Zoning Maps," Presented at TCCMAR Meeting, Napa Valley, CA, July 10-13, 1988.

3. Kariotis, El-Mustapha and Ewing, "Influence of Foundation Modeling on Uplifting of Structures," Submitted to ASCE Structural Journal, July 1988.

4. J.C. Kariotis, "End Use of Experimental Data," presented at JTCCMAR, Keystone, CO, September 1986.

5. Kariotis, El-Mustapha and Ewing, "Analytical Modeling for Reinforced Masonry Buildings and Components - TCCMAR Category 2 Program, Task 2.3 Dynamic Response of Masonry Building Systems TCCMAR Nonlinear Lumped Parameters Models (LPM), presented at La Jolla TCCMAR, August 1987.

6. Kariotis, Ewing, Hart, Englekirk, "Analytical Modeling for Reinforced Masonry Buildings and Components - TCCMAR Category 2 Program," originally presented at Fourth North American Conference, Los Angeles, CA, August 1987. Supplemented for JTCCMAR, Tomamu, Japan, October 1987.

7. "A Nonlinear Finite Element Model of Reinforced Masonry for the simulation and Extrapolation of Experimental Testing," presented at TCCMAR Meeting, Salt Lake City, UT, January 1988.

8. Ewing, El-Mustapha and Kariotis, "A Finite Element Computer Program for the Nonlinear Static Analysis of Reinforced Masonry Walls, presented at 8IBMAC, Dublin, Ireland, September 1988.

9. Ewing, El-Mustapha and Kariotis, "Correlation of Finite Element Analysis and Experiments on Reinforced Masonry Walls, presented at 8IBMAC, Dublin, Ireland, September 1988.

10. Kariotis, El-Mustapha, and Ewing, "A Nonlinear Dynamic Lumped Parameter Model for Reinforced Masonry Structures," presented at 8IBMAC, Dublin, Ireland, September 1988.

11. Kariotis, El-Mustapha, and Ewing, "Dynamic Response of Building Systems with Reinforced Masonry Shear Walls," presented at 8IBMAC, Dublin, Ireland, September 1988.

12. Kariotis, El-Mustapha, and Ewing, "Influence of Foundation Model On Uplifting of Structures," presented at TCCMAR Napa Valley, CA, July 1988.

13. Kariotis and El-Mustapha, "Correlation of Seismic Input Utilized for Research with National Seismic Zoning Maps," presented at TCCMAR Meeting, Napa Valley, CA, July 10-13, 1988.

14. Kariotis, El-Mustapha and Ewing, "Generation of Sequenced Displacements for Experimental Testing of Reinforced Masonry by a Nonlinear Dynamic Model," presented at the 4JTCCMAR Conference, October 1988.

4.3 Workshops and Seminars:

None

5.0 Budget Status

	Award Start Date	Award End Date	Award Amount	From. F.Y.	Unspent Amount
1.	10/1/85	12/31/86	$53,590	1986	-0-
2.	1/1/87	8/31/87	$41,740	1987	-0-
3.	10/1/87	3/31/88	$77,201	1988	-0-
4.	--	--	($112,029)	(1988)	($ 46,889)
	--	--	($144,225)	(1989)	($144,225)
	--	--	($150,935)	(1990)	($150,935)

6.0 Academic Component

None

TCCMAR/US

Task Status Report

Date: November 1988

Category: 2

Task No.: 2.4(a)

Task Title: Dynamic Response of Diaphragms

Principal Investigator: Max L. Porter, Ph.D., P.E.

1.0 Project Summary

This project is for a new task for the "Dynamic Response of Diaphragms". The purpose of Task 2.4(a) is to perform hysteretic modeling and response analysis for horizontal diaphragms. The analysis is also for the horizontal diaphragm interaction of out-of-plane walls. The subtask under this 2.4(a) research development includes: development of an analysis model, development of an input for walls, parametric studies of diaphragm responses, development of an interaction analysis model and the interaction analysis itself. Most of the work involved in this task will be a simple modeling of the diaphragm as coupled with the walls. The work of this Task 2.4(a) is part of the integrated task included in Category 2. The results of Category 5 TCCMAR program on the "Concrete Plank Diaphragm Characteristics" will be heavily utilized in Task 2.4(a).

Since Task 2.4(a) was just recently funded in November of 1988, only a brief description can be given for this task.

2.0 Research Justification

Buildings subjected to earthquake and wind forces must have walls and floors capable of transferring in-plane shear forces from one segment of the building to another. The dynamic response of the wall with respect to the floor diaphragm and vice versa is very important in the overall building behavior.

Adequate diaphragm action is essential for the stability of the overall masonry structure to prevent collapse. The stiffness of the floor slab will affect the amount of out-of-plane action of the walls. The relationship of the floor-to-wall interaction is extremely important in the overall building behavior in order to maintain the stability and safety of the building. The failure of either of these components in the interaction could lead to the failure of the entire structure with possible collapse and loss of life for occupants.

A means of modeling this interaction is needed for the proper design of masonry buildings. In particular, the dynamic response of the floor diaphragms coupled with the masonry walls is needed for an adequate and safe design of masonry buildings.

3.0 Project Status

A. Work to Date:

Task 2.4(a) was just recently funded in November of 1988. Consequently, only a brief amount of work has been accomplished to date; namely, the arrangement of graduate student support help and some brief interaction with the other investigators on the coordination for Category 2.

B. Work Remaining:

Essentially all of the work for Task 2.4(a) is remaining.

C. Technical Problem Areas:

Initially, one of the major problem areas will be to find an adequate model for the interaction between the dynamic response of the floors and that of the walls.

4.0 Technology Transfer

Since this project was just recently funded in November of 1988, no technology transfer has had a chance to occur as of the date of the writing of this project report.

4.1 TCCMAR Reports:

None

4.2 Conference or Journal Papers:

None

4.3 Workshops and Seminars:

None

5.0 Budget Status

The following table represents the budget status of Task 2.4(a) as of November 1988:

	Award Start Date	Award End Date	Award Amount	From. F.Y.	Unspent Amount
1.	11/1/88	03/31/90	$20,138	1988	$20,138

6.0 Academic Component

Graduate student support help is expected to carry out a significant portion of this work as indicated below:

Graduate:
Azia Sabri - Ph.D. Dissertation in progress
Francisco Yeomans - Master of Science degree thesis.

Undergraduates:
Some undergraduate support help is anticipated for data reduction as needed and to be named later.

TCCMAR/US

Task Status Report

Date: November 1988

Category: 2

Task No.: 2.4(b)

Task Title: The Transverse Response of Clay Masonry Walls Subjected to Strong Motion Earthquakes

Principal Investigator: Dr. Ronald Mayes, CES, Inc.

1.0 Project Summary

Research of masonry materials and structural components has been ongoing for many years, but with the formation of TCCMAR, it is now coordinated and focused towards an overall goal. However, the vast pool of experimental data that is now available has only been transferred in a limited way into analytical tools for the use of structural engineers to aid in the performance prediction and design of masonry structures. The development of these engineering tools is defined as one of the main goals of the overall TCCMAR program.

The objective of this task is to bridge the gap between research and analysis to provide a tool for the prediction of seismic performance of masonry structures. In particular, the program addresses the correlation and analytical modeling of out-of-plane masonry walls excited by static and dynamic motions. Various combinations of parameters from current TCCMAR out-of-plane test programs will be considered for incorporation into analytical response models. These models will form an integral part of the wall/diaphragm interaction study and also the overall structures model which are both tasks within the TCCMAR program.

2.0 Research Justification

Significant results have been obtained from the TCCMAR experimental programs on out-of-plane response of masonry walls. The tests have demonstrated that tall, slender walls with moderate to high levels of reinforcing show excellent performance during seismic disturbances. These walls, which are widely used in the United States for major athletic facilities, warehouse structures and nuclear power plants, can thus be relied upon to survive major earthquakes with only minor damage.

The experimental data has greatly extended the available knowledge on cyclic response of masonry walls loaded out-of-plane. To take full advantage of this research the next step is to develop mathematical models which will allow accurate predictions of the general out-of-plane response of masonry walls. These mathematical models will lead to the development of formulas for building response and safety predictions which will result in better and safer building codes. Consequently, the life safety of buildings relying on out-of-plane behavior of reinforced masonry walls will be enhanced.

3.0 Project Status

Progress to date on this task has been hindered by the lack of funding due to the current financial year. In spite of this handicap, the initial phase has been completed as outlined below.

A. Work to Date:

The interface between the experimental program and the commencement of the analytical work is the reduction of the experimental data. This has been the focus of the work to date. This phase has consisted of sifting the millions of data items from the test program to obtain values of the parameters which are known to be,or may prove to be, important in the subsequent development of analytical models.

The parameters extracted from the test data have consisted of the directly measurable quantities which will be included in the test report. These include the material properties and the instrumented response quantities such as wall deformations and accelerations, rebar strains, faceshell strains and gap openings. To assist in the analytical modeling a number of response quantities which are not directly measured have been computed. These include the distribution of inertial loads in the walls, the bending moment diagrams in the walls and the stiffness properties of the walls in their various states (i.e. uncracked, cracked and yielded).

The end result of this additional processing is that experimental data (e.g. strains, accelerations) have been transformed into response quantities more commonly used by structural engineers and more easily replicated by existing computer programs (e.g. lateral loads, bending moments and stiffnesses).

B. Work Remaining:

The interface between the experimental and analytical work is in place and the major effort of this task remains, the development of computer models which can duplicate the measured response of the walls. The work will require development of the finite element model, the structural component model and the lumped parameter model. At this stage initial software evaluation has been performed to determine to what extent available computer programs may be adapted. Once this process is complete, detailed modeling will commence.

C. Technical Problem Areas:

No technical problems have been encountered to date although of course the areas in which problems are most likely to be encountered are yet to begin. One area which must be addressed by the modeling group before it becomes a problem is the conception of incorporating the lumped parameter model into the overall structural model. The out-of-plane walls differ from other elements (e.g. in-plane walls, diaphragms, and foundations) in that they contribute to the load side rather than the resistance side on the equation in terms of their effect on the overall structure. The overall structural modeling procedures must take account of this.

4.0 Technology Transfer

The transfer of the technology developed by this analytical correlation will be disseminated in the form of reports, papers and presentations at selected conferences. The ultimate transfer will be in the form of design procedures incorporated into national building codes.

At this stage the data reduction is being incorporated into the TCCMAR reports from test programs. As work progresses, independent reports will be produced.

4.1 TCCMAR Reports:

None

4.2 Conference or Journal Papers:

None

4.3 Workshops and Seminars:

None

5.0 Budget Status

The table below illustrates the budget status for the correlation program as of the end of November.

	Award Start Date	Award End Date	Award Amount	From. F.Y.	Unspent Amount
1.	03/01/88	12/31/88	$29,906	1988	*
2.	01/01/89	08/31/89	$107,203	1989	$107,203

* Award amount for Task 1 not yet received by CES, Inc.

6.0 Academic Component

None

TCCMAR/US

Task Status Report

Date: November 1988

Category: 3

Task No.: 3.1(a)

Task Title: Response of Reinforced Masonry Story-Height Walls to Fully Reversed In-Plane Lateral Loads

Principal Investigator: P.B. Shing

1.0 Project Summary

Reinforced masonry construction can be frequently found in regions of high seismic activity. Shear wall panels are the major seismic load resisting elements in reinforced masonry structures. It is known that wall panels that fail in a predominantly shear mode exhibit a more brittle behavior than those dominated by flexural yielding. However, due to the complexity of the shear cracking mechanism, no rational design criteria have yet been developed to prohibit brittle shear behavior. To address this problem, twenty-two story-height reinforced masonry wall panels are being tested at the Unviersity of Colorado, as Task 3.1(a) of the TCCMAR program, to investigate the effects of various design parameters and load conditions, namely, the amount of vertical and horizontal reinforcement, and the applied axial stress on the limit-state capacities, failure mechanisms, ductilities, and energy-dissipation capabilities of masonry shear walls. To obtain a better understanding of the shear cracking mechanism, a majority of the specimens have been designed to exhibit a brittle shear behavior. The tests have been conducted with computer-controlled electro-hydraulic loading apparatus to simulate the load conditions that could be induced by earthquake excitation. The data obtained from this study are being used by other U.S. researchers of the TCCMAR program for the development and verification of mathematical models and improved seismic design recommendations.

2.0 Research Justification

Reinforced masonry is a highly anisotropic and nonhomogeneous material. In addition, for seismic resistance design, it is necessary to understand the behavior of masonry structures beyond the elastic range, such as strength, ductility, and energy-dissipation capability under large inelastic deformation. It is evident that the characterization of such behavior requires relevant experimental data as well as sophisticated mathematical models. While it has been demonstrated by prior studies that the flexural strength of a reinforced masonry wall panel can be accurately evaluated with relatively simple analytical models, no theoretical formulation has been developed to give an accurate prediction of the shear strength dominated by diagonal cracking. The shear strength of a wall panel depends on many factors, such as the tensile strength of masonry, the amount of horizontal reinforcement, the dowel action of the vertical steel, the applied axial stress, and the aggregate-interlock mechanism. These mechanisms are very difficult, if not impossible, to model with existing analytical techniques and material constitutive models. Yet, little experimental data are currently available to clarify these mechanisms. For these reasons, twenty-two reinforced masonry shear wall panels are being tested under Task 3.1(a) of the TCCMAR program. The tests are conducted under well controlled laboratory conditions with a gradual and systematic variation of each major parameter. By means of modern computer-controlled servo-hydraulic loading apparatus, the loads applied on the wall specimens are accurately controlled and varied to simulate the range of load conditions that could be induced by earthquake ground motions.

The limit-state capacities and inelastic hysteretic behavior of the wall specimens under cyclic displacement reversals are carefully monitored during the test. To enhance the understanding of wall behavior, deformations due to different mechanisms are isolated and strains at critical locations of steel reinforcement are measured. The results of these tests can be directly used to evaluate and improve the current design methodology for reinforced masonry shear walls, as well as to develop and calibrate mathematical models for predicting the inelastic behavior of wall panels.

3.0 Project Status

A. Work to Date:

Currently, about 85% of the work scheduled in this task has been completed. A total of nineteen 6-ft. by 6-ft. masonry wall specimens have been tested. Sixteen of the specimens were fabricated with 6x8x16 hollow concrete blocks and three with 6x4x16 hollow clay bricks. They were fully grouted, with uniformly distributed vertical and horizontal reinforcement. The horizontal reinforcement had 180-degree hooks around the extreme vertical steel. Each specimen had a reinforced concrete top beam and base slab. The vertical reinforcement ran continuously from the base slab to the top beam with 180-degree anchoring hooks. Bond-beam units were used throughout a wall panel to allow the placement of horizontal reinforcement and enhance the continuity of the grout. The specimens had vertical steel ratios of 0.38%, 0.54%, and 0.74%, and horizontal steel ratios of 0.14%, and 0.24%, respectively. All vertical and horizontal reinforcing bars had a uniform spacing of 16 in., except the horizontal steel in one specimen which had an 8-in. spacing.

Three servo-controlled hydraulic actuators were used to apply the axial and lateral loads to a specimen. The two vertical actuators, which were under load control, exerted a constant axial load onto a specimen during a test. The horizontal actuator controlled the in-plane lateral displacement at the top of a specimen. Each specimen was subjected to fully reversed lateral displacement cycles of gradually increasing amplitudes. Twenty-five displacement transducers were used to monitor the lateral deflection, flexural deformation, shear deformation, base slip, and base up-lift of each specimen. A strain gage was attached to each vertical reinforcing bar near the base of a specimen to monitor the strain distribution and the yielding of the steel.

Several important observations have been made in this study. First, the test results have demonstrated that reinforced masonry wall panels can exhibit a certain extent of ductility and energy-dissipation capability under cyclic displacement reversals, and are, therefore, suitable for seismic resistance design provided proper reinforcement guildelines are developed and followed. In particular, similar to previous experimental observations, wall specimens that exhibited a predominantly flexural behavior were more ductile than those dominated by diagonal shear cracking. Nevertheless, flexural ductility can be significantly reduced under high axial loads because of severe toe spalling. However, as ilustrated by some of the specimens, the use of toe confinement can substantially improve flexural ductility under high axial loads.

Brittle shear behavior dominated by diagonal cracking is undesirable and difficult to analyze. It has been found that the occurrence of the first major diagonal crack depends mainly on the tensile strength of masonry and the applied load condition, but not on the amount of reinforcement present. The postcracked shear resistance depends on the amount of both horizontal and vertical steel. Specimens with a relatively low amount of vertical steel (0.54 and 0.38) reached the ultimate resistance almost instantaneously right after the first major diagonal crack, while those with a higher amount of vertical steel (0.74%) could sustain 15 to 20% additional load. The influence of the amount of horizontal reinforcement on shear strength is not consistent. In any case, a shear specimen with a larger amount of vertical or horizontal reinforcement exhibited a better ductility and energy-dissipation capability.

Furthermore, it has been demonstrated that increasing the amount of horizontal steel can change the inelastic behavior from a brittle shear mode to a flexural mode. Increasing the axial load can change the behavior from a mixed flexural/shear mode to a brittle shear mode. Hence, axial load seems to have a more significant influence on the flexural strength than on the shear strength.

The results of this study have demonstrated the significance of different design factors on the failure mechanisms of masonry wall panels, and can be used to evaluate the adequacy of current design provisions for reinforced masonry shear walls. Furthermore, based on the results of this and previous experimental studies, inelastic finite-element models can be developed and calibrated for predicting the inelastic performance of masonry shear walls. It must, however, be realized that the inelastic behavior of a wall panel, in particular, the shear cracking mechanism, depends very much on the effective aspect ratio as well as the actual geometry of the pane. Therefore, further experimental studies and numerical experimentation with finite element models are required to acquire a better understanding of the geometry effects. Some of the analytical studies have already been conducted by other TCCMAR researchers, as well as at the University of Colorado.

B. Work Remaining:

Three clay masonry specimens remain to be tested. These specimens will be designed to exhibit a shear dominated behavior. The experimental work is expected to be completed by the end of August 1988. Final reports are currently under preparation.

4.0 Technology Transfer

4.1 TCCMAR Reports:

None

4.2 Conference or Journal Papers:

1. Shing, P.B., Noland, J.L., Spaeh, H., and Klamerus, E., "Response of Reinforced Masonry Story-Height Walls to Fully Reversed In-Plane Loads," Proceedings, Second Meeting of the Joint Technical Coordinating Committee on Masonry Research, U.S.-Japan Coordinated Program for Masonry Building Research, Keystone, CO, September 1986.

2. Shing, P.B., Noland, J.L., Spaeh, H., and Klamerus, E., "Inelastic Behavior of Masonry Wall Panels Under In-Plane Cyclic Loads," Proceedings, Fourth North American Masonry Conference, The Masonry Society, Los Angeles, August 1987.

