MASONRY ENGINEERING IN THE UNITED STATES OF AMERICA PAST DEVELOPMENT, CURRENT OVERVIEW, FUTURE IMPROVEMENTS

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In this paper, the process used to develop building codes in the United States of America (USA) is summarized, with emphasis on masonry. Masonry materials used in the USA are discussed. Types of masonry construction in the USA are reviewed, addressing historical as well as modern masonry. Current non-structural and structural applications of masonry in the USA are reviewed. Historical development of masonry codes in the USA is summarized, with emphasis on the current Masonry Standards Joint Committee (MSJC) *Code and Specification*. Future trends in that document are predicted. The paper closes with a list of challenges to the masonry industry, and a list of focused research topics intended to meet those challenges.

Keywords: *masonry, United States of America, USA, past, current, future*

INTRODUCTION TO BUILDING CODES IN THE UNITED STATES OF AMERICA

The United States has no national design code, primarily because the United States Constitution has been interpreted as delegating building code authority to the states, some of which in turn delegate it to municipalities and other local governmental agencies. Design codes used in the United States are developed by a complex process involving technical experts, industry representatives, code users, and building officials. As it applies to the development of design provisions for masonry, this process is shown in Figure 1, and is then described:

1) Consensus design provisions and specifications for materials or methods of testing are first drafted in mandatory language by technical specialty organizations, operating under consensus rules approved by the American National Standards Institute (ANSI), or (in the case of ASTM) rules that are similar in substance.

2) These consensus design and construction provisions are adopted, usually by reference and sometimes in modified form, by model code organizations, and take the form of model codes.

3) These model codes are adopted, sometimes in modified form, by local governmental agencies (such as states, cities or counties). Upon adoption, but not before, they acquire legal standing as building codes.

In the United States of America (USA), design loads and general structural requirements are provided by ASCE7 (ASCE7-10). Requirements for structural design of masonry are provided by the Masonry Standards Joint Committee (MSJC) *Code and Specification* (MSJC 2011a,b). Those document is referenced by the 2012 edition of the International Building Code (IBC 2012), which is the model code used in practically the entire USA.

