EARTHQUAKE-RESISTANT REINFORCED CONCRETE BUILDING CONSTRUCTION

Proceedings of a Workshop Held at
The University of California
Berkeley, California
July 11-15, 1977

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VOLUME I
ORGANIZATION AND FINAL RECOMMENDATIONS

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Preface

The material contained in these three volumes constitutes the proceedings of a workshop on Earthquake-Resistant Reinforced Concrete Building Construction (ERCBC) sponsored by the National Science Foundation, and held at the University of California, Berkeley, July 11-15, 1977. The main purposes of the workshop were to provide a means for the exchange of information related to the state-of-the-art and state-of-the-practice in the design and construction of seismic-resistant reinforced concrete buildings, to evaluate current progress, and to establish research needs and priorities for future work.

The specific objectives and organization of the workshop are summarized in the Introduction to the first volume. The final recommendations of the workshop form the main body of that volume. Four appendixes follow, containing the program, the list of participants, the list of working groups, and, lastly, a research directory.

Volumes 2 and 3 comprise the technical reports and papers that were presented. These furnished the background material for the discussions which ultimately resulted in the final recommendations of the workshop.

It is hoped that these proceedings will help mitigate the destructive effects of earthquakes by encouraging practitioners to implement those recent findings from the research and professional communities that will improve current practice in ERCBC, and by providing researchers and agencies sponsoring research with guidelines for ensuring that future research is oriented toward solving current problems. It is also hoped that the proceedings will serve to stimulate communication and improve cooperation between practitioners, educators, researchers, and representatives from industry and government agencies working in the field of ERCBC.

It is not possible here to thank all the individuals who contributed to the success of the workshop, but a few should be mentioned. The assistance of Dr. John B. Scalzi, Manager of the Earthquake Engineering Program of the National Science Foundation, during the planning of the workshop, and his continuous support and encouragement are gratefully acknowledged. The able assistance of Dr. Stephen A. Mahin, who acted as organizing secretary, throughout all phases of the workshop is greatly appreciated. In addition, thanks must be extended to the members of the steering committee: W. Gates, N. Hawkins, J. Scalzi, M. Sozen, and L. Wyllie, Jr., for their technical assistance; to the session chairmen; the heads and recording secretaries of the working groups; to H. Barry and L. Reid of University Extension for coordinating schedules, arranging accommodations, and making the workshop an enjoyable experience for all the participants; and to L. Tsai, not only for invaluable editorial assistance in the preparation of these volumes, but for her continued help throughout the various phases of the workshop. Finally, special and sincere appreciation goes to the authors of the technical reports and to all the participants, who took time from their busy schedules to collaborate in the workshop. The success of the workshop is the result of their individual and combined efforts.

Funding for this workshop was made possible by grant ENV76-01923 from the National Science Foundation. Their support is gratefully acknowledged. These proceedings constitute the final report to the sponsor. The conclusions and recommendations expressed herein do not necessarily reflect the views of the National Science Foundation.

Vitelmo V. Bertero
Berkeley, California
June 1978

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Introduction

Significant advancements have been achieved during the last decade in the design and construction of seismic-resistant reinforced concrete buildings. This progress has resulted from analytical and experimental research conducted at various institutions, as well as from lessons gained by inspecting damages caused by recent earthquakes. Considerable human and economic resources have been devoted to research on specific problems related to earthquake-resistant design and construction and this has produced a tremendous volume of worldwide information.

Despite advancements in this field, significant gaps still remain in our understanding of the seismic behavior of reinforced concrete buildings, and numerous areas exist in which specialists, both researchers and practitioners alike, continue to disagree. This is not surprising because of the complexity of seismic response of buildings and the multitude of reinforced concrete structural systems, configurations, and details encountered in practice. Although additional research on seismic behavior is needed to solve these problems, this may not be sufficient by itself, since achievement of efficient seismic-resistant construction requires integration of knowledge obtained from many diverse fields. This integration is difficult because of the limited communication between experts working independently in different areas. Most of the available information has been published in widely dispersed publications or presented orally, and little effort has been made to assemble and integrate these data in a form that encourages their systematic discussion, evaluation, and dissemination among the various specialists in this field.

To improve this situation, it was felt that researchers, professionals, and representatives from industry and government working in the field of earthquake-resistant reinforced concrete building construction (ERCBC), should be brought together in a workshop to discuss and evaluate the available information and to determine priorities for future research needs.

Objectives

The main objectives of the workshop were to (1) evaluate current knowledge and practice in the planning, design, and construction of earthquake-resistant reinforced concrete buildings; (2) review the objectives and scope of existing research programs and discuss their findings to provide feedback to researchers; (3) examine needs and priorities for immediate, as well as long-range, research required to remove gaps in current knowledge and to improve current practice; and (4) improve communication and cooperation (at both the national and international levels) between research and professional organizations, as well as between different research groups.

Contents and Organization

To achieve these objectives, eighty-four specialists from the professional, industrial (materials manufacturing), and research disciplines were invited to attend and participate in a workshop held at the University of California, Berkeley, during the week of July 11-15, 1977. The ERCBC Workshop was organized by Vitelmo V. Bertero with the help of Stephen A. Mahin, who acted as Organizing Secretary, and a steering committee, whose members were selected on the basis of their knowledge and extensive experience in the field. The workshop was conducted by University Extension of the University of California and sponsored by the National Science Foundation.

The workshop activities were divided into two parts. In the first part, the state-of-the-art and state-of-the-practice in ERCBC were discussed. Experts in various areas of seismic-resistant design and construction were chosen to present review articles on the different features involved in this type of construction. Open discussion followed each presentation, emphasizing comments by practitioners. The final workshop agenda, including a list of the papers presented in the eleven workshop sessions, is reproduced in appendix A. A list of the participants and their professional affiliations is included in appendix B.

In the second part of the workshop, ten working groups met to assess ongoing research in the different areas involved in ERCBC, define research needs, and establish priorities for future research. Nine working groups were originally formed; however, during the workshop it became evident that a number of participants shared a concern regarding the integration, interpretation, and utilization of experimental research. To provide a forum for this discussion, a tenth group was formed. The members of each of the working groups are listed in appendix C.

The chairmen of the nine original groups were supplied with a brief statement defining the scope of the group's task. These statements, after some modifications by the respective working groups, are reproduced at the beginning of the recommendations of each working group. The recommendations submitted by each working group were formulated after several meetings at which all interested participants could attend. These recommendations were then presented to and discussed by all of the participants, and modified when necessary during the concluding session of the workshop. The organizer, organizing secretary, and steering committee then met to review, discuss, and edit the workshop recommendations. The working group chairmen then reviewed and approved the final recommendations for their group. The final recommendations included in these proceedings have been distilled from the discussions of the various participants and working groups and consequently do not constitute an individual endorsement by a particular participant or organization.

Participation in the workshop was by invitation. Eighty-four participants were selected on the basis of their experience in the field of earthquake-resistant reinforced concrete building construction, for their knowledge of current research programs in the field, and for their awareness of research needs or practical problems in the general field of earthquake engineering.

There were two classifications of participants: *main participants* were requested to prepare a comprehensive state-of-the-art or state-of-the-practice report on at least one of the main subjects included in the workshop program; *regular participants* were invited to participate voluntarily in the discussions and to prepare a short contributing paper or discussion on any of the subjects included in the technical program of the workshop. All participants were assigned to serve on at least one of the ten working groups (see appendix C). Participants were also requested to submit a set of draft recommendations to be considered by the appropriate workshop working group. These draft recommendations were distributed to the other participants, along with preprints of the technical papers, well before the workshop.

The workshop proceedings are published in three volumes. The first volume includes the final recommendations, the program, the list of participants, list of working group members, and a compilation of research publications related to the field. The publication list is included in appendix D to serve as a directory of current research. It contains only those references supplied by different participants and is not comprehensive. It is hoped that the directory can be completed and updated in the future for the benefit of researchers and practitioners working in this field. Technical papers, which encompass state-of-the-art and state-of-the-practice reports, as well as contributing papers, presented at the workshop, are published in the second and third volumes. Responsibility for the contents of these papers rests solely with the individual authors. The texts and illustrations of the papers have been reproduced from camera-ready originals supplied by the authors; in a few instances, retyping and manuscript arrangement were necessary.

Summary of Recommendations: Identification of High-Priority Needs

The 114 recommendations formulated during the workshop deal with a wide variety of research, development, and other needs for improving ERCBC. Priorities have been assigned to these recommendations by the working group that developed them. It is hoped that recommendations in this form will serve as guidelines to researchers and sponsoring agencies for current and long-term research needs.

After reviewing the final recommendations, the organizer, organizing secretary, and steering committee attempted to identify needs of highest overall priority, or of common concern to several working groups. Among those identified, the following deserve special mention.

1. Cooperation and Communication

Every effort should be made to improve cooperation and communication between researchers and professionals, as well as between researchers themselves. Effective exchange of research information should be accomplished on both a national and international basis.

2. Evaluation and Dissemination of Available Data

Effective methods are needed for reviewing and evaluating available data and disseminating pertinent design-oriented technical information in simple, comprehensible terms. Effective evaluation and dissemination will require precise definition and agreement on the main parameters controlling building performance, and formulation of guidelines for collecting and reducing data and presenting results. Dissemination of technical information could be facilitated by publishing design and analysis guidelines and technical reviews in bulletins or pamphlets; organizing workshops and short courses on well-defined topics; encouraging roadshow-type presentations; and creating an information center.

3. Research and Development Needs

A. *General.* -- Integrated analytical and experimental research is needed on the three-dimensional linear-elastic and hysteretic behavior of real buildings and their subassemblages under seismic loading conditions. Emphasis should be placed on comprehensive studies of: the stress-strain relationship of different types of reinforced concrete materials, considering variation in combined multiaxial and shear stresses; bond-slip relationships; behavior of different types of foundations under seismic excitations and its effect on building response to determine guidelines for selecting and designing foundation systems; influence of different floor systems (including diaphragm deformability); effect of joint flexibility, considering possible bond deterioration; column behavior under biaxial lateral forces and axial loads varying from tension to compression; and effect of nonstructural components. Generic studies of connections, components, and subassemblages forming part of the primary seismic load-carrying system in prefabricated concrete buildings should be performed. Similar studies should be conducted on prestressed concrete components and assemblies.

To carry out all of these studies, it will be necessary to develop several large-scale loading facilities (structural floor-wall reaction systems); make greater use of the few available small- and medium-sized simulators; detemine the need and feasibility of a large earthquake simulator capable of testing full-scale structures; and develop efficient computer simulation techniques to model realistic structures and perform design-oriented parametric studies.

Researchers and professionals should evaluate current building code detailing requirements; establish criteria to indicate the appropriate method of design according to the expected nature of structural action; evaluate the cost-effectiveness of the added expense of providing earthquake resistance beyond that required for safety, as compared with the cost of repairing infrequent damages; and develop guidelines for seismic analysis and design that can be used by the design profession. All these should be done considering different types of buildings in different seismic regions.

B. *Existing Buildings.* -- Procedures should be developed to determine the seismic resistance and acceptable damage levels of existing buildings. Evaluation is needed of the materials and techniques presently used in repairing and retrofitting. Guides for their use should be prepared and new methods explored. Forced vibration tests up to collapse are suggested for buildings scheduled to be demolished.

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FINAL RECOMMENDATIONS

WORKING GROUP 1

MECHANICAL CHARACTERISTICS AND PERFORMANCE OF REINFORCED AND PRESTRESSED CONCRETE MATERIALS UNDER SEISMIC CONDITIONS

Working Group 1 reviewed current knowledge and practice related to the mechanical characteristics and performance of reinforced and prestressed concrete materials under seismic loading conditions and formulated recommendations for advancing the state of knowledge and for improving material behavior in ERCBC. The group evaluated the available data regarding: the mechanical characteristics of the component materials and of the composite material (confined concrete, bond, etc.); methods for determining and specifying these characteristics; quality control and quality assurance procedures; and mathematical models of material behavior. The recommendations formulated by this working group are presented in a single category in order of their priority.

A. RESEARCH AND DEVELOPMENT NEEDS

It is recommended that conventional monotonic testing procedures be supplemented by extensive cycling experiments including reversals of load and/or deformation and different rates of loading or straining. In order for work to be readily comparable, a strong effort should be made by experimenters to agree on standard testing procedures or methods for presenting experimental results. The development of mathematical models, where appropriate, should be intensively pursued.

1. CONDUCT COMPREHENSIVE STUDIES ON THE STRESS-STRAIN RELATIONSHIP OF NORMAL AND HIGH-STRENGTH CONCRETE CONFINED BY DIFFERENT ARRANGEMENTS OF TRANSVERSE AND LONGITUDINAL REINFORCEMENT AND OF PLAIN CONCRETE UNDER CYCLIC LOADING, INCLUDING VARYING MULTIAXIAL (TENSION AND COMPRESSION) AND SHEAR STRESS COMBINATIONS.

   The amount of confinement significantly affects the mechanical characteristics of concrete. Mechanisms of confinement for circular and rectangular hoops differ. For rectangular hoops most of the data available are on square or simple rectangular ties. The effect of using supplementary cross ties and overlapping ties should be studied as should the effect of different amounts and arrangements of the main longitudinal bars on the behavior of confined concrete. The use of single and double rectangular spirals should also be investigated and compared with results obtained from studies on circular spirals. These studies should include the determination of the stress-strain curves under monotonically increasing uniaxial compression, as well as the investigation of the effect of strain gradient and cyclic loading on the behavior of confined concrete. The effect of cover should be investigated by considering specimens with and without cover. Such studies should be complemented by investigations of plain concrete under multiaxial stress states representative of those encountered under seismic loading conditions. Sufficient replications of tests should conducted at different laboratories to permit the statistical treatment of data.

