CONCRETE MASONRY ELEVATOR AND STAIRWELL
BUILDING CORE DESIGN GUIDE

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THE BEAUTY OF BLOCK
CONCRETE MASONRY CHECKOFF
RMMI ROCKY MOUNTAIN MASONRY INSTITUTE
Atkinson-Noland & Associates

INTRODUCTION

Elevator and stairwell building cores are often used to provide structural stability to buildings and to transfer load from upper stories to the foundations. Such building cores are often constructed using reinforced concrete masonry. Concrete masonry construction is ideal in this function as it is durable, has a high fire resistance, excellent sound resistance, rapid construction, and is easily reinforceable.

Moment and shear resistances are two primary values that are typically calculated during the design of an elevator or stairwell building core. This design guide was created to allow for these values to be obtained quickly and with improved efficiency as compared to commonly conducted calculation methods. For example, the beneficial properties of flange action at intersecting walls is considered in this guide, whereas typical core analysis considers each wall to act independently. Moment and shear resistances that correspond with common elevator or stairwell geometries and levels of reinforcement are included herein. All moment and shear resistances were calculated in general accordance with TMS 402-22.

The contents of this design guide are laid out as described below.

APPLICATION OF THIS GUIDE
Design assumptions that limit the applicability of this guide are described in this section. Such assumptions include design details and material properties.

USE OF DESIGN TABLES
Information is provided to assist with the use of the design tables. The procedure used to select a reinforcement scheme from the design tables is described.

DESIGN TABLES
Moment and shear resistances are provided for common geometries of elevator and stairwell building cores. These results are divided into categories based on the level of reinforcement provided.

APPENDIX A: CALCULATION NOTES
Design checks and assumptions that were made during the calculations are included in this section. Failure modes, loading assumptions, and completed design checks are described.

APPENDIX B: SAMPLE CALCULATIONS
A set of sample calculations for a building core is included.

It is important to note that no calculations of deflection are included in this design guide. However, deflection should be considered during the design of a building core to ensure that applicable deflection limitations are satisfied.

APPLICATION OF THIS GUIDE

DESIGN DETAILS

All values in this guide are applicable only to building cores that meet the following requirements:

- Building cores must be composed of fully grouted concrete masonry constructed with 8-inch nominal concrete masonry units (CMUs) laid in running bond. Resistances for partially grouted building cores are expected to be included in a future version of this guide.
- Wall intersections must be designed and detailed in accordance with Section 5.2.3.5 of TMS 402-22 to allow for composite action of intersecting walls. This includes the use of running bond (interlocked corners), steel connectors, or intersecting bond beams at wall corners.
- Building cores must be within part of structures assigned to seismic design categories A, B, or C as defined in ASCE/SEI 7-22.
- The seismic detailing requirements included in Section 7.3.2.2.1 of TMS 402-22 must be satisfied. Such requirements include minimum vertical reinforcement at wall corners, at wall ends, adjacent to openings, and at a maximum spacing of 10 feet on center. Minimum horizontal reinforcement is to be provided above and below openings, at connected roof and floor levels, at the top of a wall, and at least a minimal amount of horizontal reinforcing (which can be satisfied with 9 gauge joint reinforcement).
- No control joints may be included in any of the walls of the building cores. *CMU-TEC-009-25: Crack Control Strategies for Concrete Masonry Construction* generally does not recommend control joints in walls less than 25 feet in length. This technical note also provides strategies for eliminating the need for control joints in concrete masonry construction. Such strategies typically include providing a minimum amount of horizontal reinforcement to control crack widths.
- The exterior dimensions of a building core must be equal to or greater than the exterior dimensions that correspond to a given moment or shear resistance in the design tables for such resistances to be applicable.

MATERIAL PROPERTIES

Table 1 shows the material properties that were assumed during the calculation of the moment and shear resistances included in this guide.

Table 1. Assumed material properties.

Material	Material Property	Value
Masonry	Compressive strength	2,000 psi
	Elastic modulus	1,800,000 psi
	Maximum usable compressive strain	0.0025
Steel reinforcement	Yield strength	60 ksi
	Elastic modulus	29,000 ksi
	Yield strain	0.0021

CONSTRUCTION LOADING CONSIDERATIONS

Building cores may experience loading that is specific to the construction process. For example, bracing or scaffolding is often anchored to building cores, which transfers construction period loading to the cores. Such loads should be accounted for when calculating design loads for a building core.

Building cores may also experience unique loading if they are constructed before the surrounding structure. Isolated building cores may be exposed to a higher level of lateral loading, primarily from wind, than they will experience once the surrounding structure is completed. This lateral loading should be considered during the design of building cores.

USE OF DESIGN TABLES

DESIGN TABLE INDEX

This guide considers building cores of three different general shapes that are intended to represent common building core geometries. Table 2 shows these shapes and the methodology used to calculate the moment and shear resistances included in the corresponding design tables.

Table 2. Design table contents.

Shape	Common Usage	Allowable Stress Design (ASD) Tables			Strength Design (SD) Tables		
		Moment	Min. Horiz. Rein.	Shear	Moment	Min. Horiz. Rein.	Shear
C-Shape	Elevator Core	1.1A	1.1B	2.1	3.1A	3.1B	4.1
Long C-Shape	Stair Core	1.2A	1.2B	2.2	3.2A	3.2B	4.2
G-Shape	Stair Core	1.3A	1.3B	2.3	3.3A	3.3B	4.3

REINFORCEMENT CATEGORIES

The moment and shear resistances that are included in this guide are divided into categories based on the amount of included reinforcement. Table 3 shows the reinforcement categories in terms of cross-sectional area of steel per linear foot. Table 4 shows the cross-sectional area of steel per linear foot that corresponds with each combination of reinforcing bar size and reinforcing bar spacing. The colors used in these tables are also used to indicate reinforcement categories in the design tables.

Table 3. Steel reinforcement categories.

Reinforcement category	Steel per linear foot (in^2/ft)
1	0.028 - 0.100
2	0.101 - 0.200
3	0.201 - 0.300
4	0.301 - 0.500
5	0.501 - 0.900
6	0.901 - 1.185

Table 4. Area of reinforcement provided by potential reinforcement schemes.

Reinforcing bar spacing (in)	Area of reinforcement provided (in^2/ft) for reinforcing bar size of:					
	3	4	5	6	7	8
8	0.165	0.300	0.465	0.660	0.900	1.185
16	0.083	0.150	0.233	0.330	0.450	0.593
24	0.055	0.100	0.155	0.220	0.300	0.395
32	0.041	0.075	0.116	0.165	0.225	0.296
40	0.033	0.060	0.093	0.132	0.180	0.237
48	0.028	0.050	0.078	0.110	0.150	0.198

SELECTION OF REINFORCEMENT SCHEME

The moment and shear resistances presented in this guide are the minimum design strengths associated with a given reinforcement category. Any combination of reinforcing bar size and spacing, hereafter referred to as reinforcement scheme, that is included in a given reinforcement category (as based on area of steel per linear foot) may be assumed to provide the moment or shear resistances shown in the design tables that correspond with the same reinforcement category and size of building core being designed. For example, a vertical reinforcement scheme that includes #6 reinforcing bars at 32 inches on-center is included in the reinforcement category 2 (orange color). The use of #7 reinforcing bars at 40 inches on-center would be considered to provide the same moment resistance according to this guide as this reinforcement scheme is also in reinforcement category 2.

To select a reinforcement scheme from the design tables for a specific building core, one must know the general building core shape, exterior dimensions of the building core, and the required strength. For example, in designing a G-shaped building core with an exterior length of 20'-0" and an exterior width of 12'-0" using strength design, calculated loads require the core to have a total factored ultimate shear resistance along its length (ϕV_{ny}) of 300 kip. According to design Table 4.3, a horizontal reinforcement scheme within the reinforcement category that includes reinforcement schemes with 0.201-0.300 square inches of steel per vertical linear foot (orange category) provides a total factored ultimate shear resistance of 328 kip. Therefore, one suitable horizontal reinforcement scheme to resist shear in the long direction of this building core would be #7 reinforcing bars at 32 inches on center. However, any other reinforcement scheme from the same (orange) reinforcement category could also be chosen.

Note that a given moment or shear resistance can be applied to a building core with actual dimensions that do not match those in the design tables as long as the following are true:

- The general shape (such as C-shape or G-shape) of the actual building core matches the building core shape that corresponds with the design table.
- The actual exterior dimensions exceed the assumed exterior dimensions (those shown in the design table) that correspond with the moment or shear resistance from the design table.

RELATIVE REINFORCEMENT

Consideration needs to be given to relative amounts of vertical and horizontal reinforcement. Sections 8.3.5.2 and 9.3.5.2 of TMS 402-22 contain requirements for the minimum required amount of horizontal reinforcement as a function of the amount of vertical reinforcement included in the design. Therefore, <u>all designs performed using this publication should be checked to ensure that there is at least ONE THIRD (1/3) as much vertical reinforcing as horizontal reinforcing in shear wall elements.</u> This reinforcing should be uniformly distributed with a spacing not to exceed 8'-0" on-center.

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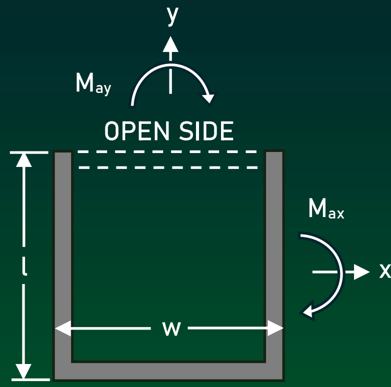
THE BEAUTY OF BLOCK — CONCRETE MASONRY CHECKOFF

1.1A MOMENT – C-SHAPE

ALLOWABLE STRESS DESIGN



The moment resistances shown on this page were calculated in accordance with the Allowable Stress Design provisions in TMS 402-22. M_{ax} is the total allowable flexural resistance of the building core (both walls) when moment is applied about the x-axis. M_{ay} is the total allowable flexural resistance of the building core when moment is applied about the y-axis. See Design Table 1.1B for minimum horizontal reinforcement.

