REPAIR, STRENGTHENING AND REHABILITATION OF BUILDINGS

Recommendations for Needed Research

Results of a Workshop Sponsored

by the

National Science Foundation

Grant No. NSF-ENV 76-83884

to the

Department of Civil Engineering
The University of Michigan

Robert D. Hanson, Director

WORKSHOP EXECUTIVE COMMITTEE

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June 9-10, 1977

Rodeway Inn, South San Francisco

BIBLIOGRAPHIC DATA SHEET	1. Report No. NSF/RA-770431	2.	3. Recipient's Accession No. PB277388
4. Title and Subtitle Repair, Strengthening and Rehabilitation of Buildings: Recommendations for Needed Research			5. Report Date October 1977 6.
7. Author(s) R.D. Hanson			8. Performing Organization Rept. No. UMEE77R4
9. Performing Organization Name and Address University of Michigan Department of Civil Engineering Ann Arbor, Michigan 48109			10. Project/Task/Work Unit No. 11. Contract/Grant No. ENV7683884
12. Sponsoring Organization Name and Address Applied Science and Research Applications National Science Foundation Washington, D.C. 20550			13. Type of Report & Period Covered 14.

15. Supplementary Notes

Results of workshop held June 9-10, 1977, San Francisco

16. Abstracts

The goal of the workshop was to define the most important research needs in the fields of repair, strengthening and rehabilitation of buildings in order to protect them and their occupants against natural hazards. The emphasis of the workshop was directed toward earthquake resistant buildings. Participants were structural designers, constructors, and materials specialists experienced in the repair, strengthening, and rehabilitation of buildings. The three working groups were given the task to identify the most urgent research efforts needed in the field. They made the following recommendations: (1) research is vital and all persons in the field are encouraged to seek financial assistance to develop the needed information; (2) the most immediate needs relate to the evaluation of existing lime-mortar brick buildings; (3) a guideline for the evaluation of existing buildings is needed; (4) a manual of practice for the use of various repair materials and techniques is needed; (5) in the rehabilitation planning, the entire building must be considered, not just its components; (6) an extensive educational effort is needed; (7) all interested parties should be involved in the decision process on the level of rehabilitation needed; and (8) governmental cooperation is needed to allow full-scale tests of buildings.

17. Key Words and Document Analysis. 17a. Descriptors.

Buildings
Construction
Earthquake resistant structures
Hazards
Maintenance
Renovating
Structural design

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
NTIS.	UNCLASSIFIED	55
	20. Security Class (This Page)	22. Price
	UNCLASSIFIED	PCA04 MFA01

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INTRODUCTION

The repair of damaged buildings and the strengthening and rehabilitation of existing buildings has been accomplished for many years. Designers and owners have had confidence in the resulting repairs and rehabilitation. Experience with earthquake damaged buildings which were repaired (strengthened) and experienced a subsequent earthquake has been mixed. In some cases the repaired building was not damaged in the subsequent earthquake. In other cases new damage was generated at other locations or within the repaired regions. Clearly, a better understanding of the structural characteristics of various repair and rehabilitation techniques is needed.

The recent change in the economic balance from removal-replacement of buildings toward rehabilitation of buildings has been rapid. Thus, the need for the most economical, effective techniques for structural rehabilitation is great. Various methods must be evaluated for their structural characteristics as well as their cost. Limited research has been directed toward obtaining data in this field throughout the country. Much of the available cost data is not widely distributed and in most cases the structural characteristics are not well documented.

The greatest problem in most of the cities which are subject to earthquakes is the danger of collapse of existing buildings. The existing inventory has buildings of all ages and pre-code construction, all types of materials, and in all stages of deterioration. These buildings will be the first to go or to suffer severe damage in the event of an earthquake. Therefore, it becomes imperative that something be done to improve these buildings before the danger is experienced.

A coordinated research effort in this rapidly developing field is needed. In our free enterprise system coordination cannot be accomplished by directives. It is best accomplished by identifying the most important research needs and objectives, and by keeping all interested parties apprised of current research efforts and results. Financial support of these research efforts by private capital and by government agencies are needed to achieve the desired results. Retrofitting, strengthening and repair have been selected as the most important aspects of the National Science Foundation earthquake engineering program for the coming year.

The National Science Foundation awarded a grant (Grant No. NSF ENV76-83884) to the University of Michigan to plan and conduct a workshop on the Repair, Strengthening and Rehabilitation of Buildings. The workshop theme was to clearly define the limitations of our current knowledge concerning the reduction of building hazards caused by acts of nature and to identify research efforts necessary to remove most of these significant limitations. The goal of this workshop was to define the most important research needs in the fields of repair, strengthening and rehabilitation of buildings in order to protect them and their occupants against natural hazards. The emphasis of the workshop was directed toward earthquake resistant buildings because that field has the most immediate problems to be solved.

Robert D. Hanson, Project Director, together with an Executive Committee, whose members were selected because of their extensive experiences in the field, recommended individuals to participate in the two-day workshop. The participants were selected on the basis of their experiences in the fields concerned with repair, strengthening and rehabilitation of buildings as structural designers, constructors, and materials specialists. All of these participants donated their time and efforts to this workshop and many also paid their own expenses. The success of the workshop is the result of the individual efforts of each participant. The National Science Foundation and The University of Michigan give their sincere appreciation and thanks to each of these outstanding individuals whose participation in the workshop contributed to its success.

During the selection of the participants it became clear that most of them would be from California. In order to minimize the man-hours spent in travel the workshop location was moved from Ann Arbor to San Francisco. The Earthquake Engineering Research Institute (EERI), Susan B. Newman, Office Manager, agreed to help with the local arrangements. This assistance made the workshop an enjoyable experience for all of the participants. Our sincere appreciation is extended to Susan and EERI.

The able assistance of Dr. John B. Scalzi, Program Manager for NSF, during the planning of the workshop and during preparation of this report is appreciated. In addition the writer extends his thanks to the members of the Executive Committee for their assistance, to Professor V. V. Bertero for releasing the preliminary recommendations from his workshop and to Reta Teachout for her assistance in preparing this report.

