

Masonry in the Americas



Daniel P. Abrams
Editor

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PREFACE

The emergence of masonry as a modern construction method has followed numerous parallel paths. Columbus is known to have introduced European masonry construction to the West Indies with the building of masonry churches. Native Americans were constructing monuments, temples and dwellings of masonry many centuries well before this time. In fact, ancient cyclopean masonry – immense irregular blocks of stone laid together without mortar – which have been found throughout Europe, have also been found in Peru. These early American masonry structures along with the ancient Aztec, Inca, and Mayan temples, and the Anasazi terraced cliff dwellings lend credence to the notion that masonry construction practices must have evolved independently throughout the Americas before trade routes or other lines of communication developed.

As a result of this parallel evolution, variations in masonry construction techniques from country to country exist even today. Basic terminology used to describe masonry construction is different throughout American countries. An opportunity exists to correlate performance of various masonry construction methods so that more can be learned about the sensitivities, or commonalities, inherent in the construction techniques that we all use.

Masonry buildings are one of the most vulnerable types of structures to seismic excitation. Improvements in engineering and construction practices are needed to improve the quality of life in all American countries. A potential exists for learning about dynamic response of such structures by correlating engineering and architectural practices with observations of seismic damage for various forms of masonry construction found across the Americas. Design practices and building code specifications for earthquake-resistant design can be contrasted from country to country in an effort to standardize engineering methods. Such an exercise also benefits design procedures for resistance to other lateral loadings such as strong winds or blasts.

Four years ago, an effort was started within the *ACI-ASCE 442 Committee on Response of Concrete Buildings to Lateral Forces* to provide a forum where masonry engineering practices could be discussed. Because of the strong interest of committee members from Latin American countries, it was decided to compile a set of papers on various masonry related topics authored by engineers from various North, Central or South American countries. Selected topics included: (a) masonry construction practices; (b)

masonry design practices; (c) masonry damage in past earthquakes; (d) evaluation and retrofit techniques; and (e) masonry research. A sampling of American countries was chosen which included Canada, the United States, Mexico, Costa Rica, Colombia, Peru, and Chile. Authors from each country were asked to write a paper summarizing these topical areas. Papers were presented during a technical session at the Fall ACI Convention in San Juan, Puerto Rico, in October of 1992. Since then, the effort has been known as the *Masonry in the Americas* project which was the title of the technical session and is the title of this publication.

Following the technical session, each of the seven "country" papers were sent out for review, revised and resubmitted for final publication. These papers comprise the last seven papers of this publication.

At a meeting of the authors at the convention in Puerto Rico, it was decided to compile five additional papers summarizing each of the topical areas. Selected individuals were solicited to prepare survey papers on materials, construction practices, engineering design, and performance in past disasters across the American countries. Drafts of these papers were reviewed, revised and resubmitted for final publication. These "subject" papers comprise the first five chapters of this publication.

One long-range goal of this publication is to serve as a resource document for the future development of building codes for lateral-load design of masonry buildings, or guidelines for their structural evaluation and rehabilitation. As well, the publication should be of worth to researchers as a compendium of masonry research projects throughout the Americas.

In the spirit of the international cooperation that made this publication possible, it is hoped that similar cooperative programs will continue in the future. This effort has already stimulated the First Pan American Masonry Symposium which was held in Bogota in October of 1993. Continued growth on this theme may encompass future symposiums, a Pan American code of masonry engineering practice, and a Pan American Masonry Society.

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Masonry Materials

by L.E. Yamin and L.E. Garcia

Synopsis

This chapter presents a summary of the materials more widely used for masonry construction in the different countries in the Americas. An attempt has been made to establish groups of similar masonry units, including typical values for some of the more important mechanical properties. Typical particularities for some countries are mentioned. However, only masonry units for structural purposes are discussed. Mechanical properties, mix characteristics and particular details related to mortar and grout used in different countries are summarized. Grades and characteristics of reinforcement steel for masonry construction are presented. A brief summary of mechanical properties of masonry assemblages for different countries is included together with a review of the appropriate local standards. Finally, some of the accessory materials for masonry construction are presented.

Keywords: Adobe; bricks; clays; concrete blocks; concrete bricks; construction practice; grout; masonry; materials; mechanical properties; mortars (material); prisms; reinforced masonry; sand-lime brick; tiles

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INTRODUCTION

Masonry is one of the most widely used construction materials in the Americas, however because the development of its use followed different paths in each country, and even within the same country, the diversity of materials and construction techniques is broad when seen in a continental basis. Some of the materials employed in masonry construction are essentially the same in all the American countries and are manufactured following similar standards, as is the case of Portland cement and reinforcing steel. On the other hand, the masonry units and the type of aggregates for mortar and grout are different from country to country, even though the same names are used to describe them. The quality of workmanship varies enormously in the Americas and specially from urban to rural areas in the same country. These characteristics render masonry construction difficult to compare from country to country. This is specially true for the materials used in masonry construction.

Materials used in masonry construction can be divided in four groups: masonry units, mortar, grout and reinforcement. Masonry units can be grouped together depending on the material employed, their geometry and the distribution of cores, when used. Following this distribution and considering the production technique, general characteristics and mechanical properties can be established. Mortar and grout also present a great variability depending on the aggregates employed, mix proportions and quality of workmanship. North American standards have had a great influence in the type of mix proportions employed and most countries describe their mortars in the same way. This has improved the quality of mortars throughout the Americas, although in some countries mortars made out of non typical materials are still used.

Reinforcement is available in different grades and characteristics, conforming to local standards, all of them very similar to ASTM A615. In those countries that do not have local steel mills, imported steel is used, thus making the diversity of quality even broader, specially when Japanese or European steels are used. The employment of the same type of reinforcing steel in reinforced concrete structures guarantees its availability. The changes that are currently occurring throughout the Americas, concerning the release of trade barriers, will have a large impact in the unification of manufacturing standards for construction materials, at least in neighboring countries.

CHARACTERISTICS AND PROPERTIES OF MASONRY UNITS USED FOR STRUCTURAL PURPOSES

An attempt has been made to establish a common classification of masonry units with regard to materials, geometry and distribution of cores. Even though it is impossible to cover all types of units available in different countries, most of the units available can be classified in one of the following groups:

- Concrete block
- Solid concrete brick
- Clay block
- Clay brick, solid or cored
- Clay tile
- Sand-lime units, solid or cored
- Adobe units

Table 1 indicates in which countries and to what degree each of the types of units are used for structural purposes.

Concrete Block

It is also called hollow load-bearing concrete masonry unit. Concrete block is typically made from low slump concrete and usually has the form shown in Figure 1.a. Manufacturing method vary from hand made artisan procedures to fully industrialized plants with large production capacities. These units are generally used for reinforced, fully grouted bearing walls and shear walls, but can also be used in cavity walls, confined masonry and non-structural masonry. The net area of the units reported is about 55% to 60% of their gross cross-sectional area. Most units are provided with two modular cores. Concrete masonry units usually comply with standard ASTM C90 (Hollow load bearing concrete masonry units) and are sampled and tested using standard ASTM C140 (Methods of sampling and testing concrete masonry units). Local standards are based on ASTM standards because this type of block is of North American origin. Typical dimensions and compressive strengths reported for different countries are presented in Table 2.

Solid Concrete Brick

This type of unit is not as widely used in the Americas as the concrete block. Only a few references to its use were found, specially in México. The manufacturing process, the quality and the general appearance are very similar to those of the concrete block just presented, except for the size of the unit. General dimensions reported are about 10 x 14 x 24 cm (4 x 5½ x 10 in.) (See Figure 1.b). Mean compressive strength varies between 5.0 and 9.0 MPa (725 to 1305 psi), depending on the manufacturing method and the quality control employed.

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Clay Block

This type of unit was developed by the clay industry as a response to the more generalized use of the concrete block. Although the shape and dimensions are very similar to those of the concrete block, general appearance and mechanical properties are quite different. It is shown in Figure 1.c. Typical nominal dimensions are 15 x 20 x 40 cm (6 x 8 x 16 in.).

Another variation from this type of unit was developed with reduced overall dimensions, intended to facilitate construction procedures thus allowing the mason to manipulate the unit with one hand and the mortar with the other. This type of unit is called Hollow Clay Brick and is shown in Figure 1.d. Typical nominal dimensions are 15 x 10 x 30 cm (6 x 4 x 12 in.). Additional variations of the previous types of units were developed specifically for uses where appearance is important. However general characteristics and mechanical properties do not change in a sensible manner. These types of units are intended for reinforced masonry, fully or partially grouted. They have become more widely used in some countries, specially developing countries, where clay products are generally less expensive than concrete products.

Manufacturing methods vary, but extrusion methods are the most widely used. The net area of the units is generally about 55% to 60% of their gross cross-sectional area. Most units have two modular cores. Table 3 presents a summary of compressive strengths reported by different countries.

Clay Brick, Solid or Cored

The clay brick, solid or cored is a very widely used variation of the clay units. Core area does not exceed 30 % of the unit area. The thickness of the external wall must be more than 2 cm (0.79 in.). This type of unit is shown in Figure 1.e. Due to its generalized use, clay brick is produced in an almost infinite number of sizes, shapes and appearances. Some are intended exclusively for structural use, some for decoration or appearance purposes. The most common size might be the "modular" unit measuring 19.5 x 5.7 x 9.2 cm (7-5/8 x 2-1/4 x 3-5/8 in.) or in some countries 24.5 x 5.5 x 12.0 cm (9.65 x 2.17 x 4.72 in.).

Table 4 summarizes typical dimensions and average compressive strengths for different clay bricks used in some American countries. This type of unit is used mainly for confined masonry walls and non-structural purposes.

Clay Tile

Clay tile (shown in Figure 1.f) is widely used for non structural purposes such as partition walls, but in some developing countries it is used as a structural element in confined masonry walls, specially for one or two story dwellings. The manufacturing process is done by extrusion. The unit is laid with the cells placed horizontally. Typical dimensions are 11.5 x 33.0 x 23.0 cm (4.53 x 13 x 9 in.) with 6 horizontal cells but recently, a great variability of dimensions and distributions of cells has appeared. Mean compressive strengths reported are about 5 MPa (725 psi) with values of initial rate of absorption about 30 gr/min/200 cm² and total absorption about 16%.

Sand-Lime Units

This type of unit is shown in Figure 1.g. It is produced using European technology. Manufacturing process is industrialized with high production rates and good quality and uniformity. Molded specimens are exposed to high pressure water steam in hermetic containers where the chemical reaction between sand and lime takes place. High strength units, with good dimensional tolerances and appearance, are produced in several American countries. Typical dimensions and average compressive strengths for different countries are presented in Table 5.

