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State-of-the Art Report
DESIGN, CONSTRUCTION AND RESEARCH IN MASONRY: CURRENT STATUS IN SELECTED REGIONS OF THE WORLD

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SUMMARY

The state-of-the-art of masonry structures materials, design, and research is presented. It is based upon a questionnaire sent to people in several countries, the literature, papers presented at the Ninth World Conference on Earthquake Engineering STS on Masonry, and the author's experience. It was observed that masonry design technology ranges from empirical to working stress based on linear-elastic behavior to ultimate strength and other limit states. A variety of masonry units are used from simple to complex. Research and development efforts address design and construction for seismic loads as well as others, unit shapes, evaluation and strengthening and codes.

INTRODUCTION

By this report, the author will present a general impression of the state-of-the-art of structural masonry technology. This impression is based upon responses to a questionnaire[2] by many people especially to assist with the preparation of the report, and the author's personal knowledge obtained from the literature and from participation in international workshops, conferences, and research projects. As the title implies, the report[3] is based upon information from a limited number of countries, however, the author has been, so far, presented with no reason to believe that this "sample" is not sufficient to establish an adequate impression of the state-of-the-art.

OVERVIEW

Masonry buildings constitute a very large proportion of the world's inventory, particularly buildings in the range of five stories in height or less. Use of masonry buildings covers a wide spectrum of applications including single and multiple family residences, stores, factories, schools, hospitals, and government facilities.

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2 Respondents are listed in Appendix 2

3 This report addresses buildings in which the use of masonry is the primary structural material. It is recognized that masonry, especially clay-unit (brick) masonry is used extensively as a veneer in many countries.

There are no doubt many reasons for the extensive use of masonry as a building medium, but among them local availability of material, such as clay, was and is probably the greatest stimulus. Additionally, it is possible to construct masonry buildings without sophisticated machinery. In recent and present times, aesthetic factors have contributed to the use of masonry and for certain applications masonry buildings can be more economical than steel or concrete buildings.

Unreinforced masonry buildings, while suitable in regions of low seismicity, have generally not performed well in earthquakes. Alternatively, reinforced masonry buildings have performed very well. Because of the unavailability or high cost of reinforcement in some areas, unreinforced masonry structures continue to be built and research by seismologists continues to reveal risk in areas thought to be "nonseismic."

Masonry design and construction technology, generally has not been developed to the technological level of reinforced concrete and structural steel. One can only speculate about the reasons. Whatever they are, the situation in many countries is that research needed to develop masonry materials and structures technology to a level compatible with that of reinforced concrete began only within the last twenty years. There is also considerable attention to evaluation and strengthening of existing masonry buildings.

Engineering education of engineers and architects in even today's technology, with some exceptions seems to be generally neglected while it is typical to receive education on concrete and steel structures technology. Further, until recently, there have been no professional societies to serve as a focal point for the exchange of information and ideas. Major conferences devoted to masonry technology began in the last twenty years on an infrequent basis although in the last ten years the frequency has increased.

REVIEW BY COUNTRY BASED ON THE SURVEY

Australia

Mortar - For use with clay units: 1 part portland cement, 1 part hydrated lime and 6 parts sand by volume. For use with calcium silicate or concrete units: 1 part portland cement, 5 parts sand plus a water thickening agent (methyl cellulose).

Grout - Portland cement at least 300 kg/m^3 and aggregate with or without fly ash or blast furnace slag.

Units - Solid, cored (perforations up to 25% volume) and hollow. Concrete units (block) are usually hollow. Clay and calcium silicate units are solid or cored with dimensions of approximately 200 x 100 x 60 mm. Hollow clay units similar to concrete block in plan view are being introduced.

Reinforcement - Not extensively used because of low seismic risk. Use limited to placement in vertical cores of hollow unit masonry 2 meters on center for resisting wind loads.

Design Methods - Empirical design rules are used only for domestic construction. The current code (as of February 1988) is based upon permissible stress and linear-elastic properties. A limit state code with load and capacity reduction factors will be adopted in 1988. Linear stress-strain properties will be used for analysis of unreinforced masonry and nonlinear properties will be used for reinforced masonry.

Current Research
Materials: Failure criterion in flexure and compression, mortar-unit bond.
Units: properties of hollow clay units (clay block)
Building components: Walls with openings, walls under concentrated loads, prestressed masonry.