Preceding page

The effect of confinement on the mechanical characteristics of concrete should be reported on a consistent basis. Some researchers currently report only the gross stress-strain curves, while others plot the stress determined on the basis of an arbitrarily defined area of the confined core versus strains computed from deformations measured on an arbitrarily selected gage length. Guidelines on what should be measured in such investigations as well as the instrumentation to be used should be established.

2. CONDUCT COMPREHENSIVE EXPERIMENTAL AND ANALYTICAL STUDIES ON BOND-SLIP RELATIONSHIPS, INCLUDING THE EFFECT OF SPLICES AND DIFFERENT TYPES OF ANCHORAGES UNDER SIMULATED SEISMIC LOADING CONDITIONS.

The amount of available information in this area is very limited. Among the topics requiring attention are the following (listed in their approximate order of priority): (a) systematic experiments for determining a generalized bond-slip relationship for a single bar embedded in stone concrete; (b) extension of the above study to include groups of bars, the effect of splices and other types of anchorage; (c) formulation of a generalized bond-slip relationship; and (d) investigation of bond and anchorage characteristics of welded wire fabric.

The implications of loading history and rates of loading and/or deformation in these problems must receive particular attention. Therefore, the above studies should consider a wide range of loading histories at various loading rates (including shock loading) and the effects of confinement, axial compression, and dowel actions. Instrumentation should be planned carefully in all of these tests to obtain reliable data on the main parameters affecting the bond-slip relationship.

The effect of bond-slip on overall structural behavior under cyclic loading should be investigated, with particular attention given to the effect of possible degradation of flexural strength and stiffness at a joint resulting from bond-slip.

3. CONDUCT STUDIES ON THE MECHANICAL CHARACTERISTICS OF LIGHTWEIGHT CONCRETE AND ITS INTERACTION WITH REINFORCING STEEL UNDER SEISMIC CONDITIONS.

Lightweight materials offer the advantage of a significant increase in strength per unit weight. Test results are needed to determine the applicability of lightweight aggregate concrete to earthquake-resistant construction, especially as related to: (a) effect of confinement on strain capacity and strength; (b) interaction of reinforcing steel and lightweight concrete in a joint; (c) bond behavior of reinforcing steel and lightweight concrete; (d) effect of lightweight aggregate on shear transfer in cracked sections; (e) behavior of high-strength lightweight concrete [greater than 5,000 psi (35 MPa)]; and (f) properties of various materials (including marginal aggregates).

4. CONDUCT INVESTIGATIONS OF BUCKLING OF THE MAIN REINFORCEMENT.

Tie spacing required for preventing buckling of compressive longitudinal reinforcement strained into the inelastic range under cyclic loading requires further investigation. The type (configuration) and size of tie, as well as the spacing and stress levels in the ties are important variables that should be considered. Yielding of the ties may result in a significant decrease in the buckling load of the main bar. The use of supplementary cross ties and their configuration should be investigated. The relationship of tie spacing to type and size of aggregate should be studied.

5. CONDUCT INVESTIGATIONS CONCERNING PROPERTIES OF DAMAGED AND REPAIRED CONCRETE.

For every structure which collapses there are hundreds which suffer damage. This damage varies from almost zero to incipient collapse. There are major questions that remain to be resolved regarding such structures. For example, (a) how can concrete damage be detected and quantified?; (b) what behavior can be expected of damaged concrete?; (c) what behavior can be expected of repaired concrete?; (d) what are the bond relationships in damaged and repaired concrete?; and (e) what correlation can be obtained between data from core and nondestructive testing, and laboratory test specimens?

Questions related to damaged and repaired structural concrete may well be major considerations in the economics of seismic-resistant design. Resolution of these questions requires cooperation among different branches of the profession.

6. CONDUCT STUDIES ON CRITERIA FOR GROUTING TENDONS AND FOR ACCEPTANCE OF PRESTRESSING SYSTEMS FOR SEISMIC LOADING SITUATIONS. CONDUCT TESTS TO DEFINE THE CYCLIC STRESS-STRAIN CHARACTERISTICS AND REQUIRED ULTIMATE STRAIN FOR PRESTRESSING STEELS.

Little information is available regarding the behavior of prestressing steels and systems under seismic loading conditions. Research is needed to develop recommendations for grouting tendons, considering the effects of possible cracking and bond-slip on desired level of corrosion resistance and anchorage. Current procedures for acceptance of tendon systems (especially anchorage devices) under seismic loading conditions should be re-evaluated in view of the large stresses that can be developed in tendons located in regions of high bending or rotation of a member. The effects of metallurgy, finishing methods, construction procedures, prior load history, fluctuating environmental conditions, strain rate and tendon type on the cyclic stress-strain characteristics of prestressing tendons need to be defined experimentally. Research is also needed to determine the ultimate strain of prestressing steel required to achieve adequate flexural ductility in members.

7. CONDUCT EXPERIMENTAL INVESTIGATIONS ON THE EFFECTS OF RATE OF LOADING OR DEFORMATION, AND CHARACTERISTICS OF VIBRATIONS (FREQUENCY AND AMPLITUDE) ON SLIDING SHEAR AND SHEAR TRANSFER.

These investigations should include studies on sliding shear over a wide range of surfaces (e.g. rough to smooth) under both tension and compression, with and without transverse steel across the sliding plane and with sliding planes intentionally created or due to cracking.

8. CARRY OUT INVESTIGATIONS OF NEW MATERIALS, OR DEVELOP INNOVATIVE WAYS OF USING TRADITIONAL MATERIALS FOR SEISMIC CONDITIONS.

Some recent advances in materials science have suggested new materials which may offer improved performance of concrete structures under seismic conditions. These materials include: (a) fiber reinforced concrete; (b) loop-fiber reinforced concrete; (c) high-strength concrete; (d) high-strength lightweight concrete; (e) polymer concrete; and (f) expansive and self-stressing concrete. Additional information is also needed on grouts and other bonding materials to establish their characteristics and interaction with concrete, particularly under seismic conditions.

9. CONDUCT STUDIES TO DETERMINE OPTIMUM SHAPE OF STRESS-STRAIN RELATIONSHIP, EFFECTS OF BENDING AND REBENDING, AND OPTIMUM SURFACE DEFORMATION CRITERION FOR REINFORCING STEEL.

Investigations should be conducted into the optimum shape of the stress-strain relationship for reinforcing bars in order to provide a member with adequate plastic hinge rotation capacity while avoiding excessive overstrength due to strain hardening. Experimental evidence is needed to reassure designers that bending and subsequent straightening or rebending of bars in cast-in-place and precast members during construction do not consume the entire strain capacity of the steel prior to the demands that an earthquake might place on the bar. Additional research is needed to determine criteria for selecting surface deformations as a function of desired bond and bendability characteristics.

10. CONDUCT STUDIES OF LONG-TERM LOADING EFFECTS IN DRYING ENVIRONMENT AND THE EFFECT OF PRIOR CRACKING ON THE BEHAVIOR OF CONCRETE UNDER SEISMIC CONDITIONS.

Present design rules assume that concrete will carry its full modular ratio share of loads. However, it is evident from column failures seen in recent earthquakes that in all probability the concrete has shrunk so much that the vertical reinforcing steel is carrying virtually all the dead load. When earthquake shock loading occurs, the bars yield and buckle outward, and all of the exterior shell is lost and cannot share the load. Most of the research on column strength under dynamic loading is based upon laboratory-prepared columns tested at relatively early ages before significant drying shrinkage has taken place. There is a need to study the effects of long-term sustained loads in a drying environment so that tensile shrinkage takes place prior to overloading from earthquake shock.

WORKING GROUP 2

METHODS OF STRUCTURAL ANALYSIS IN EARTHQUAKE-RESISTANT REINFORCED CONCRETE BUILDING CONSTRUCTION

Working Group 2 reviewed the use of computer programs in the design and analysis of ERCBC. Recommendations were developed for research and development needed to improve mathematical modeling of ERCBC; to study the effects of uncertainties in modeling; and to improve linear and nonlinear computer programs. The recommendations formulated by this group are divided into three categories. Category A contains a recommendation for improving dissemination of current knowledge to the design profession. Category B contains recommendations for improving or studying the effects of modeling in ERCBC. Category C contains recommendations for computer program development needs. Within each category, recommendations are ranked in order of their priority.

A. GENERAL RECOMMENDATION

1. DEVELOP GUIDELINES FOR DYNAMIC SEISMIC ANALYSIS AND DESIGN THAT CAN BE USED BY THE DESIGN PROFESSION.

   Current seismic codes and practices such as those recommended by the SEAOC[1] and under consideration by the ATC[2] require dynamic seismic analysis in certain situations (e.g. irregular buildings) but do not generally provide guidance in suggesting appropriate modeling assumptions, analytical methods, and design stress levels. Such a document should be based on current knowledge and be presented in such a form as to facilitate periodic upgrading as new information becomes available from research studies. It could also serve as an effective tool for technology transfer.

B. STRUCTURAL MODELING

1. PERFORM SENSITIVITY ANALYSES OF TYPICAL STRUCTURES TO GUIDE THE DESIGNER IN SELECTING STRUCTURAL SYSTEMS, STRUCTURAL MODELS, AND MEMBER STRENGTHS.

   Even with the best available structural analyses, wide ranges of numerical values can be obtained by changing modeling assumptions. Analytical studies are needed to identify, for various types of structural systems, those modeling parameters to which the response may be particularly sensitive. Such parameters might relate to, for example, floor diaphragm deformability, foundation flexibility, joint flexibility, simplified shear wall and frame idealization, loading conditions, and mass distribution.

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1. Seismology Committee. *Recommended Lateral Force Requirements and Commentary.* Structural Engineers Association of California. San Francisco, California. 1975.
2. *Final Review Draft of Recommended Comprehensive Seismic Design Provisions for Buildings.* Applied Technology Council. Palo Alto, California. January 1, 1977.

Such studies could also be used to assess the reliability of simple modeling techniques and design methods that could be employed in preliminary design. One approach to this would be to design several different common types of structural systems using a variety of analysis and modeling assumptions. The response of these designs could then be computed using various simple and complex elastic and inelastic analysis methods in order to evaluate both the reliability of the analytical methods and the accuracy of the design and modeling assumptions.

2. CONTINUE RESEARCH ON IMPROVED METHODS FOR IDEALIZING THE LINEAR-ELASTIC STIFFNESS CHARACTERISTICS OF REINFORCED CONCRETE STRUCTURAL ELEMENTS.

   Key areas requiring research are the determination of effective section properties for girders including realistic contributions from floor systems of various types, the classification and idealization of non-rigid diaphragms, the idealization of different wall configurations such as intersecting, perforated, or core walls, the modeling of joint flexibility, and the representation of flexible foundation constraints, especially in the case of shear walls.

3. CONTINUE RESEARCH AND DEVELOPMENT OF METHODS FOR MODELING THE INELASTIC CHARACTERISTICS OF REINFORCED CONCRETE STRUCTURAL ELEMENTS.

   There are still major areas of research which require additional study to define the nonlinear stiffness and damping characteristics of many reinforced concrete structural elements and nonstructural components. Realistic force-deflection relationships, including stiffness and strength degradation under cyclic loading, should be developed. Existing analytical models for flexural elements should be compared and evaluated in view of available experimental data. Reliable and economical mechanical models need to be developed to represent the overall behavior of reinforced concrete columns, floor systems, beam-column joint regions, and structural walls. Analytical models should be verified by comparing results with experimental data and with observed earthquake damage.

4. INITIATE STUDIES TO ESTABLISH METHODS FOR MODELING THE STIFFENING AND DAMPING CONTRIBUTIONS OF NONSTRUCTURAL ELEMENTS.

   The influence of nonstructural elements on building period, force distribution, and effective damping for new and existing buildings is well recognized. However, reliable methods for assessing and/or modeling the effect of these types of elements on seismic structural response are not generally available. Determination of these methods will require integrated analytical and experimental investigations on a wide variety of nonstructural elements (and methods for connecting these elements to structural components).

5. CONTINUE RESEARCH TO ESTABLISH MORE ACCURATE METHODS FOR ESTIMATING AND MODELING DAMPING.

   Damping is one of the major factors influencing dynamic response. The various types or forms of damping in a structure need to be identified and quantified for various construction materials and at varying strain levels.

6. CONTINUE VERIFICATION OF COMPUTER ANALYSIS METHODS AND MODELING TECHNIQUES USING DATA OBTAINED FROM ACTUAL REINFORCED CONCRETE BUILDINGS SUBJECTED TO EARTHQUAKE GROUND MOTIONS OR VIBRATION TESTS.

   Computer analysis methods and structural modeling techniques should be evaluated in terms of their ability to predict actual building behavior. Comparisons of experimental results obtained from ambient and forced field vibration tests or from earthquake simulator studies with analytically predicted results should be encouraged. Analytical studies of earthquake-induced building damages are of particular value since they provide a check on the reliability of analytical assumptions. It is essential to coordinate instrumentation programs for actual buildings and experimental tests to obtain sufficient data for evaluating analytical methods and improving them where necessary.

7. CONTINUE STUDIES ON THE PROBABILISTIC ASPECTS OF SEISMIC RESPONSE.

   Estimation of the seismic response of structures is not a deterministic problem, although deterministic techniques are commonly used. Studies of probabilistic techniques should continue in the hope of improving the rationality of the analysis and design process.

C. COMPUTER PROGRAM DEVELOPMENT

1. DEVELOP A COMPREHENSIVE LINEAR-ELASTIC ANALYSIS COMPUTER PROGRAM FOR USE BY THE PROFESSION.

   Currently available programs tend to be inefficient, expensive, and difficult to access, or significantly restrictive as to the types of structures that can be modeled. In developing new computer programs consideration should be given to new computer technologies and new computational and data processing techniques.