3. Shing, P.B., Noland, J.L., Spaeh, H., and Klamerus, E., "Tests of Reinforced Masonry Wall Panels Under In-Plane Cyclic Loads," Proceedings, Third Meeting of the Joint Technical Coordinating Committee on Masonry Research, U.S.-Japan Coordinated Program for Masonry Building Research, Tomamu, Japan, October, 1987.

4. Spaeh, H., "Inelastic Behavior of Reinforced Masonry Shear Walls Under In-Plane Cyclic Loads," Master Thesis, University of Colorado-Boulder, Decembe 1987.

5. Shing, P.B., Spaeh, H., Klamerus, E., and Noland, J.L., "Seismic Performance of Reinforced Masonry Shear Walls," Proceedings, Ninth World Conference on Earthquake Engineering, Tokyo-Kyoto, Japan, August 1988.

6. Klamerus, E., "Experimental and Analytical Evaluation of the Inelastic Behavior of Reinforced Masonry Shear Walls," Master Thesis, University of Colorado-Boulder, July 1988.

7. Shing, P.B., Klamerus, E., Schuller, M., and Noland, J.L., "Behavior of Single-Story Reinforced Masonry Shear Walls Under In-Plane Cyclic Lateral Loads," Proceedings, Fourth Meeting of the Joint Technical Coordinating Committee on Masonry Research, U.S.-Japan Coordinated Program for Masonry Building Research, San Diego, CA, October 1988.

8. Shing, P.B., Noland, J.L., Klamerus, E., and Spaeh, H., "Inelastic Behavior of Concrete Masonry Shear Walls," Journal of Structural Engineering, American Society of Civil Engineers, accepted for publication.

4.3 Workshops and Seminars:

1. Presentation at the Structural Group Meeting of the Colorado Section of the American Society of Civil Engineers (February 1987.

2. Seminar at the University of Wyoming, Laramie (July 1988).

3. Presentation at the meeting of the Western States Clay Products Association (September 1988).

5.0 Budget Status

	Award Start Date	Award End Date	Award Amount	From. F.Y.	Unspent Amount
1.	11/15/85	04/30/87	$77,041	1985	-0-
2.	11/15/86	04/30/88	$89,203	1987	-0-

6.0 Academic Component

Graduate degrees based on the work of this project.

Hannes Spaeh: M.S., December 1987, currently design engineer at Vail, Colorado.

Eric Klamerus: M.S., July 1988, currently engineer at Sandia National Laboratory, Albuquerque, New Mexico.

Michael Schuller: M.S., pending.

Undergraduate Assistants

Craig Kitzman
Mike Stein
Susan Huey
Daniel Hogan
Daniel Burroughs

TCCMAR/US

Task Status Report

Date: November 1988

Category: 3

Task No.: 3.1(b)

Task Title: Sequential Phased Displacement Method - Three-Story In-Plane Walls

Principal Investigators: Gil Hegemier, Frieder Seible

1.0 Project Summary

The verification of analysis and design models for reinforced masonry structures in seismic zones requires a comprehensive experimental database for the response of prototype structures under seismic loads. This behavioral database can only be established under controlled laboratory conditions with full-scale building experiments under simulated seismic loads. Since TCCMAR will be the first group to conduct a five-story full-scale building test in the U.S., see Figure 1, an appropriate test methodology based on the TCCMAR program objectives has to be defined first, followed by the development of a corresponding test procedure. It is the objective of this research project to define, develop and implement a testing procedure for full-scale structural systems under simulated seismic loads on three-story in-plane reinforced concrete masonry wall assemblages which can then be refined and applied to the five-story full-scale TCCMAR research building test.

2.0 Research Justification

The methodology for the experimental TCCMAR/U.S. program is directly derived from the principal objective of verifying and validating analytical and design models which can realistically assess structural behavior of masonry buildings under seismic loads. Thus, experiments on structural subassemblages and complete structural systems must be able to provide a realistic corresponding load/deformation environment.

Since full-scale shake table tests are unrealistic due to physical and economical constraints, full-scale testing utilizing a reaction wall system will be employed to investigate experimentally the behavior of a full-scale five-story research building. Thus a testing methodology needs to be developed which allows a realistic application of simulated seismic loads to a stiff five-story research structure. One of the most promising concepts to be employed in such a full-scale test is the on-line or pseudo dynamic test method where the dynamic response of an analytical model of the test structure is used to drive the test in on-line stepwise applications of story displacements obtained from a ground motion input into the discretized structure. However, redundant stiff structural systems require for explicit numerical time integration schemes small time steps to ensure stability; this can result in experimentally difficult to achieve small displacement steps and actuator control problems. Also, the exposure of the test building to only one particular recorded input ground motion will not necessarily test all required aspects of structural behavior of the research building.

A method which is termed GSD (Generated Sequential Displacement) is therefore proposed which modifies the conventional pseudo-dynamic testing scheme in several aspects. First, an analytical model associated with an increased mass representing nonlateral load bearing portions of the building can be employed to change the characteristics for the time integration scheme, i.e., more mass will lower the natural frequencies and allow larger time steps which in turn results in larger story level displacement steps; second, a series of recorded time history acceleration segments can be combined to a new forcing function which will exercise the research building through the full range of potential near and far field ground motions; and third, elastomeric bearings between the test structure and the load application will be investigated to reduce the stiff coupling problems between individual story displacement degrees and to amplify the on-line actuator displacements.

These and other innovations in large-scale structural testing will be investigated as part of TCCMAR Task 3.1(b) and implemented and validated on three-stroy in-plane wall specimens in an effort to develop a GSD methodology and test procedure for the experimental investigation of the five-story full-scale research building.

3.0 Project Status

A. Work to Date:

The objective of TCCMAR task 3.1(b) is the development of a test method which can be applied to the five-story full-scale research building test (Category 9), see Fig. 1 Task 3.1(b) calls for development and verification of the full-scale test methodology and procedure on three-story subassemblages of the five-story research building as shown in Fig. 2. Two specimens of each subassemblage will be tested, the first one under the SPD (Sequentially Phased Displacement) cyclic testing procedure developed by TCCMAR and the second one under sequentially phase displacements derived from the response of a parallel analytical model to actual earthquake ground motion input. The generated sequential displacements (GSD) are applied to the test structure for discrete time-steps in the ground motion time-history and structural response quantities measured on the test floor are fed back to the analytical model prior to analyzing the subsequent displacement state.

Progress to date has been limited to the development of analytical tools required to perform multi-actuator on-line testing, both for the parallel analytical modeling and the servo-control loop, see Fig. 3. The experimental portion of the project was temporarily placed on hold due to delays with the hydraulic outfitting of the Charles Lee Powell Structural Systems Laboratory. However, with the finalization of the five-story full-scale research building, the geometry of the four test specimens has now been defined, see Fig. 2, and the design of the actual test setup is now in progress.

B. Work Remaining:

With the installation of the hydraulic power generation and distribution network in the UCSD Structural Systems Laboratory scheduled for December 1988, the implementation phase of the test method for three-story in-plane walls has to be postponed until that time. However, the first two test specimens are scheduled for construction in November 1988.

The work remaining comprises all the experimental parts of Task 3.1(b) as well as validations, modifications and final verification of the proposed testing procedure.

C. Technical Problem Areas:

With the major portion, particularly the experimental part, of the three-story in-plane wall project still to be performed, technical problems have been encountered primarily in the development of a nonlinear analytical model which can parallel the experimental testing procedure. This modeling effort has reached a stage where components and subassemblages can be successfully modeled to obtain the load-deformation envelop to experimentally obtain hysteretic behavior curves. However, the required computational efforts is still prohibitive for the full five story building analysis. Thus, further development is needed to condense the behavior of substructures into structural component models which can subsequently be employed to analyze the five-story full-scale research building under simulated seismic loads.

4.0 Technology Transfer

4.1 TCCMAR Reports:

1. No. 3.1-B "Summary on Pseudo Dynamic Testing," by Freider Seible and Henriette L. La Rovere.

4.2 Conference or Journal Papers:

1. Seible, F., and Hegemier, G.A., "Full-Scale Structural Testing," ACI Concrete International: Design & Construction, Vol. 8, No. 7, July 1986, pp. 48-52.

2. Seible, F. and La Rovere, H.L., "Analytical Models for the Evaluation of Shear Walls with Openings," Proceedings of the Second Joint Technical Coordinating Committee on Masonry Research, U.S./Japan Coordinated Earthquake Research Program, Keystone, Colorado, September 1986.

3. Seible, F., and Hegemier, G.A., "From Materials and Components to Masonry Prototype Structures: the TCCMAR-U.S. Experimental Program," Proceedings of the 4th North American Masonry Conference, Los Angeles, August 1987.

4. Seible, F., Yamazaki, Y., and Teshigawara, M., "Evaluation of the Loading System of the Japanese 5-Story Full-Scale Masonry Research Building," Proceedings of the Third Joint Technical Coordinating Committee Meeting on Masonry Research, U.S. Japan Coordinated Earthquake Research Program, Tomamu, Hokkaido, Japan, October 15-17, 1987.

5. Seible, F., and Hegemier, G.A., "The Modular U.S.-TCCMAR Program for Masonry Buildings in Seismic Zones - Summary of Experimental Program," Proceedings of the Third Joint Technical Coordinating Committee Meeting on Masonry Research, U.S./Japan Coordinated Earthquake Research Program, Tomamu, Hokkaido, Japan, October 15-17, 1987.

6. Seible, F., Okada, T., Yamazaki, Y., and Teshigawara, M., "The Japanese 5-Story Full-Scale Reinforced Concrete Masonry Test - Design and Construction of the Test Building," The Masonry Society Journal, Vol. 6, No. 2, July-December 1987.

7. Seible, F., Yamazaki, Y., Kaminosono, T., and Teshigawara, M., "The Japanese 5-Story Full-Scale Reinforced Concrete Masonry Test-Loading and Instrumentation of the Test Building," The Masonry Society Journal, Vol. 6, No. 2, July-December 1987.

8. Seible, F., La Rovere, H.L., and Friedman, Z., "Modeling of Reinforced Masonry Components and Subassemblages," Proceedings of the Fourth Joint Technical Coordinating Committee on Masonry Research, U.S./Japan Coordinated Earthquake Research Program, San Diego, October 17-19, 1988.

4.3 Workshops and Seminars:

1. Academic Honors Program, Third College, UCSD, Seminar on "The Mexican Earthquake of September 19, 1985 and Research Efforts into Earthquake Damage Mitigation at UCSD," (F. Seible), November 20, 1985.

2. Coping with Disaster: The Earthquake Threat in Riverside County, Part II. Presentation on "Structural Testing in an Earthquake under Controlled Laboratory Conditions." Sponsored by the County of Riverside Department of Health, (F. Seible), September 12, 1986.

3. MTS Corporation, Minneapolis, MN. Presentation on "Real Time Pseudo Dynamic Testing," (G.A. Hegemier and F. Seible), September 15, 1986.

4. Structural Engineers Association of San Diego. Presentation on "The Charles Lee Powell Structural Systems Laboratory at UCSD-Design, Construction and Function," (F. Seible), October 21, 1986.

5. Earthquake Engineering Research Institute 1987 Annual Meeting, San Diego, CA. Report on "Current Research at the UCSD Structural Systems Laboratory," (F. Seible), February 26, 1987.

6. California Building Officials (CALBO) 1987 Annual Business Meeting, San Diego, CA. Presentation on "Earthquake-Resistant Design of Buildings," (G.A. Hegemier and F. Seible), February 26, 1987.

7. San Diego State University - Building Inspector Program. Lecture on "Design, Inspection and Testing of Masonry Structures," (F. Seible), February 26, 1987.

8. American Society of Civil Engineers, General Membership Meeting. Presentation on "The U.S.-Japan Coordinated Program on Masonry Research and the Charles Lee Powell Structural Systems Laboratory," (F. Seible), May 26, 1987.

9. North San Diego County Section American Institute of Architects and North County Civil Engineers and Land Surveyors Association. Presentation on "Local Seismic Testing at the UCSD Testing Facility," (F. Seible), May 28, 1987.

10. The Second Japan Masonry Forum. Invited speaker on "Overview of U.S.-TCCMAR program." Within the Seminar on Design Guidelines for New Reinforced Masonry Buildings, Sapporo, Hokkaido, Japan, (F. Seible), October 13, 1987.

11. Association of Independent Insurance Agents and Brokers of San Diego. Presentation on "Earthquake Hazards and Mitigation, Structural Engineering Research at the UCSD Charles Lee Powell Structural Systems Laboratory," (F. Seible), January 1, 1988.

12. American Society of Mechanical Engineering. Presentation on "The Charles Lee Powell Structural Systems Laboratory at UCSD," (F. Seible), April 1, 1988.

13. Seismic Design Seminar on Concrete and Masonry Structures, UCSD. "A Japanese Perspective," (F. Seible), June 4, 1988.

14. UCSD, AMES Structural Engineering and Solid Mechanics Seminar on "Full-Scale Testing of 5-Story Reinforced Masonry Buildings," (F. Seible), October 3, 1988.

5.0 Budget Status

	Award Start Date	Award End Date	Award Amount	From. F.Y.	Unspent Amount
1.	10/15/86	09/30/88	$199,356	1987	$63,055
2.	(10/01/88)	(09/30/89)	($199,988)	(1989)	(199,988)

6.0 Academic Component

Student involvement in Task 3.1(b) covered development of computer codes for analytical base of SPD method.

Henrietta L. La Rovere is a graduate research assistant who is expected to receive her Ph.D. in June 1989.

Zvi Friedman is a graduate research assistant who is expected to receive his Ph.D. in September 1989.

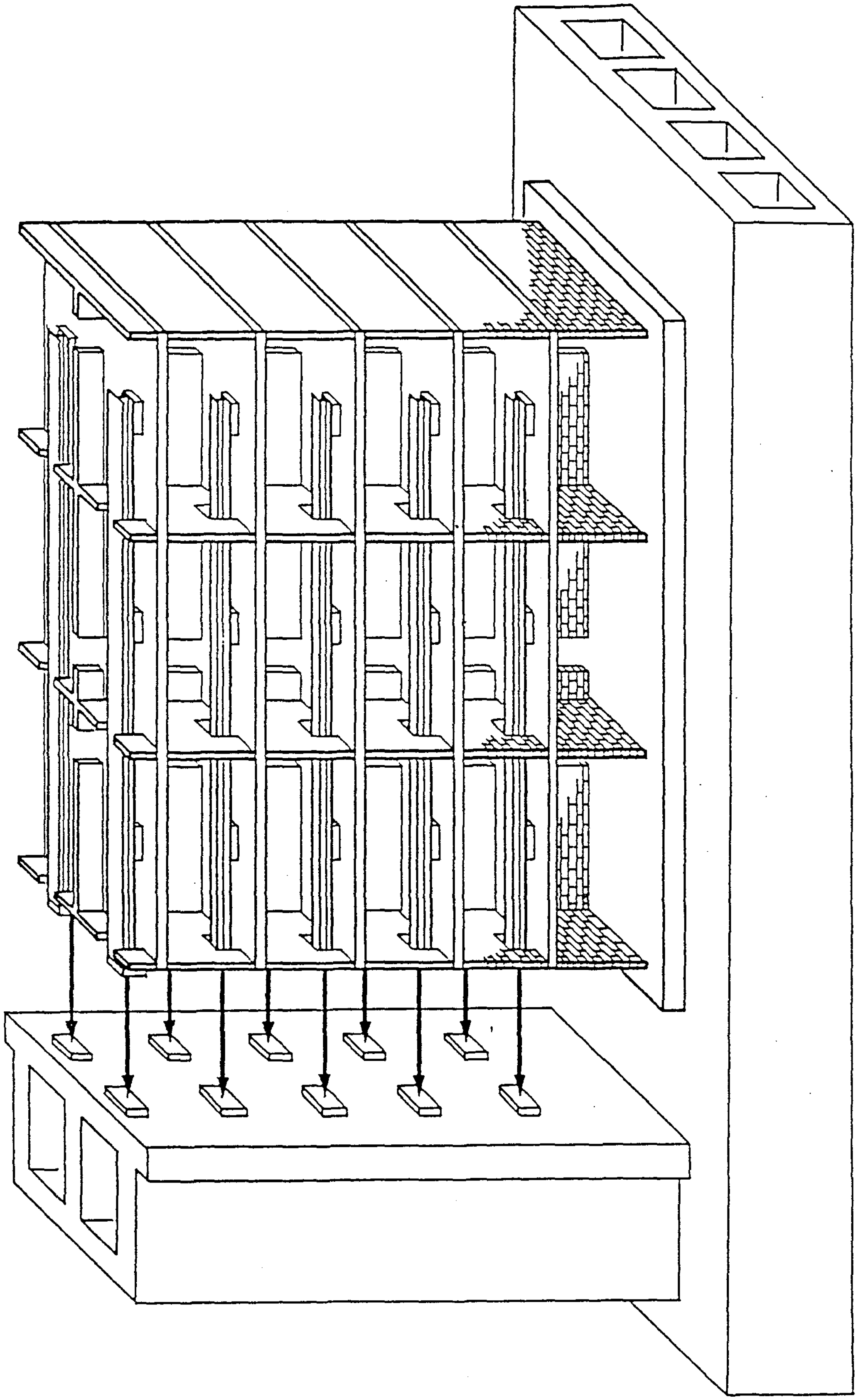
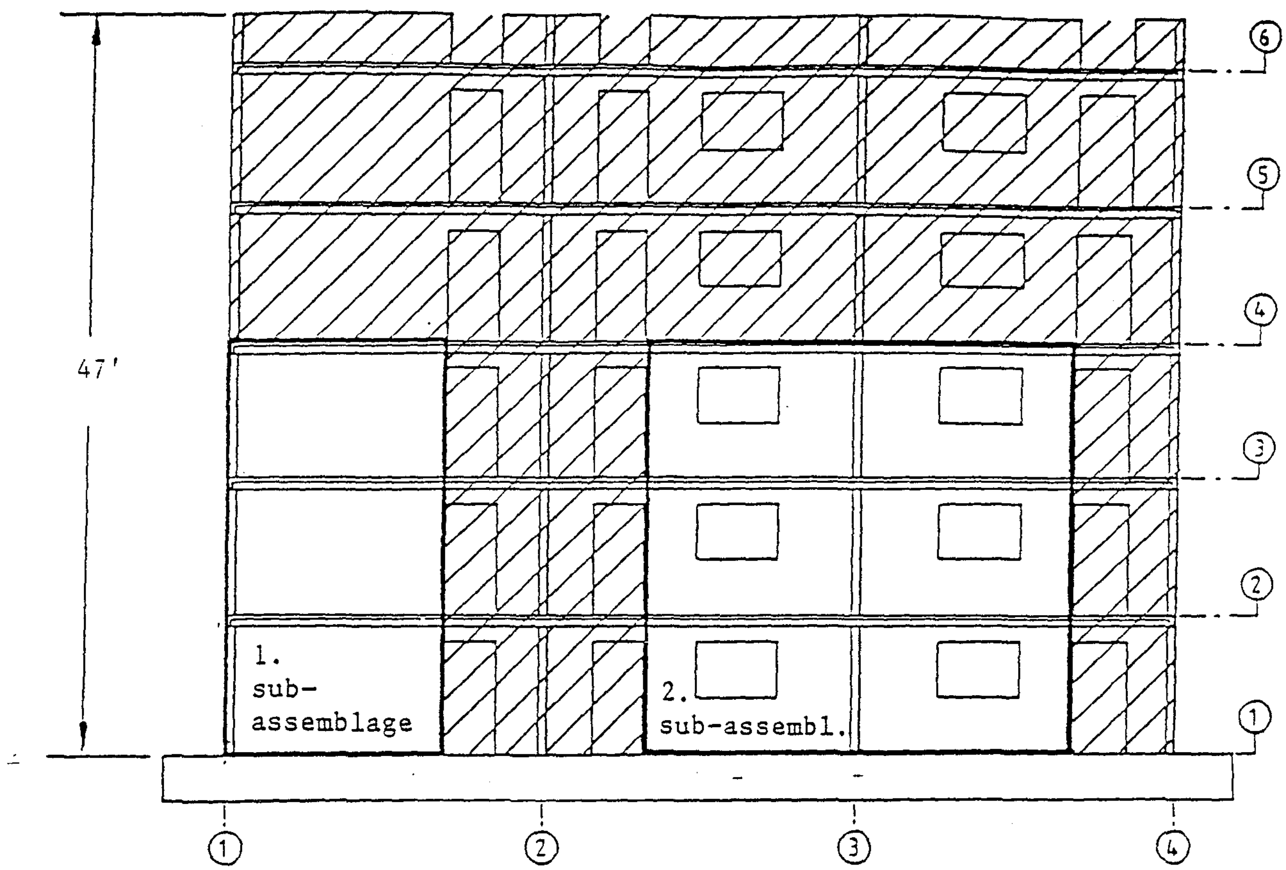
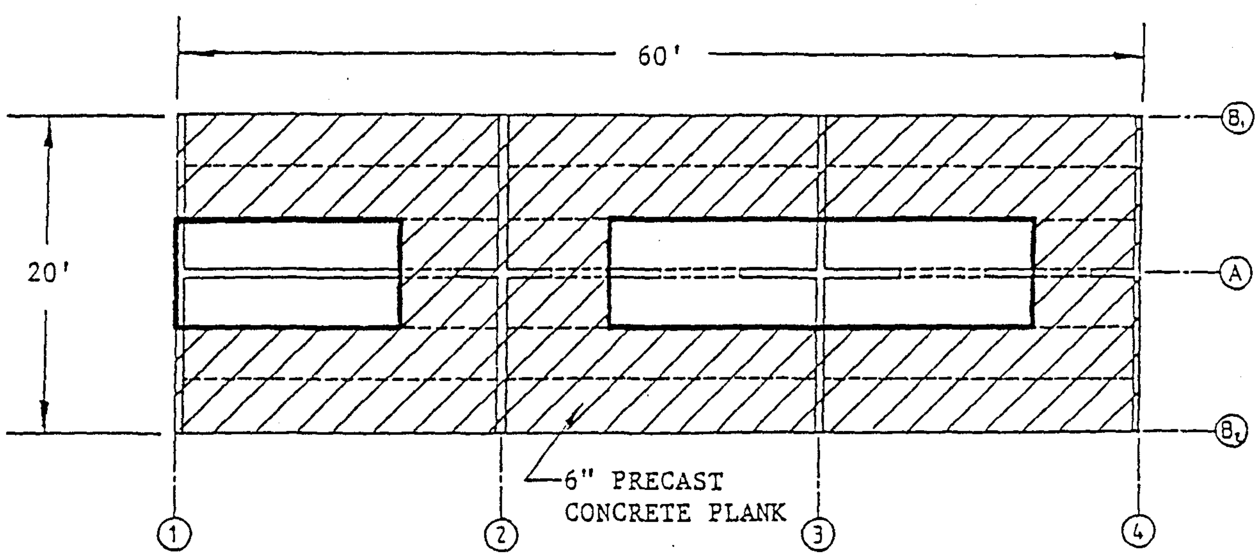