Support of the Workshop by the National Science Foundation through Grant Number NSF-ENV 76-83884 is acknowledged. However, the conclusions and recommendations expressed herein do not necessarily reflect the views of NSF.

WORKSHOP SUMMARY

After the technical presentations which summarized the state-of-the-art in repair and retrofitting, the participants were assigned to one of three working groups. Each working group was given the task to identify the most urgent research efforts needed for the repair, strengthening and rehabilitation of buildings to resist natural hazards. The results of these discussions are summarized in the RECOMMENDATIONS. Following the presentation of these recommendations to the assembled participants, an open discussion of the research needs occurred. The results of that discussion identified several high priority needs which deserve special mention in addition to the working group recommendations, and are listed here for emphasis.

1. The research needs described in the RECOMMENDATIONS are vital and _all persons with the ability and interest in any aspect of these problems are encouraged to seek financial assistance_ to develop this needed information. Financial assistance is available from many sources, public and private, including several government agencies.

2. _The most immediate needs relate to the evaluation of existing lime-mortar brick buildings_. A large scale program of evaluation and demolition or repair is under consideration in Los Angeles.

3. A GUIDELINE for the evaluation of existing buildings is needed. This guideline should present the current state of practice for the evaluation of building hazards, a recommended procedure for establishing the desired level of building performance, and evaluation of various rehabilitation materials and techniques appropriate for the desired performance. This GUIDELINE should be prepared with the knowledge available at the present time and updated as new research and construction data become available. Care must be taken to avoid stringent specifics which would limit the imagination of the designer.

4. A MANUAL of practice for the use of various repair materials and techniques is needed. This manual should provide the information necessary to specify and qualify that the rehabilitation will accomplish the planned objectives. This MANUAL should be updated as experience and research data become available.

5. In the evaluation and rehabilitation planning it should be recognized that the entire building must be considered, not just its components or subassemblies.

6. An extensive educational effort is needed. Educating engineers and architects as well as current college students with respect to the materials and techniques for repairs should be started. Product manufacturers,

construction personnel, insurance companies, financial institutions, and public policy officials should be made cognizant of the natural hazards of existing buildings and the procedures to minimize these hazards.

7. All interested parties should be involved in the decision process on the "level of rehabilitation needed or required."

8. Governmental cooperation is needed to allow full-scale tests of buildings. Even though a building is to be demolished, it is not always possible to obtain permission to perform damage level tests of the building. Without governmental support this permission is seldom granted.

RECOMMENDATIONS

WORKING GROUP ONE: Evaluation of Existing Construction and Materials for Rehabilitation and Repair

Chairman: B. Bresler
Co-Chairman: J. R. Janney
Recording Secretary: L. F. Kahn

J. Amrhein	R. G. Johnston
S. B. Barnes	J. Kariotis
L. Chang	J. Mehnert
W. G. Corley	E. O'Connor
S. A. Freeman	E. Schwartz

Everyone should recognize the interrelationships between technical activities and political, social and economic activities. Regardless of what is done in a technical capacity the engineer should be cognizant of the social-political-economic aspects of the problem of retrofitting existing structures to increase the safety of the occupants. Since the evaluation of a potential hazard cannot be perfect, risks are involved in the determination of the quality of existing buildings. The process of strengthening buildings to minimize life hazards will be expensive and will necessitate involving other parties in the decision making process.

1. THE OVERALL AIM SHOULD BE TO MINIMIZE LIFE LOSS IN THE EVENT OF AN EARTHQUAKE WITH ITS CONCOMITANT HAZARDS.

Because of the limitations of funding and time available to complete the monstrous task that lies ahead for the public to make all buildings safe, rehabilitation of hazardous buildings should be approached through criteria whose major thrust would be to protect lives. With this as the basic criteria almost everything else follows as a matter of course. For example, a great deal of discussion was concerned with the loss of industrial and commercial facilities and its effect on the employment of people involved in a tragic earthquake. A building whose collapse would create this problem would also constitute a danger to life.

2. A PRIORITY SYSTEM FOR EVALUATION OF EXISTING BUILDINGS SHOULD BE ESTABLISHED IN TERMS OF THE ESSENTIAL NATURE OF THE BUILDING, ITS OCCUPANCY, AND POTENTIAL LOSS OF LIFE.

In recognizing the very long time necessary to accomplish the required rehabilitation work, a system should be established to assign priorities for evaluation of existing structures. What that priority system should be is not known yet, but it should include life loss which has already been mentioned, the essential function of the building, and the number and type of its occupants. It might sound a little crass but the political decisions attendant to this process should consider who is housed in each individual facility.

3. PRESENT CODES ARE WRITTEN FOR NEW CONSTRUCTION AND AS A RESULT ARE NOT DIRECTLY APPLICABLE TO REHABILITATION OF EXISTING STRUCTURES.

The recommendation is more of a declaration than a statement for needed research. The consensus declaration states that codes as now known and used in new design should not assume a dominant role in the evaluation of existing structures. This is a matter of practicality because some enhancement of structural safety is better than none. Many of the participants have encountered cases where increased safety could be obtained by performing certain repair tasks which are not sufficient if constrained by strict adherence to codes. Strict adherence would result in no action on rehabilitation.

4. DIAGNOSTIC PROCEDURES ARE NEEDED FOR DETERMINING THE QUALITY OF THE LATERAL LOAD RESISTANCE FOR A BUILDING. SYSTEMATIC ASSEMBLY OF KNOWLEDGE, TECHNIQUES AND INSTRUMENTATION FOR NON-DESTRUCTIVE EVALUATION OF EXISTING CONDITIONS IS NEEDED.

The methodology or systematic diagnostic procedures for evaluating structural safety of existing buildings should include the development of nondestructive methods of evaluating the material properties of strength, the characteristics of materials, and nondestructive methods of determining the conditions which exist within a building. Guidance to engineers for examination of buildings in terms of which items are critical to the performance and behavior of the structure under seismic or other natural hazard conditions should be developed.

