








Structural Masonry Design



A Practical Seminar for Practicing Engineers
 SEAO NW Conference
 Salishan Resort, Gleneden Beach, OR, August 15 - 17, 2019
 © 2019 NWCMA and Edwin T Huston, PE, SE



Sponsors

| | | |
|---|---|---|
| | Northwest Concrete Masonry Association |  |
| Masonry Industry Promotion Group | Masonry Institute of Oregon | Masonry Institute of Washington |
|  |  |  |
| Northwest Cement Council | Structural Engineers Association of Oregon | Structural Engineers Association of Washington |
|  |  |  |

Seminar Credits and Objectives

- Present the majority of the changes to TMS 402-16 and the 2018 IBC
- Facilitate ease and efficiency of masonry design
- I would like to acknowledge the assistance of:
 - NWCMA and Tom Young
 - The Masonry Society, Phil Samblanet, Mark McGinely, and Dick Bennett
 - IMI and Brian Trimbel

Current Building Codes



4

TMS 402/602-16 CODE AND SPECIFICATION UPDATE

5

Name Change

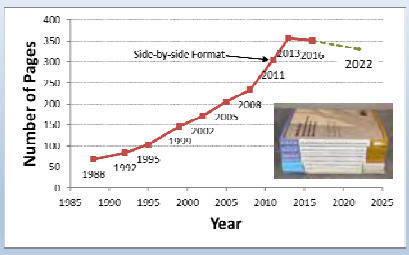
2013:
TMS 402/ACI 530/ASCE 5
TMS 602/ACI 530.1/ASCE 6
Developed by MSJC
(Masonry Standards Joint Committee)

2016:
TMS 402
TMS 602



6

Code Facts



7

Overview

- Technical Changes
 - Shear Friction
 - Anchor Bolts
 - Others
- Format/Editorial Changes
 - Reinforcement Requirements Moved to Chapter 6
 - Quality Assurance Tables
 - Others

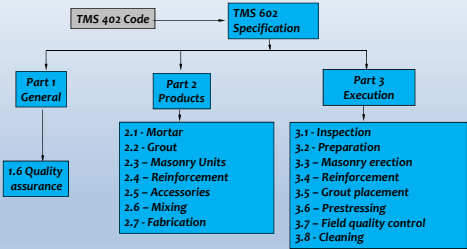
8

TMS 402/602 - relationship between Code and Specification...

- TMS 402 "Code"
 - Design provisions are given in Chapters 1 - 14 and Appendices A, B and C
 - Sections 1.2.4 and Chapter 3 require a QA program in accordance with the Specification
 - Section 1.4 invokes the Specification by reference.
- TMS 602 "Specification"
 - verify compliance with specified f_m
 - comply with specified products and execution
 - comply with required level of quality assurance

9

TMS 602 Specification – Format Consistent between editions



10

Mandatory Specification Checklist

- List of decisions that must be made by the Engineer/Architect:
 - Specify masonry materials to be used
 - Specify compressive strength of masonry (except veneer, empirical, glass block)
 - Specify quality assurance requirements
 - Show type and location of movement joints on drawings

11

Optional Specification Checklist

- List of decisions that can be made by Engineer/Architect. If not made, default values of the Specification apply .
 - Specify required submittals
 - Specify bond pattern if not running bond
 - Specify when masonry units are to be wetted prior to use
 - Specify when cross - webs are to be mortar - bedded
 - Specify masonry cleaning methods

12

First, a TMS 2013 Change

- Based on recent testing, the correlation between the compressive strength of concrete masonry units, mortar type, and resulting assembly compressive strength was substantially revised.
- Similar format revisions were made to the unit strength table for clay masonry units, although no changes to the values in the clay masonry table were made.

13

Specification & Commentary for Masonry Structures (TMS 602-11) 1.4B.2 Unit Strength Method, Table 2

For decades the unit strength table provided a quick/easy means of determining f'_m

Table 2 — Compressive strength of masonry based on the compressive strength of concrete masonry units and type of mortar used in construction

| Net area compressive strength of concrete masonry units, psi (MPa) | | Net area compressive strength of masonry, psi ¹ (MPa) |
|--|---------------|--|
| Type M or S mortar | Type N mortar | |
| 1,900 (13.10) | 1,900 (13.10) | 2,375 (9.31) |
| 2,250 (15.86) | 2,150 (14.82) | 2,500 (10.34) |
| 2,800 (19.31) | 3,050 (21.03) | 3,000 (13.79) |
| 3,500 (24.13) | 4,050 (27.92) | 2,500 (17.24) |
| 4,000 (27.58) | 5,250 (36.20) | 3,000 (20.69) |

¹ For units of less than 4 in. (102 mm) height, 85 percent of the values listed.



14

Assembly Compressive Strength (f'_m)

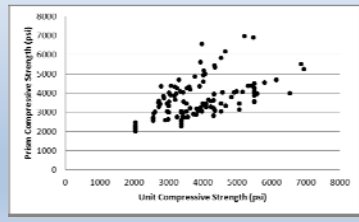
- Yet, this option has been very conservative to use due to:
- Data drawn from prism testing completed 30-60 years ago.
 - Non-standardized and varying testing procedures.
 - Correction factors needed to account for:
 - Gross vs. net area compressive strength
 - Face shell vs. full mortar bedding



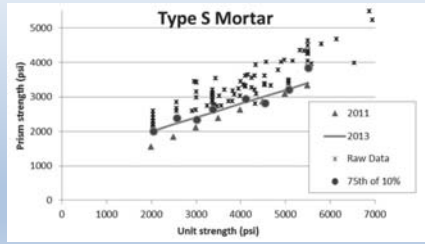
15

Assembly Compressive Strength (f'_m)

In 2010, a new research project was initiated to recalibrate the unit strength method.



