FOREWORD

The rural structures pose a serious seismic risk problem in the seismic belts of the earth. It is unfortunate that this risk is increasing, rather than decreasing at most places on account of increasing population, poverty of the people, scarcity of wood, cement and steel, lack of understanding of earthquake resistance features etc. The magnitude of seismic risk to life could be imagined by the fact that number of dwelling units and other related small scale constructions may double itself in the next 20-25 years due to the explosion of population particularly in the developing countries. There is thus a great urgency that the know how of inexpensive earthquate resistance measures in such constructions should be propogated quickly and by simple illustrations, so that these techniques could find application at least in the new constructions.(1)

The state-of-the-art panel on the Earthquake Resistant Rural Structures of the 7th World Conference on Earthquake Engineering mainly aimed at collecting views and practices of selected countries where most of the earthquake damage is suffered by the rural structures. Following panel members have been appointed by the Organizing Committee and contributed to the panel :

1. Professor A.S. Arya
   University of Roorkee, Dept. of Earthquake Engineering
   Roorkee 247667, India

2. Professor D. Benedetti
   Technical University of Milan
   P.zza L. Da Vinci, 32-20133, Milano, Italy

3. Professor Sergey Bubnov
   University of Ljubljana
   Erjavceva 15, Ljubljana, Yugoslavia

4. Professor O. Hernandez
   National Autonomous University of Mexico
   Institute of Engineering
   Ciudad Universitaria, Mexico 20, D.F. Mexico

5. Professor J. V. Neumann
   Pontifica Universidad Catolica del Peru
   Pontifica, Peru

6. Professor Yang Yu-Cheng
   Chinese Academy of Sciences
   Institute of Engineering Mechanics
   Harbin, Peoples Republic of China

Each of the panel member conveyed their experience and ideas about the general practice and theoretical or experimental studies that they have carried out in their corresponding countries about the earthquake behaviour of rural structures. In the following state-of-the-art report all the above contributions have been classified and generalized by the panel secretary.

All of the panel members except Professor Yang Yu-Chang have attended to the conference individually.

INTRODUCTION

Most of the loss of life in the past earthquakes has occurred due to the collapse of structures in rural areas constructed in traditional materials like stone, brick, adobe and wood which are not engineered to be earthquake resistant. These "rural structures" may also be called "non-engineered structures" where the term non-engineered may only be vaguely defined as a structure whose analysis for lateral earthquake forces would defy reasonable mathematical solutions and the design will be based mostly on a set of specifications derived from observed behavior of such buildings during past earthquakes and trained engineering judgement. Such structures will include load bearing masonry wall buildings (brick, stone or adobe), stud wall brick-nogged constructions in wood, and composite constructions using combinations of load bearing walls and piers in masonry, reinforced concrete, steel or wooden posts and like. Reinforced concrete or steel frame buildings, tall buildings using various types of structural systems, major industrial buildings etc. are excluded from consideration.(1)

CLASSIFICATION OF RURAL HOUSES

There are various types of rural houses existing in different countries. Common building materials used are adobe, stone, brick, concrete block which are all heavy in weight and with low tensile and shearing resistance. Another category of materials is wood or bamboo which are highly flexible. Most of the time, these materials are used individually or in combination. Sometimes, concrete and steel reinforcements are also used. According to their structural systems, the rural houses can be classified as follows :

a) Adobe, stone, concrete block or brick masonry.
b) Wood block, timber or bamboo framed.

The masonry houses of item (a) usually have a heavy flat earth type of roof, concrete block or brick masonry houses sometimes have a reinforced concrete roof slab with tile or similar roof covering. Wood block or timber framed houses have a very rough timber trussed roof. The masonry houses built in rural areas are normally unreinforced, but may have lateral wooden laths at certain places. Timber framed houses usually have filler walls of adobe, stone, brick or some other material. Some of the timber framed houses may be plastered directly or they may be wood plated. The distribution of the type of the construction used in various regions of each country depends mainly upon the availability of the construction materials, economy and social trend and traditional technology of that region. For example in Yugoslavia, the majority of the rural houses are built of brick since in the larger part of the country there is clay of good quality which could be well formed and burnt, whereas in east and southeast Turkey stone masonry and adobe masonry constructions are in majority because of their low cost, availability of the materials and good insulation provided.