Adobe Units

Although widely used during colonial times in Spanish speaking countries, it has very limited use nowadays, with a few exceptions (Bolivia, Ecuador and Perú) where adobe units are still very popular specially in rural areas. In most countries the "technology" of its use was lost. Its sensitivity to climatic humidity has promoted fired clay units, and barring ornamental uses, it could be said that adobe brick is seldom times used for structural purposes in urban areas. However, it is still used for one and two story housing, in small towns and rural areas in some countries. Some data reported indicates compressive strengths of the order of 1 MPa.

Mortar-less Units

Units which are bonded together using mechanical features incorporated within the unit without the aid of mortar have been developed in several countries. They vary in material employed and dimensional characteristics, and usually belong in proprietary systems, therefore are beyond the scope of this work.

MORTAR

Different types of mortar are used in the Americas, depending primarily on the type of masonry construction. Traditional mixes are used in non-engineered construction. Mixes established by standards are used in engineered masonry construction as a rule. The economics involved in cement usage and the required qualities of the finished product have promoted the use of ready mixed mortars and more technically proportioned mixes.

The following classification of mortars is used in several countries:

- Portland Cement-Lime mortar
- Masonry Cement Mortar
- Portland Cement-boulder sand mortar
- Ready-mixed mortar

Table 6 shows which type of mortar is used in every one of the countries reporting data for this document. Masonry mortars are characterized in terms of compressive strength, tensile bond strength, initial flow and flow after suction. In the following paragraphs, a general description and the main mix characteristics are given.

Portland Cement-Lime Mortar

This consists of different proportions of Portland cement, lime and masonry sand. It is most common batched by hand on site using material from bags, but also batched automatically on site using materials from silos. It can be specified according to proportion (the default) or according to properties (in general standard ASTM C270). Table 7 presents proportion specifications for Portland cement-lime mortar.

ASTM specifications cover cement (ASTM C150), mason's lime, and mason's sand. Lime is addressed in ASTM C207 (Hydrated lime for Masonry Purposes). That specification includes Type N mason's lime, which have no metallic oxide limits (Type NA is air-entrained) and Type S mason's lime, which have oxide limits (Type SA is air-entrained). Mason's sand, particularly regarding gradation limits, is addressed in ASTM C144 (Aggregate for Masonry Mortar). Most countries in the Americas follow these standards either directly or by local standards based on them.

Property specifications for Portland cement-lime mortar are given in Table 8. These property specifications apply only to laboratory prepared mortar, with a flow of about 110. They are not requirements for field mortar. Flow is a standard index of the fluidity of mortar, and increases with increasing water content. When fresh mortar is exposed to a standard suction or is placed on a unit for a prescribed time, it loses some water, and its flow decreases. Water retention is the ratio of the flow after suction, to the flow before suction.

In general, most American countries follow the same standards, although some variations are introduced locally, for example elimination of mortar type O for seismic regions or elimination of the hydrated lime in the mix when used with clay units.

Masonry Cement Mortar

This type of mortar has a more limited use than the previous one. It consists of different proportions of Portland cement, masonry cement and sand. Masonry cement is usually manufactured and distributed on a proprietary basis. It consists of Portland cement, plasticizing additives, air-entraining additives, water retention additives and ground limestone. It may also contain mason's lime. Masonry cement mortar is specified according to proportion (the default) or according to properties, using the provisions of ASTM C270 and ASTM C91. Proportion specifications for Masonry cement mortar are given in Table 9. Note that for mortar grade M and S, masonry cement mortar can be used directly, or made by adding Portland cement to grade N masonry cement. Property specifications for masonry cement mortar are given in Table 10. These property specifications apply only to laboratory prepared mortar, with a flow of about 110. They are not requirements for field mortar.

Portland Cement-Boulder Sand Mortars

In most Latin American countries, with the introduction of Portland Cement in the 1920's, the use of lime in the fabrication of mortars was abandoned, specially in the large cities. In cities where boulder sand was readily available, the typical bonding mortars were made using Portland Cement and boulder or mined sand. This combination gave the proper workability and strength to the mix when used with clay masonry units. The high percentage of fines, and some time organic matter, made this mixes uneconomical in most occasions. On the other hand very

little cracking was observed under normal circumstances when used with clay masonry. Mechanical properties for this type of mortars are given in Table 11. With the introduction of concrete block, joint cracking problems forced the use of cement-lime mortars using the same type of sands employed in manufacturing concrete. Current practice in several countries is to use boulder sand with no lime for mortar intended for use with clay units, and M, S and N cement-lime mortar with sand complying with ASTM C144, for concrete units.

Ready-Mixed Mortars

This is a type of mortar that is delivered to the site in containers. It contains Portland Cement, plasticizing additives, air-entraining additives, water retention additives, and set-retarding additives. Set is triggered by loss of water and set-retarders when mortar is placed in wall and units absorb water. Set can be delayed for up to 72 hours.

GROUT

Grout for masonry is composed of Portland cement, hydrated lime in small quantities, sand, and pea gravel, when unit hole size allows it. Masonry grout is specified according to ASTM C476 (Grout for Masonry). Proportion specifications are as given in Table 12. Since this type of grout comes from North American practice, standard ASTM C476 or local versions based on it, are used. When masonry grout is placed in the cells of units or between wythes of masonry, the dry units absorb water from the grout, reducing its water-cement ratio and increasing its compressive strength. When masonry grout specimens are produced under conditions that reproduce this reduction in water-cement ratio, compressive strengths of at least 140 MPa (2000 psi) are typical. This value must be in general from 1.2 to 1.5 times the value of the f'_m of the masonry.

REINFORCEMENT

In most countries, a great variety of reinforcement steels for masonry are available. These consist of deformed steel reinforcing bars, deformed reinforcing wire or wire fabric and plain bars and wires.

Typically, deformed reinforcing bars have a minimum specified yield strength of 420 MPa (60,000 psi), with diameters ranging from 9 mm (3/8 in.) to 25.4 mm (1 in.), for use in masonry structures. In some countries Grade 40 (280 MPa) deformed reinforcing bars are also available. Deformed reinforcing wire often has minimum specified strengths of 525 MPa (75,000 psi). Plain bars are usually available in 6.5 mm (1/4 in.) and 9.5 mm (3/8 in.) diameter usually of Grade 40 steel (280 MPa). Plain wires in diameters from 3.5 mm (0.14 in.) to 9.5 mm (0.38 in.) in 0.5 mm (0.02 in.) increments are usually available with a nominal yield point of 240 MPa (60 ksi). However, being cold-worked they tend to be very fragile and to have low deformation capacity after yielding. Welded wire fabric is also available for joint reinforcement in several countries, generally in truss-type or ladder-type configurations.

MASONRY PRISMS

Masonry units, mortar and grout are combined to form masonry assemblages, whose mechanical properties can also be evaluated by standardized tests. The most common assemblage is the prism test, a concentric compression test on masonry prisms, conducted in most countries as specified in ASTM E447 (Compressive Strength of Masonry Prisms). The main objective of the test is to get a reliable value of f'_m of the masonry (Fig. 2a). However, due to limitations on the available testing equipment, some variations are sometimes introduced to be able to test smaller specimens than those required by the standard. Some countries have developed special test procedures for measuring the modulus of elasticity of masonry prisms.

Prisms of clay, concrete or sand and lime bricks are normally built of at least five units, placed directly one above the other. When loaded in compression, clay assemblages typically fail by vertical splitting. The mortar, more flexible than the unit expands laterally and induces biaxial transverse tension in the units. Prisms of concrete and sand and lime bricks generally fail by pure compression or crushing of the mortar and/or unit. Prisms of clay tile are normally built of only two units one over the other. These prisms usually fail by longitudinal cracking in the joints of the vertical and horizontal faces of the unit. Total collapse is observed once these cracks generalize. Finally, prisms of concrete blocks are normally built of two units, placed directly one above the other. Sometimes, half units are used, maintaining the same aspect ratio of the prism, to be able to use reduced capacity testing machines. If the final masonry construction is grouted, the test prism is also grouted. Table 13 summarizes typical compressive strengths reported for different types of assemblages (units, mortars, with or without grout) for different countries.

Another relatively popular test, specially in recent years, is the diagonal compression test (Fig. 2b). Due to limitations on equipment available, some local modifications are usually introduced. The purpose of this test is to measure the shear strength of the masonry. Failure occurs in one of three possible ways: failure through the joints, failure through the units or combined failure. Cracks tend to form along the line joining the corners subjected to compression. Very brittle modes of failure are generally observed. Table 14 summarizes reported values of f'_v for different types of units and mortars and for different countries. Finally, Fig. 3 shows other test set-ups designed to obtain shear strength values. However, these tests are presently used only in research projects.

MATERIAL STANDARDS

Most standards for different countries in America are based on ASTM standards with some important variations on specific cases. Countries that reported having their own standards which in turn varied in some degree with the corresponding ASTM standards were:

Canada	CSA -- Canadian Standard Association
United States	ASTM -- American Society for Testing and Materials
	UBC -- Uniform Building Code Standards
México	DGN -- Dirección General de Normas
Costa Rica	Uses ASTM Standards
Colombia	ICONTEC -- Instituto Colombiano de Normas Técnicas
	Also uses several ASTM Standards
Peru	ITINTEC -- Instituto de Investigación Tecnológica Industrial
	y de Normas Técnicas
	Also uses several ASTM Standards
Chile	INN -- Instituto Nacional de Normalización

ACCESSORY MATERIALS

Accessory materials for masonry consist of the following:

Connectors (galvanized or stainless steel)

- Ties (connect a masonry wall to another wall)
- Anchors (connect a masonry wall to a frame)
- Fasteners (connect something else to a masonry wall)

Sealants

- Expansion joints (brick masonry)
- Control joints (concrete masonry)
- Construction joints

Flashing

Coatings

- Paints
- Water-repellent coatings

Vapor Barriers

These materials are used specially in the United States and Canada. Its uses in the rest of the Americas depend directly on how mild is the climate. More severe weather requires special materials to overcome the effect of the climate on the structure and the occupants. Therefore, basic references to these materials are from the two countries mentioned. In the remainder of this section, some of these accessory materials are discussed briefly

Connectors

Basic connectors in most of the Latin American countries are reinforcing bars embedded in the joint mortar. In some countries, more sophisticated connectors are readily available, usually proprietary systems. The last is specially true in the United States and Canada. Connectors for securing two or more pieces, parts or members together, including anchors, wall ties and fasteners are typical, including fasteners to connect non-structural elements to masonry. In the United States connectors must conform to ASTM A36 (plate, headed and bent bar anchors), ASTM A325 (high-strength bolt anchor), ASTM A366 (sheet steel anchors and ties), ASTM A185 (steel wire mesh ties), ASTM A82 (steel wire ties and anchors), or ASTM A167 (stainless steel sheet anchors and ties). Optional requirements for stainless steel connectors are given in ASTM A167. Optional requirements for galvanized steel connectors are given in ASTM A641, A153, or A525 as appropriate. The principal design consideration for connectors is usually durability (corrosion resistance).