Assembly Compressive Strength (f'_m)



Specification & Commentary for Masonry Structures (TMS 602) 1.4B.2 Unit Strength Method, Table 2

Table 2 — Compressive strength of masonry based on the compressive strength of concrete masonry units and type of mortar used in construction

| Net area compressive strength of concrete masonry, psi (MPa) | Net area compressive strength of concrete masonry units, psi (MPa) | |
|--|--|---------------|
| | Type M or S mortar | Type N mortar |
| 1,700 (11.72) | — | 1,900 (13.10) |
| 1,900 (13.10) | 1,900 (13.10) | 2,350 (14.82) |
| 2,000 (13.79) | 2,000 (13.79) | 2,650 (18.27) |
| 2,250 (15.51) | 2,600 (17.93) | 3,400 (23.44) |
| 2,500 (17.24) | 3,250 (22.41) | 4,350 (28.96) |
| 2,750 (18.96) | 3,900 (26.89) | — |
| 3,000 (20.69) | 4,500 (31.03) | — |


¹For units of less than 4 in. (102 mm) nominal height, use 85 percent of the values listed.

Assembly Compressive Strength (f'_m)

At lower unit compressive strength values, Type M or S mortars produce an assembly compressive strength equal to the unit compressive strength.

1,900 psi unit → 1,900 psi f'_m

2,000 psi unit → 2,000 psi f'_m




19

Assembly Compressive Strength (f'_m)

Historically $f'_m = 1,500$ psi has been the default baseline for the specified compressive strength of concrete masonry.

The recalibrated table doesn't even go as low as $f'_m = 1,500$ psi; instead starting at 1,900 psi for Type S mortar.

But $f'_m = 1,900$ psi feels 'irregular'...




20

Assembly Compressive Strength (f'_m)

$f'_m = 2,000$ psi feels 'right'.

However, ASTM C90 required a minimum unit compressive strength of 1,900 psi.

The solution...change ASTM C90. Hence, in 2014 ASTM C90 was changed to have a minimum compressive strength of 2,000 psi. This is now the minimum in TMS 402-16



21

Assembly Compressive Strength (f'_m)

TMS 402-16

Table 2 — Compressive strength of masonry based on the compressive strength of concrete masonry units and type of mortar used in construction

