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REINFORCED COMPOSITE CONCRETE MASONRY WALLS

TEK 16-3B
Structural (2006)

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INTRODUCTION

Reinforced composite concrete masonry walls can provide geometric diversity. Composite walls consist of multiple wythes of masonry connected such that they act as a single structural member. There are prescriptive requirements in both the *International Building Code* (ref. 1) and *Building Code Requirements for Masonry Structures* (ref. 2) for connecting the wythes. Reinforced composite masonry walls are designed similarly to other reinforced masonry walls, and must meet the same construction requirements for reinforcement and grout placement, tolerances and workmanship.

General composite wall information is included in TEK 16-1A, *Multiwythe Concrete Masonry Walls* (ref. 3), which is intended to be used with this TEK. Although composite walls can be reinforced or unreinforced, this TEK discusses the requirements for reinforced composite walls. Unreinforced composite walls are discussed in TEK 16-2B, *Structural Design of Unreinforced Composite Masonry* (ref. 4).

DESIGN CONSIDERATIONS

Composite masonry is defined as "multicomponent masonry members acting with composite action" (ref. 2). For a multiwythe wall section to act compositely, the wythes of masonry must be adequately connected. Provisions for properly bonding the wythes are discussed in TEK 16-1A. When wall ties are used, the collar joint – the vertical space between the two wythes of masonry – must be filled solid with grout or mortar (refs. 1, 2). However, when reinforcement is placed in the collar joint, grout must be used to fill the collar joint.

Considerations When Choosing a Cross Section

Unlike single wythe walls, where the geometric cross section is set by the product as manufactured, the cross section of a composite wall is determined by the combination of units and collar joint which can theoretically be any thickness. Practically speaking, code, structural and architectural requirements will narrow the options for wall sections. In addition to structural capacity, criteria specific to cross-section selection for reinforced composite walls include: location of reinforcement in collar joint or in unit cells; collar joint thickness; unit selection for each wythe.

Structural Reinforcement Location

The engineer has the option of locating the structural reinforcing steel in the collar joint or in one or both wythes. While there is no direct prohibition against placing reinforcement in both the collar joint and the unit cores, practically speaking there is rarely a structural reason to complicate the cross section with this configuration.

With some units, it may be easier to install reinforcement in the collar joint, such as when both wythes are solid or lack sufficient cell space for reinforcing bars. Depending on the units selected, the collar joint may or may not provide the option to center the reinforcement within the wall cross section. For example, when the units are not the same thickness, the collar joint does not necessarily span the center of the section.

Conversely, if off-set reinforcement is preferred, perhaps to accommodate unbalanced lateral loads, it may be beneficial to place the vertical bars in the unit cells. Placing reinforcement in the unit cells permits a thinner collar joint and possibly a thinner overall cross section. Unit cells may provide a larger and less congested opening for the reinforcing bars and grout since the collar joint will be crossed with connecting wall ties.

Reinforcement can also be placed in the cells of each wythe, providing a double curtain of steel to resist lateral loads from both directions, as in the case of wind pressure and suction.

Collar Joint Width

There are no prescriptive minimums or maximums explicit to collar joint thickness in either *Building Code Requirements for Masonry Structures* or the *International Building Code*, however there are some practical limitations for constructability and also code compliance in reinforcing and grouting that effect the collar joint dimension. Many of these are covered in TEK 16-1A but a few key points that are especially relevant for reinforced composite masonry walls are:

- Wall tie length: Noncomposite cavity walls have a cavity thickness limit of $4^1/_2$ in. (114 mm) unless a wall tie analysis is performed. There is no such limitation on width for filled collar joints in composite construction since the wall ties can be considered fully supported by the mortar or grout, thus eliminating concern about local buckling of the ties. Practically speaking, since cavity wall construction is much more prevalent, the availability of standard ties may dictate collar joint thickness maximums close to $4^1/_2$ in. (114 mm).