Sealants

In the United States and Canada, sealants are used in all types of movement joints. Clay masonry typically expands over time, and expansion joints are provided where this expansion can be accommodated without producing compressive stress in the masonry. Concrete masonry typically shrinks with time, therefore control joints are provided where this shrinkage can be accommodated without cracking in tension the masonry. Construction joints are typically located between separate sections of a structure. All three types of joints are often filled with elastomeric sealant. Many different kinds of sealants are used, most often silicone or latex-based. Sealants are classified with maximum tensile and compressive strain, and durability under environmental

exposure. The use of sealants in other American countries varies depending on the climatic conditions although the same type of products available in North America are marketed elsewhere.

Flashing

In the United States, flashing is used to increase the water-tightness of masonry walls. It is placed at the bottom of cavities (over shelf angles), and at the tops and bottoms of door and window openings. The most common flashing materials are plastic sheeting made of polyvinyl chloride (PVC), and copper sheeting, which is sometimes covered with PVC. Galvanized steel sheet is used for this purpose in some Latin American countries.

Coatings

Clay masonry is not normally painted, concrete masonry sometimes is. Clay masonry is sometimes coated with various water-repelling agents, typically silicones, which are available in all the reported countries.

Vapor Barriers

Vapor barriers are used in countries with large seasonal temperature changes to prevent water vapor from migrating from the warm side of a wall and condensing on the cold side. Its use in the different countries varies enormously, depending on the type of masonry and the geographical location.

CONCLUDING REMARKS

Development of masonry materials followed different paths in most of the countries in the Americas, although several common factors are encountered in current practice. This is specially true for concrete block masonry in which the United States practice is followed in most countries.

The diversity in the use of clay masonry is evident from the information presented. There is a large variation in the terminology employed for describing masonry units in the Spanish speaking countries of the Americas, and even within the same country. This makes the exchange of information about masonry difficult, and sometimes misleading. Efforts should be made to solve this situation.

REFERENCES

1. Bruneau, M., Assessing the Seismic-Performance of Existing Masonry Buildings in Canada, Paper presented at the ACI Fall Convention, San Juan, Puerto Rico, ACI-ASCE Committee 442, American Concrete Institute, October 1992
2. Klingner, R. E., A Review of Masonry Construction in the United States of America, Paper presented at the ACI Fall Convention, San Juan, Puerto Rico, ACI-ASCE Committee 442, American Concrete Institute, October 1992
3. Melt, R., Seismic Design of Masonry Buildings - The Mexican Practice, Paper presented at the ACI Fall Convention, San Juan, Puerto Rico, ACI-ASCE Committee 442, American Concrete Institute, October 1992.
4. Bermudez, J., Structural Masonry in Costa Rica, Paper presented at the ACI Fall Convention, San Juan, Puerto Rico, ACI-ASCE Committee 442, American Concrete Institute, October 1992.
5. García, L. E. and Yamín L. E., A Review of Masonry Construction in Colombia, Paper presented at the ACI Fall Convention, San Juan, Puerto Rico, ACI-ASCE Committee 442, American Concrete Institute, October 1992
6. Gallegos, H., Masonry in Perú, Paper presented at the ACI Fall Convention, San Juan, Puerto Rico, ACI-ASCE Committee 442, American Concrete Institute, October 1992.
7. Hidalgo, P. A., Seismic Behavior and Earthquake Resistant Design of Masonry Buildings in Chile, Paper presented at the ACI Fall Convention, San Juan, Puerto Rico, ACI-ASCE Committee 442, American Concrete Institute, October 1992.
8. Meli R. and Hernández, O., Propiedades de Piezas para Mampostería Producidas en el Distrito Federal, Facultad de Ingeniería UNAM, México.
9. Centro de Investigaciones de la Facultad de Ingeniería (CIFI), Bases Regionales para Elaborar Códigos de Vivienda Sismo Resistente de Bajo Costo, Universidad de los Andes, Bogotá, Colombia, Noviembre 1990
10. Centro de Investigaciones de la Facultad de Ingeniería (CIFI), Informe de Avance sobre la Investigación de Ensayo de Muros de Mampostería Confinada, Universidad de los Andes, Bogotá, Colombia, 1993
11. San Bartolomé, A., Ensayos de Carga Lateral en Muros de Albañilería Confinados por Elementos de Concreto Armado, Convenio ITINTEC-PUCP, Pontificia Universidad Católica del Perú, Lima, Perú, 1982-83

TABLE 1 — TYPES OF UNITS USED IN DIFFERENT COUNTRIES FOR STRUCTURAL PURPOSES

	Canada	Chile	Colombia	Costa Rica	México	Perú	U.S.A.
Concrete block	1	1	1	1	1	2	1
Solid concrete brick	1		2		1	2	
Clay block or hollow clay brick		1			1		2
Clay brick, solid or cored			1		1	1	1
Clay tile			1			2	
Sand-lime nits solid or cored			2		2	1	
Adobe units						2	

Note (1) Widely used
(2) Limited use

TABLE 2 — TYPICAL DIMENSIONS AND COMPRESSIVE STRENGTHS OF CONCRETE BLOCKS

Country	Typical Nominal Dimensions (cm)	Compressive Strength (MPa)	Description
Canada	20 x 20 x 40	14-35	
Chile	20 x 20 x 40 9 x 20 x 40 14 x 20 x 40	8-9 10-15 8-9	Depending on type of capping
Colombia	20 x 20 x 40 15 x 20 x 40 10 x 20 x 40	7-14 7-14 7-14	Over net area
Costa Rica	-	-	No data reported
Mexico	-	7-11	Depending on quality control
Perú	20 x 20 x 40	5-15	Over net area
U.S.A.	19.4 x 19.4 x 40	14-35	

TABLE 3 — TYPICAL DIMENSIONS AND COMPRESSIVE STRENGTHS OF CLAY BLOCKS AND HOLLOW CLAY BRICK

Country	Typical Nominal Dimensions (cm)	Compressive Strength (MPa)	Description
Chile	29 x 14 x 7.1 29 x 17.5 x 7.1	15 - 22 16 - 23	Depending on type of capping
Colombia	14.5 x 39.5 x 19.5 14.5 x 29.5 x 9.0	15 15	Over net area Over net area
Mexico	-	16 - 30	Over gross area - Hollow
U.S.A.	29.2 x 11.4 x 8.9	18 - 100	ICBO Eval. Rep 4062

TABLE 4 — TYPICAL DIMENSIONS AND COMPRESSIVE STRENGTHS OF CLAY BRICKS (SOLID OR CORED)

Country	Typical Nominal Dimensions (cm)	Compressive Strength (MPa)	Description
Canada	6.7 x 10 x 20		
Colombia	2.4 x 5.5 x 12.0	19	
Mexico	-	5.6 - 8.3	Depending on quality control
Perú	-	~3.0 - 14.0 6.0 - 25.0	
U.S.A.	19.4 x 5.7 x 9.2	5.6 - 14.0	

TABLE 5 — TYPICAL DIMENSIONS AND COMPRESSIVE STRENGTH OF SAND-LIME UNITS

Country	Typical Nominal Dimensions (cm)	Compressive Strength (MPa)	Description
Canada	-	-	No data available
Chile	-	-	No data available
Colombia	11.3 x 24 x 7.1 11.3 x 24 x 11.3	20 20	Over net area
Costa Rica	-	-	No data available
Mexico	-	~12 - 20	
Perú	great variety	13 - 20	
U.S.A.	-	-	No data available

TABLE 6 — TYPES OF MORTAR USED IN DIFFERENT COUNTRIES

Mortar	Canada	Chile	Colombia	México	Perú	U.S.
Portland cement and lime	◆	◆	◆	◆	◆	◆
Masonry cement						●
Portland cement and boulder sand			◆	●		
Ready-mixed			◆			◆

TABLE 7 — PROPORTION SPECIFICATIONS FOR PORTLAND CEMENT-LIME MORTAR
(MORTAR PROPORTIONS BY VOLUME)

Mortar Type	Portland Cement	Hydrated lime	Mason's Sand (2½ to 3 times cementitious)
M	1	≤ 1/4	3
S	1	1/2	4½
N	1	1	6
O	1	2	9

TABLE 8 — PROPERTY SPECIFICATIONS FOR CEMENT-LIME MORTAR
(MORTAR PROPORTIONS BY VOLUME)

Mortar Type	Compressive Strength (MPa)	Water Retention	Maximum Air Content
M	17.3	75%	12%
S	12.4	75%	12%
N	5.2	>75%	14% (12% if reinforced)
O	2.4	>75%	14% (12% if reinforced)

TABLE 9 — PROPORTION SPECIFICATIONS FOR MASONRY CEMENT MORTAR
(MORTAR PROPORTIONS BY VOLUME)

Mortar Type	Portland Cement	Masonry Cement			Mason's Sand (2¼ to 3 times cementitious)
		M	S	N	
M	1			1	6
M		1			3
S	1/2			1	4½
S			1		3
N				1	3
O				1	3

TABLE 10 — PROPERTY SPECIFICATIONS FOR MASONRY CEMENT MORTAR
(MORTAR PROPORTIONS BY VOLUME)

Mortar Type	Compressive Strength (MPa)	Water Retention	Maximum Air Content
M	17.3	75%	(18% if reinforced)
S	12.4	75%	(18% if reinforced)
N	5.2	75%	(18% if reinforced)
O	2.4	75%	(18% if reinforced)

TABLE 11 — TYPICAL MECHANICAL PROPERTIES FOR CEMENT-BOULDER SAND MORTAR

Country	Mix Cement Lime Sand (by weight)	Tension Strength (MPa)	Compression Strength (MPa)	Flow %	Tension/ Compression Ratio
Colombia	1:0:5	0.5	6	95	9 %
	1:0:4	1.1	11	80	11%
	1:0:3	1.7	15	93	12%
	1:0:1	3.0	31	98	10%
Mexico	1:0:3		20		
	1:½:5		7		
	1:0:6		10		
	1:1:6		5		