Exterior dimensions		Vertical Steel per linear foot (in²/ft)											
		0.028 - 0.100		0.101 - 0.200		0.201 - 0.300		0.301 - 500		0.501 - 0.900		0.901 - 1.185	
l (ft-in)	w (ft-in)	M_{ax} (kip-ft)	M_{ay} (kip-ft)	M_{ax} (kip-ft)	M_{ay} (kip-ft)	M_{ax} (kip-ft)	M_{ay} (kip-ft)	M_{ax} (kip-ft)	M_{ay} (kip-ft)	M_{ax} (kip-ft)	M_{ay} (kip-ft)	M_{ax} (kip-ft)	M_{ay} (kip-ft)
6'-8"	6'-8"	49	47	153	182	247	335	345	504	577	876	996	1737
	8'-0"	50	59	154	231	248	425	348	641	583	1112	1010	2169
	9'-4"	50	72	154	282	248	524	348	789	584	1365	1013	2654
	10'-8"	50	86	154	338	248	631	348	947	584	1636	1013	3170
	12'-0"	50	102	154	398	248	745	348	1115	584	1923	1013	3718
8'-0"	6'-8"	65	47	219	182	344	383	482	585	824	1015	1415	1799
	8'-0"	65	59	220	231	346	485	486	739	833	1280	1438	2318
	9'-4"	65	72	221	282	347	594	486	903	835	1562	1442	2865
	10'-8"	65	86	221	338	347	710	486	1078	835	1861	1442	3436
	12'-0"	65	102	221	398	347	834	486	1263	835	2178	1442	4035
9'-4"	6'-8"	82	47	283	182	458	383	642	585	1112	1015	1902	1799
	8'-0"	82	59	285	231	461	485	647	739	1126	1280	1935	2318
	9'-4"	82	72	285	282	462	594	647	903	1128	1562	1941	2865
	10'-8"	82	86	285	338	462	710	647	1078	1128	1861	1941	3436
	12'-0"	82	102	285	398	462	834	647	1263	1128	2178	1941	4035
10'-8"	6'-8"	101	47	357	182	589	383	824	585	1433	1015	2454	1799
	8'-0"	101	59	358	231	592	485	831	739	1450	1280	2501	2318
	9'-4"	101	72	359	282	593	594	832	903	1453	1562	2509	2865
	10'-8"	101	86	359	338	593	710	832	1078	1453	1861	2509	3436
	12'-0"	101	102	359	398	593	834	832	1263	1453	2178	2509	4035
12'-0"	6'-8"	123	47	438	182	735	383	1028	585	1782	1015	3072	1799
	8'-0"	123	59	440	231	740	485	1037	739	1805	1280	3133	2318
	9'-4"	123	72	440	282	741	594	1038	903	1809	1562	3143	2865
	10'-8"	123	86	440	338	741	710	1038	1078	1809	1861	3143	3436
	12'-0"	123	102	440	398	741	834	1038	1263	1809	2178	3143	4035

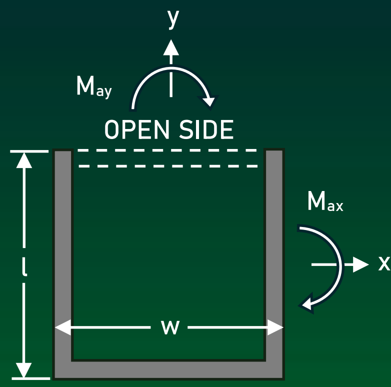
FAILURE MODE COLOR LEGEND:
(See Appendix A for explanation)

TENSION-CONTROLLED | COMPRESSION-CONTROLLED

1.1B MIN. HORIZONTAL REIN.

ALLOWABLE STRESS DESIGN

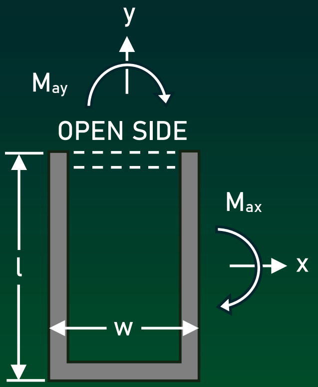
A minimum amount of horizontal reinforcement is required for the use of certain moment resistances provided in this guide due to concentrated shear stresses developed from flexure (See Appendix A for additional information). Moment resistances shown below correspond with those shown in Design Table 1.1A. A minimum reinforcement category (See Table 3) for horizontal reinforcement is shown to the right of each moment resistance when a minimum amount of horizontal reinforcement is required. Note that shear resistance of the section should still be checked against ultimate shear using Design Table 2.1.



Exterior dimensions		Vertical Steel per linear foot (in²/ft)								
l (ft-in)	w (ft-in)	0.028 – 0.100	0.101 – 0.200	0.201 – 0.300	0.301 – 500 M_{ax} (kip-ft)	0.301 – 500 M_{ay} (kip-ft)	0.501 – 0.900 M_{ax} (kip-ft)	0.501 – 0.900 M_{ay} (kip-ft)	0.901 – 1.185 M_{ax} (kip-ft)	0.901 – 1.185 M_{ay} (kip-ft)
	6'-8"							876 2		1737 5
	8'-0"							1112 3		2169 5
6'-8"	9'-4"	No minimum unless noted otherwise						1365 3		2654 5
	10'-8"							1636 3		3170 5
	12'-0"					1115 1		1923 3		3718 5
	6'-8"							1015 3	1415 1	1799 5
	8'-0"					739 1		1280 3	1438 2	2318 5
8'-0"	9'-4"	No minimum unless noted otherwise				903 1		1562 3	1442 2	2865 5
	10'-8"					1078 1		1861 3	1442 2	3436 6
	12'-0"					1263 2		2178 4	1442 2	4035 6
	6'-8"							1015 3	1902 2	1799 5
	8'-0"					739 1		1280 3	1935 2	2318 5
9'-4"	9'-4"	No minimum unless noted otherwise				903 1		1562 3	1941 2	2865 5
	10'-8"					1078 1		1861 3	1941 2	3436 6
	12'-0"					1263 2		2178 4	1941 2	4035 6
	6'-8"							1015 3	2454 2	1799 5
	8'-0"					739 1		1280 3	2501 3	2318 5
10'-8"	9'-4"	No minimum unless noted otherwise				903 1		1562 3	2509 3	2865 5
	10'-8"					1078 1		1861 3	2509 3	3436 6
	12'-0"					1263 2		2178 4	2509 3	4035 6
	6'-8"							1015 3	3072 3	1799 5
	8'-0"					739 1		1280 3	3133 3	2318 5
12'-0"	9'-4"	No minimum unless noted otherwise				903 1		1562 3	3143 3	2865 5
	10'-8"					1078 1		1861 3	3143 3	3436 6
	12'-0"					1263 2		2178 4	3143 3	4035 6

1.2A MOMENT – LONG C-SHAPE

ALLOWABLE STRESS DESIGN



The moment resistances shown on this page were calculated in accordance with the Allowable Stress Design provisions in TMS 402-22. M_{ax} is the total allowable flexural resistance of the building core (both walls) when moment is applied about the x-axis. M_{ay} is the total allowable flexural resistance of the building core when moment is applied about the y-axis. See Design Table 1.2B for minimum horizontal reinforcement.

Exterior dimensions		Vertical Steel per linear foot (in²/ft)											
		0.028 - 0.100		0.101 - 0.200		0.201 - 0.300		0.301 - 500		0.501 - 0.900		0.901 - 1.185	
l (ft-in)	w (ft-in)	M_{ax} (kip-ft)	M_{ay} (kip-ft)	M_{ax} (kip-ft)	M_{ay} (kip-ft)	M_{ax} (kip-ft)	M_{ay} (kip-ft)	M_{ax} (kip-ft)	M_{ay} (kip-ft)	M_{ax} (kip-ft)	M_{ay} (kip-ft)	M_{ax} (kip-ft)	M_{ay} (kip-ft)
16'-0"	9'-4"	199	72	736	282	1281	594	1790	903	3097	1562	5437	2865
	12'-0"	199	102	736	398	1281	834	1790	1263	3097	2178	5437	4035
	14'-8"	199	135	736	527	1281	1102	1790	1664	3097	2862	5437	5309
20'-0"	9'-4"	294	72	1106	282	1954	594	2735	903	4707	1562	8305	2865
	12'-0"	294	102	1106	398	1954	834	2735	1263	4707	2178	8305	4035
	14'-8"	294	135	1106	527	1954	1102	2735	1664	4707	2862	8305	5309
	17'-4"	294	173	1106	673	1954	1400	2735	2105	4707	3615	8305	6686
24'-0"	9'-4"	406	72	1550	282	2750	594	3869	903	6630	1562	11738	2865
	12'-0"	406	102	1550	398	2750	834	3869	1263	6630	2178	11738	4035
	14'-8"	406	135	1550	527	2750	1102	3869	1664	6630	2862	11738	5309
	17'-4"	406	173	1550	673	2750	1400	3869	2105	6630	3615	11738	6686
	20'-0"	406	215	1550	833	2750	1727	3869	2587	6630	4436	11738	8167
28'-0"	9'-4"	538	72	2067	282	3676	594	5188	903	8864	1562	15732	2865
	12'-0"	538	102	2067	398	3676	834	5188	1263	8864	2178	15732	4035
	14'-8"	538	135	2067	527	3676	1102	5188	1664	8864	2862	15732	5309
	17'-4"	538	173	2067	673	3676	1400	5188	2105	8864	3615	15732	6686
	20'-0"	538	215	2067	833	3676	1727	5188	2587	8864	4436	15732	8167
32'-0"	9'-4"	687	72	2655	282	4729	594	6693	903	11408	1562	20286	2865
	12'-0"	687	102	2655	398	4729	834	6693	1263	11408	2178	20286	4035
	14'-8"	687	135	2655	527	4729	1102	6693	1664	11408	2862	20286	5309
	17'-4"	687	173	2655	673	4729	1400	6693	2105	11408	3615	20286	6686
	20'-0"	687	215	2655	833	4729	1727	6693	2587	11408	4436	20286	8167

FAILURE MODE COLOR LEGEND:
(See Appendix A for explanation)

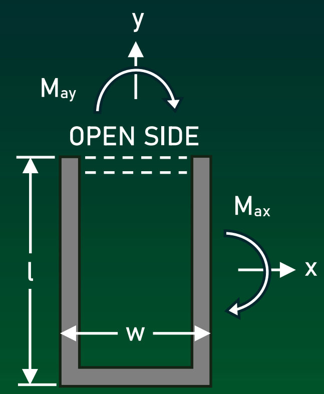
TENSION-CONTROLLED

COMPRESSION-CONTROLLED

1.2B MIN. HORIZONTAL REIN.

ALLOWABLE STRESS DESIGN

A minimum amount of horizontal reinforcement is required for the use of certain moment resistances provided in this guide due to concentrated shear stresses developed from flexure (See Appendix A for additional information). Moment resistances shown below correspond with those shown in Design Table 1.2A. A minimum reinforcement category (See Table 3) for horizontal reinforcement is shown to the right of each moment resistance when a minimum amount of horizontal reinforcement is required. Note that shear resistance of the section should still be checked against ultimate shear using Design Table 2.2.