CHARACTERISTIC DAMAGES

Different types of rural houses have suffered different degrees of damage in the past earthquakes. The main factors contributing to the damage of the masonry houses have been their heavy weight, brittle behaviour of the masonry with low tensile and shearing strength, lack of adequate structural connections, poor quality of construction and deterioration of strength by time. The study of damage after an earthquake can clearly identify the weak and strong points of the design, the materials and construction techniques.

ADOBE MASONRY

Damage patterns of adobe houses are as follows : Pull apart of the longitudinal wall from the transverse wall; occurrence of vertical cracks; outward inclination of the wall. Damage is caused by the insufficient tension of the adobe. The adobe at the corners when pulled apart leaves the walls standing freely. The wall inclines outward due to its inertia force and due to horizontal push of the roof which collapses successively. If the portion of the beam or purlin supported on the wall is too short, it will fall down the ground due to excessive displacement of the wall, with the result of the collapse of the roof.

Usually fatality increases with such a collapse due to the debris and lack of air inside. Sometimes the wall may crush at the places where the purlins are supported and inclined or diagonal cracking may also occur.

Adobe houses are known to be the worst as far as their behavior under earthquakes are concerned and even some countries abondened its use but yet it finds application in most part of the Middle East Countries, South and Central America, and even in China. If built on sound foundation with a rational structural layout, good workmanship and maintenance, this type of building will not collapse even under an earthquake of intensity VII or less than VIII (Figs. 1 and 2).

STONE MASONRY

Usually mud mortar is used to combine the stones. If the stone used is not quarried but collected from fields or river beds they will be covered with moss and dirt and will have a round shape. The bond provided by mud mortar is very poor since as time passes the mud between the stone dries, shrinks and falls out, thus no bond remains between the stones. During an earthquake also no shearing strength is left except dry friction between stones.

Usually the thick wall is made out of two vertical planes, one inside, one inside. If stones to bind these two layers are not provided, the integrity is lost between these layers and inner and outer layers are split into two (Figs. 3 and 4).

Collapse of bearing walls may be due to failure of connections between wall and wall, wall and roof and walls and foundations. Thus lack of structural integrity is the greatest source of weakness.

Similar to adobe masonry houses the collapse of the flat earth roof is the cause of loss of life. The roof besides being very heavy, has also been poorly connected to the walls. Thus failure of the weak stone walls is followed by the falling down of the heavy roof (Figs. 5 and 6).

Another possible mode of failure occurs when the walls are somewhat stronger and the roof beams have longer supported lengths on the walls. In this case the roof beams slide down on one side while stay in place on the other side. This is less dangerous than the total collapse of the roof since it leaves space and time for people inside to escape.

Stone masonry houses behave worse than adobe masonry houses, both having the same type of thick flat earth roof. This may be partly due to stone being heavier than adobe and partly due to the non-homogeneous nature of the stone walls as compared to adobe walls. Stone masonry houses with mud mortar and flat earth type of roofs are completely destroyed at intensities of VII-VIII and heavily damaged at intensities V-VI.

BRICK OR CONCRETE BLOCK MASONRY

Analysis of various damage patterns shows that damage characteristics of "rigid" and "non-rigid" brick houses are different. For "rigid" brick houses, in which transverse interior walls are closely spaced and the lateral rigidity of the floor slab system is high enough, the following three damage categories may be identified :

a) Shear failure due to diagonal tension :

Th s kind of failure is frequent. First diagonal cracks occur on the walls, sliding discolaciton, crushing of bricks, fall of debris and at last collapse of the walls follows. The collapsed walls usually fall around the building area and the floor slabs fall on top of each other (usually reinforced concrete slabs are used for more than one story houses). Some buildings totally collapse, whereas some of them have a collapsed upper story only.

b) Horizontal shear failure :

Cracking of horizontal joints, especially near the connection of the walls with the floor or roof slab is followed by horizontal sliding and dislocation of the wall.

c) Overturning failure :

This type of failure is often caused by the weak connections between exterior longitudinal walls and interior transverse walls. Exterior walls often pullapart from the interior walls. In some extreme cases exterior walls incline or even overturn due to loss of stability. Sometimes, exterior walls first collapse then the interior transverse walls, followed by the roof or floor slabs falling on top of them. As for the "non-rigid" brick houses; These are brick masonry houses with weak floor or roof slab (usually wooden floor Fig.7) and with relatively large spacing of the interior walls, thus the lateral rigidity of the floor slab system is poor. In this case the damage is characterized by the off-plane bending failure, occurence of horizontal cracks on the tension side of the wall and partial crushing on the compression side. In some extreme cases the walls incline and cause the house to overturn.

