13TH CANADIAN MASONRY SYMPOSIUM
HALIFAX, CANADA
JUNE 4TH – JUNE 7TH 2017

THE 2016 TMS 402-602 CODE REQUIREMENTS & SPECIFICATION: WHAT TO EXPECT AND WHY

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ABSTRACT

This paper reviews changes that are being made to the 2016 Edition of *Building Code Requirements and Specification for Masonry Structures* (TMS 402/TMS 602). Some of the major technical changes include the addition of shear friction provisions, changes to anchor bolt capacity in shear crushing, and deletion of prescriptive requirements for piers in strength design. Non-technical changes include simplification of quality assurance requirements, consolidating lap splice and development length requirements, and clarification of provisions. In addition, several definitions were added and consistent terminology was adopted in several cases. Because of the extent of these changes, the paper will provide background on what changes were made, and also reasons why the revisions were needed, thus allowing the paper to serve as a means to update users on these important changes and also making the paper a future historical reference on the revisions. In addition, the Committee that maintains these provisions will be moving to a 6-year revision cycle (2016-2022) for the next edition of the standard. Reasons for this change, benefits and potential drawbacks from the longer cycle, and considerations for future revision cycles are also reviewed.

KEYWORDS: *construction, design, masonry codes, specifications, standards*

INTRODUCTION

The 2016 TMS 402 *Building Code for Masonry Structures* and TMS 602 *Specification for Masonry Structures* [1] was published in late 2016. The code requirements in TMS 402 (hereafter referred to as "code") have been tentatively approved for adoption by the 2018 International Building Code (IBC) [2]. The code has 6 fewer pages than the 2013 TMS 402/602, making the 2016 edition one of the few structural codes that has fewer pages than the previous edition. This reduction was primarily made possible by the consolidation and clarification of a variety of

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provisions, especially in regard to consolidating development and lap splice requirements for allowable stress design and strength design methods in one location.

There were numerous technical and formatting/editorial changes made to the 2016 TMS 402 code and TMS 602 specification. The major changes are summarized in this paper. In addition, there were other numerous minor changes, but most of those were clarifying the standards, and should not affect design nor construction.

NAME CHANGE

Past users of the provisions will recognize a name change in the standards from TMS 402/ACI 530/ASCE 5 and TMS 602/ACI 530.1/ASCE 6 to simply TMS 402 and TMS 602. The American Concrete Institute (ACI) and the Structural Engineering Institute of the American Society of Civil Engineers (SEI/ASCE) generously relinquished their rights to the standards in 2013 to streamline Committee Operations and to support The Masonry Society's efforts to advance the knowledge of masonry. The Committee was accordingly designated more simply as TMS 402/602 to recognize the two standards it develops. This change streamlines committee operations while recognizing the stability and strength of The Masonry Society. It further aids users by identifying that questions and concerns regarding the standards should be forwarded to The Masonry Society.

TECHNICAL CHANGES

Shear Friction

Masonry walls that have a low axial compressive load and a low shear-span ratio are vulnerable to shear sliding, which normally occurs at the base. Shear sliding is resisted by three mechanisms, namely, the friction, the dowel action of the reinforcement crossing the shear plane, and the shear strength of the reinforcement. The dowel action and shear strength of the reinforcement will not be fully activated until the friction resistance has been overcome and shear sliding initiates. Shear sliding can cause severe damage to the masonry due to the simultaneous actions of the shear stress, compressive stress, and dowel action; it can weaken lap splices adjacent to the shear plane; and it can fracture the reinforcement crossing the shear plane.