   The following program features, in addition to those currently available, are desirable:

   - ability to model perforated walls and cores
   - ability to model deformable, perforated and/or multiple floor diaphragms
   - ability to analyze full three-dimensional structural behavior
   - ability to consider three-dimensional excitations
   - ability to model foundation flexibility
   - ability to model flexibility or deformability of joint regions
   - allowance for different damping ratios in different parts of a structure
   - incorporation of design-oriented input/output
   - modular construction, with a data base which is accessible to pre- and post-processors
   - restart capability
   - error checking capability

2. DEVELOP PRACTICAL COMPUTER PROGRAMS TO AID IN DESIGN.

   There is a need for computer programs to perform design checking computations in addition to structural analyses. Further studies are needed on the logic of the design checking process, using such tools as tabular decision logic. A set of guidelines for program development is also desirable to ensure that programs can be used, understood, and modified by persons other than the original developer. These guidelines should include advice on input, output, and data structures in the hope of achieving consistency among programs from various sources.

3. CONTINUE STUDIES ON IMPROVING COMPUTATIONAL EFFICIENCY AND REDUCING COMPUTER COSTS FOR BOTH ELASTIC AND INELASTIC ANALYSIS.

   Large structures may be excessively expensive to analyze elastically in terms of man-hour costs and/or computer time. Such procedures as substructuring and using "macroelements" promise major savings in total effort and should be developed further. Inelastic analyses are currently much more expensive than elastic analyses, and are not economically feasible for large three-dimensional structures. Continued research on inelastic analysis techniques will undoubtedly lead to major reductions in cost and improvements in reliability.

4. CONSIDER DEVELOPMENT, OVER THE LONG-TERM (APPROXIMATELY 10 YEARS), OF A PRODUCTION-TYPE PROGRAM FOR INELASTIC ANALYSIS OPERATING ON THE SAME DATA BASE AS PRODUCTION-TYPE ELASTIC ANALYSIS PROGRAMS.

   As computational efficiency improves and computer technology becomes more advanced, inelastic analyses will probably become feasible for practical use. In order to avoid duplication of effort in input data preparation, inelastic analysis programs intended for production use should employ the same data base and, hence, the same input data, as production-type elastic analysis programs.

WORKING GROUP 3

EXISTING BUILDINGS

Working Group 3 discussed methods for: identifying existing buildings that may be potentially hazardous; evaluating the nature and degree of the hazard, if any; and modifying the buildings through strengthening, stiffening and/or toughening of the structure. The group felt that building codes are written for new construction and are not directly applicable to repair or rehabilitation of existing buildings. Recommendations formulated by the group are divided into three categories of equal priority. Category A consists of recommendations for determining the seismic resistance of existing buildings, category B deals with methods for improving their seismic resistance, and category C concerns recommendations regarding public policy. Within each category the recommendations are in order of their priority.

A. PROCEDURES AND CRITERIA FOR DETERMINING THE SEISMIC RESISTANCE OF EXISTING BUILDINGS

There is presently insufficient information available on the seismic resistance of many types of existing buildings, and often the methodology for determining this resistance is not well developed.

1. DEVELOP DIAGNOSTIC PROCEDURES FOR DETERMINING THE SEISMIC RESISTANCE OF BUILDINGS.

   Existing procedures should be assembled, evaluated, and improved where necessary, and new methods should be developed accordingly. Guidelines should be established for evaluating the seismic resistance of existing buildings to be rehabilitated as well as buildings damaged in earthquakes. Guidelines for emergency repair of structures are also needed.

2. ESTABLISH STANDARDS AND CLASSIFICATIONS OF TYPICAL STRUCTURES AND SUBSTRUCTURES.

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

3. DETERMINE THE NUMBER AND TYPE OF EXISTING BUILDINGS SO RESEARCH PRIORITIES CAN BE ESTABLISHED FOR A GIVEN SEISMIC REGION.

   A large number of buildings must be carefully surveyed to identify the type of building and construction, and to determine the number and distribution of buildings for each type. Research priorities appropriate for each seismic region may be better established when this information is available.

4. FORMULATE A PROGRAM TO DISSEMINATE ACQUIRED KNOWLEDGE TO THE PROFESSION.

B. PROCEDURES FOR IMPROVING THE SEISMIC RESISTANCE OF EXISTING BUILDINGS

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

   These materials and techniques are often unfamiliar. Methods and procedures which have been previously proven should be catalogued.

2. IDENTIFY AND EVALUATE PERTINENT PHYSICAL MATERIAL PROPERTIES AND TECHNIQUES FOR IMPROVING THE SEISMIC RESISTANCE OF EXISTING BUILDINGS.

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

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

   In order to stimulate the development of effective and economic repair materials and techniques, performance criteria, specifications and/or standards must be established. Methods for determining compliance and procedures for updating these criteria must be developed.

C. CRITERIA FOR PUBLIC DECISION-MAKING RELATIVE TO THE SEISMIC SAFETY OF EXISTING BUILDINGS

1. ESTABLISH APPROPRIATE LEVELS OF SAFETY.

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

2. DETERMINE ACCEPTABLE DAMAGE LEVELS.

   In some types of existing buildings, more damage would be acceptable than in new buildings--provided that life safety is maintained. Criteria for historical or special structures must be determined individually.

WORKING GROUP 4

CAST-IN-PLACE REINFORCED CONCRETE SYSTEMS FOR NEW BUILDINGS

This working group reviewed and discussed current knowledge and practice related to selection of effective structural systems, design criteria, code requirements, preliminary design, final detailing, and construction and maintenance aspects of cast-in-place reinforced concrete systems for new buildings. The main recommendations formulated by the group are presented in four categories. Category A contains seven recommendations related to design criteria and methods. Category B consists of a series of eleven recommendations regarding structural behavior. In category C, three recommendations are presented dealing with research needs for improving construction. Four recommendations regarding research needs and establishment of design procedures for foundations of ERCBC are grouped under category D. Recommendations are presented in each category in their order of priority.

A. DESIGN CRITERIA AND METHODS

1. ASSEMBLE A PAMPHLET OR A SERIES OF PAMPHLETS TO PROVIDE THE STRUCTURAL DESIGNER WITH GUIDELINES FOR SELECTING STRUCTURAL SYSTEMS.

   These pamphlets should contain descriptions of alternative structural systems as well as methods and criteria for selecting these systems. The relative advantages and disadvantages of each structural system should be discussed in relation to safety, damage control, and cost for the various levels of lateral loads and various building functions.

2. DEVELOP A FEASIBLE AND RELIABLE METHOD FOR ESTIMATING THE FUNDAMENTAL PERIOD OF REINFORCED CONCRETE BUILDINGS.

   As long as the fundamental period is used as an index value in determining the lateral forces and the response displacements, it will be necessary to develop a workable and reliable method for establishing this index. Developmental work is required to reconcile information from the field, from the laboratory, and from analytical models.

3. FORMULATE A PRACTICAL METHOD FOR DETERMINING THE RELATIONSHIP BETWEEN THE THEORETICAL RESPONSE, BASED ON A LINEAR-ELASTIC MODEL, AND THE ACTUAL RESPONSE OF REINFORCED CONCRETE BUILDINGS.

   The use of spectral modal analysis in design requires a set of consistent and credible factors for modifying the response calculated using linear-response models to estimate actual seismic behavior. Studies toward this objective will require workable definitions of structural systems used in practice.

4. DEVELOP A SERIES OF "BENCHMARK STRUCTURES" FOR COMPARING AND EVALUATING THE IMPACT OF ANY PROPOSED CODE CHANGES.

   The availability of a set of benchmark designs would facilitate a reasonably uniform test of proposed code changes and would at least encourage code writers to test code changes on the basis of their effects on realistic buildings.

5. DEVELOP DESIGN PROCEDURES FOR REINFORCED CONCRETE FRAMES, COUPLED WALLS, AND FRAMES INTERACTING WITH WALLS.

   Development is needed in methods for designing and detailing these three frequently used structural systems in order to approach uniform levels of safety, serviceability, and economy. Studies should integrate analytically developed information and field and experimental observations to determine (a) explicit drift limitations related to the vulnerability of the building contents as well as the structure itself, and (b) plausible maximum toughness requirements including rules specifying dimensions and/or details necessary for satisfying these requirements.

6. REVIEW MAXIMA AND MINIMA IMPOSED BY BUILDING CODES.

   The merits of code limitations such as those of member sizes, relative amounts of longitudinal and transverse reinforcement, partial post-tensioning, and member capacities should be evaluated. Limits on moment redistribution to obtain more economical reinforcement and to reduce forces imposed on the beam-column joints should be explored.

7. ESTABLISH CRITERIA TO INDICATE THE APPROPRIATE METHOD OF DESIGN ACCORDING TO THE NATURE OF STRUCTURAL ACTION.

   There are drastic differences between methods for designing and proportioning reinforced concrete frames and walls. Walls often have openings, and the geometry of a wall with large openings may approach that of a frame. Procedures should be established for determining the method of design so that basic decisions can be made on the basis of behavioral characteristics rather than traditional definitions.

B. STRUCTURAL BEHAVIOR

1. PERFORM EXPERIMENTS TO STUDY THE BEHAVIOR OF COLUMNS SUBJECTED TO BIAXIAL FORCES.

   The behavior of columns subjected to cyclic two-directional lateral forces and axial loads ranging from tension to compression (with the axial load varying as a function of the lateral forces) should be studied. Test specimens should reproduce realistically the conditions in actual frames.

2. PERFORM EXPERIMENTAL STUDIES OF THE BEHAVIOR OF BEAM-COLUMN JOINTS SUBJECTED TO TWO- AND THREE-DIMENSIONAL LOADING.

   The experiments should investigate the behavior of joints subjected to large shear and anchorage stresses. Parameters to be studied include: (a) the amount and type of transverse reinforcement, (b) the depth-to-width ratio of the beams, (c) the column-width to beam-width ratio, (d) eccentricities of the elements framing into the joint, (e) torsional stiffening induced by the slab, (f) use of high-strength concrete within the joint, and (g) use of partial post-tensioning.

3. CONDUCT RESEARCH TO DETERMINE THE RESISTANCE MECHANISMS OF STRUCTURAL WALLS, INCLUDING BOX-TYPE CONFIGURATIONS, UNDER LOADS SIMULATING EARTHQUAKE EFFECTS.

   The behavior of structural walls under seismic loading conditions needs further study, especially for shear stresses ranging from $6\sqrt{f_c'}$ to $8\sqrt{f_c'}$, where f_c' is given in psi ($0.5\sqrt{f_c'}$ to $0.7\sqrt{f_c'}$, where f_c' is given in MPa). Problems related to buckling of walls should also be investigated. Structural walls and cores subjected to multidirectional forces should be considered.

4. OBTAIN EXPERIMENTAL DATA ON THE RESPONSE OF COUPLED WALL AND FRAME-WALL SYSTEMS INCLUDING THOSE USING FLAT PLATES AS PART OF THE STRUCTURAL SYSTEM.

   Studies should consider the interaction of walls with frames and coupled walls. The effectiveness of horizontal diaphragms in distributing forces to the components of the lateral force resisting system should be evaluated.

5. DEVELOP A CONSENSUS ON REQUIRED "DUCTILITY."

   Because of the likelihood that critical regions may be subjected to deformational reversals well into the inelastic range during severe seismic excitations, the basic design concept in which the estimated "ductility" demand on a critical region must be less than the computed or experimental value of ductility capacity based on monotonic loading is inadequate. Definitions of ductility or other parameters (including numbers of reversals) suitable for seismic-resistant design must be developed. Based on analytical studies and field observations, information regarding the required values of these response parameters should be determined for different types of buildings in different seismic regions. Information is also required regarding attainable values of these parameters based on the type of building system and pertinent structural details.

6. ENCOURAGE RESEARCH ON STRUCTURES USING COMBINATIONS OF MATERIALS.

   There is a dearth of information on the response characteristics of structures using combinations of materials such as cast-in-place and precast prestressed reinforced concrete, or cast-in-place concrete and structural steel.

7. OBTAIN INFORMATION NECESSARY TO DEVELOP DETAILS FOR ISOLATING NONSTRUCTURAL WALLS OR PARTITIONS FROM THE STRUCTURE BY PROVIDING SUFFICIENT CLEARANCE TO ALLOW FOR NON-INTERACTING SEISMIC DEFORMATIONS.

   Minimum clearances between structural and nonstructural components which are appropriate for each type of structural system (frame, shear wall, etc.) need to be established. Such clearances must allow for development of desired inelastic deformations in the structure without destruction of nonstructural components. The ultimate goal of this research is to provide a basis for inclusion of minimum design clearances in code requirements.

   Economically feasible details should be developed which will provide support for nonstructural walls against out-of-plane seismic forces and yet allow freedom for interstory drift in the plane of the walls. Details should be developed which are suitable for corners and tee-junction walls, as well as details for junctions of walls with columns. The soundness of these details should be tested in full story height sections subjected to appropriate lateral deformations.

8. DESIGN WALLS IN THE FORM OF ENGINEERED INFILL PANELS SO AS TO DISSIPATE ENERGY IN THE INELASTIC RANGE.

   Research should be conducted to find the best forms of infill panels for hysteretic energy dissipation. Criteria should include (a) gradual decay of strength and stiffness in the nonlinear range, (b) economy, (c) architectural appearance, and (d) mass reduction.

   Criteria should be devéloped for determining when engineered infill panels will increase safety and damage control of a building subjected to strong ground motions.

9. DEVELOP STANDARD SUPPORT DETAILS FOR STAIRS TO ALLOW FREEDOM OF MOVEMENT WITHIN A STAIRWELL.

   The behavior of stairs within an enclosed stairwell distorted by building drift is critical. Slip joints or other details which allow flights of stairs to remain unstressed during building response should be developed.