Earthquake Induced Damage in the Last Four Years: None.

Canada

Mortar - Portland cement, hydrated lime, and sand in volume proportions ranging from 1:1/4:3 to 1:2:9.

Grout - Portland cement and aggregate with a maximum aggregate size of 10 mm in diameter. Water content is such that a slump of 200 mm is attained.

Units - Solid, cored (perforations less than 25% of the gross area) and hollow clay units. Solid units are approximately 200 x 100 x 60 mm in size. Hollow bricks are approximately 400 x 140, 190 or 240 x 100 mm in size. Concrete units are typically hollow and approximately 400 x 100-300 x 200 mm in size. However, many different shapes of concrete block are used.

Reinforcement - Deformed reinforcing bars of fy=300 Mpa and fy=400 MPa[4] are used for primary vertical and horizontal reinforcement. Joint reinforcement may be used placed in horizontal mortar joints, but is typically not included in strength calculations.

Design Methods - Working stress assuming linear-elastic masonry and reinforcing at service loads.

Current Research
Materials: several projects on basic masonry mechanics
Units: new concrete unit shapes
Components: slenderness effects of walls, post-tensioned walls, columns, beams under reversed cycling.

Earthquake Induced Damage in the Last Four Years: None.

People's Republic of China

Mortar - Portland cement, limepaste, sand. Proportions selected according to strength requirements. Required strength is generally 10-100 kg/cm^2.

Grout - Portland cement, aggregate. Proportions selected according to strength requirements. Grout required strength is generally 100-300 kg/cm^2.

Units - Solid (no voids), perforated (many small voids) and hollow made of clay, concrete, stone, lime-sand.

Reinforcement - Plain for diameters 4-10 mm, deformed for diameters 10-32 mm. Tensile yield strength: 2400-3800 kg/cm^2.

Design Methods - Empirical rules are greatly used. Analysis is based on elastic theory to analyze stresses, but is done only for important projects. The current code stipulates ultimate limit state design with capacity factors. A separate code addresses seismic design for industrial and civil buildings.

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4 See Appendix 1 for unit conversions

The number of stories for unreinforced buildings is limited and in seismic areas unreinforced buildings are required to be strengthened.

Current Research

Material: ceramsite and aerocrete materials for units, anticorrosion of refinforcement.
Units: manufacturing technology, optimum size and shape.
Components: walls subjected to bending and axial load, slender wall stability, local bearing capacity, shear walls.
Building Systems: Precast floor stiffness, dynamic response buildings using scale models, similitude theory, reliability.
Construction: quality of grout, units designed for rapid placing.

Earthquake Damage in the Last Four Years: R7 intensity in Zigong, Sichuan 29 March 1985. Of 104 buildings inspected 3.3% were seriously damaged, 20.4% destroyed, 49.4% slightly damaged. The majority of the damage was to older houses or factories. Newer structures designed by code performed well.

R8 intensity in Luquan (north of Kunming, Yunnan) on 18 April, 1985. Only a few one-story buildings on firm foundations survived.

R9 intensity in Wugia, Xinjiang 23 Auguts, 1985. All old houses of low quality were destroyed. One of 12 two to three story buildings with concrete roofs and masonry walls designed per code was seriously damaged.

Denmark

Mortar - Proportions are denoted by weight. Lime-sand, cement-lime-sand and cement-sand mortars are used as well as masonry cement mortars.

Grout - Not described in the code.

Units - Concrete, sand-lime, light weight concrete with porous aggregate, moler and aerated concrete bricks are used as well as tile. Bricks may be solid or contain cavities. Bricks are classified by strength.

Bricks may be made of six different materials. The standard and wide brick dimensions are 228 x 108 x 55 mm and 228 x 168 55 mm.

Bricks of basic dimensions 290 x 90 x 188 mm solid or with cavities are used. Blocks are made with light weight concrete, aerated concrete, sand-lime, moler, and tile. Block is also made of standard concrete.

Reinforcement - Reinforcing steel for masonry is the same as used for reinforcing concrete.

Design Methods - The 1987 code specifies both serviceability limit states and ultimate limit states. Safety against failure must be assessed by analysis of the complete structural system. Both unreinforced and reinforced masonry is addressed by the code.

Current Research - Not known.

Earthquake Damage in the Last Four Years - None.