| Net area compressive strength of concrete masonry, psi (MPa) | Net area compressive strength of concrete masonry units, psi (MPa) | |
|--|--|-------------------|
| | Type M or S mortar | Type N mortar |
| 1,500 (10.3) | 2,000 (13.79) | 2,000 (13.79) |
| 2,000 (13.79) | 2,500 (17.24) | 2,650 (18.27) |
| 2,500 (17.24) | 3,000 (20.69) | 3,400 (23.44) |
| 3,000 (20.69) | 3,500 (24.13) | 4,350 (29.96) |
| 3,500 (24.13) | 4,000 (27.58) | 5,300 (36.89) |
| 4,000 (27.58) | 4,500 (31.03) | 6,300 (43.79) |
| 4,500 (31.03) | 5,000 (34.48) | 7,300 (50.69) |
| 5,000 (34.48) | 5,500 (37.93) | 8,300 (57.58) |
| 5,500 (37.93) | 6,000 (41.38) | 9,300 (64.48) |
| 6,000 (41.38) | 6,500 (44.83) | 10,300 (71.38) |
| 6,500 (44.83) | 7,000 (48.28) | 11,300 (78.28) |
| 7,000 (48.28) | 7,500 (51.73) | 12,300 (85.18) |
| 7,500 (51.73) | 8,000 (55.18) | 13,300 (92.08) |
| 8,000 (55.18) | 8,500 (58.63) | 14,300 (98.98) |
| 8,500 (58.63) | 9,000 (62.08) | 15,300 (105.88) |
| 9,000 (62.08) | 9,500 (65.53) | 16,300 (112.78) |
| 9,500 (65.53) | 10,000 (68.98) | 17,300 (119.68) |
| 10,000 (68.98) | 10,500 (72.43) | 18,300 (126.58) |
| 10,500 (72.43) | 11,000 (75.88) | 19,300 (133.48) |
| 11,000 (75.88) | 11,500 (79.33) | 20,300 (140.38) |
| 11,500 (79.33) | 12,000 (82.78) | 21,300 (147.28) |
| 12,000 (82.78) | 12,500 (86.23) | 22,300 (154.18) |
| 12,500 (86.23) | 13,000 (89.68) | 23,300 (161.08) |
| 13,000 (89.68) | 13,500 (93.13) | 24,300 (167.98) |
| 13,500 (93.13) | 14,000 (96.58) | 25,300 (174.88) |
| 14,000 (96.58) | 14,500 (100.03) | 26,300 (181.78) |
| 14,500 (100.03) | 15,000 (103.48) | 27,300 (188.68) |
| 15,000 (103.48) | 15,500 (106.93) | 28,300 (195.58) |
| 15,500 (106.93) | 16,000 (110.38) | 29,300 (202.48) |
| 16,000 (110.38) | 16,500 (113.83) | 30,300 (209.38) |
| 16,500 (113.83) | 17,000 (117.28) | 31,300 (216.28) |
| 17,000 (117.28) | 17,500 (120.73) | 32,300 (223.18) |
| 17,500 (120.73) | 18,000 (124.18) | 33,300 (230.08) |
| 18,000 (124.18) | 18,500 (127.63) | 34,300 (236.98) |
| 18,500 (127.63) | 19,000 (131.08) | 35,300 (243.88) |
| 19,000 (131.08) | 19,500 (134.53) | 36,300 (250.78) |
| 19,500 (134.53) | 20,000 (137.98) | 37,300 (257.68) |
| 20,000 (137.98) | 20,500 (141.43) | 38,300 (264.58) |
| 20,500 (141.43) | 21,000 (144.88) | 39,300 (271.48) |
| 21,000 (144.88) | 21,500 (148.33) | 40,300 (278.38) |
| 21,500 (148.33) | 22,000 (151.78) | 41,300 (285.28) |
| 22,000 (151.78) | 22,500 (155.23) | 42,300 (292.18) |
| 22,500 (155.23) | 23,000 (158.68) | 43,300 (299.08) |
| 23,000 (158.68) | 23,500 (162.13) | 44,300 (305.98) |
| 23,500 (162.13) | 24,000 (165.58) | 45,300 (312.88) |
| 24,000 (165.58) | 24,500 (169.03) | 46,300 (319.78) |
| 24,500 (169.03) | 25,000 (172.48) | 47,300 (326.68) |
| 25,000 (172.48) | 25,500 (175.93) | 48,300 (333.58) |
| 25,500 (175.93) | 26,000 (179.38) | 49,300 (340.48) |
| 26,000 (179.38) | 26,500 (182.83) | 50,300 (347.38) |
| 26,500 (182.83) | 27,000 (186.28) | 51,300 (354.28) |
| 27,000 (186.28) | 27,500 (189.73) | 52,300 (361.18) |
| 27,500 (189.73) | 28,000 (193.18) | 53,300 (368.08) |
| 28,000 (193.18) | 28,500 (196.63) | 54,300 (374.98) |
| 28,500 (196.63) | 29,000 (200.08) | 55,300 (381.88) |
| 29,000 (200.08) | 29,500 (203.53) | 56,300 (388.78) |
| 29,500 (203.53) | 30,000 (206.98) | 57,300 (395.68) |
| 30,000 (206.98) | 30,500 (210.43) | 58,300 (402.58) |
| 30,500 (210.43) | 31,000 (213.88) | 59,300 (409.48) |
| 31,000 (213.88) | 31,500 (217.33) | 60,300 (416.38) |
| 31,500 (217.33) | 32,000 (220.78) | 61,300 (423.28) |
| 32,000 (220.78) | 32,500 (224.23) | 62,300 (430.18) |
| 32,500 (224.23) | 33,000 (227.68) | 63,300 (437.08) |
| 33,000 (227.68) | 33,500 (231.13) | 64,300 (443.98) |
| 33,500 (231.13) | 34,000 (234.58) | 65,300 (450.88) |
| 34,000 (234.58) | 34,500 (238.03) | 66,300 (457.78) |
| 34,500 (238.03) | 35,000 (241.48) | 67,300 (464.68) |
| 35,000 (241.48) | 35,500 (244.93) | 68,300 (471.58) |
| 35,500 (244.93) | 36,000 (248.38) | 69,300 (478.48) |
| 36,000 (248.38) | 36,500 (251.83) | 70,300 (485.38) |
| 36,500 (251.83) | 37,000 (255.28) | 71,300 (492.28) |
| 37,000 (255.28) | 37,500 (258.73) | 72,300 (499.18) |
| 37,500 (258.73) | 38,000 (262.18) | 73,300 (506.08) |
| 38,000 (262.18) | 38,500 (265.63) | 74,300 (512.98) |
| 38,500 (265.63) | 39,000 (269.08) | 75,300 (519.88) |
| 39,000 (269.08) | 39,500 (272.53) | 76,300 (526.78) |
| 39,500 (272.53) | 40,000 (275.98) | 77,300 (533.68) |
| 40,000 (275.98) | 40,500 (279.43) | 78,300 (540.58) |
| 40,500 (279.43) | 41,000 (282.88) | 79,300 (547.48) |
| 41,000 (282.88) | 41,500 (286.33) | 80,300 (554.38) |
| 41,500 (286.33) | 42,000 (289.78) | 81,300 (561.28) |
| 42,000 (289.78) | 42,500 (293.23) | 82,300 (568.18) |
| 42,500 (293.23) | 43,000 (296.68) | 83,300 (575.08) |
| 43,000 (296.68) | 43,500 (300.13) | 84,300 (581.98) |
| 43,500 (300.13) | 44,000 (303.58) | 85,300 (588.88) |
| 44,000 (303.58) | 44,500 (307.03) | 86,300 (595.78) |
| 44,500 (307.03) | 45,000 (310.48) | 87,300 (602.68) |
| 45,000 (310.48) | 45,500 (313.93) | 88,300 (609.58) |
| 45,500 (313.93) | 46,000 (317.38) | 89,300 (616.48) |
| 46,000 (317.38) | 46,500 (320.83) | 90,300 (623.38) |
| 46,500 (320.83) | 47,000 (324.28) | 91,300 (630.28) |
| 47,000 (324.28) | 47,500 (327.73) | 92,300 (637.18) |
| 47,500 (327.73) | 48,000 (331.18) | 93,300 (644.08) |
| 48,000 (331.18) | 48,500 (334.63) | 94,300 (650.98) |