TIMBER-FRAME OR WOOD BLOCK

Earthquake resistance of the timber-framed or wood block houses are comparatively good among the other types of the rural houses discussed so far. In the timber-framed, filler walled type, the failure usually begins at the fill material inside the timber frame members and timber diagonals (Fig. 8). The damage is conveyed to the frame members only after the filler walls are seriously damaged. The degree of damage on the walls depends on the wall materials (adobe, brick, rubble stones etc.), the workmanship and the stiffness of the frame as a whole. The deformation of the frame during an earthquake is larger than that of the wall, thus the wall is pulled apart from the frame or pushed down by the frame. If the frame is rigid enough with small deformation and if at the same time the walls are strong enough to confine the deformation of the frame and to resist the inertia forces induced by its own weight, then the house does not suffer serious damage.

The following damages can be observed :

a) Cracks occur at the corners or at the wall-column connections, tiles may slide on the roof (slight damage).

b) Longitudinal and transverse walls are seriously damaged, top of the gable wall and the eave wall partially collapse (moderate damage) .

c) A large portion of the wall collapses, tenons full apart from the timber frame, frame is inclined (seriously damaged).

d) Roof falls down, upper part of the wood frame fractures or overturns, frame and wall collapses (collapsed).

Much difference in the damage to the timber framed houses can be found due to difference in the structure of the frame, filler wall materials, workmanship and the age of the house.

In a moderate earthquake (intensity VII-VIII) damage to the filler walls occur, in an earthquake of intensity IX, serious damage takes place the infill walls collapse but only in a few of the house total collapse of the structure as a whole takes place. Most of the collapsed houses are houses with a simple frame (very few diagonal bracings) or with a flat roof or with a timber truss poorly connected to the columns, or a timber frame with decayed members. (Fig. 8)

In case of wood-block or timber framed but wood-plated or plastered house the problem is only with the decay of wood by time, poor connections and inadequate bracing elements, since they don't contain any filler wall.

FACTORS AFFECTING THE DAMAGE

The structural action and the damage mechanisms of the rural houses discussed in the previous section bring out the critical and generalized as follows :

a) Defects in the structural configuration :

The geometry of the house in plan as well as in elevation has a significant effect on the distribution of the seismic forces. Unsymmetrical houses develop additional shearing forces due to twisting and warping. Failure commonly occurs at corners of openings at weakly built corners of the walls.

b) Weakness in the soil of the foundation :

Sometimes an inadequate foundation causes failure of a sound and strong superstructure. In many earthquakes, liquifaction of soil, occurance of sand pockets or settlement of soil lead to catastrophic failures of the buildings.

Very shallow foundations, deteriorate because of weathering, particularly when exposed to freezing and thawing in the regions of cold climate. Deterioration may also be caused by frequent flooding of foundations in tropical regions.

c) Weakness in walls :

Adobe, stone concrete block or brick masonry (unreinforced) are highly susceptible to damage because of their low tensile and shear resisting capacity. Due to door and window openings even further stress concentrations and reduction in strength occurs. A very critical source of weakness is the weak bonding material (usually mud mortar) between the masonry units.

Lack of structural integrity is the greatest source of weakness and may be responsible for severe damage or collapse. Failure of connections between wall and wall, wall and roof and walls and foundation may cause collapse of bearing walls.

d) Poor connection of roofs :

If the elements used in the roof or floors are not properly interconnected together and if the large seismic forces are not properly transferred to the supporting walls or frames through suitable connection between them, to roof and floors may be damaged severely or collapsed completely.

e) Poor construction quality :

In many instance the failure of rural houses in earthquakes have been attributed to poor quality of construction like weak materials, poor workmanship, e.g. inadequate skill in bonding units and improper and inadequate connections.