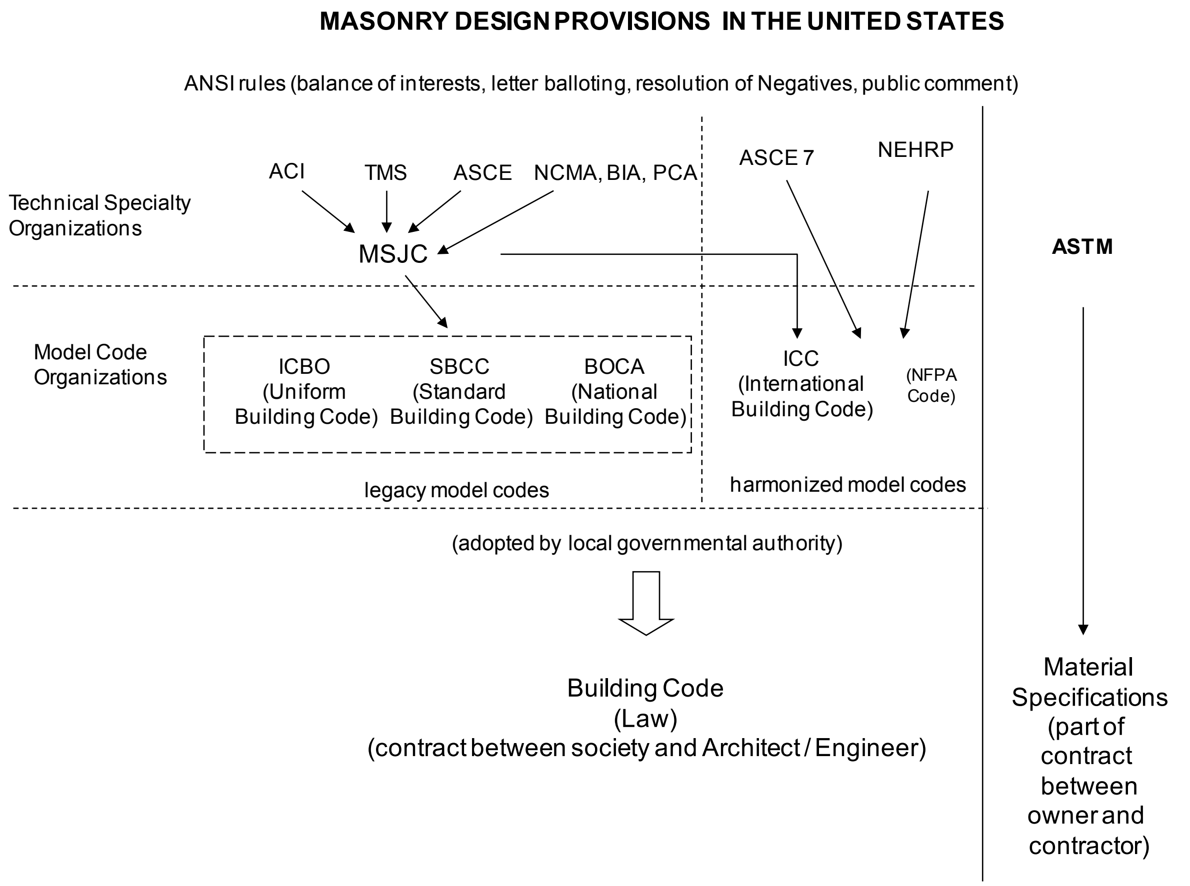

Figure 1 Code-development process in the United States of America (USA)

INTRODUCTION TO MASONRY IN THE UNITED STATES OF AMERICA

Masonry makes up approximately 70% of the existing building inventory in the United States (TMS 1989). US masonry comprises Indian cliff dwellings, constructed of sandstone at Mesa Verde (Colorado); the adobe missions constructed by Spanish settlers in Florida, California, and the southwestern United States; bearing-wall buildings such as the 16-story Monadnock Building, completed in 1891 in Chicago; modern reinforced bearing-wall buildings; and many veneer applications (use of masonry as a decorative façade).

Masonry Units

More than 20 different classifications of masonry units are commercially available in the USA. The most common are clay or shale masonry units and concrete masonry units. Clay or shale masonry units are usually almost solid, with small core holes intended to facilitate their drying and firing. Concrete masonry units are usually hollow, with vertical cells intended primarily to hold reinforcement.

Masonry Mortar

In the USA, three cementitious systems are available for masonry mortar: cement and lime; masonry cement; and mortar cement. These cementitious systems are combined with sand and water to produce mortar. Within each cementitious system, masonry mortar is also classified according to type. Types are designated as M, S, N, O and K (derived from every other letter of the phrase “MaSoN wOrK”). These designations refer to the proportion of cement in the mixture. Type M has the most; S less; and so on. Higher proportions of cement result in faster strength gain, higher compressive strength, and higher tensile bond strength;

they also result in lower long-term deformability. Mortar types S and N are typically specified.

Within each cementitious system and each type, mortar can be specified by proportion or by property, with the former being the default. For example, Type S portland cement-lime mortar, specified by proportion, consists of one volume portland cement, 1/2 volume of hydrated mason's lime, about 4-1/2 volumes of masons' sand, and sufficient water for good workability. Type S masonry cement mortar or mortar cement mortar are made with one volume of masonry cement or mortar cement respectively, 3 volumes of mason's sand, and sufficient water for good workability.

Grout for Masonry

Masonry grout is essentially fluid concrete, used to fill spaces in masonry, and to surround reinforcement and connectors. It is composed of portland cement and other hydraulic cements, sand, and (in the case of coarse grout) pea gravel. It is permitted to contain a small amount of hydrated mason's lime, but usually does not. It is permitted to be specified by proportion or by property, with the former being the default. A coarse grout specified by proportion would typically contain one volume portland cement or other hydraulic cements, about 3 volumes of mason's sand, and about 2 volumes of pea gravel. Masonry grout is placed with a slump of at least 8 in. (203 mm), so that it will flow freely into the cells of the masonry. Grout is normally consolidated by mechanical vibration. Self-consolidating grout, containing flow additives and carefully graded aggregates, is does not require consolidation.