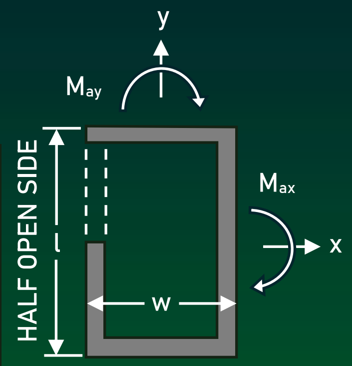


Exterior dimensions		Vertical Steel per linear foot (in²/ft)														
		0.028 - 0.100	0.101 - 0.200	0.201 - 0.300	0.301 - 500				0.501 - 0.900				0.901 - 1.185			
l (ft-in)	w (ft-in)				M_{ax} (kip-ft)		M_{ay} (kip-ft)		M_{ax} (kip-ft)		M_{ay} (kip-ft)		M_{ax} (kip-ft)		M_{ay} (kip-ft)	
16'-0"	9'-4"	No minimum unless noted otherwise					903	1	3097	2	1562	3	5437	4	2865	5
	12'-0"						1263	2	3097	2	2178	4	5437	4	4035	6
	14'-8"						1664	2	3097	2	2862	4	5437	4	5309	6
20'-0"	9'-4"	No minimum unless noted otherwise					903	1	4707	3	1562	3	8305	5	2865	5
	12'-0"						1263	2	4707	3	2178	4	8305	5	4035	6
	14'-8"						1664	2	4707	3	2862	4	8305	5	5309	6
	17'-4"						2105	2	4707	3	3615	4	8305	5	6686	6
24'-0"	9'-4"	No minimum unless noted otherwise			3869	1	903	1	6630	3	1562	3	11738	5	2865	5
	12'-0"				3869	1	1263	2	6630	3	2178	4	11738	5	4035	6
	14'-8"				3869	1	1664	2	6630	3	2862	4	11738	5	5309	6
	17'-4"				3869	1	2105	2	6630	3	3615	4	11738	5	6686	6
	20'-0"				3869	1	2587	2	6630	3	4436	5	11738	5	8167	6
28'-0"	9'-4"	No minimum unless noted otherwise			5188	2	903	1	8864	4	1562	3	15732	6	2865	5
	12'-0"				5188	2	1263	2	8864	4	2178	4	15732	6	4035	6
	14'-8"				5188	2	1664	2	8864	4	2862	4	15732	6	5309	6
	17'-4"				5188	2	2105	2	8864	4	3615	4	15732	6	6686	6
	20'-0"				5188	2	2587	2	8864	4	4436	5	15732	6	8167	6
32'-0"	9'-4"	No minimum unless noted otherwise			6693	2	903	1	11408	4	1562	3	20286	6	2865	5
	12'-0"				6693	2	1263	2	11408	4	2178	4	20286	6	4035	6
	14'-8"				6693	2	1664	2	11408	4	2862	4	20286	6	5309	6
	17'-4"				6693	2	2105	2	11408	4	3615	4	20286	6	6686	6
	20'-0"				6693	2	2587	2	11408	4	4436	5	20286	6	8167	6

1.3A MOMENT – G-SHAPE

ALLOWABLE STRESS DESIGN

The moment resistances shown on this page were calculated in accordance with the Allowable Stress Design provisions in TMS 402-22. M_{ax} is the total allowable flexural resistance of the building core (both walls) when moment is applied about the x-axis. M_{ay} is the total allowable flexural resistance of the building core (both walls) when moment is applied about the y-axis. See Design Table 1.3B for minimum horizontal reinforcement.



Exterior dimensions		Vertical Steel per linear foot (in²/ft)											
		0.028 - 0.100		0.101 - 0.200		0.201 - 0.300		0.301 - 500		0.501 - 0.900		0.901 - 1.185	
l (ft-in)	w (ft-in)	M_{ax} (kip-ft)	M_{ay} (kip-ft)	M_{ax} (kip-ft)	M_{ay} (kip-ft)	M_{ax} (kip-ft)	M_{ay} (kip-ft)	M_{ax} (kip-ft)	M_{ay} (kip-ft)	M_{ax} (kip-ft)	M_{ay} (kip-ft)	M_{ax} (kip-ft)	M_{ay} (kip-ft)
16'-0"	9'-4"	170	113	665	442	1371	844	2068	1245	3621	2183	6686	4162
	12'-0"	170	163	665	639	1371	1229	2068	1812	3621	3162	6986	5991
	14'-8"	170	221	665	866	1371	1675	2068	2465	3621	4284	7066	8071
20'-0"	9'-4"	228	113	894	442	1901	844	2846	1245	4969	2183	9292	4162
	12'-0"	228	163	894	639	1901	1229	2846	1812	4969	3162	9694	5991
	14'-8"	228	221	894	866	1901	1675	2846	2465	4969	4284	9711	8071
	17'-4"	228	287	894	1125	1901	2179	2846	3202	4969	5545	9711	10400
24'-0"	9'-4"	315	113	1236	442	2495	844	3790	1245	6587	2183	12242	4162
	12'-0"	315	163	1236	639	2495	1229	3790	1812	6587	3162	12680	5991
	14'-8"	315	221	1236	866	2495	1675	3790	2465	6587	4284	12680	8071
	17'-4"	315	287	1236	1125	2495	2179	3790	3202	6587	5545	12680	10400
	20'-0"	315	362	1236	1416	2495	2741	3790	4024	6587	6944	12680	12978
28'-0"	9'-4"	391	113	1532	442	3162	844	4773	1245	8278	2183	14692	4162
	12'-0"	391	163	1532	639	3162	1229	4773	1812	8278	3162	14883	5991
	14'-8"	391	221	1532	866	3162	1675	4773	2465	8278	4284	14994	8071
	17'-4"	391	287	1532	1125	3162	2179	4773	3202	8278	5545	15021	10400
	20'-0"	391	362	1532	1416	3162	2741	4773	4024	8278	6944	15021	12978
32'-0"	9'-4"	503	113	1965	442	3985	844	5939	1245	10268	2183	16612	4162
	12'-0"	503	163	1965	639	3985	1229	5939	1812	10268	3162	16846	5991
	14'-8"	503	221	1965	866	3985	1675	5939	2465	10268	4284	16991	8071
	17'-4"	503	287	1965	1125	3985	2179	5939	3202	10268	5545	17029	10400
	20'-0"	503	362	1965	1416	3985	2741	5939	4024	10268	6944	17029	12978

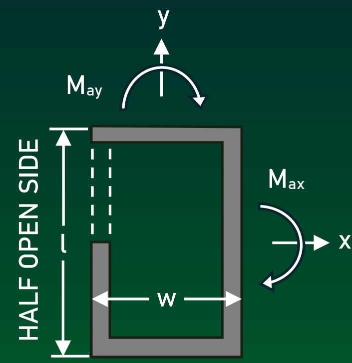
FAILURE MODE COLOR LEGEND:
(See Appendix A for explanation)

TENSION-CONTROLLED | COMPRESSION-CONTROLLED | SHEAR FLOW

1.3B MIN. HORIZONTAL REIN.

ALLOWABLE STRESS DESIGN

A minimum amount of horizontal reinforcement is required for the use of certain moment resistances provided in this guide due to concentrated shear stresses developed from flexure (See Appendix A for additional information). Moment resistances shown below correspond with those shown in Design Table 1.3A. A minimum reinforcement category (See Table 3) for horizontal reinforcement is shown to the right of each moment resistance when a minimum amount of horizontal reinforcement is required. Note that shear resistance of the section should still be checked against ultimate shear using Design Table 2.3.

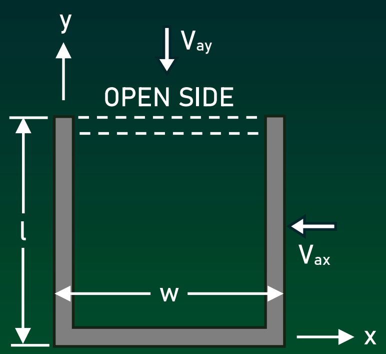


Exterior dimensions		Vertical Steel per linear foot (in²/ft)																			
l (ft-in)	w (ft-in)	0.028 - 0.100	0.101 - 0.200	0.201 - 0.300				0.301 - 500				0.501 - 0.900				0.901 - 1.185					
				M_{ax} (kip-ft)		M_{ay} (kip-ft)		M_{ax} (kip-ft)		M_{ay} (kip-ft)		M_{ax} (kip-ft)		M_{ay} (kip-ft)		M_{ax} (kip-ft)		M_{ay} (kip-ft)			
16'-0"	9'-4"	No minimum unless noted otherwise						2068	2			3621	5	2183	2	6686	6	4162	5		
	12'-0"							2068	2			3621	5	3162	3	6986	6	5991	5		
	14'-8"							2068	2			3621	5	4284	3	7066	6	8071	5		
20'-0"	9'-4"	No minimum unless noted otherwise		1901	1			2846	3			4969	5	2183	2	9292	6	4162	5		
	12'-0"			1901	1			2846	3			4969	5	3162	3	9694	6	5991	5		
	14'-8"			1901	1			2846	3			4969	5	4284	3	9711	6	8071	5		
	17'-4"			1901	1			2846	3	3202	1	4969	5	5545	3	9711	6	10400	5		
24'-0"	9'-4"	No minimum unless noted otherwise		2495	2			3790	3			6587	5	2183	2	12242	6	4162	5		
	12'-0"			2495	2			3790	3			6587	5	3162	3	12680	6	5991	5		
	14'-8"			2495	2			3790	3			6587	5	4284	3	12680	6	8071	5		
	17'-4"			2495	2			3790	3	3202	1	6587	5	5545	3	12680	6	10400	5		
	20'-0"			2495	2			3790	3	4024	2	6587	5	6944	4	12680	6	12978	6		
28'-0"	9'-4"	No minimum unless noted otherwise		3162	2			4773	3			8278	5	2183	2	14692	6	4162	5		
	12'-0"			3162	2			4773	3			8278	5	3162	3	14883	6	5991	5		
	14'-8"			3162	2			4773	3			8278	5	4284	3	14994	6	8071	5		
	17'-4"			3162	2			4773	3	3202	1	8278	5	5545	3	15021	6	10400	5		
	20'-0"			3162	2			4773	3	4024	2	8278	5	6944	4	15021	6	12978	6		
32'-0"	9'-4"	No minimum unless noted otherwise		3985	2			5939	4			10268	6	2183	2	16612	6	4162	5		
	12'-0"			3985	2			5939	4			10268	6	3162	3	16846	6	5991	5		
	14'-8"			3985	2			5939	4			10268	6	4284	3	16991	6	8071	5		
	17'-4"			3985	2			5939	4	3202	1	10268	6	5545	3	17029	6	10400	5		
	20'-0"			3985	2			5939	4	4024	2	10268	6	6944	4	17029	6	12978	6		

2.1 SHEAR - C-SHAPE

ALLOWABLE STRESS DESIGN

The shear resistances included in the table below were calculated in accordance with the Allowable Stress Design provisions in TMS 402-22. V_{ax} is the total allowable shear resistance of the building core when load is applied parallel to the x-axis. V_{ay} is the total allowable shear resistance of the building core (both walls) when load is applied parallel to the y-axis. Note that the vertical rein. ratio must be at least equal to one third of the horizontal rein. ratio as required by Section 8.3.5.2.2 of TMS 402-22.