Ireland

Mortar - Three types are used, i.e., cement:lime:sand, masonry cement: sand and cement:sand with plasticizer. The proportions of the cement:lime:sand type range from 1:¼:3 to 1:2:9 by volume with 28-day strength required from 11 MPa to 1 MPa.

Grout - Not used.

Units - Perforated clay units are used with up to 25% voids. Solid (0% void) concrete brick, 20-30% of which contain "frogs" are used as well as perforated (25-45% void) concrete block.

Reinforcement - Reinforced masonry has not been used to any great extent. There is interest, however.

Design Methods - Empirical rules are extensively used. The Irish code encourages analysis, but also contains empirical methods. The code is based on limit state philosophy which enables the degree of risk to be varied by choice of different partial safety factors.

Research - Development of a method of testing concrete block and development of characteristic strength of walls in terms of unit strengths.

Earthquake Damage in the Last Four Years - None

Japan

Mortar - Mortar is typically a cement-sand mixture. Methylcellulose and synthetic resin are occasionally used as an admixture. Proportions (C:S) are 1:2.5-3.5 by volume with corresponding minimum compressive strenths of 250 kg/cm^2 and 350 kg/cm^2.

Grout - Mortar as described above and concrete are used as grout. Minimum compressive strength is specified as 180 kg/cm^2.

Units - Hollow concrete units (block) of various shapes are used. Typical are cellular units 400 x 200 x 200 mm and bond beam units of a "U" shape. Solid, reinforced and hollow units are also used. The usual net strength of concrete units is 250 kg/cm^2 and in the case of clay units net strengths are specified as 200, 400 and 600 kg/cm^2.

Reinforcement - Plain and deformed steel bars are used. For use in masonry, diameter is restricted to 75 mm. Yield strengths for use in masonry are 24, 30, and 35 kg/mm^2.

Design Methods - Empirical rules are used for design of buildings and details. However, buildings of two or more stories or more than 200 m^2 floor area must be analyzed. Linear elastic behavior is assumed and allowable stresses are prescribed. The "wall rate" method which prescribes an amount of wall in terms of floor area is used to establish a minimum amount of structural walls. Design and construction requirements are presented in one standard and provisions for quality and testing in another.

Research
Materials: development of concrete for grouting.
Units: configurations to enhance placing and grouting.
Components: investigations into shear strength and ductility of walls and beams subjected to earthquake forces.

Building systems and subsystems: studies on the use of half precast floor panels and prefabrication masonry wall panels.
Construction Methods: development of methods to erect masonry without joint mortar. Use of prefabricated welded grid reinforcement.

Earthquake Damage in the Last Four Years - One and two storey houses and barns of partially grouted concrete masonry were damaged in the 1983 Nihonkai-chubi earthquake of Richter magnitude 7.7. Severe wall cracking occurred due to torsional vibrations and uneven ground settlement. Most of the damaged houses did not have reinforced concrete floor slabs and were not built according to code.

Mexico

Mortar - Mortar is either cement:lime:sand or masonry cement:sand. Cement:sand ratios range between 1:3 and 1:6 and compressive strengths between 20 and 100 kg/cm^2.

Grout - Grout ingredients are proportioned by volume. Maximum aggregate size is 6 mm. A high initial water content is used to enhance placement and no admixtures are used. Typical compressive strength is 100 kg/cm^2.

Units - Handmade solid clay bricks (280 x 140 x 70 mm in size) are widely used. Compressive strength varies between 30 and 100 kg/cm^2. Concrete blocks similar to those used in the U.S. and Canada are used with width equal to 150 mm. Minimum compressive strength is 60 kg/cm^2. Quality can be very good in industrialized areas and may be poor in other areas. Concrete brick is produced by small plants with compressive strengths of about 50 kg/cm^2.

Reinforcement - Deformed steel bars, 8-10 mm diameter, and minimum yield stress of 414 MPa are used commonly. Six mm diameter bars with minimum yield stress of 275 MPa are used for stirrups in concrete confining members. Ladder-type wire reinforcement is used for horizontal reinforcement in concrete block masonry.

Design Methods - The Mexico City Code and its Technical Norms for Masonry Structures are commonly used. Methods of analysis are provided, but sometimes more sophisticated methods are used for lateral load analyses. The code is on an ultimate load limit state basis. A new version of the Technical Norms was issued after the 1985 earthquake which contains increased seismic coefficients.