EARTHQUAKE RESISTANT DESIGN AND CONSTRUCTION OF RURAL HOUSES

The study of the performance of the rural houses in the past earthquakes clearly points out the structural action, damage mechanism and modes of failure and leads to the following general principles as to improve the design and construction techniques for earthquake resistance :

a) The site should be selected carefully. Stable slopes should be chosen to locate the house. The houses should not be built on very loose sands (due to liquifaction and settlement possibility during an earthquake) and on sensitive clays. Selection of construction sites is more feasible in the rural area than in urban area, such an advantage should be utilized.

b) Planning of the house should be done carefully. The house or its various parts should be kept symmetrical about both axes. A rectangular plan should be preferred without any projection. Blocks of different character should be separated from each other to keep symmetry and rectangularity.

c) An integral action of all the resisting elements should be provided by suitably connecting all the elements together, so that no seperation will take place during an earthquake.

d) Since adobe, brick, concrete block and stone are weak in tension and brittle in compression, their strength and ductility should be increased by providing some reinforcement at least at the critical sections in the form of steel bars or timber elements.

e) To increase the lateral resistance, diagonal bracing elements or walls to act as shear walls should be provided along both axes of the house.

f) The quality of construction should be improved and emphasized.

In the light of the above general principles, the following simple suggestions can be made to improve the earthquake resistance of the particular type of house:

ADOBE MASONRY HOUSES

a) To increase the ductility and strength of adobe, research work is continuing in various countries. Experiments show that 0.5% of dried grass added to mud of adobe (by weight) increases the strength by 50-100% . Also addition of a certain amount of cement or lime improves the strength of adobe.

b) To increase the integral action of the interior and exterior walls, reed straw, bamboo or wood planks should be placed at the corners and junctions of walls. A more reliable measure is to use steel bars or load wires which are anchored on a wood plate on the wall to tie the walls opposite to each other to avoid collapse. Such a measure is frequently used to repair the damaged buildings after an earthquake (Fig. 15).

c) Continuous timber lintels should be provided to prevent the top and bottom of the window openings,

d) The weight of the heavy earth roof should be reduced and its connection with the supporting walls should be done carefully. Enough projection of the roof beams or purlins (at least 50 cm) should be provided on top of the exterior walls,

e) Separately enclosed rooms should be preferred to a long barrack type, since small boxes are seismically stronger than a large single box. Therefore enough transverse walls should be provided in the layout of the house.

f) Simple shock absorbing measures can be adopted (such as a reed straw layer of about 5 cm, thick placed on the wall at a certain height of the wall may reduce the earthquake damage). (13)

STONE MASONRY HOUSES

Earthquake resistance of stone masonry houses may be improved by:

a) Increasing the shear strength of the stone walls. A better mortar than mud should be used for that purpose.

b) Quarry stone with corners should be preferred to rounded field or river bed stones.

c) In order to prevent splitting of the stone wall into two, the bond stones (or through stones) should be placed where needed.

d) The idems b, c, d and e for adobe houses are applicable here as well.

BRICK MASONRY HOUSES

Since brick or concrete block houses have also been widely used in the urban areas, their design and rules for construction have been included into the Earthquake Resistant Design Codes of most of the countires (Such as Yugoslavia, Peru, Turkey, China etc.). Their behavior is better than adobe or stone houses due to better quality and geometry of the material. The earthquake resistant rules stated for adobe and stone houses are also valid for brick or concrete block houses in addition or together with the code specifications.

TIMBER FRAMED HOUSES

a) Integrity and stiffness of the timber frame should be improved. Enough bracing members should be provided inside the timber frames.

b) Columns of the timber frame should be located near the inside face of the wall.

c) Steel plates and reinforcement should be used to tie the infill wall to the timber frame to provide integral action of the wall with the frame.

d) Light weight infill materials should be preferred.

e) Decay of structural wood members should be avoided. Columns should be placed on stone footings and should not be burried in soil. Beam-column connections should not be hidden inside the walls.

REPAIR, RESTORATION AND STRENGTHENING OF EXISTING RURAL HOUSES

In the repair, restoration and strengthening of existing rural houses the following stages should be distinguished :

a) Before an earthquake :

A survey should be carried out for the existing rural houses which are located in the seismic zones to determine the strengthening required.

b) Just after a damaging earthquake :

Damaged but standing houses should immediately be strengthened by temporary supports and emergency repairs to prevent their collapse during after shocks. By the same precautions less damaged houses should be brought back into use if necessary.

c) Long term repair after an earthquake :

Cost and feasibility studies should be carried out to decide on the demolishing or repairing a damaged house.