5. THE LACK OF INFORMATION ON THE SEISMIC RESISTANCE OF EXISTING STRUCTURES REQUIRES INTEGRATED FIELD AND LABORATORY INVESTIGATIONS. DIFFERENT TYPES OF BUILDINGS AND CONSTRUCTION MUST BE IDENTIFIED AND CRITICAL ITEMS DEFINED. THIS CAN BE ACCOMPLISHED BY FULL SCALE FIELD TESTS OF EXISTING STRUCTURES IN COMBINATION WITH ANALYTICAL AND LABORATORY STUDIES.

On the basis of the presentations and the subsequent discussions the group felt that it would be completely remiss if laboratory studies and research work were not recommended. The group felt that a combination of laboratory and field evaluation of repeatable parameters that are encountered in these buildings would be in order. For example, a great deal of discussion concerned the actual contribution, positive or negative, of certain types of infill walls in older buildings. The importance of material properties to the performance of the structure and the effects of nonengineered or nonstructural components such as floors and partition walls on the total resistance of the structure should be determined. Well conceived research projects which would combine laboratory and field studies could produce very helpful data. Such studies also would be of assistance to those who are responsible for developing innovative ideas on retrofitting buildings to increase their seismic capabilities. If certain weaknesses are discovered in these studies, they would point to possible solutions for strengthening the buildings.

6. AN INFORMATION DATA-BANK ON THE QUALITY OF EXISTING BUILDINGS, ON REPAIR AND REHABILITATION METHODS, AND OF ENGINEERING STUDIES OF EXISTING BUILDINGS IS NEEDED. EPIC, WHEN IT BECOMES A REALITY, CAN BE USED AS A POSSIBLE VEHICLE FOR THIS DATA-BANK.

It is clear that each person has a data bank in their mental storehouse of personal experiences: personal knowledge of buildings they have inspected, technical programs in which they have participated, and professional committees on which they have served. Most people draw conclusions from their own unique personal experiences. Since everyones' experiences are different the conclusions reached are also probably different. The American Society of Civil Engineers Research Council on the Performance of Structures has a project to study the feasibility of forming an Engineering Performance Information Center. This center might be one vehicle through which information gained, lessons learned, and solutions obtained during the process of upgrading buildings could be made available to other professionals. For example, suppose some California engineers receive an assignment to study half a dozen buildings each and are asked to gather appropriate data about those buildings before an event. The buildings selected should have certain characteristics that can be categorized, such that the next time a serious earthquake occurs the performance of these buildings can be evaluated on the basis of the information in the data bank. It may provide minimal information but it is much better than that which is currently available.

WORKING GROUP TWO: Design Criteria for Rehabilitation and Strengthening

Chairman: C. W. Pinkham
Co-Chairman: C. Culver
Recording Secretary: S. A. Mahin

J. R. Cagley	J. E. Minor
S. Cherry	B. L. Schmid
A. Gerich	M. A. Sozen
G. C. Hart	W. J. Warner
D. K. Jephcott	

These comments are divided into several different areas. The first presents a general set of recommendations basic to the need for an investigation philosophy. The other items are arranged into categories of Serviceability, Strength Limits and Environmental Factors.

General Recommendations

1. A SURVEY TO OBTAIN BASIC DATA REGARDING THE INVENTORY AND NATURE OF EXISTING BUILDINGS IS NEEDED.

Careful planning of such a survey is needed to identify the information that is required, the use that will be made of the data, the methods for obtaining this data, and the required accuracy of the data.

2. GREATER AMOUNTS OF DAMAGE MAY BE ACCEPTED IN SOME TYPES OF EXISTING BUILDINGS THAN IN COMPARABLE NEW STRUCTURES DEPENDING UPON THEIR USAGE AND THE HAZARD EXPOSURE, BUT LIFE SAFETY MUST REMAIN THE PRIMARY OBJECTIVE.

3. RESEARCH IS NEEDED TO OBTAIN THE INFORMATION NECESSARY FOR A DESIGNER TO DETERMINE THE APPROPRIATE LEVELS OF DESIGN FORCES AS A FUNCTION OF THE PROBABILITY OF THE ENVIRONMENTAL HAZARD, THE USE OR OCCUPANCY OF THE BUILDING, THE EXPECTED REMAINING LIFE OF THE STRUCTURE AND THE DESIRED LEVEL OF STRUCTURAL PERFORMANCE.

These design requirements may or may not be regulatory or code requirements.

4. DESIGN CRITERIA APPLICABLE TO THE HISTORICAL AND OTHER SPECIAL STRUCTURES NEED FURTHER INVESTIGATION.

If an historical building is to be rehabilitated for an unspecified useful life, then theoretically every possible event that could happen should be considered in the design. The validity of this concept should be studied.

Serviceability Loadings

1. RESEARCH IS NEEDED TO ESTABLISH CRITERIA FOR ACCEPTABLE SERVICEABILITY LIMITS FOR PROBLEMS SUCH AS VIBRATION, AND FOR DETERMINING ECONOMICAL AND RELIABLE METHODS OF ABATING THE EFFECTS OF THESE PROBLEMS.

2. RESEARCH IS NEEDED TO DETERMINE THE ACCEPTABLE LEVELS OF PERMANENT DEFORMATION OR DAMAGE IN EXISTING STRUCTURAL ELEMENTS AND FOR METHODS OF REPAIRING STRUCTURES WITH UNACCEPTABLE DEFORMATIONS OR DAMAGE.

3. RESEARCH IS NEEDED TO DETERMINE ACCEPTABLE LEVELS OF DAMAGE IN NONSTRUCTURAL ELEMENTS SUCH AS PARTITIONS, ELEVATORS, FIRE DOORS, EXIT WAY PROTECTIONS, AND MECHANICAL EQUIPMENT IN BOTH EXISTING BUILDINGS AND BUILDINGS TO BE REHABILITATED.

Strength Limits

1. RESEARCH ON THE DISTINCTION BETWEEN DESIGN CRITERIA BASED ON MEMBER STRENGTH AND THOSE BASED ON THE TOTAL STRUCTURAL STRENGTH OF THE COMPLETE BUILDING IS NEEDED. CURRENT ANALYTICAL AND EXPERIMENTAL RESEARCH ON THIS PROBLEM SHOULD BE CONTINUED AND EXPANDED.

