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A RESEARCH AND DEVELOPMENT PLAN FOR UNDERSTANDING AND REDUCING EARTHQUAKE HAZARD TO CONSTRUCTION IN REGIONS OF LOW TO MODERATE SEISMICITY

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A Report to the
National Science Foundation
Research Grant BCS 89-17674

Department of Civil Engineering
University of Illinois at Urbana-Champaign
Urbana, Illinois

February 1990

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based on

The National Science Foundation Workshop

VULNERABILITY OF CONSTRUCTION TO EARTHQUAKE HAZARD

IN REGIONS OF LOW TO MODERATE SEISMICITY

NSF Grant No. BCS 89-17674

9-10 November 1989

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NSF Workshop
Vulnerability of Construction to Earthquake Hazard in Regions of Low to Moderate Seismicity

9-10 November 1989
Urbana, Illinois

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SUMMARY

It is generally accepted that strong ground motion will occur, as it has in the past, somewhere in central and eastern U.S. Furthermore, there is relatively little disagreement in the building professions about the fact that much of the construction in those regions is vulnerable to shaking. However, there is no generally accepted set of procedures for estimating how much of the construction will suffer given a certain ground motion.

This is a report on a National Science Foundation Workshop held to develop a research and development plan toward the definition and reduction of the earthquake hazard in regions of low to moderate seismicity.

A program is outlined for (a) adapting and improving the existing vulnerability-assessment technology to suit the needs of regions with low and moderate seismicity and (b) increasing the competence of building professionals in earthquake-hazard issues of those regions. The program comprises the four components listed below. Percentages of the total resource assigned to each component are indicated in parentheses:

1. Building Inventory (*2%*)

2. Behavioral Research (*50%*)

3. New and Improved Methods for Nondestructive Testing (*18%*)

4. Codes, Design Resources, and Training Courses (*30%*).

Research and development is recommended for building structures made of masonry, concrete, and steel. Earthquake damage to timber structures was considered to be a relatively minor threat to life safety in seismic regions of central and eastern U.S. It is recommended that 50% of total available R & D resources be used for masonry, 30 % for concrete, and 20 % for steel.

For each material type, different research activities and directions are suggested. A five-year program is proposed at an average annual support of approximately $6,000,000. In view of the immense direct and indirect losses possible from an earthquake in Central or Eastern U.S., the recommended support level is based on an estimate of its efficient use by available research and development sources rather than in relation to the cost of construction and lives at risk.

INTRODUCTION

The events that led to the collapse of the elevated portion of Route 880 in Oakland, CA, provide a metaphor for construction in regions of United States with low and moderate seismicity. There was little disagreement about the fact that strong ground motion would occur in Oakland. Among professionals, there was little disagreement that the structure for the elevated highway was vulnerable. However, there must have been disagreement about when and how to fix the structure.

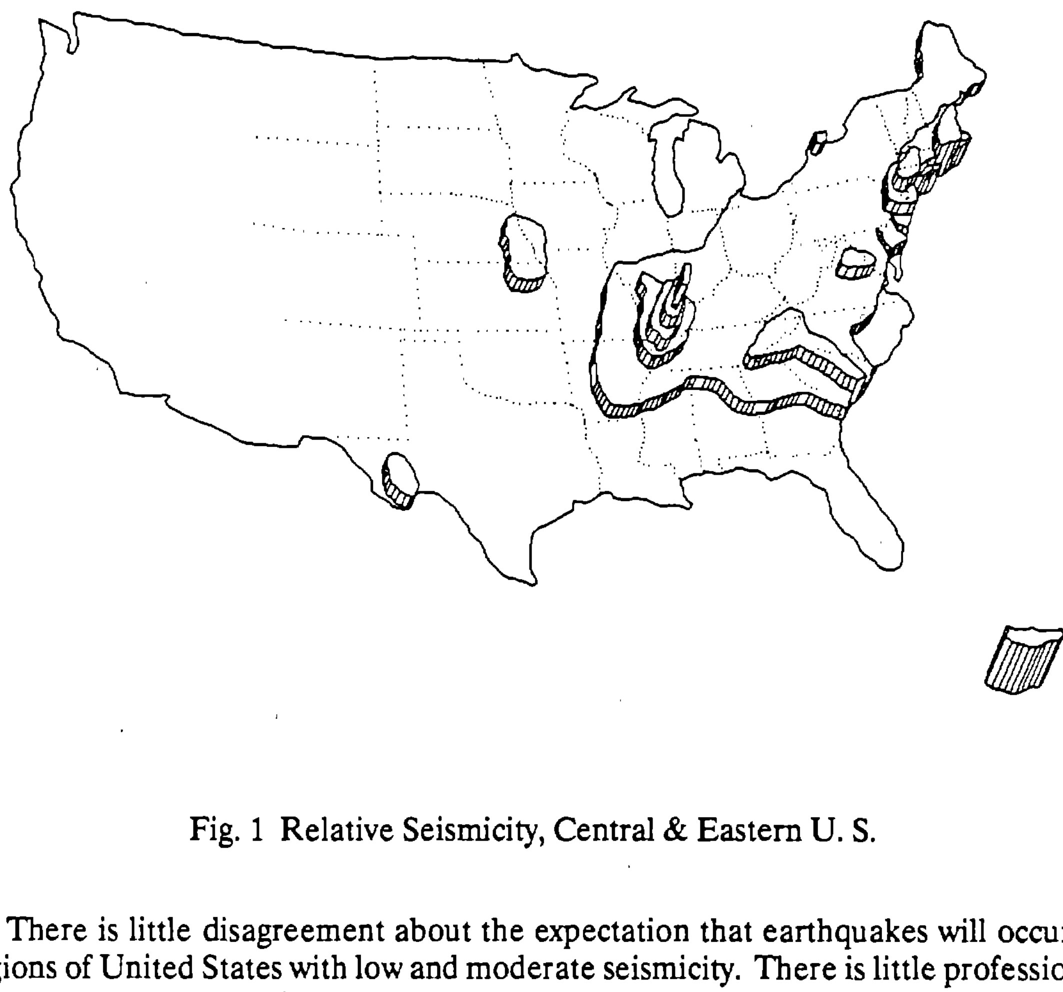


Fig. 1 Relative Seismicity, Central & Eastern U. S.

There is little disagreement about the expectation that earthquakes will occur in regions of United States with low and moderate seismicity. There is little professional disagreement about the fact that much of the construction in those regions is vulnerable to shaking. There is, however, apparent disagreement about how to assess vulnerability and what to do about it.

The disagreement is compounded by the vicious cycle that current methods for evaluating vulnerability are calibrated for regions of high/frequent seismicity. They are binary (options between yes and no are ignored) and tend to exaggerate the risk. An exaggerated risk makes the mitigation costs appear overwhelming. And the perception of an overwhelming cost defers action.

The first essential step toward the implementation of a cost effective program to manage the earthquake risk in central and eastern U.S. is the development of methods suitable for vulnerability assessment of construction in the region and the training of the professional community to use the methods. To outline a research and development program for needed improvements in the practice of vulnerability assessment, a National Science Foundation Workshop was held in Urbana, Illinois, on 9 and 10 November 1989. The workshop brought together a group of 33 professionals, most of them from central and eastern U.S. The focus of the workshop was on structure. Seismological, geotechnical, and architectural issues were not considered directly. Figure 1 provides a qualitative description of the regions considered and their relative seismicities.

In preparations for the workshop, construction was considered in four categories according to the material providing (by design or incidentally) lateral resistance: masonry, concrete, steel, and timber. Discussions during the initial phases of the workshop led to the decision to concentrate on the first three categories. Issues related to buildings with their lateral strength provided by timber were eliminated from the agenda because that type of construction was considered to represent a relatively minor risk during earthquakes to life safety in central and eastern U.S.

The need for research and development toward improvement of earthquake hazard assessment in central and eastern U.S. results from the fact that the current evaluation technology evolved primarily in relation to types of construction and risks in regions of high seismicity. For evaluating buildings in an environment where strong ground motion is frequent, it is justifiable to ignore questions of dynamic response related to structural materials and systems that hold little promise for survival in a great earthquake. On the other hand, in regions where the expected ground motion is moderate, the earthquake has a return period exceeding 300 years, and there exists a large body of construction not designed to resist lateral forces, evaluation cannot afford to be as demanding. For example, it is understandable that unreinforced concrete masonry construction must not remain as built in a region of high seismicity. However, in a region of low seismicity, there may be a valid basis for tolerating existing construction in unreinforced masonry. To rationalize that action, it is necessary to develop evaluation methods for such construction subjected to low or moderate excitation. To develop such methods, behavioral research is required on dynamic response of masonry, a topic summarily and justifiably ignored for research related to needs of highly seismic regions. Parallel examples exist for construction in concrete and steel.

It was the consensus of the workshop participants that a research and development program on evaluation techniques would have a substantial impact on life safety and economical issues related to earthquake risk in regions of low and moderate seismicity by (a) enabling realistic damage estimates, (b) reducing the volume of constructed facilities that would be slated for demolition or strengthening if evaluated on the basis of current practice, and by (c) identifying efficient strengthening techniques.

The research and development plan outlined in the following sections is based on the discussions held during the two-day workshop. The research and development plan is not intended to start from ground level but to enhance and modify the existing evaluation technology to suit needs of regions with low and moderate seismicity and to increase the competence of building professionals working in those regions in the practice of vulnerability evaluation.

A preliminary "building classes" list was developed in order to serve as a framework for discussions during the workshop. The list is included in Appendix A. Summaries of the discussions held during the workshop are in Appendices B and C.

Peer Review

In developing the program outline, it was recognized that the proposed research and development activities would be carried out in the environment of the peer-review system. Topics of research and development were identified in broad categories. The creativity that is a natural part of the peer-review system will identify the specific topics and directions. At the same time, it is expected that peer reviews will prevent, in most cases, unnecessary repetitions of work already done.

Inventory

One of the first if relatively modest requirements for a balanced program of earthquake risk management in seismic regions of central and eastern U.S. is a building inventory that will permit informed decisions about directions of the research and development plan.

It is proposed that the building inventory be developed in several phases with different breadths and depths of coverage. Phase 1 is intended to discover and consolidate existing inventories compiled by Federal and State Governments, trade organizations, insurance firms, and corporations. Activities in Phase 2 will depend on outcome of Phase 1. Its objective is to develop a building inventory that would improve general planning for resource allocation. Phase 3, which may be initiated concurrently with Phase 2, is to provide detailed information about the structural characteristics of buildings in specific locations. Its main objective is to help decide resource allocations to specific research and development projects.

Phases 1 and 2 are to be carried out by research and development organizations using, where convenient, nonprofessional help. Phase 3 must be carried out by engineers with training and experience in earthquake resistant design. It is anticipated that this portion of the program will cost approximately 2% of the total.

Overall Distribution of Resources

In the initial phase of the program, it is proposed that the research and development resources be assigned approximately in the proportion indicated in Fig. 2 to the material types considered. These relative allocations are recommended on the basis of the assumed relative volumes of buildings exposed to risk as well as estimated return, in terms of reducing the risk, on invested resources. They are likely to be changed as the results of inventory surveys become available.