| 48,500 (334.63) | 49,000 (338.08) | 95,300 (657.88) |
| 49,000 (338.08) | 49,500 (341.53) | 96,300 (664.78) |
| 49,500 (341.53) | 50,000 (344.98) | 97,300 (671.68) |
| 50,000 (344.98) | 50,500 (348.43) | 98,300 (678.58) |
| 50,500 (348.43) | 51,000 (351.88) | 99,300 (685.48) |
| 51,000 (351.88) | 51,500 (355.33) | 100,300 (692.38) |
| 51,500 (355.33) | 52,000 (358.78) | 101,300 (699.28) |
| 52,000 (358.78) | 52,500 (362.23) | 102,300 (706.18) |
| 52,500 (362.23) | 53,000 (365.68) | 103,300 (713.08) |
| 53,000 (365.68) | 53,500 (369.13) | 104,300 (719.98) |
| 53,500 (369.13) | 54,000 (372.58) | 105,300 (726.88) |
| 54,000 (372.58) | 54,500 (376.03) | 106,300 (733.78) |
| 54,500 (376.03) | 55,000 (379.48) | 107,300 (740.68) |
| 55,000 (379.48) | 55,500 (382.93) | 108,300 (747.58) |
| 55,500 (382.93) | 56,000 (386.38) | 109,300 (754.48) |
| 56,000 (386.38) | 56,500 (389.83) | 110,300 (761.38) |
| 56,500 (389.83) | 57,000 (393.28) | 111,300 (768.28) |
| 57,000 (393.28) | 57,500 (396.73) | 112,300 (775.18) |
| 57,500 (396.73) | 58,000 (400.18) | 113,300 (782.08) |
| 58,000 (400.18) | 58,500 (403.63) | 114,300 (788.98) |
| 58,500 (403.63) | 59,000 (407.08) | 115,300 (795.88) |
| 59,000 (407.08) | 59,500 (410.53) | 116,300 (802.78) |
| 59,500 (410.53) | 60,000 (413.98) | 117,300 (809.68) |
| 60,000 (413.98) | 60,500 (417.43) | 118,300 (816.58) |
| 60,500 (417.43) | 61,000 (420.88) | 119,300 (823.48) |
| 61,000 (420.88) | 61,500 (424.33) | 120,300 (830.38) |
| 61,500 (424.33) | 62,000 (427.78) | 121,300 (837.28) |
| 62,000 (427.78) | 62,500 (431.23) | 122,300 (844.18) |
| 62,500 (431.23) | 63,000 (434.68) | 123,300 (851.08) |
| 63,000 (434.68) | 63,500 (438.13) | 124,300 (857.98) |
| 63,500 (438.13) | 64,000 (441.58) | 125,300 (864.88) |
| 64,000 (441.58) | 64,500 (445.03) | 126,300 (871.78) |
| 64,500 (445.03) | 65,000 (448.48) | 127,300 (878.68) |
| 65,000 (448.48) | 65,500 (451.93) | 128,300 (885.58) |
| 65,500 (451.93) | 66,000 (455.38) | 129,300 (892.48) |
| 66,000 (455.38) | 66,500 (458.83) | 130,300 (899.38) |
| 66,500 (458.83) | 67,000 (462.28) | 131,300 (906.28) |
| 67,000 (462.28) | 67,500 (465.73) | 132,300 (913.18) |
| 67,500 (465.73) | 68,000 (469.18) | 133,300 (920.08) |
| 68,000 (469.18) | 68,500 (472.63) | 134,300 (926.98) |
| 68,500 (472.63) | 69,000 (476.08) | 135,300 (933.88) |
| 69,000 (476.08) | 69,500 (479.53) | 136,300 (940.78) |
| 69,500 (479.53) | 70,000 (482.98) | 137,300 (947.68) |
| 70,000 (482.98) | 70,500 (486.43) | 138,300 (954.58) |
| 70,500 (486.43) | 71,000 (489.88) | 139,300 (961.48) |
| 71,000 (489.88) | 71,500 (493.33) | 140,300 (968.38) |
| 71,500 (493.33) | 72,000 (496.78) | 141,300 (975.28) |
| 72,000 (496.78) | 72,500 (500.23) | 142,300 (982.18) |
| 72,500 (500.23) | 73,000 (503.68) | 143,300 (989.08) |
| 73,000 (503.68) | 73,500 (507.13) | 144,300 (995.98) |
| 73,500 (507.13) | 74,000 (510.58) | 145,300 (1002.88) |
| 74,000 (510.58) | 74,500 (514.03) | 146,300 (1009.78) |
| 74,500 (514.03) | 75,000 (517.48) | 147,300 (1016.68) |
| 75,000 (517.48) | 75,500 (520.93) | 148,300 (1023.58) |
| 75,500 (520.93) | 76,000 (524.38) | 149,300 (1030.48) |
| 76,000 (524.38) | 76,500 (527.83) | 150,300 (1037.38) |
| 76,500 (527.83) | 77,000 (531.28) | 151,300 (1044.28) |
| 77,000 (531.28) | 77,500 (534.73) | 152,300 (1051.18) |
| 77,500 (534.73) | 78,000 (538.18) | 153,300 (1058.08) |
| 78,000 (538.18) | 78,500 (541.63) | 154,300 (1064.98) |
| 78,500 (541.63) | 79,000 (545.08) | 155,300 (1071.88) |
| 79,000 (545.08) | 79,500 (548.53) | 156,300 (1078.78) |
| 79,500 (548.53) | 80,000 (551.98) | 157,300 (1085.68) |
| 80,000 (551.98) | 80,500 (555.43) | 158,300 (1092.58) |
| 80,500 (555.43) | 81,000 (558.88) | 159,300 (1099.48) |
| 81,000 (558.88) | 81,500 (562.33) | 160,300 (1106.38) |
| 81,500 (562.33) | 82,000 (565.78) | 161,300 (1113.28) |
| 82,000 (565.78) | 82,500 (569.23) | 162,300 (1120.18) |
| 82,500 (569.23) | 83,000 (572.68) | 163,300 (1127.08) |
| 83,000 (572.68) | 83,500 (576.13) | 164,300 (1133.98) |
| 83,500 (576.13) | 84,000 (579.58) | 165,300 (1140.88) |
| 84,000 (579.58) | 84,500 (583.03) | 166,300 (1147.78) |
| 84,500 (583.03) | 85,000 (586.48) | 167,300 (1154.68) |
| 85,000 (586.48) | 85,500 (589.93) | 168,300 (1161.58) |
| 85,500 (589.93) | 86,000 (593.38) | 169,300 (1168.48) |
| 86,000 (593.38) | 86,500 (596.83) | 170,300 (1175.38) |
| 86,500 (596.83) | 87,000 (600.28) | 171,300 (1182.28) |
| 87,000 (600.28) | 87,500 (603.73) | 172,300 (1189.18) |
| 87,500 (603.73) | 88,000 (607.18) | 173,300 (1196.08) |
| 88,000 (607.18) | 88,500 (610.63) | 174,300 (1202.98) |
| 88,500 (610.63) | 89,000 (614.08) | 175,300 (1209.88) |
| 89,000 (614.08) | 89,500 (617.53) | 176,300 (1216.78) |
| 89,500 (617.53) | 90,000 (620.98) | 177,300 (1223.68) |
| 90,000 (620.98) | 90,500 (624.43) | 178,300 (1230.58) |
| 90,500 (624.43) | 91,000 (627.88) | 179,300 (1237.48) |
| 91,000 (627.88) | 91,500 (631.33) | 180,300 (1244.38) |
| 91,500 (631.33) | 92,000 (634.78) | 181,300 (1251.28) |
| 92,000 (634.78) | 92,500 (638.23) | 182,300 (1258.18) |
| 92,500 (638.23) | 93,000 (641.68) | 183,300 (1265.08) |
| 93,000 (641.68) | 93,500 (645.13) | 184,300 (1271.98) |
| 93,500 (645.13) | 94,000 (648.58) | 185,300 (1278.88) |
| 94,000 (648.58) | 94,500 (652.03) | 186,300 (1285.78) |
| 94,500 (652.03) | 95,000 (655.48) | 187,300 (1292.68) |
| 95,000 (655.48) | 95,500 (658.93) | 188,300 (12 |