10. DEVELOP METHODS TO EVALUATE THE EFFECT OF ARCHITECTURAL SURFACE TREATMENTS

    Architectural surface treatments can critically affect the performance of structural elements.

11. CONDUCT FURTHER STUDIES AIMED AT REALIZING THE FULL POTENTIAL OF SPECIAL DEVICES FOR REDUCING SEISMICALLY-INDUCED FORCES IN A STRUCTURE.

    The main problem associated with the use of such devices concerns their reliability. Tests of large-scale models of the devices using available earthquake simulator facilities appear to be the best possible way of conducting reliability studies at the present time.

C. CONSTRUCTION

1. ESTABLISH LIMITATIONS FOR LOCATIONS, CONFIGURATIONS AND CONSTRUCTION OF CONSTRUCTION JOINTS IN BEAMS, GIRDERS, COLUMNS, SHEAR WALLS, AND SLABS AS THEY RELATE TO THE SEISMIC RESISTANCE OF A STRUCTURAL SYSTEM.

2. DETERMINE THE RELATIONSHIP BETWEEN CONCRETE MIX AND SHRINKAGE AND THE EFFECT OF SHRINKAGE ON CASTING SEQUENCE AND THE AREA OR DIMENSION OF CASTING ELEMENTS AS RELATED TO THE SEISMIC RESISTANCE OF BUILDING SYSTEMS.

3. PERFORM STATISTICAL STUDIES OF ACTUAL PLACING TOLERANCES OF FORMWORK, REINFORCEMENT, AND CONCRETE SURFACES TO ASSESS THEIR EFFECTS ON EARTHQUAKE RESISTANCE OF MEMBERS AND JOINTS.

D. FOUNDATIONS

1. DETERMINE METHODS TO SELECT PROPER FOUNDATION SYSTEMS.

2. ESTABLISH DESIGN PROCEDURES FOR UNDERGROUND STRUCTURES AND ELEMENTS (INCLUDING PILES, CAISSONS, AND TIE BEAMS), RECOGNIZING SOIL-STRUCTURE STIFFNESS INTERACTION AND IMPOSED DISPLACEMENTS AS WELL AS TRADITIONAL CONCEPTS OF SOIL PRESSURE. INSTALL INSTRUMENTS TO MEASURE LATERAL AND VERTICAL PRESSURE ON BURIED STRUCTURES AND FOUNDATIONS DURING EARTHQUAKES.

3. INSTALL INSTRUMENTS AND CONDUCT COMPLEMENTARY ANALYTICAL WORK TO DETERMINE THE NATURE OF OUT-OF-PHASE GROUND MOTIONS AND SURFACE WAVES AND THEIR EFFECT ON STRUCTURES.

4. CONDUCT RESEARCH FOR UNDERSTANDING THE ACTUAL MECHANISMS OF COUPLING OF STRUCTURE TO GROUND BY THE FOUNDATION SYSTEM.

   Complete understanding of this mechanism and reliable determination of appropriate soil parameters would lead to the prediction of coupling efficiency and of effects of coupling on structural response. This information can then be used to develop design criteria for all types of foundations and foundation ties to resist the effects of coupling forces, such as sliding and overturning, especially in the case of structural walls.

WORKING GROUP 5

PRESTRESSED AND INDUSTRIALIZED CONCRETE STRUCTURAL SYSTEMS

This group discussed and offered recommendations for improving ERCBC utilizing as its main seismic-resistant system prestressed and/or industrialized structural concrete elements or components. Among the different topics suggested to this group for discussion were: selection of effective structural systems; design criteria; code requirements; preliminary design; final detailing; and construction and maintenance aspects. The recommendations developed and approved by the group are compiled in three main categories. Category A deals with prefabricated concrete buildings, while category B contains recommendations concerning post-tensioned buildings. A general recommendation regarding nonstructural concrete elements is offered in category C. Within each category recommendations are listed in order of priority. The group did not prioritize recommendations between prefabricated and post-tensioned concrete but did endorse a lower priority for the nonstructural precast component recommendations.

A. PREFABRICATED CONCRETE BUILDINGS

1. DEVELOP INTERIM GUIDELINES THAT IDENTIFY APPROPRIATE PRINCIPLES AND METHODOLOGY FOR THE SEISMIC DESIGN OF PREFABRICATED CONCRETE BUILDINGS.

   There are no guidelines, code provisions, or generally accepted design principles and methodology presently available for the design and construction of prefabricated concrete buildings. An interim manual of guidelines is needed to provide immediate guidance to the profession and serve as a focal point for the identification of further research.

   A symposium should be held immediately following the development of the interim guidelines to present practitioners, researchers, code officials, and constructors a forum to discuss the guidelines and formulate code provisions.

2. MAKE GENERIC STUDIES OF CONNECTIONS AND COMPONENTS FORMING PART OF THE PRIMARY LOAD-CARRYING SYSTEM FOR SEISMIC FORCES IN PREFABRICATED CONCRETE BUILDINGS.

   There are only a few studies of a limited number of connection types under simulated seismic loading. The studies should cover non-tensioned and post-tensioned horizontal and vertical connections subjected to the full loads that would exist during an earthquake. Component studies should examine elements of various types (lightweight prestressed, precast, etc.) and various cross-sections. Of particular importance are connections and components for industrialized load-bearing concrete structures.

3. STUDY THE BEHAVIOR OF DIAPHRAGMS WITH AND WITHOUT OPENINGS AND CONSTRUCTED OF PRECAST ELEMENTS.

   Large numbers of precast floors are utilized for all types of structural systems. Knowledge of the force-transfer mechanism within and between elements, and between these floor elements and walls is needed. Of particular importance are the effects of topping and its varying characteristics.

4. STUDY THE BEHAVIOR OF WALLS WITH AND WITHOUT OPENINGS AND CONSTRUCTED OF PRECAST ELEMENTS.

   Many walls are assembled from various types of precast elements and their ability to resist seismic forces is largely unknown. Also of concern are soil-structure interaction problems for such walls, rocking effects, and differences between the behavior of walls with and without boundary elements.

5. CONDUCT ANALYTICAL AND EXPERIMENTAL STUDIES TO ASSESS THE POTENTIAL RANGE OF DYNAMIC BEHAVIOR FOR PREFABRICATED STRUCTURAL ASSEMBLIES.

   The analytical studies should intially be based on currently available experimental data. The work should include parametric studies to identify appropriate design philosophies and focus on aspects of the response where prefabricated buildings differ from cast-in-place concrete buildings.

B. POST-TENSIONED BUILDINGS

1. CONDUCT ANALYTICAL INVESTIGATIONS TO DETERMINE APPROPRIATE STRUCTURAL CONFIGURATIONS, LEVEL OF DESIGN FORCES AND DRIFT CONSTRAINTS FOR PRESTRESSED CONCRETE STRUCTURES IN SEISMIC ZONES.

   Present building code concepts for steel and concrete structures essentially assume an elasto-plastic behavior so that the simple extension of those concepts to prestressed concrete structures is inappropriate because of the more dominant elastic response of prestressed structures based on available experimental data. Various prestressed concrete structural configurations for seismic zones should be explored with an aim to recommending design lateral forces and drift constraints which would provide measures of safety against collapse and control of nonstructural damage comparable to those provided in current building codes for structural steel and reinforced concrete lateral load-resisting systems.

2. CONDUCT COORDINATED ANALYTICAL AND EXPERIMENTAL STUDIES TO DEFINE THE DEGREE OF DAMPING, STIFFNESS, ABRUPTNESS OF FAILURE, AND HYSTERETIC BEHAVIOR OF PRESTRESSED CONCRETE SUBASSEMBLAGES CONTAINING COMBINATIONS OF PRESTRESSING TENDONS AND DEFORMED BAR REINFORCEMENT SIMILAR TO THOSE LIKELY IN PRACTICE.

   Little work has been done within the United States on the seismic response of prestressed concrete structures; consequently, many fundamental questions remain unanswered for members having the proportions and combinations of tendons and deformed bars likely in practice. A basic program of investigation should be developed aimed at providing knowledge necessary to bring understanding of the behavior of prestressed concrete flexural members under reversed cyclic loading to the same level as that existing for reinforced concrete flexural members.

Recommendations should be developed for limits on the amount and distribution of prestressed and non-prestressed reinforcement, on confinement requirements, and on minimum values of M_u/M_{cr} consistent with the design assumptions for the member.

3. DEVELOP RECOMMENDED DESIGN PRACTICES FOR PRESTRESSED CONCRETE JOINTS.

   Subassemblage tests have shown that joints in prestressed structures may be less critical than those in reinforced concrete structures. If so, the building industry may move rapidly to use prestressing in the joints of critical elements in seismic zones. Research should define the contributions of the concrete, tendon forces, and hoop steel and additional bonded steel to the strength and deformational characteristics of reversed, cyclically loaded joints with particular attention to requirements for bonding of the tendons through the joints to the location of anchorages at the external faces of the joints. This research should be undertaken for both beam-column and slab-column joints with the effects of banded construction being examined in the latter case.

4. DEFINE THE CYCLIC SHEAR BEHAVIOR OF PRESTRESSED CONCRETE ELEMENTS.

   There is little information available on the behavior of members critical in shear and, especially, on effects of shear reinforcement or additional bonded longitudinal reinforcement. Systematic testing should be undertaken to define the strength and deformational characteristics of elements critical in shear, especially for regions where the tendon is draped or where the support is in the transfer zone of the member.

5. CONDUCT CYCLIC LOAD TESTS ON PARTIALLY PRESTRESSED CONCRETE COLUMNS.

   The quantity of confining steel necessary to achieve adequate curvature ductility, particularly at high compression load levels, and to prevent bar buckling, under reversed loading should be studied.

C. NONSTRUCTURAL PRECAST CONCRETE ELEMENTS

1. EVALUATE DESIGN FORCES AND DETAILS FOR CONNECTIONS ATTACHING NONSTRUCTURAL PRECAST CONCRETE ELEMENTS.

   There is ample evidence from observed earthquake damage that nonstructural precast elements are often improperly attached.

WORKING GROUP 6

EXPERIMENTAL INVESTIGATIONS

This working group dealt with issues relating to experiments on actual buildings, large-scale laboratory experiments, and correlation of analytical and experimental investigations with observed earthquake damage. The consensus of the working group was to divide the research and development needs into three main categories. Recommendations grouped in category A demand new research efforts or major departures from current experimental activities and are considered of the highest priority. Category B comprises a series of recommendations concerning the extension or improvement of current efforts. Finally, after analyzing the value of experimental investigations to engineering practice and comparing experimental research needs in ERCBC with the limited number of facilities available and research groups conducting such research, this working group formulated general policy-related recommendations which are presented under category C. Within each category the recommendations are not ordered according to priority.

A. SIGNIFICANT NEW RESEARCH AND DEVELOPMENT EFFORTS

1. CONDUCT AN IN-DEPTH STUDY ON THE NEED AND FEASIBILITY OF A LARGE EARTHQUAKE SIMULATOR CAPABLE OF TESTING FULL-SCALE STRUCTURES.

   The complexities of the earthquake response of many real structures imposes limitations on any testing technique not capable of reproducing field conditions. The need on the national level for a truly large shaking platform that could be used for full-scale testing has been recognized by many research groups and practicing engineers.

   A careful evaluation of the advantages and limitations of a large-scale earthquake simulator should be performed. This evaluation should consider the possible alternatives to such a large-scale simulator, the costs of such a facility, and the best way for the simulator to be used by all segments of the engineering profession.

2. CONSTRUCT MEDIUM-SIZED EARTHQUAKE SIMULATORS WITH A VARIETY OF CAPABILITIES.

   Earthquake simulators have proven to be extremely valuable and versatile laboratory tools. It is recommended that the few available small- and medium-sized simulators be used more intensively in research related to ERCBC, and that a few new medium-sized simulators [with characteristic dimensions between 10 ft and 30 ft (3 m and 10 m)] be constructed for research purposes. These simulators could have a variety of capabilities, depending on specific interests and applications. For example, some should include the capability of generating multiaxial motions for studying the effects of rocking and torsion. These simulators would also expand the capability for studying scaling effects and other consequences of dynamic modeling.

3. DEVELOP LOADING FACILITIES WITH THE CAPABILITY OF SUBJECTING STRUCTURAL SUBASSEMBLAGES OR SYSTEMS TO COMPLEX LOADING ARRANGEMENTS AND LOADING HISTORIES.

With the increased need for data describing the response of structures under complex loadings, laboratory facilities will need to be improved. Such improvements include the construction of structural floor-wall reaction systems with the capacity to develop multidimensional loads which can be applied to large-scale multistory structures. Laboratories should be encouraged to examine the desirability of computer-actuator on-line systems which have the capability of using computers to control the loading applied to the structure as a function of both a specified earthquake ground motion and the structural response. On-line systems will also permit an evaluation of loading histories for less complex testing arrangements. Several facilities should be developed to permit more extensive parametric studies. The different laboratories should correlate and confirm findings and exchange methodologies.

4. OBTAIN RESPONSE DATA FROM BUILDINGS SUBJECTED TO INTENSE GROUND MOTIONS; ALSO, DEVELOP INSTRUMENTATION TO RECORD STRUCTURAL DEFORMATIONS AND OTHER DATA, IN ADDITION TO BUILDING MOTION.

The response of buildings subjected to extremely strong near-field ground motions has not yet been recorded. Until this is done, we are lacking the full-scale verification that modern methods of analysis and design are leading to structures which perform as intended.

As a related problem, there is a need for significantly more in-depth measurements of the earthquake response of buildings. The response of several reinforced concrete buildings should be measured in much more detail than is possible under present programs. The measurement systems should provide information on deformations of structural elements, behavior of seismic joints, drift, development of building torsion, foundation deformations, etc. Instrumentation must be highly reliable, requiring minimal maintenance.