Accessory Materials for Masonry

Accessory materials for masonry consist of reinforcement, connectors, sealants, flashing, coatings and vapor barriers.

TYPES OF MASONRY USED IN THE UNITED STATES OF AMERICA

Historical Masonry in the United States of America

Historical masonry in the USA consisted primarily of building with unreinforced masonry bearing walls. These walls were commonly made with two wythes (leaves) of masonry, bonded by masonry headers, and sometimes also had an interior wythe of rubble masonry (pieces of masonry units surrounded by mortar). Unreinforced masonry infills in steel or reinforced concrete frames were also used. Following the Long Beach (California) Earthquake of 1933, unreinforced masonry buildings were effectively prohibited in the most seismic parts of the USA, including much of the western USA. Elsewhere in the USA, unreinforced masonry continued to be used.

Modern Masonry in the United States of America

Modern masonry in the USA consists of non-structural veneer (a decorative façade), and many kinds of structural masonry. Seismic design requirements require that modern masonry be reinforced in most but not all geographic areas of the USA. Reinforced masonry is usually constructed of hollow concrete masonry units, though hollow clay units can be used. An example of a reinforced masonry wall with an inner wythe of concrete masonry units and an outer wythe of clay units is shown in Figure 2.

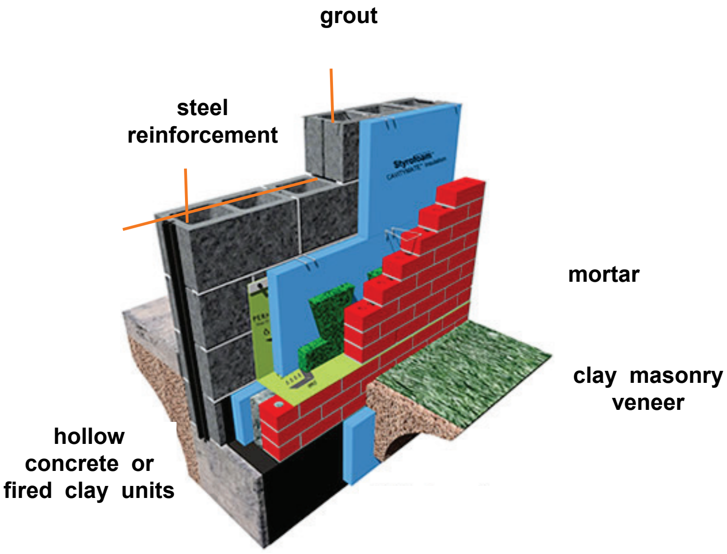

Figure 2 Example of modern masonry construction in the USA

HISTORICAL DEVELOPMENT OF MASONRY CODES IN THE USA

Early Masonry Design Documents, the MSJC, and the TCCMAR Program

Prior to the 1940s, masonry in the USA was designed based on experience, without explicit structural calculation. Codification of masonry design was marked by the publication of ANSI A41.1 (1953), of works by Plummer on clay masonry (for example, Plummer 1969), and works by Toennies on concrete masonry (for example, Toennies 1971). Work on what is now the MSJC Code began with the founding of the Masonry Standards Joint Committee in 1982, and the publication of the first MSJC Code in 1988. That document was based on allowable-stress and empirical design, and seismic design requirements were placed in an appendix so that they could be more easily deleted upon local adoption.

Of particular relevance to the development of masonry codes in the USA was the TCCMAR Program (Noland, 1990). With the support of the National Science Foundation and the masonry industry, the Technical Coordinating Committee for Masonry Research (TCCMAR) was formed in February 1984 for the purpose of defining and performing both analytical and experimental research and development necessary to improve masonry structural technology, and specifically to lay the technical basis for modern, strength-based design provisions for masonry. Based largely on the results of that program, strength design was added to the MSJC Code in 1999.

Reorganization and Recent History of the MSJC

In 2002, the MSJC was reorganized under its three sponsoring societies (The Masonry Society, the American Concrete Institute, and the American Society of Civil Engineers). The Masonry Society became the lead sponsor in 2005. Autoclaved aerated masonry (AAC) design provisions were added in 2005, and infill design provisions were added in 2011. The overall organization of the 2011 MSJC Code (MSJC 2011a) is shown in Figure 3.