TABLE 12 — PROPORTION SPECIFICATIONS FOR GROUT FOR MASONRY
(MORTAR PROPORTIONS BY VOLUME)

Grout Type	Portland Cement	Hydrated Lime	Mason's Sand (2-1/4 to 3 times cementitious)	Coarse Aggregate (1-2)
Fine Grout	1	≤1/10	3	-
Coarse Grout	1	≤1/10	3	2

TABLE 13 — TYPICAL COMPRESSIVE STRENGTH OF MASONRY PRISMS

Country	Type of Masonry Unit	Mortar Proportions	f'_m (MPa)	E (MPa)
Chile	Hollow clay brick		5-7	5300
	Concrete block No grouting Full grouting		4-5 13-16	2800-3600 11000-15000
Colombia	Clay Brick	(3) 1:5	12	8700
		(3) 1:3	14	8080
		(3) 1:1	13	4880
	Clay Tile	(3) 1:5 (3) 1:3 (3) 1:1	2 3 3	1560 1410 1570
Costa Rica				
México	Hand made clay brick	1:0:3	5	
		1:2:9	3	
	Concrete Block	1:0:3	8	
		1:1:6	7	
	Cored brick	1:0:3	14	
		1:2:9	8	
	Perforated Brick	1:0:3	7	
		1:2:9	6	
	Sand-lime brick	1:0:3	11	
		1:2:9	10	
Perú	Good quality masonry		8-14	2000-4500
U.S.A.	Clay Brick		21-42	
	Concrete Blocks (grouted)		14-28	

Notes: Type of mortar.

(1) = Portland Cement-lime mortar

(2) = Masonry Cement mortar

(3) = Cement-Boulder Sand mortar (Cement:Sand by volume)

TABLE 14 — TYPICAL SHEAR STRENGTH OF MASONRY PRISMS

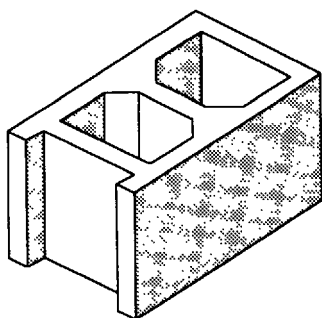
Country	Type of Unit	Type of Mortar	f'_v (MPa)
Chile			
Colombia	Clay Brick	(3) 1:5	0.9
		(3) 1:3	1.0
		(3) 1:1	0.9
	Clay Tile	(3) 1:5	0.4
		(3) 1:3	0.5
		(3) 1:1	0.5
Costa Rica			
México	Hand made clay brick	1:0:3	0.65
		1:2:9	0.40
	Concrete Block	1:0:3	
		1:1:6	0.57
	Perforated Brick	1:0:3	0.36
		1:2:3	0.26
	Cored brick	1:0:3	0.46
		1:2:9	0.31
	Sand-lime brick	1:0:3	0.63
		1:2:9	0.38
Perú			0.5 - 1.0
U.S.A.			

Notes: Type of mortar

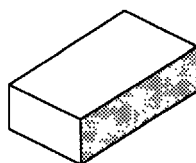
(1) = Portland Cement-lime mortar

(2) = Masonry Cement mortar

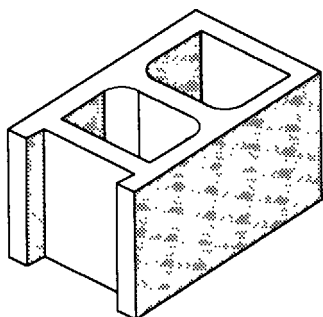
(3) = Cement-Boulder Sand mortar (Cement Sand by volume)



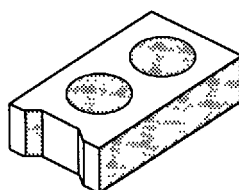
a) Concrete block



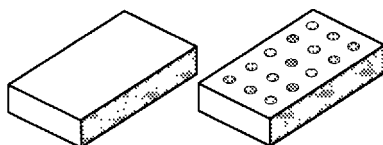
b) Concrete solid brick



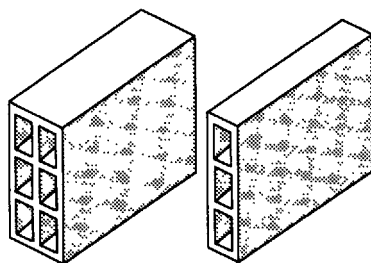
c) Clay block



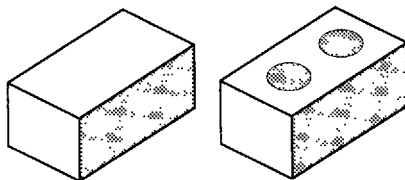
d) Hollow clay brick



e) Solid clay brick

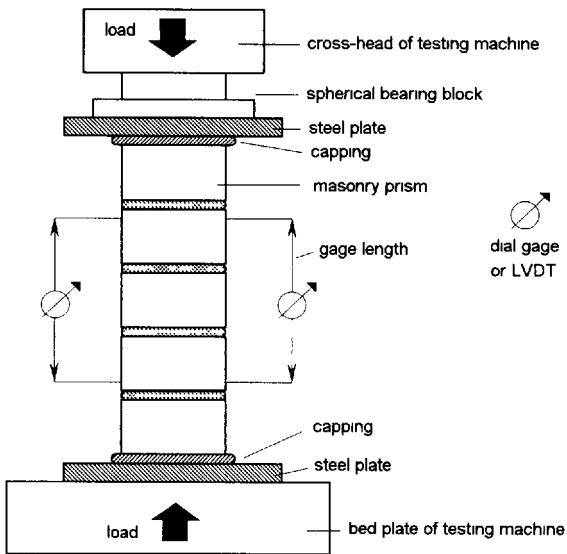


f) Clay tile



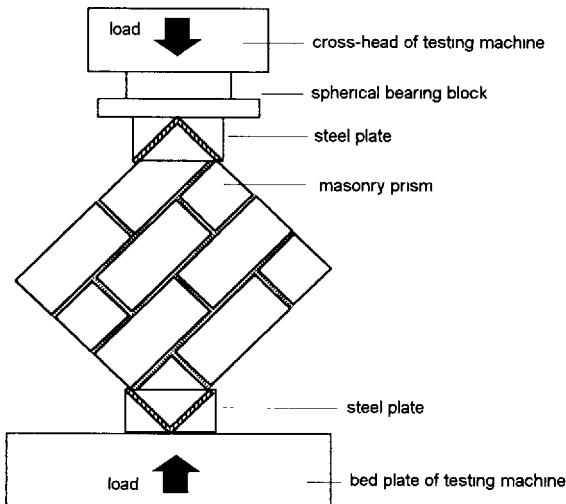
g) Sand-lime brick

Fig. 1—Typical masonry units



dial gage
or LVDT

a) Compressive strength test of masonry prism



b) Diagonal compression test of masonry prism

Figure 2

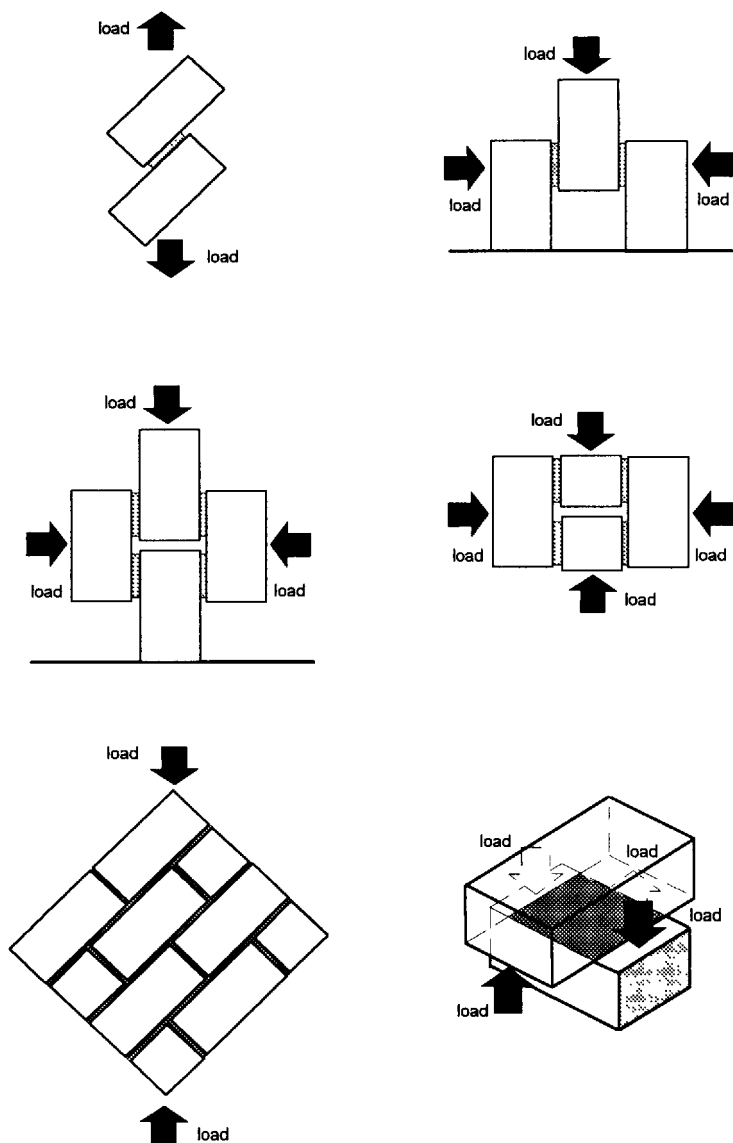


Fig. 3—Various shear strength tests

SP 147-2

General Description of Systems and Construction Practices

by C. Casabbone

Synopsis: This chapter presents the general description of masonry systems and construction practices in the Americas. As the most important use of masonry is in the construction of mid height buildings destined to housing, emphasis is given in this chapter to the use of masonry in the construction of bearing wall diaphragm buildings.

Keywords: Bearing walls; buildings; confined masonry; connections (mechanisms to transfer stress); construction practice; diaphragms (concrete); masonry; masonry walls; quality control; reinforced masonry

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INTRODUCTION

Masonry is perhaps the oldest construction material still in extensive use around the world. It dates to the onset of civilization in Sumer, and has been the most important construction and structural material until the introduction of the new materials, steel and reinforced concrete, not more than a century ago. While in the developing world it is still the most important building material for housing construction, in the developed world --Europe and North America--, masonry is witnessing a revival and renewed interest that has transformed masonry into a sophisticated material with a variety of structural applications.