2. RESEARCH IS NEEDED REGARDING FAILURE MECHANISMS OF EXISTING BUILDINGS AND METHODS FOR ESTABLISHING ASSOCIATED FORCE AND/OR DEFORMATION LEVELS.

In particular structural systems such as flat slab structures, nonductile reinforced concrete frames, braced steel frames, building frames with masonry filler walls, unreinforced masonry bearing walls, and other combinations should be investigated.

3. RESEARCH IS NEEDED FOR DEVELOPING CRITERIA OF PROOF LOAD TESTS ON EXISTING BUILDINGS AS AN ALTERNATE DESIGN PROCEDURE.

4. RESEARCH IS NEEDED ON THE MECHANICAL CHARACTERISTICS OF COMPOSITE MEMBERS AND MEMBERS WITH COMBINATIONS OF MATERIALS.

5. RESEARCH IS NEEDED ON PERMISSIBLE STRESSES AND/OR DEFORMATIONS OF NONSTRUCTURAL ELEMENTS.

Environmental Factors

1. RESEARCH IS NEEDED ON THE STRUCTURAL CONSEQUENCES OF DEGRADATION OF MATERIALS AND MEMBERS DUE TO ENVIRONMENTAL INFLUENCES SUCH AS CORROSION, CHEMICAL ATTACK, AND INSECT AND FUNGAL INFESTATIONS.

2. RESEARCH ON ACCEPTABLE FIRE DAMAGE IN STEEL, REINFORCED CONCRETE, PRESTRESSED CONCRETE, TIMBER BUILDINGS AND METHODS OF REPAIRING SUCH DAMAGES ARE NEEDED.

Toxicity and smoke problems of original and repair materials should be included in this research effort.

WORKING GROUP THREE: Standards for Repair Materials and Techniques

Chairman: L. A. Wyllie, Jr.
Co-Chairman: J. Warner
Recording Secretary: J. K. Wight

V. V. Bertero	L. A. Lee
H. A. Davis	J. M. Plecnik
A. E. Fiorato	F. R. Preece
J. C. Fredericks	A. Rossi
W. C. Hodges	W. K. Tso

The lively discussions on repair materials included the merits and demerits of various construction materials to be used for different purposes. Individual biases have been eliminated as much as possible by dividing the research needs into the four categories of Shotcrete, Epoxy, Connections and Connectors, and Miscellaneous. In each of these categories the discussions were directed toward what is not known, what should be known, and what research, if any, is needed.

Shotcrete

1. DEVELOP QUALITY CONTROL TESTS FOR COMPRESSIVE STRENGTH, SHEAR STRENGTH, CHARACTERISTICS OF BONDING TO OTHER MATERIALS, PULL-OUT CHARACTERISTICS, AND TENSILE STRENGTH.

One of the major problems at the present time is the dependence of shotcrete quality on workmanship without an independent procedure to check the quality.

2. CYCLIC TESTS OF SHOTCRETE USED IN CONJUNCTION WITH EXISTING MATERIALS IS NEEDED.

Full-scale field tests and field samples tested in the laboratory are needed to determine the characteristics of the resulting repair. These tests must be as realistic as possible in construction and type of loading. Correlation with smaller size specimens should be made. Shotcrete applied to brickwalls is particularly urgent, but applications to other surfaces such as concrete block and reinforced concrete walls also are needed.

3. TESTS TO VERIFY THE STRENGTH OF VARIOUS ANCHORAGE SYSTEMS BETWEEN SHOTCRETE AND EXISTING MATERIALS AND MEMBERS ARE NEEDED.

A major question is the effect of connection eccentricities and sag of shotcrete on the bond characteristics of the reinforcement. There is a need to consider realistic dynamic conditions with forces parallel and perpendicular to the wall.

4. DETERMINE THE APPLICABILITY OF SHOTCRETE FOR USE IN BEAMS, COLUMNS AND JOINTS.

Use of shotcrete in situations other than flat surfaces is increasing. Correlation between the behavior of these members when produced with cast-in-plate concrete and when produced with shotcrete is needed. The effect of reinforcement congestion, heavy ties and spirals on shotcrete placement and member strength, and the effects of combined loading of shotcrete members should be determined.

5. BEHAVIOR OF SHOTCRETE FOR FIRE PROOFING, UNDER HIGH TEMPERATURE EXPOSURE, AND UNDER IMPACT LOADING NEEDS TO BE ESTABLISHED.

Very little data is available on this subject.

Epoxy

1. ESTABLISH MATERIAL STANDARDS-DEFINING TERMS AND USAGE.

Standards for these materials need to be established in a manner that neutralizes competition and removes the current mysticism for engineers and other designers. Education of future engineers of the characteristics and physical and chemical properties of epoxy materials is needed.

2. RESEARCH IS NEEDED TO DEFINE AND ESTABLISH CRITERIA AND PROPERTIES FOR ACCEPTANCE OF EPOXY MATERIALS.

Performance type specifications for repair usage with specific limitations for different environments are needed. Specific areas to be included are:

a. Effects of exposure to fire or high heat.

b. Exotherm potential.

c. Variation of elasticity properties with formulation and curing environment.

d. Creep properties.

e. Sensitivity of mix and proportions.

3. DEVELOP GUIDELINES FOR USE AND APPLICATION OF EPOXY FOR THE REPAIR OF BUILDINGS.

Appropriate applications and uses of epoxy repair materials and methods are needed. Surface preparation, moisture conditions, injection techniques, bonding of reinforcing bars, bonding of new to old concrete, and bonding of mixed materials such as shotcrete and concrete should be considered.

4. NEED TO ESTABLISH QUALITY ASSURANCE METHODS FOR EPOXY INJECTION AND OTHER USAGES. EMPHASIS NEEDED ON NONDESTRUCTIVE PROCEDURES.

5. RESEARCH IS NEEDED ON USAGE OF EPOXIES IN PROVIDING ADEQUATE BONDING BETWEEN NEW CONCRETE AND OLD.

6. RESEARCH IS NEEDED TO IMPROVE THE BOND OF REINFORCING STEEL IN DAMAGED STRUCTURES.

7. MORE RESEARCH IS NEEDED TO UNDERSTAND THOROUGHLY THE PERFORMANCE OF EPOXY REPAIR IN FIRE ENVIRONMENTS, INCLUDING REALISTIC FIRE CONDITIONS.

