TMS 404

Section 1
General

1.1 — Scope

This standard provides minimum requirements for the design of non-structural cast stone systems and elements.

COMMENTARY

Section 1
General

1.1 — Scope

This standard covers the minimum requirements for the design and detailing of cast stone systems and serves as part of the legally adopted building code. ~~Because the requirements for cast stone in this standard are interrelated with requirements for cast stone in other standards and codes, this standard may need to be superseded when there are conflicts between the provisions of this standard and the legally adopted building code or with documents referenced by this standard. The user must resolve such conflicts where they arise. Generally, the requirements of the locally adopted building code govern where conflicts exist.~~

Much of the information and many of the requirements of this standard have been drawn from historical practices and successful means and methods of designing and detailing ~~detailing and designing~~ cast stone systems and structures. More information on the use of cast stone products along with industry recommendations intended to supplement this standard is available through the Cast Stone Institute (www.caststone.org).

This standard governs the design of non-structural cast stone, which may on occasion have structural design aspects that warrant additional consideration. Examples of nonstructural cast stone include veneers, cladding, sills, and quoins. The structural design aspects of nonstructural cast stone include, but are not limited to, gravity and lateral support and load transfer to supporting elements. Examples of structural cast stone may include columns, lintels, and similar elements that support loads other than their own weight. The design of structural cast stone is outside the scope of this standard. For such applications, users are referred to Section 2 of this standard and to TMS 402, *Building Code Requirements for Masonry Structures* (TMS 402, 2016), for the design of dry-cast or mortared structural cast stone or ACI 318, *Building Code Requirements for Structural Concrete* (ACI 317, 2014), for the design of wet-cast structural cast stone.

The provisions of this standard address the minimum requirements for the design of non-structural cast stone. As such, some specific applications or conditions may warrant exceeding these minimum requirements; however, these provisions should not be reduced or relaxed below the minimum threshold defined by this standard.

As many projects involving cast stone components include some degree of delegated design, whereby fabrication and anchorage details for cast stone are supplied by the installer or manufacturer of the cast stone, each party must understand their role and intended services to be provided and clearly communicate project variables.

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1.2 — Governing building code

This standard supplements the legally adopted building code and shall govern in matters pertaining to the design of cast stone, except where this standard is in conflict with requirements in the legally adopted building code. In areas without a legally adopted building code, this standard defines the minimum acceptable standard for the design of cast stone.

1.3 — SI information

The SI values shown in parentheses are not part of this standard. The equations in this standard are for use with the specified inch-pound units only.

Section 2
Alternative Design or Method of Construction

The provisions of this standard, and those of TMS 504 and TMS 604 referenced within this standard, shall not be construed as prohibiting a method of design or construction not specifically prescribed, provided such method of design or construction has been approved by the authority having jurisdiction.

COMMENTARY

Topics may include special loading conditions, resolving conflicting details from separate third parties, coordination of trades and installation schedules, limitations on the scope of services, and completeness of work to be provided.

1.2 — Governing building code

Within the United States, the vast majority of states and municipalities have adopted a building code that covers the minimum requirements for the design, construction, and inspection of buildings and similar structures. In those jurisdictions where the building code references or adopts this standard, the provisions of this standard become part of the building code's requirements as if fully transcribed therein. In jurisdictions that have not adopted a building code, the provisions of this standard can still be used as reference material and guidance for the design of cast stone. By reference, the minimum requirements for the fabrication and installation of cast stone are covered in TMS 504 and TMS 604, respectively.

Because the requirements for cast stone in this standard are interrelated with requirements for cast stone in other standards and codes, this standard may need to be superseded when there are conflicts between the provisions of this standard and the legally adopted building code or with documents referenced by this standard. The user must resolve such conflicts where they arise. Generally, the requirements of the locally adopted building code govern where conflicts exist.

1.3 — SI information

The equivalent SI values and equations are provided for information to the user.

Section 2
Alternative Design or Method of Construction

New methods of design, new materials, and new uses of materials must undergo a period of development before being specifically addressed by a code or standard. Hence, valid systems or components might be excluded from use by implication if means were not available to obtain acceptance. This section permits proponents to submit supporting documentation substantiating the adequacy of their system or component for approval.

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Section 3
Cited Standards

Standards of the American Society of Civil Engineers, ASTM International, the American Welding Society, and The Masonry Society cited in this standard are listed below with their serial designations, including year of adoption or revision, and are declared to be part of this standard as if fully set forth in this document.

~~TMS 504-16 Standard for the Fabrication of Architectural Cast Stone~~

~~TMS 604-16 Standard Specification for Installation of Architectural Cast Stone~~

ASCE 7-22~~16~~ – Minimum Design Loads and Associated Criteria for Buildings and Other Structures

ASTM C426-16 – Standard Test Method for Linear Drying Shrinkage of Concrete Masonry Units

ASTM E111-17~~04(2010)~~ – Standard Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus

AWS D1.4/D1.4M-18~~11~~ – Structural Welding Code – Reinforcing Steel

TMS 504-23 – Standard for the Fabrication of Architectural Cast Stone

TMS 604-23 – Standard Specification for Installation of Architectural Cast Stone

COMMENTARY

Section 3
Cited Standards

The standards cited are referenced in this standard as part of the design requirements for cast stone. Specific editions of each cited standard are listed because changes to the referenced standard may result in changes of properties or procedures. Contact information for the organizations maintaining these standards is provided below:

American Society of Civil Engineers (ASCE)
1801 Alexander Bell Drive
Reston, VA 20191
www.asce.org

ASTM International (ASTM)
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959
www.astm.org

American Welding Society (AWS)
550 N.W. LeJeune Road
Miami, FL 33126
www.aws.org

The Masonry Society (TMS)
105 South Sunset Street, Suite Q
Longmont, CO 80501-6172
www.masonrysociety.org

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Section 4
Notation and Definitions

4.1 — Notation

d_b = nominal diameter of reinforcement or anchor bolt, in. (mm)

E_{MCS} = modulus of elasticity of cast stone in compression, psi (MPa)

E_S = modulus of elasticity of steel, psi (MPa)

E_{VCS} = modulus of rigidity (shear modulus) of cast stone, psi (MPa)

f'_{cs} = specified compressive strength of cast stone, psi (MPa)

f'_g = specified compressive strength of grout, psi (MPa)

f_y = specified yield strength of steel for reinforcement and anchors, psi (MPa)

l_d = development length or lap length of straight reinforcement, in. (mm)

4.2 — Definitions

Cast stone (Architectural Cast Stone) – An architectural precast concrete building unit manufactured to simulate natural cut stone.

Contract documents – Documents establishing the required work, including in particular, the project drawings and project specifications.

Dry-cast – Cast stone manufactured from zero slump concrete.

COMMENTARY

Section 4
Notations and Definitions

4.1 — Notations

No commentary.

4.2 — Definitions

For consistent application in this standard, terms are defined here that have particular meaning in the context of these provisions. The definitions given here are for use in application of this standard only and do not always correspond to ordinary usage.

Cast stone (Architectural Cast Stone) – Cast stone products can be manufactured using wet-cast or dry-cast procedures, depending upon the facilities and equipment used by a particular manufacturer or as needed to produce a desired profile or feature. The method of manufacturing should not be specified, but instead be at the discretion of the cast stone producer who has the knowledge and understanding to employ the appropriate manufacturing method for the product specified. Because of its near exclusive use as an architectural enhancement, the terms 'cast stone' and 'architectural cast stone' are used interchangeably.

Contract documents – Contract documents are the vehicle of communicating the designer's intent, and do not, by default, address means and methods of construction.

Dry-cast – Dry-casting procedures for cast stone production generally consist of two methods: 1) vibrant dry-tamp (VDT) casting method, which consists of vibratory ramming of zero-slump concrete against a rigid mold until it is densely compacted; and 2) machine casting method, which consists of zero-slump concrete compacted by machinery using vibration and pressure against a mold until it becomes densely consolidated.

TMS 404

Element, cast stone – A single cast stone unit or a combination of individual cast stone units that are assembled into a final configuration to create a unique component.

Vertically aligned bond – Any architectural bond pattern where:

a) head joints in successive courses are horizontally offset less than one-quarter of the length of the unit;

b) or where more than 55% of the total cumulative length of the head joints in an assembly are vertically aligned in a single plane.

Wet-cast – Cast stone manufactured from measurable slump concrete.

Section 5
Contract Documents

5.1 — General

Project drawings and project specifications for cast stone construction shall be consistent with design intent ~~assumptions~~ and shall identify the individual responsible for their preparation.

COMMENTARY

Element, cast stone – A cast stone element may be comprised of multiple individual pieces of cast stone. For example, window surrounds and columns often consist of multiple pieces of cast stone that are field assembled into the final cast stone element.

Vertically aligned bond – The selection of a bond pattern is often driven by the desire to achieve a specific aesthetic effect. There are, however, performance implications associated with bond patterns that should be addressed when designing and detailing a cast stone assembly. For the purposes of this standard, cast stone assemblies laid in mortar using a bond pattern that meets the definition of vertically aligned bond must be reinforced horizontally in accordance with Section 9.6.1 to provide continuity across the heads joints. Stack bond, which is commonly interpreted as a bond pattern with vertically aligned heads joints, is one bond pattern that is required to be reinforced horizontally. Examples of bond patterns meeting the requirements of vertically aligned bond are illustrated in Figure C4.2-1. Examples of bond patterns that do not meet the requirements of vertically aligned bond are illustrated in Figure C4.2-2. (Shaded portions of the figures illustrate the repeating pattern for ashlar bond assemblies.) Cast stone may also consist of discrete elements or components of larger assemblies where bond pattern is irrelevant. Examples include balusters, keystones, and signage.