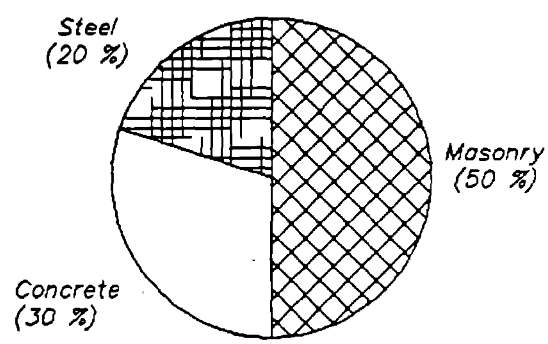


Fig. 2 Distribution to Materials

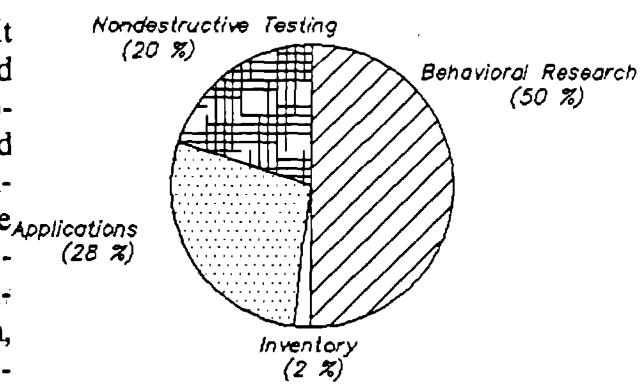


Fig. 3 Distribution to Tasks

Research and Development Activities

The proposed research and development activities are divided into three main categories:

- Behavioral Research
- Improvement of Nondestructive Testing Methods
- Applications

For each building material type, these categories include different tasks, but the objectives for each category are similar.

Behavioral research includes experimental and analytical studies leading to understanding of earthquake response of constructed facilities. Experimental projects may involve tests of materials, structural components, component assemblies, and actual structures (field tests). Experimental projects on response of structural systems are expected to include extensive analytical work with the object of modeling the observed phenomena. The work is expected to be accomplished by a mix of research laboratories (university) and development laboratories as suggested in Fig. 4. It is recommended that approximately one half of the total resources be assigned to behavioral research (Fig. 3).

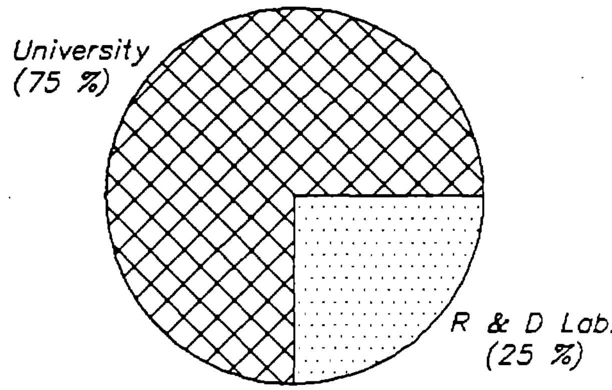


Fig. 4 Distribution to Sources, Behavioral Research

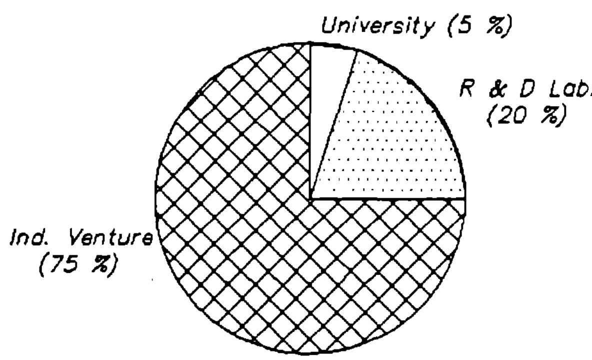


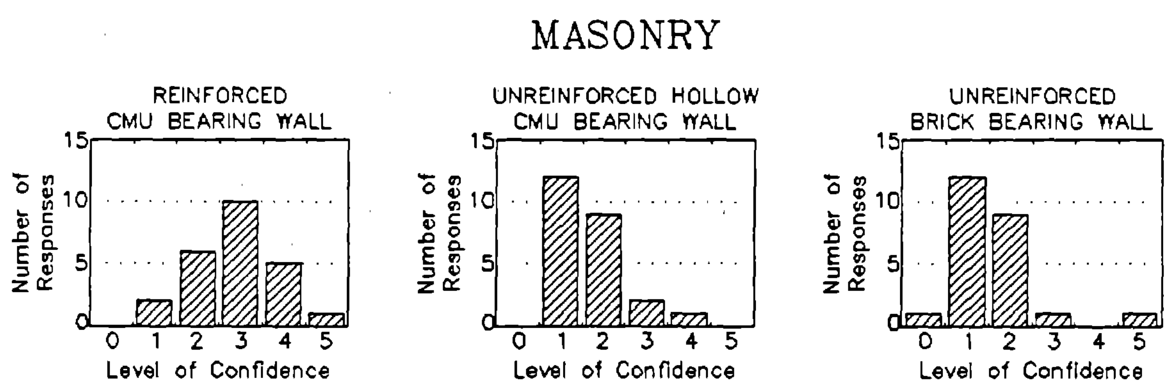
Fig. 5 Distribution to Sources, Nondestructive Testing

Work toward improvements in nondestructive testing is considered to be the proper domain of venture industries encouraged by incentives from federal government. The function of research and development laboratories is seen as one of defining the needs for new and improved techniques and evaluating the venture products. The relative allocation of resources indicated in Fig. 5 is based on that perspective. It is recommended that this component of the program be assigned approximately 18% of the total resources (Fig. 3).

The scope of applications includes development of technical manuals, building codes, and education of students and building professionals. These activities are to be carried out by architectural/engineering firms, professional institutes, and universities. It is anticipated that a substantial portion of the operation will be done by consortia bringing individuals from firms, institutes, and universities together in activities related to design of manuals and dissemination of information. Approximately 28% of the total resources should be assigned to this task (Fig. 3).

MASONRY

In central and eastern U.S., reinforced masonry buildings represent a relatively small portion of the building inventory. Furthermore, a reinforced masonry building is likely



Column "0" indicates no opinion.

Fig. 6 Confidence Level in Vulnerability Assessment,Masonry to pose a much smaller threat in the event of being subjected to an earthquake. And current evaluation methods promise a higher degree of success in identifying vulnerability in reinforced masonry than in unreinforced masonry. Therefore, the emphasis of research and development in vulnerability assessment is placed on unreinforced masonry.

Figure 6 shows the results, for masonry, of an opinion poll conducted before the workshop among the workshop participants. A general lack of confidence is indicated in current methods of practice for estimating degree of damage. That observation coupled with the information that the inventory of unreinforced masonry construction is large in regions of interest leads to the conclusion that it is proper to assign a substantial portion of available research and development resources to unreinforced masonry as indicated in Fig. 2. In the event of a strong earthquake, life and property losses caused by collapse of unreinforced masonry construction are likely to be heavy.

Behavioral Research

Because it has been correctly considered to be unsuitable for highly seismic regions, behavioral research in unreinforced masonry has been meager. There is a considerable amount of work to be done on the fundamental aspects of in-plane response under static and dynamic loading of unreinforced masonry. Much of the work is in the experimental field with appropriate analytical support to generalize the results. The needed work ranges from investigations into basic behavior of solid wall panels to studies of the effects of openings, joints, and mortar quality. Available research on out-of-plane response needs to be enhanced. Opportunities to test to failure actual buildings and their components should be fully exploited. There is a strong need to understand three-dimensional response of unreinforced masonry.

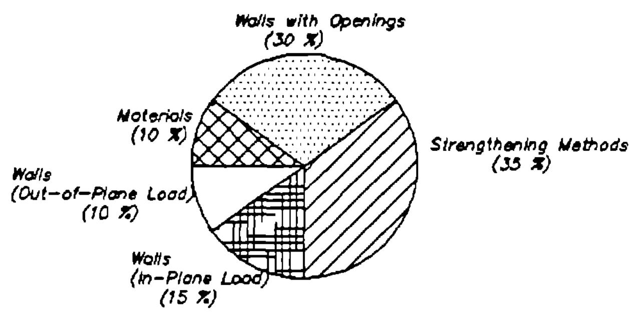


Fig. 7 Distribution of Behavioral Research, Masonry

Because it is believed that a large fraction of existing masonry will require remedial action, it is proposed that some of the research work be coupled directly with work toward methods of repair and strengthening (Fig. 7).

Nondestructive Testing

Methods to determine material properties of in-place block, brick, and mortar need to be improved. Equipment and methods are needed for determining conveniently whether and how in-place masonry is reinforced and for locating wall ties in masonry cladding.

Applications

There is a need for catalogs that define probable characteristics of masonry built during various epochs of construction in the affected regions. The profession should be provided with methods to evaluate the degree of deterioration in existing masonry.

A reference book containing annotated photographs of recurrent cases of damage to unreinforced masonry subjected to moderate and low ground motion would play an important role in the education of the engineering and architectural communities.

Manuals should be developed describing (1) possible load paths for lateral-force resistance, (2) methods of evaluating overall resistance, and (3) probable causes of serious damage. These manuals should also address questions on behavior of diaphragm-wall connections.

CONCRETE

Concern about behavior of low and medium-rise reinforced concrete buildings in regions of low to moderate seismicity arises primarily from the perception that such buildings are seldom designed for lateral loads, they often have bashibazouk framing that does not fit into the canon of framing types for earthquake resistance, and they lack detail needed for continuity. The state of the art for vulnerability assessment of such structures is not that far away from that for unreinforced masonry. Research and development efforts may demonstrate the feasibility of continued use, under certain ground-motion demands, of a substantial portion of the reinforced concrete inventory that would be considered to be unsuitable on the basis of current assessment practice. Figure 8 indicates a measure of the current level of confidence, based on a poll of the workshop participants, in vulnerability assessment for various general classes of construction in concrete.

Behavioral Research

Research is needed on behavior of frames with "typical" details required under various versions of the ACI Building Code. Emphasis on research on earthquake resistance of reinforced concrete has been concerned primarily with structural systems having adequate details and on development of such details. There is very little

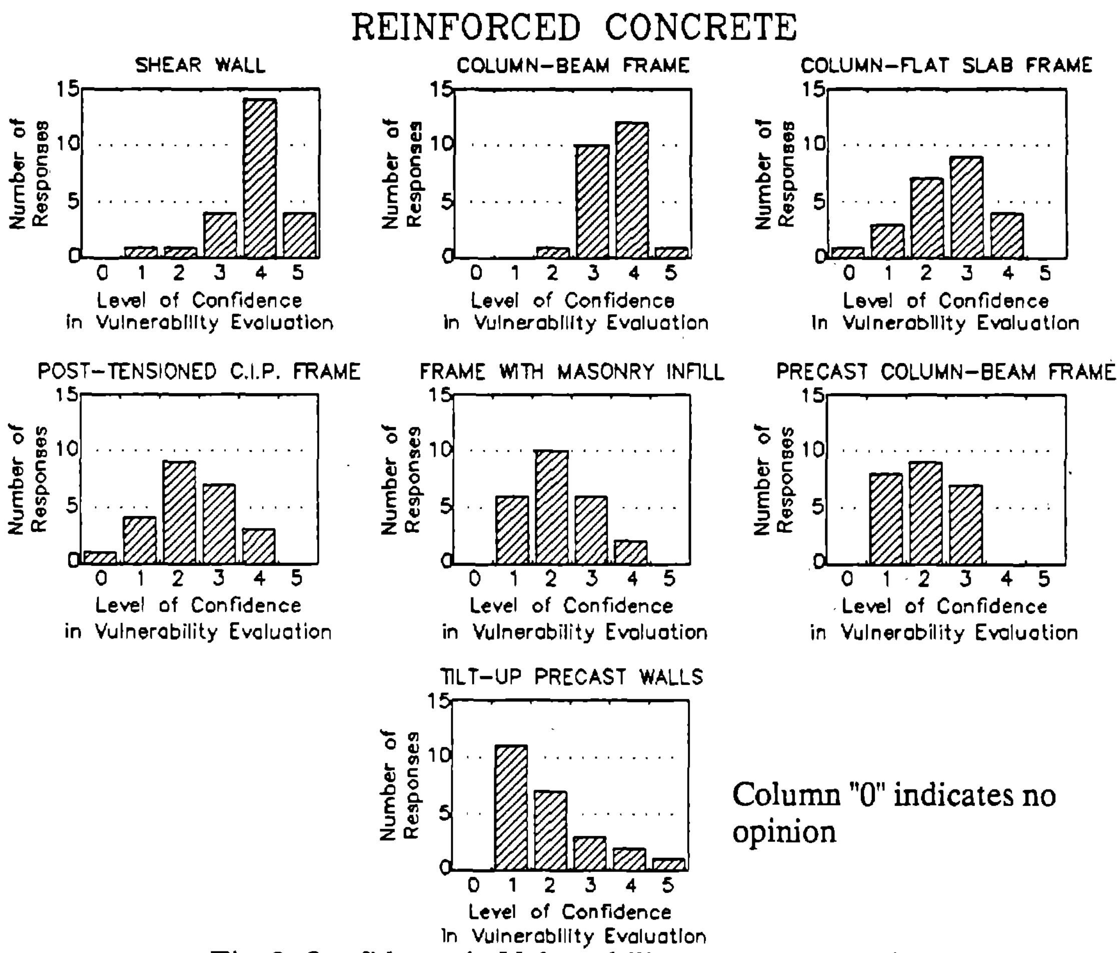


Fig. 8 Confidence in Vulnerability Assessment, RC

experimental information available on behavior under lateral static/dynamic loading of structural systems that would be considered substandard by current concepts of earthquake resistance and their connections.