8. FULL SCALE TESTING OF EPOXY REPAIRED MEMBERS IS NEEDED: BOTH FIELD AND LABORATORY TESTS UNDER REALISTIC EARTHQUAKE SIMULATED CONDITIONS.

9. RESEARCH AND TESTS ARE NEEDED FOR THE LONG TERM EFFECTS OF EPOXY REPAIR UNDER CONTINUOUS LOAD.

How does the epoxy repair affect the shrinkage and creep of the structure?

Connections and Connectors

1. A MAJOR RESEARCH EFFORT IS NEEDED TO DETERMINE THE STATIC AND DYNAMIC PROPERTIES OF ANCHORS. PULL-OUT, SHEAR, TORSION AND COMBINATIONS OF LOADING SHOULD BE CONSIDERED.

These connection tests should include bolts cast in concrete as a standard, expansion bolts, bolts grouted in concrete, bolts grouted in masonry, bolts epoxied in concrete, bolts epoxied in masonry of various types, reinforcing steel grouted or epoxied in existing materials, proprietory resin systems, and driven anchors. Actual field material samples for installation and various drilling techniques should be used because they may have a major effect.

2. THERE IS A NEED TO EVALUATE THE STRENGTH OF A DOG ANCHOR IN WOOD AND TO EXPLORE POSSIBLE IMPROVEMENTS IN ITS PERFORMANCE.

3. RESEARCH ON THE CONNECTION OF WOOD MEMBERS, INCLUDING PLYWOOD OVERLAYS, AND THE USE OF ADHESIVES IN ADDITION TO MECHANICAL CONNECTORS NEEDS STUDY.

4. SPLICING OF REINFORCING STEEL TO EXISTING REINFORCING STEEL AND ANCHORAGES SHOULD BE EVALUATED.

5. METHODS AND TECHNIQUES FOR WELDING NEW MATERIAL TO EXISTING STEEL MEMBERS AND OTHER OLD METALS SHOULD BE DEVELOPED. WELDING TO STEEL MEMBERS UNDER LOAD NEEDS STUDY.

Miscellaneous

1. EVALUATE THE EFFECTIVENESS OF PLYWOOD OVERLAYMENTS NAILED INTO STRAIGHT SHEATHING.

2. GUIDELINES NEED TO BE DEVELOPED IN DEFINING METHODS OF REDUCING THE CORROSIVE EFFECTS OF ANCHORS AND REPAIRS.

3. RESEARCH ON THE EFFECTIVENESS OF PLASTER SYSTEMS TO STRENGTHEN UNREINFORCED MASONRY.

Cement plasters and ferro-cement systems need to be evaluated. Cyclic dynamic tests are essential.

4. RESEARCH IS NEEDED ON STRENGTHENING AND BRACING OF UNREINFORCED MASONRY AND CLAY TILE WALLS AND PARTITIONS FOR FORCES PERPENDICULAR TO THE PLANE OF THE WALL.

New materials may have application for membrane action. For membrane action the resulting in-plane shear characteristics should be investigated together with the effect on stiffness and strength. Anchorage of exterior cladding and ornamentation should be included.

5. RESEARCH IS NEEDED IN THE USE OF POST-TENSIONING SYSTEMS AND MATERIALS IN STRENGTHENING BUILDINGS.

Panel construction is becoming more significant in this country. The need to tie the elements of a building together will be very important to this type of new construction as well as in the rehabilitation of existing buildings.

6. THERE IS A NEED TO DEVELOP NEW MATERIALS AND TECHNIQUES FOR BUILDING REPAIR.

This new information should be transmitted to the designers and constructors in a form which permits immediate utilization.

7. RESEARCH ON THE REPAIR OF DISTRESSED OR FAILED TIMBER MEMBERS BY VARIOUS METHODS IS NEEDED. RESEARCH IS NEEDED TO ARREST THE GROWTH OF DRY ROT IN TIMBER STRUCTURES OTHER THAN CUTTING IT OFF AND THEN COMING BACK IN A FEW YEARS AND CUTTING SOME MORE OFF.

8. INVESTIGATION OF POLYMER IMPREGNATION FOR THE REPAIR OF ALL TYPES OF MATERIALS IS NEEDED.

9. EVALUATION OF LONG-TERM PERFORMANCE OF REPAIRED STRUCTURES SHOULD BE MADE. A DATA BANK OF THE APPROPRIATE INFORMATION WOULD BE DESIRABLE.

The data bank should contain information on the structural system, how the repair was performed, and other pertinent factors which will permit an evaluation of the repaired structure when an earthquake occurs.

WORKSHOP ON THE REPAIR, STRENGTHENING AND REHABILITATION OF BUILDINGS

AGENDA

Thursday, June 9, 1977

9:00-10:00 a.m.	Registration of Participants
10:00	Introductory Comments - R. D. Hanson, J. B. Scalzi

Presentations

1. L. A. Wyllie, Jr.-Nicaragua Repair Examples
2. V. V. Bertero and S. A. Mahin-Guatemala Repair Examples
3. D. K. Jephcott-Seismic Performance of Rehabilitated Buildings
4. L. A. Wyllie, Jr.-Seismic Performance after Repairs
5. A. Gerich-HUD Rehabilitation for Seismic Areas
6. C. W. Pinkham-Six-Story Apartment Building
7. L.M.H. Chang-History of HUD Standards
8. L. A. Lee-California State Capitol Restoration
9. H. A. Davis-Far West Laboratory
10. J. C. Fredericks-Witmer Apartment Complex

12:00-1:30	Group Workshop Luncheon
1:30 p.m.	Presentations

11. E. O'Connor-Auto Agency

12. J. R. Cagley-Augusta, Georgia Veterans Administration Hospital
13. W. C. Hodges-Roosevelt High School
14. S. A. Freeman-Memphis, Tennessee Veterans Administration Hospital
15. W. G. Corley-Fire Damage Repair and Refire
16. J. Warner-West Orange County Court-house
17. S. B. Barnes-UCLA Parking Structure
18. J. R. Cagley-Atlanta Veterans Administration Hospital