Wet-cast – Wet-casting procedures for cast stone consist of vibrating a measurable slump concrete into a mold until it becomes densely consolidated.

Section 5
Contract Documents

5.1 — General

The provisions for preparation of project drawings, project specifications, and issuance of permits are, in general, consistent with those of most legally adopted building codes and are intended as supplements to those codes.

The contract documents must accurately reflect design requirements and modeling assumptions. For example, joint and opening locations assumed in the design should be coordinated with locations shown on the drawings. Verification that cast stone construction conforms to the contract documents is required by this standard. A program of quality assurance must be included in the contract documents to satisfy this requirement as required by Section 5.4. This standard is intended to be referenced by the contract documents; however, the contractor should not be required through contract documents to assume

responsibility for design (Code) requirements, unless the construction entity is acting in a design-build capacity.

COMMENTARY

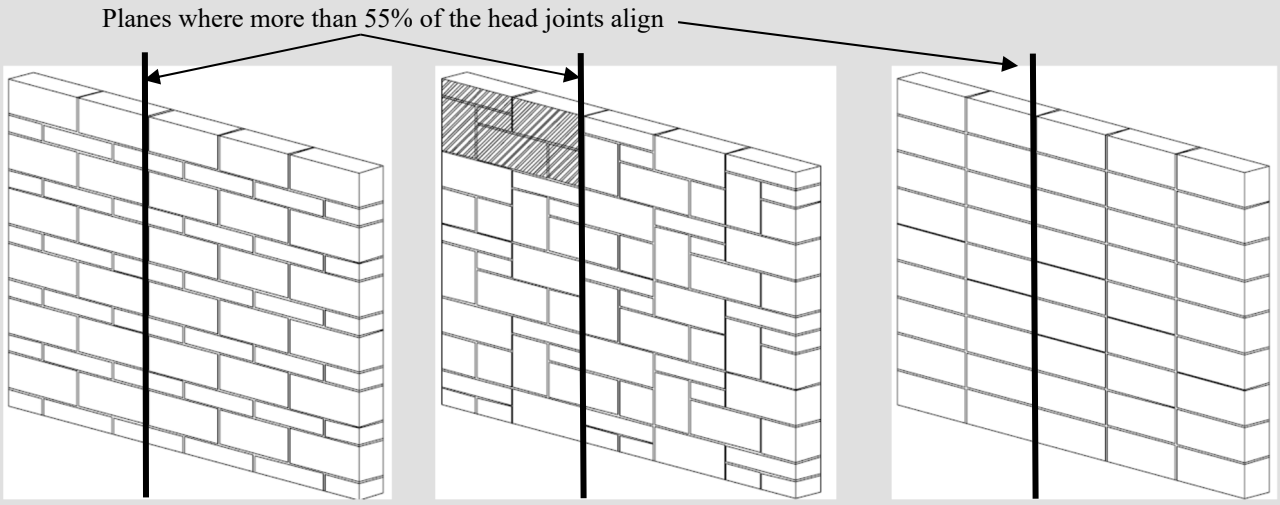

Figure C4.2-1 Vertically Aligned Bond Patterns

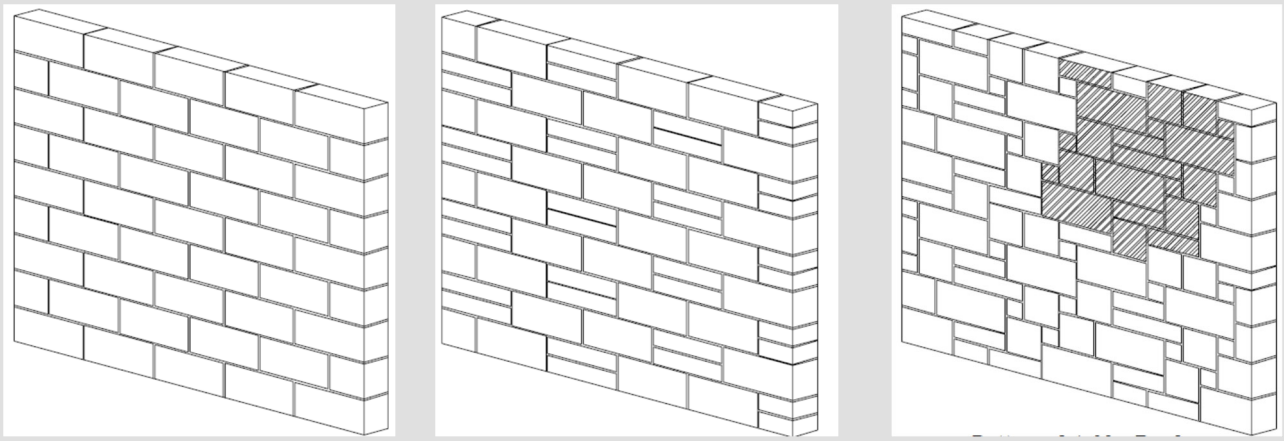

Figure C4.2-2 Non-Vertically Aligned Bond Patterns

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5.2 — Project Drawing Information

The project drawings shall show all applicable and required information including:

a) Name and date of issue of code and supplement to which the design conforms.

b) Loads used in the design of cast stone systems.

c) Specified compressive strength of cast stone at stated ages or stages of construction.

d) Size and location of structural elements supporting cast stone.

e) Details of anchorage of cast stone to structural members, frames, and other construction, including the type, size, and location of connectors.

f) Connections to be welded and welding requirements.

g) Provision for dimensional changes resulting from moisture, vibrations, impact, shrinkage, expansion, temperature changes, creep, unequal settlement of supports, and differential movement.

h) Size and permitted location of conduits, pipes, and sleeves.

i) Dimensioning of areas where cast stone is to be placed.

5.3 — Fabrication and Installation

Cast stone assemblies and their components shall be designed in accordance with the provisions of this design standard. The fabrication of cast stone elements shall be specified to comply with the requirements of TMS 504. The installation of cast stone elements and systems shall be specified to comply with the requirements of TMS 604.

5.4 — Quality Assurance

Contract documents ~~shall specify the minimum level of quality assurance as defined by this standard, or~~ shall include an itemized quality assurance program that equals or exceeds the requirements of TMS 604.

COMMENTARY

5.2 — Project Drawing Information

This standard lists some of the more important items of information that must be included in the project drawings. This is not an all-inclusive list and additional items may be required by the designer, the building official or legally adopted building code.

5.3 — Fabrication and Installation

The successful outcome of a cast stone project depends not only on good detailing and design, but also the use of quality products and the implementation of good construction practices and workmanship. The requirements of this standard are inherently built upon the assumption that cast stone products meet the requirements of TMS 504, *Standard for Fabrication of Architectural Cast Stone*, which in turn are installed in accordance with the minimum requirements of TMS 604, *Standard Specification for Installation of Architectural Cast Stone*.

5.4 — Quality Assurance

TMS 604 defines the minimum quality assurance requirements to ensure the quality of product, assembly, and workmanship meet the performance assumptions inherent in the design requirements defined by this standard and the fabrication requirements of TMS 504.

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Section 6
Loading

6.1 — General

Cast stone shall be designed to resist applicable loads. A continuous load path or paths, with adequate strength and stiffness, shall be provided to transfer forces from the point of application to the final point of resistance.

6.2 — Load provisions

Design loads shall be in accordance with the legally adopted building code. In the absence of design loads in the legally adopted building code, the load provisions of ASCE 7 shall be used.

6.3 — Lateral force-resistance

Structures shall be provided with a structural system designed to resist wind and earthquake loads and to accommodate the effect of the resulting deformations. Cast stone designed in accordance with this standard shall not be used as part of a building's lateral force-resisting system.

6.4 — Load transfer at intersections

Cast stone elements and assemblies shall be designed to resist applied loads, moments, and shears. The effect of lateral displacement, drift, and translation of members providing lateral support to cast stone systems shall be considered. Devices used for supporting cast stone shall be designed to resist the forces involved. Cast stone elements and assemblies shall not be connected to structural frames unless the connections and the cast stone are designed to resist interconnecting design forces and to accommodate calculated deflections.

COMMENTARY

Section 6
Loading

6.1 — General

Cast stone must be designed and detailed to safely transfer applied design loads to its supports and into the structural system.

6.2 — Load provisions

If the design loads specified by the legally adopted building code differ from those of ASCE 7, the legally adopted building code governs. The designer may choose to use more stringent design load requirements than the legally adopted building code.

6.3 — Lateral force-resistance

Cast ~~Instead, cast~~ stone is commonly incorporated as nonstructural components and cladding of a building or otherwise structurally isolated from the lateral force-resisting system. Portions of a building's structural system supporting loads applied from, or resisting loads induced from cast stone, must be designed to accommodate such forces. This standard does not include provisions for using cast stone systems as part of the lateral force-resisting system. Such uses should be considered under Section 2 for special systems.

6.4 — Load transfer at intersections

Cast stone systems may be connected to horizontal or vertical elements of the structure and may rely on these elements for lateral support and stability. The mechanism through which the interconnecting forces are transmitted may involve bond, mechanical anchorage, friction, bearing, or a combination thereof. The designer must assure that, regardless of the type of connection, the interacting forces are resisted. In flexible frame construction, the relative movement (drift) between floors may generate forces within the members and the connections that must be considered in design.

