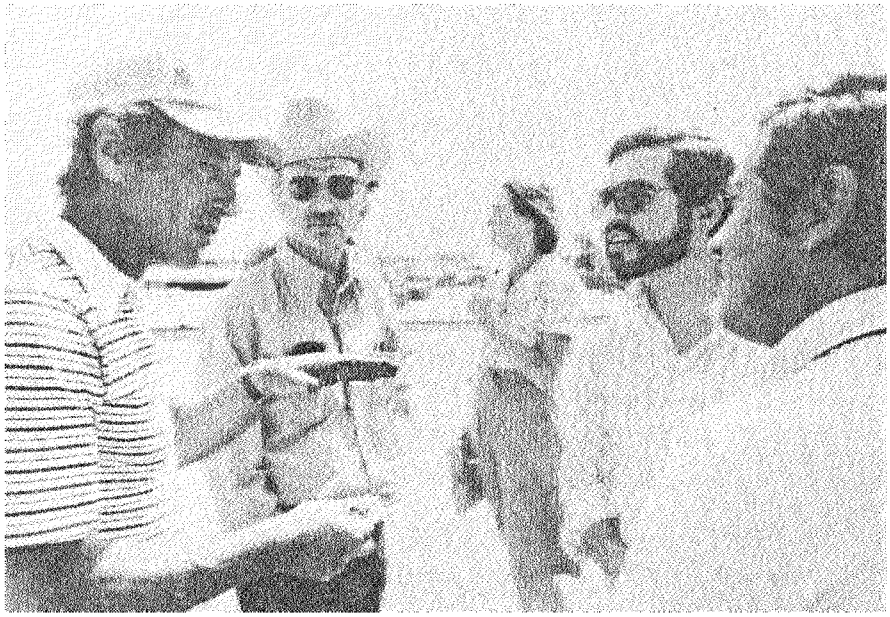

Figure 12. In discussion with the owner of the adobe yard.

Figure 13. An interview with TV reporters.

SUBJECT AREA 1: STRUCTURES

A. State of The Art

While structural testing and research on earthen buildings in seismic areas has not been extensive in the United States, major research projects and activities have been conducted overseas, especially in Latin America. It was felt that U.S. participation in this area could benefit both the developing countries and the United States. By committing American research facilities and equipment to the effort, testing procedures and data could be developed which could aid not only research on earthen buildings in seismic areas, but also parallel research on related structural types such as low-quality masonry buildings.

Coordination of research efforts to date has been on an informal basis with the most coordination occurring among researchers in Latin America. A wide variety of testing methods and procedures have been developed to simulate earthquake loading conditions ranging from high technology shake tables to low technology tilt tables. To date, however, there has been no attempt to standardize testing procedures or to develop comparisons or establish the relationship between different testing methods.

No standardized classification of earthen buildings, materials or structures exists. This, combined with language difficulties, was seen as a major obstacle to coordination of research efforts.

The participants noted that post-disaster reconnaissance has developed little data to aid research. Increased reconnaissance activities and more data collection on the performance of earthen buildings in earthquakes was deemed to be essential for expanded research efforts.

The testing of earthen buildings and their components was seen to be at an early stage. Participants noted a need to establish priorities for the next decade of research and to identify opportunities for comprehensive cooperative research using

the various laboratory facilities that are currently engaged in this work.

Before international cooperative efforts can be established, however, it was felt that certain activities to standardize testing practice sould be initiated. Among the activities listed were:

1. Development of testing standards.
2. Defining the intent of testing.
3. Establishing valid scaling laws for experimental tests.
4. Establishing the relationship of different testing procedures and methods.

It was noted that more research to date has concentrated on adobe buildings. While it was recommended that adobe should retain a high priority, other types of earthen buildings are also found in large numbers in the seismic regions. Participants noted the need to especially examine rammed earth and wattle-and-daub construction commonly found throughout Latin America.

Participants also noted a need for closer liaison with related earthquake engineering research, especially in low-quality, unreinforced masonry construction. It was felt that much of the work on earthen buildings could be related to research on low-quality masonry, especially the development of testing procedures, terminologies, etc.

The difficulties of instrumentation of earthen buidings under actual seismic loading conditions were also noted. Instrumentation is difficult due to the nature of the materials and variations in construction techniques and workmanship. Thus, most information to date has been limited to "before and after" comparisons and studies of buildings damaged in earthquakes. New methods for instrumenting and/or observing earthen buildings under seismic conditions was deemed a high priority.