Because it is necessary to ensure that masonry construction is consistent with design intent, the MSJC *Code* references and is linked to the MSJC *Specification*. The organization of the 2011 MSJC Specification is shown in Figure 4.

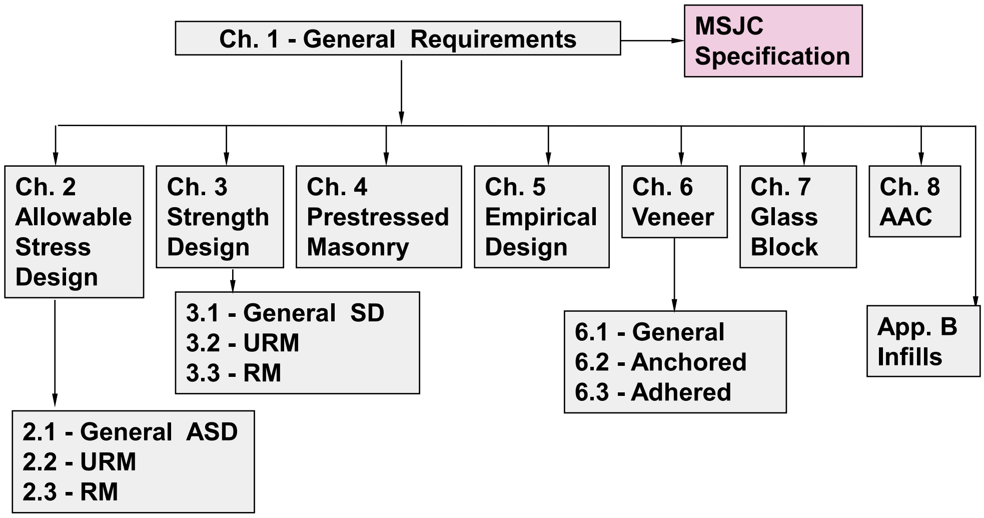

Figure 3 Overall organization of 2011 MSJC Code

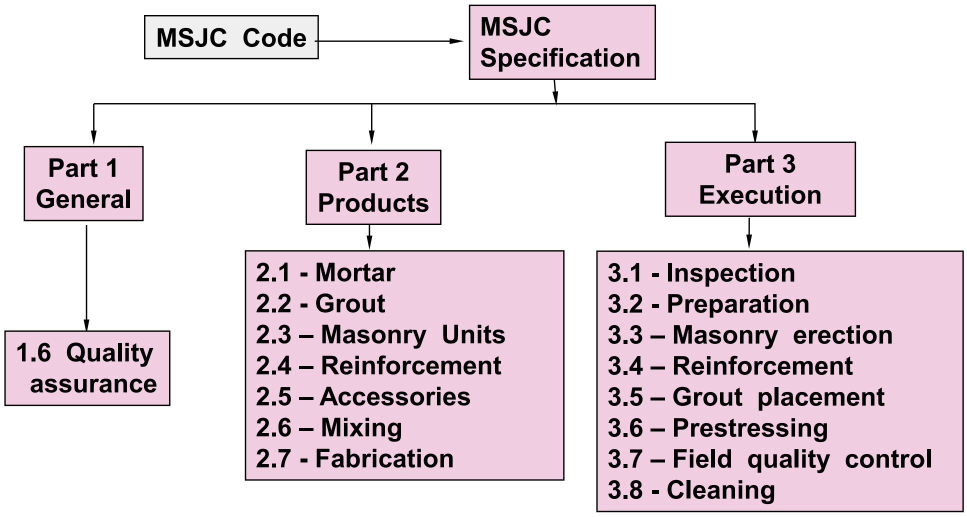

Figure 4 Overall organization of 2011 MSJC Specification

Overview of Strength Design of Reinforced Masonry in the 2011 MSJC Code

In the 2011 MSJC Code, strength design of masonry is quite similar to that of reinforced concrete. Design for combinations of flexure and axial load is based on plane sections, elasto-plastic steel reinforcement, and an equivalent rectangular stress block. Sections are required to be tension-controlled using a critical strain gradient that is tied to the assumed ductility demand in a design earthquake. Design for shear is based on combined resistance from masonry and resistance from transverse reinforcement. Design for anchorage is based on development lengths that address bond failure and splitting.