Research - Extensive research was done on the structural behavior of masonry, especially for seismic loads, in the 60's and 70's. Recent interesting research projects concern the performance of masonry structures in recent strong earthquakes.

Earthquake Damage in the last Four Years - The most significant recent earthquake was on 10 September, 1985. Modern masonry buildings performed well. Significant damage and collapse has been reported in unreinforced poor quality masonry (mainly adobe) houses and in masonry infill walls in concrete buildings.

Hungary

Mortar and Grout - no information.

Units - Clay unit masonry is predominant. About twenty types of clay

block are used. All are hollow except for a special dense brick for chimneys. New clay blocks are made which satisfy new high heat insulation requirement. Concrete block masonry is used mainly for basement and retaining walls.

Reinforcement - Generally not used except in retaining walls.

Design Methods - Uniform mandatory codes govern masonry construction and design. It provides for service and ultimate limit states.

Research - No information.

Earthquake Damage in the Last Four Years - Damage and collapse of one-story unreinforced dwellings due to a minor earthquake in August, 1985.

Norway

Mortar - Both portland cement:hydrated lime:sand and masonry cement:sand mortars are used. Proportions by weight of cement:lime:sand mortar range from 20:80:440 to 35:65:610 with corresponding compression strengths of 12 to 5 N/mm^2. Masonry cement:sand mortars are proportioned by weight from 100:380 to 100:760 and with corresponding compression strengths from 12 to 3 N/mm^2. Property specifications are used for control.

Grout - Grout is seldom used. When used, requirements and methods are based on U.S. practice.

Units - Solid and cored bricks are used. Net cross-sectional area of cored units is 76-80% of gross area. "Normal" brick are 228 x 108 x 62 mm in size and "Modular" brick are 188 x 88 x 87 mm and 288 x 88 x 87 mm in size. Brick compressive strength ranges from 15 to 16 N/mm^2.

Light weight concrete block with insulation sandwiched between faces is very common as well as more typical unit shapes, e.s., two-cell and bond beam units. Widths are from 150 to 250 mm, heights from 150 to 250 mm and lengths from 250 to 500 mm.

Reinforcement - Vertical reinforcement is just being introduced. Horizontal bars are used in lintels and window beams. Corrosion is a serious concern. In the future galvanized or stainless steel will be required. Required yield stress is 37-50 N/mm^2.

Design Methods - Design is based on ultimate limit state with partial safety factors. Design is governed by a national standard which mainly addresses unreinforced masonry.

Research
Materials: clay brick with light color, pigmented concrete units, insulated "sandwich blocks" for facades, unit-mortar shear.
Components: capacity of columns and pilasters with vertical steel reinforcement.

Earthquake Damage in the Last Four Years - None.

Peru

Mortar - Both cement:hydrated lime:sand and cement:sand:mortars are used. Proportions, by volume, of cement:lime:sand range from 1:1:4 to 1:1:6 and for cement:sand mortar proportions range from 1:4 and 1:6. Other compositions are allowed if strength and durability requirements are met.

Grout - Grout (fluid mortar) is a mixture by volume of 1 part cement: 1½ parts hydrated lime: 3 parts fine aggregate.

Units - Calcium silicate and clay bricks and concrete blocks of various shapes are used. Compressive strength requirements for bricks are from 60 to 180 kg/cm^2. Four types of mortarless masonry have been developed.

Reinforcement - Reinforcement is used in zones 1 and 2 for individual walls which carry 10% of the seismic force and in groups of walls, including perimeter walls, which carry 70% of the seismic force. In seismic zone 3 at least perimeter walls will be reinforced.

Design Methods - Working stress design is presently followed, but the code is being revised to exclude this method and will be based upon ultimate strength design concepts.

Research
Components: indirect tensile strength experiments, shear-friction studies, shear wall tests.
Systems: mortarless masonry

Earthquake Damage in the Last Four Years - None.

United States

Mortar - Portland cement:hydrated lime:sand is the most common mortar. Proportions, by volume, range from 1:1:6 to 1:2:9. Masonry cement:sand mortar is also used but is not permitted in the higher seismic zones. Minimum compressive strength requirements are from 17 MPa to 2.5 MPa for both types. Normally, actual strengths attained are much higher than the minimums.