Break

19. J. E. Minor-Wind Effects and Tornado
20. J. M. Plecnik-Temperature Effects on Epoxy
21. B. Bresler-Temperature Effects on Epoxy Repairs
22. W. K. Tso-Externally Reinforced Walls
23. L. F. Kahn-Infill Wall Characteristics
24. M. A. Sozen-Repair and Retest of Reinforced Concrete Walls
25. V. V. Bertero-Repair and Retest of Reinforced Concrete Walls
26. A. E. Fiorato-Repair and Retest of Reinforced Concrete Walls

5:00 p.m.	General Discussion of Problems and Research Needs
5:20	Formation of Working Groups
5:30	Free Time (cash bar)
6:30	Group Workshop Dinner
8:30-10:30 p.m.	Working Groups Meet

Friday, June 10, 1977

8:30 a.m.	Working Groups Meet
10:00	Coffee Break
	Final Meeting of Working Groups
12:00	Free Time - Lunch
1:30 p.m.	Presentations by Working Group Chairmen J. R. Janney L. A. Wyllie, Jr. C. W. Pinkham
	Open Discussion
	Summary Statement
3:00	Closing Comments - J. B. Scalzi
3:15	Adjournment

SUMMARY OF PRESENTATIONS

The presentations provided all participants a concise summary of the current state-of-the-art on repair, strengthening, retrofitting and rehabilitation of buildings. Some of the presentations were available in written form while others concern cases which cannot be described in written form. Therefore, it was decided to eliminate all written presentations from this report. The reader should contact the workshop director as to the availability of additional detail on specific presentations.

The following summaries of the oral presentations are given in the hope that the reader can sense the open discussions of repair and rehabilitation problems preparatory to the working group meetings. The presentations were selected and arranged to include the following areas: Repair of earthquake damaged buildings, Performance of rehabilitated or repaired buildings in a subsequent earthquake, Rehabilitation criteria, Execution of retrofitting of brick and unreinforced masonry buildings, Execution of retrofitting of reinforced concrete buildings, Planned retrofitting of steel framed buildings, Wind effects, and Research efforts under way or just completed.

1. L. A. WYLLIE, JR. - NICARAGUA REPAIR EXAMPLES

Repair plans for the Banco Central were discussed. The basic strengthening was to be accomplished with a U-shaped shear wall around the stair-elevator end of the building and a transverse cross wall at the far end of the building. The wall spandrels were to be strengthened to help the floor diaphragms collect the lateral forces and deliver them to the resisting shear walls.

Repair of precast concrete housing was designed and implemented. Timber, steel and precast concrete schemes for repair were developed and the steel plan was utilized for the rehabilitation.

2. V. V. BERTERO and S. A. MAHIN - GUATEMALA REPAIR EXAMPLES

From inspection of the repair of several buildings, it was clear that no uniform criteria have been used in the repair and retrofitting (strengthening, stiffening and/or toughening) of existing buildings damaged during the Guatemala earthquakes of 1976. Different solutions or techniques were used for similar buildings. While nearly all structural systems observed were stiffened, and most were strengthened, it is doubtful in some cases whether the toughness of the building was increased and the seismic resistance of the structural system was improved. The keys to increased strength and toughness are proper detailing and workmanship. The placement of additional, properly detailed reinforcement in existing columns and beams to increase the toughness of these elements, posed serious problems in the field. Quality workmanship in the placement of additional reinforcement, which would guarantee reinforcing continuity and good concrete confinement, was also difficult to achieve. Several examples were presented and discussed.

3. D. K. JEPHCOTT - SEISMIC PERFORMANCE OF REHABILITATED BUILDINGS

The rehabilitation of school buildings was shown to be excellent by the 1971 San Fernando earthquake experience.

The selected system of rehabilitation must be determined on an individual basis for each building. This is a challenge to the ingenuity of the engineer to obtain the best, most economical solution.

Experience has shown that shotcrete bonds well to brick walls in the repair of masonry buildings.

Needed research includes cyclic loading of shotcrete-brick wall panels and shotcrete-concrete wall panels. Quality control of the shotcrete process is also needed.

4. L. A. WYLLIE, JR. - SEISMIC PERFORMANCE AFTER REPAIRS

Examples from the Phillipines, Peru and Managua were used for illustration. In one building masonry walls were separated from columns to make all columns about the same stiffness. There was no damage in the subsequent earthquake. It is not immediately apparent that this more flexible building would be adequate for a more severe earthquake.

5. A. GERICH - HUD REHABILITATION FOR SEISMIC AREAS

A summary of the Housing and Urban Development (HUD) criteria for rehabilitation of buildings was presented. The level of seismic resistance is not as important as the details of providing lateral resistance.

6. C. W. PINKHAM - SIX-STORY APARTMENT BUILDING

A current HUD manual for the evaluation of existing buildings was described. The necessity of reviewing the entire building before selecting a repair-retrofitting concept was emphasized. A six-story apartment building and six-story hotel were used as example structures in this manual.

7. L.M.H. CHANG - HISTORY OF HUD STANDARDS

A brief review of the historical approach to rehabilitation was presented. If the rehabilitation costs were 20% to 30% of the replacement cost then it was considered to be economical. Three specific points were raised:
(a) How does one estimate existing strength and stiffness?,

(b) How does one handle torsion problems, and (c) Since shotcrete is expensive, how does one treat infill walls?

8. L. A. LEE - CALIFORNIA STATE CAPITOL RESTORATION

A review of the rehabilitation of the 110-year old State Capitol building was given. The fundamental problem was to restore the building to its 1900 status - with earthquake resistance equal to present day California seismic design standards.

The structure, of unreinforced brick masonry, with an interior masonry dome and rotunda, required extensive structural investigation and dynamic analysis to satisfy seismic criteria. The final rehabilitation scheme calls for the removal of interior masonry walls and brick arch floors and the construction of a reinforced concrete shear wall structure within the masonry exterior walls.