Exterior cast stone façades connected to structural frames are used primarily as non-load-bearing curtain walls. Regardless of the structural system used for support, there are differential movements between the structural support and the cast stone~~structure and the wall~~. These differential movements may occur separately or in combination and may be due to the following:

1) Temperature increase or decrease of either the structural frame or the cast stone.
2) Shrinkage resulting from moisture loss or carbonation of the cast stone.
3) Elastic shortening of elements or assemblies from axial loads, shrinkage, or creep.
4) Deflection of supporting beams.

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6.5 — Other effects

Consideration shall be given to effects of forces and deformations resulting from moisture, vibrations, impact, shrinkage, expansion, temperature changes, creep, unequal settlement of supports, and differential movement, including movement between different materials in the same plane or assembly.

6.6 — Deflection limits

Unless a less stringent deflection limit is verified through engineering analysis, the out-of-plane deflection of assemblies supporting cast stone shall not exceed l/600.

Section 7
Material Properties

7.1 — General

Unless otherwise determined by test, the material properties of Section 7 shall be used for the design of cast stone.

7.2 — Elastic moduli

7.2.1 *Steel reinforcement* — Modulus of elasticity of steel reinforcement, E_S, shall be taken equal to 29,000,000 psi (200,000 MPa).

7.2.2 *Cast stone* — The modulus of elasticity of cast stone, E_{MCS}, shall be taken equal to the chord modulus of elasticity taken between 0.05 and 0.33 of the maximum

COMMENTARY

5) Drift in multiple-story buildings.
6) Foundation movement.

These differential movements must be accommodated by sufficient clearance between the frame and the cast stone to prevent the unintended transfer of loads into the cast stone. Flexible or slip-type connections may also facilitate such differential movement.

6.5 — Other effects

Applied loads are not the sole source of stresses. The cast stone may also be required to resist forces from other sources, the nature and extent of which may be greatly influenced by the choice of materials, structural connections, and geometric configuration as cast stone does not always behave in the same manner as its structural supports or adjacent construction. The designer should consider differential movements and the forces resulting from their restraint. While load transfer usually involves cast stone attached to structural elements, such as beams or columns, the connection of nonstructural elements, such as door and window frames, should also be addressed.

Connectors used in the construction of cast stone systems are available in a variety of sizes, shapes, and uses. In order to perform properly they should be identified on the project drawings as required by Section 5.2.

6.6 — Deflection limits

These deflection limits apply to any material providing out-of-plane support of cast stone. The deflection limit of l/600 is intended to prevent visible deflections and serviceability problems under short-term loading conditions. When considering deflections resulting from sustained loads, a more stringent deflection limit may be warranted.

Section 7
Material Properties

7.1 — General

No commentary.

7.2 — Elastic moduli

7.2.2 *Cast stone* — ~~The modulus of elasticity of cast stone, E_{MCS}, shall be taken equal to the chord modulus of elasticity taken between 0.05 and 0.33 of the maximum~~

TMS 404

compressive strength of the cast stone product or system when tested in accordance with ASTM E111. The modulus of rigidity of cast stone, E_{VCS}, shall be taken equal to $0.4E_{MCS}$.

COMMENTARY

~~compressive strength of the cast stone product or system when tested in accordance with ASTM E111. The modulus of rigidity of cast stone, E_{VCS}, shall be taken equal to $0.4E_{MCS}$.~~

Limited test data exists correlating the compressive strength of cast stone to its modulus of elasticity as either a material or system. As such, testing is required in situations where the modulus of elasticity is required for design. Bounding the chord modulus at 5% and 33% of the maximum compressive strength captures the typical range of service-level stresses for masonry systems (TMS 402, 2016). The modulus of rigidity has historically been taken as 40% of the modulus of elasticity for concrete systems.

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7.3 — Coefficient of thermal expansion

The coefficient of thermal expansion for cast stone shall be taken as 0.0000045 in./in./°F (0.0000081 mm/mm/°C).

7.4 — Coefficient of shrinkage

The coefficient of shrinkage for cast stone shall be taken as one-half of the linear drying shrinkage determined in accordance with ASTM C426. ~~0.000325 in./in. (0.000325 mm/mm).~~

7.5 — Allowable flexural stress of unreinforced cast stone units

The allowable flexural stress of unreinforced cast stone units shall be taken equal to $5\sqrt{f'_{cs}}$.

COMMENTARY

7.3 — Coefficient of thermal expansion

The coefficient of thermal expansion for cast stone is assumed similar to that used for concrete masonry construction (TMS 402, 2016; NCMA TEK 10-3, 2003). All concrete-based materials have a range of thermal expansion depending upon mix design, constituent materials, and method of manufacturing. The typical range of the coefficient of thermal expansion varies from 0.000003 in./in./°F (0.0000054 mm/mm/°C) to 0.000007 in./in./°F (0.0000126 mm/mm/°C).

7.4 — Coefficient of shrinkage

~~The total linear drying shrinkage of cast stone is determined in accordance with ASTM C426 (2015) and is limited to 0.065% in accordance with ASTM C1364 (2016).~~ For design, the coefficient of shrinkage is assumed to be one-half of the maximum linear drying shrinkage determined in accordance with ASTM C426, which is consistent with similar assumptions for concrete masonry construction (TMS 402, 2016). ASTM C426 (2016) requires that linear drying shrinkage be measured and reported, but does not stipulate a maximum linear drying shrinkage value. This reflects the wide array of applications in which cast stone systems are used, including mortared and non-mortared systems, each of which has different considerations with respect to crack mitigation strategies due to shrinkage. Where shrinkage is a design consideration, care should be taken to verify units are not installed too soon following production, during which time volume loss due to drying and cement hydration is the largest.

7.5 — Allowable flexural stress of unreinforced cast stone units

The allowable flexural stress of cast stone units is drawn from corresponding concrete research and has been used successfully in practice for many years. This value applies to the cast stone unit, not the assembly. The allowable flexural stress of assemblies of cast stone units would depend upon whether the individual units are dry-set or mortared.

Cast stone designed in accordance with this standard is limited to non-structural, architectural applications. As a cladding, the cast stone is designed to transfer out-of-plane loads to the backing through the supporting anchors or frame. Because there is no consideration of assembly stresses in the cast stone cladding, there are no allowable flexural design stresses included in this standard that are applicable to the assembly. Where such values may be needed, they would need to be determined by test for the materials to be used on a project.

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Section 8
Material Properties

8.1 — Stress determination

Cast stone members shall be designed using section properties based on the minimum net cross sectional area of the member under consideration. Section properties shall be based on specified dimensions.

8.2 — Stiffness

Computation of stiffness of reinforced cast stone assemblies shall first be checked on an uncracked section analysis under service loads, then checked on a cracked section analysis under factored nominal loads. Computation of stiffness of unreinforced cast stone assemblies shall be based on an uncracked section analysis.

COMMENTARY

Section 8
Material Properties

8.1 — Stress determination

Configurations, and therefore section properties, of cast stone products vary depending upon the product being produced and its application. Computation of stresses, including flexure, compression, tension, and shear, for cast stone assemblies is not often necessary, but when appropriate, the net cross-sectional properties of the cast stone assembly are required to be used in calculating stresses.

8.2 — Stiffness

Because unreinforced cast stone assemblies rely upon the flexural tensile strength of the cast stone to resist applied loads, they must be designed to remain uncracked. As such, stiffness computation of unreinforced cast stone is based on uncracked section properties. For reinforced cast stone assemblies, the cast stone is assumed to crack to transfer tensile stresses to the reinforcement; however, the stiffness is a function of the extent of cracking within an element or assembly. Lacking a more sophisticated cracked section analysis, the cracked moment of inertia of a section can be assumed to be 50% of the uncracked moment of inertia of the section. For serviceability, reinforced cast stone assemblies are checked under service-level loads using uncracked sections. Design strength of cast stone assemblies is then verified using cracked section properties subjected to full design loads.

The section properties of cast stone members may vary from point to point. For example, a cast stone column may taper along its length. For stiffness computations, an average value of the appropriate section property (cross-sectional area or moment of inertia) is considered adequate for most design applications.

Stiffness calculations are based upon whether the assembly is continuously reinforced, not whether an individual cast stone element contains reinforcement. For example, it is common practice to incorporate reinforcement into large panels of cast stone for handling and shrinkage purposes. Such panels may be laid together in mortar to create a larger assembly, however, because the reinforcement is discontinuous at the mortar joints, the assembly would be considered to be unreinforced even though the individual panels contain reinforcement.

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8.3 — Radius of gyration

Radius of gyration shall be computed using average net cross-sectional area of the member considered.

COMMENTARY

8.3 — Radius of gyration

The radius of gyration is the square root of the ratio of bending moment of inertia to cross-sectional area. Because stiffness is based on the average net cross-sectional area of the member considered, the same area should be used in the computation of radius of gyration. The radius of gyration is calculated as follows:

$$r = \sqrt{\frac{I}{A}}$$

Where:
r = radius of gyration
I = net moment of inertia
A = net cross-sectional area

Section 9
Details of Reinforcement and Metal Accessories

Section 9
Details of Reinforcement and Metal Accessories

The provisions of Section 9 are largely based on historically accepted practice for cast stone construction augmented with similar practices used for masonry construction (TMS 402, 2016). Reinforcing options for cast stone elements include ferrous-based metals as well as non-metals, such as fiberglass reinforcement

9.1 — Embedment

Reinforcing bars shall be embedded in cast stone.