Precast and post-tensioned systems, especially those with "dry" connections or connections that are not made using cast-in-place concrete, need considerable behavioral research in order to provide the appropriate base of experimental and analytical information for development of evaluation tools.

Frames with masonry infill represent another important topic of needed research. The focus should be on frames with details that are typical for existing construction.

As in the case of unreinforced masonry, tests to destruction of existing construction, whenever there is an opportunity to test a "typical" structure at an appropriate cost, are recommended. Instrumentation of existing buildings to capture strong-motion response is an option that deserves consideration.

Based on the evaluation of confidence in existing practice and estimates of relative populations of construction types, it is proposed that behavioral research and development resources be committed in the proportions shown in Fig. 9.

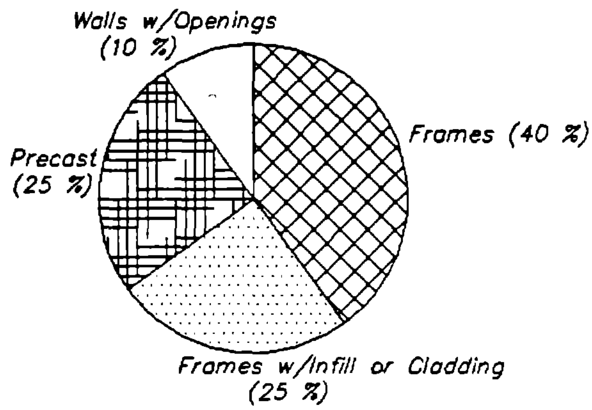


Fig. 9 Distribution of Behavioral Research, Concrete

Nondestructive Testing

To establish the load resistance mechanisms of reinforced concrete structures, it is essential to have reliable information about the arrangement, location, and amount of reinforcement. Industry should be encouraged to develop portable devices that will provide the needed information about reinforcement in an existing building. Combination of existing radar or other technologies with image-processing methods may provide a solution to this important problem.

Methods and devices for determining concrete strength in existing construction should also be improved.

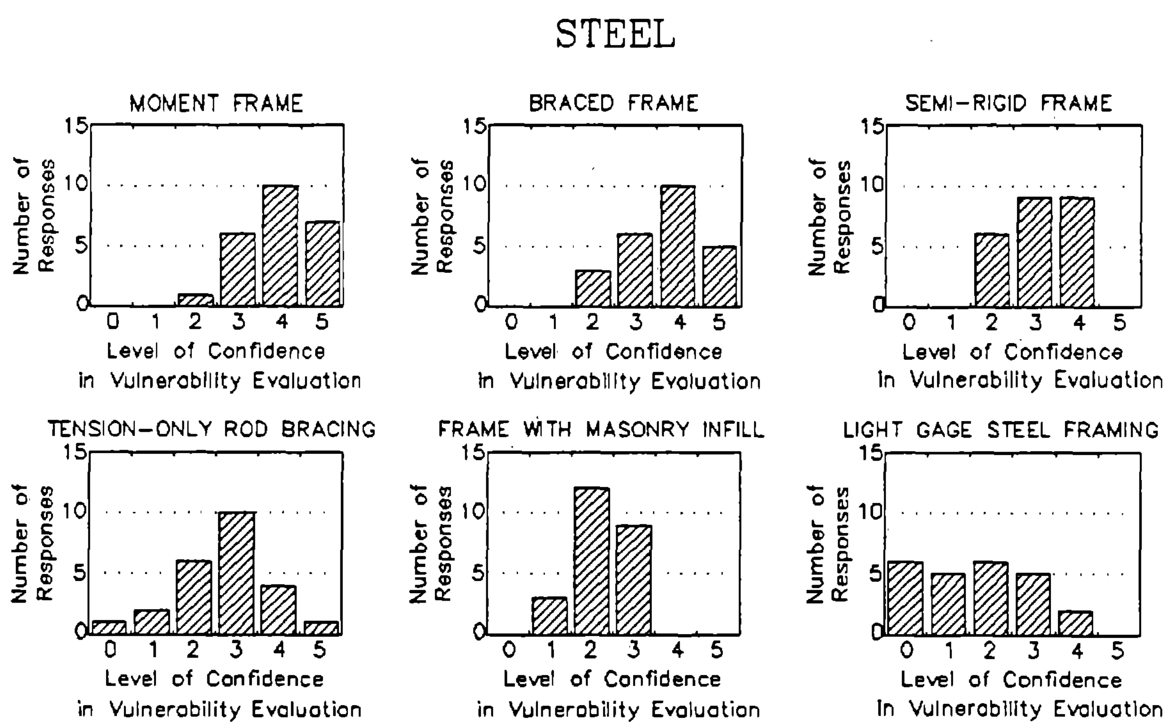
Applications

Because reinforced concrete construction has gone through a rapid and strong evolution, current practitioners are not always in a position to be familiar with the structural details of an existing building. A valuable practical resource for evaluating reinforced concrete buildings is a series of manuals/catalogs that describe the critical structural characteristics and material strength ranges of reinforced concrete buildings built at different times. The manuals should also provide the engineers with procedures of observation and/or testing to determine effects of deterioration as well as alerting the engineer to conditions under which certain types of construction is likely to be susceptible to aging/exposure effects. This series of manuals should be complemented by a set of manuals for detailed evaluation.

As in the case of masonry, effective applications in this topic require education of the professional community as well as the development or re-orientation of courses at universities.

STEEL

Many construction types and details used in central and eastern U.S. have never been evaluated for response to earthquakes. To make improvements in applications, it is essential first to develop information on behavior of such structures under reversals of



Column "0" indicates no opinion.

Fig. 10 Confidence in Vulnerability Assessment, Steel lateral load. Figure 10 shows the results of a poll conducted among the workshop participants to determine their confidence in the success of current practice to evaluate earthquake hazards for steel construction.

Behavioral Research

It is proposed that experimental information, under conditions simulating earthquake effects, be developed on behavior of flexible connections, concrete-encased steel sections, light bracing elements, built-up sections, diaphragm connections, and base-plate connections. Effects of deterioration with age should be considered in the investigations.

Behavior of frames with masonry infill and with attached cladding need to be investigated.

Tests to destruction of actual structures should be conducted.

Nondestructive Testing

Improvements are needed in methods for determining structural properties such as steel type, steel condition, and weld quality.

Because steel structures in central and eastern U.S. tend to be flexible, low-amplitude vibration tests are proposed primarily to raise the consciousness of the engineering community about the likelihood of serious nonstructural damage.

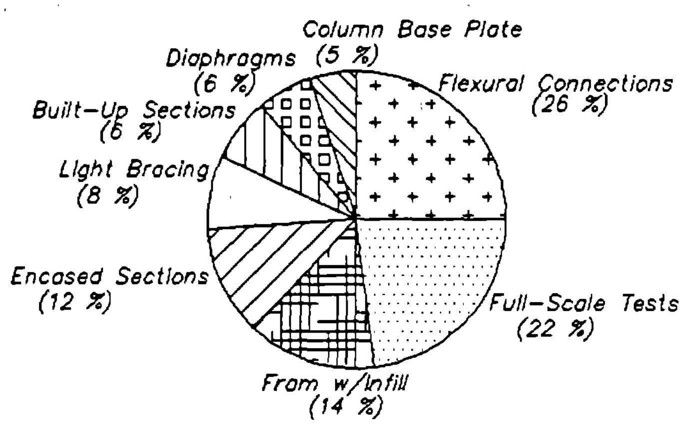


Fig. 11 Distribution of Behavioral Research, Steel

It is proposed that available support for behavioral research be distributed in the proportions shown in Fig.11.

Applications

There is a need for documents containing information on recurring and anticipated structural problems with the types of steel construction used at various times in central and eastern U.S. need to be produced. These documents must also address questions of deterioration caused by age and exposure.

Manuals and supporting courses need to be developed to transmit the technology to practicing professionals as well as to students.

SCHEDULE

The rate of progress of the proposed research and development program depends not only on the availability of support and urgency of the need but also on the capacity of the existing laboratories and professional firms willing and capable to implement the program. Although it is not essential, it is desireable that most of the work, especially the developmental part, be carried out in the regions where the results will be applied. Fortunately, various components of the National Earthquake Hazard Reduction Program have involved many laboratories and firms in central and eastern U.S. The

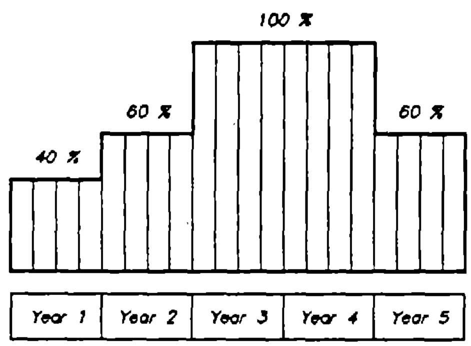


Fig. 12 Schedule

facilities in the region for research and development in problems related to earthquake effects are adequate. The program could be initiated in full size during its first year. But in any such undertaking there are bound to be startup problems as well as redefinitions of the goals. Therefore, it is proposed (Fig. 12) that the program reach its maximum level of $8 million (1989 dollars) in the third year. Whether it is reduced in the fifth year will depend on needs and accomplishments of the first four years. It is important to note that the proposed amount represents a trivial fraction of the cost of the existing construction at risk. The suggested support was based on an estimate of efficient utilization of funds by current research and development sources.

APPENDIX A
CLASSIFICATION OF BUILDINGS

The classification of building structures and questionnaire in Appendix A were mailed to participants before the workshop. The classification was modified as a result of discussions during the workshop.

A PRELIMINARY CLASSIFICATION OF BUILDING STRUCTURES

by

N. Gavlin
10 October 1989

A structure classification system has been developed to facilitate the evaluation of the earthquake hazard in regions of low and moderate seismicity.

Two approaches to structure classification were considered to be significant for this project. Therefore, two different sets of structure classification have been developed.

Each set of structure classification is subdivided into Classes and Subclasses. Classes and Subclasses are then further subdivided into Types. Individual Class Types are intended to represent unique characteristics of the structure classification set.