The shear sliding failure mode had not been addressed in previous editions of the TMS 402 code. The 2016 edition added provisions in both strength design (SD) and allowable stress design (ASD). The shear friction strength is determined as shown in Table 1. For shear span ratios ($M/(Vd_v)$ or $M_u/(V_u d_v)$) between those shown, linear interpolation is used. In Table 1, F_f is the allowable shear friction stress, A_{sp} is the cross-sectional area of reinforcement within the net shear area, F_s is the allowable stress in the reinforcement, P is the allowable stress level axial load, A_{nv} is the net shear area, V_{nf} is the nominal shear friction strength, f_y is the yield strength, f'_m is the compressive strength of the masonry, and A_{nc} is the area of masonry in compression at nominal moment capacity. The coefficient of friction, μ, is 1.0 for masonry on concrete with an unfinished surface, or concrete with a surface that has been intentionally roughened and 0.70 for all other conditions. The 1997 Uniform Building Code [3] required concrete abutting structural masonry to be roughened to a full amplitude of 1/16 inch, and this can be considered as a surface that has been intentionally roughened. In comparison to experimental data, the ratio of the predicted shear friction capacity to the measured shear friction capacity is 0.97, with a coefficient of variation of 0.05.

For μ=1, the impact of the proposed provisions is minimal for ASD. Although shear friction will govern in a few cases, in general the reduction in the capacity of the wall is small. In SD, the provisions will have almost no impact on design of flexure-dominated walls ($M_u/(V_u d_v)>1$). Shear friction can govern with shear-dominated walls ($M_u/(V_u d_v)<<1$). However, long walls (such as those in big box structures) are generally governed by architectural requirements and not structural requirements; and as such, there is usually more than sufficient structural strength.

Table 1. Shear Friction Requirements in TMS 402-16

Allowable Stress Design	Strength Design
Where $M/(Vd_v) \leq 0.5$ $$F_f = \frac{\mu(A_{sp}F_s + P)}{A_{nv}}$$	Where $M_u/(V_u d_v) \leq 0.5$ $$V_{nf} = \mu(A_{sp}f_y + P_u)$$
Where $M/(Vd_v) \geq 1.0$ $$F_f = \frac{0.65(0.6A_{sp}F_s + P)}{A_{nv}}$$	Where $M_u/(V_u d_v) \geq 1.0$ $$V_{nf} = 0.42f'_m A_{nc}$$

Anchor Bolt Strength

When strength design (SD) was added to the TMS 402 code in 2002, there was a difference in how the shear strength of an anchor bolt was determined between SD and allowable stress design (ASD). ASD had one equation for "masonry crushing" and one for "steel yielding" while SD had one equation for "masonry breakout" and one for "steel yielding." A major revision of the anchor bolt provisions occurred in the 2008 code, and the ASD and SD provisions were harmonized. The original proposal had three equations for both ASD and SD, which accounted for masonry breakout, steel yielding, and bolt pryout. Due to persuasive negatives, an equation to account for masonry crushing was added but a thorough validation of that equation was not conducted. Designers have expressed concerns about the shear crushing equation, which generally governs the design and appeared to be overly conservative.

The committee reexamined test data of anchor bolts in shear. A total of 345 tests were considered and for each test, the capacity was calculated using the 2013 TMS 402 SD code provisions. Table 2 presents the results. Pryout is not included since it did not control in any of the tests. The limit state controlling the design is not necessarily the way the anchor bolt actually failed; in many cases, several limit states contributed to the actual anchor bolt failure. The results show that the current equation for masonry crushing is quite conservative with the experimental load being on the average 2.33 times the calculated strength.

Several alternate equations for shear crushing were examined, with the equation in FEMA 369 [4] being chosen, of a shear crushing strength of $1750\sqrt[4]{f'_m A_b}$. Table 3 shows the reanalysis of the 345 tests with this new equation. A similar change was made in ASD.

Table 2. Anchor Bolt Design Strength Using TMS 402-13

	TMS 402-13 Governing Equation		
	Breakout	Crushing	Yielding
Design Strength	$4A_{pv}\sqrt{f'_m}$	$1050\sqrt[4]{f'_m A_b}$	$0.6A_b f_y$
Number of tests	95	188	62
Average of Experimental/Calculated	1.23	2.33	1.45
Standard Deviation of Ratio	0.14	0.73	0.20
Coefficient of Variation	0.11	0.31	0.14

Note: A_{pv} = projected shear area; f'_m = specified compressive strength of masonry; A_b = area of anchor bolt; f_y = specified yield strength of anchor bolt.