Fig. 1 FULL SCALE RM RESEARCH BUILDING



(a) Elevation



(b) Plan

Figure 2. Three Story Subassemblages of Five Story Research Building

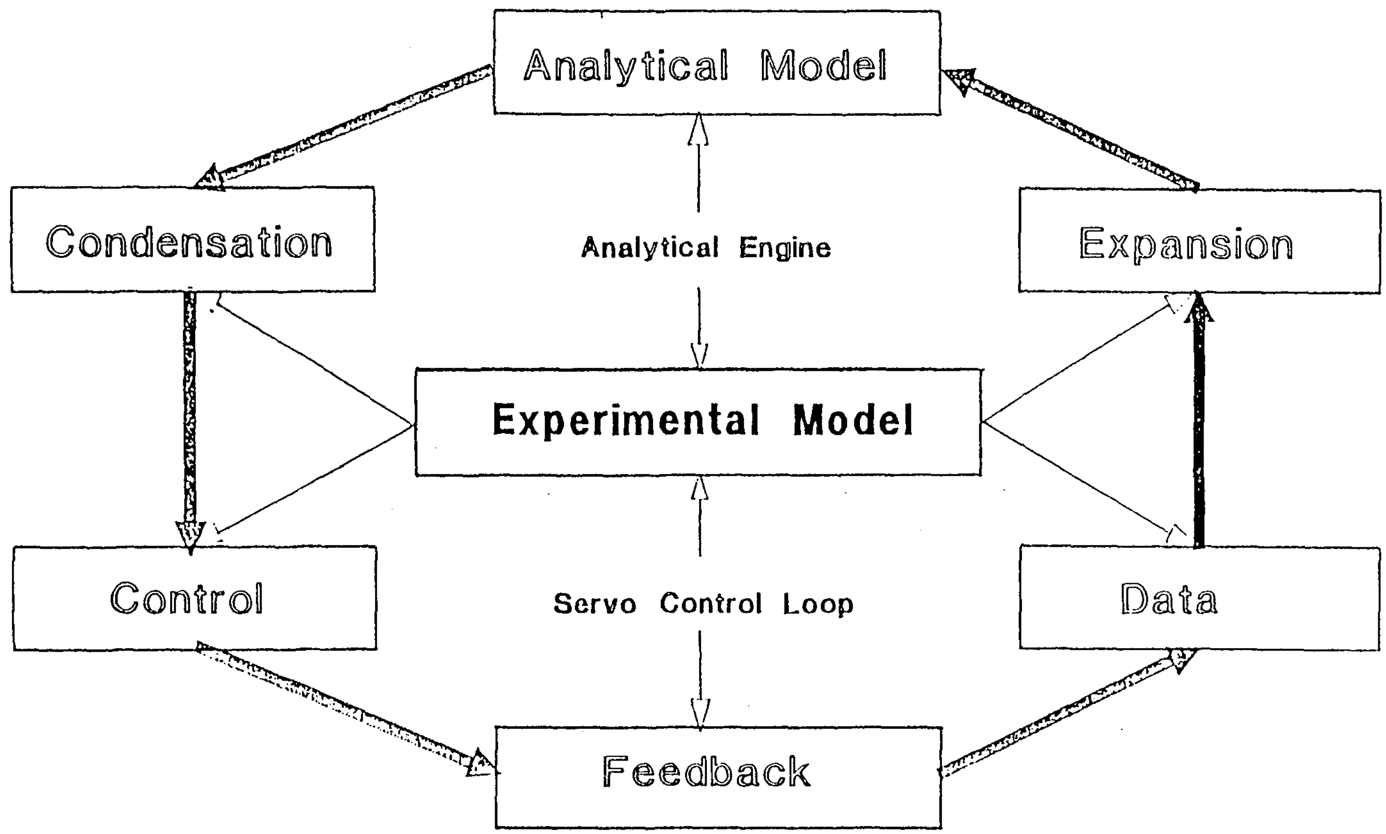


Fig. 3 Schematic Outline of test Methodology

TCCMAR/US

Task Status Report

Date: November 1988

Category: 3

Task No.: 3.1(c)

Task Title: In-Plane Seismic Resistance of Two-Story Concrete Masonry Walls with Openings

Principal Investigator: Richard E. Klingner, University of Texas at Austin

1.0 Project Summary

In this project, two types of 2-story masonry wall specimens will be constructed and tested in the laboratory. The objective of this project is to examine how the in-plane seismic resistance of multi-story concrete masonry walls is affected by floor-wall joints, wall openings, and floor elements.

Three Type 1 specimens will be constructed, each representing a shear wall with door and window openings, and forming part of a two-story building. Three Type 2 specimens will be constructed, each representing a pair of coupled shear walls of a two-story building. Each specimen will be loaded vertically by constant loads representing gravity loads on the shear wall's tributary area, and horizontally by quasi-static, reversed in-plane shear loads at the two floor levels. Test results will be correlated with analytical predictions made as part of this and other TCCMAR tasks, and will be analyzed, documented and disseminated.

2.0 Research Justification

This project is justified technologically and intellectually. On a technological level, it will supply needed information about how to design masonry wall structures for strong lateral loads. That information is not now available, and is needed to improve the cost-effectiveness of this country's investment in its stock of masonry buildings. On an intellectual level, it will supply information about how to correlate advanced nonlinear analysis methods with actual specimen behavior, and how to use the results of such advanced analysis methods for design purposes.

3.0 Project Status

A. Work to Date:

The test apparatus, loading system and data acquisition system have been designed, constructed, and placed into position. Work is complete on the preliminary design of the Type 1 specimens. The Type 2 specimens have been completely designed. The first Type 2 specimen (Specimen 2a) has been constructed and instrumented, and was tested during the second week of September 1988. The specimen was loaded vertically by constant loads representing gravity loads on the shear wall's tributary area, and horizontally by quasi-static, reversed cyclic shear loads applied in the plane of the walls at the two floor levels. Equal loads were applied at each floor level.

Specimen 2a, a pair of walls coupled by a cast-in-place slab, behaved as intended in that test. Load capacity was limited by formation of a flexural mechanism. Shearing cracks formed near the base of both walls, but did not widen. Displacement capacity was limited by buckling of the longitudinal bars at the base of both walls, and by the subsequent lateral (out-of-plane) slip of the bases of both walls with respect to the base beam. Specimen 2a showed satisfactory maintenance of strength and stiffness, and satisfactory energy dissipation up to story drifts in excess of 1%.

In terms of the specific objectives of the Type 2 specimen tests, this experiment can be considered a success:

a) the cyclic shear resistance of coupled wall Specimen 2a was satisfactory, and Specimen 2a did behave as intended and as anticipated in design.

b) the floor-wall joints of Specimen 2a behaved satisfactorily. No evidence of slip was noted, except at the base of the walls.

c) the floor slab of Specimen 2a was effective in coupling the two walls. Both floor slabs yielded across their entire width of 6 ft.

d) the test setup behaved satisfactorily.

e) the observed load-deflection behavior of Specimen 2a corresponded closely to that predicted analytically using design-type flexural models. Results from more complex finite element models are still under study, and are being reported on by other investigators.

In terms of its specific objectives, the test of Specimen 2a can be considered a success:

1) the specimen showed satisfactory cyclic shear resistance.

2) the specimen showed satisfactory floor-wall joint behavior.

3) the specimen behave as intended and as anticipated in design.

Based on this satisfactory performance, it has been recommended that work proceed with construction and testing of Specimens 2b and 2c, and with the final design of the Type 1 specimens. Work should continue on analytical prediction of the behavior of this type of wall specimen. Although simple design-type models were very satisfactory for Specimen 2a, they may not be as satisfactory for other specimens of Task 3.1(c).

At this point, work on Task 3.1(c) is approximately 50% complete.

B. Work Remaining:

The other two Type 2 specimens will be constructed and tested over the next 4 months. Analytical predictions of behavior will be compared with test results and used to refine the analysis methods used.

Design of the Type 1 specimens will be completed during Fall 1988, and construction will begin in Spring 1989. The Type 1 specimens will be tested during Spring and Summer 1989.

C. Technical Problem Areas:

No unusual technical problems have been encountered. Som preliminary difficulties with stability of the multi-floor loading system were resolved by mechanical and electronic adjustments.

4.0 Technology Transfer

4.1 TCCMAR Reports:

None

4.2 Conference Papers or Journals:

1. Antrobus, N., Leiva, G., Merryman, M. and Klingner, R.E., "Preliminary Report on Testing of Specimen 2a, TCCMAR Task 3.1(c): In-Plane Seismic Resistance of Two-Story Concrete Masonry Walls with Openings," Proceedings, 4th JTCCMAR Meeting, October 16-19, 1988, Rancho Bernardo, California.

4.3 Workshops and Seminars:

1. "U.S.-Japan Coordinated Program for Masonry Building Research (TCCMAR): Task 3.1(c) - In-Plane Seismic Resistance of two-Story Concrete Masonry Walls with Openings," (poster session) 4th North American Masonry Conference, Los Angeles, California (August 1987)

2. "Current Anchor Bolt Research at The University of Texas at Austin," Mission from Ministry of International Trade and Industry in Japan - Committee on "Model Tests for Evaluation ofSeismic Behavior of Reactor Buildings, visit to The University of Texas, Austin, Texas (August 24, 1987)

3. "Current Masonry Research at The University of Texas at Austin," Associated Masonry Contractors of Houston, Houston, Texas (September 1987)

4. "U.S.-Japan Coordinated Program for Masonry Building Research," International Council for Building Research, Studies and Documentation (CIB), Commission W23, Wall Structures, Stockholm, Sweden (September 1987)

5. "Current Masonry Research at The University of Texas at Austin," Soviet Delegation, Project Working Group 10.04 (Construction in Seismic Areas), visit to The University of Texas, Austin, Texas (May 1988)

6. "U.S.-Japan Cooperative Research Program in Masonry," Board of Directors, Brick Institute of Texas, Arlington, Texas (July 1988)

7. "Structural Engineering Research at The University of Texas at Austin," Gradevinski Institute, Zagreb, Yugoslavia (September 1988)

8. "Preliminary Report on Testing of Specimen 2a, TCCMAR Task 3.1(c): In-Plane Seismic Resistance of Two-Story Concrete Masonry Walls with Openings," Proceedings, 4th JTCCMAR Meeting, Rancho Bernardo, California (October 1988)

9. "In-Plane Seismic Resistance of a Two-Story Concrete Masonry Coupled Wall," International Council for Building Research, Studies and Documentation (CIB), Commission W23, Wall Structures, Austin, Texas (October 1988)

5.0 Budget Status

	Award Start Date	Award End Date	Award Amount	From. F.Y.	Unspent Amount
1.	02/01/87	01/01/90	$173,462	1987	$45,539

6.0 Academic Component

The following students are working/have worked on TCCMAR Task 3.1(c):

Graduate Students:
Nicholas A. Antrobus (M.S. degree 5/88)
Gilberto Leiva (Ph.D. degree in progress)
Mark Merryman (M.S. degree in progress)

Undergraduate Students:
Mahamed Alyusuf
Alex Gonzales
David Franzen
Tom Estrel

All undergraduate students participated actively in the project (for example, in formwork and specimen setup design), in addition to general grant work. Their work did not satisfy any specific degree requirements. Nevertheless, some of the top graduate students have been drawn from the pool of former undergraduate research assistants. This form of undergraduate participation has been strongly encouraged. All undergraduate students will eventually get their B.S. degrees in Civil or Architectural Engineering.

TCCMAR/US

Task Status Report

Date: November 1988

Category: 3

Task No.: 3.2(a)

Task Title: Response of Reinforced Masonry Walls Under Out-of-Plane Static Loads

Principal Investigators: Drs. A.A. Hamid and H.G. Harris

1.0 Project Summary

For adequate performance under seismic loading, reinforced masonry walls should be ductile and capable of dissipating energy through inelastic response. Analytical procedures related to seismic failure analyses necessitate the establishment of the hysteretic response and failure envelope of masonry walls. In this research, an experimental study has been conducted to provide test data about cracking, strength, deformations and post-yield behavior of reinforced block masonry walls under out-of-plane monotonic and cyclic loadings. A total of 14 full scale walls were tested which covers different materials, geometric and construction details. The hysteretic response of the walls are presented. Idealized envelopes of the hysteretic loops will be developed.

2.0 Research Justification

The primary intellectual content of Task 3.2(a) is the establishment of idealized load-deflection curves, which are not yet available for reinforced block masonry. This is crucial to the development of an appropriate limit states design methodology. The research under this task provides new data on the unique shape of the hysteretic curves for centrally reinforced block masonry walls. The data base provided by this research would improve our understanding of the mechanics and behavior of reinforced masonry which will lead to improved design methods and, consequently, more cost efficient masonry structures. This places on a more economic footing the design of reinforced masonry structures in relation to more established structural materials such as steel and reinforced concrete when used in earthquake resistant applications.

3.0 Project Status

A. Work to Date:

Testing of the 14 walls has been completed. Preliminary data reduction has been carried out. The complete load-deflection curves for the walls are presented. Preliminary analysis of the results indicate that the wall behavior is sensitive to the percentage and location of vertical steel. Extent of grouting (fully vs. partially grouted) seems to affect the cracking load and the stiffness under service load. There is no significant effect, however, on wall strength. Mortar type and block size have no significant effect on behavior. The monotonic load-deflection curves match well the envelopes of the hysteresis loops.

B. Work Remaining:

Completion of data analysis of all walls will be conducted. Development of analytical methods to predict wall deflection, strength and ductility will be carried out. Idealized load-defelection curves will be developed to be used in analytical models.

C. Technical Problem Areas:

None

4.0 Technology Transfer

4.1 TCCMAR Reports:

None

4.2 Conference or Journal Papers:

1. Hamid, A.A., Hatem, M., Harris, H.G., and Abboud, B., "Nonlinear Response of Reinforced Block Masonry Walls Under Out-Of-Plane Cyclic Loading," Proceedings of the Fourth Meeting of the Joint Technical Coordinating Committee on Masonry Building Research, San Diego, California, October 1988.

4.3 Workshops and Seminars:

1. Overall U.S./TCCMAR Program presented during the Fourth Canadian Masonry Symposium, Fredericton, New Brunzwick, June 1986.

2. Overall U.S./TCCMAR program presented to architects, engineers, contractors and manufacturers, 1/2-day seminar sponsored by the Delaware Valley Masonry Institute and Pennsylvania Concrete Masonry Association, Philadelphia, April 7, 1987.