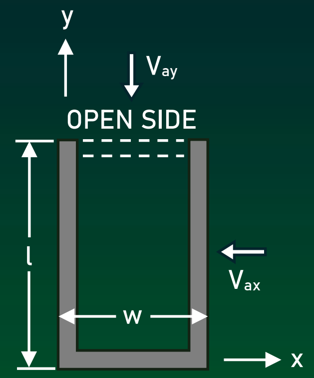
Exterior dimensions		Horizontal Steel per linear foot (in^2/ft)									
		No Rein.		0.028 – 0.100		0.101 – 0.200		0.201 – 0.300		0.301 – 0.500	
l (ft-in)	w (ft-in)	V_{ax} (kip)	V_{ay} (kip)	V_{ax} (kip)	V_{ay} (kip)	V_{ax} (kip)	V_{ay} (kip)	V_{ax} (kip)	V_{ay} (kip)	V_{ax} (kip)	V_{ay} (kip)
6'-8"	6'-8"	26	52	35	69	43	87	55	109	55	109
	8'-0"	31	52	42	69	52	87	65	109	65	109
	9'-4"	36	52	48	69	61	87	76	109	76	109
	10'-8"	41	52	55	69	69	87	87	109	87	109
	12'-0"	47	52	62	69	78	87	98	109	98	109
8'-0"	6'-8"	26	62	35	83	43	104	55	131	55	131
	8'-0"	31	62	42	83	52	104	65	131	65	131
	9'-4"	36	62	48	83	61	104	76	131	76	131
	10'-8"	41	62	55	83	69	104	87	131	87	131
	12'-0"	47	62	62	83	78	104	98	131	98	131
9'-4"	6'-8"	26	73	35	97	43	122	55	153	55	153
	8'-0"	31	73	42	97	52	122	65	153	65	153
	9'-4"	36	73	48	97	61	122	76	153	76	153
	10'-8"	41	73	55	97	69	122	87	153	87	153
	12'-0"	47	73	62	97	78	122	98	153	98	153
10'-8"	6'-8"	26	83	35	111	43	139	55	175	55	175
	8'-0"	31	83	42	111	52	139	65	175	65	175
	9'-4"	36	83	48	111	61	139	76	175	76	175
	10'-8"	41	83	55	111	69	139	87	175	87	175
	12'-0"	47	83	62	111	78	139	98	175	98	175
12'-0"	6'-8"	26	93	35	125	43	156	55	196	55	196
	8'-0"	31	93	42	125	52	156	65	196	65	196
	9'-4"	36	93	48	125	61	156	76	196	76	196
	10'-8"	41	93	55	125	69	156	87	196	87	196
	12'-0"	47	93	62	125	78	156	98	196	98	196

COLOR LEGEND: CALCULATED USING MASONRY AND STEEL CONTRIBUTIONS (EQ. 8-20 OF TMS 402-22)

LIMITED BY MASONRY STRENGTH (EQ. 8-22 OF TMS 402-22)

2.2 SHEAR – LONG C-SHAPE

ALLOWABLE STRESS DESIGN



The shear resistances included in the table below were calculated in accordance with the Allowable Stress Design provisions in TMS 402-22. V_{ax} is the total allowable shear resistance of the building core when load is applied parallel to the x-axis. V_{ay} is the total allowable shear resistance of the building core (both walls) when load is applied parallel to the y-axis. Note that the vertical rein. ratio must be at least equal to one third of the horizontal rein. ratio as required by Section 8.3.5.2.2 of TMS 402-22.

Exterior dimensions		Horizontal Steel per linear foot (in²/ft)									
		No Rein.		0.028 – 0.100		0.101 – 0.200		0.201 – 0.300		0.301 – 0.500	
l (ft-in)	w (ft-in)	V_{ax} (kip)	V_{ay} (kip)	V_{ax} (kip)	V_{ay} (kip)	V_{ax} (kip)	V_{ay} (kip)	V_{ax} (kip)	V_{ay} (kip)	V_{ax} (kip)	V_{ay} (kip)
16'-0"	9'-4"	36	124	48	166	61	208	76	262	76	262
	12'-0"	47	124	62	166	78	208	98	262	98	262
	14'-8"	57	124	76	166	96	208	120	262	120	262
20'-0"	9'-4"	36	155	48	208	61	261	76	327	76	327
	12'-0"	47	155	62	208	78	261	98	327	98	327
	14'-8"	57	155	76	208	96	261	120	327	120	327
	17'-4"	67	155	90	208	113	261	142	327	142	327
24'-0"	9'-4"	36	186	48	249	61	313	76	393	76	393
	12'-0"	47	186	62	249	78	313	98	393	98	393
	14'-8"	57	186	76	249	96	313	120	393	120	393
	17'-4"	67	186	90	249	113	313	142	393	142	393
	20'-0"	78	186	104	249	130	313	164	393	164	393
28'-0"	9'-4"	36	218	48	291	61	365	76	458	76	458
	12'-0"	47	218	62	291	78	365	98	458	98	458
	14'-8"	57	218	76	291	96	365	120	458	120	458
	17'-4"	67	218	90	291	113	365	142	458	142	458
	20'-0"	78	218	104	291	130	365	164	458	164	458
32'-0"	9'-4"	36	249	48	332	61	417	76	524	76	524
	12'-0"	47	249	62	332	78	417	98	524	98	524
	14'-8"	57	249	76	332	96	417	120	524	120	524
	17'-4"	67	249	90	332	113	417	142	524	142	524
	20'-0"	78	249	104	332	130	417	164	524	164	524

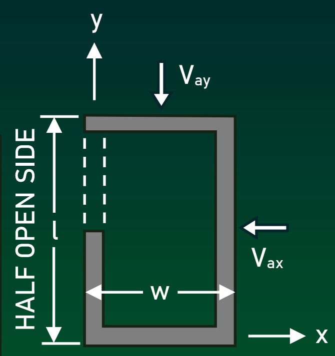
COLOR LEGEND:

CALCULATED USING MASONRY AND STEEL CONTRIBUTIONS (EQ. 8-20 OF TMS 402-22)

LIMITED BY MASONRY STRENGTH (EQ. 8-22 OF TMS 402-22)

2.3 SHEAR – G-SHAPE

ALLOWABLE STRESS DESIGN



The shear resistances included in the table below were calculated in accordance with the Allowable Stress Design provisions in TMS 402-22. V_{ax} is the total allowable shear resistance of the building core (both walls) when load is applied parallel to the x-axis. V_{ay} is the total allowable shear resistance of the building core (both walls) when load is applied parallel to the y-axis. Note that the vertical rein. ratio must be at least equal to one third of the horizontal rein. ratio as required by Section 8.3.5.2.2 of TMS 402-22.

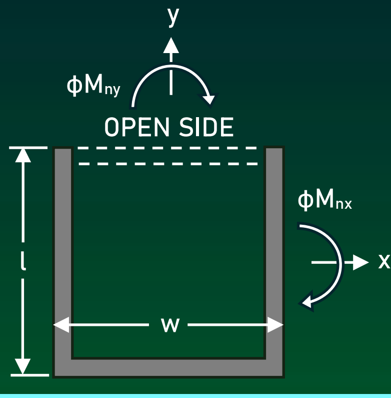
Exterior dimensions		Horizontal Steel per linear foot (in²/ft)									
		No Rein.		0.028 – 0.100		0.101 – 0.200		0.201 – 0.300		0.301 – 0.500	
l (ft-in)	w (ft-in)	V_{ax} (kip)	V_{ay} (kip)	V_{ax} (kip)	V_{ay} (kip)	V_{ax} (kip)	V_{ay} (kip)	V_{ax} (kip)	V_{ay} (kip)	V_{ax} (kip)	V_{ay} (kip)
16’-0”	9’-4”	76	81	101	108	126	134	159	169	160	171
	12’-0”	98	81	130	108	162	134	204	169	206	171
	14’-8”	119	81	159	108	198	134	249	169	252	171
20’-0”	9’-4”	76	101	101	135	126	168	159	212	160	214
	12’-0”	98	101	130	135	162	168	204	212	206	214
	14’-8”	119	101	159	135	198	168	249	212	252	214
	17’-4”	141	101	188	135	234	168	295	212	298	214
24’-0”	9’-4”	76	122	101	162	126	202	159	254	160	257
	12’-0”	98	122	130	162	162	202	204	254	206	257
	14’-8”	119	122	159	162	198	202	249	254	252	257
	17’-4”	141	122	188	162	234	202	295	254	298	257
	20’-0”	163	122	217	162	270	202	340	254	343	257
28’-0”	9’-4”	76	137	101	182	126	227	159	286	160	289
	12’-0”	98	142	130	189	162	235	204	297	206	300
	14’-8”	119	142	159	189	198	235	249	297	252	300
	17’-4”	141	142	188	189	234	235	295	297	298	300
	20’-0”	163	142	217	189	270	235	340	297	343	300
32’-0”	9’-4”	76	137	101	182	126	227	159	286	160	289
	12’-0”	98	162	130	216	162	269	204	339	206	342
	14’-8”	119	162	159	216	198	269	249	339	252	342
	17’-4”	141	162	188	216	234	269	295	339	298	342
	20’-0”	163	162	217	216	270	269	340	339	343	342

COLOR LEGEND: CALCULATED USING MASONRY AND STEEL CONTRIBUTIONS (EQ. 8-20 OF TMS 402-22)

LIMITED BY MASONRY STRENGTH (EQ. 8-22 OF TMS 402-22)

3.1A MOMENT – C-SHAPE

STRENGTH DESIGN



The moment resistances shown on this page were calculated in accordance with the Strength Design provisions in TMS 402-22. ϕM_{nx} is the total factored ultimate flexural resistance of the building core (both walls) when moment is applied about the x-axis. ϕM_{ny} is the total factored ultimate flexural resistance of the building core when moment is applied about the y-axis. See Design Table 3.1B for minimum horizontal reinforcement.