Following the removal of two wythes of brick, the masonry exterior walls are strengthened by the addition of 12 inches of shotcrete drilled anchors tying the brick to the concrete structure. Strengthening of the rotunda and inner dome will be similarly accomplished by the application of shotcrete anchored to the brick surfaces.

9. H. A. DAVIS - FAR WEST LABORATORY

This six story concrete structure with masonry exterior required extensive new seismic reinforcement.

Thousands of holes and chases were drilled, using pneumatic tools, into the existing concrete and masonry construction. Pneumatic drilling is preferred over core drilling because it provides better anchorage properties for epoxy compounds, and minimizes the probability of cutting existing reinforcing bars. Extensive shotcrete was added to concrete and masonry elements while essentially preserving the existing exterior and interior character of the building.

10. J. C. FREDERICKS - WITMER APARTMENT COMPLEX

The brick bearing walls had one brick wythe removed and #6 reinforcing bars added with shotcrete filling the one brick wythe. Anything less than a 100% repair must be pretested to determine the achievable level of repair. The repairs to this apartment complex amounted to approximately $3.50 per square foot.

11. E. O'CONNOR - AUTO AGENCY

The rehabilitation of this brick building utilized new diagonal rods for the roof. The reduction of an excessive hazard is the primary goal with minimum requirements needed for the repair.

12. J. R. CAGLEY - AUGUSTA, GEORGIA VETERANS ADMINISTRATION HOSPITAL

The 1913 to 1954 buildings were built with unreinforced clay tile bearing walls. Laboratory tests of the racking shear strength of the walls with confined concrete plaster added were conducted by Law Engineering Testing Company, Atlanta. The ultimate shear strength on the gross section of exterior walls was 45-65 psi and for interior partitions was 90 psi. The use of shotcrete and cut-in boundary elements provided an easy, economical solution. For a specified 0.18 g lateral design force, the 1975 cost was approximately $7.50 per square foot.

13. W. C. HODGES - ROOSEVELT HIGH SCHOOL

One of the major problems with this building was the separation between the wall surfaces and the architectural tile. To remove and replace the tile would cost four times that of grouting the tile in place. Nondestructive methods for determining the size of void spaces are needed. A direct reading device to determine the void space would save time and money.

14. S. A. FREEMAN - MEMPHIS, TENNESSEE VETERANS ADMINISTRATION HOSPITAL

The new Veterans Administration design criteria specified a peak ground acceleration of 0.25 g. For the existing 15-story building with a calculated fundamental period of 1.9 seconds, the resulting base shear is 0.06 g for the first mode and 0.10 g for the square root of the sum of the squares (SRSS). This base shear is substantially greater than the capacity of the structure. The proposed modification scheme stiffens the building to a period of 0.8 second. Taking into account the lower reduction factor (α = 1/3 instead of 2/3, Veterans Administration Handbook H-08-8), the resulting base shear for the modified structure is 0.07 g for the first mode and 0.13 g for SRSS. The estimated cost of the proposed modification is roughly $13 per square foot with about one-half of this cost for structural work. The balance is for architectural, mechanical and electrical costs that result from the structural modifications.

15. W. G. CORLEY - FIRE DAMAGE REPAIR AND REFIRE

A structure subjected to severe fire damage was repaired. After the repair was completed, a second fire occurred in the same area. The structure survived the second fire without structural failure. However, more information is needed on (a) structural capacity recovery, (b) fire resistance restoration, and (c) ductility added by the repair process.

16. J. WARNER - WEST ORANGE COUNTY COURTHOUSE

The rehabilitation or repair of many buildings will require that continued use of the building may be maintained - as in this case. The added expense of keeping the building functional must be included in the repair cost. Large settlements required jacking the building with a central control to avoid differential movements. Welding of reinforcing steel required that 4 to 5 inches adjacent to the weld must be exposed and wrapped with asbestos to have a slow cooling rate.

17. S. B. BARNES - UCLA PARKING STRUCTURE

The prestressed concrete parking structure was four stories high and had exterior cast-in-place columns. Several oversights in the construction process resulted in the splitting of the columns and damage to the corbels. The repaired structure survived the 1971 San Fernando earthquake with minor damage (one corbel failed).

18. J. R. CAGLEY - ATLANTA VETERANS ADMINISTRATION HOSPITAL

This welded steel frame building was redesigned for a basic earthquake of 0.13 g using the criteria of the Veterans Administration. The transverse direction was adequate, but K-bracing was needed in the longitudinal direction. The rehabilitation cost was about $1.50 per square foot.

19. J. E. MINOR - WIND EFFECTS AND TORNADO

The differences between wind and earthquake effects were emphasized. Wind cannot be allowed to violate the building envelope. If it does the internal pressures will be additive to the external pressures. The building must have a complete closure envelope and the structural elements must be tied together.

Tornado winds are not unmanageable for structural engineers. The maximum wind velocities are about 275 mph and 90% of all tornados have a maximum wind velocity of 150 mph or less.

20. J. M. PLECNIK - TEMPERATURE EFFECTS ON EPOXY

Care must be taken to avoid reactive aggregates. The ASTM E119 fire tests have shown that epoxy above 400^{o}F has lost all of its strength. A compression load-temperature curve was given. Impact resistance tests on epoxy repairs are needed.

21. B. BRESLER - TEMPERATURE EFFECTS ON EPOXY REPAIRS

Tension strength-temperature curves were presented for the range of 0^{o}-400^{o}F. The temperature distribution in a structural member can be calculated and the amount of epoxy strength lost by high temperature can be estimated. The ASTM E119 fire test is not appropriate for buildings. A more realistic fire model should be developed.

22. W. K. TSO - EXTERNALLY REINFORCED WALLS

Experimental results of applying external reinforcement and mortar on existing masonry walls was reviewed. The placement of new reinforcement on both sides of the existing wall, "sandwich wall," was much more effective than the one side strengthening.

23. L. F. KAHN - INFILL WALL CHARACTERISTICS

A review of structural reinforcement by adding multiple panel infill walls, single panel infill walls, and cast-in-place walls was presented. The advantages of multiple panel infill walls for interior walls was described.