Individual Subclass Types are intended to be general attributes of the structure classification and are not unique to a particular Class Type. Each Subclass Type may ber applied to more than one Class Type, and each Class Type may have more than one Subclass Type associated with it.

The first classification set outlined on the following pages is based on the characteristics of the structural fraqming system. The Class Types represent possible sources of lateral force resistance. These sources of lateral force resistance could either have been intentionally designed as part of the original structural system, or could be an accidental characteristic of the structural system.

The Subclass Types within the first classification set represent characteristics of the structural framing system that affect the evaluation and effectiveness of the lateral force resisting system.

The second structure classification set is based on the structure function. The Class Types represent different uses and occupancies of structures. The Subclass Types represent different types of structures that may apply to each Class Type.

STRUCTURE CLASSIFICATION

I. STRUCTURAL FRAMING SYSTEMS

A. Classes - Possible Sources of Lateral Force Resistance

1. Steel
   - a. Moment Frame
   - b. Semi-Rigid Frame
   - c. Braced Frame
   - d. Tension Only Rod Bracing
   - e. Frame with Masonry Infill
   - f. Light Gage Steel Framing

2. Reinforced Concrete
   - a. Frame
     - i. Column-Beam Frame
     - ii. Column-Flat Slab Frame
     - iii. Post-Tensioned, Cast-in-Place Frame
     - iv. Precast Column-Beam Frame
   - b. Shear Wall
   - c. Frame with Masonry Infill
   - d. Tilt-Up Precast Walls

3. Masonry
   - a. Unreinforced Masonry
   - b. Unreinforced Reinforced Masonry

4. Wood
   - a. Load Bearing Stud Walls with Diagonal Bracing
   - b. Load Bearing Stud Walls with Shear Walls

B. Subclasses

1. Diaphragms
   - a. Cast-In-Place Concrete
     - i. Composite with Frame
     - ii. Non-Composite
   - b. Precast Concrete
     - i. Topped
     - ii. Untopped
   - c. Steel Deck
     - i. Topped
     - ii. Untopped
   - d. Wood
     - i. Plywood or Diagonal Boards
     - ii. Straight Boards

2. Vertical Force Resisting Systems

   a. Steel Columns and Beams, Cast-in-Place Concrete Slabs
   b. Steel Columns and Beams, Concrete Slab on Metal Deck
   c. Steel Columns and Beams, Precast Concrete Slabs
   d. Steel Columns, Beams and Bar Joists, Shallow Metal Deck, and Concrete Slab
   e. Steel Columns, Beams and Bar Joists, and Shallow Metal Deck (no Concrete)
   f. Concrete Columns and Beams, Cast-in-Place Concrete Floor Framing
   g. Post-Tensioned Concrete Column, Beam, and Slab System
   h. Steel Columns and Beams, Timber Joists, and Deck
   i. Timber Columns, Beams, and Deck
   j. Long-Span Framing Systems

      i. Steel Trusses
      ii. Post-Tensioned Concrete
      iii. Precast Concrete
      iv. Timber

3. Material Properties

   a. Concrete Compressive Strength
   b. Reinforcing Bar Yield Strength
   c. Reinforcing Bar Finish
   d. Prestressing Wire Yield Strength
   e. Structural Steel Yield Strength
   f. Masonry Compressive Strength
   g. Type and Grade of Wood

4. Foundations

   a. Footing
   b. Pile
   c. Drilled Pier
   d. Mat

5. Nonstructural Systems

   a. Partitions
   b. Facade

II. FUNCTION

A. Classes

1. Transportation
2. Educational
3. Medical
4. Residential
5. Governmental
6. Commercial
7. Industrial
8. Emergency Response
9. Utilities
10. Assembly

B. Subclasses

1. Bridges
2. Tunnels
3. Tanks
4. Towers
5. Dams
6. Reservoirs
7. Harbor Facilities
8. Power Plants
9. Buildings

QUESTIONNAIRE
TABLE 1

CLASSES		Confidence Level
Material	**Type**	*Very High Confidence* ↘ 5; *Very Low Confidence* ↘ 1; *No Opinion* → 0 0 1 2 3 4 5
STEEL	Moment Frame	0 1 2 3 4 5
	Semi-Rigid Frame	0 1 2 3 4 5
	Braced Frame	0 1 2 3 4 5
	Tension-Only Rod Bracing	0 1 2 3 4 5
	Frame with Masonry Infill	0 1 2 3 4 5
	Light Gage Steel Framing	0 1 2 3 4 5
RC	Column-Beam Frame	0 1 2 3 4 5
	Column-Flat Slab Frame	0 1 2 3 4 5
	Post-Tensioned C.I.P. Frame	0 1 2 3 4 5
	Precast Column-Beam Frame	0 1 2 3 4 5
	Shear Wall	0 1 2 3 4 5
	Frame with Masonry Infill	0 1 2 3 4 5
	Tilt-Up Precast Walls	0 1 2 3 4 5
MASONRY	Unreinforced Brick Bearing Wall	0 1 2 3 4 5
	Unreinforced Hollow CMU Bearing Wall	0 1 2 3 4 5
	Reinforced CMU Bearing Wall	0 1 2 3 4 5
WOOD	Load Bearing Stud Walls w/ Diag. Bracing	0 1 2 3 4 5
	Load Bearing Stud Walls w/ Plywood Walls	0 1 2 3 4 5
	Load Bearing Stud Walls w/ Plaster Walls	0 1 2 3 4 5

Please mail, after completing this sheet and/or the following sheet to M.A. Sozen, 1245 Newmark, 205 N. Mathews, Urbana, Illinois 61801. No need to identify respondent.

QUESTIONNAIRE
TABLE 2

Complete by inscribing number indicating confidence level, as indicated in Table 1, in the appropriate cell.
The numerals indicate vertical force resisting systems identified →

CLASSES		Confidence Level									
Material	**Type**	1	2	3	4	5	6	7	8	9	10
STEEL	Moment Frame										
	Semi-Rigid Frame										
	Braced Frame										
	Tension-Only Rod Bracing										
	Frame with Masonry Infill										
	Light Gage Steel Framing										
RC	Column-Beam Frame										
	Column-Flat Slab Frame										
	Post-Tensioned C.I.P. Frame										
	Precast Column-Beam Frame										
	Shear Wall										
	Frame with Masonry Infill										
	Tilt-Up Precast Walls										
MASONRY	Unreinforced Brick Bearing Wall										
	Unreinforced Hollow CMU Bearing Wall										
	Reinforced CMU Bearing Wall										
WOOD	Load Bearing Stud Walls w/ Diag. Bracing										
	Load Bearing Stud Walls w/ Plywood Walls										
	Load Bearing Stud Walls w/ Plaster Walls										

Please mail, after completing this sheet and/or the previous sheet to M.A. Sozen, 1245 Newmark, 205 N. Mathews, Urbana, Illinois 61801. No need to identify respondent.

VERTICAL FORCE RESISTING SYSTEMS

1. Steel Columns and Beams, Cast-In-Place Concrete Slabs
2. Steel Columns and Beams, Concrete Slab on Metal Deck
3. Steel Columns and Beams, Precast Concrete Slabs
4. Steel Columns, Beams, and Bar Joists, Shallow Metal Deck and Concrete Slab
5. Steel Columns, Beams, and Bar Joists, and Metal Deck (No Concrete)
6. R.C. Columns and Beams, Cast-In-Place Concrete
7. Post-Tensioned Concrete Column, Beam, Slab Systems
8. Steel Columns and Beams, Timber Joists and Deck
9. Timber Columns, Beams, and Deck
10. Long-Span Framing Systems
    (i) Steel Trusses
    (ii) Post-Tensioned Concrete
    (iii) Precast Concrete
    (iv) Timber

PLEASE NOTE THAT NOT ALL CELLS REPRESENT VALID COMBINATIONS.

APPENDIX B
WORKSHOP SCHEDULE

The workshop schedule and discussion group assignments are presented in the following pages. During the first day of the workshop, the participants formed three groups. As shown diagramatically in Fig. B.1, each group discussed the needs for each of three building materials: steel, concrete, and masonry/timber. Chairs were given a set of questions to start the discussion. After each session, the reporters moved to the next groups that were scheduled to discuss the same materials. For example, after the 10-12 a.m. session, Dr. Foutch joined Group B, Dr. Hanson joined group C, and Dr. McCabe joined Group A.

The workshop participants formed three different groups for the morning session on 10 November 1989. Each discussion group included the chairs and reporters from the 9 November 1989 sessions on the individual materials. Discussions of these three groups were summarized during the general sessions.

NSF Workshop
Vulnerability of Construction to Earthquake Hazard in Regions of Low to Moderate Seismicity

Department of Civil Engineering
University of Illinois

Thursday, 9 November 1989

8:30	**General Session**			**269–273 Illini Union** (South)
	Introductory Comments			
9:30	**Coffee Break**			**269–273 Illini Union** (South)
10:00	**Group Discussions**			
	Group A	**Steel**		**261 Illini Union** (South)
		Chair:	L.W. Lu	
		Reporter:	D.A. Foutch	
	Group B	**Reinforced Concrete**		**211 Illini Union** (North)
		Chair:	R.N. White	
		Reporter:	J.M. Hanson	
	Group C	**Masonry/Timber**		**263 Illini Union** (South)
		Chair:	J.C. Theiss	
		Reporter:	S.L. McCabe	
12:00	**Lunch**			**210 Illini Union** (North)
1:00	**Group Discussions**			
	Group A	**Masonry/Timber**		**261 Illini Union** (South)
		Chair:	D.P. Abrams	
		Reporter:	A.E. Aktan	
	Group B	**Steel**		**211 Illini Union** (North)
		Chair:	I.G. Buckle	
		Reporter:	S.C. Goel	
	Group C	**Reinforced Concrete**		**263 Illini Union** (South)
		Chair:	W.G. Corley	
		Reporter:	A.E. Schultz	
3:00	**Coffee Break**			**269 Illini Union** (South)
3:15	**Group Discussions**			
	Group A	**Reinforced Concrete**		**261 Illini Union** (South)
		Chair:	J.O. Jirsa	
		Reporter:	C.E. French	
	Group B	**Masonry/Timber**		**211 Illini Union** (North)
		Chair:	J.Lefter	
		Reporter:	R.R. Lopez	
	Group C	**Steel**		**263 Illini Union** (South)
		Chair:	K.D. Hjelmstad	
		Reporter:	C.W. Roeder	
5:15	**End of Afternoon Sessions**			
5:30	**Wine and Cheese Reception**			**209 Illini Union** (North)
6:30	**Dinner**			**210 Illini Union** (North)

NSF Workshop
Vulnerability of Construction to Earthquake Hazard in Regions of Low to Moderate Seismicity

Friday, 10 November 1989

8:30	**Group Discussions**			
	Masonry/Timber			**261 Illini Union** (South)
		Chair:	J.K.Wight	
		Majority Reporter:	M.L. Porter	
		Minority Reporter:	J. Millin	
	Reinforced Concrete			**263 Illini Union** (South)
		Chair:	S.L. Wood	
		Majority Reporter:	J.R. Harris	
		Minority Reporter:	A.J. Durrani	
	Steel			**267 Illini Union** (South)
		Chair:	N. Gavlin	
		Majority Reporter:	P.L. Gould	
		Minority Reporter:	J.E. Beavers	
10:30	**Coffee Break**			**322 A&B Illini Union** (North)
11:00	**General Session** Presentations by Majority/Minority Reporters			**322 A&B Illini Union** (North)
12:00	**Lunch**			**Colonial Room Illini Union** (North)
1:00	**General Session** Presentations by Majority/Minority Reporters Discussion			**322 A&B Illini Union** (North)
3:30	**End of Afternoon Session**			

NSF Workshop
Vulnerability of Construction to Earthquake Hazard in Regions of Low to Moderate Seismicity

Discussion Group Assignments

Thursday, 9 November 1989

GROUP A

D.P. Abrams
A.E. Aktan
D.A. Foutch
C.E. French
J.R. Harris
J.O. Jirsa
L.W. Lu
J. Millin
M.L. Porter
J.K. Wight

GROUP B

P.A. Brady
I.G. Buckle
A.J. Durrani
S.C. Goel
W.J. Hall
J.M. Hanson
J. Lefter
R.R. Lopez
R.N. White
S.L. Wood

GROUP C

J.E. Beavers
W.G. Corley
P.L. Gould
K.D. Hjelmstad
S.L. McCabe
C.W. Roeder
A.E. Schultz
M.A. Sozen
J.C. Theiss
J.W. Wallace

.