Table 3. Anchor Bolt Design Strength Using TMS 402-16

	TMS 402-13 Governing Equation		
	Breakout	Crushing	Yielding
Design Strength	$4A_{pv}\sqrt{f'_m}$	$1750\sqrt[4]{f'_m A_b}$	$0.6A_b f_y$
Number of tests	95	131	119
Average of Experimental/Calculated	1.23	1.49	1.44
Standard Deviation of Ratio	0.14	0.44	0.35
Coefficient of Variation	0.11	0.29	0.24

The second change related to anchor bolt strength is related to the interaction under combined shear and tension. Previously the Code used a linear interaction diagram for anchor bolts under combined shear and tension. For the 2016 provisions, this was changed to an elliptical interaction diagram. For allowable stress, the interaction equation is now $\left(\frac{b_a}{B_a}\right)^{\frac{5}{3}} + \left(\frac{b_v}{B_v}\right)^{\frac{5}{3}} \leq 1$ and for strength design the interaction equation is now $\left(\frac{b_{au}}{\phi B_{an}}\right)^{\frac{5}{3}} + \left(\frac{b_{vu}}{\phi B_{vn}}\right)^{\frac{5}{3}} \leq 1$, where b_a is the design axial force, b_{au} is the factored axial load, b_v is the design shear load, b_{vu} is the factored shear load, B_a is the allowable axial load, B_{an} in the nominal axial strength, B_v is the allowable shear load, and B_{vn} is the nominal shear strength. This change was justified based on the work of Fabrello-Streufert et al [5] and McGinley [6]. The effect of the exponent increase from 1 to 5/3 is shown Table 4, which presents the allowable ratio of b_v/B_v for n=1 and the proposed n=5/3 for different ratios of b_a/B_a.

Table 4. Effect of Exponent on Combined Axial and Shear in Anchor Bolts in Masonry

b_a/B_a	b_v/B_v	
	$n = 1$	$n = 5/3$
0.25	0.75	0.94
0.5	0.50	0.80
0.75	0.25	0.56

Increased Cavity Width for Prescriptive Design of Veneers

Increased energy requirements for building envelopes have encouraged the use of wider cavities in brick veneer walls to accommodate increased insulation thicknesses. TMS 402-16 was changed to allow an increased cavity width from 4-1/2 inch to 6-5/8 inch for prescriptive design of veneer anchors under certain conditions. The increase was primarily to allow for increased thicknesses of insulation, and secondarily to recognize that 5/8 inch sheathing is typically used instead of 1/2 inch sheathing. The requirements for anchors for the increased cavity width are:

- Adjustable anchors
  - Two pintles
  - Maximum span of adjustable portion is 2 in.
  - Part of anchor attached to backing either 1/4 in. barrel anchor, a plate or prong anchor at least 0.074 in. thick and 1-1/4 in. wide; or a tab or two eyes formed of minimum size W2.8 wire welded to joint reinforcement.
- Joint reinforcement: Cross and longitudinal wires of wire size W2.8

Anchor capacities of adjustable anchors are primarily controlled by bending of the pintles at maximum allowed offset of 1.25 in. This capacity is independent of cavity width, and is not affected by the code change. The tensile capacity of the anchor is also not affected by the cavity width. The compression capacity of the anchor is affected by the cavity width. The requirements for anchors for increased cavity widths have compression capacity that equals or exceeds current requirements.

Following the balloting of TMS 402/602, appeals were received by The Masonry Society (TMS) related to the increase from 4 ½ in. to 6 5/8 in. Concerns were raised that the change was not technically justified, that limited research on such anchors did not justify the extent of the changes, and that additional research was required. The Masonry Society's Technical Activities Committee (TAC) carefully considered these and other concerns, while TMS's Board of Directors considered concerns with the procedures used to ballot the changes. The appeals were found non-persuasive for a number of reasons including that the limited research cited was not used to justify the changes made, but rather engineering calculations were used to ensure the strength of the anchors was in excess of that currently permitted for prescriptively detailed anchored veneer.