Shear Friction Provisions

| Allowable Stress Design | Strength Design |
|--|--|
| Where $M/(Vd_v) \leq 0.5$ $F_f = \frac{\mu(A_{sp}F_s + P)}{A_{nv}}$ | Where $M_u/(V_u d_v) \leq 0.5$ $V_{nf} = \mu(A_{sp}f_y + P_i)$ |
| Linear interpolation for intermediate values | |
| Where $M/(Vd_v) \geq 1.0$ $F_f = \frac{0.65(0.6A_{sp}F_s + P)}{A_{nv}}$ | Where $M_u/(V_u d_v) \geq 1.0$ $V_{nf} = 0.42f'_m A_{nc}$ <small>A_{nc} = area of masonry in compression at nominal moment capacity</small> |

- $\mu = 1.0$ for masonry on concrete with unfinished surface, or concrete with a surface that has been intentionally roughened
- $\mu = 0.70$ for all other conditions
- UBC (1997) required concrete abutting structural masonry to be roughened to a full amplitude of 1/16 inch.

25

Shear Friction: Special Reinforced Shear Walls

Shear Capacity Design: (7.3.2.6.1)

- Strength Design
 - $\phi V_n >$ shear corresponding to the development of $1.25M_n$
 - V_n need not exceed $2.5V_u$
- Allowable Stress Design
 - Calculated shear stress increased by 1.5

Per commentary, shear capacity provisions do not apply to shear friction

- Strength Design
 - The provisions of this Section only apply to the nominal shear strength, V_n , and do not apply to the nominal shear friction strength, V_{nf} .
- Allowable Stress Design
 - The 1.5 multiplier should not be applied to V when calculating the M/Vd_v ratio, or for shear friction design.

26

Overview

- Technical Changes
 - Shear Friction
 - **Anchor Bolts**
 - Others
- Format/Editorial Changes
 - Reinforcement Requirements Moved to Chapter 6
 - Quality Assurance Tables
 - Others

27

Anchor Bolts: Two Major Changes

| | Allowable Stress Design | Strength Design |
|------------------|--|--|
| Masonry Crushing | $P_{vc} = 350 \sqrt{f'_m A_b}$ $P_{vc} = 580 \sqrt{f'_m A_b}$ | $P_{mrc} = 1050 \sqrt{f'_m A_b}$ $P_{mrc} = 1750 \sqrt{f'_m A_b}$ |
| Interaction | $\frac{b_u}{B_u} + \frac{b_v}{B_v} \leq 1$ $\left(\frac{b_u}{B_u}\right)^{\frac{5}{3}} + \left(\frac{b_v}{B_v}\right)^{\frac{5}{3}} \leq 1$ | $\frac{b_{un}}{\phi B_{un}} + \frac{b_{vn}}{\phi B_{vn}} \leq 1$ $\left(\frac{b_{un}}{\phi B_{un}}\right)^{\frac{5}{3}} + \left(\frac{b_{vn}}{\phi B_{vn}}\right)^{\frac{5}{3}} \leq 1$ |

28

Anchor Bolts: Masonry Crushing

| | TMS 402-13 Governing Equation | | |
|-----------------------------|-------------------------------|-----------------------|--------------|
| | Breakout | Crushing | Yielding |
| Design Strength | $4A_{pv}\sqrt{f'_m}$ | $1050\sqrt{f'_m A_b}$ | $0.6A_b f_y$ |
| Number of Tests | 95 | 188 | 62 |
| Average of Test/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 |

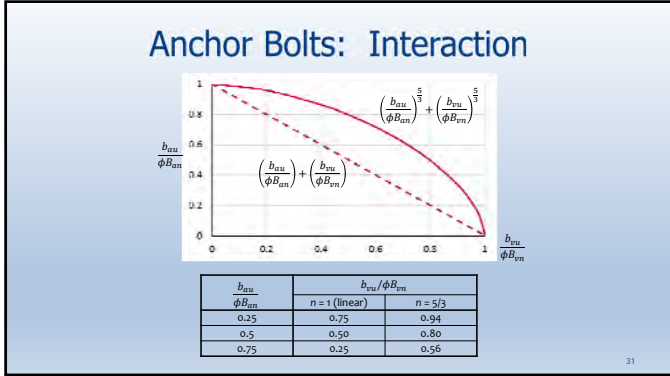
- Several alternate equations for shear crushing were examined
- FEMA 369 equation chosen: $1750\sqrt{f'_m A_b}$.