5. CARRY OUT LARGE AMPLITUDE FORCED VIBRATION TESTS OF FULL-SCALE STRUCTURES IN WHICH BUILDINGS ARE TESTED WELL INTO THE DAMAGING RANGE OF AMPLITUDES.

Within the last year, two full-size building frames have been subjected to large amplitude motions generated by newly-employed high capacity shaking machines. In these tests, one conducted on a test structure in Nevada, and another on a building that was to be torn down in St. Louis, Missouri, the structures were shaken hard enough to cause spalling and cracking of the concrete, formation of plastic hinges, and other forms of degradation and damage. Thus, this type of test has the potential of shaking structures at amplitude levels comparable to those generated by actual earthquakes. These tests obviously provide valuable results, particularly concerning the overall behavior of the structure which can otherwise be evaluated only by post-earthquake studies.

The two tests mentioned above were conducted with ad-hoc, prototype vibration generators, inferring a need for the design and development of reliable, general-purpose shaking machines capable of high force levels. As a complement to the large amplitude, forced vibration tests, the possibility of static field tests of full-scale structures should be considered.

B. EXTENSION OR IMPROVEMENT OF CURRENT RESEARCH EFFORTS

1. CONTINUE FIELD INSPECTION, STUDY, AND INTERPRETATION OF EARTHQUAKE DAMAGE IN MAJOR EARTHQUAKES THROUGHOUT THE WORLD.

Earthquake inspection requirements are broad in scope and dependent on the characteristics of individual earthquakes. They can, however, be divided into three types: (a) field observations immediately after the earthquakes; (b) preliminary interpretation of earthquake damage; and (c) comparison of measurements of earthquake response with results of experimental and analytical investigations. Each of these efforts requires different characteristics of personnel and has different funding requirements. For example, the effectiveness of post-earthquake field observations requires that funding and modes of operation and cooperation be pre-established and maintained.

2. EXPAND FIELD TESTING OF BUILDING STRUCTURES TO INCLUDE EXAMINATION OF A MUCH WIDER SELECTION OF CHARACTERISTICS OF STRUCTURAL RESPONSE.

The structural response characteristics of various structural and nonstructural systems should be investigated at various stages of construction. Research is needed on various types of structural systems, including cast-in-place, large-panel, and prestressed concrete structures. Additional information is also needed on the soil-structure interaction phenomenon and the in-plane bending of the floor systems for very stiff reinforced concrete buildings. The amplitude-dependent properties of reinforced concrete structures need to be determined for amplitudes up to and including minor structural damage.

3. CORRELATE VIBRATION TEST DATA ON CONCRETE STRUCTURES FROM AMBIENT, FORCED VIBRATION TESTS, AND EARTHQUAKE RESPONSE.

A number of studies on multistory, steel frame structures has noted good correlation of frequencies, mode shapes, and damping values between forced and ambient (wind-excited) vibration data. Few correlative studies, however, have been made on concrete structures. This correlation should also be expanded to include the response of structures to recorded earthquake motions. These tests cover several orders of magnitude of structural response, and it is therefore necessary to determine the relations among the test data so that the best indication of earthquake response can be obtained from tests made at lower amplitudes of motion.

4. DEVELOP ADDITIONAL METHODS OF TESTING FULL-SCALE STRUCTURES INCLUDING THE EXAMINATION OF EXPLOSION-GENERATED GROUND MOTIONS AND THE DEVELOPMENT OF NEW TECHNIQUES.

The generation of potentially damaging ground motions has been achieved in the Soviet Union by the use of controlled detonation of chemical explosives. The feasibility of this technique should be investigated, in particular, its ability to generate ground shaking having the same spectral characteristics as a strong earthquake motion. In addition, strong ground shaking generated by underground nuclear explosions should be used as opportunities present themselves. Other techniques of testing, such as pull-back tests and methods for generating large forces at low frequencies, should also be explored.

C. GENERAL POLICY-RELATED RECOMMENDATIONS

1. CONSOLIDATE EXISTING DATA AND DEVELOP GUIDELINES FOR STANDARDIZING DATA OBTAINED FROM EXPERIMENTAL INVESTIGATIONS OF BUILDINGS.

The value of experimental investigations for engineering practice can be greatly enhanced if comparisons can be made among data from various sources. For this to be effective, however, comparable data must be included in the investigations, and the terminology must be defined and standardized. Standardization should not restrict the development of innovative procedures, but should, for example, be used to acknowledge that some data are dependent on amplitude of motion (e.g. period, stiffness, damping), while others require qualitative definitions (e.g. elastic limit, ultimate strength). The guidelines should also be useful in planning testing programs.

2. ENCOURAGE DEVELOPMENT OF INNOVATIVE TESTING FACILITIES AND PROGRAMS SUITABLE FOR SMALL RESEARCH GROUPS.

Because much of the current experimental work is concentrated in a limited number of institutions, there is a need for additional investigators and research groups to become significantly involved in experimental research.

It is believed that with sufficient innovation such experimental research can be conducted with modest commitment of expenditures and staff. As a complementary means of involving additional researchers in the experimental efforts in earthquake-resistant design of concrete structures, the increased participation of visiting staff members from other institutions in the programs of the larger facilities should be encouraged.

3. EVALUATE THE COST-EFFECTIVENESS OF THE ADDED EXPENSE OF PROVIDING EARTHQUAKE RESISTANCE BEYOND THAT REQUIRED FOR SAFETY, AS COMPARED WITH THE COST OF REPAIRING INFREQUENT DAMAGE SUSTAINED IN EARTHQUAKES.

There is a need to understand relations between costs of preventing damage and costs of repairing possible damage, due, both to moderate earthquakes with a strong probability of occurrence, as well as to extremely strong shaking, which is much less likely.

This knowledge is required in choosing the appropriate level of earthquake resistance for new construction, for existing buildings with substandard earthquake resistance, and for damaged buildings which require repair. Experimental investigations of selected buildings can be used to determine the susceptibility to damage of existing buildings. This will contribute to the evaluation of cost-effectiveness of programs for abating the earthquake hazard posed by old buildings.

WORKING GROUP 7

PROFESSIONAL USER NEEDS

This group was primarily concerned with the following problems: (1) to assess current knowledge and practice in ERCBC; (2) to evaluate the relevancy of present research results to actual user needs; (3) to recommend means for more effective cooperation between researchers and professional users; and (4) to identify and develop strategies for more rapidly disseminating, evaluating, and screening research findings which may be beneficial to ERCBC so that they can be implemented in design practice.

This working group, after discussing and developing recommendations for the above issues, compiled them into two categories. Included in category A are recommendations regarding means for improving cooperation between researchers and professional users and for more rapidly disseminating, evaluating, and screening research findings. In category B, the working group identified research and development needs. In this category, the first eight recommendations were identifed as having higher priority than the subsequent recommendations.

A. IMPROVEMENT OF COMMUNICATION AND COOPERATION BETWEEN RESEARCHERS AND PROFESSIONALS

1. INCLUDE PRACTICAL ENGINEERING CONSIDERATIONS IN PROPOSED DESIGN-ORIENTED RESEARCH PROJECTS TO MAXIMIZE THE EFFECTIVENESS AND USEFULNESS OF THE RESULTS FOR THE PROFESSION.

   Proper planning of a research project to utilize results cannot be overemphasized. Researchers should avail themselves of consultants and professionals to assist in carefully conceiving reseach projects both needed by the profession and which will be useful to structural designers.

2. ENCOURAGE RESEARCHERS TO WORK IN A PROFESSIONAL ENGINEERING OFFICE OR A CONSTRUCTION COMPANY TO GAIN PRACTICAL UNDERSTANDING OF SEISMIC DESIGN PROBLEMS AND CONSTRUCTION.

   Considerable research is currently being conducted by young people who, immediately after receiving their degree, have obtained an academic or research position at a research institution without being exposed to the practical problems that face the profession. For the researcher engaged in applied research aimed at design usage, an application of practical engineering realities is essential. Researchers in this area are thus encouraged to spend sabbatical leaves or summers gaining this practical knowledge in design offices or through similar experiences.

3. ORGANIZE MULTIDISCIPLINARY TEAMS OF RESEARCHERS TO INVESTIGATE MANY OF THE NEEDS IN THE FIELD OF ERCBC.

   In order to solve the many complex problems in earthquake engineering which require knowledge in different disciplines (such as structure-soil-seismic-input questions), multidisciplinary research teams are essential for thorough understanding. Even within the purely structural fields, multidisciplinary teams of computer, materials, and laboratory experts are needed for maximum profitability of effort on many problems.

4. DEVELOP AN EFFECTIVE TRANSFER MECHANISM BETWEEN RESEARCHERS AND THE PROFESSION.

   The profession needs to convey its needs to the research community through workshops, advisory committees, and the like. Research results must be compiled, evaluated, and disseminated to the average engineer. Knowledgeable groups should be supported to compile and disseminate research findings in road-show-type presentations with printed notes for all interested communities at a nominal cost to the design profession. Additional programs should be organized and presented to the related professions, such as architecture, and mechanical and electrical engineering. New reseach findings should also be integrated into college curricula.

5. CREATE SPECIALIZED INFORMATION CENTERS AS CLEARING HOUSES TO COLLECT AND DISSEMINATE INFORMATION AS REQUESTED IN SPECIFIC AREAS.

   The volume of literature generated today is staggering and often hard to locate. Information centers or clearing houses, located in various universities, should be established in the many related fields of ERCBC to collect, digest, catalog, and disseminate research. Funding should be sufficient to permit the entire profession to avail themselves of this service at costs not to exceed those of reproduction. International research efforts and results should also be actively solicited, translated, and made available.

B. RESEARCH AND DEVELOPMENT NEEDS

1. DEVELOP DESIGN GUIDELINES, WITH DETAILS AND DESIGN EXAMPLES, BASED ON RESEARCH FINDINGS TO GUIDE PRACTICING ENGINEERS IN THE SEISMIC DESIGN OF NEW STRUCTURES.

   Seismic design requirements have become increasingly complex, and much of this can be attributed to research findings. The practicing structural engineer has received little assistance in interpreting these requirements in his or her design. Guidelines, with details and design examples, offer relief in several ways: (1) tested and reliable details instead of those used over the years based on the "judgments" of years ago; (2) reduction in construction cost; and (3) reduction of the time lag from research to practical application.

2. REVIEW ANSI, ASTM, AND OTHER NATIONAL STANDARDS TO DETERMINE WHETHER THOSE CITED BY STRUCTURAL ENGINEERS ARE APPLICABLE TO SEISMIC DESIGN.

   Engineers and building code officials must cite standard material tests and material composition, but such standards are derived from various sources and seldom reflect seismic design considerations. Research is needed to determine whether these are applicable to seismic design.

3. CONDUCT RESEARCH ON THE CAPACITY OF ANCHOR BOLTS EMBEDDED IN CONCRETE.

   Little work has been done to assess the capacity of anchor bolts embedded in concrete under cyclic loading. Present values are based on estimated factors of safety, generally derived from static loading, yet failure of this component can be as critical as failure of an embedded reinforcement bar. This research should include inserts, expansion bolts, and bolts with combined bending and shear.

4. DIRECT MORE RESEARCH TOWARD IMPROVING SHRINKAGE CHARACTERISTICS OF CONCRETE.

   One of the most prominent adverse characteristics of concrete is shrinkage, which is frequently manifested as extensive cracking. In recent years the development and use of expansive concrete has successfully counteracted the effects of drying shrinkage in certain applications, but its availability is limited at present.

5. CONDUCT RESEARCH ON BASIC BUILDING COMPONENTS SUCH AS SLABS, WALLS, ETC.

   Research to date has generally concentrated on beam-column frames. The ductility, stiffness characteristics, and design requirements for slab-column and slab-wall systems need further study. Such structural systems may be useful in many structural applications, especially in low-rise structures located in regions of low seismicity. Shear walls may also provide efficient and economical systems for resisting seismic lateral forces in some types of buildings. The inelastic behavior of slabs and walls needs to be investigated. Research is needed to improve understanding of diaphragm behavior, especially in terms of their stiffness and load transfer capabilities.

6. EVALUATE THE COST-BENEFIT RELATIONSHIPS FOR VARIOUS MODIFICATIONS OF SEISMIC DESIGN REQUIREMENTS AND DIFFERENT DEGREES OF RESISTANCE.

   Implications of design and construction costs associated with various alternative seismic design methods need evaluation and documentation. Further studies of a spirit similar to the ATC-2 document are needed, especially for areas of lower seismicity.

7. CONDUCT RESEARCH PROGRAMS IN ERCBC CONSIDERING THE APPLICABILITY OF REDUCED DUCTILITY AND FORCING REQUIREMENTS FOR AREAS OTHER THAN THOSE OF HIGHEST SEISMICITY.

   Research appropriately concentrates on maximization of seismic resistance. However, consideration of reduced requirements for zones of lower seismicity should be included in research efforts, especially when easily available from spin-offs of other projects.

8. ENCOURAGE RESEARCH TO DEVELOP PRACTICAL PROCEDURES WHICH IDENTIFY SYSTEMATICALLY THE DAMPING, DUCTILITY, BOND, AND OTHER ENERGY DISSIPATION CHARACTERISTICS OF STRUCTURAL COMPONENTS AND SYSTEMS.

   There is a great need in the profession for realistic values of parameters such as damping in the elastic and inelastic stages, the available and required ductilities in a structure, the reserve bond after the initiation of slippage, and other energy dissipation characteristics of structures. These are all parameters associated with reducing the expected responses to seismic action and aid in the development of economic designs when these parameters can be defined as realistic and practical.

9. CONDUCT RESEARCH ON THE PERFORMANCE OF LIGHTWEIGHT CONCRETE COMPONENTS UNDER CYCLIC LOADING.

   Lightweight concrete offers a potential advantage in seismic design because it weighs less than normal concrete. However, little research has been done on its behavior under cyclic loading. It is suspected of being brittle and subject to severe strength degradation under such loading conditions. Research is needed to offer guides for the proper use of this material.