N.L. Gavlin
S.C. Liu
C.P. Siess

NSF Workshop
Vulnerability of Construction to Earthquake Hazard In Regions of Low to Moderate Seismicity

Discussion Group Assignments

Friday, 10 November 1989

MASONRY/TIMBER

D.P. Abrams
A.E. Aktan
J. Lefter
R.R. Lopez
S.L. McCabe
J. Millin
M.L. Porter
J.C. Theiss
J.K. Wight

REINFORCED CONCRETE

W.G. Corley
A.J. Durrani
C.E. French
B.J. Goodno
J.O. Jirsa
J.M. Hanson
J.R. Harris
A.E. Schultz
C.P. Siess
J.W. Wallace
R.N. White
S.L. Wood

STEEL

I.G. Buckle
D.A. Foutch
J.E. Beavers
N.L. Gavlin
S.C. Goel
P.L. Gould
W.J. Hall
K.D. Hjelmstad
L.W. Lu
C.W. Roeder

*** ***

S.C. Liu
M.A. Sozen

NSF Workshop
Vulnerability of Construction to Earthquake Hazard in Regions of Low to Moderate Seismicity

9-10 November 1989
University of Illinois

QUESTIONS FOR CHAIR

Listed below are a few questions that may be used to start each session. As soon as a "sense" if not the consensus of the group is reached, the reporter should record the result and the chair or one of the members of the group should place another topic in discussion. The list below does not contain all the relevant questions nor is it necessary to address all of them for each building class. The underlying issues are "Do we have a manual or a text book that contains all the information that a nonspecialist engineer needs to make a reliable estimate of the earthquake hazards associated with a given building class?" and "If we do not, what do we need to develop and how should we develop it?"

GENERAL

1. Does the "Classes" list need to be changed?
2. Will an inventory help planning for earthquake hazard reduction?
3. What is the optimum way of developing inventories?
   - Municipal Government
   - State Government
   - Federal Government
   - Census by Mail
   - Aerial Photography
   - Landsat Photographs
   - Other Sources/Means
4. What are the important attributes that should be identified for each building in the inventory?
   - Location
   - Construction Materials
   - Number of Stories
   - Structural System
   - Year of Construction
   - Code used for Design
   - Other
5. What are the main factors for developing a priority list to determine which building classes should receive attention before others?
   - Quantity
   - Criticality
   - Location
   - Efficiency of Fix
6. Priority of Classes (Subclasses)

NSF Workshop
Vulnerability of Construction to Earthquake Hazard in Regions of Low to Moderate Seismicity

FOR EACH CLASS/SUBCLASS CONSIDERED

1. Evaluation by nonprofessionals:
   - Is it feasible?
   - Is it efficient?

2. If evaluation by nonprofessionals is feasible/efficient, how should it be developed?
   - Contracts to practicioners
   - Contracts to R/D institutes
   - Contracts to universities
   - Combinations of above

3. What materials should be developed to enable nonspecialist professionals to make reliable evaluations:
   - Manuals
   - Special Purpose Codes
   - Courses

4. Nondestructive evaluation of material properties:
   - Is it needed?
   - Is it feasible?
   - Is it efficient? (Will it improve evaluation in proportion to effort expended?)
   - What are the current methods/procedures/tools?
   - Are new methods/tools needed?
   - If new methods/tools are needed, how may they be developed?

5. Destructive evaluation of material properties:
   - Is it needed?
   - Is it feasible?
   - Is it efficient? (Will it improve evaluation in proportion to effort expended?)
   - What are the current methods/procedures/tools?
   - Are new or improved methods/tools needed?
   - If new or improved methods/tools are needed, how may they be developed?

6. Nondestructive tests for structural response.

7. Destructive tests for structural response.

8. What type of behavioral research is needed?

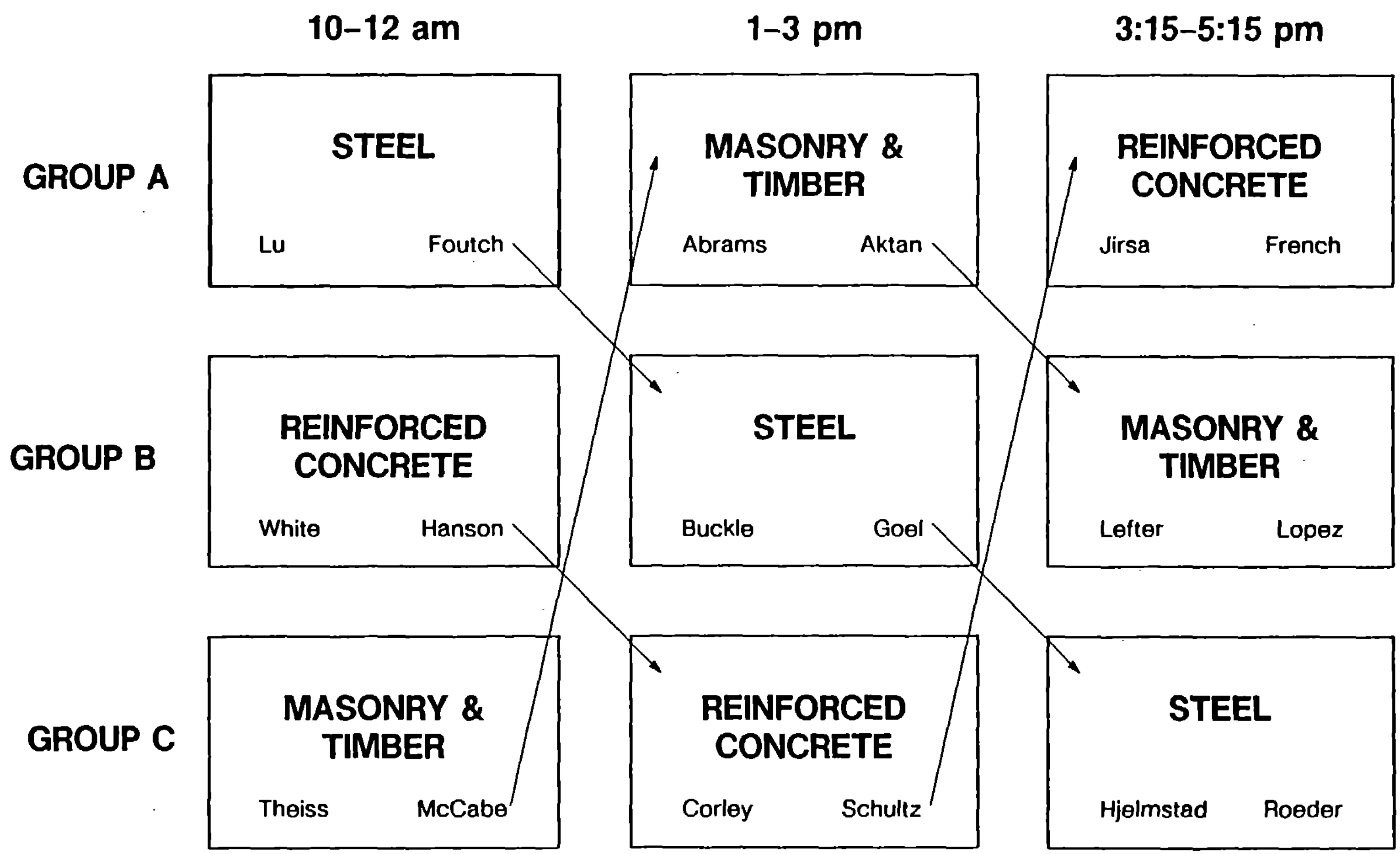


Figure B.1 Discussion Groups – Thursday, 9 November 1989

APPENDIX C
SUMMARY OF DISCUSSIONS

Summaries of the group discussions are presented in this appendix.

MASONRY AND TIMBER

Discussions of 10 November 1989
Reported by J. K. Wight, M. L. Porter and J. Millin

Although timber buildings were included in the discussion, they were deemed to be of little importance for engineered construction in the eastern U.S. Three general topics were covered by the masonry and timber group:

(1) The need for an inventory,
(2) The classification of structural elements within this category, and
(3) Needed research.

Under the heading of needed research, the group defined three general areas (all of the same priority) and then developed some specific topics for these areas. A recommended percentage of dollars to be expended in each area and a rough priority list for the specific research topics were developed. Details are given below.

Because unreinforced masonry buildings were considered to be the major hazard in the eastern U.S., following the group presentation to the workshop audience, a general question was posed to test the importance of the proposed research topics. The workshop participants were asked to estimate how many of the unreinforced masonry buildings in Memphis (for example) would be assessed as being able to survive a code-defined earthquake event. The assessment was to be done by practicing engineers using their existing knowledge. The workshop participants settled on an answer of 25 percent, meaning that 75 percent of the buildings would be judged as inadequate and would require strengthening or demolition.

The workshop participants were then asked to answer the same question, now assuming it five years hence and the proposed research had been completed and had been distributed in the form of manuals, textbooks and the like. The workshop participants now settled on an answer of 50 percent. The significance of this change is that by increasing our understanding of the strength and behavior of unreinforced masonry, the presumed vulnerability of such buildings could be reduced by one-third. Considering the large number of unreinforced masonry buildings in the east, this constitutes a very significant saving of capital investment.

Inventory/Evaluation: A good inventory is required to assess the magnitude of the risk exposure for unreinforced masonry building in the eastern U.S. The survey should have increasing layers of sophistication. Classification: Masonry structures should be divided into two broad groups: reinforced and unreinforced. The only significant timber classification would be its use as a horizontal diaphragm.

Research Needs: The three general categories of research are listed below along with the recommended relative funding levels.

Category	Relative Allocation of Resources
Evaluation Studies	20%
Existing Structures and Components (Behavior and System Response)	40%
Strengthening Solutions (Behavior and System Response)	40%

The funding levels do not represent priorities. None was established. The percentages above reflect the presumed relative funding levels required to obtain significant results in each area.

The following list of more specific research topics are given in order of priority as established by the group.

1. Nondestructive evaluation techniques: Existing methods should be improved and new methods should be developed.

2. Response modeling and dynamic testing.

3. Masonry infill walls and cladding, within reinforced concrete frames and steel frames.

4. Field testing of structures: Both existing and strengthened.

5. In-Plane behavior of unreinforced masonry walls.

6. Structural continuity: Connections and load path considerations.

7. Instrumentation of existing buildings in the east.

8. Behavior of timber diaphragms.

REINFORCED CONCRETE
Discussions of 10 November 1989
Reported by S. L. Wood, J. R. Harris and A. J. Durrani

Five general categories of research were identified as being needed to improve the practicing engineer's ability to evaluate the seismic vulnerability of reinforced concrete structural systems. The categories are listed in the order of relative importance below. Emphasis is placed on evaluation of "ordinary" reinforced concrete construction, which is defined as structural systems that were designed using the vertical load provisions of the governing building code, but do not have the special reinforcement details required in regions of high seismicity.