Distribution of Concentrated Loads

TMS 402 has had provisions for distributing concentrated loads in walls based on a 2 vertical to 1 horizontal dispersion terminating at half the wall height, or the edge or opening of a wall. This resulted in very small distribution lengths for concentrated loads near the edge of a wall, and no dispersion for loads at the edge of a wall or an opening. This could result in unconservative designs as the axial load generally increases the moment capacity. Figure 1 shows the provisions that were added for distribution of concentrated loads near the edge of the wall or an opening. This steeper dispersion will continue away from the opening up to ½ the height of the masonry below the load ($H_{below\ load}$) so the dispersions can be truncated independently on each side of the bearing.

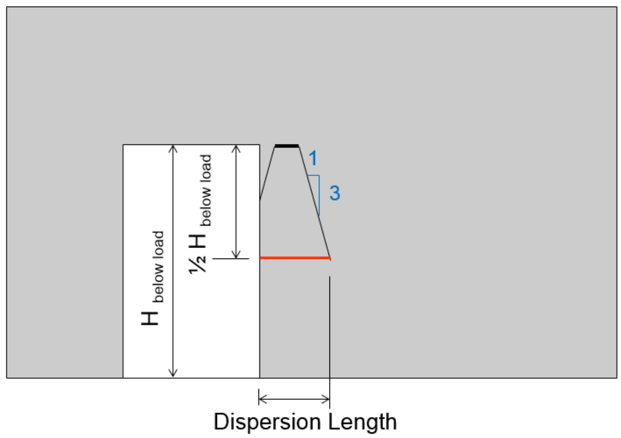

Figure 1: Distribution of concentrated loads near the edge of a wall or an opening

Qualifications of Inspectors and Testing Technicians

The TMS 602 Specification was modified to improve the confidence in the quality, strength, and consistency of masonry through qualified inspection and testing services. To improve the quality of inspection on masonry projects, a new article was added to TMS 602 to require a submittal of the qualifications of the special inspector. TMS 602 was also modified to require, when used, qualified field technicians and laboratory technicians. References are added into the commentary to the International Code Council (ICC) as a source for qualifications of special inspectors through their Structural Masonry Special Inspector's program, and to the American Concrete Institute (ACI) as a source for qualifications of testing technicians through their Masonry Field Testing Technician Certification (MFTT) program and Masonry Laboratory Certification (MLTT) program. Special inspectors and testing technicians qualified under other acceptable agencies could be used if chosen by the Contractor.

Other Technical Changes

Other technical changes include the following.

- Prescriptive requirements for masonry piers were deleted from strength design; most of the requirements were redundant with current prescriptive seismic design provisions.
- The requirement that the nominal bar diameter not exceed one-eighth of the least nominal member dimension that was in strength design was also added to allowable stress design.

This provision minimizes the chances of splitting of the masonry. The IBC had required this provision to apply to both ASD and SD, so this results in no change in practice.

- Tables for the prescriptive design of partitions in Chapter 14 were expanded to include out-of-plane loadings from 5 psf to 50 psf.
- Cast stone (ASTM C1364-16 Standard Specification for Architectural Cast Stone) and manufactured stone (ASTM C1670-15 Standard Specification for Adhered Manufactured Stone Masonry Veneer Units) were added as approved materials for veneer in TMS 602.

ORGANIZATION, FORMAT, AND EDITORIAL CHANGES

There were several major changes in terms of organization and format of the code, with no significant changes to the actual provisions.

Consolidation of Reinforcement Requirements

Reinforcement requirements, particularly development and splice length requirements, had been scattered across three chapters: Chapter 8 – Allowable Stress Design, Chapter 9 – Strength Design, and Chapter 11 – AAC Masonry. These requirements were consolidated and moved to Chapter 6 - Reinforcement, Metal Accessories, And Anchor Bolts. Table 5 compares Chapter 6 in the 2013 and 2016 TMS 402 Code. This consolidation of provisions helped not only reduce the length of the standard, but also helped clarify the provisions by being in one location, so that requirements were not accidentally missed.