9.1 — Embedment

Cast stone units are often manufactured with reinforcement incorporated into the product in accordance with TMS 604. This standard does not address the field installation of reinforcing bars within cast stone assemblies.

9.2 — Size of reinforcement ~~within the cast stone element~~

9.2.1 The diameter of reinforcement embedded in cast stone units shall not exceed one-fourth the minimum dimension of the unit. The maximum size of reinforcement used in dry-cast cast stone units and systems shall be No. 4 (M #13). The maximum size of reinforcement used in wet-cast cast stone units and systems shall be No. 8 (M #25).

9.2 — Size of reinforcement ~~within the cast stone element~~

9.2.1 The limitation on the maximum size of reinforcement permitted to be embedded within a cast stone element is a direct means of ensuring relatively large diameter reinforcing bars are not placed within relatively small cast stone units, which in turn can lead to performance or aesthetic problems when placed in service. It is also an indirect means of providing cover and corrosion protection of the reinforcement. For a cast stone slab measuring 2 in. (51 mm) in thickness, the maximum diameter of reinforcement permitted by this requirement would be a No. 4 (M#13) bar. Larger cover distances may be required for corrosion protection of reinforcement in accordance with Section 9.4.

The limitation on reinforcing bar size is arbitrary based on historically accepted practice. Wet-casting procedures generally allow for larger cast stone products to be manufactured, hence the larger permitted size of reinforcement.

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9.2.2 Longitudinal and cross wires of joint reinforcement shall have a minimum wire size of W1.1 (MW7) and a maximum wire size of one-half the joint thickness.

9.3 — Placement of reinforcement within the cast stone element

9.3.1 The clear distance between parallel bars shall not be less than the nominal diameter of the bars, nor less than 1 in. (25.4 mm), whichever is greater. The clear distance between a contact lap splice and adjacent splices or bars shall not be less than the nominal diameter of the bars, nor less than 1 in. (25.4 mm), whichever is greater.

9.3.2 Reinforcing bars shall not be bundled.

9.3.3 Welded wire reinforcement shall not be embedded in dry-cast cast stone elements.

9.4 — Protection of reinforcement and metal accessories

9.4.1 Cover of reinforcing bars provided by the cast stone or grout shall not be less than twice the diameter of the reinforcement nor less than 1½ in. (38.1 mm), whichever is greater. For wet-cast cast stone incorporating reinforcing bars larger than No. 5 (M #16), the minimum cover shall be increased to 2 in. (51 mm).

9.4.2 Wire reinforcement shall be fully embedded in mortar, grout or cast stone with a minimum cover of $^{5}/_{8}$ in. (15.9 mm) when exposed to earth or weather and ½ in. (12.7 mm) when not exposed to earth or weather. Wire reinforcement shall be stainless steel or protected from corrosion by hot-dipped galvanized coating or epoxy coating when used in cast stone exposed to earth, weather, or a mean relative humidity exceeding 75 percent. All other wire reinforcement shall be mill galvanized, hot-dip galvanized, epoxy coated, or stainless steel.

COMMENTARY

9.2.2 Note that Section 9.3.3 does not permit welded wire reinforcement to be embedded into dry-cast cast stone elements during manufacturing. There is, however, no limit on the use of wire reinforcement within the joints of a cast stone assembly. The maximum wire size of one-half the joint thickness is to ensure that the wire is sufficiently bonded to the mortar in which it is embedded. W1.1 (MW7) wire has a nominal diameter of 0.121 in. (3.1 mm). As such, bed joint reinforcement cannot be used when the mortar joint thickness is less than 0.25 in. (6.4 mm).

9.3 — Placement of reinforcement within the cast stone element

9.3.1 These requirements help to ensure that there is sufficient clearance around reinforcement to adequately consolidate the concrete in which the reinforcement is embedded.

9.3.2 No commentary.

9.3.3 Due to the difficulty in adequately consolidating dry-cast, zero-slump concrete around welded wire reinforcement, its use is permitted only with wet-cast manufactured cast stone elements.

9.4 — Protection of reinforcement and metal accessories

9.4.1 No commentary.

9.4.2 The provisions of Section 9.4.2 apply to wire reinforcement used in the mortar joints between cast stone units or placed within the units during manufacturing of wet-cast cast stone units.

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9.4.3 Wall ties, anchors, plates, dowels, and similar embedded metal accessories exposed to earth, weather, or a mean relative humidity exceeding 75 percent shall be stainless steel. Wall ties, anchors, plates, dowels, and similar embedded metal accessories not exposed to earth, weather, or a mean relative humidity exceeding 75 percent shall be stainless steel, hot-dip galvanized, mill galvanized, or epoxy coated.

9.5 — Reinforcement detailing

9.5.1 *Standard hooks* — Standard hooks shall consist of the following:

(a) 180-degree bend plus a minimum $4d_b$ extension, but not less than 2 $^1/_2$ in. (64 mm) at free end of bar;

(b) 90-degree bend plus a minimum $12d_b$ extension at free end of bar; or

(c) for stirrup and tie hooks, either a 90-degree or 135-degree bend plus a minimum $6d_b$ extension, but not less than 2 $^1/_2$ in. (64 mm) at free end of bar.

9.5.2 *Minimum bend diameter for reinforcing bars* — The diameter of bend measured on the inside of reinforcing bars shall not be less than $6d_b$.

9.5.3 *Development and splicing of reinforcement*

9.5.3.1 *General* — The calculated tension or compression in the reinforcement at each section shall be developed on each side of the section by development length, hook, mechanical device, or combination thereof. Hooks shall not be used to develop bars in compression.

9.5.3.2 *Development of bars in tension or compression* — The required development length of reinforcing bars shall not be less than $48d_b$ or 12 in. (305 mm), whichever is greater. Development length of epoxy-coated bars shall be increased 50 percent.

COMMENTARY

9.4.3 Unlike wire reinforcement and reinforcing bars that are completely embedded within, and protected by, the cast stone assembly, other steel embeds may be partially or completely exposed to the effects of weathering and subsequent corrosion. As such, this standard requires metal accessories embedded within a cast stone unit to be stainless steel when exposed to weather. Metal accessories used in interior applications where the mean relative humidity is 75 percent or less are permitted to be protected from corrosion by hot-dip or mill galvanizing or epoxy coating. This requirement only applies to metal items that are embedded within a cast stone assembly and does not apply to metal items that are simply in contact with a cast stone assembly; for example, relief angles used to support cast stone.

9.5 — Reinforcement detailing

9.5.1 *Standard hooks* — No commentary.

9.5.2 *Minimum bend diameter for reinforcing bars* — No commentary.

9.5.3 *Development and splicing of reinforcement*

9.5.3.1 *General* — No commentary.

9.5.3.2 *Development of bars in tension or compression* — The scope of this standard does not address the design of cast stone elements that are part of the lateral force-resisting system. As such, the system ductility implicit within the lap splice and development length requirements of similar concrete and masonry design standards is not required in cast stone systems. Requiring a minimum lap and development length of 48 bar diameters ensures that sufficient bond can be developed between the reinforcing bar and the material within which it is embedded to transfer stresses and distribute loads encountered during transport, installation, and service.

TMS 404

9.5.3.3 *Splices of reinforcement* — Lap splices, welded splices, or mechanical splices are permitted in accordance with the provisions of this section. Welding shall conform to AWS D1.4.

9.5.3.3.1 *Lap splices* — The minimum length of lap for bars in tension or compression shall be determined in accordance with Section 9.5.3.2, but shall not be less than 12 in. (305 mm).

9.5.3.3.2 *Welded splices* — Welded splices shall have the bars butted and welded to develop in tension at least 125 percent of the specified yield strength of the bar. Welded splices shall not be permitted in dry-cast cast stone.

9.5.3.3.3 *Mechanical splices* — Mechanical splices shall have the bars connected to develop in tension or compression, as required, at least 125 percent of the specified yield strength of the bar.

9.6 — Prescriptive detailing requirements

9.6.1 *Cast stone laid in vertically aligned bond* — For cast stone ~~assemblies~~ laid in mortar and constructed in vertically aligned bond, the minimum area of horizontal wall reinforcement shall be 0.00028 multiplied by the gross vertical cross-sectional area of the cast stone assembly using specified dimensions. Horizontal wall reinforcement shall be placed at a maximum vertical spacing of 48 in. (1219 mm) on center in horizontal mortar joints.

9.6.2 *Minimum reinforcement* — Cast stone units shall be reinforced in each principal dimension greater than 24 in. (610 mm). The minimum area of reinforcement shall be 0.25 percent of the minimum cross-sectional area of the unit.

COMMENTARY

9.5.3.3 *Splices of reinforcement* — No commentary.

9.6 — Prescriptive detailing requirements

9.6.1 *Cast stone laid in vertically aligned bond* — The amount of horizontal reinforcement required for cast stone construction laid in vertically aligned bond patterns is based on similar requirements for concrete masonry construction~~1~~. This reinforcement is prescriptive and is intended to provide continuity across head joints. This reinforcement can also be used to resist design loads. The requirements of Section 9.6.1 only apply to cast stone laid in mortar. Cast stone assemblies constructed using soft joints finished with sealant or are otherwise isolated (such as balusters, stair treads, etc.) are not required to contain horizontal reinforcement within the mortar joints.

9.6.2 *Minimum reinforcement* — This prescriptive requirement is based on successful past practices to ensure cast stone units are not damaged during handling or transport. Additional reinforcement may be necessary for larger cast stone elements placed by crane or similar methods requiring anchor points within the unit or where loading requirements dictate additional reinforcement is necessary.