Development of manuals for evaluation of existing construction: Existing building codes are recognized as being inappropriate means of evaluating ordinary reinforced concrete construction. The procedures are overly conservative for existing, nonductile construction.

The manuals should be written for the nonspecialist professional engineer and should include four main topics: a summary of the behavior of ordinary construction subjected to cyclic loads, quick checks for hazards that require little analysis, aids for detailed evaluation, and a catalog of archaic construction practices.

It is believed that a significant portion of the information required to develop such a manual is currently available in other forms. It is important that the manual be developed in the near future, and be revised as additional information becomes available from the research community. Using the manual to evaluate various type of existing structural systems would be useful to identify areas where future research is needed.

Destructive testing of existing structures: Tests of existing structures offer two distinct advantages: the influence of actual materials is included in the test, and tests can be designed to include the influence of floor diaphragms, infill, and cladding. In-situ tests of existing structures was identified as an appropriate means of evaluating the strength and stiffness of the nonstructural elements and diaphragms. Laboratory tests of components taken from existing buildings could provide detailed information about materials that were used in past and are no longer available and about the effect of aging.

Buildings slated for demolition were identified as a source of much needed information. However, detailed long-term planning is needed to work within tight construction schedules. Funds would have to be available on short notice to take advantage of isolated opportunities.

Development of nondestructive techniques for condition assessment: A major concern in older construction is determining the location, quantity, and condition of reinforcing bars. Current procedures include removing the concrete to expose bars. This approach is time consuming and expensive. The development of a portable device to identify reinforcing bars nondestructively is viewed as an important need. Existing radar techniques combined with advanced image processing were identified as a potential solution. The needed developmental research was identified as being costly.

The existing methods of taking cores to determine the in situ concrete strength was considered to be adequate.

Behavioral research: A preliminary distribution of research funds is indicated below. A building inventory is required to determine the needs within each group.

Ordinary Frames (includes moment frames, shear walls, and cast-in-place post-tensioned construction)	35%
Ordinary Frames with Infill/Cladding	25%
Precast Systems (includes frame and wall systems)	25%
Structural Walls with Irregular Openings	15%

Instrumentation of buildings that are representative of the inventory of buildings in the east: Strong-motion instruments are frequently positioned in new buildings along the west coast. Therefore, no information is available about the behavior of older or ordinary construction during an earthquake.

STEEL

Discussions of 10 November 1989

Reported by N. L. Gavlin, P. L. Gould, and J. E. Beavers

I. Steel design practice east of the Rocky Mountains has employed design methods and details that have never been evaluated for behavior under seismic load.

Included are: semi-rigid beam to column connection design for moment frames
concrete encasement of steel members for fireproofing
tension only diagonal bracing for lateral load
resistance of light one and two story structures
column and beam sections built up of welded, riveted or bolted angles and plates

Research is needed to study these items for their behavior under cyclic loading as individual components, and their effect on the stiffness of the entire building system. All behavioral research should be used to calibrate and improve analytical methods.

In order to be able to evaluate steel buildings it is also necessary to be able to identify structural components, material properties, and the condition of the structure. Current methods of accomplishing this are expensive, time consuming, and require special expertise that is not available to most practicing engineers. It may be possible to develop methods of simple on-site material identification and defect detection.

Items that could be determined on-site are:

steel type
steel condition
member sizes and shapes where obscured by fireproofing
connection types and configuration where obscured by fireproofing
weld quality
actual building frequencies

Finally, methods of educating practitioners to evaluate existing buildings for seismic vulnerability are required. These methods should include manuals and courses. Manuals would identify typical methods of detailing structural steel, potential sources of problems, and methods of evaluating the problems.

II. Resource Allocation

A. Destructive Testing (Overall 57%)

1. Cyclic Tests of Flexible Connections (26%)
2. Full Scale Tests (22%)
3. Steel Frames with Masonry infill (14%)
4. Concrete Encased Steel Sections (12%)
5. Light Bracing Elements (8%)
6. Cyclic Tests of Built-Up Sections (7%)
7. Diaphragm Connections (6%)
8. Column-Base Plate Connections (5%)

B. Nondestructive Testing (Overall 24%)

1. Dynamic Properties (58%)
2. Methods of Evaluating Materials and Existing Conditions (42%)

C. Manuals and Education (Overall 19%)

Discussions of Group C
9 November 1989
on
MASONRY AND TIMBER
Session No. 1
Reported by S. L. McCabe

Discussion of the group concerned masonry and the philosophy of how to define the problem. There was a spirited debate that led to majority and minority opinions. A clear consensus was not really reached, however, the following items were defined:

1. Classification System

The group generally accepted the proposed classifications. Some concern was voiced that masonry should only be reinforced versus unreinforced categories.

A discussion of including the building function also was conducted. No clear consensus was reached, however, some consideration of "life safety" from a society standpoint was considered to be needed. Essential services (fire stations, hospitals, hazardous chemical facilities) etc. should be considered in the classification scheme.

2. Inventory

A clear majority favored a form of reliable inventory of how many types of building forms are present in the Eastern United States - as well as the numbers of unreinforced masonry structures.

The inventory would be phased as follows:

Phase 1 - A survey of available information from building departments, insurance companies etc. to assess the existing data. A detailed survey would be conducted by nonprofessional personnel to accumulate the data. This phase would be overseen by engineers. Some statistical sampling could be performed to ensure that the survey results were accurate - this to be done by engineers.

Phase 2 - A detailed survey of a selected number of unreinforced buildings to determine the actual details of construction, condition of masonry etc. This would permit the survey of Phase 1 to be supplemented by a detailed evaluation so as to make the Phase 1 survey more useful - without an enormous expense in Phase 1. Evaluating is to be done by engineers but not necessarily by earthquake specialists.

Phase 3 - An in-depth survey of a small number of significant types of those structures identified in Phases 1 and 2. This phase to be performed by dynamics specialists together with the engineers involved in the earlier phases.

The emphasis in this phase would be to determine the behavior, and evaluate the behavior, of these limited number of buildings. The result would be as accurate an assessment of these structures as possible. Obviously, this would require time and resources and would involve state-of-the-art methods.

These three phases would be integrated so as to provide a quantifiable basis for determining

- how big the problem is (number of unreinforced masonry buildings)
- how well would "typical" unreinforced masonry structures would do.

A minority opinion developed against this approach. The objection centered on the value of the survey and the relevance of the data that could be gathered. The various types of structures and the low to moderate risk in the east may not justify the expense.

Another problem with the survey is that improperly done, the statistics could be seriously flawed.

It was pointed out that pilot studies by FEMA, ATC, and the US Post Office provided starting points. Whatever the process, the available data and procedures should be organized and used as a starting point.

3. Research Needs

A consensus developed that not enough is understood about dynamic response of unreinforced masonry. The research must provide basic data on unreinforced masonry behavior, connections, state of repair etc. From the additional knowledge of behavior, the judgment of the behavior and how well a structure can perform its job.

Another area mentioned was strengthening options. Additional research into new repair/strengthening options should be conducted.

Some discussion occurred in a variety of other areas such as need for study of diaphragm action, structural connections of floors to walls and the amount of gravity loads placed on the masonry elements.

No discussion of timber occurred.

Summary

It was agreed that more information on behavior is definitely needed. There is a lack of basic understanding of behavior as well as a lack of capability to evaluate earthquake resistance of unreinforced masonry structures. The inventory, if properly done, could significantly aid in defining the problem as well as determining what to study.

Discussions of Group A
9 November 1989
on
MASONRY AND TIMBER
Reported by A. E. Aktan

Problems exist with unreinforced masonry. We must develop a proper survey technique and develop a research agenda to investigate unreinforced masonry.

Some individuals suggested adding "reinforced brick" to the class list, it was determined to simplify the list to just "reinforced versus unreinforced masonry". These categories include brick.

The primary comment with respect to general issues was the suggestion of a simplification of the classes list. Rather than identify every permutation in the classes list, two types of systems should be identified: (1) Lateral load resisting systems and (2) Gravity load resisting systems. The determination of these systems would be made by pulling out the appropriate structural system from two tables. One table would list the vertical elements or frame type, and the second table would list the diaphragm type.

Priority of Classes (Subclasses) - Vulnerability

Unreinforced masonry (multistory)

Instrument existing buildings (at least get wind loads)

Build weak buildings in highly seismic regions

Interested in 3-D box action or 1-D behavior?

Flexible floor diaphragms versus stiff diaphragms

Nondestructive tests to determine if structure is well-reinforced or reinforced at all, also is grout good, and bars lapped?

Timber structures- importance with deterioration of the wood and the performance of the connections.

For Each Class/Subclass Considered:

Nonprofessionals should provide information only for a "general" inventory. They would not be able to detect whether the system is reinforced or unreinforced. It may be possible to utilize information from insurance policies.

It was thought that the insurance companies would be interested in developing an inventory regarding the evaluation of structures and may even contribute to the funding as well as the database. Also of use for the inventory of masonry buildings would be information from the U.S. Masonry Institute.

It is extremely important to know whether or not a masonry wall is reinforced. Consequently NDT would be extremely valuable for such information.

The detection of voids between wythes of brick or block is important, as well as, a condition assessment of the grout used around the rebar and corrosion condition of rebar. It was noted that there is a corrosion problem with any kind of veneer.

The level of vertical compressive stress in masonry walls is useful in evaluating the systems.

Other items: condition of wall anchors, out-of-plane bending strength, and in-plane shear strength.

Also of importance is the detection of rot or deterioration in timber.

Destructive tests may be required to verify the quality of grout, and the length of lap splices. Some destructive testing is also required to calibrate the nondestructive tests.

What type of behavioral research is needed:

There is a need for destructive tests to determine structural response. Existing masonry buildings should be instrumented. Building officials should be made aware of the need for tests. Structures to be demolished should be identified and load tested to obtain information on the lateral load resistance.

Discussions of Group B
9 November 1989
on
MASONRY AND TIMBER
Reported by R. R. Lopez

Session starts with Dr. Aktan reading his report. Group A has proposed a different classification of structures, which consists of:

A. General categories

1. Vertical elements
2. Horizontal elements

These can be subdivided into two subcategories:

a. Lateral load resistant components of building
b. Vertical load resistant components of building

B. Other issues

1. Footings
2. Nonstructural components (cladding, etc.)
3. Building configuration (plan and elevation)
4. Proximity to other buildings
5. Materials

Question of for whom are we developing the evaluation is posed. Refer to first paragraph on "QUESTIONS FOR CHAIR": "Do we have a manual or a textbook that contains all the information that a nonspecialist engineer needs ...". The answer is that we are working on an evaluation method for a nonspecialist engineer. It is pointed out that above (Group A) classification has to be done by a professional.

Dr. Aktan continues his report with a list for nondestructive evaluation of material properties (means of location of reinforcement; ways of detecting rot and other degradation in timber; ways of determining levels of compressive stress in masonry; condition assessment of masonry; wall anchors; out of plane flexural strength of walls). Group B adds anchorage of cladding and veneer to rest of structure as a research topic. Also, masonry in the east has very little reinforcement so we should concentrate on unreinforced masonry. Rotten timber can be detected by visual inspection.

It is suggested that buildings about to be demolished offer a good research opportunity. Important point: find economical ways to reinforce masonry buildings. End of report by Aktan.

Most members of Group B agree with the proposed classification if it is used for teaching purposes because it has less possible combinations. Old and new classifications will be similar for many types of buildings.

Do we need research on behavior of masonry walls? Yes

Do we need to consider timber houses? Have to consider flexibility of horizontal timber diaphragms.