5.0 Budget Status

	Award Start Date	Award End Date	Award Amount	From. F.Y.	Unspent Amount
1.	01/01/86	08/31/86	$41,500	1985	-0-
2.	09/01/86	06/30/87	$53,052	1986	-0-

6.0 Academic Component

The following students are working on TCCMAR Task 3.2(a):

Mauris Farah (M.S. degree in process)
Mitchell Hatem (M.S. degree in process)

TCCMAR/US

Task Status Report

Date: November 1988

Category: 3

Task No.: 3.2(b1)

Task Title: Out-of-Plane Dynamic Testing of Concrete Masonry Walls

Principal Investigators: Samy A. Adham, Mihran S. Agbabian, Samy F. Masri

1.0 Project Summary

This task involves the dynamic testing of several reinforced concrete block masonry walls, subjected to out-of-plane dynamic earthquake loading.

The basic objectives of these tests were: (a) verify analytical models for out-of-plane response of tall slender walls, (b) support the development of strength design procedures for masonry walls, (c) evaluate the seismic response of tall slender walls as designed by current building codes, (d) evaluate a significant number of parameters used in the design and construction of these walls.

A unique experimental program was designed to test these walls to represent part of a masonry building. A typical full-scale wall panel segment was selected. Representative Kinematic seismic motions were applied at the stations along the height of the wall and strains were recorded reinforcing bars. Preliminary processing of test results was conducted. This program was closely coordinated with a similar program on clay block masonry.

The most important finding in the present research is that tall slender reinforced masonry walls can sustain a large number of moderate and severe earthquakes without the risk of instability or sudden brittle failure.

2.0 Research Justification

2.1: The experimental program is unique. It allows for the full scale testing of reinforced concrete block masonry walls which are as high as approximately three stories subjected to full excursions of simulated strong earthquake motion.

2.2: The experimental results will provide for the verification of analytical models for the propagation of cracks and stiffness degradation of masonry walls under repeated dynamic earthquake loading.

2.3: The experimental results will allow for the use of system identification techniques to develop damage index criteria for masonry walls.

2.4: The experimental program provided a unique evaluation of the dynamic stability of tall slender walls under combined large lateral seismic loads and eccentric vertical roof loads.

2.5: The test set-up allows for earthquake motion input at the base and top of the wall at the diaphragm level, thus providing for a full scale representation of the wall-roof diaphragm interaction effects.

2.6: The test program included different levels of earthquakes with different dynamic characteristics and different roof diaphragm stiffness, thus allowing for a representation of various building conditions in different seismic zones of the United States.

3.0 Project Status

A. Work to Date:

1. Test plan completed in coordination with Dr. Hamid and Dr. Mayes.
2. Design wall panels
3. Instrumentation plan
4. Modify test set-ups for additional vertical load
5. Build wall panels (4 walls)
6. Check equipment and data acquisition system
7. Calibrate systems
8. Test walls
9. Preliminary processing of data at University of Southern California
10. Draft final report

The results of this test program indicate the following: (1) these walls will be dynamically stable during earthquakes, (2) all panels responded elastically to Sequences 1 through 6 which represent typical earthquake motions in various seismic zones of the United States, (3) the first two wall panels began to go into inelastic range only after repeated earthquake shaking of 15 to 18 earthquakes, (4) the partially grouted wall panels had less mass and sustained 30 earthquake shakings without going into inelastic range, (5) the response of wall panels with and without reinforcing bar lap splices was identical, and (6) all wall panels exhibited considerable ductility.

The most important finding of the present research program is that tall slender reinforced masonry walls, constructed with adequate quality control, can safely sustain a large number of moderate and severe earthquakes. The slenderness and reduced mass of these walls result in a more ductile lighter wall that can sustain severe shaking without the risk of instability or sudden brittle failure.

B. Work Remaining:

Incorporate comments of different reviews in Final Report.

C. Technical Problem Areas:

1. The measurement of accelerations can result in noise interference and contamination of results. disposition: measure velocities instead of accelerations.

2. The strongback frequency was 12Hz. This frequency can resonate with earthquake input frequencies in that range. disposition: filter frequencies above 10Hz. This is justified since most of the earthquake energy content is for frequencies below 5 Hz. There is almost negligible energy available above 10 Hz.

3. The good quality of construction of masonry walls coupled with the ductility of these walls extended the period of testing beyond original test plan. disposition: four walls rather than six walls were tested.

D. Percentage Complete:

98%

4.0 Technology Transfer

4.1 TCCMAR Reports:

1. Report No. 3.2(b1) "Out-of-Plane Dynamic Testing of Concrete Masonry Walls Volume 1 & 2" by S. Adham, V. Avanessian, and I. Traina, October 1988.

4.2 Conference Papers or Journals:

1. S. Adham, "Some Potential Problems Associated with Dynamic Testing of Slender Walls" Second Meeting of U.S.-Japan Committee on Masonry Research, Keystone, Colorado, September 1986.

4.3 Workshops and Seminars:

None

5.0 Budget Status

	Award Start Date	Award End Date	Award Amount	From. F.Y.	Unspent Amount
1.	01/01/87	12/31/88	$105,920	1988	-0-

6.0 Academic Component

None

TCCMAR/US

Task Status Report

Date: November 1988

Category: 3

Task No.: 3.2(b2)

Task Title: The Transverse Response of Clay Masonry Walls Subjected to Strong Motion Earthquakes

Principal Investigator: Dr. Ronald Mayes, CES, Inc.

1.0 Project Summary

A number of test programs have been performed during the past decade to evaluate the in-plane performance of masonry walls. The results of these programs are currently being utilized to develop ultimate strength design procedures for in-plane shear resistance of masonry.

Of equal importance to the in-plane performance is the ability of walls to resist transverse or out-of-plane loads. This has not been considered to be a major safety problem with walls in the 8-12 ft. height category, however, for higher single-story warehouse type structures, this design consideration generally governs. As a consequence increased attention has been given to the out-of-plane capacity of masonry walls subjected to seismic loads.

The major limitaton with previous test programs on out-of-plane behavior of masonry and the ultimate strength design procedure developed from the results of those test programs is that the applied loads were quasi-static and at the same time monotonic in nature. Clearly, seismic loads are dynamic and cyclic and to enhance and broaden the applicability of the results from these previous test programs, walls of similar size must be subjected to realistic seismic loads. It was the aim of this particular task and category of the TCCMAR project to perform and evaluate the response from such dynamic tests.

With that purpose a significant test program has been performed over the last two years on the out-of-plane response of slender hollow clay brick masonry walls subject to earthquake loading. This test program, which is an integral part of the overall U.S./Japan Coordinated Program for Masonry Building Research, has been performed by Computech Engineering Services, Inc. (CES) at the Earthquake

Engineering Research Center, University of California, Berkeley.

The objective of this program is to evaluate the influence of several variables (vertical reinforcement ratios, vertical ledger load, H/t ration, splices and partial grouting) on the out-of-plane earthquake response of hollow clay brick masonry walls. In addition to generating the test data and evaluating the performance of the walls, the test data is also to be used to develop and refine analytical models as part of TCCMAR/US Task 2.4(b).

The experimental program consists of eleven full-scale hollow clay block reinforced masonry walls that have been tested by using a unidirectional shake table built specifically for such testing. Each wall was placed on the shake table and actuators attached to its top and base. This setup was used for dynamic testing. By adding a restrainer system at the third points along the wall height, the setup becomes the quasi-static test setup. To date, all testing has been completed.

2.0 Research Justification

The most significant item that has been learned from this research is that tall and slender reinforced clay masonry walls with moderate to high levels of reinforcing show excellent performance out-of-plane during seismic disturbances. These walls, which are widely used in the United States for major athletic facilities, warehouse structures and nuclear power plants, can thus be relied upon to ride out a major earthquake without sustaining major damage.

These out-of-plane full scale dynamic tests, being the first such public domain tests ever performed, vastly increase the knowledge of such behavior beyond the current "state of art". Previous tests had been static and monotonic in nature and had left questions as to how valid the results were for earthquake loading. These current tests will answer those questions.

The tremendous amount of data gathered during these tests are being interfaced with specially developed computer graphics software that allows each test to be replayed on a computer screen. These test replays can be specified to show, in real time, deflection profiles, steel and masonry strain distributions and inertia load, moment and curvature distributions as the specified test progresses. This feature significantly enhances the value of the data for further studies and correlation with analytical reproductions of the tests and easier access to the knowledge base that is now being established.

The data gathered from the tests will be used to develop mathematical models that will allow accurate prediction of general out-of-plane response of single story warehouse and athletic facilities. These mathematical models will be used to develop simpler formulas for building response and safety predictions which eventually will result in better and safer building codes. Consequently, buildings depending on good out-of-plane behavior of reinforced masonry walls will be safer thus ultimately saving lives.

3.0 Project Status

The current status of this project will be outlined in the subsections below.

A. Work to Date:

The work to date has consisted of performing the required full scale tests on the walls. In all, eleven walls were tested over a period of nine months. Two of those walls were tested statically and the remaining nine were subjected to a variety of realistic seismic input motions at both top and base of walls. These seismic motions ranged in intensity from 0.1 EPA to 0.8 EPA, where the 0.4 EPA motions represent the design level earthquake for California. The test data has been processed for the two static tests and for four of the nine dynamic tests. Writing of the test reports has commenced.

Preliminary conclusions from this experimental work can be expressed in the following:

1. The reinforced steel experiences little or no yielding for any of the tests up to and including the 0.4 EPA input.

2. The walls returned to their undeformed position for all tests up to and including the 0.4 EPA input.

3. None of the variables included in the test program (vertical ledger load, amount of rebar, splicing, partial grouting) had a deleterious impact on the response of the walls up to and including the 0.8 EPA input.

It is estimated that to date 90% of the work in this task has been completed.

B. Work Remaining:

Since all the tests have been completed the remaining work will focus on the data reduction. Data from all the tests needs to be processed and reduced down to managable pieces of information specifically aimed at:

1. understanding the influence of the various test parameters, such as vertical ledger load, partial grouting, etc.

2. preparing conclusions from each of the tests and from the test program as a whole

3. preparing data for the development of the analytical models of Task 2.4(b)

CES is currently working on these tasks and it is hoped that the first set of detailed results will be available later this year.

It is anticipated that the results from each wall test will be presented in a separate report. The overall conclusions and comparisons between the various tests will then be summarized in a follow-up report. Since the number of tested walls was eleven this task of TCCMAR should produce twelve reports.

C. Technical Problem Areas:

No significant technical problems arose during the testing of the walls. Minor problems that were encountered included less than perfect reproduction of the input command signals, i.e. the seismic input, feedback noise from the shake table roller system and command module reliability. All these minor problems were satisfactorily resolved.

4.0 Technology Transfer

The transfer of the technology developed for this test program, the knowledge gained from the program and the final conclusions from the program will be disseminated in the form of reports, papers and presentations at selected conferences.

4.1 TCCMAR Reports:

As mentioned above this test program will produce a total of eleven test reports and a single summary report. The first of these reports, Report 3.2(b2)-10, is being prepared and should be available for general distribution later this year. The other reports will follow at regular intervals.

4.2 Conference or Journal Papers:

1. B.I. Sveinsson, M. Blondet, R.L. Mayes, "Out-Of-Plane Dynamic Response of Clay Masonry Walls". Proceedings of the 1988 SEAOC Conference in Hawaii, October 1988.

2. B.I. Sveinsson, M. Blondet, R.L. Mayes, "Out-Of-Plane Dynamic Response of Clay Masonry Walls - A Progress Report". The Fourth Meeting of the Joint Technical Coordinating Committee on Masonry Research (JTCCMAR), San Diego, California, USA, October 1988.

3. B.I. Sveinsson, R.L. Mayes, M. Blondet. "The Transverse Response of Clay Masonry Walls Subjected to Strong Motion Earthquakes - Preliminary Results from Static Tests". The Third Meeting of the Joint Technical Coordinating Committee on Masonry Research (JTCCMAR), Tomamu, Hokkaido, Japan, October 1987.

4. B.I. Sveinsson, T.E. Kelley, R.L. Mayes, L.R. Jones. "Out-Of-Plane Response of Masonry Walls to Seismic Loads". Fourth North American Masonry Conference, Los Angeles, California, August 1987.

5. B.I. Sveinsson, T.E. Kelley, R.L. Mayes. "The Transverse Response of Clay Masonry Walls Subjected to Strong Motion Earthquakes - Research Plan". The Second Meeting of The Joint Technical Coordinating Committee on Masonry Research (JTCCMAR), Keystone, Colorado, September 1986.

4.3 Workshops and Seminars:

In addition to the presentations of the above papers, general presentations of the overall TCCMAR project and more specifically Task 3.2(b2) have been made to Western States Clay Products Association and SEAOC, California by Dr. Ronald L. Mayes.

5.0 Budget Status

The table below illustrates the budget status for the test program as of the beginning of July 1988. However, these figures do not reflect yet to be billed testing charges from the EERC.

	Award Start Date	Award End Date	Award Amount	From. F.Y.	Unspent Amount
1.	09/01/85	07/31/87	$ 8,992	1985	-0-
2.	03/18/86	07/31/87	$ 40,038	1986	-0-
3.	05/21/87	07/31/88	$155,713	1987	$27,691.35

6.0 Academic Component

None

TCCMAR/US

Task Status Report

Date: November 1988

Category: 4

Task No.: 4.1

Task Title: Flanged Wall Dynamic Model

Principal Investigator: Nigel Priestley

1.0 Project Summary

The project involves a theoretical and experimental investigation of the seismic performance of flanged masonry shear walls. Theoretical studies will develop predictive models for effective flange width under lateral loading and also develop load-displacement component models for lateral hysteretic responses that incorporate the separate displacement components resulting from flexure, shear and base-slip deformation. Particular emphasis will be placed on the asymmetrical strength, stiffness and ductility characteristics of T-section walls loaded parellel to their web. The studies will be generalized for multi-degree of freedom response.

Experimental studies involve static cyclic load testing of four T-section masonry walls and dynamic shake table testing of five T-section walls. The tests are on full-scale elements and will be used to verify and calibrate the models developed during theoretical studies carried out as part of this project and as part of the Task 2 analytical studies.

2.0 Research Justification

The seismic performance of flanged masonry shear walls, particularly those of asymmetrical cross section such as "T" section walls, has not been established to date. The asymmetrical strength stiffness and ductility characteristics (see Fig. 1) make prediction of seismic response of structures incorporating these elements difficult. There has been no relevant research in the area of reinforced concrete shear walls to assist in the development of analytical methods for masonry walls. The research carried out in Task 4.1 will thus provide important basic information which can be expected to be applicable to reinforced concrete as well as masonry structures.

The challenge of Task 4.1 is, however, wider than merely providing the basic data described above: it must make the transition from two dimensions to three dimensions in the understanding of the performance of masonry structures, and must explore the influence of dynamic rates of loading on the seismic performance of masonry elements responding inelastically to seismic excitation. Task 4.1 is pivotal to the TCCMAR program in that it provides the link between simplistic pseudo-static cyclic tests of planar masonry elements and real dynamic seismic response of complex 3-D masonry buildings.

Although the test program and subsequent data analysis represent significant intellectual content in that the design and planning aspects must be based on a clear design philosophy of desired performance, it is primarily in the analytical modeling and predictive performance response that the major intellectual challenges exist. Analytical methods developed in task 2.1 must be extended from 2-D to 3-D, and adapted to provide techniques for developing full dynamic inelastic 3-D time history response prediction, rather than just modeling the envelope load-displacement performance. This will represent a significant advance in modeling capability.

The challenges associated with destructive shake table testing of large masonry elements should not be overlooked. This requires development of new experimental techniques, instrumentation and data acquisition. Elements of the size to be tested in this program (full-scale) have not been subjected to destructive testing previously and will provide invaluable data for future experimental research.

3.0 Project Status

A. Work to Date:

A preliminary study on the theoretical seismic response of T-section masonry shear walls loaded parallel to the web has been completed. A part of this study a single T-section wall was tested dynamically to failure on a shake table. Experimental results were generally in good agreement with analytical predications. This work has been reported in [1] and is the basis for the main body of research which has been active since approval was received in March 1988. Currently, research effort is directed towards construction and testing of 12 ft. high wide-flange T-section walls under quasi-static cyclic loading. Walls F1 to F4 (see Table 1) have been constructed, and the first wall was tested in October. The remaining three static load-test walls will be tested by December 1988.

Concurrently, analytical studies on the shear-lag effect in flanged walls have been initiated. At this early stage of the program, the non-symmetric strength, stiffness and ductility characteristics of T-section walls have been established qualitatively. Further stages of the test and analysis program will refine quantitative data relating to seismic response.

B. Work Remaining:

Construct and test remaining walls in Table 1; develop shear-lag model for flanged walls; apply analytical and experimental results to the calibration of F.E.M., L.P.M. and S.C.M. models of Task 2 to enable flanged walls to be adequately analyzed.

C. Technical Problem Areas:

At this stage there are no significant technical problem areas to be resolved. However, it is anticipated that the dynamic tests will involve significant developmental work, as these will be the first experiments on the new shake table.

4.0 Technology Transfer

4.1 TCCMAR Reports:

1. No. 4-1-1 "Seismic Behavior of Flanged Masonry Shear Walls - Preliminary Studies," by Limin He and M.J. Nigel Priestley.

4.2 Conference or Journal Papers:

1. Priestley, M.J.N. and He, L., "Seismic Behavior of Flanged Masonry Shear Walls - Preliminary Studies," University of California, San Diego, Structural Systems Research Project, Report No. SSRP-88/01, May 1988, 119 pp.

4.3 Workshops and Seminars:

1. "Seismic Design of Masonry Structures," Seismic Design Seminar on Concrete and Masonry Structures, University of California, San Diego, June 4, 1988.

5.0 Budget Status

	Award Start Date	Award End Date	Award Amount	From. F.Y.	Unspent Amount
1.	03/01/88	02/28/89	$ 93,068	1988	$ 56,525
2.	(03/01/89)	(02/28/90)	($119,044)	(1989)	($119,044)
3.	(03/01/90)	(02/28/91)	($ 92,233)	(1990)	($ 92,233)

6.0 Academic Component

Student involvement in Task 4.1 consisted of the construction, instrumentation and testing of experimental models.

He Limin, Graduate Research Assistant, Ph.D. March 1990.

John Kelly, Engineering Aid, B.S., December 1988.

Dan Jansen, Engineering Aid, B.S., December 1988.