- Grout pour and lift height: Collar joint width influences the lift height. Narrow collar joints may lead to low lift or pour heights which could impact cost and construction schedule. See Table 1 in TEK 3-2A, *Grouting Concrete Masonry Walls* (ref. 5) for more detailed information.
- Course or fine grout: Codes require a minimum clear distance of ¼-in. (6.3-mm) for fine grout and ½-in. (13-mm) for coarse grout between reinforcing bars and any face of the masonry unit.
- Grout or mortar fill: Although codes permit collar joints to be filled with either mortar or grout, grout is preferred because it helps ensure complete filling of the collar joint without creating voids. Note that collar joints less than ¾ in. (19 mm), unless otherwise required, are to be filled with mortar as the wall is built. Increasing the slump of the mortar to achieve a solidly filled joint is preferred. This effectively requires a ¾-in. (19-mm) minimum collar joint when reinforcement is placed in the collar joint, because reinforcing bars must be placed in grout.
- Reinforcing bar: The reinforcing bar diameter cannot exceed one-half the least clear dimension of the collar joint.
- Horizontal bond beams: Bond beams may be required to meet prescriptive code requirements such as seismic detailing. The collar joint then must be wide enough to accommodate the horizontal and vertical reinforcement along with the accompanying clearances for embedment in grout.

Unit Selection for Each Wythe

Aesthetic criteria may play a primary role in unit selection for reinforced composite walls. Designing the composite wall to match modular dimensions may make detailing of interfaces much easier. Window and door frames, foundations, connectors and other accessories may coordinate better if typical masonry wall thicknesses are maintained. Additional criteria that influence the selection of units for reinforced composite walls include:

- Size and number of reinforcing bars to be used and the cell space required to accommodate them.
- Cover requirements (see ref. 6) may come into play when reinforcement is placed in the cells off-center. Cover requirements could affect unit selection, based on the desired bar placement; face shell thickness and cell dimensions.
- If double curtains of vertical reinforcement are used, it is preferable to use units of the same thickness to produce a symmetrical cross section.

Structural Considerations

Some structural considerations were addressed earlier in this TEK during the discussion of cross section determination. Since reinforced composite masonry by definition acts as one wall to resist loads, the design procedures are virtually the same as for all reinforced masonry walls. TEK 14-7A, *Allowable Stress Design of Concrete Masonry* (ref. 7) details design procedures. A few key points should be stressed, however:

- Design and construction follow the same procedures as all reinforced concrete masonry walls, however, empirical design methods are not permitted to be used.
- Section properties must be calculated using the transformed section method described in TEK 16-1A (ref. 3).
- Shear stress in the plane of interface between wythes and collar joint is limited to 5 psi (34.5 kPa) for mortared collar joints and 10 psi (68.9 kPa) for grouted collar joints.

DESIGN TABLES

Design tables for select reinforced composite walls are included below. The tables include maximum bending moments and shear loads that can be sustained without exceeding allowable stresses (refs. 1, 2). These can be compared to Tables 1 and 2 of TEK 14-19A, *Allowable Stress Design Tables for Reinforced Concrete Masonry Walls* (ref. 8) for walls subject to uniform lateral loads to ensure the wall under consideration is not loaded beyond its design capacity.

The examples are based on the following criteria:

- $F_b = {}^1/_3 f'_m$ $\quad$ F_s = 24,000 psi (165 MPa)
  $F_v = \sqrt{f'_m}$, 50 psi (0.35 MPa) maximum
- f'_m = 1,500 psi (10.3 MPa)
- f'_g = 2,000 psi (13.7 MPa) minimum
- $E_m = 900 f'_m$ for concrete masonry = 1,350,000 psi (9,310 MPa)
- $E_g = 500 f'_g$ or 1,000,000 psi (6,890 MPa)
- E_s = 29,000,000 psi (200,000 MPa)
- Type M or S mortar
- running bond or bond beams at 48 in. (1,219 mm) or less o.c.
- reinforcement spacing does not exceed the wall height
- where indicated, allowable stresses are increased by one-third as prescribed in the IBC and the MSJC (refs. 1, 2) for load combinations including wind or seismic
- wythes are bonded with wall ties and the collar joint is filled solid with grout
- both wythes are concrete masonry units with the same f'_m

In addition to these tables, it is important to check all code requirements governing grout space dimensions and maximum reinforcement size to ensure that the selected reinforcing bar is not too large for the collar joint. The designer must also check shear stress at the unit/grout interface to ensure it does not exceed the code allowable stress for the design loading.