29

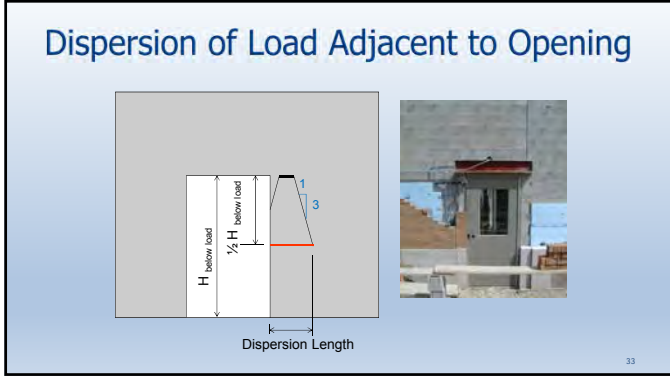
Anchor Bolts: Masonry Crushing

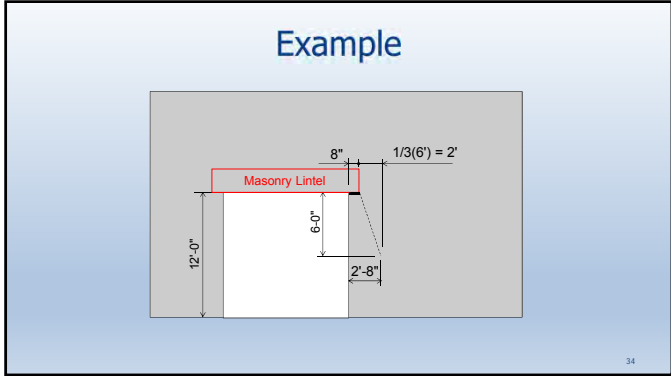
| | TMS 402-16 Governing Equation | | |
|-----------------------------|-------------------------------|-----------------------|--------------|
| | Breakout | Crushing | Yielding |
| Design Strength | $4A_{pv}\sqrt{f'_m}$ | $1750\sqrt{f'_m A_b}$ | $0.6A_b f_y$ |
| Number of Tests | 95 | 131 | 119 |
| Average of Test/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 |

30



- ### Overview
- Technical Changes
 - Shear Friction
 - Anchor Bolts
 - **Others**
 - Format/Editorial Changes
 - Reinforcement Requirements Moved to Chapter 6
 - Quality Assurance Tables
 - Others





Deleted Piers: Strength Design

9.3.4.3 Piers
9.3.4.3.1 The factored axial compression force on piers shall not exceed $0.3A_p f'_m$.
9.3.4.3.2 Longitudinal reinforcement —

- symmetrically reinforced
- at least one bar in each end cell
- minimum area of longitudinal reinforcement shall be $0.0007 bd$.

9.3.4.3.3 Dimensional limits —

- nominal thickness of a pier shall not exceed 16 in.
- distance between lateral supports of a pier shall not exceed 25 times the nominal thickness or design as a wall
- nominal length shall not be less than three times the nominal thickness nor greater than six multiplied by its nominal thickness. The clear height of a pier shall not exceed five multiplied by its nominal length.

35

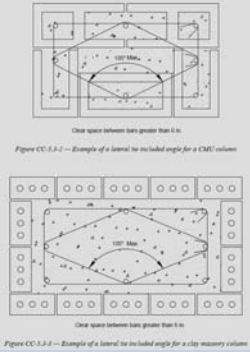
Harmonized One Reinforcement Requirement

6.1.2 Size of reinforcement
6.1.2.1 The maximum size of reinforcement used in masonry shall be No. 11. (No. 9 in strength design, 9.3.3.1)
6.1.2.2 The diameter of reinforcement shall not exceed one-half the least clear dimension of the cell, bond beam, or collar joint in which it is placed. (one-quarter least clear dimension in strength design, 9.3.3.1)
6.1.2.3 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.
6.1.2.4 Area of vertical reinforcement shall not exceed 6 percent of the area of the grout space. (4 percent in strength design, 9.3.3.1)
6.1.2.5 The nominal bar diameter shall not exceed one-eighth of the least nominal member dimension. (Previously only in strength design)

36

Added Figure for Tie Requirements

5.3.1.4 Lateral ties — Lateral ties shall conform to the following; (c) Lateral ties shall be arranged so that every corner and alternate longitudinal bar shall have lateral support provided by the corner of a lateral tie with an included angle of not more than 135 degrees. No bar shall be farther than 6 in. (152 mm) clear on each side along the lateral tie from such a laterally supported bar.

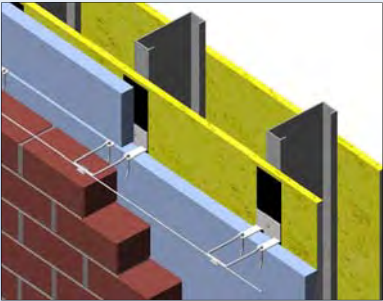


Veneer Anchors

Increased allowed cavity width for prescriptive design to 6-5/8 in. under certain conditions

- 4 in. to 6 in. to accommodate increased insulation thicknesses
- 1/2 in to 5/8 in. to accommodate 5/8 in. sheathing
- Required conditions
 - Adjustable anchors
 - Two pintles required
 - Maximum span of adjustable portion is 2 in.
 - Part 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

Veneer Anchors



Expanded Tables for Partition Walls

Table 14.3.1 – Maximum l/t or h/t for partition walls of ungrouted or partially grouted hollow units

| Maximum combined allowable stress level out-of-plane load acting on single-span partition wall | Mortar type | | | |
|--|---------------------------------------|----|--|----|
| | Portland cement-lime or mortar cement | | Masonry cement or air-entrained portland cement-lime | |
| | M or S | N | M or S | N |
| 5 psf (0.239 kPa) | 26 | 24 | 22 | 18 |
| 10 psf (0.479 kPa) | 18 | 16 | 14 | 12 |
| 15 psf (0.718 kPa) | 15 | 13 | 12 | 9 |
| 20 psf (0.958 kPa) | 13 | 11 | 10 | 8 |
| 30 psf (1.436 kPa) | 10 | 9 | 8 | 6 |
| 40 psf (1.915 kPa) | 9 | 8 | 7 | 5 |
| 50 psf (2.394 kPa) | 8 | 7 | 6 | 5 |

Cast Stone and Manufactured Stone

Added to TMS 602 SPECIFICATION
2.3 — Masonry unit materials
2.3 F. Provide cast stone that conforms to ASTM C1364 as specified.
2.3 G. Provide manufactured stone that conforms to ASTM C1670 as specified.