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TMS 504

Section 1
General

1.1 — Scope

This standard provides minimum requirements for the fabrication of cast stone elements.

1.2 — Governing building code

This standard supplements the legally adopted building code and shall govern in matters pertaining to the fabrication of cast stone, except where this standard is in conflict with requirements in the legally adopted building code. In areas without a legally adopted building code, this standard defines the minimum acceptable standard for the fabrication of cast stone.

1.3 — SI information

The SI values shown in parentheses are not part of this standard. The equations in this standard are for use with the specified inch-pound units only.

COMMENTARY

Section 1
General

1.1 — Scope

This standard covers the minimum requirements for the fabrication of cast stone units and elements.

Much of the information and many of the requirements of this standard has been drawn from historical practices and successful means and methods of designing and detailing ~~detailing and designing~~ cast stone systems and structures. More information on the use of cast stone products along with industry recommendations intended to supplement this standard is available through the Cast Stone Institute (www.caststone.org).

The provisions of this standard address the minimum requirements for the fabrication of cast stone. As such, some specific applications or conditions may warrant exceeding these minimum requirements; however, these provisions should not be reduced or relaxed below the minimum threshold defined by this standard.

1.2 — Governing building code

See Commentary Section 1.2 of TMS 404 for additional information.

1.3 — SI information

The equivalent SI values and equations are provided for information to the user.

TMS 504

Section 2
Cited Standards

Standards of ASTM International and The Masonry Society cited in this standard are listed below with their serial designations, including year of adoption or revision, and are declared to be part of this standard as if fully set forth in this document.

ASTM A36/A36M-19~~14~~ – Standard Specification for Carbon Structural Steel

ASTM A123/A123M-17~~15~~ – Standard Specification for Zinc (Hot Dip Galvanized) Coatings on Iron and Steel Products

ASTM A153/A153M-16a – Standard Specification for Zinc Coating (Hot Dip) on Iron and Steel Hardware

ASTM A240/A240M-20a~~16~~ – Standard Specification for Chromium and Chromium Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications

ASTM A307-21~~14~~ – Standard Specification for Carbon Steel Bolts and Studs, 60,000 psi Tensile Strength

ASTM A480/A480M-20a~~16a~~ – Standard Specification for General Requirements for Flat Rolled Stainless and Heat Resisting Steel Plate, Sheet, and Strip

ASTM A580/A580M-18~~15~~ – Standard Specification for Stainless Steel Wire

ASTM A615/A615M-20~~16~~ – Standard Specification for Deformed and Plain Carbon Steel Bars for Concrete Reinforcement

ASTM A641/A641M-1909a~~(2014)~~ – Standard Specification for Zinc Coated (Galvanized) Carbon Steel Wire

ASTM A653/A653M-20~~15e1~~ – Standard Specification for Steel Sheet, Zinc Coated (Galvanized) or Zinc Iron Alloy Coated (Galvannealed) by the Hot Dip Process

ASTM A666-15 – Standard Specification for Annealed or Cold Worked Austenitic Stainless Steel Sheet, Strip, Plate, and Flat Bar

ASTM A706/A706M-16 – Standard Specification for Low Alloy Steel Deformed and Plain Bars for Concrete Reinforcement

ASTM A767/A767M-1909~~(2015)~~ – Standard Specification for Zinc Coated (Galvanized) Steel Bars for Concrete Reinforcement

ASTM A775/A775M-19~~16~~ – Standard Specification for Epoxy Coated Steel Reinforcing Bars

COMMENTARY

Section 2
Cited Standards

The standards cited are referenced in this standard as part of the design fabrication requirements for cast stone. Specific editions of each cited standard are listed because changes to the referenced standard may result in changes of properties or procedures. Contact information for the organizations maintaining these standards is provided below:

ASTM International (ASTM)
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959
www.astm.org

The Masonry Society (TMS)
105 South Sunset Street, Suite Q
Longmont, CO 80501-6172
www.masonrysociety.org.

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ASTM A884/A884M-19e1~~14~~ – Standard Specification for Epoxy Coated Steel Wire and Welded Wire Reinforcement

ASTM A899- 91(2021~~2014~~) – Standard Specification for Steel Wire, Epoxy Coated

ASTM A996/A996M-16 – Standard Specification for Rail Steel and Axle Steel Deformed Bars for Concrete Reinforcement

ASTM A1008/A1008M-21~~15~~ – Standard Specification for Steel, Sheet, Cold Rolled, Carbon, Structural, High Strength Low Alloy, High Strength Low Alloy with Improved Formability, Solution Hardened, and Bake Hardenable

ASTM A1064/A1064M-18a~~16a~~ – Standard Specification for Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete

ASTM C1116/C1116M-10a(2015) – Standard Specification for Fiber Reinforced Concrete

ASTM C1364-19~~16~~ – Standard Specification for Architectural Cast Stone

ASTM D7957/D7957M-17 – Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement

TMS 404-23~~16~~ – Standard for Design of Cast Stone

COMMENTARY

TMS 504

Section 3
Notation and Definitions

The notation and definitions defined in Section 4 of TMS 404 shall apply.

Section 4
Shop Drawings

The shop drawings shall show all applicable and required information including:

a) Name of manufacturer.

b) Details of anchorage of cast stone to structural members, frames, and other construction, including the type, size, and location of connectors.

c) Identification of each cast stone unit.

d) Location of reinforcement in the cast stone element.

e) Unit dimensions, including copes, cuts, and openings.

f) Unit color and architectural finish, where applicable.

Section 5
Materials

5.1 — Cast stone

Cast stone elements shall comply with the requirements of ASTM C1364. The maximum length of cast stone elements shall not exceed 15 multiplied by the average thickness of the element unless designed to exceed this limit. The minimum specified thickness of cast stone shall be 2.0 in. (51 mm). Cast stone elements shall be manufactured to the following tolerances:

a) Cross-sectional dimensions: shall not exceed $\pm 1/8$ in. (3.2 mm) from the specified dimensions.

b) Length of units: shall not exceed the greater of $1/360$ of the specified length or $\pm 1/4$ in. (6.4 mm) maximum.

c) Warp, bow, and twist: shall not exceed the greater of $1/360$ of the specified length or $\pm 1/8$ in. (3.2 mm) from the specified dimensions.

d) Location of features: shall not exceed $\pm 1/8$ in. (3.2 mm) from the specified dimensions on the formed side of the unit and shall not exceed $\pm 3/8$ in. (9.5 mm) from the specified dimensions on the unformed side of the unit.

COMMENTARY

Section 3
Notations and Definitions

See commentary to Section 4 of TMS 404 for additional discussion.

Section 4
Shop Drawings

This standard lists some of the more important items of information that must be included in the shop drawings. This is not an all-inclusive list and additional items may be required for each ~~individual~~ project.

Section 5
Materials

5.1 — Cast stone

No commentary.

TMS 504

5.2 — Reinforcing steel

Reinforcing steel shall be Grade 40 (476 MPa) or Grade 60 (414 MPa) deformed and shall conform to one of the following as specified:

a) ASTM A615/A6115M

b) ASTM A706/A706M

c) ASTM A767/A767M

d) ASTM A775/A775M

e) ASTM A996/A996M

5.3 — Wire reinforcement

Wire reinforcement shall conform to ASTM C1064/C1064M.

5.4 — Fiber reinforcement

Fiber reinforcement used in cast stone shall conform to ASTM C1116/C1116M.

5.5 — Anchors, ties, and accessories

Anchors, ties, and accessories shall conform to the following specifications:

a) Plate and bent-bar anchors: ASTM A36/A 36M

b) Sheet-metal anchors and ties: ASTM A1008/A1008M

c) Wire ties and anchors: ASTM C1064/C1064M

d) Headed anchor bolts: ASTM A307, Grade A

5.6 — Stainless steel

Stainless steel items shall be AISI Type 304 or Type 316, and shall conform to the following:

a) Joint reinforcement: ASTM A580/A580M

b) Plate and bent-bar anchors: ASTM A480/A480M and ASTM A666

c) Sheet-metal anchors and ties: ASTM A480/A480M and ASTM A240/A240M

d) Wire ties and anchors: ASTM A580/A580M

COMMENTARY

5.2 — Reinforcing steel

No commentary.

5.3 — Wire reinforcement

Section 9.3.3 of TMS 404 does not permit welded wire reinforcement to be embedded into dry-cast cast stone elements during manufacturing. Welded wire reinforcement is permitted only in wet-cast cast stone elements.

5.4 — Fiber reinforcement

No commentary.

5.4 — Anchors, ties, and accessories

No commentary.

5.6 — Stainless steel

No commentary.

TMS 504

5.7 – Composite reinforcement

Glass fiber reinforced polymer bars shall conform to ASTM D7957/D7957M.