The most important structural use of masonry around the world is in the construction of bearing walls of buildings destined for housing. It is also used extensively in the construction of enclosure and partition walls in all types of buildings, and as infill walls to stiffen frame structures.

This chapter describes the systems and construction practices of masonry in the Americas, as a structural material, in particular when used in the construction of buildings where masonry walls form part of the lateral load resisting system.

Masonry, a Structural Material?

There is no doubt that nowadays masonry is considered a structural material when it is used for the construction of bearing walls, even in the large informal construction sector of countries in Latin America.

The revaluation of masonry as a structural material is a consequence of the growing awareness of the vulnerability of unreinforced masonry to earthquake forces and the fact that this material, when properly used, offers a less costly solution for the construction of housing in a world increasingly short of resources.

Engineering Masonry?

The need to protect constructions against earthquakes and the particular vulnerability of unreinforced masonry to lateral forces has forced the engineering community not only to consider masonry as a structural material but to develop, through testing and analysis, new materials and construction practices. In fact, during the last decades and in most countries, masonry construction is engineered

particularly in areas where earthquakes are the main hazard. The engineering of masonry is also forced through code and construction regulations.

This assertion is valid for most of the developed world and for the formal construction sector of developing countries. It is not valid in the rural areas of developing countries and is only partly valid for the informal sector of urban centers where masonry construction, particularly individual housing units, are usually non-engineered imitations of formal construction models, leading to unsafe and/or wasteful construction.

In the United States and Canada, despite the existence of code and regulations, masonry construction is very often non-engineered and follows empirical rules.

MASONRY USES

In Low Rise Buildings

Masonry is the preferred construction material for the construction of small one or two story buildings, particularly for single housing units of large urban centers in Latin America. This preference is due to several factors, among them: a) material availability, b) low relative cost, c) durability, d) isolating properties. For these buildings the structural system consists of bearing walls in two directions. Very frequently though, the amount of wall area in one direction, due to the reduced width of the plot of land, is larger than in the other. Consequently the seismic load carrying system in the smaller dimension of the building consists of a combination of short walls and reinforced concrete frames. The ceiling of the first floor is usually a concrete slab that forms a rigid diaphragm, the roof is usually built on light panels --tin or asbestos corrugated plates-- over wood joists and does not form a rigid diaphragm (Fig. 1a).

In the United States and Canada the preferred type of residential construction comprises wood elements for the vertical and horizontal structural systems combined with masonry veneer in the exterior, as shown in Fig. 1b. For these small buildings the floors and roof can either form a rigid diaphragm, a flexible one or not form a diaphragm at all, the selection of which is usually determined on the basis of cost or architectural reasons. Masonry walls do not form part of the structural system and serve only as architectural elements and environmental protection.

Unreinforced masonry construction, widely used in the past, is still permitted for one story buildings, in countries with low seismic hazard areas. Building codes, in these cases, put restrictive limits to the allowable shear stresses used in their design.

In Medium and High Rise Buildings

For larger structures, to make masonry competitive with other construction materials it has been necessary to optimize every aspect of construction. This has lead to the bearing wall horizontally-diaphragmed buildings where the masonry wall is simultaneously the load bearing element, the partition, enclosure and, often, the finished architectural element.

The need to provide rigidity and resistance to lateral forces and the knowledge which has been gained concerning the behavior of bearing wall structures under heavy earthquakes has lead to structural buildings that are fully diaphragmed i.e., with floors and roofs that form rigid diaphragms and with walls almost uniformly distributed in the two principal horizontal directions of the building as shown in Fig. 2. In the configuration of these buildings, the importance of symmetry and continuity --in particular the vertical continuity of bearing walls-- are explicitly recognized. Walls act either as a system of coupled walls or as a series of cantilever walls connected by the slab serving as the horizontal diaphragm, depending upon the presence or absence of rigid beams at floor levels as illustrated in Fig. 3.

The diaphragm building has been developed in each country according to its construction tradition and availability of materials. In the United States and Canada, using concrete block reinforced walls and concrete slabs, apartment buildings of 30 stories have been built in seismic regions (Fig. 4). In Latin America, with the exception of Costa Rica where eight story reinforced concrete block masonry buildings are being built, the competitive height limit for masonry buildings is four to six stories, as illustrated in Fig. 5. In some countries i.e. Costa Rica and Peru it is a common practice to combine masonry walls with reinforced concrete walls to provide relief to the masonry from a substantial portion of the seismic base shear, this is particularly true when thin masonry walls --10 to 15 cm thick-- are used, in four to five story buildings and when taller buildings are built, as shown in Fig. 6. There is a marked preference in all countries to provide horizontal diaphragms in engineered masonry buildings with solid concrete slabs 10 to 15 cm thick. In some countries --USA, Canada, Colombia, Venezuela-- prefabricated slabs are used and diaphragm continuity is restored through the use of a thin concrete slab poured on top of the previous one or through mechanical connections.

In Multistory Frame Buildings

Closure and partition walls, in multistory frame buildings in many Latin America countries, are usually built of masonry in full contact with columns and beams as shown in Fig. 7, and because of that the structure is stiffened. This fact can have detrimental or beneficial effects on the seismic performance of the building,

depending on the way they alter its structural configuration, particularly its torsional characteristics and its stiffness continuity.

In some countries, such is the case of Colombia, Mexico and Peru, masonry infill walls--without window or door openings--are many times used as part of the lateral load resisting system. In this structural system, which is quite different from the confined masonry system of a bearing wall building, walls do not carry vertical load as they are built after the frame has been built.

THE WALL

The single most important masonry element is the wall. Structurally speaking, walls are classified as either load bearing or non-load bearing. To this latter category belong closures and partitions, fences, parapets, and exterior wythes of multi-wythe walls that are subjected mainly to horizontal loads perpendicular to the plane of the wall. The following paragraphs apply primarily to load bearing walls: walls that belong to the structural system of a building and as such, are subject to vertical and horizontal in-plane loads.

Types of Masonry Walls

Walls can be single-wythe or multi-wythe as illustrated in Fig. 8. Multi-wythe walls are used especially in the exterior walls. They are very common in Canada and in the United States particularly in areas of heavy rainfall and cold climates. In those areas they are used to provide a barrier to water permeance and thermal isolation, rather than for structural reasons; the outer wythe has also been used to give the building the desired architectural appearance. Only for high rise buildings are multi-wythe walls a structural requirement. In warmer areas of the continent such as Mexico, Central America and South America, multi-wythe wall construction is the exception, and it is used exclusively to obtain a determined architectural appearance.

Various attempts have been made to reduce the labor element in masonry construction, because it is a high cost component, particularly in the United States and Canada, and because it introduces variability in finished masonry (especially through mortar preparation and laying of masonry units). Mortarless or dry stack systems were developed with these objectives, such as the Haener system in Western United States shown in Fig. 9 and the Mecano (Fig. 10) and Practibloque systems in Peru. These systems have had successful applications and they offer savings in construction time, labor costs, and supervision; additionally, the relevant mechanical properties of the final product have a lower variability compared with conventional systems.

The typical bond pattern for structural walls is running bond.

Wall Reinforcement

In many countries the need to reinforce masonry has been borne out of tragedy: in the United States the 1933 Long Beach earthquake, in Chile the 1930 the Chilean earthquake, in Peru the 1940 Lima earthquake and in Colombia the 1983 Popayan earthquake. The very low tensile strength of masonry makes it extremely vulnerable to lateral forces from earthquakes and strong winds. Tensile stresses imposed on the structural elements by these forces, mainly diagonal tension and flexural tension, frequently exceed the capacity of masonry, rendering the structure fragile.

The need to provide masonry with resistance to tensile stresses and with sufficient ductility to successfully withstand lateral forces, particularly in seismic regions, forced engineers to reinforce masonry walls with steel.

The method in which reinforcement was introduced into the walls followed the availability of masonry units. In North America the extended use of concrete blocks permitted placing reinforcing in the vertical cells distributed along the wall, as shown in Fig. 11a and 11b. Even with solid units the distribution of reinforcement along the wall was achieved with two wythe walls in the so called laminar masonry construction, as shown in Fig. 11c. In the Latin American countries where masonry units, following the Spanish construction tradition, were mainly solid clay bricks, reinforcement was concentrated in the perimeter of the wall, embedded in concrete elements, giving birth to the system called confined masonry shown in Fig. 12.

MASONRY SYSTEMS

Reinforced Masonry

This name applies to masonry walls strengthened with distributed reinforcement along its length and height. There are two basic ways to incorporate distributed reinforcement in the wall: a) in single wythe walls using hollow core units, placing the vertical reinforcing inside the cells and the horizontal reinforcing in the mortar joints or in recesses of top recessed masonry units, and b) in two-wythe walls, in the cavity between wythes. In both cases, the reinforced cells and the cavities are filled with grout.

Reinforced masonry in the United States and Canada.

Although both systems of reinforcing walls are used in the United States and Canada, the single-wythe reinforced block system is by far the most common. The masonry unit most widely used for this type of masonry is the concrete block. As explained in Chapter 2, blocks are factory produced in a variety of types that

permit the placing of vertical and horizontal reinforcing bars. In commercial earthquake-resistant masonry construction in the seismic areas of western United States and of Canada, horizontal reinforcement is placed in hollow concrete units with recessed top faces, called bond beam units, Fig. 11a, and not in the mortar joints. The interior spaces provided in cells and in the top recessed units allow for adequate placing of concrete grout assuring good bonding and protection of bars. Walls are fully grouted. Reinforcement used complies with ASTM 615.

Reinforced masonry in Latin America.

In Latin American countries reinforced masonry is used only in single- wythe walls and the use of this system varies from country to country.

In Mexico its use is very restricted due mainly to the poor performance of reinforced masonry walls subjected to earthquakes. The main cause of this poor behavior has been traced to improper construction practices in the placing of reinforcement and grouting of cells.