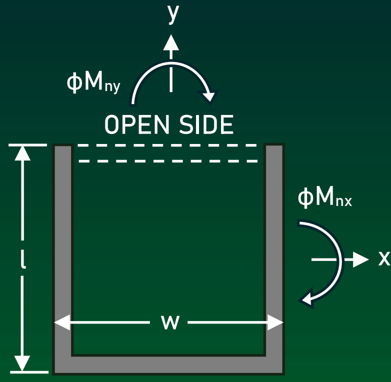
Exterior dimensions		Vertical Steel per linear foot (in²/ft)											
		0.028 – 0.100		0.101 – 0.200		0.201 – 0.300		0.301 – 500		0.501 – 0.900		0.901 – 1.185	
l (ft-in)	w (ft-in)	ϕM_{nx} (kip-ft)	ϕM_{ny} (kip-ft)	ϕM_{nx} (kip-ft)	ϕM_{ny} (kip-ft)	ϕM_{nx} (kip-ft)	ϕM_{ny} (kip-ft)	ϕM_{nx} (kip-ft)	ϕM_{ny} (kip-ft)	ϕM_{nx} (kip-ft)	ϕM_{ny} (kip-ft)	ϕM_{nx} (kip-ft)	ϕM_{ny} (kip-ft)
6'-8"	6'-8"	103	89	364	353	605	661	857	1011	1498	1776	2339	3235
	8'-0"	103	112	365	448	606	869	858	1313	1509	2306	2421	4244
	9'-4"	103	142	365	564	606	1095	858	1647	1511	2893	2495	5332
	10'-8"	103	173	365	691	606	1321	858	2012	1511	3535	2572	6429
	12'-0"	103	205	365	817	606	1613	858	2407	1511	4233	2638	7595
8'-0"	6'-8"	134	89	498	353	858	751	1215	1155	2124	2022	3305	3262
	8'-0"	134	112	498	448	859	971	1217	1489	2139	2608	3430	4252
	9'-4"	134	142	498	564	859	1214	1217	1853	2142	3251	3533	5331
	10'-8"	134	173	498	691	859	1471	1217	2249	2142	3948	3622	6540
	12'-0"	134	205	498	817	859	1757	1217	2676	2142	4699	3716	7846
9'-4"	6'-8"	177	89	662	353	1155	751	1635	1155	2857	2022	4422	3270
	8'-0"	177	112	663	448	1157	971	1637	1489	2879	2608	4586	4263
	9'-4"	177	142	663	564	1157	1214	1638	1853	2882	3251	4731	5345
	10'-8"	177	173	663	691	1157	1471	1638	2249	2882	3948	4854	6536
	12'-0"	177	205	663	817	1157	1757	1638	2676	2882	4699	4960	7844
10'-8"	6'-8"	225	89	840	353	1486	751	2117	1155	3691	2022	5694	3259
	8'-0"	225	112	841	448	1488	971	2120	1489	3727	2608	5895	4275
	9'-4"	225	142	841	564	1488	1214	2121	1853	3732	3251	6076	5360
	10'-8"	225	173	841	691	1488	1471	2121	2249	3732	3948	6241	6533
	12'-0"	225	205	841	817	1488	1757	2121	2676	3732	4699	6382	7842
12'-0"	6'-8"	272	89	1049	353	1875	751	2662	1155	4635	2022	7107	3244
	8'-0"	272	112	1050	448	1877	971	2666	1489	4681	2608	7357	4274
	9'-4"	272	142	1050	564	1878	1214	2667	1853	4689	3251	7575	5374
	10'-8"	272	173	1050	691	1878	1471	2667	2249	4689	3948	7776	6548
	12'-0"	272	205	1050	817	1878	1757	2667	2676	4689	4699	7961	7842

FAILURE MODE COLOR LEGEND: TENSILE RUPTURE | TENSILE | COMPRESSION | TRANSITION
(See Appendix A for explanation)

3.1B MIN. HORIZONTAL REIN.

STRENGTH DESIGN

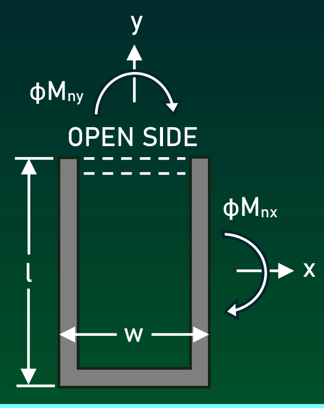
A minimum amount of horizontal reinforcement is required for the use of certain moment resistances provided in this guide due to concentrated shear stresses developed from flexure (See Appendix A for additional information). Moment resistances shown below correspond with those shown in Design Table 3.1A. A minimum reinforcement category (See Table 3) for horizontal reinforcement is shown to the right of each moment resistance when a minimum amount of horizontal reinforcement is required. Note that shear resistance of the section should still be checked against ultimate shear using Design Table 4.1.



Exterior dimensions l (ft-in)	Exterior dimensions w (ft-in)	Vertical Steel per linear foot (in²/ft): 0.028 - 0.100	0.101 - 0.200	0.201 - 0.300	0.301 - 500 ϕMnx (kip-ft)	0.301 - 500 ϕMny (kip-ft)	0.501 - 0.900 ϕMnx (kip-ft)	0.501 - 0.900 ϕMny (kip-ft)	0.901 - 1.185 ϕMnx (kip-ft)	0.901 - 1.185 ϕMny (kip-ft)
6'-8"	6'-8"							1776 3	2339 1	3235 5
	8'-0"							2306 3	2421 2	4244 5
	9'-4"	No minimum unless noted otherwise						2893 3	2495 2	5332 5
	10'-8"					2012 1		3535 3	2572 2	6429 5
	12'-0"					2407 1		4233 4	2638 2	7595 6
8'-0"	6'-8"							2022 3	3305 2	3262 5
	8'-0"							2608 3	3430 2	4252 5
	9'-4"	No minimum unless noted otherwise				1853 1		3251 4	3533 2	5331 5
	10'-8"					2249 2		3948 4	3622 2	6540 6
	12'-0"					2676 2		4699 4	3716 3	7846 6
9'-4"	6'-8"							2022 3	4422 3	3270 5
	8'-0"							2608 3	4586 3	4263 5
	9'-4"	No minimum unless noted otherwise				1853 1		3251 4	4731 3	5345 5
	10'-8"					2249 2		3948 4	4854 3	6536 6
	12'-0"					2676 2		4699 4	4960 3	7844 6
10'-8"	6'-8"						3691 1	2022 3	5694 3	3259 5
	8'-0"						3727 1	2608 3	5895 3	4275 5
	9'-4"	No minimum unless noted otherwise				1853 1	3732 1	3251 4	6076 3	5360 5
	10'-8"					2249 2	3732 1	3948 4	6241 3	6533 6
	12'-0"					2676 2	3732 1	4699 4	6382 3	7842 6
12'-0"	6'-8"						4635 2	2022 3	7107 3	3244 5
	8'-0"						4681 2	2608 3	7357 4	4274 5
	9'-4"	No minimum unless noted otherwise				1853 1	4689 2	3251 4	7575 4	5374 5
	10'-8"					2249 2	4689 2	3948 4	7776 4	6548 6
	12'-0"					2676 2	4689 2	4699 4	7961 4	7842 6

3.2A MOMENT – LONG C-SHAPE

STRENGTH DESIGN



The moment resistances shown on this page were calculated in accordance with the Strength Design provisions in TMS 402-22. ϕM_{nx} is the total factored ultimate flexural resistance of the building core (both walls) when moment is applied about the x-axis. ϕM_{ny} is the total factored ultimate flexural resistance of the building core when moment is applied about the y-axis. See Design Table 3.2B for minimum horizontal reinforcement.

Exterior dimensions		Vertical Steel per linear foot (in²/ft)											
		0.028 – 0.100		0.101 – 0.200		0.201 – 0.300		0.301 – 500		0.501 – 0.900		0.901 – 1.185	
l (ft-in)	w (ft-in)	ϕM_{nx} (kip-ft)	ϕM_{ny} (kip-ft)	ϕM_{nx} (kip-ft)	ϕM_{ny} (kip-ft)	ϕM_{nx} (kip-ft)	ϕM_{ny} (kip-ft)	ϕM_{nx} (kip-ft)	ϕM_{ny} (kip-ft)	ϕM_{nx} (kip-ft)	ϕM_{ny} (kip-ft)	ϕM_{nx} (kip-ft)	ϕM_{ny} (kip-ft)
16’-0”	9’-4”	458	142	1792	564	3254	1214	4677	1853	8208	3251	12968	5361
	12’-0”	458	205	1792	817	3254	1757	4677	2676	8208	4699	13595	7866
	14’-8”	458	282	1792	1122	3254	2378	4677	3622	8208	6327	14127	10681
20’-0”	9’-4”	690	142	2740	564	5005	1214	7131	1853	12702	3251	19699	5336
	12’-0”	690	205	2740	817	5005	1757	7131	2676	12702	4699	20579	7855
	14’-8”	690	282	2740	1122	5005	2378	7131	3622	12702	6327	21354	10681
	17’-4”	690	366	2740	1458	5005	3094	7131	4690	12702	8136	21527	13771
24’-0”	9’-4”	970	142	3864	564	7054	1214	10232	1853	17978	3251	27756	5353
	12’-0”	970	205	3864	817	7054	1757	10232	2676	17978	4699	28902	7846
	14’-8”	970	282	3864	1122	7054	2378	10232	3622	17978	6327	29930	10681
	17’-4”	970	366	3864	1458	7054	3094	10232	4690	17978	8136	30056	13771
	20’-0”	970	461	3864	1837	7054	3840	10232	5883	17978	10126	30056	17054
28’-0”	9’-4”	1297	142	5167	564	9527	1214	13899	1853	24068	3251	37142	5403
	12’-0”	1297	205	5167	817	9527	1757	13899	2676	24068	4699	38551	7841
	14’-8”	1297	282	5167	1122	9527	2378	13899	3622	24068	6327	39844	10681
	17’-4”	1297	366	5167	1458	9527	3094	13899	4690	24068	8136	39901	13771
	20’-0”	1297	461	5167	1837	9527	3840	13899	5883	24068	10126	39901	17054
32’-0”	9’-4”	1672	142	6608	564	12370	1214	18120	1853	30968	3251	47853	5433
	12’-0”	1672	205	6608	817	12370	1757	18120	2676	30968	4699	49535	7888
	14’-8”	1672	282	6608	1122	12370	2378	18120	3622	30968	6327	51056	10681
	17’-4”	1672	366	6608	1458	12370	3094	18120	4690	30968	8136	51056	13771
	20’-0”	1672	461	6608	1837	12370	3840	18120	5883	30968	10126	51056	17054

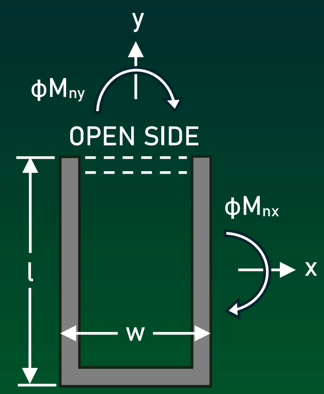
FAILURE MODE COLOR LEGEND: (See Appendix A for explanation)

TENSILE RUPTURE | TENSILE | COMPRESSION | TRANSITION

3.2B MIN. HORIZONTAL REIN.

STRENGTH DESIGN

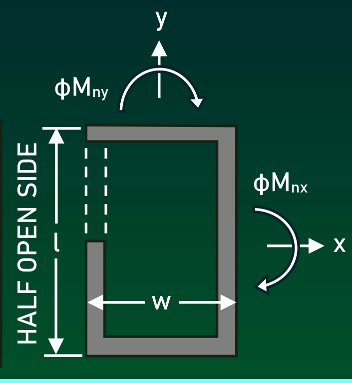
A minimum amount of horizontal reinforcement is required for the use of certain moment resistances provided in this guide due to concentrated shear stresses developed from flexure (See Appendix A for additional information). Moment resistances shown below correspond with those shown in Design Table 3.2A. A minimum reinforcement category (See Table 3) for horizontal reinforcement is shown to the right of each moment resistance when a minimum amount of horizontal reinforcement is required. Note that shear resistance of the section should still be checked against ultimate shear using Design Table 4.2.