10. DEVELOP DESIGN GUIDELINES FOR THE PRACTICING ENGINEER, WITH DETAILS AND DESIGN EXAMPLES, IN THE "RETROFITTING" OF EXISTING BUILDINGS BASED ON RESEARCH FINDINGS.

    Many existing buildings fail to meet current seismic design requirements and may therefore pose a great safety hazard. Seismic "retrofitting" of these buildings is in many respects more complex and challenging than designing new structures, but few guidelines are available. Engineers need a reliable guide, with details of design examples, so that they can design reliable, economic schemes for retrofitting existing buildings. Much research is needed on retrofitting techniques before such guidelines can be written.

11. CONDUCT RESEARCH ON THE PERFORMANCE OF PRESTRESSED CONCRETE COMPONENTS AND JOINTS UNDER CYCLIC LOADING INTO THE INELASTIC RANGE.

    Prestressed concrete offers potential advantages in seismic design but the behavior of components and joints under inelastic cyclic loading is questionable. Prestressed concrete generally has little ability to dissipate energy in its present methods of use. Research is needed to offer guides to the intelligent use of prestressed concrete in seismic design.

12. DEVELOP PRACTICAL METHODS OF INELASTIC DESIGN.

    Inelastic dynamic analysis is impracticable as a design tool for the typical design case and will probably remain so. An efficient and reliable design method which accounts for possible yielding is needed, however. This design method should be aimed at a structural response with energy dissipation occurring at desired places, eliminating all mechanisms containing brittle elements or other situations which can limit stable behavior such as local instability. Methods should be capable of allowing the designer to estimate and limit inelastic deformations and displacements.

13. DEVELOP A SIMPLE, WORKABLE CODE FOR DESIGN OF REINFORCED CONCRETE STRUCTURES.

Structural engineers, whether or not designing in seismic zones, need a simple, workable reinforced concrete design code. The design of reinforced concrete does not generally warrant complex mathematical expressions in view of the many variables that cannot be quantitatively recognized in design, e.g., variations in load, material properties, construction tolerances, shrinkage and creep effects, and stresses induced by reshoring, curing, and differential settlement of foundations.

WORKING GROUP 8

NATIONAL COOPERATION

This working group was requested to recommend means for improving communication at the national level between producers, professionals, and researchers; and for integrating more closely the research carried out at different institutions. The recommendations developed by this group are separated into two categories. Category A consists of recommendations for improving nationwide communication between those involved in ERCBC and category B is related to methods for integrating research activities.

A. IMPROVEMENT OF COMMUNICATION CONCERNING ERCBC

1. DETERMINE EFFECTIVE MEANS OF TRANSMITTING RESEARCH RESULTS TO PRACTICING ENGINEERS.

There is a great need to collect, distill, and present research results for practical application. Special reports, booklets, journal articles, specialty meetings, and short courses containing practical design examples may serve this purpose. Regular research reports containing practical design information should also be widely disseminated and published in journals.

2. ESTABLISH EFFECTIVE MEANS WHEREBY PRACTITIONERS CAN INFORM RESEARCHERS OF PROBLEM AREAS THAT NEED TO BE INVESTIGATED.

Short courses or meetings should be organized by universities, professional associations, local engineering groups, or others, to permit and encourage dialogue between practitioners and researchers. Such discussions might be organized around a specific topic of interest or problem area. Periodic surveys by universities or professional engineering groups of professional questions and suggestions regarding research may also be useful.

3. PROVIDE DESIGN GUIDELINES AND TECHNICAL BULLETINS ILLUSTRATING PROPER APPLICATION OF PRODUCTS.

Trade associations, marketing groups, producers, and/or suppliers, as well as technical committees of professional societies, should provide professional engineers and others with design guidelines for proper application of products. Such technical guides or bulletins should contain detailed quantitative examples illustrating common design solutions. The adequacy of such guides and bulletins should be evaluated by appropriate technical professional committees or others of demonstrated competence.

4. DEVELOP EFFECTIVE MEANS OF COMMUNICATING THE ESSENTIALS OF EARTHQUAKE ENGINEERING TO PLANNERS, GOVERNMENT OFFICIALS, ARCHITECTS, AND BUILDING OFFICIALS.

   There are many misconceptions regarding the nature of earthquake-resistant design, the risks involved, the efforts that must be devoted to design, and the added costs of construction. Special seminars and publications should be developed directed to the interests of the various nonengineering professions involved in effecting seismic-resistant design.

5. ADVANCE COOPERATION BETWEEN RESEARCHERS, PRACTITIONERS, AND MODEL CODE WRITING BODIES WITH RESPECT TO SEISMIC EFFECTS.

B. INTEGRATION OF RESEARCH IN ERCBC

1. DEVELOP METHODS FOR EXCHANGING RESEARCH INFORMATION.

   Regular (e.g. annual) meetings of researchers and practitioners in ERCBC should be organized where research results and needs can be discussed. Regular exchange of research reports must be encouraged.

2. INTEGRATE RESEARCH PROGRAMS IN SIMILAR AREAS OF ERCBC.

   Whenever possible, research programs conducted at different institutions should be integrated and coordinated in such a way that the total information obtained will be maximized. This may be accomplished in a variety of ways including voluntary cooperation between researchers, inclusion of researchers on program advisory panels, and funded workshops of researchers and professionals interested in a specific area of research related to ERCBC.

WORKING GROUP 9

INTERNATIONAL COOPERATION

This working group assessed the means and effectiveness of international communication and cooperation between researchers and professionals working in the field of ERCBC. The group developed and agreed on a series of recommendations of a general nature which are separated into two categories. Category A consists of a general recommendation and category B contains a number of more specific recommendations for improving ERCBC.

A. GENERAL RECOMMENDATION

1. ENCOURAGE IMPLEMENTATION OF THE INTERNATIONAL ASSOCIATION FOR EARTHQUAKE ENGINEERING (IAEE) RECOMMENDATIONS FOR INTERNATIONAL COOPERATION.

   The group reviewed and discussed the report of the IAEE Committee on International Cooperation and generally agreed with the suggestions of this committee. Topics suggested by the IAEE Committee include: (a) publication of monograph series in earthquake engineering; (b) collaboration on formulating basic concepts for seismic codes; (c) organization of regional courses on earthquake engineering; (d) publication of pamphlet on "Inspection of Earthquake Damage"; (e) publication of pamphlet on "Protection Against Earthquake"; and (f) international planning of dense, strong-motion seismograph arrays.

B. MEANS OF IMPROVING ERCBC

1. ENCOURAGE COOPERATION IN THE FIELD OF BEHAVIOR OF STRUCTURAL CONCRETE UNDER REPEATED LOADING.

   It was recognized that distances between research centers have hindered cooperation on a worldwide basis. It is recommended that national and international organizations take steps to improve cooperation in this area.

2. ENCOURAGE WORKSHOPS AND INTERNATIONAL SEMINARS ON WELL-DEFINED TOPICS FOR INTERNATIONAL INTERCHANGE OF IDEAS AND RESEARCH FINDINGS.

   The format of the workshop, Earthquake-Resistant Reinforced Concrete Building Construction (University of California, Berkeley, July 1977) is a good example to follow.

3. ENCOURAGE INTERCHANGE OF INFORMATION AND RESEARCH PERSONNEL TO AID IN MORE UNIFIED RESEARCH EFFORTS. LARGE TESTING FACILITIES SHOULD BE MADE AVAILABLE ON A COOPERATIVE BASIS.

4. ORGANIZE REGIONAL, SPECIALIZED SHORT COURSES TO HELP IMPLEMENT RESEARCH RESULTS INTO PROFESSIONAL PRACTICE.

5. ENCOURAGE COOPERATION BETWEEN TEAMS CARRYING OUT POST-EARTHQUAKE INSPECTION.

WORKING GROUP 10

SEISMIC TESTING AND PERFORMANCE

During the workshop it became evident that a number of the participants on different working groups shared concerns regarding the integration, interpretation, and utilization of experimental research. In order to provide a forum for this discussion, Working Group 10 was formed to discuss general problems related to seismic testing and performance. This working group formulated the single recommendation presented below.

A. GENERAL RECOMMENDATION

1. EXPERTS INCLUDING RESEARCHERS AND PRACTICING ENGINEERS SHOULD BE CONVENED IN A PANEL TO:

(a) SURVEY, ANALYZE, AND EVALUATE THE MAIN PARAMETERS (AS WELL AS THEIR DEFINITIONS) THAT ARE PRESENTLY USED IN RESEARCH (ANALYTICAL AND EXPERIMENTAL) AND IN PRACTICE TO DESCRIBE THE INELASTIC MECHANICAL CHARACTERISTICS OF REINFORCED CONCRETE MATERIALS, SECTIONS, REGIONS, MEMBERS, SUBASSEMBLAGES, STRUCTURES, AND WHOLE SOIL-BUILDING SYSTEMS.

In order to realize the maximum benefit from research conducted at various institutions, it is desirable that results be presented whenever possible in terms of unambiguous parameters. All too often researchers present results in terms of different parameters without providing sufficient information to allow comparison.

One parameter of particular concern is ductility. While ductility is a useful concept, it has a precise definition and quantitative meaning only for the idealized case of monotonic, linear elasto-perfectly plastic behavior. Its use in real cases where behavior significantly differs from this idealized case leads to much ambiguity and confusion. It is thus difficult to make valid comparisons of "available" ductility values reported by different researchers because they are often based on different response parameters or on yielding values determined using different and/or unexplained definitions.

These experimentally obtained "available" ductility values are also often misused in analytical studies of the "demand" or "required" ductility due to the difficulty of establishing realistic values for the "linear-elastic stiffness and yielding strength." Attempts should be made to integrate the definitions of response parameters that are used in experimental test programs and in analytical investigations.

Furthermore, it is highly questionable whether the performance of different building systems can be properly described and evaluated on the sole basis of elastic stiffness, yielding strength, and ductility. Consequently, there is a need to introduce additional parameters for describing the total hysteretic dissipation, number of cycles of reversed deformations, and the degradation in stiffness and strength that has been observed under seismic conditions.

(b) PROVIDE GUIDELINES FOR CONDUCTING *CONTROL OR REFERENCE TESTS* IN EXPERIMENTAL INVESTIGATIONS WHICH WOULD PERMIT VALID COMPARISON BETWEEN RESULTS OBTAINED BY DIFFERENT RESEARCHERS. THESE GUIDELINES SHOULD COVER: SPECIMENS, LOADING CONDITIONS (RATE AND HISTORY), INSTRUMENTATION, REDUCTION AND PRESENTATION OF DATA, AND RESULTS (MINIMUM INFORMATION TO BE PRESENTED IN RESEARCH REPORTS).

Note that these guidelines refer only to *control or reference tests,* and should not be used to restrict the development of innovative testing procedures.

(c) EVALUATE PERFORMANCE OBTAINED IN DIFFERENT ANALYTICAL STUDIES AND EXPERIMENTAL INVESTIGATIONS (CARRIED OUT IN THE FIELD OR IN THE LABORATORY) AND ASSESS THE IMPLICATIONS OF SUCH PERFORMANCE ON SEISMIC-RESISTANT DESIGN AND CONSTRUCTION IN REGIONS OF *DIFFERENT* SEISMICITY.

Before results of analytical or experimental studies are used to formulate design standards, they should be carefully evaluated in terms of the level of structural performance expected and realistic estimates of the severity of inelastic deformational demands required of structural components in various types of soil-building systems accounting for site seismicity. The use of analytical or experimental results obtained using loading conditions that do not realistically reflect those resulting from actual earthquake ground motions expected at a site during the life of a structure may result in unnecessarily increased construction and design costs on one hand or in unconservatively designed structures on the other. Furthermore, the use of simplified design criteria based on lower bounds of strength and deformational capacities, while facilitating application by professional engineers, can in some cases result in costly and overconservative designs, especially in areas of low seismicity. Thus, design requirements to achieve economical structures that perform satisfactorily during earthquakes should account for the type of soil-building system employed and the local seismicity.

Because of the complex nature of these problems and the scarcity of reliable data, the cooperation of foreign experts in this field should be sought by including them as participants in the group or as consultants.