Architectural repair aims in bringing back the architectural shape of the house so that functioning of the house is resumed quickly.

The main purpose of restoration is to carry out structural repairs of the load carrying elements. It may require removal of some of the damaged elements so that the original strength is more or less restored.

If an existing house has original structural inadequancies (e.g. material may have degraded by time, alterations might have been carried out like providing new openings or adding new parts to destroy the symmetry etc.). They should be strengthened against earthquakes if it is not possible to replace it with an earthquake resistant one due to economic, social or historical reasons. The main items related to seismic strengthening are as follows :

a) Modification of the roofs :

Heavy flat earth roofs should be placed with lighter ones. Roof tiles are brittle and easily dislodged, where possible they should be replaced by corrugated iron or asbestos sheating. Roof truss frames should be braced by adding suitable bracing members in the vertical as well as in the horizontal planes. Anchors of roof trusses or roof beams (or purlins) should be improved and the roof thrust on walls should be eliminated (Fig. 9).

b) Substitution or strengthening of slabs :

A rigid slab inserted into existing walls plays an important role in the resisting mechanism of the house keeping the walls together.

If the slab is reinforced concrete a new reinforced concrete slab can be inserted by means of proper keys. The existing wooden slabs can be stiffened by placing a reinforced concrete thin slab on the old one or nailing planks perpendicularly to the existing ones. (Figs. 10,11).The slabs should also be properly connected to the walls by special detailing (Figs. 12, 13).

c) Adding new walls or strengthening the existing walls :

If the existing house is not symmetrical, it can be made symmetrical by adding new walls at proper places. For long barrack type houses transverse walls should be added to gain better box action and more rigidity in the transverse direction. In such modifications care should be paid to the connection details of the new walls with the old ones.

Existing walls whether they are cracked or uncracked can be strengthened by grouting a suitable cement mixture through special holes, by providing steel meshes on the two sides of the wall and connecting them through the wall and applying microconcrete on top of these meshes or by prestressing (place two steel nods on the two sides of the wall and stretch then by turnbuckles, thus shear streng of the walls increase and the connections with the orthagonal walls are improved) (Figs. 14,15).

As a variation and for economy of the technique of using wire mesh and microconcrete, the covering may be in the form of vertical splints between openings and horizontal bandages over spandrel walls at suitable number of points only (method is called "splints and bandages method") (Fig. 16).

OUTLINE OF THE CURRENT RESEARCH WORK ON THE SUBJECT

Most of the research work on rural houses are directed towards shear strength of masonry piers and panels (stone, hollow brick, adobe). Some static tests (cyclic) or shaking table tests have been carried out on small scale models of stone, adobe or brick houses or building fragments.

a) Tests on masonry piers :

Mayes, Omote and Clough (2) carried out cyclic in-plane shear tests on seventeen fixed-ended piers. Each test specimen was a full scale panel about 15 ft. square consisting of two piers and a top and bottom spandrel. The panels were constructed from 6 inch wide X 8 inch high X 16 inch long hollow concrete block units. The main variables were; amount and distribution of reinforcement, rate of load application, vertical bearing stress and effect of partial grouting. The main conclusion of this paper was that much more research is required on the shear strength of masonry piers. It was also concluded that sufficient amount of horizontal bar reinforcement provides ductile behavior to the piers which mainly fail in shear, partial grouting produces an elasto-plastic force-deflection relationship prior to failure in shear mode and finally inclusion of 1/8 inch plates in the toes of the piers produces desirable ductile behavior before failing in flexural mode.

Sheppard, Terjelj and Turnsek (3) studied the flexural resistance of masonry walls to combined horizontal and vertical loads. The tests were specifically designed so that true flexural failures would occur. The results of the tests were generalized to provide a method for the calculation of the flexural resistance of unreinforced masonry walls, and a basis for the treatment of reinforced walls.

Benedetti and Casella (4) Tests were carried out on brick masonry panels to evaluate the shear strength. The tests were carried out by means of an experimental set-up which simulated the actual boundary conditions as close as possible. Post-cracking behavior of the panels, comparison of the nominal tensile strength derived by different criteria, possibility of the use of these values to define local strength values were the topics studied.