Quality Assurance Tables

The Quality Assurance (QA) tables were developed nearly twenty years ago and introduced in the 1999 version of the TMS 402/602. When the QA tables were first generated, they were intentionally formatted differently to clearly differentiate between the "periodic inspection" table and the "continuous inspection" table. The "frequency" columns were not included at that time and the tables were identified as QA Levels 1, 2 and 3. It was not until much later that the columns that defined the frequency of inspection for each task were added so that we would be more consistent with International Building Code (IBC). The IBC (2000 thru 2009) also contained masonry inspection tables. The inspection tables were termed as Levels 1, 2 and 3, so TMS 402/602 changed to Levels A, B and C in the 2005 edition to avoid confusion. Over this period, the IBC and TMS 402/602 Quality Assurance tables evolved to a duplicative state, and subsequently, the masonry inspection tables were removed in the 2012 IBC [7].

The 2013 TMS 402/602 had three quality assurance tables (Quality Assurance Level A, B, and C), and the tables were repeated in both the code (TMS 402) and the specification (TMS 602). For the 2016 edition, the tables were removed from TMS 402, and TMS 402 now just references TMS 602. This avoids duplication and the possibility for conflicting requirements. The tables were also modified so that there are now two tables, one table for Minimum Verification Requirements, and one table for Minimum Special Inspection Requirements. This approach segregates minimum test requirements from the inspection provisions. It also keeps the required tasks consistent and removes the duplicative listing of Reference for Criteria between QA Levels B and C.

Additionally, the QA levels were changed from A, B, and C to 1, 2, and 3 primarily to avoid confusion of 'C' for Level C and 'C' for Continuous. Requirements are given in the minimum verification table and minimum inspection table for Quality Assurance Levels 1, 2, and 3.

Table 5. Comparison of Chapter 6 in the 2013 and 2016 TMS 402 Code

2013 TMS 402	2016 TMS 402
6.1 Details of reinforcement and metal accessories 6.1.1 Embedment 6.1.2 Size of reinforcement 6.1.3 Placement of reinforcement 6.1.4 Protection of reinforcement and metal accessories 6.1.5 Standard hooks 6.1.6 Minimum bend diameter for reinforcing bars	6.1 Reinforcement 6.1.1 Embedment 6.1.2 Size of reinforcement 6.1.3 Placement or reinforcement 6.1.4 Protection of reinforcement 6.1.5 Development 6.1.5.1 Development of bar reinforcement in tension or compression 6.1.5.2 Development of wires in tension 6.1.6 Splices 6.1.6.1 Splices of bar reinforcement 6.1.6.2 Splices of wires in tension 6.1.7 Shear reinforcement 6.1.7.1 Horizontal shear reinforcement 6.1.7.2 Stirrups 6.1.7.3 Welded wire reinforcement 6.1.8 Standard hooks and bends for reinforcing bars, stirrups, and ties 6.1.9 Embedment of flexural reinforcement 6.1.9.1 General 6.1.9.2 Development of positive moment reinforcement 6.1.9.3 Development of negative moment reinforcement
	6.2 Metal accessories 6.2.1 Protection of metal accessories
6.2 Anchor bolts	6.3 Anchor bolts

Use of Tables

Some formatting changes include combining requirements that were in multiple sections and difficult to follow using tables. This is for the ease of users and is similar to ACI 318-14 [8]. For example, there is now a table that gives all the hook geometry and inside bend diameter requirements for reinforcement in one location rather than the requirements being in multiple sections with rather confusing wording. Other tables include minimum quality assurance requirements, elastic moduli, coefficients of thermal expansion, coefficients of creep, effective flange width, and the internal lever arm for deep beams. Consideration of use of additional tables to consolidate and clarify other requirements is being given for future editions of the standards.