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Appendix A

WORKSHOP PROGRAM

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WORKSHOP ON EARTHQUAKE-RESISTANT REINFORCED CONCRETE BUILDING CONSTRUCTION
University of California, Berkeley, July 11-15, 1977

PROGRAM

MONDAY, JULY 11

7:45 REGISTRATION

8:30 INTRODUCTION *V. Bertero, J. Scalzi*

9:00 SESSION I AN OVERVIEW OF THE STATE-OF-THE-ART IN EARTHQUAKE-RESISTANT REINFORCED CONCRETE BUILDING CONSTRUCTION

Co-Chairmen: *H. Degenkolb, J. Penzien*
Recording Secretary: *D. Row*

I.1 Accomplishments and Research and Development Needs

AN OVERVIEW OF THE STATE-OF-THE-ART IN EARTHQUAKE-RESISTANT REINFORCED CONCRETE BUILDING CONSTRUCTION IN THE UNITED STATES OF AMERICA
J. Blume

AN OVERVIEW OF THE STATE-OF-THE-ART IN EARTHQUAKE-RESISTANT CONCRETE BUILDING CONSTRUCTION IN CANADA
S. Uzumeri, S. Otani, M. Collins

A EUROPEAN VIEW ON EARTHQUAKE-RESISTANT REINFORCED CONCRETE BUILDING CONSTRUCTION
J. Ferry Borges

A REVIEW OF RECENT RESEARCH IN JAPAN AS RELATED TO THE EARTHQUAKE-RESISTANT DESIGN OF REINFORCED CONCRETE BUILDINGS
H. Aoyama

BREAK

SEISMIC DESIGN REQUIREMENTS IN A MEXICAN 1976 CODE
E. Rosenblueth (presented by L. Esteva)

EARTHQUAKE-RESISTANT REINFORCED CONCRETE BUILDINGS IN MEXICO : RESEARCH NEEDS AND PRACTICAL PROBLEMS
L. Esteva

ACCOMPLISHMENTS AND RESEARCH AND DEVELOPMENT NEEDS IN NEW ZEALAND
R. Park

I.2 Design Earthquakes

DESIGN EARTHQUAKES - UNCERTAINTIES IN GROUND

MOTION INPUT AND THEIR EFFECTS ON BUILDING CONSTRUCTION
N. Donovan
STATE-OF-THE-ART IN ESTABLISHING DESIGN EARTHQUAKES
V. Bertero

Contributing Paper:
UNCERTAINTIES IN SEISMIC INPUT AND RESPONSE PARAMETERS - DEVELOPMENT OF STABLE DESIGN PARAMETERS
H. Shah, C. Mortgat

I.3 Discussion: Panel and Participants

LUNCH

14:00 SESSION II AN OVERVIEW OF THE STATE-OF-THE-PRACTICE IN EARTHQUAKE-RESISTANT REINFORCED CONCRETE BUILDING CONSTRUCTION

Co-Chairmen: *J. Blume, J. Ferry Borges*
Recording Secretary: *L. Malik*

II.1 Summary of Present Codes and Standards in the World Related to ERCBC; Future Codes

EVOLUTION OF CODES AND STANDARDS FOR EARTHQUAKE-RESISTANT REINFORCED CONCRETE BUILDING CONSTRUCTION (ERCBC)
R. Sharpe

SUMMARY OF PRESENT CODES AND STANDARDS IN THE WORLD
M. Watabe

II.2 Seismic Codes Based on Semi-Probabilistic Approach

SEISMIC CODE BASED ON SEMI-PROBABILISTIC APPROACH
J. Benjamin

Contributing Paper:
THE PURPOSE AND EFFECTS OF EARTHQUAKE CODES - A CASE STUDY OF SEMI-PROBABILISTIC APPROACH
H. Shah, T. Zsutty

BREAK

II.3 An Overview of the State-of-the-Practice and User Needs for Improving ERCBC

AN OVERVIEW OF USER NEEDS FOR IMPROVING EARTHQUAKE-RESISTANT REINFORCED CONCRETE BUILDING CONSTRUCTION
B. Olsen

AN OVERVIEW OF THE STATE-OF-THE-PRACTICE AND OF USER NEEDS FOR IMPROVING ERCBC (EMPHASIS ON CALIFORNIA)
E. Teal

AN OVERVIEW OF THE STATE-OF-THE-PRACTICE AND OF USER NEEDS FOR IMPROVING ERCBC (CANADIAN ASPECTS)
F. Knoll

Contributing Paper:
USER NEEDS FOR IMPROVING EARTHQUAKE-RESISTANT REINFORCED CONCRETE BUILDING CONSTRUCTION
E. Zacher

II.4 Discussion: Panel and Participants

FORMATION OF WORKING GROUPS AND GENERAL INSTRUCTIONS

19:00 WORKSHOP BANQUET

Faculty Club, preceded by reception at 18:00
Keynote Address: SOCIAL AND ECONOMIC EFFECTS OF EARTHQUAKE PREDICTIONS
R. Turner

TUESDAY, JULY 12

8:00 SESSION III MECHANICAL CHARACTERISTICS AND PERFORMANCE OF REINFORCED AND PRESTRESSED CONCRETE MATERIALS UNDER SEISMIC CONDITIONS

Co-Chairmen: *B. Bresler, W. Corley*
Recording Secretary: *J. Komendant*

III.1 Concrete

MECHANICAL PROPERTIES OF CONCRETE
R. Preece (presented by R. Schwein)

CONSTITUTIVE RELATIONS FOR CONCRETES UNDER SEISMIC CONDITIONS
M. Taylor

Contributing Papers:
CONFINED CONCRETE: RESEARCH AND DEVELOPMENT NEEDS
V. Bertero, J. Vallenas
STRENGTH AND DUCTILITY OF REINFORCED CONCRETE COLUMNS WITH RECTANGULAR TIES
S. Uzumeri, S. Sheikh
A NOTE ON THE FAILURE CRITERION FOR DIAGONALLY CRACKED CONCRETE
M. Collins

III.2 Reinforcing Steel

MECHANICAL CHARACTERISTICS AND PERFORMANCE OF REINFORCING STEEL UNDER SEISMIC CONDITIONS
J. Mc Dermott

MECHANICAL CHARACTERISTICS AND BOND OF REINFORCING STEEL UNDER SEISMIC CONDITIONS
E. Popov

Contributing Papers:
CONSTITUTIVE RELATIONS OF STEEL: EFFECTS ON HYSTERETIC BEHAVIOR OF STRUCTURAL CONCRETE MEMBERS AND ON STRENGTH CONSIDERATIONS IN SEISMIC DESIGN
R. Park
DEVELOPMENT LENGTH REQUIREMENTS FOR REINFORCING BARS UNDER SEISMIC CONDITIONS
N. Hawkins

III.3 Discussion: Panel and Participants

BREAK

10:00 SESSION IV REINFORCED AND PRESTRESSED CONCRETE STRUCTURAL SYSTEMS INCLUDING TYPES OF FOUNDATIONS: IMPORTANCE OF CONCEPTUAL DESIGN

Co-Chairmen: *T. Okada, B. Olsen*
Recording Secretary: *J. Axley*

IV.1 New Buildings:

(a) Cast-in-Field and Precast and Prestressed

STRUCTURAL SYSTEMS FOR EARTHQUAKE RESISTANT CONCRETE BUILDINGS
M. Fintel, S. Ghosh

Contributing Papers:
SOFT STORY CONCEPT APPLIED AT ST. JOSEPH HEALTH CARE CENTER
A. Popoff, Jr.
THE 18-STORIED SHIINAMACHI BUILDING
N. Ohmori

(b) Precast Concrete Composite Systems

Contributing Paper:
STATE OF THE ART OF PRECAST CONCRETE TECHNIQUE IN JAPAN
A. Ikeda, T. Yamada, S. Kawamura, S. Fujii

IV.2 Existing Buildings: Methods for Repairing and Retrofitting (Strengthening, Stiffening, and Toughening)

METHODS FOR REPAIRING AND RETROFITTING (STRENGTHENING) EXISTING BUILDINGS
J. Warner

METHODS AND COSTS OF REINFORCING VETERANS ADMINISTRATION EXISTING BUILDINGS
J. Lefter

REPAIR AND STRENGTHENING OF REINFORCED CONCRETE MEMBERS AND BUILDINGS
R. Hanson

Discussion:
D. Jephcott

IV.3 Discussion: Panel and Participants

LUNCH

13:30 SESSION V METHODS OF STRUCTURAL ANALYSIS

Co-Chairmen: *E. Elsesser, L. Esteva*
Recording Secretary: *S. Mahin*

V.1 Problems in Modeling and Its Influence in Estimating Dynamic Characteristics

THE ART OF MODELING BUILDINGS FOR DYNAMIC SEISMIC ANALYSIS
W. Gates

MODELING OF REINFORCED CONCRETE BUILDINGS
L. Selna

Contributing Papers:
PROBLEMS IN THE PRACTICAL APPLICATION OF COMPUTER ANALYSIS TO REINFORCED CONCRETE BUILDING DESIGN
C. Poland
EFFECTS OF TWO-DIMENSIONAL EARTHQUAKE MOTION ON RESPONSE OF R/C COLUMNS
D. Pecknold, M. Saharwardy

BREAK

V.2 Computer Programs Available for Analysis of Seismic Response of Reinforced Concrete Buildings (two- and three-dimensional); Future Improvements and Developments

AN OVERVIEW OF THE STATE-OF-THE-PRACTICE OF THE USAGE OF COMPUTER PROGRAMS
G. Brandow

COMPUTER PROGRAMS FOR ANALYSIS OF SEISMIC RESPONSE OF REINFORCED CONCRETE BUILDINGS
G. Powell

Contributing Paper:
ELASTIC ANALYSIS OF WALLS WITH OPENINGS
E. Popov

V.3 Preliminary Design vs. Analysis: Use of Computers for Preliminary Design and Final Detailing in ERCBC

COMPUTER AIDED DESIGN OF EARTHQUAKE RESISTANT REINFORCED CONCRETE BUILDINGS
N. Greve

ON THE USE OF COMPUTERS IN THE SEISMIC-RESISTANT DESIGN OF REINFORCED CONCRETE BUILDINGS
S. Mahin

V.4 Discussion: Panel and Participants

15:30 WORKING GROUP MEETINGS

19:30 WORKING GROUP MEETINGS

WEDNESDAY, JULY 14

8:00 SESSION VI DESIGN METHODS AND EXPERIMENTAL AND ANALYTICAL INVESTIGATIONS RELATED TO THE EARTHQUAKE-RESISTANT REINFORCED CONCRETE BUILDING CONSTRUCTION OF MOMENT-RESISTING FRAMES; CORRELATION WITH FIELD OBSERVATIONS OF EARTHQUAKE DAMAGE

Co-Chairmen: *R. Englekirk, R. Park*
Recording Secretaries: *S. Zagajeski, R. Klingner*

VI.1 Design of R/C Moment-Resisting Frames: Practical and Ideal Methods

DESIGN OF REINFORCED CONCRETE MOMENT-RESISTING FRAMES
D. Strand

CAPACITY DESIGN OF REINFORCED CONCRETE DUCTILE FRAMES
T. Paulay

Contributing Paper:
REINFORCED CONCRETE DUCTILE FRAMES - THE USE OF DIAGONAL REINFORCING TO SOLVE THE JOINT PROBLEM
R. Poole

VI.2 Problem of Damage to Nonstructural Components and Equipment

THE PROBLEM OF DAMAGE TO NONSTRUCTURAL COMPONENTS AND EQUIPMENT
K. Merz

Contributing Paper:
PROBLEM OF DAMAGE TO NONSTRUCTURAL COMPONENTS AND EQUIPMENT: WALLS AND STAIRS
G. Mc Kenzie

VI.3 Use of Optimization Procedures in Design of Moment-Resisting Frames

COMPUTER-AIDED OPTIMUM DESIGN OF DUCTILE R/C MOMENT-RESISTING FRAMES
S. Zagajeski, V. Bertero

VI.4 Experimental and Analytical Investigations on Elements and Subassemblages of R/C Frames

EXPERIMENTAL AND ANALYTICAL INVESTIGATIONS OF REINFORCED CONCRETE FRAMES SUBJECTED TO EARTHQUAKE LOADING
P. Gergely

BEHAVIOR OF ELEMENTS AND SUBASSEMBLAGES - R.C. FRAMES
J. Jirsa

Contributing Paper:
A METHOD FOR DELAYING SHEAR STRENGTH DECAY OF RC BEAMS
C. Scribner, J. Wight

VI.5 Importance of Reinforcement Details

Contributing Paper:
REINFORCING BARS IN EARTHQUAKE-RESISTANT REINFORCED CONCRETE BUILDING CONSTRUCTION
W. Black

VI.6 Behavior of Flat Slab Systems, Diaphragms, and Infilled Frames under Seismic Conditions

SEISMIC RESPONSE CONSTRAINTS FOR SLAB SYSTEMS
N. Hawkins

Contributing Paper:
HYSTERETIC BEHAVIOR OF INFILLED FRAMES
R. Klingner

VI.7 Discussion: Panel and Participants

BREAK

10:30 SESSION VII DESIGN METHODS AND EXPERIMENTAL AND ANALYTICAL INVESTIGATIONS RELATED TO THE EARTHQUAKE-RESISTANT REINFORCED CONCRETE BUILDING CONSTRUCTION OF FRAME-WALL STRUCTURES; CORRELATION WITH FIELD OBSERVATIONS OF EARTHQUAKE DAMAGE

Co-Chairmen: *J. Benjamin, E. Popov*
Recording Secretary: *J. Hollings*

VII.1 Design of R/C Frame-Wall Structures: Practical and Ideal Methods

DESIGN OF FRAME-WALL STRUCTURES
A. Derecho

DESIGN OF REINFORCED CONCRETE FRAME-WALL STRUCTURES: CRITERIA AND PRACTICAL CONSIDERATIONS
E. Elsesser

EARTHQUAKE RESISTANT STRUCTURAL WALLS
T. Paulay

Contributing Papers:
DESIGN OF R/C FRAME-WALL STRUCTURES
T. Takeda

A PRACTICAL METHOD TO EVALUATE SEISMIC CAPACITY OF EXISTING MEDIUM- AND LOW-RISE R/C BUILDINGS WITH EMPHASIS ON THE SEISMIC CAPACITY OF FRAME-WALL BUILDINGS
H. Umemura, T. Okada
SHEAR WALL RESEARCHABLE ITEMS
J. Meehan

VII.2 Experimental and Analytical Investigations on Elements and Subassemblages of Frame-Wall Structures: Single Walls, Coupled Walls, Frame-Walls, etc.