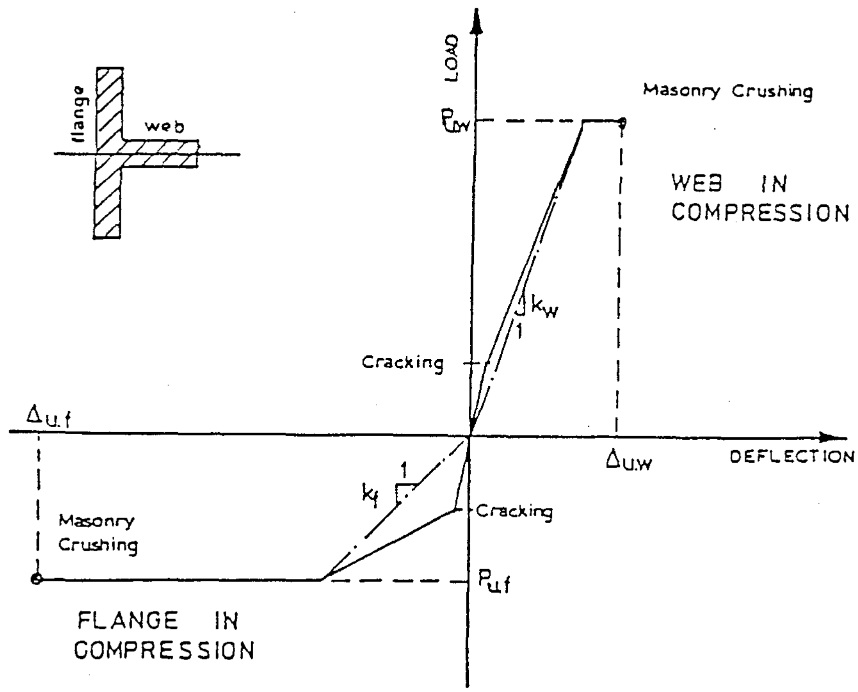
Scott Schoenfeld, Engineering Aid, B.S., June 1989.

Scott Thomas, Engineering Aid, B.S., June 1988.

Table 1. Test Matrix for TCCMAR Task 4.1

WALL	TEST REGIME	WALL DIMENSIONS H x Lf x Lw	AXIAL LOAD	VERTICAL REINFORCEMENT	ADDITIONAL DATA
F1	Static	12'x8'-8"x3'-10"	100 psi	#6 @ 16" crs	
F2	Static	12'x8'-8"x3'-10"	100 psi	#4 @ 16" crs	
F3	Static	12'x16'-8"x3'-10"	100 psi	#4 @ 16" crs	
F4	Static	12'x8'-8"x3'-10"	100 psi	#6 @ 16" crs	Confined toe
F5	Dynamic	12'x8'-8"x3'-10"	100 psi	#6 @ 16" crs	
F6	Dynamic	12'x8'-8"x3'-10"	100 psi	#4 @ 16" crs	
F7	Dynamic	6'x8'-8"x3'-10"	100 psi	#4 @ 16" crs	
F8	Dynamic	12'x8'-8"x3'-10"	100 psi	#6 @ 16" crs	Confined toe
F9	Dynamic	12'x8'-8"x3'-10	100 psi	#6 @ 16" crs	Skewed 45° Table Axis

H - wall height, L_f - flange length, L_w - web length



$$\frac{P_{uw}}{P_{uf}} > 1 \quad , \quad \frac{k_w}{k_f} > 1 \quad , \quad \frac{\Delta_{uw}}{\Delta_{uf}} < 1$$

FIG. 1 IDEALIZED MONOTONIC LOAD-DISPLACEMENT SKELETON CURVE FOR T-SECTION WALL

TCCMAR/US

Task Status Report

Date: November 1988

Category: 4

Task No.: 4.2

Task Title: Floor-to-Wall Intersections

Principal Investigator: G.A. Hegemier

1.0 Project Summary

The objective of TCCMAR task 4.2 is (1) to summarize research results obtained under a previous NSF sponsored experimental program and (2) to construct a mathematical model of the observed floor-to-wall response. It is intended that the latter be adopted by the Category 2 modeling team and be incorporated into numerical response simulations of both multistory walls (Category 3) and the full-scale five-story research building (Category 9).

2.0 Research Justification

The relevance of task 4.2 stems from the fact that evidence of floor-to-wall slip is often observed during post-earthquake investigations of masonry structures. Since such slip may significantly alter the overall building response characteristics, slip phenomena must be incorporated into a building response model. This necessitates a mathematical description of the slip mechanism.

The primary intellectual content of task 4.2 concerns the formulation of a theoretical model for floor-to-wall intersection behavior. The underlying theoretical problem is common to many modeling problems associated with the nonlinear response of brittle matrix, fiber reinforced composite materials. This class of composites includes structural materials such as reinforced concrete and reinforced concrete masonry, and advanced materials such as carbon/carbon and fiber reinforced ceramic composites. The problem common to these material-types is the prediction of the overall shear resultant transmitted across an interface, the plane of which is penetrated by reinforcing "fibers." In practice, this plane may represent a construction joint, the intersection of two wall elements, or a crack. The most difficult segment of the modeling problem is the treatment of that part of the resultant force which is contributed by the fibers. Within the context of reinforced concrete, this is the classical dowel-action problem. Researchers working on task 4.2 have achieved a first nonphenomenological solution to this fundamental problem.

3.0 Project Status

A. Work to Date:

All necessary work on task 4.2 has been completed with the exception of that described under section B below. In particular, a model of floor-to-wall behavior for in-plane deformations has been constructed and validated. The model includes both dowel action effects and friction, and applies to general hysteretic floor-to-wall slip histories. Model validation has been achieved by comparing simulated and experimental data for a variety of test conditions.

B. Work Remaining:

A report covering research performed under task 4.2 is approximately ninety percent complete to-date. The final section of this document has been delayed by technical difficulties associated with an important suite of validation comparisons. The latter is noted in section C below.

C. Technical Problem Areas:

Completion of this project has been delayed for a considerable time interval due to a technical problem that was encountered concerning the mathematical description of the frictional aspect of the model for general deformation time-histories. This problem was recently overcome and final model validations are currently in progress. It is anticipated that completion of all work, including the final report, can be accomplished within a thirty day period.

4.0 Technology Transfer

4.1 TCCMAR Reports:

1. No. 4.2-1 "On the Behavior of Floor-to-Wall Intersections in Concrete Masonry Construction: Part I: Experimental
2. No. 4.2-2 "On the Behavior of Floor-to-Wall Intersections in Concrete Masonry Construction: Part II: Theoretical

4.2 Conference or Journal Papers:

1. Hegemier, G.A. and Murakami, H., "On the Simulation of Interface Response in Reinforced Concrete and Concrete Masonry Systems," submitted to Int. Journ. Solids and Structures.

4.3 Workshops and Seminars:

None

5.0 Budget Status

All funds for task 4.2 have been expended.

6.0 Academic Component

Mr. T. Impelluso, a Ph.D. candidate in Applied Mechanics and Engineering Sciences, contributed to the numerical validation segment of the study. In general, the nature of the effort necessitated experienced, professional work; this was carried out by the principal investigators.

TCCMAR/US

Task Status Report

Date: November 1988

Category: 5

Task No.: 5.1 and 5.2

Task Title: Plank Diaphragm Characteristics

Principal Investigator: Max L. Porter, Ph.D., P.E.

1.0 Project Summary

In masonry buildings, diaphragm slabs are required to transmit the lateral loads, such as those from earthquake and wind forces, from one wall to another. Adequate diaphragm action is necessary so that the floor system can transmit these in-plane loads and the resulting energy. The objectives of Task 5.1 and 5.2 are to determine the basic failure modes, ascertain the behavioral characteristics, and investigate analytical strength predictions for prestressed concrete hollow-core planks and to collect data from other diaphragm tests.

To achieve the task objectives, sixteen full-scale plank diaphragms have been tested at the Structural Laboratory at Iowa State University. The key parameters established for these tests were:

a. the orientation of the individual planks with respect to the loading direction,

b. the existence of concrete topping (2" was tested),

c. the boundary conditions (i.e. the number of sides connected to the loading frame),

d. the thickness of the slab, and

e. the number of seam ties in the absence of topping.

The following key characteristics of the diaphragm were established:

a. the initial stiffness,

b. the first major event (FME), and

c. the peak strength.

A hysteretic model was adopted to define the diaphragm behavior under seismic loading. A special sequential-phased-displacement (SPD) loading program was developed and then adopted for the entire TCCMAR research program.

The majority of the failures for the untopped diaphragms occurred at the seams between the individual planks. This led to the implementation of a series of elemental tests. These elemental tests provided the seam behavior and the shear and tension strengths of the seams. These strengths could then be used to determine the overall diaphragm strength.

2.0 Research Justification

Buildings subjected to earthquake and wind forces must have floors capable of transferring in-plane shear forces from one wall to another. These floors are termed as diaphragms and are typically made of hollow-core planks, reinforced concrete, composite steel deck reinforced slabs, or timber. Since no previous experimental research has been done on the diaphragm strength of plank slabs, this project has concentrated on determining information needed for the behavior and design of the plank diaphragms. Proper connections between the diaphragm and masonry walls, as well as between the individual plank elements, are essential to the development of this diaphragm action. In short, the structural integrity of the whole masonry building is linked directly to the resistivity of the diaphragm to lateral in-plane forces resulting from earthquake loads. The failure of the diaphragm could lead to the failure of the entire structure with the possible collapse and loss of life for the occupants.

The plank orientation was determined to be one of the most important parameters affecting the strength of the untopped diaphragms. Test results indicated that placing the planks perpendicular to the applied loads, significantly increased the diaphragm strength. The tests showed an increase of 376% in the FME when the orientation of the plans was perpendicular to the shear wall direction. This behavior is also linked to the number of sides connected to the loading frame. The tests with three sides connected were capable of resisting more load than that for the tests with only two sides connected. the same applies for the tests with four sides connected to the loading frame. The tests showed an increase of 110-120% in strength when three or four sides were connected as opposed to two sides.

The addition of a two-inch concrete topping to the planks increased the diaphragm capacity and produced a stiffer diaphragm. The largest change recorded was for slabs connected on all four sides. The results showed an increase of 718% in the FME load when the topping was added. The effect of the slab thickness was less noticable. However, for untopped slabs, the number of weld ties increased the load carrying capacity. The tests showed an increase of 100% in the peak load when the weld ties were increased.

The results of this research emphasize the importance of the diaphragm action in buildings for resisting the lateral in-plane loads. For design, the most favorable combination of parameters to produce the strongest diaphragms would be achieved with the planks oriented perpendicular to the building shear wall, connected on all four sides, and topped (or connected with the extra seam fasteners, if not topped). The special SPD loading technique worked very well and led to the formulation of hysteretic models for earthquake loading.

Adequate diaphragm action is essential for the stability of the overall masonry structure to prevent collapse. The safety and stability of masonry can be significantly improved by the implementation of the results of research. In particular, the use of the proper boundary connections can provide for redistribution of forces in a "box-type" of structural design to prevent collapse.

3.0 Project Status

A. Work to Date:

Sixteen full-scale slabs have been tested in the Structural Laboratory at Iowa State University. The seam strengths were determined through a series of elemental tests. This experimental stage of the research has been completed.

The key parameters affecting the behavior characteristics have been established. These parameters include: the orientation of the planks with respect to the applied load, the number of sides connected to the loading mechanism, the plank thickness, the existence of topping, and the number of weld ties in the absence of topping.

The analytical phase consisted of four parts:

a. predict the initial stiffness,

b. calculate the FME strength,

c. predict the peak load,

d. develop the hysteretic model, and

e. verify the model using finite element techniques.

The first four parts have been completed. The results showed good agreement with the experimental data.

The data collection for Task 5.2 has mostly been completed.

B. Work Remaining:

The verification of the hysteretic model by finite element techniques is underway. The final report is currently being prepared.

C. Technical Problem Areas:

Two problem areas still to be investigated:

1. Relationship of diaphragm boundary conditions to the real masonry building to be tested,

2. Relationship of static to dynamic testing.

4.0 Technology Transfer

4.1 TCCMAR Reports:

No TCCMAR reports have been issued. The following presentations were made at TCCMAR and JTCCMAR meetings.

1. "Diaphragm Floor Slabs for TCCMAR Study", Porter, M.L. and Sabri, A.A., October 1988.

2. "Concrete Plank Diaphragm Characteristics", Porter, M.L. and Sabri, A.A., July 11, 1988.

3. "Concrete Plank Diaphragm Characteristics", Porter, M.L., Ekberg, C.E., Tremel, P.M. and Meyer, R.J., Jan. 11, 1988.

4. "Sequential Phased Displacement Loading for TCCMAR", Porter, M.L., August 1986, revised September 1986.

5. "Task Status Report of Research on Concrete Plank Diaphragm", Porter, M.L., et. al., August 1987.

6. "Task Status Report of Research on Concrete Plank Diaphragm", Porter, M.L., Feb. 1987.

7. "Report on Working Group B-Components", Matsumura, A., and Porter, M.L., September 1987.

8. "Report on Working Group B and C - Components and Systems", Porter, M.L., Seible, F., Kanah, Y. and Matsumura, A., October 1987.

9. "A Preliminary Data Summary of Diaphragm Tests 1-3", Porter, M.L., Ekberg, C.E., Meyer, R.J., Mashlab, H.A., and Tremel, P.M., November 1986.

10. "Preliminary Summary of Diaphragm Tests 1-6", Porter, M.L., Ekberg, C.E., Meyer, R.J., and Tremel, P.M., March 1987.

11. "Diaphragm Floor Slabs for TCCMAR Study", Porter, M.L., September 1986.

12. "Behavior, Analysis, and Design of Steel-Deck-Reinforced Concrete Diaphragm", Porter, M.L. and Easterling, W.S., March 1988.

4.2 Conference or Journal Papers:

1. Porter, M.L., Ekberg, C.E., Meyer, R.J., Tremel, P.M., "Diaphragm Floor Slabs for TCCMAR Study", Proceedings of the Third Meeting of the Joint Technical Coordinating Committee on Masonry Research of the U.S.-Japan Coordinated Earthquake Research Program, Sapporo, Japan, Oct. 15-17, 1987.

2. Porter, M.L., "Sequential Phased Displacement (SPD) Procedure for TCCMAR Testing", Proceeding of Third Meeting of the Joint Technical Coordinating Committee on Masonry Research of the U.S.-Japan Coordinated Earthquake Research Program, Sapporo, Japan, Oct. 15-17, 1987.

3. Porter, M.L., "Diaphragm Floor Slabs for TCCMAR Study", proceedings of the Second Meeting of the Joint Technical Coordinating Committee on Masonry Research with U.S. and Japanese researchers, Keystone, CO, Sept. 8-10, 1986.

4. Porter, M.L., Tremel, P.M. and Meyer, R.J., "Diaphragm Research Related to Masonry Buildings", Paper in draft form.

4.3 Workshops and Seminars:

All reports listed in Sections 4.1 and 4.2 were presented orally at each TCCMAR or JTCCMAR meeting, in addition to the following:

1. Porter, M.L., "Composite Brick and Block Masonry Walls", Paper presented in the First Workshop on U.S.-Japan Masonry Research Program, Tokyo, Japan, August 26-27, 1985.

2. Porter, M.L., "Structural Research in Japan" (TCCMAR Research in Japan), Presentation given as a seminar in Structural Engineering, Iowa State University, March 4, 1986.

3. Abendroth, R.E., Dunker, K.F., Ekberg, C.E., Fanous, F., Girton, D.D., Greimann, L.F., Porter, M.L., Thomas, M.B. and Wipf, T.J., "Everything You Wanted to Know About a Current Structural Engineering Research Project...But Were Afraid to Ask", Seminar in Structural Engineering, Iowa State University, February 25, 1986.

4. Porter, M.L., "Concrete Structural Research at Iowa State University", Program and tour of the Structural Engineering Test Laboratory at Iowa State University, presented for the Iowa-Minnesota Chapter of the American Concrete Institute, September 25, 1986.

5. Porter, M.L., Oral presentation of paper entitled, "U.S.-Japan Coordinated Program on Masonry Research", by Okamato, S. and Noland, J., presented at the UJNR Meeting, May 1986.

6. Porter, M.L., "U.S. Japan Masonry Research Program (TCCMAR)", Presentation of TCCMAR U.S. and Japan NSF research program to Masonry Institute of Iowa, Des Moines, IA, 1986.

5.0 Budget Status

The following table represents the budget status of Task 5.1 and 5.2 as of 9/30/88:

	Award Start Date	Award End Date*	Award Amount**	From F.Y.	Unspent Amount
1.	09/01/85	02/28/86	$ 15,000	1985	-0-
2.	11/01/86	10/31/87	$ 52,490	1986	-0-
3.	11/01/87	10/31/87)	$ 52,490	1997	$1,102

*does not include any unfunded flexibility periods
**does not include REY Supplements (two)

6.0 Academic Component

A significant educational student component has been involved in this research. The following graduate and undergraduate students were involved as indicated below:

Graduate:

Ron Meyer - Effect of Plank Depth Parameter on Seismic Resistance of Precast Hollow-Core Diaphragm", Master's Thesis completed 1988.

Hasan Mashlab - Elemental Tests and initial frame design report.

Paul Tremel - "Boundary Concitions and Orientation Behavioral Characteristics for Hollow-Core Planks", Master's Thesis completed 1988.

Aziz Sabri - Ph.D. Dissertation in progress.

REU Undergraduates:
Karen Gilbertson
Teri Smith Braughler
Tammy Techau

Undergraduates:
Brian Corzine, Ewsard Matt, Jon Lutz, Eric Motlz, Anthony Fenning, Randy Preters, Richard Khoury, Joseph Flanagan, Bret Chase, Russ Myer, Brian Goedken, Tom Hiett, Scott Anderson, Randy Tweeden, Peter Nilles, Steve Zeller, Lamont Harris, Chuck Bartenhagen.

TCCMAR/US

Task Status Report

Date: November 1988

Category: 5

Task No.: 5.3

Task Title: Continued Work on Concrete Plank Diaphragm Characteristics - Task 5.3

Principal Investigator: Max L. Porter, Ph.D., P.E.

1.0 Project Summary

The overall U.S. TCCMAR program involves the experimental and analytical research of various components and segments of building design analysis of masonry structures. Category 5 of the overall TCCMAR program is being conducted at Iowa State University on the floor slabs involving "Plank Diaphragm Characteristics". The objective of Task 5.3 is to determine the behavioral and limit state modes of failure for these diaphragms when coupled with a masonry wall segment. Experimental tests are to be conducted where the masonry wall segment is substituted in place of the previously used steel beam diaphragm loading system. An analytical model is expected to be created that will describe this overall coupled action of the plank floor slab together with the masonry wall joint. Task 5.3 has just recently commenced as of November 1, 1988. Therefore, items of output resulting from the research cannot be documented at this time. For additional information on Category 5, see Task Summary for the associated tasks 5.1 and 5.2.

2.0 Research Justification

Buildings subjected to earthquake and wind forces must have floors capable of transferring in-plane shear forces from one wall to another. These floors are termed as diaphragms and are typically made of hollow-core planks, reinforced concrete, composite steel deck reinforced slabs, or timber. The overall research program for masonry buildings has included experimental and analytical research on the strength and design modes and associated behavioral characteristics for concrete plank floor slab elements. A very important extension of this work is to couple the behavior of the floor slab together with the masonry wall segment and associated connecting joint to the floor slab.