Steinmann, Anicic and Zamolo (5) carried out tests on wall specimens (approximately 1.0 m x 1.0 m) with or without reinforcement in the horizontal mortar joints, made by hollow brick blocks. The specimens were subjected to diagonal tension and also to cyclic and continuing monotonic load until failure. High strength mortar provided high static strength but brittle failure.

Turnsek, Terjelj, Sheppard and Tomazevic (6) carried out tests on stone-masonry walls, reproduced in the laboratory different from their natural environment. The walls were built of two outer layers of uncoursed stones, the middle of the wall being filled with rubble, poorly bound together with lime mortar.

The walls tested were repaired by the injection of cement grout into them and than retested. The test results showed that the basic strength of stone-masonry walls as they exist in ordinary houses is very low. However if the walls are repaired by cement grouting than the shearing resistance increased tremendously.

Vargas (7) studied the behavior of adobe piers. He carried out two series of tests. In the first series (overturning tests) it was possible to apply yield-line theory. The second series of tests demonstrated validity of the method also for the walls which are subjected to forces acting on plane normal to the wall.

b) Tests on small scale model houses and structural elements (Static and Shaking Table Tests) :

Vargas (8) carried out a research program to determine models of structural behavior practical rules and design procedures could be developed. Compression tests on adobe, splitting tests, flexure tests, axial compression tests on adobe piles with mortar joints, diagonal compression tests, shear tests on walls, flexure tests on walls, overturning tests on walls and module tests were carried out.

Meli, Hernandez and Padilla (9) Tests were carried out on a shaking table in order to evaluate the efficiency of three strengthening methods, which are : a reinforced concrete bond beam at the top of the walls, a welded mesh nailed to both faces of the walls and covered by mortar rendering, steel rods tied to both faces of the walls in their upper parts. Mechanical properties of adobe and structural behavior of adobe walls were also studied.

The test results showed that the siesmic intensity that can be withstood without major damage is increased at least twice by any of the strengthening methods studied, the most efficient being the welded mesh reinforcement. The emphasis is focused on adobe houses but most results are stated to be valid for unreinforced masonry in general.

Benedetti and Castellani (10) carried out tests on stone masonry buildings of scale 1/2, which intended to represent typical rural house without a rigid slab and without particular connections of orthogonal walls. The original and the repaired structures were loaded statically simulating earthquake effects. The load system represented one story plus roof above the model under test. Vertical loads were kept constant while horizontal loads repeated. The repairing technique proved to be efficient in restoring even increased the original strength of the structures.

Jabarov, Kozharinov and Lunyov (11) applied static and dynamic horizontal loads to a two-story fragment of a building with brick walls. At the first stage of the tests dynamic characteristics of the building and cracking and ultimate strength of the building were studied. At the second stage, damaged brick masonry was strengthened by 2.5 cm thick reinforced mortar layers and tested under both static and dynamic loads. The test results showed that complete gain of initial strength and stiffness strengthened by this procedure was possible.

Gülkan, Mayes, Clough and Hendrickson (12) studied the seismic behavior of a simple masonry house subjected to simulated earthquake motions on a shaking table. The house was constructed such that similar masonry components were placed both parallel and transverse to the table motion. The test results indicated that the overall response is effected in a complex manner by the orientation of the timber truss, fixity of the in-plane walls and cracks developed in the walls. A nominal amount of reinforcement prevented the formation of cracks which could lead to failure.

Arya, Qamaruddin and Chandra (13) proposed a new system of brick buildings for improved behavior during earthquakes. In this system it is claimed that a clear joint between the superstructure and foundation masonry at plinth level would increase the earthquake resistance. Reinforced concrete bond beams are introduced just above and below the joint for integral action of respective components. Tests carried on shaking table on half size specimens and analytical seismic response calculations proved the reduction of effective acceleration acting on the superstructure masonry as compared with conventional buildings. Collapse is avoided and cracking damage is also seen to be much reduced.