B. Research Agenda

The structures research agenda is divided into four parts: Standardization and coordination of research, documentation, testing, and priorities.

1. Standardization and Coordination

a. Coordination of Research Efforts

(1) Statement

Due to the limited number of researchers and institutions involved in research on earthen buildings in seismic areas, research efforts sould be more coordinated and cooperative research programs should be instigated.

(2) Action

To provide cordination and stimulation of cooperative research, an international network of researchers and institutions engaged in the field should be established. To be effective, this network should have a central information clearing house and should publish periodic newsletters and organize periodic meetings, both in the regions and at an international level, to encourage further exchange of information among researchers.

(3) Implementation

As a result of the workshop, a group of the participants agreed to formally establish an International Working Group on the Improvement of Earthen Buildings in Seismic Areas. The objectives of this group are to promote continued research into all aspects of the problems of earthen building in seismic areas to stimulate cooperative research; to provide a focal point for the exchange of information; and to work with the existing earthquake engineering research organizations to stimulate new interest in this topic.

It is hoped that the sponsors of this conference and other organizations will support the working group and its activities.

b. Standardization

(1) Statement

In order to facilitate coordination and to encourage cooperative research, standard classification and nomenclature must be established.

(2) Action

It is recommended that an international committee of researchers be convened to establish common classifications and nomenclature required for international research. Standardization should cover:

(a) Materials

(b) Building systems

(c) Building forms

(d) Damage descriptions

It is recommended that the classifications be in both English and Spanish.

(3) Implementation

It is the intent of the newly formed International Working Group to convene within one year an international meeting of experts to define common terminology and classifications. It is hoped that the sponsors of the workshop will continue to support this activity and provide assistance to enable members of the committee to attend the meeting.

2. Documentation

a. Reconnaissance

(1) Statement

Increased post-disaster reconnaissance efforts are required in order to develop a base of data for structural research.

(2) Action

In order to improve the quality of the data developed by reconnaissance surveys, the adoption of standard evaluation procedures and forms is required.

In order to provide the needed data, increased reconnaissance missions should be supported. Reconnaissance teams now responding to earthquakes should be expanded to include specialists in earthen construction. Regional researchers in this field should be supported to participate in international efforts.

Reconnaissance should not only examine buildings which failed but also those that survived. The surveys should also seek to identify traditional forms of architecture and construction which are effective against earthquakes but which have fallen into disuse.

(3) Implementation

The international committee established to develop standards (mentioned above) should develop and adopt standard reconnaissance procedures and formats.

It is recommended that NSF encourage the Earthquake Engineering Research Institute and other organizations engaged in reconnaissance activities to include specialists on earthen buildings in the reconnaissance teams where applicable.

It is recommended that the International Working Group identify a number of researchers in various regions who could participate in reconnaissance efforts. This list should be provided to EERI and other organizations engaged in reconnaissance activities.

b. Defining the Scope of the Structural Research Agenda

(1) Statement

Research to date has concentrated on the types of buildings found in those countries where the research efforts have been undertaken. It is recognized that a wide variety of other types of architectural forms, construction techniques, and uses of earthen materials exist. It is, therefore, necessary to undertake a broad examination of the use of earthen

buildings in seismic areas and to identify the various structural systems now in use.

(2) Action

Coordinated research efforts to identify the principal and most critical structural aspects of earthen buildings should be undertaken on both macro and micro levels. Using the standard classification recommended earlier, efforts should be supported to identify the various structural systems in use and to determine the prevalence of various non-structural components and features (such as partitions, stairs, parapets and ornamental features).

(3) Implementation

The collection of the data at a macro level will require support from numerous organizations. Some of the data may in fact, already exist from other sources. Efforts, therefore, should be focused on supporting research, compiling existing data, and supporting efforts to identify and classify structures where data is not now available.

c. Compilation of Data

(1) Statement

The compilation and dissemination of data concerning structural aspects of traditional housing should be centralized.

(2) Implementation

This activity sould be a function of the International Working Group established as a result of the workshop.

3. Testing

a. Standardization of Testing Procedures

(1) Statement

Various methods have been developed to test earthen buildings under simulated earthquake loading

conditions. The relationship between the various methods utilized however, has not been established. Comparative data needs to be developed in order to be able to equate the different systems.