LABORATORY TESTS OF EARTHQUAKE-RESISTANT STRUCTURAL WALL SYSTEMS AND ELEMENTS
A. Fiorato, W. Corley

VII.3 Importance of Reinforcement Details for ERCBC

Contributing Papers:
IMPORTANCE OF REINFORCEMENT DETAILS IN EARTHQUAKE-RESISTANT STRUCTURAL WALLS
A. Fiorato, R. Oesterle, W. Corley
COUPLING BEAMS OF REINFORCED CONCRETE SHEAR WALLS
T. Paulay

VII.4 Discussion: Panel and Participants

LUNCH

13:30 SESSION VIII FOUNDATIONS AND RETAINING STRUCTURES

Co-Chairmen: *P. Jennings, M. Velkov*
Recording Secretary: *M. Oliva*

VIII.1 Design and Detailing of Different Types of R/C Foundations and Retaining Structures; Determination of Soil Pressure and Design Forces

SEISMIC ROCKING PROBLEM OF RIGID COMPENSATED FOUNDATIONS
L. Zeevaert

Discussion:
I. Idriss

Contributing Papers:
COMMENTS ON STRUCTURE-SOIL INTERACTIONS DURING EARTHQUAKES
L. Wyllie, Jr.
DISCUSSION OF "COMMENTS ON STRUCTURE-SOIL INTERACTIONS DURING EARTHQUAKES"
W. Holmes
CAST-IN-FIELD REINFORCED CONCRETE FOR NEW BUILDINGS - DESIGN OF FOUNDATIONS
S. Teixeira

VIII.2 Discussion: Panel and Participants

14:10 SESSION IX — EXPERIMENTAL INVESTIGATIONS OF REAL BUILDINGS, MODELS OF COMPLETE BUILDINGS, AND LARGE SUBASSEMBLAGES OF BUILDINGS; CORRELATION WITH ANALYTICAL INVESTIGATIONS AND WITH DATA FROM FIELD OBSERVATIONS OF EARTHQUAKE DAMAGE

Co-Chairmen: *H. Aoyama, R. Hanson*
Recording Secretary: *R. Stephen*

IX.1 Real Buildings: Strong-Motion Instrumentation; Dynamic Testing of R/C Buildings

DYNAMIC RESPONSE INVESTIGATIONS OF REAL BUILDINGS
S. Freeman, K. Honda, J. Blume

EXPERIMENTAL INVESTIGATIONS - CORRELATION WITH ANALYSIS
R. Shepherd, P. Jennings

Contributing Papers:
LARGE-SCALE DYNAMIC SHAKING OF 11-STORY REINFORCED CONCRETE BUILDING
R. Mayes, T. Galambos
DYNAMIC BEHAVIOR OF AN ELEVEN-STORY MASONRY BUILDING
R. Stephen, J. Bouwkamp
STRONG-MOTION INSTRUMENTATION OF REINFORCED CONCRETE BUILDINGS
C. Rojahn

BREAK

IX.2 Use of Earthquake Simulators and Large-Scale Loading Facilities

EARTHQUAKE SIMULATION IN THE LABORATORY
M. Sozen

THE EXPERIMENTAL INVESTIGATION ON ERCBC WITH EMPHASIS ON THE USE OF EARTHQUAKE RESPONSE SIMULATORS IN JAPAN
T. Okada

USE OF EARTHQUAKE SIMULATORS AND LARGE-SCALE LOADING FACILITIES IN ERCBC
V. Bertero, R. Clough, M. Oliva

Contributing Paper:
EXPERIMENTAL RESEARCH NEEDS FOR EARTHQUAKE-RESISTANT REINFORCED CONCRETE BUILDING CONSTRUCTION
H. Krawinkler

IX.3 Post-Earthquake Damage Analysis: Correlation of Field Damage Observations with Laboratory Behavior

Open Discussion

IX.4 Discussion: Panel and Participants

19:30 WORKING GROUP MEETINGS

THURSDAY, JULY 14

8:00 SESSION X

DESIGN METHODS AND EXPERIMENTAL AND ANALYTICAL INVESTIGATIONS RELATED TO THE EARTHQUAKE-RESISTANT REINFORCED CONCRETE BUILDING CONSTRUCTION OF PRESTRESSED AND PREFABRICATED STRUCTURES; CORRELATION WITH FIELD OBSERVATIONS OF EARTHQUAKE DAMAGE

Co-Chairmen: *M. Fintel, T. Paulay*
Recording Secretary: *W. Hester*

X.1 Design of Prestressed Structures for ERCBC

DESIGN OF EARTHQUAKE-RESISTANT, PRESTRESSED CONCRETE STRUCTURES
T. Y. Lin, F. Kulka, J. Tai

DESIGN OF PRESTRESSED CONCRETE STRUCTURES
R. Park

X.2 Design of Prefabricated Structures for ERCBC

SEISMIC DESIGN OF PRECAST CONCRETE PANEL BUILDINGS
J. Becker, C. Llorente

AN EVALUATION OF THE STATE OF THE ART IN THE DESIGN AND CONSTRUCTION OF PREFABRICATED BUILDINGS IN SEISMICALLY ACTIVE AREAS OF THE UNITED STATES
R. Englekirk

SOME ASPECTS OF APPLICATION AND BEHAVIOUR OF LARGE PANEL SYSTEMS IN SEISMIC REGIONS OF EUROPE
M. Velkov, D. Jurukovski

Contributing Papers:
EARTHQUAKE RESISTANT DESIGN OF PRECAST CONCRETE BEARING WALL TYPE STRUCTURES - A DESIGNER'S DILEMMA
V. Mujumdar
SEISMIC RESISTANCE VS. PROGRESSIVE COLLAPSE OF PRECAST CONCRETE PANEL BUILDINGS
R. Fuller

X.3 Production and Repair Aspects of Industrialized Buildings

Contributing Paper:
PRODUCTION AND REPAIR ASPECTS OF INDUSTRIALIZED BUILDINGS
W. Hester

X.4 Experimental and Analytical Investigations on Cast-in-Field or Precast Elements and their Subassemblages used in Prefabricated and/or Prestressed Structures for ERCBC

ANALYTICAL AND EXPERIMENTAL STUDIES OF PRESTRESSED AND PRECAST CONCRETE ELEMENTS
N. Hawkins

EXPERIMENTAL INVESTIGATIONS OF SUBASSEMBLAGES OF PARTIALLY PRESTRESSED AND PRESTRESSED CONCRETE FRAMED STRUCTURES
R. Park, K. Thompson

X.5 Discussion: Panel and Participants

BREAK

10:45 SESSION XI USER NEEDS

Co-Chairmen: *F. Knoll, E. Teal*
Recording Secretary: *R. Mayes*

XI.1 Applicability of Presented Research Output; Needs for Integrating Research Programs and for Research and Development by Teams of Researchers and Professionals

EARTHQUAKE RESEARCH AND USER NEEDS
B. Bresler

APPLICABILITY OF EARTHQUAKE RESEARCH FROM THE USER'S VIEWPOINT
L. Wyllie, Jr.

XI.2 Discussion

LUNCH

13:00 OPTIONAL TOUR OF EARTHQUAKE SIMULATOR LABORATORY, RICHMOND FIELD STATION, AND STRUCTURES LABORATORY, DAVIS HALL, UNIVERSITY OF CALIFORNIA, BERKELEY

13:30 WORKING GROUP MEETINGS

19:30 WORKING GROUPS MEETINGS

FRIDAY, JULY 15

9:00 SESSION XII WORKING GROUP PRESENTATIONS

Co-Chairmen: *C. Pinkham, S. Uzumeri*
Recording Secretary: *S. Mahin*

XII.1 Recommendations Presented by Chairman of Each Group

XII.2 Discussion: Panel and Participants

11:30 SESSION XIII SUMMARY

Closing Remarks: *V. Bertero*

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Appendix B

LIST OF PARTICIPANTS

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WORKSHOP ON EARTHQUAKE-RESISTANT REINFORCED CONCRETE BUILDING CONSTRUCTION (ERCBC)
University of California, Berkeley, July 11-15, 1977

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Appendix C

LIST OF WORKING GROUP MEMBERS

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WORKSHOP ON EARTHQUAKE-RESISTANT REINFORCED CONCRETE BUILDING CONSTRUCTION (ERCBC)
University of California, Berkeley, July 11-15, 1977

WORKING GROUP MEMBERS

1. MECHANICAL CHARACTERISTICS AND PERFORMANCE OF REINFORCED AND PRESTRESSED CONCRETE MATERIALS UNDER SEISMIC CONDITIONS

   Chairman: E. Popov
   Recording Secretary: J. Komendant

   W. Black, M. Collins, W. Corley, A. Derecho, R. Englekirk, N. Hawkins, W. Hester, P. Gergely, S. Ghosh, J. Jirsa, R. Park, M. Polivka, R. Preece, J. Mc Dermott, M. Taylor

2. METHODS OF STRUCTURAL ANALYSIS IN EARTHQUAKE-RESISTANT REINFORCED CONCRETE BUILDING CONSTRUCTION

   Co-Chairmen: W. Gates, G. Powell
   Recording Secretary: J. Hollings

   G. Brandow, A. Derecho, S. Freeman, N. Greve, K. Merz, S. Otani, D. Pecknold, C. Poland, L. Selna, J. Tai

3. EXISTING BUILDINGS

   Chairman: R. Hanson
   Recording Secretary: J. Axley

   A. Repairing

      J. Warner (Vice-Chairman), R. Bentson, A. Fiorato, D. Jephcott, F. Knoll, N. Ohmori

   B. Retrofitting

      B. Bresler (Vice-Chairman), T. Okada, R. Preece, E. Teal, J. Wight

4. CAST-IN-PLACE REINFORCED CONCRETE SYSTEMS FOR NEW BUILDINGS

   Chairman: M. Sozen
   Recording Secretaries: R. Klingner, S. Zagajeski, with J. Hollings, L. Malik, M. Oliva, D. Row

   A. Selection of Effective Structural Systems

      M. Fintel (Vice-Chairman), J. Benjamin, P. Gergely, R. Hanson, Y. Yamada

B. Design Criteria

E. Elsesser (Vice-Chairman), H. Aoyama, J. Ferry Borges, R. Park, J. Wight

C. Code Requirements

R. Sharpe (Vice-Chairman), M. Watabe (Vice-Chairman), L. Esteva, J. Lefter, A. Popoff, Jr., H. Shah, S. Uzumeri

D. Design and Analysis

1) Foundations

S. Teixeira (Vice-Chairman), W. Black, N. Donovan, W. Holmes, I. Idriss, L. Wyllie

2) Ductile Moment-Resisting Frames

D. Strand (Vice-Chairman), M. Collins, J. Jirsa, H. Krawinkler, N. Ohmori, T. Okada

3) Frame-Wall Systems

W. Corley (Vice-Chairman), S. Ghosh, T. Paulay, R. Poole, S. Sugano, T. Takeda, E. Teal, E. Zacher

E. Effects of Nonstructural Components

K. Merz (Vice-Chairman), R. Klingner, G. Mc Kenzie

F. Construction and Maintenance Aspects

C. Pinkham (Vice-Chairman), J. Meehan, R. Preece, B. Olsen

5. PRESTRESSED AND INDUSTRIALIZED CONCRETE STRUCTURAL SYSTEMS

Chairman: N. Hawkins
Recording Secretary: M. Oliva

J. Becker, R. Englekirk, M. Fintel, G. Fuller, W. Hester, V. Mujumdar, R. Park, A. Popoff, Jr., R. Spencer, M. Velkov, T. Yamada

6. EXPERIMENTAL INVESTIGATIONS

Chairman: P. Jennings
Recording Secretaries: R. Stephen, R. Mayes

A. Real Buildings

P. Jennings (Chairman), W. Black, S. Freeman, F. Knoll, C. Rojahn, R. Stephen

B. Earthquake Simulators

S. Otani (Vice-Chairman), H. Krawinkler, T. Okada, M. Sozen

C. Loading Facilities

J. Jirsa (Vice-Chairman), A. Fiorato, R. Klingner, N. Ohmori, T. Paulay, S. Sugano, M. Watabe

D. Correlation of Experimental and Analytical Results with Observational Data from Field Inspection of Earthquake Damage

L. Selna (Vice-Chairman), H. Aoyama, J. Benjamin, S. Ghosh, R. Mayes, K. Merz, T. Takeda, M. Taylor, S. Uzumeri, J. Wight

7. PROFESSIONAL USER NEEDS

Chairman: L. Wyllie, Jr.
Recording Secretary: L. Malik

V. Bertero, E. Elsesser, S. Freeman, W. Gates, N. Greve, W. Holmes, F. Knoll, J. Lefter, B. Olsen, J. Scalzi, M. Taylor, S. Teixeira, E. Zacher

8. NATIONAL COOPERATION

Co-Chairmen: P. Gergely, J. Scalzi
Recording Secretary: S. Mahin

J. Becker, M. Fintel, W. Gates, N. Hawkins, P. Jennings, J. Jirsa, J. Mc Dermott

9. INTERNATIONAL COOPERATION

Chairman: J. Ferry-Borges
Recording Secretary: D. Row

H. Aoyama, V. Bertero, L. Esteva, N. Hawkins, P. Jennings, R. Park, J. Penzien, M. Velkov, S. Uzumeri

10. SEISMIC TESTING AND PERFORMANCE

Chairman: W. Corley
Recording Secretary: S. Zagajeski

V. Bertero, M. Collins, A. Derecho, J. Ferry Borges, A. Fiorato, P. Gergely, N. Hawkins, P. Jennings, J. Jirsa, F. Knoll, H. Krawinkler, G. Mc Kenzie, S. Otani, R. Park, T. Paulay, L. Selna, R. Spencer, D. Strand, M. Taylor, S. Uzumeri, J. Wight

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Appendix D

RESEARCH DIRECTORY RELATED TO ERCBC

(compiled from information supplied by participants)

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CANADA

McMaster University, Hamilton, Ontario

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University of British Columbia, Vancouver

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2. Spencer, R. A., "Nonlinear Response of Coupled Shear Walls."

University of Calgary

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University of Toronto

1. Uzumeri, S. M., "Strength and Ductility of R/C Columns with Rectangular Ties."

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JAPAN

Building Research Institute, Ministry of Construction, Tokyo

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Hokkaido University

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Kajima Institute of Construction Technology, Tokyo

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Kyoto University

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