Arya (14) carried out model studies of masonry buildings as related earthquake resistant design requirements. The items included were the strength tests on brick mortar composite, strength of shear walls with openings, lateral strength of small scale single room structures reinforced with steel bars in various ways, later a strength and free vibration tests on three storied single room buildings of one-third full-size, and shaking table tests to ultimate failure of half-size single room specimens reinforced in various ways. The last test were carried out on a specially made shock-type platform on an old railway wagon chassis. The test programs mentioned clearly brought out the critical sections of the walls requiring reinforcement in such buildings. With a little extra cost it seemed possible to prevent widening of cracks and also to prevent collapse.

Algabian (15) carried out a series of full-scale pseudostatic and dynamic tests of wood and steel deck diagrams. In addition a series of dynamic tests were performed on unreinforced masonry walls to study their behavior when subjected to out-of-plane excitation.

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PANEL DISCUSSIONS

The following panel members were present during the panel discussions : Prof. Arya, Prof. Bubnov, Prof. Benedetti, Prof. Hernandez and Prof. Neumann. Following are the general comments made by each panel member in summary in addition to their contributions to the general state-of-the art report :

Prof. Arya : Rural buildings account for the 95% of the loss of life during earthquakes. From the classification of the rural buildings it can be observed that all the good building materials are absent, besides construction quality is inferior, the buildings themselves are generally heavy in weight and the connections between the various elements are poor.

From the engineering point of view, since most of the rural buildings are one storied and generally very rigid, plastic no crack design is almost impossible. Also there is lack of communication between the engineers and the actual builders. The solution for the improvement of the seismic resistance of rural buildings should therefore be simple, along the traditional line and economical.

Prof. Bubnov : In Yugoslavia most of the rural houses are one or two story brick masonry structures. This type of construction may as well be found in the urban areas. Three types of seismicity should be considered : small, medium and strong. Measures should be taken according to these types. In general to increase the earthquake resistance of rural buildings the quality of the mortar should be improved, light roof covers should be used (many buildings collapsed due to that), tie-bands should be provided at various levels (could be reinforced concrete or steel). The corners are very sensitive, they must be reinforced and well constructed. In Yugoslavia reinforced concrete columns are placed at the corners; they do not carry vertical loads, they only provide good connection. Also for good earthquake resistance, the layout of the structure should be simple and a good foundation should be provided. A strong foundation is necessary not only for the earthquake loads but for carrying vertical loads as well.

In order to solve the problem, the following two aspects should be considered :

a - Economical aspects : This is the most difficult part of the problem since funds are limited.

b - Educational aspects : People should be educated. They must be taught what to do and how to do.

Some earthquake resistant solutions are not very expensive as compared to the usual construction. Additional reinforcement provided for earthquake resistance does not exceed 1% of the total cost. Tie bands are very effective, yet they are not expensive. Thus builders should be educated about all these effective measures.

Prof. Benedetti : Repair and Strengthening of Existing Stone Masonry Structures : (Demonstration Through Slides)

Some remarks : Most of the rural buildings in central Europe, especially in Italy are already existing structures. New ones are rather rare. Stone buildings may be 2 or 3 story high. Major damages may be due to : Separation of the two faces of stone walls, poor connection of slabs with walls and structural modifications (such as providing a new opening or adding a new wall etc.).

Due to economic reasons it is not possible to make these structures completely seismic resistant, but nevertheless their resistance can be improved through certain repair procedures and they can be used again.

Prof. Hernandez : Repair and Strengthening Adobe Houses (Demonstration through slides)

Some remarks : Many strengthening methods have been proposed but very few have been tested under actual conditions.

Model tests of rural adobe houses have been carried out in Mexico to see the effect of different kinds of strengthening procedures (9). Most effective strengthening procedure is found to be the use of wire mesh.

Prof. Neumann : Tests carried out at the Universidad Catolica del Peru (7, 8). (Demonstration through slides)

After oral presentation of each panel member, Prof. Arya made an announcement to inform about the new Monograph on Rural Structures which was prepared by Commettee II of IAEE (1).

After that, discussion continued with the audiance. Mainly questions raised by the audiance pointed out the importance of education and the problem of lack of communication between engineers and builders and also between goverment authorities and the builders.

Prof. Arya had some comments about the improvement of communication; he suggested to prepare illustrative booklets (UNESCO is preparing a digest of 20-25 pages, to illustrate how and what is to be done) and even model houses for demonstration.

Prof. Bubnov commented on the level of the problem : The problem is not of University level but it is lower level. Supervision is important and different economic possibilities of each country should be taken into consideration.