Future Trends for the MSJC

Over the past 15 years, and particularly since its reorganization in 2002, the MSJC and its *Code and Specification* have matured, with changes becoming fewer and fewer. Allowable-stress design and strength design are increasingly harmonized to give similar results. Strength design is the overwhelming favorite of younger designers, who prefer it because of its similarity to design in reinforced concrete. The coming years will probably see the gradual removal of empirical design, of unreinforced masonry, and even of allowable-stress design.

As the MSJC continues to mature, the masonry industry continues to face the challenge of remaining competitive is a difficult construction market. That challenge was explored in a workshop sponsored by the masonry industry in the USA in January 2001 in Tempe, Arizona. Part of that workshop included recommendations for focused research in many areas of masonry. The recommendations of that workshop remain valid 10 years later. They are repeated below, in updated form.

RECOMMENDATIONS FOR FOCUSED MASONRY RESEARCH

Masonry Research to Improve the Performance of Masonry as Building Envelope

1) Effectively communicate proper masonry design, detailing and construction practices to those responsible for establishing them and carrying them out.

2) Effectively communicate proper installation practices for ventilation and drainage details to those responsible for establishing them and carrying them out.

3) Increase the effectiveness and life of sealants, or reduce the envelope's dependence on them for performance.

4) Effectively communicate proper design, specification and installation practices for air and vapor barriers to those responsible for establishing them and carrying them out.

5) Increase the thermal insulation value of masonry units and assemblies.

6) Find ways of increasing the sound absorption (surface porosity) of masonry, while retaining durability.

7) Find ways to increase the fire-resistance rating of a given thickness of masonry.

8) Find ways to justify and encourage the use of non-combustible materials such as masonry in compartmentalization of buildings.

9) Develop and disseminate effective material specifications for impact resistance of masonry.

10) Develop user-friendly stiffness requirements for backup systems and connectors so that cracks in the masonry veneer will not permit an objectionable amount of water to pass through the building envelope.

11) Enhance the corrosion resistance of connectors and backup systems to prolong the effective life of masonry veneers.

12) Develop standard, user-friendly guidelines for locating and constructing movement joints.

13) Find effective ways to introduce masonry specification and detailing into undergraduate engineering and architecture curricula.

14) Find ways to encourage more university professors to become involved in the ASTM process, where they can learn about specification issues.

15) Encourage the continuing education about masonry, of practicing architects, engineers, contractors, building officials and inspectors.

Masonry Research to Improve the Performance of Masonry as Architecture

1) Find ways to increase the variety of architectural forms that can be laid using a relatively small number of different unit sizes, and with little or no cutting of units.

2) Develop formwork and scaffolding that will make it easier to construct masonry arches and domes.

3) Find ways to increase the variety of architectural details (such as corbels, racks, quoins, and different bond patterns) that can be laid without cutting units or unduly increasing cost.

4) Develop construction techniques or tools that will make it easier to construct masonry architectural details more quickly and reliably.

5) Find ways to improve the consistency of color of units and mortar.

6) Find ways to decrease cracking and chipping of masonry units.

7) Find better ways to control the alignment of units and mortar joints, the variation in thickness of mortar joints, and the variation of masonry walls from level and plumb.

8) Find better ways to control staining, and improve cleaning techniques.

9) Find better ways to decrease or eliminate efflorescence.

Masonry Research to Improve the Performance of Masonry as Structure

1) Develop simplified design provisions, consistent with the more complex ones, for the design of structural elements that we use often.

2) Develop user-friendly design aids to take the drudgery out of complex calculations.

3) Develop "deemed-to-comply" designs for simple masonry structures.

4) Continue to harmonize allowable-stress and strength designs.

5) Continue to scrutinize the adequacy of empirical design provisions.

6) Use the performance of all masonry, including empirically designed masonry, to identify areas where analytical design provisions may not recognize significant

resistance mechanisms, and incorporate those resistance mechanisms into analytical provisions.