Suggest destructive tests on cavity walls filled with some material.

To the question of if we should use evaluation methods developed for California or develop new methods, answer is we should at least try the expanded ATC-14. East buildings are likely to be different than buildings on the west.

Do we need an inventory? Yes, in order to know conditions of critical facilities and to determine magnitude of the problem.

Foundations are difficult to determine by visual inspection.

Need to know behavior characteristics of masonry walls and how to strengthen them so that collapse is prevented. A measure of strength of a masonry building is wall area divided by plan area.

Importance of bringing the problem of vulnerability of buildings to the attention of public and decision makers.

Research on tanks containing hazardous waste important.

Facade walls important.

Our work should be to develop technical evaluation for engineers and public awareness

Discussions of Group B
9 November 1989
on
REINFORCED CONCRETE
Reported by J. M. Hanson

Introductory Discussion
Considered whether we really have a problem with vulnerability of construction subjected to earthquake hazards. Consensus was that we need to be concerned about vulnerability, and that connections, redundancy and deterioration were factors to be considered.

General Questions

Agreed that classes were appropriate, but it was felt that "attributes" needed to be considered for classes to assess confidence of our capability of evaluating each class.

Importance of whether original design considered lateral loads was recognized.

One person felt strongly that a non-engineered class was needed.

Strong agreement that an inventory was needed. Should be developed by regions.

Felt that many ways needed to be used to develop the inventory. Could an agency such as FEMA manage such an effort?

Attributes need to include soil conditions, exposure or environment, connections and redundancy. However, the group found it difficult to define redundancy in buildings. Other features may be important, such as garage in a house. Also need to consider facade.

Question of whether a "mixed" class was needed was raised.

Felt that developing a priority list should also consider degree of occupancy, usage and cost. One person felt that remaining life should be considered.

Questions Considering Each Class/Subclass

While one person felt that evaluation by non-professionals could be part of the process, consensus of group was that it was not feasible.

Value of manuals and courses was recognized, but doubt was expressed about special purpose codes. Understanding of life-safety issues needed and important. Should build on ATC documents.

Felt that nondestructive and destructive evaluation needed to be broadened from material properties to condition assessment.

Value of improved pulse-echo techniques was recognized. Bring in technology from other professions.

General feeling was that "forced response" tests only identify gross faults. Need to be coupled with system identification package.

Need for behavioral research on integrity of joints and on ductility was pointed out.

Discussions of Group C
9 November 1989
on
REINFORCED CONCRETE
Reported by A. E. Schultz

1. A summary was presented by J. M. Hanson on the discussion on Reinforced Concrete of Group B .

2. M. A. Sozen reminded the Group C participants that they had previously concluded that reinforced masonry buildings were not a seismic risk to be reckoned with east of the Rockies. He then asked the group if reinforced concrete buildings, by the same token, would be considered to be safe.

(a) J. M. Hanson stated that aging and deterioration has affected the structural integrity of many r/c buildings rendering them a high risk.

(b) P. Gould added that many older r/c buildings were designed to codes that are no longer considered adequate.

(c) Finally, M. A. Sozen summarized the sentiment of many of the Group C participants by stating that structural engineers had taken many challenges, in reinforced concrete building construction, that have not been taken with reinforced masonry, such as multistory flat plate building construction.

(d) M. A. Sozen suggested that attention should be focused on low-rise and mid-rise buildings (up to 10 stories), but not on high-rise construction.

3. Initially the discussion digressed to the ability of many practicing engineers to conduct seismic evaluations of existing buildings.

(a) M. A. Sozen indicated that a significant investment would have to be made to retrain engineers.

(b) J. M. Beavers indicated that many engineers in the Eastern U.S. have an inadequate background in earthquake-resistant design.

(c) P. L. Gould added that this problem should be addressed through continuing education programs.

(d) W. G. Corley thought that though most engineers will need training, the training need only encompass low-rise construction because 96% of most existing r/c buildings have four stories or less.

4. The discussion continued by addressing the classifications presented in Table 2.

(a) J. Theiss stated that the classifications for lateral load resisting systems was not compatible, in all cases, with those for gravity load resisting systems.

(b) The group agreed that within the classifications listed are not sufficient to accurately describe mixed construction. However, subsets to the classifications listed in Table 2 can be developed at a later time to include buildings of mixed construction, and the classification was allowed to remain intact.

(c) M. A. Sozen asked the group to decide, for each classification listed in Tables 1 and 2, if the existing knowledge base is sufficient to enable seismic evaluation. If not, the group needs to decide how much effort and resources need to be spent to increase the knowledge base.

5. The group agreed that an inventory of existing buildings is of utmost importance. However, such an inventory is time-consuming and must be conducted by well-trained engineers.

6. For each classification listed in Table 1, a brief discussion was used to decide if the existing knowledge base is sufficient.

(a) Column-Beam Frames

If the questions of age, deterioration and inadequate details (of reinforcement) are eliminated, it was agreed that the existing knowledge base of column-beam frames is sufficient. W. G. Corley added that existing documents (such as building codes) are too conservative, i.e. many nonductile frames will perform better than what existing building codes imply. The group decided that additional effort needs to be expended on considerations of aging, such as deterioration, and inadequate designs and details for older buildings that were designed to codes that are no longer current.

(b) Column-Flat Slab Frames

After much debate, the members of the group did not appear to agree on the amount of research available on column-flat slab frames. There was a strong sentiment to develop tools and manuals for effects of aging and exposure. Catalogs should be developed informing practicing engineers about reinforcing schemes and materials to be expected in structures built in different decades.

(c) Post-Tensioned Cast-in-Place (C.I.P.) Frames

The group agreed that the knowledge base on post-tensioned C.I.P. frames is very limited, and that the existing inventory is large. It was concluded that a great need exists for extending the knowledge base on dynamic response of such structures.

(d) Precast Column-Beam Frame

J. M. Hanson made a distinction between precast frames with dry connections (welded or mechanical) and those with wet connections (cast in place). J. M. Hanson pointed out that precast frames with dry connections have tended to perform poorly under gravity loads. The group agreed that the knowledge base was very limited and that the inventory was large. It was concluded that additional information on behavior needs to be developed and the emphasis should be on precast frames with dry connections.

(e) Shear Wall Buildings

The group expressed a reasonably high degree of confidence in state of the art with respect to evaluation of this classification. However, it was agreed that additional information is needed on irregular shear wall buildings, i.e. those with openings, changes in profile along elevation, and connections with coupling girders and boundary elements.

(f) Frame with Masonry infill

The group agreed that a large amount of research was needed to extend the existing knowledge base. This classification encompasses a large variety of structural systems. Little is known about the effect of infill on building response: When does it help? When is it detrimental? How long will the infill remain in place?

(g) Tilt-Up Precast Walls

The group agreed that except for the Denver area, the population of tilt-up precast buildings was small (east of the Rockies). Furthermore, these buildings usually have a low occupancy. While past performance is contradictory and little confidence was expressed on our ability to evaluate such buildings, the group assigned a low priority to this classification.

7. After a brief discussion, the group agreed that financial resources ought to be spent on the following four items:

(1) "friendly manuals" on column-beam frames, flat slab frames, and shear wall buildings,

(2) research on post-tensioned C.I.P. frames,

(3) research on precast column-beam frames,

(4) research on frames with masonry infill.

(a) The "friendly manuals" ought to be easy-to-use manuals guiding engineers on the evaluation of existing buildings. The scope of the manual(s) was limited to column-beam frames, flat slab frames and shear wall buildings because insufficient information was available on the other classifications.

(b) For every dollar spent on these 4 items, $ 0.40 ought to be spent on the manuals. The remaining $0.60 ought to be allocated to the remaining three items roughly according to the inventory.

8. The group agreed that evaluation by nonprofessionals was not feasible. While some data could be gathered by nonprofessionals, evaluation requires the judgment and knowledge of an engineer.

9. Discussion turned to nondestructive and destructive evaluation techniques.

(a) P. L. Gould indicated that the NDE technology in the aerospace industry ought to be monitored, and those techniques which hold promise for NDE of r/c buildings ought to be studied in more detail.

(b) W. G. Corley informed the group that radar-imaging technology is a the threshold of being able to view r/c structures internally.

(c) The group agreed that better techniques, including the previously mentioned radar-imaging technique, are needed to determine the location and configuration of reinforcement in existing structures.

(d) The group also agreed that money need not be spent on techniques (destructive or nondestructive) for determining material properties.

(e) The group also agreed that full-scale structural tests are needed.

10. The group concluded that financial resources should be spent on the following items:

(1) developing an inventory of existing r/c buildings east of the Rockies,

(2) non-destructive evaluation, particularly those techniques for determining the location and configuration of reinforcement,

(3) destructive testing techniques.

For every dollar spent on these items, $ 0.40 ought to be spent on item 1 (inventory), $ 0.50 on item 2 (non-destructive) evaluation techniques, and $ 0.10 on item 3 (destructive) evaluation techniques.

Discussions of Group A
9 November 1989
on
REINFORCED CONCRETE
Reported by C. W. French

General:

1. **Does the "Classes" list need to be changed?**
   Yes.

I. Structural Framing Systems

A.1 Lateral Load Resisting Systems

A.2 Vertical Load Resisting Systems

[For A.1 and A.2 choose frame (vertical) and diaphragm systems from Tables 1 and 2, respectively.

Table 1 - Frame (Vertical) Systems

1. Steel
   a. Moment Frame
   b. Semi-Rigid Frame
   c. Braced Frame
   d. Tension Only Rod Bracing
   e. Frame with Masonry Infill
   f. Light Gage Steel Framing

2. Concrete
   a. Frame
      i. Column-Beam Frame
      ii. Column-Flat Slab Frame
      iii. Post-Tensioned, Cast-in-Place Concrete Frame
   b. Shear Wall
   c. Frame with Masonry Infill
   d. Precast
      i. Frames

   (1) Joints emulate monolithic r/c (factory cast)
   (2) "Jointed" precast (failure in field-constructed joints)
   some systems may not have continuity at joints

      ii. Precast Wall Panels
      (incl. multistory precast wall panel buildings and tilt-up)

3. Masonry
   a. Unreinforced
   b. Reinforced

4. Wood
   a. Load Bearing Stud Walls

Table 2 - Diaphragms

1. Cast-in-Place
    a. Composite with Frame
    b. Noncomposite

2. Precast
    a. Topped
    b. Untopped

3. Steel Deck (untopped)

4. Wood
    a. Plywood, Diagonal Board
    b. Straight Board

[Include horizontal in diaphragm section bracing]

B. OTHER ISSUES

1. Foundations
    a. Footing
    b. Pile
    c. Drilled Pier
    d. Mat

2. Remainder of Structural System
    a. Nonstructural Elements
    b. Cladding

3. Layout/Geometry
    a. Horizontal
    b. Vertical
        i. Irregularity with Height
        ii. Composite construction
        (e.g. steel frame upper stories, concrete frame lower stories)

4. Materials
    a. Concrete Compressive Strength
    b. Rebar Yield Strength
    c. (etc. as given in original list)

5. Contents
    a. Hazardous
    b. Fragile

6. Proximity to Nearby Structures
    a. Pounding
    b. Adjoining Structures with Different Floor Heights

2. **Will an inventory help planning for earthquake hazard reduction?**

    Yes.