ASTM C1364-16 Standard Specification for Architectural Cast Stone
 ASTM C1670-15 Standard Specification for Adhered Manufactured Stone Masonry Veneer Units

Qualifications of Inspectors and Testing Technicians

| 2016 TMS 602 Specification | 2016 TMS 602 Commentary |
|--|--|
| 1.6 A. Testing Agency's services and duties 1. Utilize qualified laboratory technicians to perform required laboratory tests. | 1. Masonry testing laboratory personnel who are certified in accordance with ACI Masonry Laboratory Testing Technician Certification Program, or equivalent program, are qualified. |
| 1.6 B. Inspection Agency's services and duties 1. Utilize qualified field testing technicians to observe or perform the preparation and handling of grout specimens, mortar specimens and/or masonry prisms. | 1. Field technicians who are certified in accordance with the requirements of ACI Masonry Field Testing Technician Certification Program, or an equivalent program, are qualified to observe and/or prepare masonry specimens. |
| 2. Utilize qualified Special Inspectors to inspect and evaluate construction. | 2. Special inspectors who are certified for this service by International Code Council, or other acceptable agency, are qualified. |

Overview

- Technical Changes
 - Shear Friction
 - Anchor Bolts
 - Others
- Format/Editorial Changes
 - **Reinforcement Requirements Moved to Chapter 6**
 - Quality Assurance Tables
 - Others

43

Chapter 6: Reinforcement, Metal Accessories, And Anchor Bolts

| 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 6.1.6.1.1 Lap splices 6.1.6.1.2 Welded splices 6.1.6.1.3 Mechanical splices 6.1.6.1.4 End-bearing splices 6.1.6.2 Splices of wires in tension 6.1.6.2.1 Lap splices 6.1.6.2.2 Welded splices 6.1.6.2.3 Mechanical splices |

44

Chapter 6: Reinforcement, Metal Accessories, And Anchor Bolts




45

Chapter 6: Reinforcement, Metal Accessories, And Anchor Bolts

| 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 6.1.7 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 |

46

Quality Assurance Tables

| 2013 TMS 402 | 2016 TMS 402 |
|--|---|
| Tables were in TMS 402 Chapter 3 and TMS 602 Article 1.6. | Tables just in TMS 602 and referenced from TMS 402 Chapter 3. |
| Three tables: • Quality Assurance Level A • Quality Assurance Level B • Quality Assurance Level C | Two tables: • Minimum verification requirements • Minimum special inspection requirements |

47

2013 Quality Assurance Tables

Table 4 – Level B Quality Assurance

| MINIMUM TESTS | | | | |
|--|----------------|----------------|-----------------------------------|---------------------------|
| Verification of Strong Floor and Vertical Seismic Index (VSI) as defined in the project site requirements with Article 1.9.B.1 for the self-insulating joint | | | | |
| Verification of F_u and F_w in accordance with Article 1.4.B.1 in conjunction, except where specifically exempted by the Code. | | | | |
| MINIMUM SPECIAL INSPECTIONS | | | | |
| Inspection Task | Frequency | | Reference to Criteria | |
| | Continuous | Periodic | TMS 402 ACI 308 ACI 309 ACI 308.4 | TMS 602 ACI 309 ACI 308.4 |
| 1. Verify compliance with the approval submittals | | X | | Art. 1.4 |
| 2. All assembly construction phases, verify that the following are in compliance: | | | | |
| a. Preparation of cast-in-place concrete | | X | | Art. 2.1.2.4.A |
| b. Construction of masonry joints | | X | | Art. 3.3.B |
| c. Grade and site of precast concrete members and assemblies | | X | | Art. 2.4.D, 2.4.E |
| d. Location of reinforcement, connectors, and reinforcing bars and welds | | X | | Art. 1.4.3.4.A |
| e. Formwork techniques | | X | | Art. 3.6.B |
| f. Preparation of steel deck for A/C concrete | X ^a | X ^b | | Art. 1.1.C |
| 3. Prior to pouring, verify that the following are in compliance: | | | | |
| a. Clear space | | X | | Art. 7.2.D, 3.2.F |

48

2016 Verification Requirements

Table 3 — Minimum Verification Requirements

| Minimum Verification | Required for Quality Assurance ^(a) | | | Reference for Criteria |
|---|---|---------|---------|------------------------|
| | Level 1 | Level 2 | Level 3 | |
| Prior to construction, verification of compliance of submittals. | R | R | R | Art. 1.5 |
| Prior to construction, verification of f'_m and f'_{AAC} , except where specifically exempted by the Code. | NR | R | R | Art. 1.4 B |
| During construction, verification of Slump flow and Visual Stability Index (VSI) when self-consolidating grout is delivered to the project site. | NR | R | R | Art. 1.5 & 1.6.3 |
| During construction, verification of f'_m and f'_{AAC} for every 5,000 sq. ft. (465 sq. m). | NR | NR | R | Art. 1.4 B |
| During construction, verification of proportions of materials as delivered to the project site for permitted or prohibited mortar, prestressing grout, and grout other than self-consolidating grout. | NR | NR | R | Art. 1.4 B |

(a) R=Required, NR=Not Required

2016 Inspection Requirements

Table 4 — Minimum Special Inspection Requirements

| Inspection Task | Frequency | | | Reference for Criteria | |
|---|-----------|------------------------------------|---------|------------------------|--------------------------------|
| | Level 1 | Level 2 | Level 3 | TMS 402 | TMS 602 |
| 1. As masonry construction begins, verify that the following are in compliance: | | | | | |
| a. Proportions of pre-cast/meter units. | NR | P | R | | Art. 2.1, 2.6 & 2.5.A.C. |
| b. Grade and size of prestressing tendons and anchors. | NR | P | P | | Art. 2.4.B & 2.4.D. |
| c. Grade, type and size of reinforcement: masonry, mortar beds, and prestressing tendons and anchors. | NR | P | R | | Art. 2.1 & 2.6.A. |
| d. Prestressing technique. | NR | P | P | | Art. 1.6.B |
| e. Properties of duct-bed mortar for AAC masonry. | NR | C ^(a) /P ^(b) | C | | Art. 2.1.C.1 |
| f. Sample grout construction. | NR | P | C | | Art. 1.4.D |
| 2. After in progress, verify that the following are in compliance: | | | | | |
| g. Grout space. | NR | P | C | | Art. 1.2.D & 2.2.F |
| h. Placement of prestressing tendons and anchors. | NR | P | P | | Art. 2.4 & 2.5. |
| i. Placement of reinforcement (tendons and mortar beds). | NR | P | C | | See 2.1, 2.3.1, 2.3.2, & 2.3.7 |
| j. Proportions of pre-cast/meter grout and prestressing grout for basket tendons. | NR | P | R | | Art. 2.6.B & 2.4.1.D. |