CONSTRUCTION AND DETAILING REQUIREMENTS

Although two composite masonry wythes are not required to be built at the same time unless the collar joint is less than ¾ in. (19 mm), practically speaking, it is easier to build both wythes at the same time to facilitate placing grout in the collar joint at the code-required pour heights.

Grouting composite walls may be more complex than single wythe. For example, while the entire collar joint is grouted, the unit cells may only need to be grouted at the reinforcement locations. Installing reinforcement and grout in the collar joint can also be more time-consuming because of congestion due to the wall ties.

In addition, nonmodular composite wall sections require more care at points where they interface with modular elements such as window and door frames, bonding at corners and bonding with modular masonry walls.

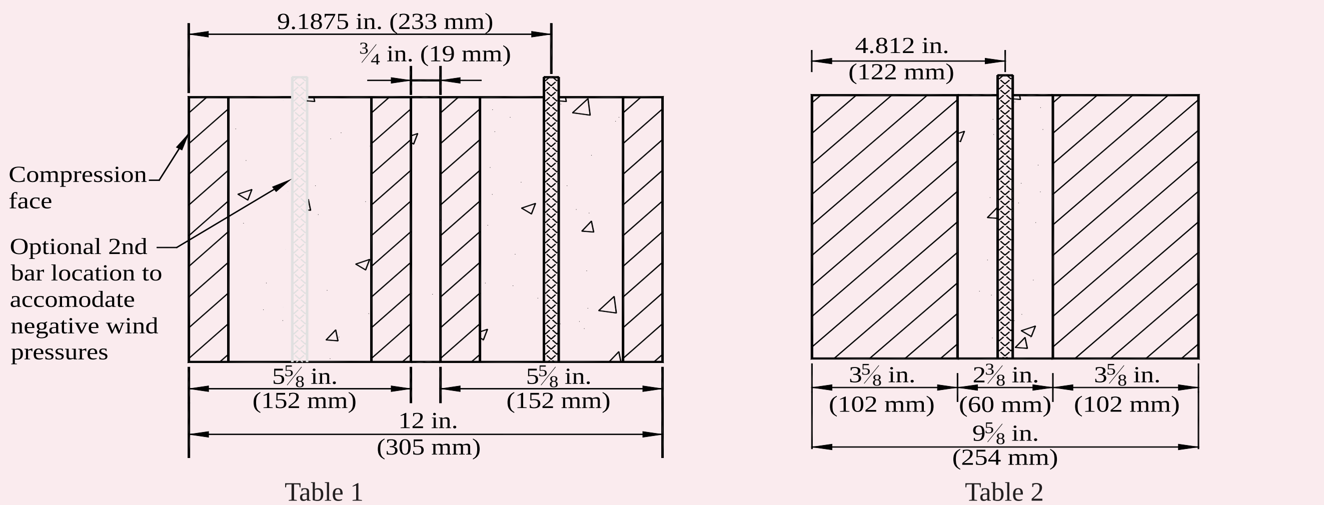

Figure 1—Wall Sections for Tables 1 and 2

Table 1—Two 6-in. (152-mm) Wythes, Off-Center Reinforcement[A]