Exterior dimensions		Vertical Steel per linear foot (in^2/ft)																	
l (ft-in)	w (ft-in)	0.028 - 0.100	0.101 - 0.200	0.201 - 0.300				0.301 - 500				0.501 - 0.900				0.901 - 1.185			
				ϕM_{nx} (kip-ft)		ϕM_{ny} (kip-ft)		ϕM_{nx} (kip-ft)		ϕM_{ny} (kip-ft)		ϕM_{nx} (kip-ft)		ϕM_{ny} (kip-ft)		ϕM_{nx} (kip-ft)		ϕM_{ny} (kip-ft)	
16'-0"	9'-4"	No minimum unless noted otherwise								1853	1	8208	3	3251	4	12968	5	5361	5
	12'-0"									2676	2	8208	3	4699	4	13595	5	7866	6
	14'-8"									3622	2	8208	3	6327	5	14127	5	10681	6
20'-0"	9'-4"	No minimum unless noted otherwise						7131	1	1853	1	12702	4	3251	4	19699	5	5336	5
	12'-0"							7131	1	2676	2	12702	4	4699	4	20579	5	7855	6
	14'-8"							7131	1	3622	2	12702	4	6327	5	21354	6	10681	6
	17'-4"							7131	1	4690	3	12702	4	8136	5	21527	6	13771	6
24'-0"	9'-4"	No minimum unless noted otherwise						10232	2	1853	1	17978	5	3251	4	27756	6	5353	5
	12'-0"							10232	2	2676	2	17978	5	4699	4	28902	6	7846	6
	14'-8"							10232	2	3622	2	17978	5	6327	5	29930	6	10681	6
	17'-4"							10232	2	4690	3	17978	5	8136	5	30056	6	13771	6
	20'-0"					3840	1	10232	2	5883	3	17978	5	10126	5	30056	6	17054	6
28'-0"	9'-4"	No minimum unless noted otherwise		9527	1			13899	3	1853	1	24068	5	3251	4	37142	6	5403	5
	12'-0"			9527	1			13899	3	2676	2	24068	5	4699	4	38551	6	7841	6
	14'-8"			9527	1			13899	3	3622	2	24068	5	6327	5	39844	6	10681	6
	17'-4"			9527	1			13899	3	4690	3	24068	5	8136	5	39901	6	13771	6
	20'-0"			9527	1	3840	1	13899	3	5883	3	24068	5	10126	5	39901	6	17054	6
32'-0"	9'-4"	No minimum unless noted otherwise		12370	2			18120	3	1853	1	30968	5	3251	4	47853	6	5433	5
	12'-0"			12370	2			18120	3	2676	2	30968	5	4699	4	49535	6	7888	6
	14'-8"			12370	2			18120	3	3622	2	30968	5	6327	5	51056	6	10681	6
	17'-4"			12370	2			18120	3	4690	3	30968	5	8136	5	51056	6	13771	6
	20'-0"			12370	2	3840	1	18120	3	5883	3	30968	5	10126	5	51056	6	17054	6

3.3A MOMENT – G-SHAPE

STRENGTH DESIGN



The moment resistances shown on this page were calculated in accordance with the Strength Design provisions in TMS 402-22. ϕM_{nx} is the total factored ultimate flexural resistance of the building core (both walls) when moment is applied about the x-axis. ϕM_{ny} is the total factored ultimate flexural resistance of the building core (both walls) when moment is applied about the y-axis. See Design Table 3.3B for minimum horizontal reinforcement.

Exterior dimensions		Vertical Steel per linear foot (in²/ft)											
		0.028 – 0.100		0.101 – 0.200		0.201 – 0.300		0.301 – 500		0.501 – 0.900		0.901 – 1.185	
l (ft-in)	w (ft-in)	ϕM_{nx} (kip-ft)	ϕM_{ny} (kip-ft)	ϕM_{nx} (kip-ft)	ϕM_{ny} (kip-ft)	ϕM_{nx} (kip-ft)	ϕM_{ny} (kip-ft)	ϕM_{nx} (kip-ft)	ϕM_{ny} (kip-ft)	ϕM_{nx} (kip-ft)	ϕM_{ny} (kip-ft)	ϕM_{nx} (kip-ft)	ϕM_{ny} (kip-ft)
16'-0"	9'-4"	389	231	1549	918	3171	1807	4786	2673	8434	4708	12133	7824
	12'-0"	389	341	1549	1360	3171	2700	4786	4034	8434	7054	12391	11800
	14'-8"	389	479	1549	1908	3171	3751	4786	5625	8434	9844	12583	16394
20'-0"	9'-4"	529	231	2107	918	4542	1807	6649	2673	11911	4708	17183	7824
	12'-0"	529	341	2107	1360	4542	2700	6649	4034	11911	7054	17599	11800
	14'-8"	529	479	2107	1908	4542	3751	6649	5625	11911	9844	17939	16394
	17'-4"	529	633	2107	2518	4542	4997	6649	7351	11911	13020	18077	21604
24'-0"	9'-4"	761	231	3033	918	6074	1807	9170	2673	16362	4708	22998	7824
	12'-0"	761	341	3033	1360	6074	2700	9170	4034	16362	7054	23575	11800
	14'-8"	761	479	3033	1908	6074	3751	9170	5625	16362	9844	24068	16394
	17'-4"	761	633	3033	2518	6074	4997	9170	7351	16362	13020	24285	21604
	20'-0"	761	807	3033	3213	6074	6392	9170	9416	16362	16550	24285	27411
28'-0"	9'-4"	949	231	3779	918	7712	1807	11775	2673	20861	4708	27924	7824
	12'-0"	949	341	3779	1360	7712	2700	11775	4034	20861	7054	28288	11800
	14'-8"	949	479	3779	1908	7712	3751	11775	5625	20861	9844	28497	16394
	17'-4"	949	633	3779	2518	7712	4997	11775	7351	20861	13020	28549	21604
	20'-0"	949	807	3779	3213	7712	6392	11775	9416	20861	16550	28549	27411
32'-0"	9'-4"	1252	231	4987	918	10006	1807	15053	2673	26391	4708	31574	7824
	12'-0"	1252	341	4987	1360	10006	2700	15053	4034	26391	7054	32018	11800
	14'-8"	1252	479	4987	1908	10006	3751	15053	5625	26391	9844	32294	16394
	17'-4"	1252	633	4987	2518	10006	4997	15053	7351	26391	13020	32365	21604
	20'-0"	1252	807	4987	3213	10006	6392	15053	9416	26391	16550	32365	27411

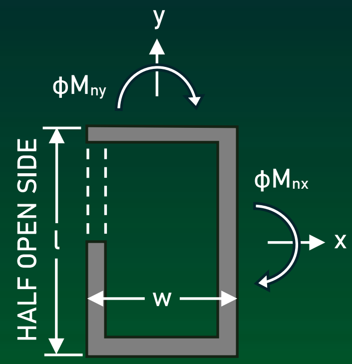
FAILURE MODE COLOR LEGEND:
(See Appendix A for explanation)

TENSILE RUPTURE | TENSILE | COMPRESSION | TRANSITION | SHEAR FLOW

3.3B MIN. HORIZONTAL REIN.

STRENGTH DESIGN

A minimum amount of horizontal reinforcement is required for the use of certain moment resistances provided in this guide due to concentrated shear stresses developed from flexure (See Appendix A for additional information). Moment resistances shown below correspond with those shown in Design Table 3.3A. A minimum reinforcement category (See Table 3) for horizontal reinforcement is shown to the right of each moment resistance when a minimum amount of horizontal reinforcement is required. Note that shear resistance of the section should still be checked against ultimate shear using Design Table 4.3.

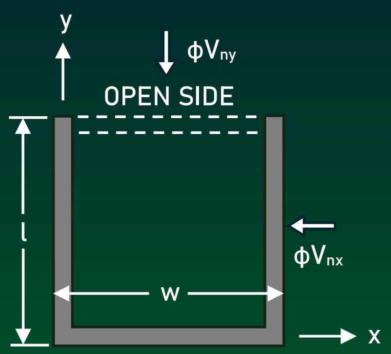


Exterior dimensions		Vertical Steel per linear foot (in²/ft)																	
l (ft-in)	w (ft-in)	0.028 - 0.100	0.101 - 0.200	0.201 - 0.300				0.301 - 500				0.501 - 0.900				0.901 - 1.185			
				ϕM_{nx} (kip-ft)		ϕM_{ny} (kip-ft)		ϕM_{nx} (kip-ft)		ϕM_{ny} (kip-ft)		ϕM_{nx} (kip-ft)		ϕM_{ny} (kip-ft)		ϕM_{nx} (kip-ft)		ϕM_{ny} (kip-ft)	
16'-0"	9'-4"	No minimum unless noted otherwise		3171	1			4786	3			8434	5	4708	2	12133	6	7824	5
	12'-0"			3171	1			4786	3			8434	5	7054	3	12391	6	11800	5
	14'-8"			3171	1			4786	3	5625	1	8434	5	9844	4	12583	6	16394	5
20'-0"	9'-4"	No minimum unless noted otherwise		4542	2			6649	3			11911	5	4708	2	17183	6	7824	5
	12'-0"			4542	2			6649	3			11911	5	7054	3	17599	6	11800	5
	14'-8"			4542	2			6649	3	5625	1	11911	5	9844	4	17939	6	16394	5
	17'-4"			4542	2			6649	3	7351	2	11911	5	13020	4	18077	6	21604	6
24'-0"	9'-4"	No minimum unless noted otherwise		6074	2			9170	4			16362	6	4708	2	22998	6	7824	5
	12'-0"			6074	2			9170	4			16362	6	7054	3	23575	6	11800	5
	14'-8"			6074	2			9170	4	5625	1	16362	6	9844	4	24068	6	16394	5
	17'-4"			6074	2			9170	4	7351	2	16362	6	13020	4	24285	6	21604	6
	20'-0"			6074	2			9170	4	9416	2	16362	6	16550	5	24285	6	27411	6
28'-0"	9'-4"	No minimum unless noted otherwise		7712	3			11775	5			20861	6	4708	2	27924	6	7824	5
	12'-0"			7712	3			11775	5			20861	6	7054	3	28288	6	11800	5
	14'-8"			7712	3			11775	5	5625	1	20861	6	9844	4	28497	6	16394	5
	17'-4"			7712	3			11775	5	7351	2	20861	6	13020	4	28549	6	21604	6
	20'-0"			7712	3			11775	5	9416	2	20861	6	16550	5	28549	6	27411	6
32'-0"	9'-4"	No minimum unless noted otherwise		10006	3			15053	5			26391	6	4708	2	31574	6	7824	5
	12'-0"			10006	3			15053	5			26391	6	7054	3	32018	6	11800	5
	14'-8"			10006	3			15053	5	5625	1	26391	6	9844	4	32294	6	16394	5
	17'-4"			10006	3			15053	5	7351	2	26391	6	13020	4	32365	6	21604	6
	20'-0"			10006	3			15053	5	9416	2	26391	6	16550	5	32365	6	27411	6

THE BEAUTY OF BLOCK CONCRETE MASONRY CHECKOFF

4.1 SHEAR – C-SHAPE

STRENGTH DESIGN



The shear resistances shown in the table below were calculated in accordance with the Strength Design provisions in TMS 402-22. ϕV_{nx} is the total factored ultimate shear resistance of the building core when load is applied parallel to the x-axis. ϕV_{ny} is the total factored ultimate shear resistance of the building core (both walls) when load is applied parallel to the y-axis. Note that the vertical rein. ratio must be at least equal to one-third of the horizontal rein. ratio as required by Section 9.3.5.2 of TMS 402-22.