Overview

- Technical Changes
 - Shear Friction
 - Anchor Bolts
 - Others
- Format/Editorial Changes
 - Reinforcement Requirements Moved to Chapter 6
 - Quality Assurance Tables
 - **Others**

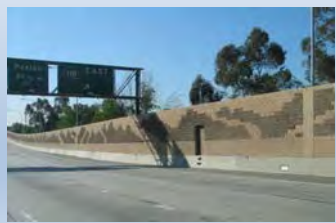
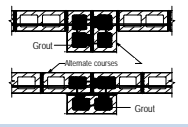
Definitions

New definitions
Beam - A member designed primarily to resist flexure and shear induced by loads perpendicular to its longitudinal axis.
Lintel - See Beam.
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.

New and modified definitions: eliminated inconsistencies in usage
Cavity — A continuous air space, between wythes, which may contain insulation.
Collar joint — Vertical longitudinal space between wythes of composite masonry or between masonry wythe and backup construction, which that is permitted to be filled with mortar or grout.

55

Pilasters



56

Other Changes

- References
Updated references to a consistent format and citation method.
- Member vs. Element
- "member" and "element" used somewhat interchangeably.
 - Committee and ACI 318 agreed to move toward using "member" for physical members, and "element" for a representation of the member, such as finite element.
 - Some of the exceptions include:
 - boundary elements
 - collectors – elements that act in axial tension or compression
 - seismic topics, where "element" such as "lateral-force-resisting element" has a long history of use and good understanding.

57

ASCE 7-16 Code Changes Affecting Masonry

Chapters 13, 14, and 15

The minimum design strength of anchors not governed by tensile yielding or shear yielding was reduced from 2.5 times the factored force to 2.0 times the factored force.

Chapter 14

- One-third stress increase restrictions removed: TMS 402-11 removed the allowable one-third stress increase
- Deep beam provisions removed: TMS 402-11 added deep beam provisions
- Lap splice provisions changed

58

The I-Codes and the IBC

- I-Codes or "International" Codes
 - Model Building Code prepared for adoption (with or without amendments) by local jurisdictions
- Replaced former "legacy" codes
 - UBC, BOCA NBC, SBC
- Published on a 3 year cycle
- IBC = International Building Code (our focus for this seminar)



6

Relationship between IBC & MSJC



- IBC and other I-Codes
 - reference standards (with or without modification) related to material, design & construction requirements
- IBC and IRC referenced the "MSJC" for the design & construction of structural masonry.
- Each IBC referenced the latest edition of MSJC
 - 2012 IBC references the 2011 MSJC
 - 2015 IBC references the 2013 MSJC
- **2018 IBC updated to reference TMS 402/602-16**



40

2018 International Building Code (IBC)

- Chapter 14 - Masonry veneer
- Chapter 17 - Special Inspection and Testing
- Chapter 18 - Foundations
- Chapter 21 - Masonry design
- References TMS 402-16
- State amendments, if any



61

Major Changes in 2018 IBC related to Masonry Quality Assurance

- None
- IBC Chapter 17 continues to refer to TMS 602 for Special Inspection and Testing
- TMS 602 did consolidate tables as noted for Quality Assurance

62

New to Chapter 21 of the 2018 IBC

- Standards for Architectural Cast Stone (TMS 404-16, TMS 505-16 and TMS 604-16) referenced in the IBC for the design, fabrication, and installation of architectural cast stone.



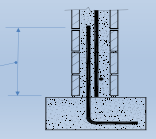
63

New to Chapter 21, Masonry, of the 2018 IBC

- Other structural changes related to masonry.
 - 72d_b cap on ASD lap splice lengths added consistent with SD
 - Equation requires long lap lengths at small cover depths, or with large bars. Some feel research was not consistent with how splices actually are loaded and perform

$$l_d = \frac{0.13 d_b^2 f_y \gamma}{K \sqrt{f'_m}}$$

Lap Splice Length may be reduced to 72 d_b, despite what may be required by lap length equation



Chapter 21, Masonry, of the 2018 IBC

- Few other major structural changes. Some other changes you may wish to know about:
 - AAC masonry unit standards updated based on changes in ASTM (from ASTM C 1386 to ASTM C1691 and ASTM C1693 for the strength class specified)
 - Adhered manufactured stone masonry veneer units conforming to ASTM C1670 added (consistent with TMS 602)

65

Chapter 21, Masonry, of the 2018 IBC

- Other structural changes related to masonry.
 - ASD (Allowable Stress Design) Modification to TMS 402/602 related to "Maximum" Bar Size (2015 IBC Section 2107.4) eliminated because this is now addressed directly in TMS 402, Section 6.2.1

66

Chapter 21, Masonry, of the 2018 IBC

- Other structural changes related to masonry.
 - Empirical Design requirements limited for “conventional” masonry and expanded for adobe masonry
 - TMS 402/602 almost deleted empirical design during the 2016 cycle. Problem was IBC referenced those requirements
 - IBC change to remove link. Now clay and concrete masonry must be designed by ASD or SD
 - Adobe industry not prepared for change. Slightly expanded/clarified their requirements. Will change further in future editions of IBC.

67

Structural Masonry Design

Questions?



68