Bar size	Bar spacing, in. (mm)	A_s, in.^{2}/ft (mm^2/m)	Not including wind or seismic: M_r, in.-lb/ft (N·m/m)	Not including wind or seismic: V_r, lb/ft (kN/m)	Including wind or seismic: M_r, in.-lb/ft (N·m/m)	Including wind or seismic: V_r, lb/ft (kN/m)
No. 7 (M#22)	8 (203)	0.9000 (1,903)	95,486 (35,377)	4,270 (62)	127,314 (47,169)	5,693(83)
No. 6 (M#19)	8 (203)	0.6600 (1,396)	86,781 (32,151)	4,270 (62)	115,707 (42,868)	5,693 (83)
No. 5 (M#16)	8 (203)	0.4650 (983)	77,242 (28,618)	4,270 (62)	102,990 (38,157)	5,693 (83)
No. 7 (M#22)	16 (406)	0.4500 (952)	76,372 (28,295)	4,270 (62)	101,829 (37,727)	5,693 (83)
No. 6 (M#19)	16 (406)	0.3300 (698)	65,488 (24,263)	4,270 (62)	87,317 (32,350)	5,693 (83)
No. 7 (M#22)	24 (610)	0.3000 (634)	59,790 (22,152)	4,270 (62)	79,720 (29,536)	5,693 (83)
No. 4 (M#13)	8 (203)	0.3000 (634)	59,790 (22,152)	4,270 (62)	79,720 (29,536)	5,693 (83)
No. 5 (M#16)	16 (406)	0.2325 (492)	46,839 (17,353)	4,270 (62)	62,452 (23,138)	5,693 (83)
No. 7 (M#22)	32 (813)	0.2250 (476)	45,387 (16,816)	4,270 (62)	60,516 (22,421)	5,693 (83)
No. 6 (M#19)	24 (610)	0.2200 (465)	44,418 (16,456)	4,270 (62)	59,224 (21,942)	5,693 (83)
No. 7 (M#22)	40 (1,016)	0.1800 (381)	36,619 (13,567)	4,270 (62)	48,826 (18,090)	5,693 (83)
No. 6 (M#19)	32 (813)	0.1650 (349)	33,673 (12,475)	4,270 (62)	44,897 (16,634)	5,693 (83)
No. 5 (M#16)	24 (610)	0.1550 (328)	31,701 (11,745)	4,270 (62)	42,267 (15,660)	5,693 (83)
No. 7 (M#22)	48 (1,219)	0.1500 (317)	30,712 (11,379)	4,270 (62)	40,950 (15,171)	5,693 (83)
No. 4 (M#13)	16 (406)	0.1500 (317)	30,712 (11,379)	4,270 (62)	40,950 (15,171)	5,693 (83)
No. 6 (M#19)	40 (1,016)	0.1320 (279)	27,141 (10,055)	4,270 (62)	36,188 (13,407)	5,693 (83)
No. 7 (M#22)	56 (1,422)	0.1286 (272)	26,458 (9,803)	4,270 (62)	35,278 (13,070)	5,693 (83)
No. 5 (M#16)	32 (813)	0.1163 (246)	23,998 (8,891)	4,270 (62)	31,997 (11,855)	5,693 (83)
No. 6 (M#19)	48 (1,219)	0.1100 (233)	22,745 (8,427)	4,270 (62)	30,327 (11,236)	5,693 (83)
No. 4 (M#13)	24 (610)	0.1000 (211)	20,735 (7,682)	4,270 (62)	27,647 (10,243)	5,693 (83)
No. 7 (M#22)	72 (1,829)	0.1000 (211)	20,735 (7,682)	4,270 (62)	27,647 (10,243)	5,693 (83)
No. 6 (M#19)	56 (1,422)	0.0943 (199)	19,583 (7,255)	4,270 (62)	26,110 (9,674)	5,693 (83)
No. 5 (M#16)	40 (1,016)	0.0930 (197)	19,323 (7,159)	4,270 (62)	25,764 (9,545)	5,693 (83)
No. 5 (M#16)	48 (1,219)	0.0775 (164)	16,181 (5,995)	4,270 (62)	21,575 (7,993)	5,693 (83)
No. 4 (M#13)	32 (813)	0.0750 (159)	15,672 (5,806)	4,270 (62)	20,896 (7,742)	5,693 (83)
No. 6 (M#19)	72 (1,829)	0.0733 (155)	15,333 (5,681)	4,270 (62)	20,443 (7,574)	5,693 (83)
No. 5 (M#16)	56 (1,422)	0.0664 (140)	13,923 (5,158)	4,270 (62)	18,563 (6,878)	5,693 (83)
No. 4 (M#13)	40 (1,016)	0.0600 (127)	12,605 (4,670)	4,270 (62)	16,807 (6,227)	5,693 (83)
No. 5 (M#16)	72 (1,829)	0.0517 (109)	10,891 (4,035)	4,270 (62)	14,521 (5,380)	5,693 (83)
No. 4 (M#13)	48 (1,219)	0.0500 (106)	10,547 (3,907)	4,270 (62)	14,062 (5,210)	5,693 (83)
No. 4 (M#13)	56 (1,422)	0.0429 (91)	9,068 (3,360)	4,270 (62)	12,091 (4,480)	5,693 (83)
No. 4 (M#13)	72 (1,829)	0.0333 (70)	7,086 (2,625)	4,270 (62)	9,448 (3,501)	5,693 (83)

[A] Double curtain reinforcement option for wind loading: because wind loads can act in either direction, a bar must be included in each wythe when using off-center reinforcement.