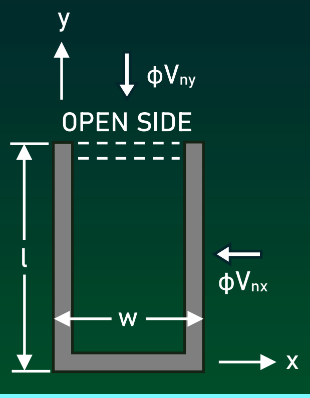
Exterior dimensions		Horizontal Steel per linear foot (in²/ft)									
		No Rein.		0.028 – 0.100		0.101 – 0.200		0.201 – 0.300		0.301 – 0.500	
l (ft-in)	w (ft-in)	ϕV_{nx} (kip)	ϕV_{ny} (kip)	ϕV_{nx} (kip)	ϕV_{ny} (kip)	ϕV_{nx} (kip)	ϕV_{ny} (kip)	ϕV_{nx} (kip)	ϕV_{ny} (kip)	ϕV_{nx} (kip)	ϕV_{ny} (kip)
6'-8"	6'-8"	50	100	55	109	68	135	85	171	87	175
	8'-0"	60	100	65	109	81	135	102	171	105	175
	9'-4"	70	100	76	109	95	135	119	171	122	175
	10'-8"	80	100	87	109	108	135	136	171	140	175
	12'-0"	90	100	98	109	122	135	154	171	157	175
8'-0"	6'-8"	50	120	55	131	68	162	85	205	87	210
	8'-0"	60	120	65	131	81	162	102	205	105	210
	9'-4"	70	120	76	131	95	162	119	205	122	210
	10'-8"	80	120	87	131	108	162	136	205	140	210
	12'-0"	90	120	98	131	122	162	154	205	157	210
9'-4"	6'-8"	50	140	55	153	68	190	85	239	87	244
	8'-0"	60	140	65	153	81	190	102	239	105	244
	9'-4"	70	140	76	153	95	190	119	239	122	244
	10'-8"	80	140	87	153	108	190	136	239	140	244
	12'-0"	90	140	98	153	122	190	154	239	157	244
10'-8"	6'-8"	50	160	55	174	68	217	85	273	87	279
	8'-0"	60	160	65	174	81	217	102	273	105	279
	9'-4"	70	160	76	174	95	217	119	273	122	279
	10'-8"	80	160	87	174	108	217	136	273	140	279
	12'-0"	90	160	98	174	122	217	154	273	157	279
12'-0"	6'-8"	50	180	55	196	68	244	85	307	87	314
	8'-0"	60	180	65	196	81	244	102	307	105	314
	9'-4"	70	180	76	196	95	244	119	307	122	314
	10'-8"	80	180	87	196	108	244	136	307	140	314
	12'-0"	90	180	98	196	122	244	154	307	157	314

COLOR LEGEND: CALCULATED USING MASONRY AND STEEL CONTRIBUTIONS (EQ. 9-15 OF TMS 402-22.)

LIMITED BY MASONRY STRENGTH (EQ. 9-17 OF TMS 402-22)

4.2 SHEAR – LONG C-SHAPE

STRENGTH DESIGN



The shear resistances shown in the table below were calculated in accordance with the Strength Design provisions in TMS 402-22. ϕV_{nx} is the total factored ultimate shear resistance of the building core when load is applied parallel to the x-axis. ϕV_{ny} is the total factored ultimate shear resistance of the building core (both walls) when load is applied parallel to the y-axis. Note that the vertical rein. ratio must be at least equal to one-third of the horizontal rein. ratio as required by Section 9.3.5.2 of TMS 402-22.

Exterior dimensions		Horizontal Steel per linear foot (in^2/ft)									
		No Rein.		0.028 – 0.100		0.101 – 0.200		0.201 – 0.300		0.301 – 0.500	
l (ft-in)	w (ft-in)	ϕV_{nx} (kip)	ϕV_{ny} (kip)	ϕV_{nx} (kip)	ϕV_{ny} (kip)	ϕV_{nx} (kip)	ϕV_{ny} (kip)	ϕV_{nx} (kip)	ϕV_{ny} (kip)	ϕV_{nx} (kip)	ϕV_{ny} (kip)
16'-0"	9'-4"	70	240	76	262	95	325	119	409	122	419
	12'-0"	90	240	98	262	122	325	154	409	157	419
	14'-8"	110	240	120	262	149	325	188	409	192	419
20'-0"	9'-4"	70	301	76	327	95	406	119	512	122	524
	12'-0"	90	301	98	327	122	406	154	512	157	524
	14'-8"	110	301	120	327	149	406	188	512	192	524
	17'-4"	130	301	142	327	176	406	222	512	227	524
24'-0"	9'-4"	70	361	76	392	95	487	119	614	122	629
	12'-0"	90	361	98	392	122	487	154	614	157	629
	14'-8"	110	361	120	392	149	487	188	614	192	629
	17'-4"	130	361	142	392	176	487	222	614	227	629
	20'-0"	150	361	164	392	203	487	256	614	262	629
28'-0"	9'-4"	70	421	76	458	95	569	119	717	122	733
	12'-0"	90	421	98	458	122	569	154	717	157	733
	14'-8"	110	421	120	458	149	569	188	717	192	733
	17'-4"	130	421	142	458	176	569	222	717	227	733
	20'-0"	150	421	164	458	203	569	256	717	262	733
32'-0"	9'-4"	70	481	76	523	95	650	119	819	122	838
	12'-0"	90	481	98	523	122	650	154	819	157	838
	14'-8"	110	481	120	523	149	650	188	819	192	838
	17'-4"	130	481	142	523	176	650	222	819	227	838
	20'-0"	150	481	164	523	203	650	256	819	262	838

COLOR LEGEND:

CALCULATED USING MASONRY AND STEEL CONTRIBUTIONS (EQ. 9-15 OF TMS 402-22)

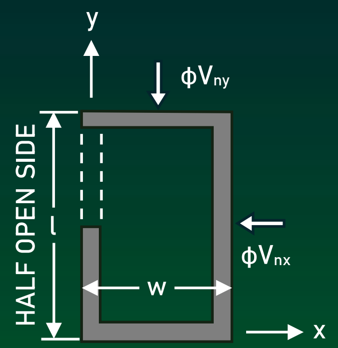
LIMITED BY MASONRY STRENGTH (EQ. 9-17 OF TMS 402-22)

THE BEAUTY OF BLOCK — CONCRETE MASONRY CHECKOFF

4.3 SHEAR – G-SHAPE

STRENGTH DESIGN

The shear resistances shown in the table below were calculated in accordance with the Strength Design provisions in TMS 402-22. ϕV_{nx} is the total factored ultimate shear resistance of the building core (both walls) when load is applied parallel to the x-axis. ϕV_{ny} is the total factored ultimate shear resistance of the building core (both walls) when load is applied parallel to the y-axis. Note that the vert. rein. ratio must be at least equal to one-third of the horiz. rein. ratio as required by Section 9.3.5.2 of TMS 402-22.



Exterior dimensions		Horizontal Steel per linear foot (in²/ft)									
		No Rein.		0.028 – 0.100		0.101 – 0.200		0.201 – 0.300		0.301 – 0.500	
l (ft-in)	w (ft-in)	ϕV_{nx} (kip)	ϕV_{ny} (kip)	ϕV_{nx} (kip)	ϕV_{ny} (kip)	ϕV_{nx} (kip)	ϕV_{ny} (kip)	ϕV_{nx} (kip)	ϕV_{ny} (kip)	ϕV_{nx} (kip)	ϕV_{ny} (kip)
16'-0"	9'-4"	149	157	161	170	198	210	248	262	256	274
	12'-0"	190	157	206	170	254	210	317	262	330	274
	14'-8"	231	157	251	170	309	210	386	262	403	274
20'-0"	9'-4"	150	196	163	213	200	262	249	328	256	342
	12'-0"	191	196	207	213	255	262	318	328	330	342
	14'-8"	233	196	252	213	310	262	388	328	403	342
	17'-4"	274	196	297	213	365	262	457	328	476	342
24'-0"	9'-4"	151	236	164	255	201	314	250	393	256	411
	12'-0"	193	236	209	255	256	314	319	393	330	411
	14'-8"	234	236	253	255	311	314	389	393	403	411
	17'-4"	275	236	298	255	367	314	458	393	476	411
	20'-0"	316	236	343	255	422	314	528	393	550	411
28'-0"	9'-4"	153	275	165	297	202	364	251	453	256	462
	12'-0"	194	275	210	298	257	367	321	459	330	479
	14'-8"	235	275	254	298	313	367	390	459	403	479
	17'-4"	276	275	299	298	368	367	459	459	476	479
	20'-0"	318	275	344	298	423	367	529	459	550	479
32'-0"	9'-4"	154	277	166	299	203	366	252	455	256	462
	12'-0"	195	314	211	340	258	419	322	525	330	548
	14'-8"	236	314	256	340	314	419	391	525	403	548
	17'-4"	277	314	300	340	369	419	461	525	476	548
	20'-0"	319	314	345	340	424	419	530	525	550	548

COLOR LEGEND:

CALCULATED USING MASONRY AND STEEL CONTRIBUTIONS (EQ. 9-15 OF TMS 402-22)

LIMITED BY MASONRY STRENGTH (EQ. 9-17 OF TMS 402-22)

APPENDIX A: CALCULATION NOTES

OMMITED DESIGN CHECKS

Design checks and effects that were not considered include:

- The checks required by TMS 402-22 for Intermediate or Special Reinforced Masonry Shear Walls were not conducted during the development of this guide. Therefore, the values included in this guide are suitable for Ordinary Reinforced Masonry Shear Wall Design only.
- Shear friction was not considered because axial load is unknown.
- P-delta effects were not considered because axial load is unknown.
- No calculations of deflection due to lateral loading were conducted because exact building core height is unknown.

SHEAR RESISTANCE CALCULATIONS

Shear resistances were calculated in accordance with Sections 8.3.5 and 9.3.5 of TMS 402-22 for allowable stress design and strength design, respectively. A phi factor of 0.80 was applied to all strength design shear resistances in accordance with Section 9.1.4.5 of TMS 402-22. Note that a compressive axial load was used to increase shear resistances and was calculated assuming a 10 ft total height of fully grouted concrete masonry with a self-weight of 75 psf as included in Table C3.1-1a of ASCE 7-22 for lightweight (105 pcf) fully grouted masonry with a nominal thickness of 8 inches.

The negative effect of torsion on shear resistance was considered for all building cores in this guide. This was necessary as the shapes of the building cores have centroids of rigidity that are off center in either one or both orthogonal directions. This often creates eccentricity between the assumed loading and the centroid of rigidity, which results in a torsional moment. Shear capacities were reduced as necessary to ensure that building core walls are not over stressed due to distribution of applied shear from this torsional moment.

MOMENT RESISTANCE CALCULATIONS

Moment resistances were calculated with consideration of multiple failure modes. A governing failure mode was identified for each building core configuration for both allowable stress design and strength design. The failure modes that were considered for each design methodology are described herein. The moment resistances of all applicable failure modes were calculated and the lowest is included in the design tables in this guide.