(2) Action

Four activities are required in order to establish the relationship between various testing methods:

(a) Identical structures should be tested dynamically at full scale and at several smaller scales to establish reliable scaling laws.

(b) Tests on the large scale test platforms (tilt table, and rolling stock test bed) should be conducted to determine the relationship between the various testing methods.

(c) Blast tests on full scale buildings should be conducted and equated with both the large-scale and small-scale tests.

(d) The relationship between the full-scale tests and small-scale tests should be established.

(3) Implementation

Establishment of the relationship between the various testing procedures and methods will require an international cooperative effort. Unique testing facilities have been developed in India (the rolling stock test facility) and Peru (tilt table) which could be equated and compared to various-sized shake tables in the United States.

Cooperative research could be supported under a number of funding programs within the National Science Foundation and through monies from other interested organizations such as A.I.D., UNESCO, and Andean Pact.

b. Instrumentation

(1) Statement

The instrumentation of earthen buildings under actual or simulated seismic loading conditions is difficult

due to the nature of the materials and variations in construction techniques and workmanship. New methods for instrumenting and/or observing earthen buildings under various seismic conditions is required.

(2) Action

New methods and equipment for instrumenting and observing earthen buildings should be developed. Instrumentation techniques developed for research on unreinforced, low-quality masonry may be applicable for use in earthen buildings.

c. Implementation

NSF is encouraged to support research on new methods of instrumenting and observing earthen buildings during seismic events.

4. Repair and Strengthening of Earthen Buildings

a. Statement

To date, little research on the repair and strengthening of earthen buildings in seismic areas has been conducted.

b. Action

Increased research on repair and strengthening of earthen buildings should be conducted. Especially important is research on surface coating which would increase seismic resistance, epoxy injection, and retrofitting strategies.

c. Implementation

It is recommended that current research on the use of surface coatings and epoxies be broadened to include the potential for the application of these materials to earthen buildings.

5. Research Priorities

The following is a list of research priorities identified by the workshop participants:

a. Architectual forms and structural systems which will result in more uniform stress distribution to minimize reinforcement requirements should be identified.

b. Research on different types of reinforcing systems including wood and steel should be expanded.

c. Research on alternative lightweight roofing systems that are culturally acceptable should be conducted.

d. Studies on reinforced concrete or other frames using adobe as an infill material should be conducted.

e. Research on the effects of non-structural components on the earthquake resistance of adobe structures should be conducted. Research should include:

(1) Interior partitions
(2) Stairs
(3) Parapets
(4) Ornamental features
(5) Verandas and porches

f. Research to determine the behavior of poured adobe should be initiated.

g. Research on the behavior of rammed each structure should be expanded.

h. Research on the causes of understress should be conducted.

i. In situ testing of full size structures should be conducted.

j. Blast tests to determine the dynamic resistance and response of earthen structures should be conducted.

k. Research on strengthening and repair of earthen buildings should be initiated.

l. Simple analytical methods for design application should be developed.

m. The effect of soil/foundation interaction should be investigated.

n. Simple methods of fiels testing for use by building officials and local builders should be developed.

SUBJECT AREA 2: MATERIALS

A. State of The Art

Most research on earthen materials used in houses in seismic areas has concentrated on examinations of various types of adobe buildings. Extensive research on adobe was conducted at three different periods. At the turn of the century, extensive research on adobe was carried out by the Department of Agriculture and several universities in the Land Grant system. The research focused on means of improving individual adobe blocks. Little of this research addressed seismic issues.

In the 1930's and 1940's, earthen building materials were again examined in some detail. During this time, asphalt was introduced and promoted as a stabilizer for adobe. Some limited research was conducted on the properties of adobe buildings and their seismic resistance.

In the 1970's, an extensive international research effort was begun in response to the widespread damage that was observed in the 1970 Peruvian earthquake. Research efforts to develop low-cost, stabilized adobe were conducted under a joint effort of the National Bureau of Standards, Fresno State University and several private companies in conjunction with several Latin American counterparts. In Peru, a major program of research on earthen buildings and adobe was conducted by the government of Peru and several participating universities.