Table 2—Two 4-in. (102-mm) Wythes, Reinforcement Centered in Collar Joint

Bar size	Bar spacing, in. (mm)	A_s, in.^{2}/ft (mm^2/m)	Not including wind or seismic M_r, in.-lb/ft (N·m/m)	Not including wind or seismic V_r, lb/ft (kN/m)	Including wind or seismic M_r, in.-lb/ft (N·m/m)	Including wind or seismic V_r, lb/ft (kN/m)
No. 6 (M#19)	8 (203)	0.6600 (1,396)	28,810 (10,674)	2,237 (33)	38,413 (14,232)	2,982 (43)
No. 5 (M#16)	8 (203)	0.4650 (983)	26,093 (9,667)	2,237 (33)	34,790 (12,889)	2,982 (43)
No. 4 (M#13)	8 (203)	0.3000 (634)	22,737 (8,424)	2,237 (33)	30,317 (11,232)	2,982 (43)
No. 6 (M#19)	24 (610)	0.2200 (465)	20,456 (7,579)	2,237 (33)	27,275 (10,105)	2,982 (43)
No. 6 (M#19)	32 (813)	0.1650 (349)	17,188 (6,368)	2,237 (33)	22,917 (8,491)	2,982 (43)
No. 5 (M#16)	24 (610)	0.1550 (328)	16,191 (5,999)	2,237 (33)	21,588 (7,998)	2,982 (43)
No. 6 (M#19)	40 (1,016)	0.1320 (279)	13,884 (5,144)	2,237 (33)	18,511 (6,858)	2,982 (43)
No. 5 (M#16)	32 (813)	0.1163 (246)	12,290 (4,553)	2,237 (33)	16,387 (6,071)	2,982 (43)
No. 6 (M#19)	48 (1,219)	0.1100 (233)	11,654 (4,318)	2,237 (33)	15,539 (5,757)	2,982 (43)
No. 4 (M#13)	24 (610)	0.1000 (211)	10,633 (3,940)	2,237 (33)	14,178 (5,253)	2,982 (43)
No. 5 (M#16)	40 (1,016)	0.0930 (197)	9,915 (3,674)	2,237 (33)	13,221 (4,898)	2,982 (43)
No. 5 (M#16)	48 (1,219)	0.0775 (164)	8,316 (3,081)	2,237 (33)	11,088 (4,108)	2,982 (43)
No. 5 (M#16)	56 (1,422)	0.0664 (140)	7,164 (2,654)	2,237 (33)	9,552 (3,539)	2,982 (43)
No. 4 (M#13)	40 (1,016)	0.0600 (127)	6,491 (2,405)	2,237 (33)	8,654 (3,206)	2,982 (43)
No. 4 (M#13)	48 (1,219)	0.0500 (106)	5,438 (2,015)	2,237 (33)	7,250 (2,686)	2,982 (43)

NOTATIONS

A_s = effective cross-sectional area of reinforcement, in.^{2}/ft (mm^2/m)
d = distance from extreme compression fiber to centroid of tension reinforcement, in. (mm)
E_g = modulus of elasticity of grout, psi (MPa)
E_m = modulus of elasticity of masonry in compression, psi (MPa)
E_s = modulus of elasticity of steel, psi (MPa)
F_b = allowable compressive stress due to flexure only, psi (MPa)
F_s = allowable tensile or compressive stress in reinforcement, psi (MPa)
F_v = allowable shear stress in masonry, psi (MPa)
f'_g = specified compressive strength of grout, psi (MPa)
f'_m = specified compressive strength of masonry, psi (MPa)
M_r = resisting moment of wall, in.-lb/ft (kNm/m)
V_r = resisting shear of wall, lb/ft (kN/m)

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