7) Evaluate the adequacy of our existing analytical design provisions with respect to:
    a) in-plane flexural tension in masonry shear walls;
    b) minimum and maximum flexural reinforcement;
    c) moment magnifiers for masonry beam-column;
    d) the 1/3 stress increase;
    e) effective shear area for non-rectangular sections;
    f) effective width in compression around grouted reinforcement;
    g) effective distribution of bearing stresses under bond beams;
    h) effective width associated with a prestressing tendon;
    i) effective shear area for non-rectangular sections; and
    j) mixed-approach designs.

8) Develop a designer-friendly alternative to the bewildering array of classifications for lateral force-resisting systems ("ordinary," "intermediate," "special").

9) Develop reliable displacement-based design approaches for masonry structural systems without severe detailing requirements for inelastic response.

10) Develop reliable, user-friendly tools for predicting the inelastic response of masonry structural systems without severe detailing requirements.

11) Examine current tools for the performance-based seismic design of reinforced concrete structural systems, and modify them appropriately for masonry structural systems.

12) Apply rudimentary seismic rehabilitation techniques for old, unreinforced masonry throughout the country:
    a) brace or remove parapets;
    b) install through mechanical connectors between walls and horizontal diaphragms;
    c) brace walls out-of-plane; and
    d) verify the basic integrity of masonry by "shove tests" or other means.

13) Develop reliable tools for estimating the earthquake resistance of existing masonry buildings that were designed and constructed in compliance with the criteria of the 1950's, and develop reliable seismic retrofitting techniques for them.

14) Verify the strength of existing veneer tie systems, and develop new systems if necessary.

15) Investigate the behavior of connections between floor diaphragms and masonry.

16) Identify or develop a rational primer on engineering probabilities for non-mathematicians, and use it to estimate probabilities of failure under design loads during different recurrence intervals.

17) By instrumenting standard buildings around the country, obtain specific data on the response of masonry structures to extreme loads.

Masonry Research to Improve the Cost-Competitiveness of Masonry

1) Develop and disseminate standard specifications for typical masonry construction (veneer on houses, veneer on frame buildings, or low-rise commercial construction).

2) Find ways to decrease the capital investment and time required to bring new concrete and clay masonry plants on line.

3) Find more economical ways to comply with environmental restrictions on emissions and dust.

4) Find ways to decrease the production cost of masonry units even more.

5) Find ways to decrease the weight or thickness of masonry units, so that a wall of the same surface area can weigh less.

6) Develop:
   a) ways to encourage specifiers to use modular design;
   b) cost-effective ways to decrease breakage and chippage of masonry units;
   c) masonry mortars with improved performance;
   d) better materials and techniques for grouting;
   e) better techniques for hot- and cold-weather construction;
   f) more cost-effective ways (such as silo systems) to batch, mix and deliver mortar;
   g) more cost-effective scaffolding systems;
   h) more cost-effective flashing, insulation, and air and vapor barriers;
   i) more cost-effective ways of protecting masonry during construction;
   j) more cost-effective ways of keeping masonry clean during construction; and
   k) more cost-effective ways of cleaning masonry after construction.

7) Continue efforts to recruit and train masons, and conduct focused research on better ways to accomplish this.

8) Develop standard wall types with uniform specifications and construction details (for example, a standard residential veneer wall; a rain-screen wall; a standard drainage wall with CMU backup; a standard drainage wall with steel stud backup; a standard fully grouted barrier wall; and a standard partially grouted barrier wall).
   a) prepare design procedures, examples, specifications and drawings for each wall type.
   b) prepare step-by-step instructions, in words and pictures, and in different languages, showing the proper assembly of each wall type.

8) Identify ways of reducing maintenance and repair costs of masonry buildings (for example, reducing efflorescence).

9) Identify strategies for reducing the cost of insurance premiums for masonry buildings, and implement those strategies.

10) Update criteria for compiling life-cycle costs for buildings of different materials, and update the corresponding values for masonry buildings.

11) Update criteria for compiling life-cycle environmental costs for buildings of different materials, and update the corresponding values for masonry buildings.

12) Continue research on potential obstacles to the use of masonry in niche markets (such as chimneys), and on ways of overcoming those obstacles.

13) Continue to regularly examine the potential of new markets (such as prestressed masonry, segmental masonry retaining walls, and AAC masonry), and prepare to be competitive in those markets.

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