The results of this research will emphasize the importance of the coupled connection and masonry wall segment behavior on the floor slab diaphragm behavior. An adequate wall-to-diaphragm coupled behavior is essential for the stability of the overall masonry structure to prevent collapse. The safety and stability of the masonry building is very much dependent upon the strength of this coupled wall joint to floor interaction. A significant amount of strength in masonry buildings can be obtained if they can be designed as a "box-type" structural design concept to prevent collapse. Hence, the connection between the floor slab and the diaphragm and the associated coupled system is extremely important.

3.0 Project Status

A. Work to Date:

Since the project just commenced in November of 1988, the work to date has amounted to essentially preparation of the portion of the test frame and in administratively arranging for graduate student personnel.

B. Work Remaining:

Essentially, all of the experimental and analytical work is remaining for this task.

C. Technical Problem Areas:

A key technical problem area at the onset of this investigation entails the design of the masonry wall segment that will be coupled with the diaphragm. Proper design of the connection and the load arrangement to the wall is important for this particular project.

4.0 Technology Transfer

Since the project just commenced in November of 1988, no technology transfer has had a chance to occur as of the date of this project report.

5.0 Budget Status

The following table represents the budget status of Task 5.3 as of November 1988:

	Award Start Date	Award End Date	Award Amount	From F.Y.	Unspent Amount
1.	11/01/88	03/31/90	$75,485	1988	$75,485

6.0 Academic Component

A significant educational student component is expected to be involved in this research. The following graduate and undergraduate students are to be involved as indicated below:

Graduate:
Aziz Sabri - Ph.D. Dissertation
Two masters degree students to be named later.

Undergraduate Students:
A number of undergraduate students will be working on the experimental phases of this research. These students will be named later.

TCCMAR/US

Task Status Report

Date: November 1988

Category: 6

Task No.: 6.2

Task Title: Construction Practices Involving Bond & Splices in Reinforced Masonry (NSF Grant No. ECE-8517029)

Principal Investigator: Leonard G. Tulin, Professor, Civil Engineering, University of Colorado

1.0 Project Summary

The purpose of this project was two-fold. The first objective was to evaluate the effect of shrinkage and bridging defects on the bond between grout and cavity wall and between grout and reinforcing steel in the steel-grout-masonry unit composite. The second objective was to examine force transfer from grout to reinforcing steel and from one steel bar to the other in a spliced pair in reinforced masonry members and to analyze and describe the mechanisms associated with this transfer process.

The first objective was reluctantly deleted from the scope of the project when it was determined that funds would be available for only 55% of the original proposal. This reluctance arose from the fact that the probability of occurrence of construction defects, a serious concern for designers because of the uncertainties they introduce, often leads to overly conservative design limitations.

The second objective was pursued because, while carefully controlled construction techniques in the laboratory can assure a reasonably defect-free grout mass, the mechanism of the bond phenomenon was not well understood in reinforced masonry. A similar mechanism in reinforced concrete had undergone considerable scrutiny in the past, but there were sufficient differences in the two materials and systems to justify such a study.

An experimental program was designed to observe the development of bond between grout and reinforcing steel under both monotonically increasing and cyclic loading conditions. Mathematic models were then developed to describe this bond development in situations when the steel was either continuous or spliced.

2.0 Research Justification

A number of specimens were tested to develop a basic understanding of the bond mechanism in reinforced masonry. While reinforced masonry is in many ways similar to reinforced concrete, it has unique characteristics which must be understood and respected. However, previous experience with reinforced concrete was useful in planning the experimental program and in developing models of the bond mechanism.

The problems associated with pouring a very fluid grout mixture into void spaces and around the reinforcing steel are significant, but proper placement techniques and the use of water reducing, expansive additives can make these problems manageable at least in the laboratory if not realistically in the field. It is therefore possible to construct reinforced masonry walls, beams, and columns of sufficient strength and stiffness to resist expected loads. However, it is the detailing of the reinforcement, in particular, the location and length of splices and the configuration of the anchorage devices which demand a basic understanding of the bond mechanism. The transfer of force from the grout to the steel, or vice versa, is a complex process, complicated by the intricate geometry of the lug deformations on the reinforcing steel, the limitations on the thickness of the masonry members, and the discontinuities at the mortar joints.

This research was able to clarify the manner in which the bond stress distribution developed and degraded under increasing load and was affected by progressive cracking in the masonry. It was concluded that progressive deterioration of bond was not initiated by the limiting value of the maximum developable bond stress at a point, which was unexpectedly large, but rather by the progressive formation of secondary cracks emanating from the tips of the lugs on the reinforcing steel. In addition it was possible to extend previous work in reinforced concrete and to describe, analytically, the nature of the transfer of force from one member to the other in a splice. Furthermore, it was observed that current requirements for length of splice were excessive for reinforcing bars of relatively small diameter and insufficient for bars of larger diameter.

While this research was able to respond to a number of problems associated with reinforced masonry construction, it like much research, asked more questions than it was able to answer. In particular, it pointed up the need to expand the data base provided by this work so that answers to questions on limitations on maximum size reinforcement to prevent splitting, permissible bond stress, required length of lap as a function of size of reinforcement, and use of welding or mechanical devices as a substitute for lapping in splices could be provided.

3.0 Project Status

A. Work to Date:

The first phase of this project began 1st September 1985 with a starting balance of $46,773 for the period 9/1/85 through 8/31/86. The second phase of the project did not begin until December 1986 instead of the originally anticipated September 1986 starting date. Phase II was funded in the amount of $36,975 for the period 12/1/86 through 8/31/87 with an unfunded flexibility period extending to 2/29/88. The unfunded flexibility period was later extended to 8/31/88.

Zorislav Soric was the Graduate Research Assistant on this project. In its early stages, he devoted his efforts to a preliminary pilot study of reinforced concrete masonry beams to gain experience with the materials and techniques involved, and he tested several beam specimens. As a result of this preliminary study, a proposed experimental program was designed and described to the TCCMAR Group at its meeting in Colorado in October, 1985. That proposed experimental program was modified and expanded after incorporating comments received from the other TCCMAR researchers and consultants at the October meeting, and a much more detailed experimental plan was reported to the TCCMAR group at its meeting in El Segundo in February 1986. The details of the experimental plan were included in the 1986 and 1987 progress reports and will not be repeated here. Suffice it to say that the plan with minor modifications has now been completed.

The results of the experimental program and its interpretation were summarized in a 296 page report, U.S.-Japan Coordinated Program for Masonry Research Report No. 6.2-2, "Bond and Splices in Reinforced Masonry," which was distributed to all TCCMAR Researchers and Consultants at the August 1987 Meeting in San Diego. In addition, a number of papers based upon the results of this research have been written or are in preparation. These papers are listed and described in Part 4.2 of this status report.

B. Work Remaining:

While the experimental program has been completed, progress on several as yet unfinished papers continues. Collaboration between the co-authors, who are now separated geographically, has been impeded because it is necessary to communicate by mail rather than by personal interaction. As a result, frustratingly long turn around times frequently dampen enthusiasm, but progress is being made. One paper has been accepted by the ASCE Journal of Structural Engineering, subject to minor revisions suggested by the reviewers. Two other papers are in preparation. One being prepared for submission to ACI Structural Journal must be modified to SI units with accompanying replotting of the graphs and charts. The other is in its draft stages. It will be offered to an appropriate forum for presentation/publication upon completion. While it was not possible to complete these various editorial activities before 31st August 1988, when the extended unfunded flexibility period ended, work will continue until all papers have been finished.

C. Technical Problem Areas:

This study was limited in its scope because of financial and time constraints. As a result some of the conclusions were hedged because of loss of generality in the limited investigations. The study could be expanded as follows:

1. The effect of size of concrete and clay masonry units should be considered.

2. The effect of size of reinforcing steel should be studied by increasing the range of bar sizes.

3. The problem of splicing of reinforcement must be studied in much more detail. In particular, the determination of the required lap lengths for bar sizes from #3 to #11 would provide much needed information. Consideration of alternatives to lapped splices such as welds or mechanical fastening devices should be included.

4. Further research should focus on the problem of splitting failure. Confinement of grout by spirals or other restraining schemes should be included.

5. The classical Pull-Out test in which the steel is in tension and the masonry is in compression does not represent a realistic loading condition. Its use should be avoided, and a new configuration in which both steel and masonry are in tension should be developed. This may challenge ingenuity in satisfying both realism and economy.

6. There is a need for instrumentation capapble of measuring relative displacement between two spliced bars in Pull-Pull or Push-Pull specimens without affecting the bond stress distribution unduly.

4.0 Technology Transfer

4.1 TCCMAR Reports:

1. U.S.-Japan Coordinated Program for Masonry Building Research Report No. 6.2-2, "Bond & Splices in Reinforced Masonry,"Zorislav Soric and Leonard G. Tulin, August 1987.

4.2 Conference or Journal Papers:

The following papers, based upon Task 6.2 have been written or are in preparation:

1. Soric, Zorislav and Tulin, Leonard G., "Analytical Bond Stress/Slip Model for Reinforced Masonry," presented at the Second Meeting of the Joint Technical Coordinating Committee on Masonry Research and published in the proceedings of that meeting, Keystone, Colorado, Sept. 1986, 20 pp.

2. Soric, Zorislav and Tulin, Leonard G., "Comparison between Predicted and Observed Responses for Bond Stress and Relative Displacement in Reinforced Concrete Masonry," presented at the Fourth North American Masonry Conference and published in the proceedings of that conference, Los Angeles, California, August 1987, 15 pp.

3. Soric, Zorislav and Tulin, Leonard G., "Bond in Reinforced Concrete Masonry," presented at the Fourth North American Masonry Conference and published in the proceedings of that conference, Los Angeles, California, 1987, 17 pp.

4. Soric, Zorislav and Tulin, Leonard G., "Bond and Splices in Reinforced Masonry," poster presentation at the Fourth North American Masonry Conference, Los Angeles, California, August 1987.

5. Soric, Zorislav and Tulin, Leonard G., "Bond Stress and Slip in Masonry Reinforced with Spliced Reinforcement," The Masonry Society Journal, Vol. 6, No. 1, Jan-June 1987, pp T13-T27.

6. Soric, Zorislav and Tulin, Leonard G., "Analytical Study of Bond Stress/Slip in Masonry Reinforced with Spliced Reinforcement," presented at the Third Meeting of the Joint Technical Coordinating Committee on Masonry Research and published in the proceedings of that meeting, Tomamu, Hokkaido, Japan, October 1987, 29 pp.

7. Soric, Zorislav and Tulin, Leonard G., "Length of Lap for Spliced Reinforcement in Masonry Structures," presented at the 8th International Brick/Block Masonry Conference 1988, Dublin, Ireland and published in its proceedings (published by Elsevier), Sept. 1988, 15 pp.

8. Soric, Zorislav and Tulin, Leonard G., "Bond/Slip Behavior of Deformed Reinforcement in Grouted Concrete Masonry Beams," presented at the Fourth Meeting of the Joint Technical Coordinating Committee on Masonry Research and published in the proceedings of that meeting, San Diego, California, October, 1988, 21 pp.

9. Soric, Zorislav and Tulin, Leonard G., "Investigation of Bond/Deformation in Pull-Out Type Masonry Specimens," accepted for publication in ASCE Journal of Structural Engineering, subject to minor revision at suggestion of reviewers, Spring 1988, 18 pp.

10. Soric, Zorislav and Tulin, Leonard G., "Behavior of Hooked Horizontal Bars in Reinforced Masonry Structures," in preparation for submission to ACI Structural Journal, approx. 12 pp.

11. Soric, Zorislav and Tulin, Leonard G., "Bond Stress and Slip in Reinforced Masonry Subjected to Reversed Cyclic Loadings, in preparation for submission to an appropriate forum for presentation/publication, approx. 15 pp.

4.3 Workshops and Seminars:

None

5.0 Budget Status

This project was funded by the National Science Foundation under Grant and Proposal No. ECE-8517029 in the amount of $46,773 for Phase I, beginning 1st September 1985 and ending 28th February 1987 (including a 6 month unfunded flexibility period). Phase II was funded by NSF under Proposal No. ECE-8740850 for the period beginning 1st December 1986 and ending 29th February 1988 (including the unfunded flexibility period). The unfunded flexibility period was later extended to 31st August 1988.

	Award Start Date	Award End Date	Award Amount	From F.Y.	Unspent Amount
1.	09/01/85	08/31/86	$46,773	1985	-0-
2.	12/01/86	08/31/87	$36,975	1987	-0-

6.0 Academic Component

Zorislav "Zoran" Soric, the Research Assistant on this project, received the Ph.D. degree in August 1987, and returned to his native Yugoslavia and his position at the Civil Engineering Institute (Gradevinski Institute) of the University of Zagreb. During the experimental phase of the project, a procession of students, both graduate and undergraduate, assisted Zoran in constructing specimens and in performing the various experiments necessary to accumulate data. This work was done on an ad hoc hourly basis as needed and as the budget permitted. No record was maintained regarding the identity of those students or the duration of time they were engaged in such activity.

TCCMAR/US

Task Status Report

Date: November 1988

Category: 7

Task No.: 7.1

Task Title: Dynamic Response of Building Models

Principal Investigator: Daniel P. Abrams
Associate Professor of Civil Engineering
University of Illinois at Urbana-Champaign

1.0 Project Summary

The object of the research is to study dynamic response of reinforced masonry building systems. One-quarter scale test structures are subjected to simulated earthquake motions using a shaking table. Each reduced-scale structure is three stories in height and is comprised of two parallel walls with flanges and openings. The parameter of the dynamic experiments is the layout and size of the wall openings, and thus the distribution of story shear to individual piers is of concern.

One of the three test structures is subjected to a series of static lateral forces which are prescribed based on measured accelerations and displacements of a twin structure tested dynamically. This is done to define story hysteresis relations for input to dynamic analysis models, and to study effects of strain rate and wall inertia as related to testing methods that are commonly used for large scale structures.

The focus of the study is on the interdependence of structural stiffness and lateral inertia for a specific sequence of base motion. The immediate goal of the research is to provide a set of measured response histories that can be used as benchmark data for calibration of numerical models. The long-range goal is to develop a better understanding of how reinforced masonry buildings respond to earthquakes of varying intensity.

2.0 Research Justification

The reduced-scale test structures are not intended to be models of full-size structures, but rather building structures with a known hysteresis that are subjected to known excitations. Measured data on their response is irreplaceable for stimulating knowledge of how actual buildings may respond to earthquakes. With an improved conceptual understanding of how masonry systems vibrate, particularly within the nonlinear range, oversights or errors might be avoided when formulating computational models for general use, or when testing much larger and more expensive structures.

The solution approach involved the innovation of a new construction technique. Buildings had to be built at one-quarter of their regular size, and still possess similar stiffness and strength characteristics under repeated and reversed loading. Model concrete blocks had to be fabricated and mortared together using a specially developed mix of cementious materials. Mechanical properties of the reduced-scale masonry materials had to be determined so that structural design parameters could be identified. Construction techniques had to be improvised to lay the small blocks and to place grout within them. Testing of each structure revealed that the new construction process was viable for replicating crack patterns and damage observed with full-scale buildings.

The test structures were the stiffest and heaviest of all specimens that have been tested on the Illinois shaking table, and thus were the most demanding from an experimental point of view. Before testing, it had to be confirmed that the simulator platform could be programmed to move through a prescribed motion to simulate an earthquake motion. Because frequencies of the simulator were found to be in the same range as the expected fundamental frequency of the test structure, a considerable amount of fine tuning was necessary before the first test so that it could be assured that a nonrepresentative resonance would not occur.

Ranges of response for each test structure had to be estimated analytically so that intensities of input motion could be selected for each test run. In addition, response maxima had to be estimated before a test so that ranges of all of the 64 channels of electronic instrumentation could be set. Because no other reinforced masonry structure had been tested before this series, these predictions had to be made without any reference data.

Dynamic tests of each specimen generated approximately a million numbers. Test data had to be calibrated in engineering units, and classified by channel. This required a substantial amount of data processing effort. The data was then reduced to give response histories of lateral deflections and accelerations, and shear forces and overturning moments at each story. Frequency contents of these records were studied by plotting Fourier Transforms, and were correlated to identify response mechanisms.

Apparent spectral accelerations were measured and compared with spectral response curves calculated from measured input motions. the decrease in amplification of base accelerations was studied as each structure incurred more and more damage. Apparent natural frequencies were identified from measured displacement histories and were correlated with average stiffnesses of hysteresis loops. Acceleration maxima were correlated with displacement maxima by the square of the apparent frequencies to study how well the nonlinear systems could be represented with simpler linear concepts. Deflected shapes were studied for their variation at several different amplitudes of motion. Lateral force distributions were studied also for their variation with time. Moment diagrams were plotted and correlated with observed cracking and yielding of vertical reinforcement. Base moments were plotted versus top-level deflections to study hysteretic relations. Final response mechanisms were analyzed to determine why the test structures did behave the way they did.

The significance of the research to structural engineering practice is suggested in the next section where things that have been learned from the research are listed.

3.0 Project Status

A. Work to Date:

All dynamic testing is completed. A total of four, three-story test structures have been constructed at one-quarter scale. Two have been tested to destruction on a shaking table. A third test structure has also been tested on the shaking table, but was subjected to nondestructive forces as a result of being mounted on base isolators. This structure will be tested statically in the near future. A fourth structure has been constructed of concrete and will be tested statically as well (see next section).

At the start of the project, a series of material tests were done on the reduced-scale masonry. These included compressive tests of prisms, tensile tests of lap splices, splitting tests of square panels subjected to diagonal compression, and tensile tests of model reinforcement.

Information from these preliminary tests were used for the structural design of each three-story test structure.

The amount of work completed is nearly proportional with the time expended to date. Twenty-two months of the thirty-month project are now in the past, and it is fair to say that 70% of the proposed accomplishments have been made to date.

Apart from providing response histories for calibration of numerical models, the following has been learned from the experimental program.

a. For two different structural configurations, cracking and yield of reinforcement were predictable for a given base-motion intensity.

b. Amplification of base accelerations diminished as each structure was subjected to earthquake motions of increasing intensity. A partially damaged structure was more tolerant of excitation than a virgin one because of the shift in frequency and the increase in damping.

c. Measured deflected shapes were invariant for all amplitudes of motion. This suggests that a single generalized coordinate may be used to represent dynamic response of systems responding in either the linear, or nonlinear range.

d. Despite nonlinearity, each test structure responded with a dominant frequency which could be calculated using an average stiffness per hysteresis cycle. This finding suggests that a simplified linear method of analysis might be appropriate for estimating response maxima of nonlinear behaving systems.

e. Inelastic deformability of one structure was limited because of sliding shear along a flexural crack. As a result, the distribution of story shear was not in accordance with that predicted by conventional stiffness models.

f. The use of base isolators can significantly limit the amount of lateral inertial force.