Until the late 1970's , the majority of efforts focused on improving the quality of the adobe block through the addition of asphalt and other synthetic stabilizers. However, as petroleum costs increased during the 70's, the asphalt materials most favored have become too costly for use in building in the Third World. In the United States, the materials are still relatively affordable, though here too rising costs are beginning to have an effect. Thus, in materials research, a plateau of sorts has been

reached. It was felt by the participants that alternative means of stabilizing earthen materials need to be examined and newer low-cost methods, especially those which utilize local materials which can be obtained at little or no cost, should be explored. The types of materials which should be examined include natural resins and fibers found in the plants of many developing countries, as well as low-cost industrial products.

The participants also identified the need to conduct research on other types of earthen construction methods found in seismic areas. While it was agreed that adobe should continue to receive a high priority, more work should be directed toward rammed earth structures and other types of earthen buildings.

Alternative means of providing protection for earthen buildings was also felt to be a high priority. It was noted that there has been some research on the use of exterior coatings for prolonging the life of earthen materials as well as limited research on surface bonding. It was felt that both areas required further research and that priorities should be given first to developing surface treatment for low-cost housing in areas of high rainfall and second, to developing treatments for preserving historic buildings.

While participants noted that there were a number of notable research efforts and recent publications on material-related topics, international exchange of information has been relatively limited due to both linguistic barriers and lack of a central coordinated network among those working in this field. It was felt that the existing earthquake engineering organizations should be encouraged to give more attention to this area and that a formal network of researchers engaged in work on earthen materials should be established.

B. Research Agenda

1. Establishment of a Data Bank

a. Statement

A considerable amount of both experimental and performance data about various types of earthen buildings in seismic areas has already been developed. Hence, the first priority should be the creation of a data bank on all existing information available on earthen materials and earthen construction.

b. Action

As an outgrowth of this workshop, a number of the participants voted to formally establish an international network of researchers and practicioners to coordinate and exchange information on activities related to earthen buildings in seismic areas. As a part of this effort, the participants asked the conference organizers to establish a center for the collection and dissemination of information related to this effort.

c. Implementation

The conference organizers are currently working to establish the network and information center as recommended by the conference participants. It is hoped that the sponsors of the conference and other interested organizations can help provide resources and support for these activities.

2. Standardization of Terminology and Testing Procedures

a. Statement

It was found that variations in the terminology relating to earthen buildings and the non-standardization of tests often hamper international exchanges of information on materials research related to earthen buildings in seismic areas.

b. Action

It is recommended that classification, nomenclature and testing procedures be standardized. An international

committee of the principal researchers in the field should be established to define common terminology and to establish common testing procedures.

c. Implementation

The international committee recommended above should accomplish its tasks through regional meetings of experts coordinated under the direction of the International Working Group established at this workshop. The first meetings of the committee should coincide with other international meetings which numbers of the committee would normally attend, thereby reducing costs.

It is recommended that American participation in these committees be supported by NSF and that foreign participation in these standardization efforts be supported by A.I.D., HABITAT, Appropriate Technology International and UNESCO.

3. Material Properties

a. Statement

Further research on the key factors and properties of adobe blocks and their influence on seismic resistance of earthen buildings is required.

b. Action

It was recommended that further research should be conducted to determine the effect of material properties of adobe blocks on seismic resistance of structures. The following research topics were identified:

(1) The effect of soil gradation and type.

(2) The effect of water impurities (such as salinity).

(3) The effect of water content on fabrication and strength.

(4) The identification of alternative types of stabilizers.

(5) The relative effectiveness of various types of stabilizers commonly used (example: straw, cement, lime, asphalt, etc.) and their relative effectiveness in increasing strength and durability.

(6) Research on the optimum size and shape of adobe blocks for purposes of seismic resistance in different sizes of structures.

c. Implementation

It was recognized that substantial progress in this research has already been made in several foreign laboratories. Thus, it was recommended that the majority of the research effort be continued in these locations and that American researchers be supported to participate in these efforts.

It is recommended that NSF continue to support American participation in these activities through programs such as Science in the Developing Countries and through cooperative U.S. and foreign projects.

It is recommended that U.S. institutions which have extensive experience or recent work in stabilization and materials research be encouraged to expand these efforts and that their work be supported by NSF.

It is recommended that A.I.D continue to support international research efforts and foreign national research in this field.

It was felt that both A.I.D. and NSF could play a central role in coordinating research efforts and the exchange of information simply through the use of their good offices and awareness of activities in both the foreign and domestic sectors. Thus, the participants urged that NSF and A.I.D. establish an informal liaison group to keep each organization apprised of developments in this field.