In Central American countries, both concrete and clay hollow blocks are used for reinforced masonry walls. In a general sense, the construction practice follows the USA and Canadian practice, however important differences are noted:

- a) The quality of masonry units is not always adequate. Clay blocks exhibit liberal dimensional tolerances and low resistance characteristics. Although concrete block production is highly industrialized in some countries (like Costa Rica and Colombia) in most places concrete blocks are produced with low quality equipment (with very little compaction of the concrete) and consequently, have low resistance and large dimensional tolerances.
- b) Walls are usually partially grouted since only the cells carrying reinforcement are filled with grout, Fig. 11b. When low resistance blocks are used, the possibility of brittle failures due to diagonal compression increases.
- c) Horizontal reinforcement is placed in the joints and not in units with recessed top, Fig. 11b. Joint reinforcement is made of small diameter straight bars usually wire, connected by shop welded transverse bars in the form of ladder or truss. When single bars are used, they are placed in the middle of the wall thickness, and in this position the bar is not covered by mortar or grout in its entire length as it bridges freely over non-grouted cells. Its effectiveness as a tension reinforcement, which depends partially on the bond between bar and mortar, could be impaired if the bars have splices along the wall. The bars are also subjected to corrosion problems due to being only partially embedded in concrete or mortar, Fig. 13.

In Colombia both clay and concrete blocks with similar dimensional characteristics are used for the construction of reinforced masonry bearing walls. There is a marked preference thought for clay units due to its low contraction cracking and better appearance. Construction follows the USA practice, except that horizontal reinforcement is placed in the joints when clay blocks are used, and the walls are seldom grouted fully. Comments, b and c indicated in the previous paragraph, apply.

In Peru the use of concrete block reinforced masonry is very limited in large urban centers due to the absence of industrially produced blocks, though its use is generalized for housing construction in mining towns, where without alternative products, a concrete block producing plant is usually installed to satisfy this demand. In these cases, construction follows the USA practice, although horizontal reinforcement is place in the joints. Reinforced masonry has had a tremendous development though, using different types of cored masonry units specially designed< for this purpose in clay, sand-lime, and concrete, which for its dimensions and ease of handling, qualify more as brick than as block. The current practice calls for the use of 12 to 15 cm thick walls, both with mortar laid units and with mortarless stacked units; in the former case clay, sand-lime or concrete units are used, in the latter sand-lime or concrete units. Horizontal reinforcement, in walls with mortar laid units is placed in the mortar joints; when mortaless units are used, it is embedded in grout in bond beam units. Usually, only walls in the first two stories of four and five stories buildings are fully grouted. This system has been used successfully in Venezuela as well, Fig. 5c. In mortarless stack masonry wall construction, walls are fully grouted.

In Chile, reinforced concrete masonry follows the USA practice. Reinforced masonry with clay cored units practice has undergone a complete revision after the 1985 earthquake that includes requirements for: a) horizontal reinforcement in the joints, b) reinforced concrete c) grouting of cells (the height of grouting is made dependent on cells dimensions).

Confined Masonry

The name applies to masonry walls confined with a reinforced concrete frame cast around its perimeter. Although confinement of masonry is done mainly on walls built up with solid units, and particularly hand-crafted clay units, the fact is that walls constructed with sand-lime units, concrete units or hollow blocks --both of clay and concrete-- are also confined in this manner. This is the case in Costa Rica, Guatemala, Nicaragua and Colombia where concrete and clay hollow block walls are confined with reinforced concrete elements.

Vertical confinement.

Vertical confinements are placed at the end of walls and at distances that do not exceed twice its clear height. The common tendency is to obtain square confined wall panels.

As shown in Fig. 14, the vertical reinforcement consists of a number of bars tied with stirrups. Although there is not a uniform criterion about the number of vertical bars --in some countries, codes require a minimum number of bars: Mexico four bars, Colombia three bars-- it is customary to use at least four bars in each confining element. These bars are tied with a nominal amount of uniformly-spaced transverse stirrups. In some countries, as in the case of Peru, the code requires a concentration of stirrups at the end of the vertical confinement near the corners, to provide the vertical confinement element with better shear resistance. The vertical reinforcement is anchored to the wall foundation and extends the total height of the wall. Bars are lap spliced usually at the same section, the splice length calculated as for tension members.

Vertical confining elements are cast usually after the masonry panel has reached the bottom of the collar beam elevation.

Horizontal confinement.

The horizontal confinement consists of reinforced concrete beams, called collar beams, which are placed at every floor level and are continuous over the walls. The height of the collar beam depends on the designer. When the height of collar beams is larger than the slab thickness they usually act as a lintel over openings, and as coupling beams in the wall system. For both vertical and horizontal confinement elements, deformed bars complying with ASTM 615 are generally used. In some countries --Colombia for example-- cold-worked steels are permitted as concrete reinforcement.

Confinement is used both: a) with unreinforced masonry walls, which some times have a nominal amount of joint reinforcement to distribute diagonal cracking and prevent transverse collapse of the cracked masonry panel and b) with reinforced masonry walls with sufficient joint reinforcing to resist all the shear force in the wall.

Joint reinforcement.

In some countries masonry walls do not have joint reinforcement, such is the case of Mexico, Colombia and Chile. In Peru the new tendency, in four or five stories buildings, is to reinforce the horizontal joints of walls to resist the total shear force thus rendering the system a reinforced masonry with the vertical reinforcement concentrated at the ends of the wall, Fig. 15. Joint reinforcement is anchored in the end vertical confinements. Joint reinforcement is made of small diameter straight

bars, usually wire, either as independent bars or as parallel bars connected by shop welded transverse bars in the form of a ladder or truss, similar to that used for joint reinforcement in reinforced masonry walls.

In Costa Rica, where solid units are seldom used, confined masonry is done with concrete blocks, joint reinforcement is replaced by an intermediate bond beam placed at mid wall height as shown in Fig. 16.

Wall Openings

There is not a common practice on the treatment given to lintels and window sills and as their treatment is not regulated by codes, the practice varies even in each country. These two architectural features usually are responsible for damage to structural walls.

Lintels cause stress concentration in walls. The tendency in engineered masonry building construction is to avoid discontinuities in the masonry panel. For this purpose either lintels are incorporated with the collar beam or the opening is extended up to the bottom of the slab. Fig. 17.

Window sills are by far more pernicious than lintels when they are continuous and integral with the wall. By reducing wall proportions, they alter expected behavior and make the wall prone to shear failures. Although some efforts been made in some countries to isolate window sills from adjacent walls (Chile and Peru), in other countries, as Mexico and Costa Rica sills are integral with the walls and they are so considered in the design. Fig. 18.

Wall Connections

The practice of wall connections varies greatly. In the USA and Canada a variety of systems have been developed to address the connection of multi-wythe walls and veneer walls and these are unique for that part of the continent. As the focus here is primarily in single-wythe structural walls in diaphragmed buildings, the following paragraphs treat these connections both for reinforced masonry and confined masonry. For the connections of structural walls, practices differ in each region. Differences depend primarily on the type of masonry units.

Wall connections for reinforced masonry

Wall to wall connections have been solved in different ways, some of them are solutions common to all countries. At corners, walls are joined together in a masonry bond; at intersection the practice varies greatly. In the United States and Canada intersecting walls are seldom joined together in concrete block construction and wall to wall connection is achieved with metal tiebar as shown in Fig. 19.

In Latin America walls are usually joined together in a masonry bond. In Peru masonry walls are not necessarily joined together to avoid asymmetrical shapes.

Wall to foundation connections and wall to floor connections

In the first case, the connection is achieved with dowels that are anchored to the foundation and extend into the wall with a tension lap splice length.

Wall to floor connections

The upper end of the vertical bar extends, beyond the floor level, a tension lap splice length; and the lower end laps with the dowel anchored to the foundation or to the dowel left by the vertical bars from the wall below, as shown in Fig. 20.

In wall to roof connections, the vertical bar ends with a hook, usually a 90-degree bend, to anchor in the roof slab.

Wall connections for confined masonry construction.

For confined masonry construction, wall to wall connections are achieved through the confining concrete element. Sometimes, the walls are dented to create a mechanical shear connection with the vertical confinement. When the interface between concrete and masonry has to be left as a vertical plane for appearance reasons, steel connectors are left in the horizontal joints to anchor the masonry panel to the confinement element as shown in Fig. 14. There is not a uniform practice for the spacing of these connectors (in Colombia they are placed in each joint; in Peru every three or four courses).

Wall to floor and wall to roof connection are achieved through the vertical confinement elements, and there is no mechanical connection between masonry and the slabs. The connection between vertical confinements and collar beams or slabs is similar to the connection between reinforced concrete elements in frame construction, as shown in Fig. 14.

CONSTRUCTION PRACTICES

Clay brick masonry construction practices have been transmitted from generation to generation for millennia. Our practices, in the Americas, follow the European tradition with variations and local accents in each country. In the last 50 years or so, due to the arrival of new masonry units (concrete and clay blocks, cored units, etc.), made possible with the introduction of new materials and fabrication processes, and of the various forms of reinforcing masonry walls, construction practices have evolved adapting traditional methods to the requirements imposed by the new circumstances.

Although there are commonalities in the construction practices different Latin America countries, there are practices that are unique to some countries or regions.

Joints

In Latin American countries, joints in masonry walls of low cost buildings are preferably flush or rough cut, either to leave a completely exposed surface or to receive later some kind of surface finishing such as mortar plaster or paint. The reason behind this practice is not only the extra labor cost demanded for tooling the joints but the recognition that a stronger wall will be that one with full head and bed joints.

Joint thickness is similar in all countries for industrially produced units, around 10 mm as shown in Fig. 21a. For hand-crafted units, joint thickness varies greatly depending on the dimensional characteristics of the unit as shown in Fig. 21b.

Laying of Units

The techniques used for maintaining wall alignment and plumbness are practically the same through out the Americas. There are, however, some differences. In Latin America countries there is a marked preference for the use of scaled corner poles for leveling the courses and aligning instead of building corner lead walls.

In the forming of vertical joints, USA and Canadian practice differ from that of other countries. In the former, after the mortar bed has been prepared and before the unit is laid, mortar is applied to the vertical face that will form the vertical joint with the unit already in place as shown in Fig. 22 and later, in the laying process, the unit is pressed laterally, assuring in that way the development of adhesion. In Latin American practice, the vertical joints are generally filled with mortar after the unit has been laid. This practice which probably owes its origins, to the lack of mortars with proper workability, to preclude dropping away while handling, has the disadvantage of jeopardizing, if not destroying, the initial adhesion between mortar and unit. This holds true particularly with sand-cement mortars.

Grouting Practice

In the western United States fully grouted walls are mandatory while in Canada and eastern United States walls are generally partially grouted. In Canada non shrinkage grout is rarely used, in the United States its use is a contractor's choice. In both countries low, medium and high lift grouting are used, the choice depending fully on the contractor. Clean out holes are mandatory for medium and high lift grouting. The preferred grouting processes are the medium and high lift

grouting because they reduce the grouting operation and because a single clean-out hole at the bottom is sufficient to ensure that the cell is clean from mortar droppings before grouting. For the cleaning of cells, high pressure air blowers are usually employed.