5.7 — Coatings for corrosion protection

Carbon steel joint reinforcement, ties, anchors, and steel plates and bars shall be protected from corrosion by galvanizing or epoxy coating in conformance with the following minimums:

a) Galvanized coatings:

1) Mill galvanized coatings:

i. Joint reinforcement: ASTM A641/A641M (0.1 oz/ft^2) (31 g/m^2)

ii. Sheet-metal ties and sheet-metal anchors: ASTM A653/A653M Coating Designation G60

2) Hot-dip galvanized coatings:

i. Joint reinforcement, wire ties, and wire anchors: ASTM A153/A153M (1.50 oz/ft^2) (458 g/m^2)

ii. Sheet-metal ties and sheet-metal anchors: ASTM A153/A153M Class B

iii. Steel plates and bars (as applicable to size and form indicated): ASTM A123/A123M or ASTM A153/A153M, Class B

b) Epoxy coatings:

1) Joint reinforcement: ASTM A884/A884M Class A, Type 1 — 7 mils (175 µm)

2) Wire ties and anchors: ASTM A899/A899M Class C — 20 mils (508 µm)

3) Sheet-metal ties and anchors 20 mils (508 µm) per surface

5.8 — Reinforcement details

Detailing of reinforcement shall comply with the requirements of Section 9 of TMS 404

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COMMENTARY

5.7 – Composite reinforcement

Glass fiber reinforced polymer (GFRP) reinforcement has applications in cast stone near electromagnetic equipment and highly corrosive environments where the use of ferrous reinforcement is undesirable. While GFRP tends to exhibit less ductility than conventional mild reinforcement, given the limits of TMS 404/504/604 to non-structural applications, the structural response of cast stone containing GFRP is outside the scope of these standards.

5.7 — Coatings for corrosion protection

No commentary.

5.8 — Reinforcement details

No commentary.

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Delivery

Cast stone units shall be marked as shown on the shop drawings and shall be packaged to protect them from staining and damage during shipping and storage.

Delivery

No commentary.

TMS 604

Section 1
General

1.1 — Scope

This standard provides minimum requirements for the installation of cast stone and defines the minimum acceptable standards of construction practice.

1.2 — Governing building code

This standard supplements the legally adopted building code and shall govern in matters pertaining to the installation of cast stone, except where this standard is in conflict with requirements in the legally adopted building code. In areas without a legally adopted building code, this standard defines the minimum acceptable standard for the installation of cast stone.

1.3 — SI information

The SI values shown in parentheses are not part of this standard. The equations in this standard are for use with the specified inch-pound units only.

COMMENTARY

Section 1
General

1.1 — Scope

This standard covers the minimum requirements for the installation of cast stone.

Much of the information and many of the requirements of this standard has been drawn from historical practices and successful means and methods of installing ~~detailing and designing~~ cast stone. More information on the use of cast stone products along with industry recommendations intended to supplement this standard is available through the Cast Stone Institute (www.caststone.org).

The provisions of this standard address the minimum requirements for the installation of cast stone. As such, some specific applications or conditions may warrant exceeding these minimum requirements; however, these provisions should not be reduced or relaxed below the minimum threshold defined by this standard.

1.2 — Governing building code

See Commentary Section 1.2 of TMS 404 for additional information.

1.3 — SI information

The equivalent SI values and equations are provided for information to the user.

TMS 604

Section 2
Cited Standards

Standards of ASTM International and The Masonry Society cited in this standard are listed below with their serial designations, including year of adoption or revision, and are declared to be part of this standard as if fully set forth in this document.

ASTM C270-19ac~~14a~~ – Standard Specification for Mortar for Unit Masonry

ASTM C920-18~~14a~~ – Standard Specification for Elastomeric Joint Sealants

ASTM C1107/C1107M-20~~14a~~ – Standard Specification for Packaged Dry, Hydraulic Cement Grout (Nonshrink)

ASTM C1194-19~~03(2011)~~ – Standard Test Method for Compressive Strength of Architectural Cast Stone

ASTM C1195-21~~03(2011)~~ – Standard Test Method for Absorption of Architectural Cast Stone

ASTM D2000-18~~12~~ – Standard Classification System for Rubber Products in Automotive Applications

ASTM D2287-19~~12~~ – Standard Specification for Nonrigid Vinyl Chloride Polymer and Copolymer Molding and Extrusion Compounds

TMS 404-23~~16~~ – Standard for Design of Architectural Cast Stone

TMS 504-23~~16~~ – Standard for Fabrication of Architectural Cast Stone

TMS 602-22~~16~~ – Specification for Masonry Structures

COMMENTARY

Section 2
Cited Standards

The standards cited are referenced in this standard as part of the design requirements for cast stone. Specific editions of each cited standard are listed because changes to the referenced standard may result in changes of properties or procedures. Contact information for the organizations maintaining these standards is provided below:

ASTM International (ASTM)
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959
www.astm.org

The Masonry Society (TMS)
105 South Sunset Street, Suite Q
Longmont, CO 80501-6172
www.masonrysociety.org.

TMS 604

Section 3
Notation and Definitions

The notation and definitions defined in Section 4 of TMS 404 shall apply.

Section 4
Work

4.1 — Scope of work

In addition to the requirements of this standard, the following shall be included within the scope of work:

1. Furnishing and placing cast stone, grout, mortar, lintels, sills, copings, through-wall flashing, and connectors.
2. Furnishing, erecting, ~~and~~ maintaining, and removal of bracing, forming, scaffolding, rigging, and shoring.
3. Furnishing and installing other equipment for constructing cast stone assemblies.
4. Cleaning cast stone and removing surplus material and waste.
5. Installing items to be built into the cast stone assembly and other items furnished and located by other trades.
6. Any other information necessary for the installation of cast stone.

4.2 — Submittals

The following items shall be submitted for approval:

1. Samples of the cast stone that are representative of the general range of finish and color proposed to be furnished to the project. Approved samples shall be retained throughout the project.
2. Shop drawings and supporting documentation related to design and detailing used by the cast stone manufacturer to produce elements proposed to be furnished to the project.
3. Construction plans, which shall include at a minimum the hot and cold weather construction procedures.
4. Material certificates, certifying that each of the following materials is in compliance with its respective standard.
   a. Reinforcement
   b. Anchors, ties, fasteners, and metal accessories
   c. Cast stone units
   d. Mortar
   e. Grout

COMMENTARY

Section 3
Notations and Definitions

See commentary to Section 4 of TMS 404 for additional discussion.

Section 4
Work

4.1 — Scope of work

This list includes the scope of work typical to most construction projects incorporating cast stone. All of these tasks and materials will not be required for every project.

4.2 — Submittals

Materials and processes used for manufacturing cast stone vary according to the aggregates locally available to the manufacturer and the processes and techniques used to obtain the desired appearance and physical properties. Of paramount importance in molding cast stone is the need to use a properly proportioned mixture of white and/or grey cements, manufactured or natural sands, carefully selected crushed stone or well graded natural gravel, and mineral coloring pigments to achieve the desired appearance while maintaining durable physical properties. As with any product manufactured using natural constituent materials, ~~slight~~ variations in color and appearance are to be expected in the final product similar to natural stone. ASTM C1364 defines permissible variations in color and hue of cast stone from approved samples.

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COMMENTARY

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Section 5
Materials

5.1 — Cast stone

Supply cast stone complying with the requirements of TMS 504

5.2 — Mortar

For each mortar mix, one of the following shall be submitted for approval:

1. Mix design indicating material types and their proportions meeting the proportion requirements of ASTM C270, Type N; or
2. Mix design and test results meeting the property requirements of ASTM C270, Type N.

5.3 — Grout

Grout used in the construction of cast stone assemblies shall meet the requirements of ASTM C1107/C1107M.

5.4 — Joint material

Contraction joint material shall conform to one of the following standards:

1. ASTM D2000, M2AA-805 Rubber shear keys with a minimum durometer hardness of 80.
2. ASTM D2287, Type PVC 654-4 PVC shear keys with a minimum durometer hardness of 85.
3. ASTM C920.

5.5 — Cleaner

Cleaning materials and processes shall be approved by the licensed design professional~~architect of record or engineer of record~~.

5.6 — Delivery, storage, and handling

Materials that are damaged or contaminated shall not be used. Cementitious materials shall be protected from precipitation and groundwater. Reinforcement, ties, and metal accessories shall be protected from permanent distortions and stored off the ground.

COMMENTARY

Section 5
Materials

5.1 — Cast stone

TMS 504, *Standard for Fabrication of Architectural Cast Stone*, defines the minimum requirements for the fabrication of cast stone.

5.2 — Mortar

The limitation to use only ~~on the use of~~ Type N mortar is based on past successful performance.

5.3 — Grout

Grout complying with ASTM C476 is not appropriate for use with cast stone masonry. Grout meeting ASTM C1107 is required when used as a bedding material or for embedding items.

5.4 — Joint material

No commentary.

5.5 — Cleaner

~~No commentary.~~Manufacturers of the cast stone products often have cleaning recommendations and should be consulted accordingly as they are familiar with options that work with their products.

5.6 — Delivery, storage, and handling

No commentary.

TMS 604

Section 6
Quality Assurance

6.1 — General

A quality assurance program shall be defined in the construction documents and shall include at a minimum the requirements of Section 6.2 through 6.4.5 and the following:

(a) Procedures for reporting and review.

(b) Procedures for resolution of non-compliance.

(c) Qualifications for testing laboratories and inspection agencies.

(d) Requirements for verifying conformance of material composition, quality, storage, handling, preparation, and placement.

6.2 — Cast stone

For each 500 ft^3 (14.2 m^3) of cast stone product, or fraction thereof, sample three units and test in accordance with ASTM C1194 for compressive strength and ASTM C1195 for absorption. At least one sample consisting of three units shall be obtained for each mix design supplied to a project.

6.3 — Sample panels

Using approved materials and procedures, construct a sample panel having minimum dimensions of 4 ft by 4 ft (1.22 m by 1.22 m). The acceptable standard for the work is established by the accepted panel. Retain sample panel at the project site until cast stone work is installed and accepted.