4. Mortar Joints

a. Statement

Analyses of adobe structures following recent earthquakes suggest that the majority of failures occur at the brick-mortar interface.

b. Action

Research studies on the development of greater bond strength between the adobe block and mortar joints should be conducted.

c. Implementation

It was felt that the international organizations and institutions which have already conducted extensive research on earthen material should be supported for research on bonding. It is recognized however, that recent developments and research from related fields (such as unreinforced, low-quality masonry) may play a significant role in this task. A study should be made to determine the applicability of this information to adobe masonry. Therefore, increased interchange between U.S. and foreign research institutions is encouraged, and support for joint U.S. and foreign cooperative research should be supported by a variety of institutions including NSF, A.I.D., UNESCO and HABITAT.

5. Field Test Procedures

a. Statement

Standardized experimental tests which can be readily performed, even in remote locations, to determine the properties of earthen materials and what is needed to effectively prepare and strengthen the materials for use in construction should be developed.

b. Action

Research should be conducted to develop simplified field methods for soil sampling and testing for earthen materials to be used in construction of housing. These construction aids should be designed to:

(1) Assist local builders in determining the best soils for use in preparing earthen materials.

(2) Provide guidance on the best types of stabilizing materials to use with the soils.

(3) Provide guidance on the best types of mortar to use with the blocks.

(4) Provide information on the related construction aspects such as recommended reinforcing systems, maximum size and width of walls, and general data relating to the configuration of the building.

This data should be standardized to the greatest extens possible and should include only those tests which can be readily performed with minimum scientific knowledge.

c. Implementation

It is recommended that Appropriate Technology International and other appropriate technology groups support the development of these construction aids.

Since construction aids of this type would be beneficial in any locale where earthen buildings are used, cooperative research and development should be encouraged.

6. Research on Non-Earthen Materials Commonly Used in Conjunction With Earthen Buildings

a. Statement

Research on non-earthen materials commonly used in construction of earthen buildings (such as wood, cane, straw, etc.) and their properties and performance when used in earthen buildings under seismic loading conditions is not presently adequate.

b. Action

First, research is needed to define the durability and performance of wood and other non-earthen materials in adobe construction. Especially important is an analysis of the

interaction between earthen materials and reinforcement under seismic loading conditions. Both full-scale and small-scale testing is required.

Second, research is needed on durability of wood and other structural elements commonly used. Priority should be given to simple, lowcost methods of prolonging the life of wood in earthen buildings.

c. Implementation

It is recommended that NSF support research in this area. Bracing systems of wood, concrete, etc., using earthen materials as an infill, were seen as a research objective which could benefit from U.S. testing facilities.

7. Effect of Climatic Conditions on Earthen Buildings

a. Statement

Little information exists concerning the effects of extreme climatic conditions on the seismic performance of earthen buildings.

b. Action

Research should be carried out to improve earthen materials under varying climatic conditions, including rain, freeze/thaw cycles and various wind and erosion conditions. Research should include:

(1) Development of information on the changes to the material properties under various climatic conditions.

(2) Development of recommendations for reducing adverse climatic effects (such as the use of coatings and sealants).

c. Implementation

It is recommended that research in this field be carried out in two parallel programs. First, foreign research institutions with extensive earthen materials research capabilities and experience should be supported for further research on

the changes in material properties due to climatic exposure. Second, it is recommended that NSF support domestic research related to development of coatings, sealants, and stabilizing materials which could strengthen the materials under varying conditions.

The overall research should be coordinated through periodic meetings of the researchers involved and an exchange of researchers during parts of the program.

It is recommended that NSF support the domestic research component under a joint U.S. and foreign cooperative research program.

8. Effect of Material Properties on Structural Behavior

a. Statement

The interaction betwen structural design and material characteristics of earthen buildings under seismic loading conditions is not fully known.

b. Action

The interaction between structural design and material characteristics should be investigated by means of both full-scale and small-scale tests.

c. Implementation

Joint U.S. and foreign cooperative research should be supported on this topic with full-scale tests being conducted internationally and small-scale tets being conducted at U.S. facilities. It is recommended that NSF support the small-scale testing components as part of a comprehensive U.S. and foreign research program and that A.I.D. participate in the support of the foreign research institutions.