In high lift grouting, it is a general practice to grout in a continuous operation without intermediate construction joints, placing the grout in successive 1.20 m lifts, with a 30 to 60 minutes span time to allow for settlement, shrinkage and unit absorption of excess water to take place. Grout is consolidated by vibration.

In some Latin America countries, such as Costa Rica, block cells are preferably filled with concrete; low lift concreting 60 to 80 cm high is used and no clean out holes are required. Concrete is mechanically consolidated.

The practice of filling with mortar the reinforced cell of masonry walls built with clay, sand-lime and concrete cored units, immediately after laying each course, as was used in Chile and Peru in the early stages of the developing of reinforced masonry in those countries, has been abandoned for the high lift grouting of the vertical reinforced cells, leading to a partially grouted wall. The main reason behind the change in practice was the difficulty of guaranteeing a dense and continuous fill along cell height to offer sufficient bonding to the vertical bar and protection against corrosion.

The general practice for ensuring that the cells are unobstructed is to provide clean out holes at the bottom or to grout the cell with a low lift grouting sequence preferably after finishing each course. In Peru, the vertical cells are plugged with a sponge during the laying of units to avoid the blocking of vertical cells with mortar dropping as illustrated in Fig. 23. The sponge is attached to a 30 or 40 cm piece of plastic pipe placed temporarily in the cell of the upper course while the mortar bed for the next course is placed. The sponge is lifted though the cell of the last unit laid and is ready to further protect from contamination the next reinforced cell as the laying operation continues. This operation while cumbersome, has proved effective in keeping vertical cells free from mortar droppings and eliminates the need of creating clean out holes at the bottom of each reinforced cell. Clean out holes are not desirable, especially when the clay brick surface is the finished element, as is usually the case, in low cost housing.

In the mortarless block systems, clean out holes are not required and the grouting operation follows a procedure that leads to a fully grouted wall. Grouting starts in the cell at one extreme of the wall, and continues to the next vertical cell after ensuring that the bond beams are completely filled.

Treatment of Units

Masonry units receive various treatments immediately before being laid, depending up on its initial rate of absorption -- suction -- characteristics.

The common practice calls for preventive measures when the initial rate of absorption exceeds 20 g/min/200 cm².

The general practice is to lay concrete and sand-lime units dry because of their low suction. Clay units have a very wide range of initial rate of absorption; suction will be lower for industrially produced units and very high when units are hand-crafted. Clay units usually receive a water treatment to reduce suction that varies from spraying units with a hose for low suction units to water immersion. The water immersion treatment can last from a few minutes for industrialized units, to several hours for handmade units. Invariably the practice is to lay each unit with surfaces dry. In the United States and Canada water retentive mortars are used to control suction effects of clay units on mortar.

Sand lime units have low suction characteristics. Usually these units arrive at the job site with a layer of fine surface dust due to the fabrication process. To ensure a good adhesion, it is general practice in Peru to remove the fabrication dust before laying the unit; for this purpose a barely humid sponge a hand broom or a compressed air jet is used.

Mortar Preparation

It is a general practice to measure ingredients by volume despite the variation that this procedure generates in the amount of sand for different water contents.

In large projects it is now customary to install a central batching plant for the dry mixing of components. In the United States and Canada and recently in some other countries, there is a tendency in large jobs, to deliver to the job site ready mixed mortar, usually a retardant is used.

In most Latin American countries the usual practice in small projects is to prepare the dry mix by hand in a central place and to supply this mix to the mason. It is the responsibility of the mason to add the adequate amount of water to obtain the desired consistency. Retempering of mortar is an acceptable practice all over the continent.

Mechanical Installations

In bearing wall construction it is important to coordinate the location of the different subsystems so as not to impair the structural capacity of the wall. This applies particularly to plumbing and electric conduits.

In reinforced masonry construction, the common practice in the Americas is to provide the building with vertical ducts to house the water and sewer plumbing close to the bathrooms. The water pipes to connect each bathroom are placed inside the slabs, the sewer pipe reaches the vertical duct suspended from the slab. Electrical and communication conduits are placed inside the cell of hollow block walls as shown in Fig. 24.

In single-wythe solid brick construction, both confined and unreinforced, the common practice in Latin America countries, is to place all piping and conduits inside the walls. The water and sewer pipes along vertical paths and the conduits for electrical and communication installation, in horizontal, vertical or inclined paths, are placed at the convenience of the corresponding subcontractor. For this purpose channels are chiseled in the brick wall as shown in Fig. 25 and Fig. 26c. There is no need to elaborate on the tremendous damage this practice does to the bearing wall. In the past, when walls were at least 25 cm thick, this practice was tolerated; today, with the use of thinner walls it is no longer accepted. Good practice calls for the provision of vertical ducts for water and sewer pipes and to place all conduits inside vertical cells as shown in Fig. 26a and 26b or in vertical paths inside recesses left in the wall during the construction process.

In the bathrooms area in engineered buildings, when thin slabs are used, the slab bottom is usually placed at a lower elevation, leaving bathrooms with a shorter floor to roof clear distances. All water and sewer piping is placed in the floor depression which afterward is filled with poor concrete to regain the general floor elevation. In some countries, such as Colombia, the practice is to leave the slab at the same general floor elevation and suspend piping underneath the slab. Later a suspended ceiling is placed to hide the piping from view. When hollow block joist slabs are used, the usual practice is to place all piping, embedded in concrete inside the slab. This latter practice has several inconveniences: the construction process is slower as all plumbing has to be installed and tested before pouring the concrete, and it does not allow for easy maintenance of plumbing.

QUALITY CONTROL

It is to note that masonry inspection and testing is done only in large jobs in most Latin American countries. In most jobs there is no resident inspector. Inspection is usually the responsibility of the designer.

Workmanship

The quality of a masonry wall depends to a great extent on the quality of workmanship and on the procedures that masons follow.

In very few fields is such dependence as notorious as in masonry construction, where the expertise of the mason in performing his job is the single most important factor in achieving the desired quality. In most countries, the expertise is gained through practical experience on the job and is transmitted by experienced masons, and formal training outside the job is not required.

Official training programs, offered in some Latin American countries, are limited in scope and as mentioned above are not a requirement; the selection and training of masons remain the sole responsibility of the contractor. In Canada and the United States there are available community college training courses that, followed by a period of training experience, are granted official recognition.

Masonry Components

Quality control of materials is code regulated and is mandatory in all countries. Furthermore, in engineered construction, project specifications call for tests on materials and on masonry samples. Quality control of materials is treated on Chapter 2. The usual quality testing during the job are performed on mortar, grout and masonry. Quality control tests follow the USA practice and are based mainly on ASTM provisions.

REFERENCES

1. Beall, C., *Masonry Design and Detailing for Architects, Engineers, and Builders*. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1984.
2. Bermudez J., "Structural Masonry in Costa Rica", this publication.
3. Bruneau, M., University of Ottawa, Ontario. "Assessing the Seismic Performance of Existing Masonry Buildings in Canada", this publication.
4. Garcia, L. E., and Yamin L. "A Review of Masonry Construction in Colombia", this publication.
5. Gallegos, H., *Disenando y Construyendo con Albanileria*. Publicado por LACASA, 1987.
6. Gallegos, H., "Albanileria Estructural", Pontificia Universidad Catolica del Peru, Fondo Editorial, 1991.
7. Gallegos, H., "Masonry in Peru", this publication.
8. Hidalgo, P., "Seismic Behavior and Earthquake Resistant Design of Masonry Buildings in Chile", this publication.
9. Kicklighter, Cl. E., *Modern Masonry*. The Goodheart-Willcox Company, INC. Publishers.
10. Klingner, R.E., "Masonry Practice in the United States", this publication.

11. Meli, R., "Seismic Design of Masonry Buildings: The Mexican Practice", this publication.
12. Schneider, R. R. and W.L. Dickey, *Reinforced Masonry Design*, Second Edition. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1980.