B. Work Remaining:

Test structure RM2 which is a replica of structure RM1 will be tested statically. Top-level displacements and loading distributions will be in accordance with measured response of RM1. In addition, a concrete replica of RM1 will be tested first to verify operation of the loading system. Both structures have been constructed and the loading rig has been fabricated. Work is being done on development of a computer-based load control system, and on instrumentation of each specimen.

Over the next year, data from all test structures will be reduced and interpreted, and a final report will be compiled.

It is expected that a supplement to grant will be awarded in the next few months, and run for a period of one year. The supplement was requested so that the P.I. may interact with investigators involved with development of analytical modes.

C. Technical Problem Areas:

None

4.0 Technology Transfer

4.1 TCCMAR Reports

None

4.2 Conference or Journal Papers

1. Abrams,D.P., "Measured Hysteresis in a Masonry Building System," Proceedings of Third U.S. Conference on Earthquake Engineering, Charleston, South Carolina, August 1986, pp. 1371-1382.

2. Abrams, D.P., "Lateral Resistance of a Two-Story Reinforced Concrete Block Building," Proceedings of Session on Advances in Analysis of Structural Masonry, ASCE Structures Congress, New Orleans, September 1986, pp. 41-57.

3. Abrams, D.P., "Large-Scale Testing of a Masonry Building," Proceedings of Seminar on Structural Assessment Based on Full and Large Scale Testing, Building Research Establishment, Garston, England, April 1987, 7pp.

4. Abrams, D.P., "Dynamic and Static Testing of Reinforced Concrete Masonry Structures," Proceedings of Ninth World Conference on Earthquake Engineering, Tokyo-Kyoto, August 1988.

5. Abrams, D.P. and T. J. Paulson, "Dynamic Testing of One-Quarter Scale Reinforced Concrete Masonry Building Structures," Proceedings of Fourth Meeting of US-Japan Joint Technical Coordination Committee on Masonry Research, Rancho Bernardo, California, October 1988, 22pp.

6. Abrams, D.P., "Dynamic and Static Testing of Reinforced Concrete Masonry Structures," Journal of The Masonry Society, December 1988.

7. Abrams, D.P. and T.J. Paulson, "Measured Nonlinear Dynamic Response of Reinforced Concrete Masonry Building Systems," abstract submitted for paper to be published in Proceedings of Fifth Canadian Masonry Symposium, Vancouver, British Columbia, June 1989.

8. Abrams, D.P. and T. J. Paulson, "Modeling Concrete Masonry Building Structures at One-Quarter Scale," abstract submitted for paper to be presented at symposium on Recent Studies on Scale Models of Special Concrete Structures, Fall Convention of American Concrete Institute, San Diego, California, November 1989.

4.3 Workshops and Seminars:

1. "The Role of Reinforced Masonry in Seismic Design: An Overview of the TCCMAR Research Program," Annual Convention of the International Masonry Institute, St. Louis, November 1987.

2. "The U.S.-Japan Coordinated Masonry Research Program," to be presented at Institute for Testing Materials and Structures, Ljubljana, Yugoslavia, December 1988.

5.0 Budget Status

As of July 1, 1988, a sum of $47,785 is left of the original $179,291 which reflects an expenditure of 73% of the grant to this date. A summary of the budget is as follows.

	Award Start Date	Award End Date	Award Amount	From F.Y.	Unspent Amount
1.	01/01/87	12/31/87	$92,992	1987	-0-
2.	01/01/88	12/31/88	$86,299	1988	$47,785
3.	(12/01/88)	(11/30/89)	($27,561)	(1989)	($27,561)

6.0 Academic Component

Mr. Thomas J. Paulson has been working on the project since the summer of 1987, and will writer a doctoral dissertation on the project. He has been supported on a 25%-time research assistantship from the grant, and a departmental fellowship. He plans on receiving a Ph.D. by the Spring of 1990.

Mr. Arturo Tena-Colunga will start working on the project in January of 1989 and will pursue a doctoral dissertation on analytical modeling of dynamic response. He will be supported on a 50%-time research assistantship from the grant. He is from UNAM in Mexico City.

Approximately eight undergraduate civil engineering students have worked on various phases of the laboratory investigation since its start. Two have been women.

Dr. Tamas Balogh, a visiting researcher from a government testing institute in Budapest, supervised construction of test structures and assisted with instrumentation. He visited Urbana from September of 1987 to January of 1988, and was funded by the Hungarian Civil Engineers Association of America.

TCCMAR/US

Task Status Report

Date: November 1988

Category: 8

Task No.: 8.1

Task Title: Limit State Design Methodology for Reinforced Masonry

Principal Investigator: Gary C. Hart, UCLA

1.0 Project Summary

This research developed a limit state design methodology which is the foundation for reinforced masonry evaluation of experimental and analytical research results. It also is the basis for the eventual development of design recommendations. The key elements in the methodology which the research identified and defined are behavior states, limit states, and probabilistic based capacity reduction factors. The methodology has been illustrated using preliminary experimental and analytical TCCMAR research results obtained as part of the shear wall and slender wall tasks.

2.0 Research Justification

Seismic design criteria for reinforced masonry has historically been based on limited experimental data and considerable subjective judgment. The creative aspect of the research in this task is that it has proposed an entirely new methodology upon which seismic design of masonry structures can be based. The intellectual challenge was to develop a scientifically rigorous probabilistically based methodology which can incorporate experimental test data, analytical modeling accuracy and the uncertainty in material properties and workmanships. This challenge was met by the developed methodology. For example one creative example is the inclusion of a random variable in the structural reliability equations to reflect analytical modeling uncertainty. This inclusion directly rewards the more accurate and sophisticated analytical modeling of masonry structures and thus speeds up technology transfer. Another example of a creative contribution is the putting forth of the proposition that future design criteria should be based on probable values of parameters and not minimum values. This position if followed will enable the scientific development of probable response estimates to be compared with experimental test data and resultant differences to be quantified for rational inclusion into the structural reliability analysis.

3.0 Project Status

The research on this task has been completed and all of the research objectives identified in the project summary have been met. The following major research contributions have been made:

1. A limit state design methodology based on probabilistic methods has been developed which will serve as the foundation for Task 8.2. This is an entirely new direction for masonry design criteria and differs fundamentally from the currently used working stress design procedures.

2. The shear wall and slender wall behavior and limit states have been identified.

4.0 Technology Transfer

4.1 TCCMAR Reports:

1. "A Limit State Design Methodology for Reinforced Masonry," by Gary C. Hart

4.2 Conference or Journal Papers:

1. "Technology Transfer, Limit State Design and the Critical Need for a New Direction in Masonry Code Design Criteria," by Gary C. Hart, Proceedings of Fourth North American Masonry Conference, August 1987.

2. "Limit State Design Criteria for Minimum Flexural Steel by Gary C. Hart, M. Ali Basharkhah and George T. Zorapapel, proceedings of Fourth North American Masonry Conference, August 1987.

4.3 Workshops and Seminars:

1. Engineers Week, California State University at Los Angeles, April, 1987.

2. U.S./China Masonry Research Workshop presentation in Harbin, China, May, 1987.

3. U.S./Japan Cooperative Research Seminar in Haikaido, Japan, September, 1987.

4. Structural Engineers Association of San Diego Student Night Dinner Talk, at California State University, San Diego, May, 1988.

5.0 Budget Status

The final expenditure of funds was within the NSF budget. The budget is shown below.

	Award Start Date	Award End Date	Award Amount	From F.Y.	Unspent Amount
1.	09/01/85	09/31/86	$21,798	1986	-0-
2.	10/31/86	06/31/87	$22,782	1987	-0-

6.0 Academic Component

Two students were involved in a supporting role in this project, Mr. Won Kee Hong and Mr. George T. Zorapapel. Both were involved in the very early stages of their Ph.D. thesis work. Their thesis will involve research funded in Task 8.2.

TCCMAR/US

Task Status Report

Date: November 1988

Category: 8

Task No.: 8.2

Task Title: Limit State Design Methodology and Reliability Analysis

Principal Investigator: Gary C. Hart

1.0 Project Summary

The research being performed in this task involves the development of the analytical equations and data base necessary to implement the limit state design methodology developed in Task 8.1. the data base contains for each TCCMAR experimental research task the numerical values obtained for such random variables as unit strength, grout mortar, reinforcing steel and prism strength. The research in analytical equation development involves extending the boundaries of structural reliability theory to enable the identification of limit state and the accurate calculation of capacity reduction factors. These equations will be developed for the limit states in evidence in shear walls, coupled walls, flange walls and masonry frames.

2.0 Research Justification

A limit state design methodology must be refined and developed using scientific techniques. The research developed in this task will involve many examples of innovation. For example, the development of the analytical equations to perform a structural reliability analysis of the yield force, yield stiffness and displacement ductility will require creativity. These equations include the development of sensitivity coefficient calculation and ranking algorithms. Another example is the development of nonlinear statistical and Monte Carlo models that will be used to determine values of capacity reduction factors for serviceability and strength limit states. The structuring of the material property computer data base and the statistical characterization of the data will be a new innovation. The reason for this is that the move to a limit state design that uses probable values will require this task to develop methods for field evaluation of the acceptability of during construction test data. The current approach of test values above a minimum value are not valid. The identification of which statistical parameters are optimal to calculate and the establishment of accept or reject limits will require creativity.

3.0 Project Status

A. Work to Date:

Funding for this task started on March 1, 1988. The work between March 1 and July 31, 1988 involved the development and acquisition of data for the materials data base computer program. In this time span research also involved the initiation of efforts aimed at the identification of the factors that are impacted by the move toward a probable value based limit state design methodology.

B. Work Remaining:

The work remaining involves the development of:

1. The structural reliability equations for single shear walls, coupled shear walls, flanged walls and masonry frames.

2. Equations and computer algorithms that can be used to calculate values of capacity reduction factors.

3. The methodology to be used to establish the quality control criteria for field testing of prisms for use with probable value limit state design.

4. A data base of earthquake ground motion records for use in the structural reliability studies.

5. The probabilistic description of the ductility demand induced on masonry structures by an ensemble of earthquake ground motion records.

C. Technical Problem Areas:

No technical problem areas are evident at this time and none are anticipated.

4.0 Technology Transfer

4.1 TCCMAR Reports

None to date because research was just funded.

4.2 Conference or Journal Papers:

None to date because research was just funded.

4.3 Workshops and Seminars:

None to date because research was just funded.

5.0 Budget Status

The expenditure of funds to date is consistent with the approved NSF funding budget. The budget status is shown below.

	Award Start Date	Award End Date	Award Amount	From F.Y.	Unspent Amount
1.	03/01/88	02/28/89	$54,000	1988	-0-
2.	03/01/89	02/28/90	$64,642	1989	$64,642
3.	03/01/90	02/28/91	$68,815	1990	$68,815
4.	03/01/91	02/28/92	-	1991	-

6.0 Academic Component

Ms. Jan Gregory is a Civil Engineering Masters Degree student who is working on the material data base phase as part of her masters comprehensive. Her degree is anticipated to be awarded December 20, 1988.

Mr. Won Kee Hong is a Civil Engineering Ph Degree student who is working on the single cantilever wall behavior and limit state identification and the development of capacity reduction factors for this part of the research. He anticipates completion of his Ph.D. in June 1989.

Mr. George T. Zorapapel is a Civil Engineering Ph Degree student who is working on the direct incorporation of the load side of the equation into the structural reliability aspects of the problem. He anticipates completion of his Ph.D. in June, 1990.

TCCMAR/US

Task Status Report

Date: November 1988

Category: 9

Task No.: 9.1(a)

Task Title: Design of Reinforced Masonry Research Building

Principal Investigator: John C. Kariotis

1.0 Project Summary

Reinforced masonry research building Type A has been designed. Building Type A represents a typical multi-story apartment/condominium occupancy. Reinforced masonry walls perpendicular to the in-plane test wall subdivide the units. The center of the laboratory strong wall is concurrent with the axis of the single reinforced masonry wall that is designated as the test wall. Building Type A has been selected by TCCMAR as the research building.

The test wall has window and door openings. These openings occur at each level in an identical pattern. this opening pattern will include in the full scale test wall the following subtypes of shear walls:

a. A shear wall with central opening, a wall intersection (flange at one wall edge, minimal coupling beams at one wall edge).

b. A cantilever shear wall with a wall intersection at the center of the pier section.

c. A broad based cantilever shear wall with symmetrical openings through the wall. The spandrel section over the openings will provide substantial restraint to the piers between the openings.

d. A flexible cantilever shear wall with minimal coupling beams at one edge and a wall intersection at one edge.

The configuration of the subassemblies of the test wall will stretch the ability of the analytical program to predict complete cyclic load-displacement relationships. It is our understanding that a loading-data acquisition method termed Generated Sequential Dynamic Displacements will be the test technique.

The construction materials of the test building are fully described in the final report. Six inch concrete masonry units were selected to minimize the strength and stiffness of the test building. The test building is considered to be a segment of a multi-story building. The design of this segment will assume that the full prototype structure is located in a seismic risk zone other than the California, Nevada, and Alaska seismic zones.

The concrete masonry units will be fully grouted and reinforced for shear capacities in excess of flexural capacity. The shear reinforcement pattern is that shown by element testing to have acceptable shear ductility. Splices in the vertical reinforcement were considered to be unacceptable in critical flexural zones. This restriction would require that open end blocks be used for placement around the vertical reinforcement.

Special planning for horizontal construction joints at the foundation and at each floor level has been noted on the final report. These details deviate from usual construction practices that depend on omission of a part of the face shell of the unit at the vertical reinforcement for removal of accumulated debris. The method of construction of experimental wall elements should be nearly identical to the methods that are planned for the test building.

An elastic finite element analysis of the UCSD test wall that includes probable post-tensioning losses and uncertainties has been made. This analysis of the UCSD test wall has confirmed that its elastic strength greatly exceeds the probable loading that will be required to displace the test building into the inelastic displacement range.

Methods of loading the five level building by equivalent inertial loads has been investigated. Materials with constant shear properties over an adequate displacement range are available. Possible methods of loading to better determine the loading system are part of future tasks.

This task was not intended to solve the technical problem of testing a full scale building. The task was intended to define a test building. In addition, the test building provides guidance for the design of experimental test specimens.

This task has developed the following opinions for the construction of certain problem areas of the test structure.

Construction joints: Construction joints will be at each floor level and will be prepared as indicated on the enclosure.

Minimum number of reinforcing bars in any pier: The minimum number of bars in a pier is four. This will cause the pier to reach its peak yield strength at the maximum possible displacement.

Shear design criteria: The formula developed by Japanese researchers was used for the determination of shear reinforcement.

Splicing of vertical reinforcement: The splicing of flexural reinforcement in maximum moment zones is not permitted. Vertical splicing in stress zones of 70-80 percent of maximum stress is permitted. UBC laps will be used.

Base sliding at zone of maximum moment: Shear keys will be used in the middle half of pier that are calculated to have critical base shear. It has not been confirmed that shear key will be required in the selected pier configuration.

2.0 Research Justification

The final design of the test building used vertical reinforcement quantities that are considerably less than current design for the highest seismic zone in the United States. This quantity of reinforcement was generally determined by prescribed strengths for wind or earthquake loading normal to the wall surface. This quantity, determined by normal loading, generally exceeded the requirements for in-plane loading. The decision to distribute the design vertical in-plane reinforcement uniformly across the width for walls and piers greatly reduced the quantity of vertical reinforcement.

The design procedure adopted clearly indicated that minimization of in-plane flexural strength is very beneficial in reducing the quantities of required horizontal reinforcement. The final design that has a balanced in-plane flexural and shear strength has reinforcement patterns greatly differing from current masonry construction. The analysis of required reinforcement patterns indicated that the majority of masonry reinforcement should be horizontal in lieu of vertical. This conclusion corresponds to reinforcement patterns that are prescribed by design codes for reinforced concrete. It is clearly indicated that the masonry design codes should be modified to require the same relationship of minimum vertical and horizontal reinforcement.

Another conclusion is drawn from this proposed reinforcement pattern. As the quantity of horizontal reinforcement increases, the construction cost economy of partial grouting of hollow unit masonry drastically decreases. The need for in-plane shear strength in the masonry structure probably indicates that only walls with an in-plane strength, determined by partially grouted shear analysis as equal to elastic response shear, should be partially grouted.

This conclusion also indicates that a separate research item is to determine the horizontal reinforcement quantities that are needed to control shrinkage and temperature related dimensional charges.

3.0 Project Status

A. Work to Date:

Task 9.1(a) Phase I has been completed.

B. Work Remaining:

Phase II of the project has been proposed to the National Science Foundation and is pending at this time.

C. Technical Problem Areas:

The critical problem areas were as follows:

Determining the stiffness and peak sustained strength of coupling beams between shear walls. FEM's or SCM's are not available for use in the determination of force-displacement relationships. Flexural yield has been assumed for small coupling beams and the slender coupled shear walls. Approximate relationships of stiffness is estimated for the large piers that have window openings.

Additional stiffness effects of wall flanges: The effect of the wall flange is estimated as 20 percent of the wall height.

Shear keys at wall base: The influence of shear keys on base sliding has not been determined experimentally. The shear key may have an adverse effect on the splicing of vertical reinforcement near the sliding zone.

4.0 Technology Transfer

4.1 TCCMAR Reports:

1. "Design of Reinforced Masonry Research Building Phase I," Kariotis and Johnson, TCCMAR Report 9.1-1, National Science Foundation, September 1987.

4.2 Conference or Journal Papers:

1. Kariotis, J.C., "Design of the Research Building," presented at JTCCMAR, Keystone, Colorado, September 1986.

2. Kariotis, J.C., "Design of the Research Building," presented at TCCMAR meeting in Los Angeles, CA, February 1985, and La Jolla, CA, August 1986.

4.3 Workshops and Seminars:

None

5.0 Budget Status

	Award Start Date	Award End Date	Award Amount	From F.Y.	Unspent Amount
1.	10/01/85	09/30/87	$21,920	1987	-0-

6.0 Academic Component

None

TCCMAR/US

Task Status Report

Date: November 1988

Category: 11.0

Task No.: 11.1

Task Title: Coordination of U.S. Coordinated Program for Masonry Building Research

Principal Investigator: J.L. Noland

1.0 Project Summary

The U.S. side of the U.S.-Japan Coordinated Program consists of twenty-eight specific research tasks which must be integrated and coordinated to produce the desired program goals. Coordination activities include organizing and conducting general and special meetings for data exchange and planning, monitoring research progress, identifying and resolving budget, schedule and other difficulties, interfacing with the industry to arrange for support and to promote program-user group communication, participating as required in UJNR activities, communicating with the Japanese side as required for information exchange and for arranging joint meetings, promoting public relations and general planning.