Definitions and Terminology

Definitions were added for beams and pilasters. Achieving consensus on these definitions was surprisingly difficult due in part to differences in the use of masonry in various areas. The resulting definitions are specific enough to help new designers understand provisions to be applied to various masonry members, while broad enough to allow seasoned designers flexibility.

The definition for collar joint was modified and a definition was added for cavity to eliminate inconsistencies in usage. Also to clarify usage, the definition of walls was revised, consistent to revisions to the column definition during the last revision cycle, to remove the arbitrary length to thickness requirement. These definitions are shown below.

- *Beam* - A member designed primarily to resist flexure and shear induced by loads perpendicular to its longitudinal axis.
- *Cavity* — A continuous air space, between wythes, which may contain insulation.
- *Collar joint* — Vertical longitudinal space between wythes of composite masonry that is filled with mortar or grout.
- *Pilaster* - A vertical member, built integrally with a wall, with a portion of its cross -section typically projecting from one or both faces of the wall.
- *Wall* — A member, usually vertical, used to enclose or separate spaces or uses.

There has been an inconsistency in definitions of loads, particularly since ASCE 7 [9] began specifying seismic and wind loads at strength levels during recent revision cycles. For example, allowable stress design was defined as a design method in which the calculated stresses resulting from nominal loads must not exceed permissible masonry and steel stresses. However, ASCE 7 defines nominal loads as "the magnitudes of the loads specified in this [that is ASCE 7] standard for dead, live, soil, wind, snow, rain, flood, and earthquake loads". This is inconsistent with a load factor of 0.6 for wind and 0.7 for seismic loads in allowable stress design. In addition, TMS 402-13 defined service loads as the load specified by the legally adopted building code, and ASCE 7-16 has added a definition of service load that related to a load used for serviceability. As a result of the inconsistencies, TMS 402-16 now just has two definitions of load based on the load combination used to determine the load. The definitions are:

- *Load, allowable stress level* – Loads resulting from allowable stress design load combinations.
- *Load, strength level* – Loads resulting from strength design load combinations.

Editorial changes included updating the references to a consistent format and changing "element" to "member" in many locations. The latter was consistent with ACI 318, where "member" is used for physical members, and "element" is used for a representation of the member, such as finite elements. There are numerous exceptions, such as boundary elements, and "lateral-force-resisting element," which has a long history of use and good understanding.

THE NEXT CYCLE

At the request of the Chair of TMS/602-16 and many of its members, The Masonry Society's Board of Directors approved a trial of a six-year code revision cycle because of concerns that a three-year code revision cycle is just too quick, does not allow designers, contractors and users adequate time to learn and use the provisions before they are again modified, and because a short revision cycle may not allow vetting of some complex issues. Opponents countered that a 6 year revision cycle delays important enhancements including the use of new materials and technologies. Moreover, because standards developers receive a significant portion of their operating budgets from sales of those publications, some feared that a longer revision cycle would undermine TMS finances thus potentially compromising future development of this and other standards. After careful consideration of these and other issues, TMS's Board of Directors permitted a one-time 6-year revision cycle, at which point it will evaluate the effectiveness of the cycle. TMS hopes to use the longer revision cycle to develop additional products since volunteers and staff should have additional time between publishing standards. This change has been overwhelmingly positively received by designers and most industry segments who have noted that many states have effectively gone to a six-year cycle by not adopting a new code every three years and many other standards including ASCE 7 and ACI 318 are currently using 6-year revision cycles. Thus, the next edition of TMS 402/602 is projected to be the 2022 edition.

SUMMARY

There were numerous technical changes, and format/editorial changes in the TMS 402/602 document. These changes were made to enhance the ease of use of the document, and most important, to keep masonry as a safe, competitive material for the design of structures. New materials including architectural cast stone and adhered manufactured stone veneer are now permitted by the standard in appropriate applications. Provisions have been clarified, unified and in some cases tabulated to aide users.

ACKNOWLEDGEMENTS

The authors would like to acknowledge and thank the members of the 2016 TMS 402/602 committee for their work in vetting issues to enhance these standards for the betterment of the users and those that live in, and work in, masonry structures.

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