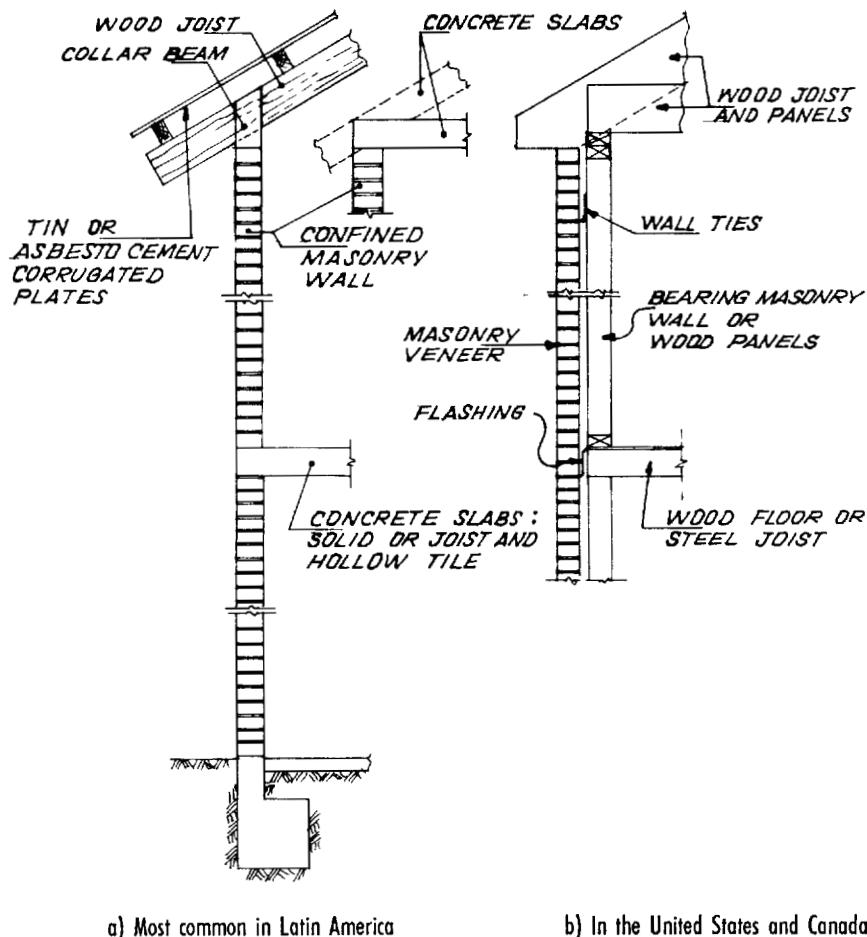


Fig. 1—Low rise buildings structural systems

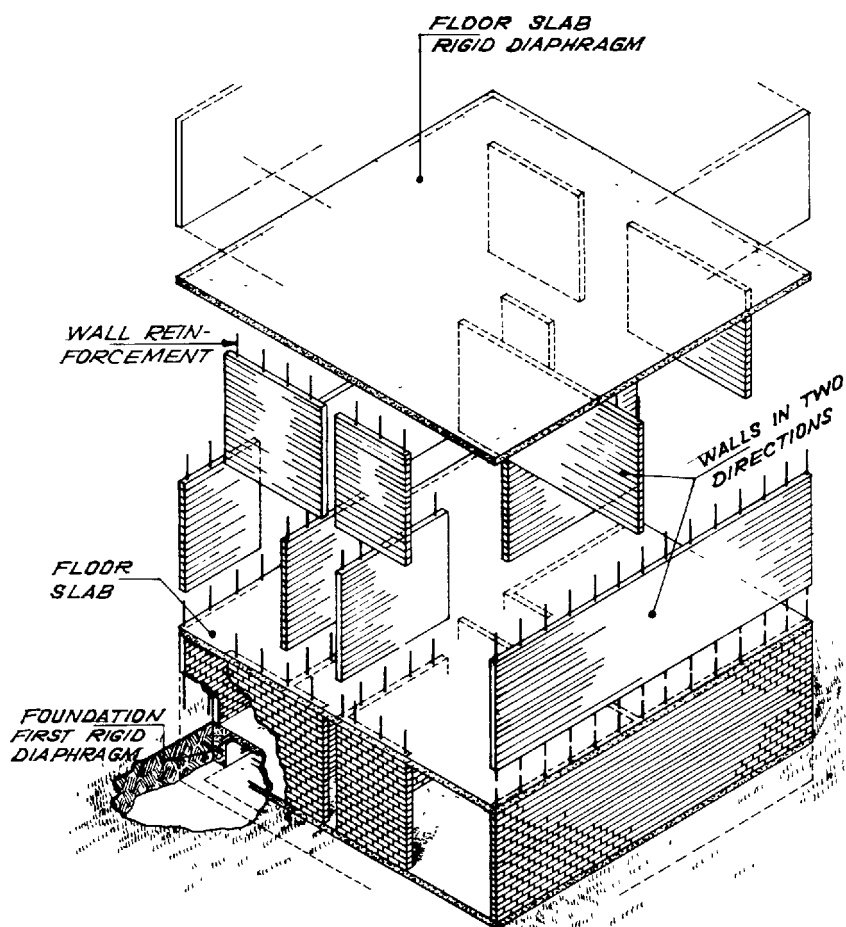


Fig. 2—Masonry building structural system (5)

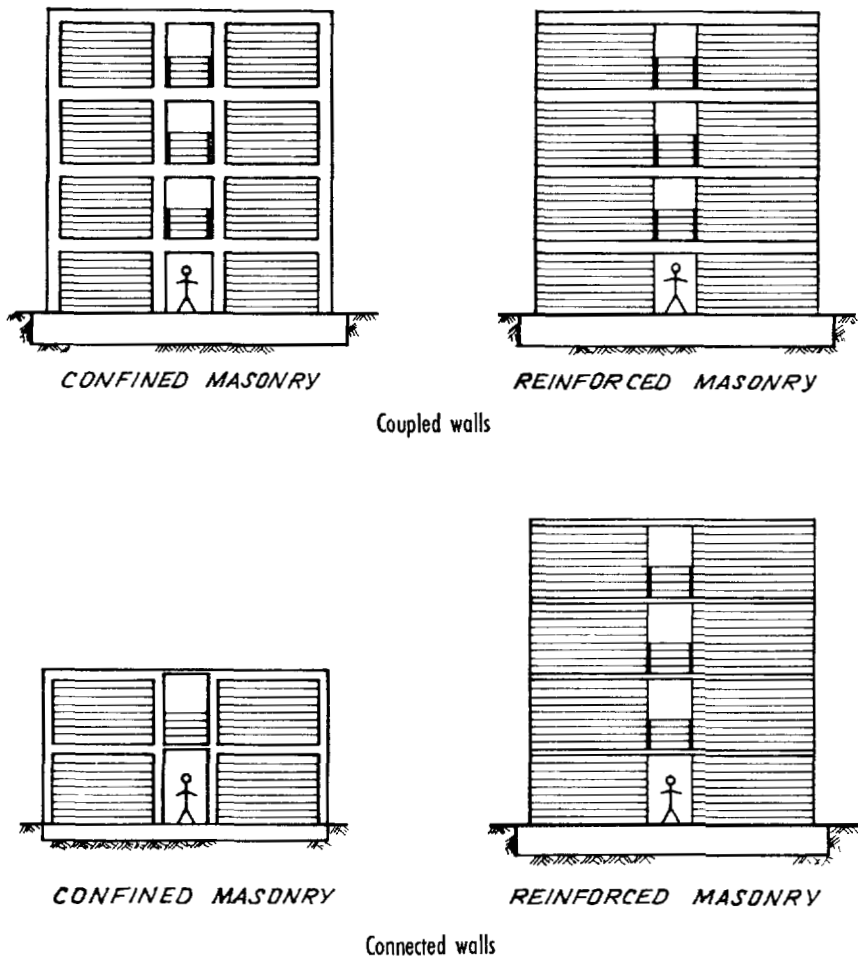


Fig. 3—Wall systems (6)

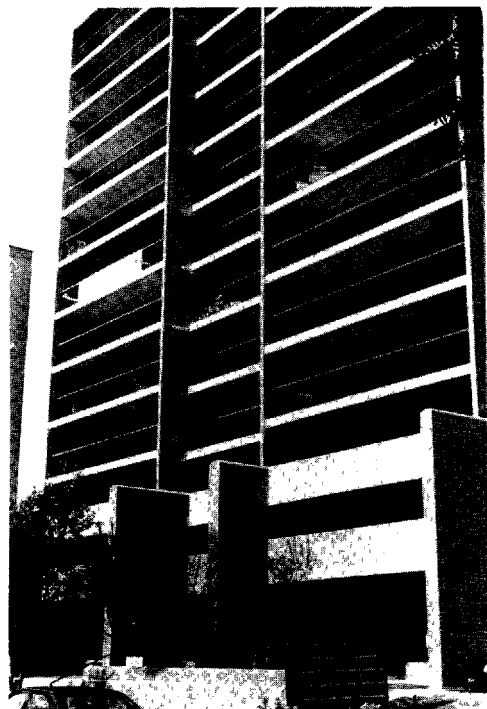


Fig. 4—Reinforced masonry building in Sand Diego, USA



Fig. 5a—Masonry building in Latin America — Colombia



Fig. 5b—Masonry building in Latin America — Peru

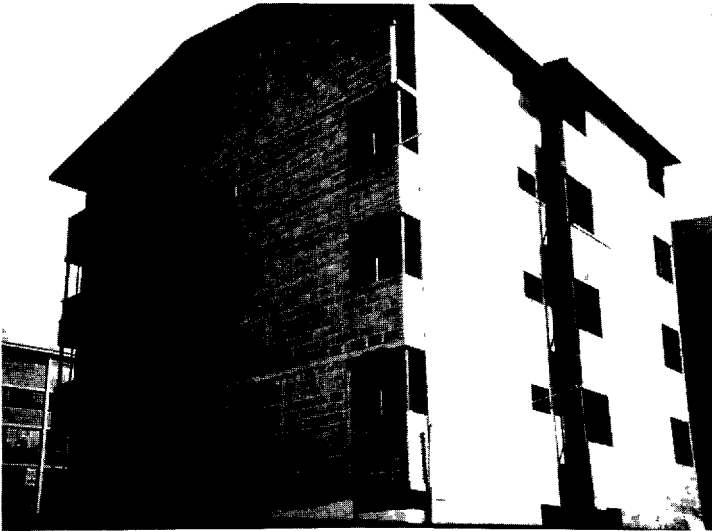


Fig. 5c—Masonry building in Latin America — Venezuela

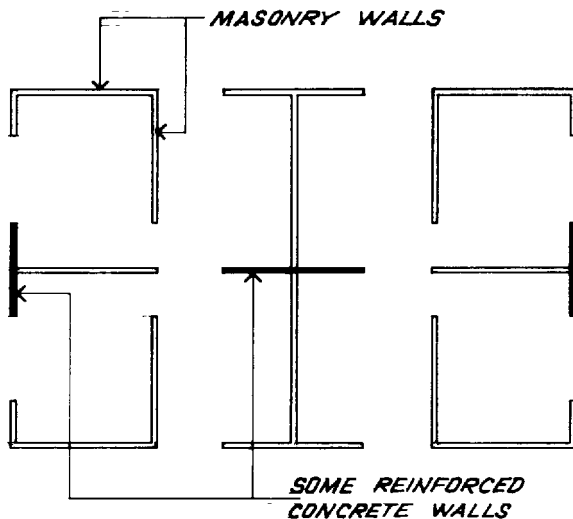


Fig. 6—Typical structural layout of four- to five-story masonry buildings

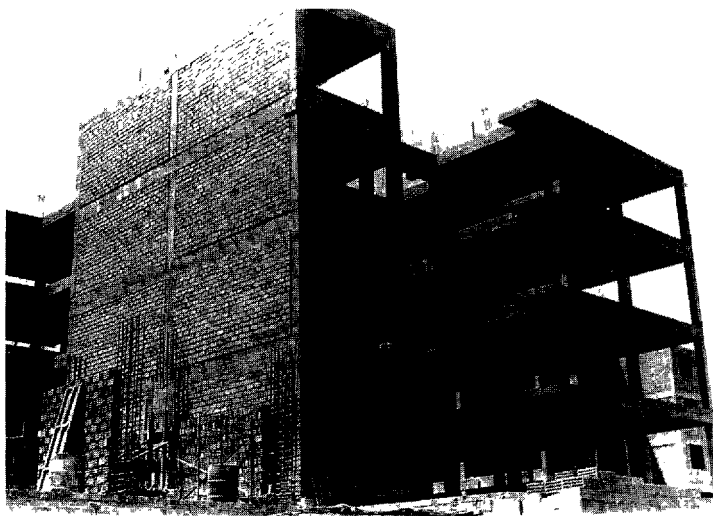


Fig. 7—Infill masonry in frame buildings