24. M. A. SOZEN - REPAIR AND RETEST OF REINFORCED CONCRETE WALLS

A discussion of the need for more and better education of current design professionals as well as students was stressed. It was felt that the major need in this field was the transfer of information of what can be done in the repair of walls from the researchers and specialists to the persons responsible for the policy decisions and actual designs.

25. V. V. BERTERO - REPAIR AND RETEST OF REINFORCED CONCRETE WALLS

When ductile reinforced concrete walls are stressed just to first yielding, epoxy repair can be effected. Although the original initial stiffness cannot be fully recovered, the yield strength can be attained at nearly the same deformation as that in the original wall. The greater the damage due to inelastic deformation beyond first yielding, the less efficient the epoxy repair. Reinforced concrete is a composite material; its toughness under cyclic loading with reversals of deformations depends on the bond between steel and concrete. The restoration of bond by epoxy injection poses serious difficulties.

Research needs are: (a) to determine whether the bond between steel and concrete can be repaired by epoxy injections; (b) to develop methods for economic and efficient repair and strengthening of wall panels that have been damaged without switching to more brittle failure modes; (c) to properly locate and detail construction joints and establish methods for their repair and strengthening.

26. A. E. FIORATO - REPAIR AND RETEST OF REINFORCED CONCRETE WALLS

The repair and retest of a structural wall with column boundary elements was described. The wall was repaired by removing damaged web concrete and then casting new web concrete.

In the inelastic range, the strength and deformation capacities of the repaired wall were similar to the original wall. However, the initial stiffness of the repaired wall was lower than that of the original wall.

WORKSHOP ON REPAIR, STRENGTHENING AND
REHABILITATION OF BUILDINGS

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APPENDIX

During July 11-15, 1977 a Workshop on Earthquake-Resistant Reinforced Concrete Building Construction (ERRCBC) was held at the University of California at Berkeley. This workshop was sponsored by the National Science Foundation and was organized by Professor Vitelmo V. Bertero. Working Group 3 was selected to study research needs as they apply to Existing Buildings. The preliminary recommendations of this working group are relevant to this report and provide slightly different perspective on the research needs.

The proceedings of the Berkeley Workshop has several papers on repair and rehabilitation and each paper has an extensive list of references.

ERRCBC WORKSHOP, WORKING GROUP ON EXISTING BUILDINGS

Chairman: R. Hanson
Vice Chairmen: B. Bresler, J. Warner
Recording Secretary: J. Axley

B. Bentson	T. Okada
A. Fiorato	R. Preece
D. Jephcott	E. Teal
F. Knoll	J. Wight
N. Ohmori	

PRELIMINARY RECOMMENDATIONS FOR RESEARCH

Present codes are written for new construction and are not directly applicable to rehabilitation or repair of existing buildings. In order to reduce hazardous structural conditions, it is necessary to identify buildings that may be potentially hazardous, to evaluate the nature and degree of hazard, if any, and to modify the buildings through strengthening, stiffening and/or toughening the structure.

1. DEVELOP PROCEDURES AND CRITERIA FOR THE DETERMINATION OF THE SEISMIC RESISTANCE OF EXISTING AND DAMAGED BUILDINGS.

There is presently insufficient information available on the seismic resistance of many types of existing structures and the methodology for determining this resistance is not well developed. The knowledge is essential to a realistic assessment of the seismic hazard.

1A. DIAGNOSTIC PROCEDURES ARE NEEDED FOR DETERMINING THE SEISMIC RESISTANCE OF THE BUILDING.

--Retrieval, evaluation and improvement of known procedures.

--Creation of new methods.

--Establish guidelines.

1B. ESTABLISH STANDARDS AND CLASSIFICATIONS OF TYPICAL STRUCTURES AND SUBSTRUCTURES.

Integrated field, laboratory and analytical studies will be needed to determine material, member and structure characteristics as well as failure mechanisms for existing buildings.

1C. BASIC DATA REGARDING THE NUMBER AND TYPE OF BUILDINGS ARE NEEDED TO ESTABLISH THESE RESEARCH PRIORITIES.

A large number of buildings must be carefully surveyed to identify the number and type of buildings and construction in order to establish research priorities.

1D. FORMULATE A PROGRAM TO DISSEMINATE ACQUIRED KNOWLEDGE TO THE PROFESSION.

2. PROCEDURES FOR IMPROVING THE SEISMIC RESISTANCE OF EXISTING AND DAMAGED BUILDINGS MUST BE IDENTIFIED AND ESTABLISHED.

These procedures often involve unfamiliar materials and techniques. Methods necessary to insure adequate and economic seismic reinforcement must be determined.

2A. PREPARE A GUIDELINE OF APPROPRIATE MATERIALS AND TECHNIQUES FOR BOTH REPAIR AND RETROFITTING.

Methods and procedures which have been previously proven should be catalogued.

2B. EVALUATE AND IDENTIFY PERTINENT PHYSICAL MATERIAL PROPERTIES AND TECHNIQUES FOR SEISMIC REINFORCEMENT OF EXISTING AND DAMAGED BUILDINGS.

Although many materials and techniques have been used in the past, limited data concerning their characteristics and the properties of the completed reinforcement are available. Full scale and laboratory experiments are needed to determine these important characteristics and properties.

2C. ESTABLISH SPECIFICATIONS, STANDARDS AND/OR PERFORMANCE CRITERIA FOR THESE METHODS AND TECHNIQUES.

In order to stimulate the development of effective and economical materials and construction methods for repair and retrofitting, performance criteria (or specifications or standards) must be established. Methods for determination of compliance and procedures for updating these criteria must be developed.

3. PROVIDE CRITERIA FOR PUBLIC DECISION MAKING RELATIVE TO THE SEISMIC SAFETY OF EXISTING BUILDINGS.

Structural engineers should assist society by providing not only technical analysis but technical guidance.

3A. APPROPRIATE LEVELS OF SAFETY MUST BE ESTABLISHED.

A reasonable level of structural performance must be a function of the risk, the use or occupancy of the building and the expected remaining life of the building.

3B. ACCEPTABLE DAMAGE LEVELS MUST BE DETERMINED.

In some types of existing buildings, more damage would be acceptable than in new buildings - provided that life safety is maintained.

Damage criteria for historical or special structures must be determined individually.