Grout - Grout is classified as "fine" or "coarse" depending upon the presence of coarse aggregate. Fine grout consists of 1 part portland cement and three parts sand. Coarse grout consists of 1 part portland cement, 3 parts sand and 1 to 2 parts coarse aggregate. Coarse aggregate diameter is usually 10 mm diameter or less. Grout is characterized by its high initial water content to facilitate placement. Additives are permitted to enhance filling of grout spaces.

Units - Clay units - solid, cored, and hollow and concrete units - solid and hollow are used. A large variety of shapes and sizes of each type are used. A popular clay unit is approximately 200 x 100 x 60 mm in size with 3 cores each of about 2.5 cm in diameter. A large (30-40 x 10-20 x 10 cm) hollow brick similar in plan view to concrete block is used in the western U.S. for reinforced clay-unit masonry. Concrete block with two large cells of 400 x 200 x 200 cm dimensions is the most common and is used extensively for reinforced masonry.

Reinforcement - Deformed steel bars with minimum yield stresses of 275 Mpa and 414 Mpa are used for horizontal and vertical reinforcement. Horizontal ladder and truss wire reinforcement is used in concrete masonry for shrinkage crack control.

Design Methods - No single national code is in effect. All codes presently are based on working stress and linear-elastic behavior although the Uniform Building Code which is effective over the western two-thirds of the U.S. includes limited provisions for ultimate strength design. Development of a complete ultimate strength design method is in progress.

Research

Materials: basic behavior of grouted hollow clay and concrete masonry.
Units: limited studies on geometry of hollow units.
Components: flexure of walls, one, two and three story walls under shear and compression, bond and splices or rebar in grouted masonry, concrete plank floor systems for masonry buildings.
Systems: tests of a full sized building.
Modeling: development of models for detailed analyses and for building response to lateral seismic loads.
Existing Masonry: application of non-destructive evaluation methods.

Earthquake Damage in the Last Four Years - The Whittier earthquake in the Los Angeles area in 1987 caused damage to many unreinforced masonry buildings. Reinforced masonry buildings performed very well.

West Germany

Mortar - Portland cement:hydrated lime:sand mortars are used. Compressive strength required for quality tests ranges from 5 MPa to 20 MPa.

Units - A large variety of units are used made of both clay and concrete. Among them are solid aerated concrete units with face frog or tongue and groove on the ends in sizes from 240 x 115 x 115 mm to 750 x 375 x x 249 mm. Compressive strengths range from 2 to 8 MPa. Perforated calcium silicate units are used. They are considered solid if the perforation area is less than 15% of the gross area. Sizes range from 240 x 115 x 52 mm to 490 x 300 x 238 mm with strengths from 4 to 60 Mpa. Clay units with horizontal perforations in sizes from 240 x 115 x 52 mm to 240 x 300 x 113 mm are available. Light weight concrete units, with tongue and grooved ends and grip holes are used in sizes from 260 x 115 x 115 mm to 245 x 365 x 238 mm. Strengths range from 2 to 12 MPa.

Grout - Not used except in reinforced lintels.

Reinforcement - Used primarily in lintels.

Design Methods - The working (permissible) stress is used and linear-elastic behavior assumed. Masonry is in two strength classes; one based upon unit/mortar combinations and the other based on assemblage tests. Walls are considered as part of a floor-wall frame system. The present code addresses unreinforced masonry although reinforced lintels have long been used. A draft of a reinforced masonry code has been prepared.

Research - The recent developments include the introduction of light-weight concrete units placed dry, units with a variety of tongue and groove systems, large formate blocks, units with integrated thermal insulating materials and framework units. Tools and machinery have been developed to assist unit placement. Efforts on units and equipment were directed toward improvement in productivity.

Future research topics include flexural tensile strength, effect of concentrated loads, eccentricity effects and reinforced masonry.

Earthquake Damage in the Last Four Years - None, however, in 1978 an earthquake in southern Germany caused cracking and other local damage to buildings.

Yugoslavia

Mortar - Three types are listed in the code: pure lime-sand (seldom used), cement:lime:sand, and cement:sand (not allowed in seismic regions). No proportions are required; quality of a mortar mix must be determined by test for each specific case. Mortar is classified into four strength categories from 0.5 MPa, 2.5 Mpa, 5 MPa, and 10 MPa. Only mortars of the second and third of the preceding strength levels are allowed for construction in seismic regions and only the third category is permitted in high intensity seismic zones.

Grout - No specifications exist.