6.4 — Inspection

COMMENTARY

Section 6
Quality Assurance

6.1 — General

Verification that cast stone construction conforms to the construction documents is required by this standard. Because the design and complexity of cast stone construction can vary from project to project, so must the extent of the quality assurance program. The contract documents must indicate the type and timing of the testing, inspection, and other measures that are required to assure that the work is in conformance.

6.2 — Cast stone

Samples for compression and absorption testing may be selected by the purchaser or the purchaser's authorized representative after delivery; or alternatively, samples may be obtained from the manufacturer prior to delivery. It is common practice for cast stone manufacturers to test their mix designs and products at regular intervals. When such documentation is available, it is acceptable to reference such quality control test reports to supplement or replace field testing of products.

6.3 — Sample panels

The sample panels are permitted to be a predefined segment of the cast stone construction or a separate stand-alone panel.

6.4 — Inspection

The inspection requirements cover what typically must take place for most cast stone projects prior to, during, and following construction. In addition, when test samples are obtained in the field, the inspection program must include procedures to ensure the samples are properly obtained.

Onsite inspection and acceptance of cast stone units should be performed at the time of delivery and again after all material has been installed, pointed and cleaned. Final inspection should be done prior to application of water repellents or similar coatings, if applicable. The onsite inspector should be familiar with the project specification as well as the applicable referenced standards. Test reports of compressive strength, absorption and other physical properties should be on file as well as the approved sample(s).

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COMMENTARY

Before installation, check the color and texture of the approved sample against the delivered product. Cast stone should approximate the color and texture of the approved sample when viewed under good, typical lighting conditions at a 10 ft (3.0 m) distance and should show no obvious imperfections other than minimal color and texture variations from a 20 ft (6.1 m) distance. The texture should not be appraised under a sun wash when sunlight is skimming across the surface parallel to the plane of the stone face, as this will unfairly accentuate minor irregularities. In addition to issues concerning color and texture, the inspector and contractor must be familiar with the dimensional requirements of the installation as they pertain to joint sizes and interfaces with other materials.

Cast stone ~~Stones~~ should always be appraised for color when dry, as dampness may darken the surface color and make it appear blotchy. Curing time differential may affect color because moisture can be retained within units for months, even in dry weather. Samples that have been stored for long periods may look considerably different than a product that was manufactured only a short time before delivery.

Minor variations in color and texture from element-to-element should be accepted within the limits of the accepted range, either established by several samples, mockups or by deviations from instrumentally measured color coordinates. In general, expect color variation to be approximately equal to a good natural cut limestone project. More color variation should be expected than from building materials with painted or applied finishes.

Some units will show more color variation than others. Units containing gray cement will show more light-dark variations than those containing white cement. Colors that require high amounts of integral pigments, such as reds and browns, will vary more than ~~moderately~~ neutral shades such as buff. Special mixes containing contrasting and multi-colored aggregates may be subject to extreme color deviations when compared to homogeneous facing mixes.

Variations in color within the same unit may be caused by efflorescence or free lime migrating to the outer surface. This can usually be remedied by proper wash down. Staining, mortar smears or uneven washing can also cause color variations within units and the manufacturer should be consulted for recommended treatment of these problems.

Touch up and repair is perhaps the greatest source of dissatisfaction with finished installations. When months have elapsed between the date of manufacture and the date of repairs, significant differences in color may exist between properly repaired areas and the remainder of the unit. These areas should be left alone and will blend in over time through curing, natural weathering and ultraviolet light. Assessment of color matching should be evaluated

TMS 604

COMMENTARY

following at least 28 days of curing and typical environmental exposure.

Common deficiencies include:

(a) Bug holes or air voids on the finished surfaces.

(b) Ragged or chipped edges on formed edges.

(c) Stains on exposed faces from foreign substances.

(d) Twist, warp, out-of-square or bow exceeding tolerances.

(e) Out-of-plane or pie shaped joints, or large or small joints out of tolerance.

(f) Areas of rough texture or smoothness not matching sample when viewed from 10 ft (3.0 m).

(g) Backup concrete bleeding through exposed faces.

(h) Visible cracks exceeding 0.005 in. (0.13 mm).

(i) Reinforcing shadows or exposure on face.

(j) Rust on surface caused by staining, reinforcement or iron pyrites.

(k) Installation not matching joint layout on approved shop drawings.

(l) Form marks or local depressions in excess of 0.030 in. (0.76 mm).

Sample units should demonstrate a variety of shapes and casting configurations, including surfaces cast in different orientations, in order to convey the potential full range of appearances that can occur once constructed. Sample panels, required by Section 6.3, are necessary to allow for the project team to visualize the appearance of the cast stone in a format larger than 12 in. samples. Careful quality control at the plant and during installation is critical to obtain an acceptable finished product.

6.4.1 *Qualifications* — The quality assurance program shall define the qualifications for testing laboratories and for inspection agencies.

6.4.1 *Qualifications* — The entities verifying compliance must be competent and knowledgeable of cast stone construction and the requirements of this standard. Therefore, minimum qualifications for those individuals must also be established by the quality assurance program in the contract documents.

The responsible party performing the quality control measures should document the organizational representatives who will be a part of the quality control segment, their qualifications, and their precise conduct during the performance of the quality assurance phase.

ASTM C1093 (ASTM C1093, 2022) defines the duties and responsibilities of testing agency personnel and defines the technical requirements for equipment used in testing cast stone materials. Testing agencies who are accredited or inspected for conformance to the requirements of ASTM C1093 by a recognized evaluation authority are qualified to evaluate cast stone. In addition, the Cast Stone Institute offers a certification program for the testing of cast stone

TMS 604

6.4.2~~1~~ *Pre-construction* — Prior to the start of construction, compliance with the approved submittals shall be verified.

6.4.3~~2~~ *During construction* — During construction, the following shall be verified for compliance:

a. Proportions of site-prepared mortar and grout.
b. Construction of mortar joints.
c. Grout space and grout placement.
d. Grade, type, and size of reinforcement, anchors, and connectors.
e. Location and placement of reinforcement, anchors, and connectors.
f. Preparation, construction, and protection of cast stone during cold weather (temperature below 40°F (4.4°C) or hot weather (temperature above 90°F (32.2°C).

At a minimum, inspection during construction shall be conducted periodically.

6.4.4~~3~~ *Sample preparation* — When cast stone, mortar, or grout specimen samples are required to be obtained, their preparation in the field shall be verified for compliance with applicable governing standards.

6.4.5~~4~~ *Post-construction* — Following the completion of cast stone work, compliance with the approved sample panel shall be verified.

Section 7
Project Conditions

7.1 — Protection

Cover top of unfinished cast stone work to protect it from the weather.

7.2 — Hot and cold ~~Cold~~ weather construction

Hot and cold ~~Cold~~ weather construction shall comply with the requirements of Article 1.8D and Article 1.8C of TMS 602, respectively.

~~**7.3 — Hot weather construction**~~

COMMENTARY

materials. More information on this program is available at www.caststone.org.

6.4.2~~1~~ *Pre-construction* — No commentary.

6.4.3~~2~~ *During construction* — No commentary.

6.4.4~~3~~ *Sample preparation* — ~~No commentary.~~ See Section 2 for a list of ASTM standards governing the preparation of test samples obtained from the field.

6.4.5~~4~~ *Post-construction* — No commentary.

Section 7
Project Conditions

7.1 — Protection

No commentary.

7.2 — Hot and cold ~~Cold~~ weather construction

The hot and cold weather construction procedures defined in TMS 602 (2016) have a track record of successful use in cast stone construction. Additional background and supporting information for these provisions can be found in the commentary to TMS 602. These requirements apply when the ambient air temperature is 40 degrees F (4.4 degrees C) or less or when the ambient air temperature is 90 degrees F (32.2 degrees C) or more. The installer must take measures to ensure that the quality of the installation is not compromised from low and high temperatures.

~~**7.3 — Hot weather construction**~~

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~~Hot weather construction shall comply with the requirements of Article 1.8D of TMS 602.~~

COMMENTARY

~~Special precautions must be taken when setting cast stone in hot weather. The installer must take measures to ensure that the quality of the installation does not suffer from high temperatures. Hot weather requirements may apply when the ambient air temperature is 90°F (32.2°C) or more.~~

~~The primary concern to the masonry contractor during hot weather is evaporation of water from the mortar. If sufficient water is not present, bond between the cast stone unit and mortar will be compromised. The increased rate of hydration of the cement and favorable curing conditions in hot, humid weather will help develop masonry strength provided sufficient water is present at the time of construction and for a curing period of three days.~~

~~Temperature of the materials can be adjusted to aid the construction of quality masonry in hot weather conditions. TMS 602 specifies construction methods to produce quality masonry in hot weather conditions.~~

~~Cast stone units are one of the materials in masonry construction least affected by hot weather, however, the interaction between the cast stone and the mortar or grout is critical. As the temperature of the cast stone units increases, they will absorb more water from the mortar. Lower bond strength between the mortar and the units may result if enough water is not present in the mortar when the units are laid.~~

~~According to industry associations, (i.e., Brick Industry Association (BIA), Mason Contractors Association of America (MCAA), National Concrete Masonry Association (NCMA) and the Portland Cement Association (PCA)), mortar in hot weather will tend to lose its workability rapidly due to evaporation of the water from the mix and the increased rate of hydration of the cement. The use of admixtures (sometimes called modifiers) to increase workability is not recommended unless their full effect on the mortar is known and that they comply with ASTM C1384 (2012) *Standard Specification for Admixtures for Masonry Mortars*. Retempering of the mortar should be permitted except for pigmented mortars. Mortar mixed at high temperatures often has higher water content, lower air content, and a shorter board life than those mixed at normal temperatures.~~