3. **What is the optimum way of developing inventories?**

    Municipal/State/Federal Government
    Insurance Records, Sanbourne Map

4. **What are the important attributes that should be identified for each building in the inventory?**
   Location
   Construction Materials
   Number os Stories/Size
   Structural System
   Year of Construction (implies code used for design)
   Cladding
   Microzonation
   Occupancy
   Structural Condition

5. **What are the main factors for developing a priority list to determine which building classes should receive attention before others?**
   Quantity (economics, life)
   Criticality
   Expected Performance
   Life Safety, Production, Function
   Consequence of Nonperformance
   Site
   Efficiency of Fix
   Don't know performance of building
   Don't know how to fix building
   Don't know performance of fix
   Risk sufficient to warrant cost?
   For R/C Buildings in Particular - System is greatly influenced by its large mass. Therefore, low-rise precast is as much of a hazard as unreinforced masonry because of the mass.

6. **Priority of Classes (Subclasses) - Vulnerability**
   Depends on outcome of inventory and research topics listed below in item 8.

For Each Class/Subclass Considered:

1. **Evaluation by nonprofessionals?**
   Nonprofessionals cannot evaluate, however they can contribute to the development of the inventory or database (Location, Construction Material, Year Built,) with the exception of the identification of the lateral load resisting system.

2. **If evaluation by nonprofessionals is feasible/efficient, how should it be developed?**
   Not applicable.

3. **What materials should be developed to enable nonspecialist professionals (registered engineers) to make reliable evaluations?**
   Manuals
   For R/C Buildings in Particular - Develop manual as soon as possible, giving as much information as possible on precast systems (connections) as well as the cast-in-place systems classified above. As more information becomes available, following research, complete the manual.

NOTE: It is to be emphasized that current codes are design documents and are not the foundation upon which this manual should be based.

Equipment (for nondestructive tests to determine the field condition and location of reinforcement) Extremely important for structural evaluation.

Courses

Require "Certification/Continuing Education Units (CEUs)" for individuals trained to evaluate seismic vulnerability.

4. **Nondestructive evaluation of material properties <u>and structural condition</u>:**
Yes they are required!!!
Extremely important to determine location and size of reinforcement in members and in the joints.
Develop instrumentation to identify reinforcement in elements deeper than current 12 in. limitation of NDT equipment (How do we see inside joint regions??).

Important to determine corrosion condition of external elements (direct application of methods developed for bridge structures are not necessarily applicable to building systems).

Condition of anchors.

NDT Methods are of a very high priority.

New methods should be developed to investigate the items above, perhaps methods developed for other fields (e.g. geology medical, NASA) could be adapted.

New methods might also be developed through support to the Small Business (SBIR) Program.

5. **Destructive evaluation of material properties.**
Cores used to correlate with NDT. No further research required.

6. **Nondestructive tests for structural response.**
Vibration tests of structural systems will not give insight to the quality of details and connections. They will not provide much useful information for the assessment of structural vulnerability. In USSR vibration tests were actually misleading (constructural panels contributed to resistance at low levels of load--gave unjustified confidence).

7. **Destructive tests for structural response.**
Yes, very important!!!!

Demolition - Structures slated for demolition should be tested to failure.
Instrumentation - Find similar building in region which has high rate of seismic activity and instrument it.

Build a "midwest-east coast" structure in region which has high rate of seismic activity and instrument it.

Instrument some existing buildings in midwest and east coast (is it economical considering lower rate of return).

Tests on actual buildings provide information on connections, effect of cladding, soil/<u>foundation</u> effect, represent "existing" construction practice as opposed to models constructed in controlled laboratory conditions, actual details.

Impose enough deformation on the building to take the connections to their full capacity.

Tests can include push-over tests, eccentric mass tests.

These tests would be used to verify analytical models and serve as a "proof test" for similar structural systems.

Include buildings in poor condition (corroded systems).
Systems to be tested include:
multistory precast wall panel systems
untopped precast diaphragm systems

8. **What type of behavior research is needed?**

Type of system to be investigated	Percent of Available Resources
Nonductile frames (without infill)	35
beam-col frames	
slab-col frames	
post-tens. col frames	
Frames with infill (including cladding)	25
Precast systems frames/walls (w. precast floor panels)	25
Irregular walls (with openings/discontinuities)	15

DEPENDING ON THE INVENTORY

Other Comments:

* Consider precast wall panel systems to be a significant part of the building inventory (Denver/Iowa,Illinois/Texas/Minnesota/etc.). Particularly in Denver, multistory precast wall panel buildings are common.

* Issue of details is very important for lateral load resistance.

* Connections may fail in precast systems because of volume changes in the structural system.

Discussions by Group A
9 November 1989
on
STEEL
Reported by D. A. Foutch

5. The main factors for developing a priority list to determine which building classes receive attention before others include:

Expected or typical construction obtained from the inventory.
Consequences of nonperformance.

Steel structures in particular - Frames with masonry infill with facades rigidly attached is an area of which we know little about (West coast construction requires flexible connections between the facade and system).

Important to determine whether the risk justifies retrofit.

6. Priority of Classes (Subclasses) - Vulnerability

Masonry walls on steel frames

Braced frames - details (investigate method of construction--maybe this would be first priority if the construction method is unusual?)

Importance of Foundation effect.

Priority also depends on result of inventory (life dependency)

For each class/subclass considered:

1. Evaluation must be conducted by a professional. The inventory can be developed primarily by non-professionals.

3. Evaluations should be conducted by practitioners. It is extremely important to develop manuals and conduct courses to educate the evaluators. The use of indices to evaluate buildings is very important (as available in ATC Evaluation manuals for west coast). With the indices, some buildings may be classified immediately as low risk. Others will be questionable and must be looked at in greater detail. Requiring a "tiered" approach for evaluation. At the upper tier, would be a detailed analysis by an "expert". There would also be an intermediate tier as a first pass if the structure is considered to be at risk from the initial screening with the indices. Those structures which fail the intermediate tier could be investigated in more detail at the upper tier.

4. Nondestructive tests to determine material properties and structural condition. Nondestructive methods should be investigated and developed. Of particular interest are techniques to "look through" fireproofing. The welds are of particular importance. It was thought that the material properties of the steel itself may not be so critical (not much of a variation) unless there is a problem with deterioration (corrosion). It would also be very nice to determine the condition of type of foundation present to determine if the foundation is adequate to resist the lateral loads.

5. Destructive test methods are rarely needed (except to remove cast-in-place "fire-proofing" to look at welds/connections. Try to avoid this. One individual expresses the concern of an earthquake occurring in a cold climate region--suggested the possibility of brittle fracture.

6. Nondestructive forced vibration was not deemed to be worthwhile. It was though that vibration tests could be used to pinpoint the weak links in steel structures. However, it was deemed to be not feasible except as a research tool. It may also provide some information on foundation compliance.

7. Destructive tests on the structural system were deemed not worthwhile.

8. **What type of behavior research is needed?**

Gravity load systems such as semirigid frames (some of this has been done)

Light gage steel framing

Light gage steel studs with shear panels

Steel masonry infill interaction

The aforementioned items were considered "high pay-off items"

Discussions of Group B
9 November 1989
on
STEEL
Reported by S. Goel

General:
Other important points in addition to the information given by Doug Foutch from Group A-Steel:

The inventory based on soil condition may be important for some areas.

4. **Important attributes that should be identified for each building in the inventory:**

Connections are the most important.

Redundancy
Facade

For Each Class/Subclass Considered:

Evaluation by nonprofessionals is not feasible; it requires trained professionals.

3. **Materials to enable professionals to make reliable evaluations:**

Manuals and courses are required (ATC 14 is good example for manual).

No special purpose codes.

4. NDT evaluation of steel properties and structural data is necessary. It was not known whether feasible, efficient tools are currently available. New techniques are required. NDT checking of connection details could be helpful because in most cases there are no connection drawings available with the plans. The connection details were left up to the discretion of the fabricators. NDT tests should be developed such that fireproofing would not have to be removed. We may be able to borrow technology developed by other industries (e.g. aerospace).

5. Destructive evaluation of material properties is not required. The destructive evaluation of structural components and connections is most needed as there is very little information available from laboratory tests. These tests would be both feasible and efficient. Methods are available. So are capacity and procedures.

6. NDT tests for structural response are not of much value except in special cases such as period dominated response. Such as observed for structures located on soft soils which have 1-1/2 to 4 sec. periods. NDT tests yield information at very low levels of excitation.

7. Destructive tests on structures as assemblies are very valuable and necessary:
   (1) Laboratory tests

   (2) Buildings slated for demolition provide an excellent opportunity for a variety of tests:

      (a) Vibration tests on full structures

      (b) Components of actual connections and assemblies tested in the laboratory.

      (c) Investigation of retrofitting schemes.

   (3) Small scale tests may be used to investigate the global response of systems. Tests on connections and details must be carried out on large-scale specimens.

8. **Behavioral research needed:**

Connections between masonry infill and flexible framing

Tension only rod bracing with strap welds at the end (These have been found to be quite vulnerable in past experience)

Light gage industrial structures

Connectivity between diaphragms and frames

Built-up members - Columns, joists, are very common in older structures.

Compilation and dissemination of research already done on details typical of eastern U.S. practice.

Discussions of Group C
9 November 1989
on
STEEL
Reported by C. W. Roeder

The Group C meeting on steel was the final meeting on steel. S. Goel reported on the results of the earlier meetings on steel.

Previous Meetings

The earlier meetings recommended that the lateral load distribution system (diaphragms) be included with the lateral load system, and that occupancy and building use be included in the inventory and evaluation. They noted that steel frames with infill masonry are not well understood. They indicated that light gage steel systems and tension only X- bracing may perform poorly and be vulnerable. They recommended that nondestructive test procedures are valuable and feasible and should be pursued. They felt that there was no great need for new destructive test procedures for materials but there was great need for destructive component tests. They expressed considerable concern over the uncertain seismic performance of "strap welds" used to attach light tension rods and concrete encased steel sections with old details.

Discussion

It was noted that most eastern steel frames use partially restrained Type 2 or 3 connections. These connections are flexible and weaker than the members. They concentrate the plastic strain and deformations into the connection rather the member. The seismic behavior of these connections is therefore uncertain.

Severe problems are noted with welds and other details. Spliced jumbo sections in tension have had problems. Partial penetration welds are very possible with eastern construction, and this may lead to brittle behavior. It was recommended that a manual be devised to summarize seismic concerns for steel structures, the numerous problems which could occur, and techniques for avoiding them.

It was noted that steel frames are very flexible. Particularly with the flexible connections used in eastern construction. This flexibility may result in much greater damage to the contents of the building during an earthquake. Most engineers do not have a good idea of the natural period of their steel structure, and experimental measurements of the dynamic properties of eastern steel structures are needed.

The group agreed that it was important to do research on encased steel sections and connections. This is particularly important with older structures with concrete encasing used as fire protection. These older components usually do not have adequate calculable strength or ductility to satisfy modern seismic requirements, and the composite action due to encasement may result in more economical rehabilitation or repair. It may also help avoid problems due to overstrength or brittle members.

The group agreed with concern regarding some light bracing systems. They indicated that age deterioration, and the change in design practice should be a major concern in any experimental research.

Recommendations

The group agreed that an inventory was an important element of eastern vulnerability research, and the safety hazard is probably less critical with steel structures than masonry or reinforced concrete. Economics (financial loss, cost of rehabilitation, etc.) are important considerations for steel. In view of this, the group recommended that funds for experimental research be divided in proportion of approximately

Masonry	50%
Reinforced Concrete	30%
Steel	20%
Timber	0%

It was recommended that nondestructive test procedures and inventory for steel structures be pursued as for other systems. Diaphragm research was felt to be generic rather than particular to steel. The experimental research requirements for eastern steel structures were weighted relatively as follows:

Cyclic partially restrained connections	45%
Light bracing systems (X bracing)	5%
Behavior of encased steel sections and connections (particularly older details)	10%
Steel frames with masonry infill	10%
Manual of guidance for steel frames	30%