Units - Solid or perforated bricks and differently shaped hollow blocks are used. Dimensions and shapes are standardized. Typical dimensions for bricks are 250 x 120 x 65 mm and for hollow block: 390 x (190 or 240 or 290) x 190 mm. Structural walls must be made with hollow blocks with vertical cells. Solid and perforated brick are made of clay and blocks are made of ceramic materials, concrete, light weight concrete and fly ash concrete. Typical strengths are 10 MPa for brick and 7.5 MPa for block (based on gross area).

Reinforcement - Deformed steel bar with a minimum yield stress of 400 MPa. For horizontal reinforcement only, smooth bars with a minimum yield of 240 MPa are allowed as well as ladder or truss reinforcement. The latter must have a yield stress of 500 MPa.

Design Methods - Seismic resistance of all buildings exceeding 2 stories must be verified by calculation. No specific method is prescribed for verification of stability and either allowable stress or limit states methods may be used. Shear resistance must be checked by a specific formula.

Research - Research has, and will address: the behavior of masonry shear walls and masonry infilled concrete frames under cyclic in plane loads; the repair and strengthening of existing and earthquake-damaged masonry buildings; reinforcing bar bond and splicing in grouted masonry; and the seismic behavior of mixed concrete-masonry buildings. The research is for the purpose of improving codes and standards for masonry construction in seismic zones.

OTHER ACTIVITIES PERTAINING TO MASONRY STRUCTURES

Eurocode EC6- By agreement, the 16 common market countries are drafting common technical codes and standards. EC6, "Common Unified Rules for Masonry Structures" has been prepared on draft form and is similar to ISO TC 179, "Code of Practice for Unreinforced Masonry." Ultimate limit states and serviceability limit states are addressed. Partial safety factors are provided. The code also requires that several issues related to durability of the structure be addressed.

ISO TC179- The International Standards Organization began work on a three-part standard in 1986. The parts are SC1 - unreinforced masonry, SC2 - reinforced masonry, SC3 - masonry tests.

RILEM 76LUM- Committee 76 LUM has been working several years to produce a document containing standard tests pertaining to units and materials, small walls and prisms, full-scale elements and in-situ and non-destructive evaluation. The first draft is complete and is available from ISO for review.

Conseil International Du Batiment (CIB)- Commission W23, Wall Structures, has been addressing topics pertient to masonry buildings for many years. Recent work includes preparation of design standards for unreinforced and reinforced masonry. Current work includes discussing the relationship between various national masonry codes and CIB international standards, and evaluation and strengthening of existing masonry.

PROFESSIONAL ORGANIZATIONS

Two non-profit orgnaizations devoted to the assimilation, review, and dissemination of information related to masonry materials and structures and other professional activities have been formed. They are: The Masonry Society organized in 1977 in the United States and the British Masonry Society organized in the U.K. in 1986. Both societies sponsor conferences, publish a journal and engage in various other activities.

Addresses are:

The Masonry Society
2619 Spruce Street
Boulder, Colorado 80302
U.S.A.

British Masonry Society
c/o British Ceramic Research Limited
Queens Road, Penkhull, Stoke-on-Trent
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CONCLUSION

Based on responses to the questionnaire, information in the literature, papers presented in this session and other sources, the current state-of-the-art of masonry structures covers a wide spectrum. A plethora of types of units are used; mortars are similar; reinforcement is used in seismic areas, if available; both permissible stress-linear elastic and ultimate strength limit state design methods are used; and empirical methods of design are common. Essentially, materials, construction and design range from simple to sophisticated.

A great amount of research and development has been done recently, is under way and is planned in many locations. Much is directed toward seismic design considerations, but much also is in the area of masonry units and materials, behavior of subassembleges, evaluation and strengthening of existing structures, design methodologies, analytical techniques, and construction processes.

Experience has shown that well-designed and constructed masonry buildings perform well in seismic and other load environments. Much work remains to be done, beyond that alluded to here, to realize the potential of masonry. Sessions such as this, and other mechanisms are necessary for the exchange of ideas and information to promote progress.

APPENDIX I CONVERSIONS

1 kg/cm^2 = 9.806 (10^4)Pa
1 lb/in^2 = 6.895 (10^3)Pa
1 lb = 4.45N

1 kg/mm^2 = 9.807 (10^6)Pa
1 kg = 9.807 N
1 inch = 2.54 cm

APPENDIX 2 - SURVEY RESPONDENTS

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