~~Mortar temperatures need to be controlled per the ambient air temperatures as specified in TMS 602. Cold water may be used to help control the temperature of the mortar. Ice is highly effective in reducing the temperature of the mix water. When used, ice should be completely melted before combining the water with any other ingredients. In any case, mortar should be used within two hours of initial mixing.~~

~~During periods of hot weather, the temperature of the materials should be controlled for best results. Storing cast stone units and sand under cover of shade will help control heat gain of the materials. Sand should be stored on a raised platform and not in contact with a cover during the hot part~~

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Section 8
Execution

8.1 — Site tolerances

Cast stone shall be constructed within the following tolerances from the specified dimensions:

1. Dimension of elements
   a. In cross section or elevation
      .....-1/4 in. (6.4 mm), +1/2 in. (12.7 mm)
   b. Mortar joint thickness
      bed: .....±1/8 in. (3.2 mm)
      head: .....- 1/4 in. (6.4 mm), + 3/8 in. (9.5 mm)
      collar: .....-1/4 in. (6.4 mm), + 3/8 in. (9.5 mm)
   c. Grout space or cavity width:
      -1/4 in. (6.4 mm), + 3/8 in. (9.5 mm)
2. Elements
   a. Variation from level:
      bed joints: ±1/4 in. (6.4 mm) in 10 ft (3.05 m) not to exceed ±1/2 in. (12.7 mm) maximum
      top surface of bearing walls: ±1/4 in. (6.4 mm) in 10 ft (3.05 m) not to exceed ±1/2 in. (12.7 mm) maximum
   b. Variation from plumb
      ..... ±1/4 in. (6.4 mm) in 10 ft (3.05 m)
      ..... ±3/8 in. (9.5 mm) in 20 ft (6.10 m)
      ..... ±1/2 in. (12.7 mm) maximum
   c. True to a line
      ..... ±1/4 in. (6.4 mm) in 10 ft (3.05 m)
      ..... ±3/8 in. (9.5 mm) in 20 ft (6.10 m)
      ..... ±1/2 in. (12.7 mm) maximum
   d. Alignment of columns and walls
      .....±3/4 in. (19.1 mm)
3. Location of elements
   a. Indicated in plan
      ..... ±1/2 in. (12.7 mm) in 20 ft (6.10 m)
      ..... ±3/4 in. (19.1 mm) maximum
   b. Indicated in elevation

COMMENTARY

~~of the day. Sand piles should be kept in a damp condition by sprinkling with water during times of high evaporation. This can help lower the temperature of the sand through evaporative cooling.~~

~~When possible, shade should also be provided for laborers, whose productivity decreases with increasing temperature and humidity. Starting work earlier in the day and scheduling masonry construction, avoiding the hot mid-day periods, can reduce the effect of high temperatures on laborers and materials.~~

Section 8
Execution

8.1 — Site tolerances

The tolerances for construction are intended to capture both structural stability as well as minimum aesthetic criteria.

TMS 604

.....±1/4 in. (6.4 mm) in story height
..... ±3/4 in. (19.1 mm) maximum

8.2 — Construction

Construction of cast stone assemblies shall comply with Section 8.2.1 or 8.2.2

8.2.1 *Setting in mortar* — Cast stone units shall be wetted prior to setting in mortar. Units having face dimensions of less than 3.75 ft^2 (0.35 m^2) shall be laid in in bed joints and head joints that are fully mortared or shall be dry-set in accordance with Section 8.2.2. Dowel holes and anchor slots shall be completely filled with mortar or non-shrink grout. Specified mortar joint thickness shall not exceed 3/8 in. (9.5 mm). After placing cast stone units, the mortar shall be raked back not less than 3/4 in. (19 mm) while the mortar is still plastic. Unless specified otherwise, joints shall be tuck-pointed to a concave profile.

8.2.2 *Dry setting* — Units having face dimensions greater than or equal to 3.75 ft^2 (0.35 m^2) shall be laid without the use of mortar and shimmed to the specified joint thickness. Specified joint thickness shall not exceed 3/8 in. (9.5 mm). After placing cast stone units, the joints shall be sealed with an approved sealant over backer rod.

8.3 — Cleaning and repair

Chips and cracks in cast stone shall be repaired using materials supplied by the cast stone manufacturer. Final acceptance of the repair method shall be approved by the licensed design professional~~architect of record~~ or owner.

COMMENTARY

8.2 — Construction

8.2.1 *Setting in mortar* — Typical joints thicknesses for cast stone construction include:

3/8 in. (9.5 mm) at cast stone/brick joints;
1/4 in. (6.4 mm) at cast stone/cast stone head joints; and
3/8 in. (9.5 mm) at cast stone/cast stone bed joints.

Historical practices have generally limited the size of cast stone units set in mortar to a maximum of 2.5 ft by 1.5 ft (0.76 m by 0.46 m) in face dimensions. Field investigations have shown that units larger than this size are difficult to set in plastic mortar without shimming due to their weight and often result in cracking of the finished assembly as the mortar cures. Smaller cast stone units can be either set in mortar in accordance with Section 8.2.1 using any anchor or tie permitted by Sections 5.5 and 5.6 of TMS 504 or dry-set in accordance with Section 8.2.2, although the latter option is used less frequently with small cast stone units given the added expense and complexity of dry-setting cast stone units .

8.2.2 *Dry setting* — See Commentary Section C8.2.1 for additional discussion on the selection of joint types.

8.3 — Cleaning and repair

The best insurance against chipping and cracking is care in handling and protection of the unit after installation. Even with all of the special care and protection, cast stone may still become chipped from time to time and a certain amount of touch up is to be expected. Damage to stone either while in transit or during installation is usually classified as repair.

Touch up – Any chip obvious from a 20 ft (6.1 m) distance should be touched up with material provided by the manufacturer. Chips measuring 1/4 in. (6.4 mm) or less across the face are usually left alone. The stone mason should include touch up as part of the ordinary pointing and washdown operations prior to final inspection.

Repair – Chips measuring larger than 1/4 in. (6.4 mm) across the face are usually addressed in a separate operation as soon as possible following occurrence of damage. The procedure for repair will include dressing the damage and applying fresh material to achieve the desired finish and shape, covering the repair with a wet rag and/or plastic

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cover, then taking steps to blend the repair into the adjacent areas.

Cast stone units with unsupported edges exhibiting chips larger than 8 in.^{2} (51.6 cm^2) should be replaced. Units that are broken should be replaced unless the damaged portion can be salvaged and epoxied back to the unit. Units with cracks near anchor points should be replaced.

Most cracks can be repaired if the units are reinforced. Units should be epoxy injected after the cause of the cracking has been identified and remedied. Alternatively, cracks that are observed in installed units can be grouted with a constituent material if the crack is less than 0.007 in. (0.18 mm) and the forces that caused the crack have been eliminated.

Climatic conditions must be taken into consideration before repair is to commence. Repair procedures should not proceed in freezing weather or if a freeze is anticipated within 24 hours. On hot sunny days, repair should be done during the morning hours where the cast stone is shaded or at temperatures less than 90°F (32°C). Repairs should be covered with a damp cloth and plastic sheet to prevent the cement from hydrating too quickly.

The same material that was used to manufacture the cast stone should be used for touch up and repair. Experimental batches should not be used in an effort to obtain an instant color match. The water/cement ratio used should be as close as possible to the mix at the time of manufacture. Acrylic bonding agents may be used, but not in place of water. When used, wetting agents should be limited to less than a tablespoon (14.8 cm^3) per handful of the cast stone material. Metal tools should not be used for applying a repair. Cast stone units that have been acid etched at the factory will require the same treatment applied to the touch up or repair.

A properly executed repair will not match in color immediately. Dry cast products will appear lighter where repaired; wet cast products may appear darker. Repairs that match, immediately or in two or three days, have a tendency to change color after weathering. Through curing, weathering, and ultraviolet light, the patch will eventually change to match the adjacent unit. This process could take 3 months to a year or longer depending on the climatic conditions and exposure to the weather.

Repairs that cannot be seen from a 20 ft (6.1 m) distance when viewed in good, typical lighting should be accepted.

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Commentary References to Standards for Architectural Cast Stone

TMS 404 Commentary References

ACI 318, 2014. ACI 318-14 – *Building Code Requirements for Structural Concrete*, American Concrete Institute, Farmington Hills, MI, 2014.

ASTM C426, 2015. ASTM C426-15e1, Standard Test Method for Linear Drying Shrinkage of Concrete Masonry Units, ASTM International, West Conshohocken, PA, www.astm.org, 2015.

ASTM C1364 2016. ASTM C1364-16, Standard Specification for Architectural Cast Stone, ASTM International, West Conshohocken, PA, www.astm.org, 2016.

NCMA TEK 10-3, 2003. "Control Joints for Concrete Masonry Walls – Alternative Engineered Method," NCMA TEK 10-3, National Concrete Masonry Association, Herndon, VA, 2003.

TMS 402, 2016. TMS 402-16, *Building Code Requirements for Masonry Structures*, The Masonry Society, Longmont, CO, 2016.

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ASTM C1384, 2012. ASTM C1384-12a – *Standard Specification for Admixtures for Masonry Mortars*, ASTM International, West Conshohocken, PA, www.astm.org, 2012.

TMS 602, 2016. TMS 402-16, *Specification for Masonry Structures*, The Masonry Society, Longmont, CO, 2016.