2.0 Research Justification

Coordination is required to focus and integrate the efforts of the many researchers comprising TCCMAR to attain program objectives in an efficient manner, on a timely basis and such that the results constitute a consistent and compatible body of knowledge. It is recognized that individual researchers in structural engineering may produce valuable results on specific topics. However, utilization of their results in the past has often been deficient. For example, committees within professional societies have collected research results on given topics from different investigators and produced design recommendations, analytical methodologies, criteria, etc. However, the process is inherently slow and frequently rendered difficult by the lack of common approaches, common materials, common methods for presentation and interpretation of data and so on. The primary justification for a coordinated effort is to enable the results of the individual tasks to be combined in a building block manner to produce the body of knowledge referred to above, and to thus enhance the transfer of the knowledge to practice. This is particularly important for the U.S. Coordinated Program because the paramount objective is to develop design criteria and recommendations for limit state design of reinforced masonry buildings.

Coordination is theoretically possible among a large number on a group consensus basis. This can be and often is a time-consuming process. Further, many operational factors simply do not require group agreement. Therefore, in order to expedite progress and allow the researchers to concentrate primarily on their individual tasks, the U.S. Program relies upon a single coordinator, with the advice and council of an executive panel and consultants panel as shown in Figure 1 in Section 3.1, to initiate and execute coordination activities.

The challenges in the coordination effort are many. Among them are 1) to meld the individuals, each of whom has many demands on his time, possibly different attitudes, perspectives and background, into a functioning team, 2) to anticipate, if possible, and resolve individual task and overall program problems of a technical, operational and budgetary nature, 3) to communicate with industry and professional groups to promote their support and understanding of the program, and 4) to, above all, keep the program focused upon the overall objectives.

3.0 Project Status

A. Work to Date:

Principal activities performed to date include the following:

1. Organized (with Japanese counterparts) four U.S.-Japan joint project meetings.

2. Organized and conducted TCCMAR/U.S. meetings twice per year.

3. Organized several sub-group meetings as required to resolve issues of a coordination or technical nature.

4. Worked with the Industry Participation Panel to arrange and coordinate industry contributions.

5. Interfaced with various industry and professional groups, e.g., BIA, NOMA, CMR, MRF, TMS, ACI, WSCP, ASTM, and CNCMA to keep them informed of project goals and progress.

6. Instigated proposals leading to Tasks 2.4(a), 2.4(b), 3.1(c).

7. Stimulated broadening of Category 2 (Modeling) to include participation of other TCCMAR researchers.

8. Coordinated preparation and submittal of proposals to support Programwork in FY `88, `89, `90.

9. Coordinated and arranged U.S.-Japanese researcher exchanges.

10. Maintained contact with and participated in the UJNR Panel on Wind and Seismic Effects.

11. Initiated planning for Task 10.1 Design and Criteria Recommendations.

B. Work Remaining:

Principal remaining work includes:

1. Planning with the Japanese side, the fifth joint U.S.-Japan technical meeting.

2. Arranging and conducting the 1989 TCCMAR/U.S. meetings.

3. Work with industry to obtain materials and labor to fabricate specimens at UCSD for Tasks 3.1(b), 4.1, and 9.4.

4. Continue working with ASTM to improve masonry material and subassemblage test standards using TCCMAR input.

5. Initiating/instigating proposals for new Tasks, i.e.,

   a. Task 1.3 - Critical Review and Development of Masonry Material and Assembly Standard Tests

   b. Task 6.1 - Grouting Procedures for Reinforced Hollow Unit Masonry (originally planned but not funded)

   c. Task 6.2 - Continued Development of Rebar Bond and Splice Technology for Grouted Hollow Unit Masonry

   d. Task 9.3/9.4 - Test Planning and test of Full-Scale Masonry Research Building

e. Task 10.1 - Design Recommendations and Criteria Development

6. Work with Professor Shing of University of Colorado to obtain industry support for his PYI and define research complementary to the U.S. Coordinated program.

7. Continued coordination duties to stimulate/expedite flow of information and ideas among program researchers, consultants and industry.

8. Coordinate program activities and needs with NSF.

9. Periodic reporting to UJNR.

10. Continued presentation of Program Plans and accomplishments at symposia, conferences, etc. and other PR activities.

11. Continued monitoring of individual task progress and needs.

12. Continued communication with the Japanese TCCMAR to arrange meetings, researcher exchange, etc.

C. Technical Problem Areas:

Principal problems encountered and probably which will continue in various degrees include:

1. Keeping communication active. There is a natural tendency for each Task researcher to be insular. Team research, especially when team members are scattered around the country, is not conducive to frequent communication. Budget limitations preclude frequent meetings, hence researchers must rely upon mail, electronic mail, FAX, and telephone to communicate. Communication is essential for conduct of a program of this nature and special effort is required.

2. Industry support - The masonry industry is, due to its origins, fragmented. Further, it is a relatively small industry and has an inadequate technological base. Hence, obtaining industry support for the program has been difficult. The Indusrty Participation Panel has been very active and has succeeded in providing masonry units and some other materials for all test specimens. The big challenge ahead is the construction of specimens for tasks to be conducted at UCSD, particularly the five-story research building.

3. Funding - NSF has provided the financial support for the program and the amount has been substantial. However, because of various pressures, initial funding (FY`85, `86, and `87) was less than requested and funding for FY `88, `89, and `90 was not possible compatible with the time phasing requested. This led to eliminating or reducing some research and rescheduling and stretching out other research. The situation was unavoidable, but resulted in the program being less efficient and longer than it could have been.

4.0 Technology Transfer

4.1 TCCMAR Reports:

1. Summary Report: U.S. Coordinated Program for Masonry Building Research, Sept. 1985 to August 1986.

4.2: Conference or Journal Papers:

1. Okamoto, S., Noland, J., "U.S.-Japan Coordinated Program on Masonry Research, Proc. - Third Conference on Dynamic Response of Structures, ASCE, Hart & Nelson, ed. March 31-April 2, 1986.

2. Okamoto, S., Noland, J., "U.S.-Japan Coordinated Program on Masonry Research," Proc. - Fourth Canadian Masonry Symposium, University of New Brunswick, J. Dawe, ed., June 1986, paper no. 71.

3. Noland, J., "A Review of the U.S. Coordinated Program for Masonry Building Research," Proc. - Fourth North American Masonry Conference, UCLA, August 1987, paper #38.

4. Noland, J., "A Review of U.S. Coordinated Program for Masonry Building Research," Proc. - Third Meeting of the Joint Technical Coordinating Committee on Masonry Research, Tomamu, Japan, Oct. 1987.

5. Noland, J., "U.S. Coordinated Program for Masonry Building Research - 1986/87," Proc. - 19th Joint Meeting of the U.S.-Japan Cooperative Program in Natural Resources, Panel on Wind and Seismic Effects, N. Raufaste, ed., Center for Building Technology, National Bureau of Stadards, January 1988.

6. Noland, J., "Status of the U.S. Coordinated Program for Masonry Building Research," Proc. - Fourth Meeting of the Joint Technical Coordinating Committee on Masonry Research, San Diego, October 1988.

7. Noland, J., "Current Status of the U.S. Coordinated Program for Masonry Building Research," Proc. - 20th Joint Meeting of the U.S.-Japan Cooperative Program in Natural Resources, Panel on Wind and Seismic Effects, N.Raufaste, ed., National Institute for Science and Technology.

4.3 Workshops and Seminars:

Presentations presenting an overview of The U.S. Coordinated Program for Masonry Building Research have been made to the following groups and other meetings.

1. First Joint U.S.-Japan Masonry Workshop - Tsububa, Japan, March 1984.

2. Concrete Masonry Association of California and Nevada, September 1984.

3. Western States Clay Products Association, October 1984.

4. Masonry Research Foundation, July 1985.

5. First Joint Technical Coordinating Committee on Masonry Research, Tokyo, Japan, August 1985.

6. ASCE Structures Congress, September 1985.

7. Concrete Masonry Association of California and Nevada, September 1986.

8. Structural Engineers Association of California, San Diego, CA, October 1987.

9. Masonry Structures Design Course, U.S. Army Engineers
   Savannah, GA, April 1987
   Fort Worth, TX, July 1987
   Huntsville, AL, May 1988

10. National Science Foundation, Washington, D.C., May 1988 (with G. Hart)

11. TMS - Masonry Industry Meeting on strength Design of Masonry, Los Angeles, July 1988

12. Technical Session - ASTM Committee E-6, Toronto, Oct. 1988.

5.0 Budget Status

The funds for Task 11.1 from Fiscal Years `85, `86, and `87 have been exhausted as shown in the table. Support for Task 11.1 from FY `88 funds began in March 1988 with approximately 1/3 unspent as of the date of this report.

	Award Start Date	Award End Date	Award Amount	From F.Y.	Unspent Amount
1.	09/01/85	11/30/86	$42,275	1985	-0-
2.	10/31/86	11/30/87	$44,540	1986	-0-
3.	04/27/87	01/30/88	$37,540	1987	-0-
4.	04/01/88	08/31/89	$90,120	1988	$ 33,260
5.	--	--	$114,935	1989	$114,935
6.	--	--	$125,453	1990	$125,453

6.0 Academic Component

No students have participated in Task 11.1.

APPENDIX 2

AGENDA AND RESOLUTIONS FROM JOINT U.S.-JAPAN MEETINGS

AGENDA

Fourth Meeting of the Joint Technical Coordinating
Committee on Masonry Research

U.S.-Japan Coordinated Program
on
Masonry Building Research

October 17-19, 1988
San Diego, California, U.S.A.

Monday, October 17, 1988

8:30 A.M.	Call to Order	James Noland
8:35 A.M.	Welcome	A.J. Eggenberger
8:50 A.M.	Review of Agenda & Activities	James Noland
9:00 A.M.	Review of Japanese Program	Shin Okamato
9:20 A.M.	Review of U.S. Program	James Noland
*************	**SESSION 1** **Co-chair: Y. Kanoh, R. Atkinson**	*************
9:35 A.M.	Effect on Uniaxial Behavior of Grouted Prisms Affected by Geometry of Masonry Walls (A)	Osamu Senbu
10:00 A.M.	*************BREAK*************	
10:20 A.M.	Compressive Stress Distribution of Grouted Hollow Brick Masonry (A)	Russell Brown
10:45 A.M.	A Proposal on Predictive Method of Shear Strength of Grouted Masonry Based on Material Properties (A)	Suenori Arinaga
11:10 A.M.	Bond/Slip Behavior of Deformed Reinforcement in Grouted Concrete Masonry Beams (A)	Leonard Tulin

*The letter in parantheses denotes the category to which the paper has been assigned. the paper may be found in the corresponding section of the proceedings.

11:35 A.M.	Elastic Moduli of Grouted Masonry Walls (A)	Akio Baba
NOON	*************LUNCH*************	

************* **SESSION 2** *************

Co-chair: T. Okada, G. Hart

1:00 P.M.	Behavior of Single-Story Reinforced Masonry Shear Walls Under In-Plane Cyclic Lateral Loads (B)	Benson Shing
1:25 P.M.	Flexural Behavior of Reinforced Concrete Block Beams (B)	Fumitoshi Kumazawa
1:50 P.M.	Seismic Behavior of Flanged Masonry Shear Walls (B)	Nigel Priestley He Limin
2:15 P.M.	Effectiveness of Shear Reinforcement in Fully Grouted Hollow Clay Masonry Walls (B)	Akira Matsumura
2.40 P.M.	*************BREAK*************	

************* **SESSION 3** *************

Co-chair: Y. Yamazaki, D. Abrams

3:00 P.M.	Non-linear Response of Reinforced Block Masonry Walls Under Out-of-Plane Cyclic Loading (B)	Ahmid Hamid
3:25 P.M.	Strength and Deformation of Grouted Masonry Walls with Casting Joints (B)	Akio Baba
3:50 P.M.	Out-of-Plane Dynamic Testing of Concrete Masonry Walls (B)	Samy Adham
4:15 P.M.	Flexural Failute Test of Reinforced Concrete Masonry Walls - Effect of Lap Joint Reinforcement (B)	Toshiyuki Kubota
4:40 P.M.	The Transverse Dynamic Response of Clay Masonry Walls - Progress Report (B)	Bjorn Sveinsson Ronald Mayes Marcial Bondet
5:05 P.M.	Structural Component Models of Flexural Walls	Gary Hart Robert Englekirk W.K. Hong
5:30 P.M.	*************CLOSE*************	

Tuesday, October 18, 1988

8:30 A.M.	Call to Order	Shin Okamato
*************	**SESSION 4** **Co-chair: A. Baba, R. Brown**	*************
8:35 A.M.	Correlation Study Between Fundamental Structure Test and Seismic Performance of RM Walls: Test Planning (B)	Takaaki Nishi Masaomi Teshigawara
9:00 A.M.	Diaphragm Floor Slabs for TCCMAR Study (B)	Max Porter
9:25 A.M.	Seismic Behavior of Reinforced Masonry Walls with Small Openings (B)	Hiroshi Imai
9:50 A.M.	Preliminary Report on Testing of Specimen 2A, TCCMAR Task 3.1(c): In-Plane Resistance of Two Story Concrete Masonry Walls with Openings (C)	Nicholas Antrobus Gilberto Leiva Mark Merryman Richard Klingner
10:15 A.M.	*************BREAK*************	
*************	**SESSION 5** **Co-chair: T. Kubota, M. Porter**	*************
10:35 A.M.	Seismic Test of Five-Story Full Scale Reinforced Masonry Building: Outline of Test and Service and Yield Phase Response (C)	Yutaka Yamazaki
11:00 A.M.	Seismic Test of Five-Story Full Scale Reinforced Masonry Building: Pseudo-Dynamic Test and Ultimate Loading Pase Response (C)	Takashi Kaminosono
11:25 A.M.	Seismic Test of Five-Story Full Scale Reinforced Masonry Building: Forced Vibration Test (C)	Mototaka Matsuno
11:50 A.M.	*************LUNCH*************	
*************	**SESSION 6** **Co-chair: H. Imai, M.J.N. Priestly**	*************
1:00 P.M.	Seismic Test of Five Story Full Scale Reinforced Masonry Building: Analysis on Service & Yield Phase Responses (C)	Masaomi Teshigawara

1:25 P.M.	The First RM Building Being Built in Japan	Hiroshi Nei
1:50 P.M.	Dynamic Testing of One-Quarter Scale Reinforced Concrete Masonry Building Structures (C)	Daniel Abrams
2:15 P.M.	Modeling of Reinforced Masonry Components and Subassemblages (D)	Frieder Seible
2:40 P.M.	*************BREAK*************	
*************	**SESSION 7** **Co-Chair: M. Teshigawara, L. Tulin**	*************
3:00 P.M.	Correlation Between Analysis and Experiments on Two-Story Reinforced Masonry Shear Walls (D)	Robert Ewing John Kariotis Ahmad El-Mustapha
3:25 P.M.	Generation of Sequence Displacements for Experimental Testing of Reinforced Masonry by a Non-linear Model (D)	John Kariotis
3:50 P.M.	The Cost of Structural Construction of Five-Story Reinforced Masonry Building and Prospect of Demand for RM Apartment House (D)	Yoshio Inoue
4:15 P.M.	Philosophy of Structural Design Guidelines for Medium-Rise RM Buildings	Tsuemo Okada
4:40 P.M.	Probable Values of Reliability Indices	Gary Hart
5:05 P.M.	*************CLOSE**************	

Wednesday, October 19, 1988

8:30 A.M.	Call to Order Divide into Working Groups	James Noland
**************	**SESSION 8**	**************
8:45 A.M.	Working Group A - Materials & Small Specimens Co-chair: A. Baba, A. Hamid	
	Working Group B - Components Co-chair: A. Matsumura, M. Porter	
	Working Group C - Systems Co-chair: Y. Kanoh, G. Hegemier	
	Working Group D - Modeling & Design Co-chair: T. Okada, J. Kariotis	
10:45 A.M.	*************BREAK*************	
11:00 A.M.	Resolutions Discussion of 5th JTCCMAR	
NOON	*************CLOSE*************	

RESOLUTIONS

THE FOURTH MEETING OF THE JOINT COORDINATING COMMITTEE
ON MASONRY RESEARCH (JTCCMAR)
SAN DIEGO, CALIFORNIA, U.S.A.
October 17, 18, and 19, 1988

1. The fourth meeting of JTCCMAR was held in San Diego, California, U.S.A. on October 17, 18, and 19, 1988. The meeting was attended by 18 researchers from the United States, 16 researchers from Japan, 7 observers from the United States and 10 observers from Japan.

2. There was a successful exchange of information and ideas between the researchers from both countries on the subjects of masonry material behavior, behavior of assemblies, behavior of systems, testing procedures, analytical/modeling methods, results of the Japanese tests on a 5-story building, seismic design procedures and future work.

3. It was recognized that, while progress has been made in developing an understanding of the behavior of masonry, there is still an urgent need for additional information. The participants therefore recommend that sponsoring agencies take appropriate measures to continue support for masonry research.

4. The participants recognize that both countries have many common research needs regarding masonry construction as well as mechanical properties of masonry units, components, and systems.

5. It was recognized that continuous and in-depth effort is required to establish the seismic performance characteristics of masonry structures and to develop improved construction and design procedures. However, the participants realize that the research programs of both countries primarily address central issues. They also recognize that, while the knowledge developed will provide a basic foundation for improved masonry technology, many other important issues exist which should be addressed.

6. Significant progress has been made by both sides in testing and modeling masonry materials, components, subassemblages, and prototypes which will lead to a better understanding of masonry structural behavior and to the development of adequate seismic design procedures for masonry buildings.

7. The participants recognized that the full-scale test carried out in japan has and will make a great contribution to the understanding of the overall behavior and performance of masonry structural systems. They recommend that another full-scale test on a masonry structural system be carried out in the United States. It is also recommended that information obtained from both full-scale tests be exchanged.

8. The technical communication which has been carried out by sub-groups and individuals of TCCMAR/U.S. and TCCMAR/Japan has been valuable and should be continued. Researchers should be exchanged as required to enable a meaningful exchange of concepts and information between individuals and groups with similar research interest.

9. The participants from both countries agree that proper seismic performance of masonry structures requires consideration of damage control and minimization of life safety threats.

10. It was recognized that the joint project will result in an improved technological base for the design of RM buildings.

11. It was recognized that the results of this coordinated research program could also be beneficial to other countries which have a seismic hazard, especially developing countries.

12. Considering that the U.S. program is planned to continue until 1993 and considering the benefits of the mutual exchange between the U.S. and Japanese programs, it is hoped that the joint relationship be continued so the mutual benefits may be maximized.

13. The participants realized that a reinforced masonry building association should be established in Japan as soon as possible to promote, by continuous effort, the development and promulgation of a more rational design procedure for RM buildings, including the low-rise category, so that the joint U.S.-Japan relationship may be continued.

14. It was recognized, by both sides, that new concepts in masonry technology should be investigated to enhance economy and reliability.

15. The fifth meeting of JTCCMAR will be held in Japan in the fall of 1989.