GENERAL ASSUMPTIONS

The following general assumptions apply for all moment resistance calculations:

- No axial compression from self-weight or loading was used to increase moment resistances.
- A minimum story height of 10 feet was assumed. This affects the effective tensile flange widths as described in Section 5.2.3 of TMS 402-22.

ALLOWABLE STRESS DESIGN

The design assumptions included in Section 8.3.2 of TMS 402-22 were used during the calculation of allowable stress design moment resistances. Moment resistances were calculated for each building core configuration considering two general failure modes: tension-controlled failure and compressive controlled-failure. Table A-1 shows the criteria for the applicability of these two failure modes.

Table A-1. Allowable stress design failure mode criteria.

Failure Mode	Maximum Tensile Steel Strain	Maximum Compressive Masonry Strain
Tension-Controlled Failure	$\varepsilon_s = 0.0011$[a]	$\varepsilon_m < 0.0005$[b]
Compression-Controlled Failure	$\varepsilon_s < 0.0011$[a]	$\varepsilon_m = 0.0005$[b]

[a]Equal to the maximum allowable steel strain provided in Section 8.3.3(b) of TMS 402-22 for grade 60 reinforcement. Corresponds to the strain in the steel at a tensile stress level of 32,000 psi when an elastic modulus of 29,000,000 psi is assumed.
[b]Equal to the maximum allowable masonry strain provided in Section 8.3.4.2.2 of TMS 402-22. Corresponds to the strain in the masonry at a compressive stress level of $0.45f'_m$ when an f'_m of 2,000 psi is assumed.

While compressive axial loading was not utilized to increase allowable stress design moment resistances, the negative effect of axial loading on moment resistance was considered using a compressive-controlled failure mode. This failure mode was considered to govern when the criteria for a compression-controlled failure mode were satisfied and the resulting moment resistance of the building core with a supplemental axial force was less than the moment resistance calculated for all other applicable failure modes. The axial force that was considered for allowable stress design was the product of 4,940 pounds multiplied by the perimeter length of a given building core in feet. This axial force was developed considering a section at the bottom of the building core with the following load contributions:

- 3,240 plf from self-weight of the masonry, considering a self-weight of 81 psf as included in Table C3.1-1a of ASCE 7-22 for normal weight (125 pcf) fully grouted masonry with a nominal thickness of 8 inches and a total height of 30 feet (typically associated with a three-story building height).
- 1,400 plf from two floors framing into the elevator/stair core (700 plf per floor).
- 300 plf from a roof framing into the elevator/stair core.

In addition to average shear due to applied lateral loads, concentrated shear stresses associated with bending are also present in building cores acting as cantilever beams. Since this guide takes advantage of flange behavior, the flow of stresses between the tensile and compressive flange elements can create a concentration of stresses in the web element due to the phenomenon generally described as “shear flow”. For simple rectangular shapes, the concentrated shear flow stresses at the centroid of the section are 50% more than the average shear stress, but for flanged sections, these concentrated shear flow stresses can be significantly higher than the average applied shear stress. Therefore, there are situations considered by this guide, especially with heavily-reinforced flanged shapes, where concentrated shear flow stresses exceed the shear strength of the unreinforced masonry and some minimum amount of shear reinforcing is required to resist the shear flow stresses. The minimum amount of horizontal reinforcement that is required to resist concentrated shear stresses was calculated, as needed, based on each moment resistance given in the design tables. The steps for calculating the minimum shear reinforcing required to account for concentrated shear flow stresses are described below:

1. An allowable masonry shear stress (in psi) for the masonry without any shear reinforcing was determined based on Section 8.2.6.2 of TMS 402-22 ($1.5\sqrt{f'_m}$). This value will, hereafter, be referred to as τ_m.
2. Using this τ_m value, the shear force (in pounds) that results in this shear flow stress was calculated based on the geometry of a given core section. This was done by rearranging the typical shear flow equation ($\Phi\tau_m=VQ/Ib$) to solve for V.
3. In order to calculate a bending moment value associated with this shear force, a “worst case” building geometry and lateral load distribution was assumed to relate flexure (M) and shear (V). This building geometry consisted of three levels with 10-foot-tall story heights. The lateral load was distributed to each of the levels according to tributary areas: 40% of the load to the second-floor diaphragm, 40% of the load to the third-floor diaphragm, and 20% of the load to the roof diaphragm. This results in a relationship between shear and moment as follows: M_m=(18’-0”)*V. Using this relationship, the calculated moment (M_m) is the maximum

moment that can be applied to a given section before the concentrated shear flow stresses exceed the factored shear capacity of the masonry alone (i.e., without any horizontal shear reinforcing).

4. In the moment capacity tables (Tables 3.1A, 3.2A, and 3.3A), the moment capacities shown for a given geometry (M_{ax} and M_{ay}) are then compared to the corresponding values of M_m for the same geometry and direction of loading. If the moment capacity in the table exceeds M_m, horizontal shear reinforcing is required in order to resist concentrated shear flow stresses.
5. In order to calculate the amount of horizontal reinforcing required to resist shear flow stresses, the difference between the moment capacities in the table (M_{ax} and M_{ay}) and the moment limit for unreinforced masonry shear flow (M_m) is calculated. We will refer to this difference as M_s, and it is the additional moment capacity for which the shear flow must be resisted by horizontal shear reinforcing steel.
6. Since shear flow stresses are a function of shear force rather than bending moment, we convert this value to a shear force, V_s, using the same conservative building geometry equation, where $V_s=M_s/(18'\text{-}0")$. V_s corresponds to the additional shear force required to be resisted by horizontal shear reinforcing steel in order to use the maximum moment capacities provided in the table.
7. Using the geometry of the core, this value of shear, V_s, can be converted to a shear flow stress τ_s using the typical shear flow equation: $\tau_s=V_sQ/Ib$. This shear flow stress, τ_s, can be considered the unit shear stress demand that must be resisted by horizontal reinforcing steel.
8. For the given bar sizes and spacing in each horizontal reinforcing category (Categories 1 through 6 shown in Tables 3 and 4 of this guide), a corresponding shear capacity (in psi) associated with the minimum steel reinforcing in each category can be calculated. This was done by multiplying the cross-sectional area of each bar by the allowable stress for steel (32,000 psi) then dividing by the effective area associated with each bar (spacing x thickness). Therefore, $\tau_{as}=A_sf_a/(s*t)$.
9. By comparing the shear stress reinforcing demand, τ_s, to the various options for shear reinforcing capacity, τ_{as}, an appropriate minimum horizontal reinforcing category can be selected that will allow the full moment capacities in the tables (M_{ax} and M_{ay}) to be used without concentrated shear flow stress failure.
10. In cases where the highest category of shear reinforcing used in this guide cannot provide sufficient shear flow resistance to use the full calculated moment capacities, the moment capacities in the table are reduced to the maximum moment capacities achievable with the highest shear reinforcing ratio considered in this guide (Category 6). Where this limit controls design, the table is marked in bright green, corresponding with the limit state identified as… SHEAR FLOW

STRENGTH DESIGN

The design assumptions included in Section 9.3.2 of TMS 402-22 were generally used during the calculation of strength design moment resistances. Moment resistances were calculated for each building core configuration considering five general failure modes: tensile rupture failure, tensile failure, transition failure, and compressive failure, and shear flow failure. Table A-2 shows the criteria for each failure mode and the respective phi factors that were applied to the calculated moment resistances in accordance with Table 9.1.4 of TMS 402-22.

Table A-2. Strength design failure mode criteria and phi factors.

Failure Mode	Maximum Steel Strain	Phi Factor
Tensile Rupture Failure	$0.07 = \varepsilon_s$	$\emptyset = 0.90$
Tensile Failure	$0.0051 < \varepsilon_s < 0.07$	$\emptyset = 0.90$
Transition Failure	$0.0021 \leq \varepsilon_s \leq 0.0051$	$0.65 \leq \emptyset \leq 0.90$
Compressive Failure	$\varepsilon_s < 0.0021$	$\emptyset = 0.65$
Shear Flow Failure	n/a	$\emptyset = 0.80$

Note that moment resistance calculations for the tensile rupture failure mode were conducted using a method that is alternative to that provided in TMS 402-22. For these calculations, the maximum steel strain was initially assumed to be 0.07. This assumption required an exception to be made to the design assumptions included in Section 9.3.2 of TMS 402-22: the masonry was assumed to exhibit linear elastic stress-strain behavior instead of using the commonly used compressive stress block. This was necessary as the limitation of maximum steel strain rendered the compressive stress block not applicable. The assumption of linear-elastic stress-strain behavior for the masonry was considered to be reasonable as the tensile rupture failure mode is, by definition, a tension-controlled failure mode. The masonry, therefore, is not assumed to experience compressive failure before the tensile steel yields. Note that the moment arm used for the calculation of moment resistance for this failure mode was multiplied by a factor of 0.909 to account for the relatively smaller moment arm that results from using a standard stress block as compared to a linear-elastic stress block. Also note that this calculation method is considered an alternative method, the use of moment resistances that were calculated using it, therefore, requires approval from the appropriate building official.

While compressive axial loading was not utilized to increase strength design moment resistances, the negative effect of axial loading on moment resistance was considered by applying a supplemental axial force. The axial force that was considered for strength design was the product of 6,378 pounds multiplied by the perimeter length of a given building core. This axial force was developed considering a section at the bottom of the building core with the following load contributions:

- 3,888 plf from self-weight of the masonry after applying a load factor of 1.2, considering a self-weight of 81 psf as included in Table C3.1-1a of ASCE 7-22 for normal weight (125 pcf) fully grouted masonry with a nominal thickness of 8 inches and a total height of 30 feet (typically associated with a three-story building height).
- 2,100 plf from two floors framing into the elevator/stair core (1,050 plf per floor). This was the result of considering 700 plf of unfactored load per floor and applying a load factor of 1.5.
- 390 plf from a roof framing into the elevator/stair core. This was the result of considering 300 plf of unfactored load from the roof and applying a load factor of 1.3.

Concentrated shear stresses associated with bending, as described in the previous section for Allowable Stress Design, were also considered for Strength Design. The minimum amount of horizontal reinforcement that is required to resist concentrated shear stresses was calculated, as needed, based on each moment resistance given in the design tables. The steps for calculating the minimum shear reinforcing required to account for concentrated shear flow stresses are described below:

1. A masonry shear strength (in psi) for the masonry without any shear reinforcing was determined based on Section 9.2.6 of TMS 402-22 ($3.8\sqrt{f'_m}$) with an applied phi factor of 0.80. This value will, hereafter, be referred to as $\Phi\tau_m$.
2. Using this $\Phi\tau_m$ value, the shear force (in pounds) that results in this shear flow stress was calculated based on the geometry of a given core section. This was done by rearranging the typical shear flow equation ($\Phi\tau_m=VQ/Ib$) to solve for V.
3. In order to calculate a bending moment value associated with this shear force, a "worst case" building geometry and lateral load distribution was assumed to relate flexure (M) and shear (V). This building geometry consisted of three levels with 10-foot-tall story heights. The lateral load was distributed to each of the levels according to tributary areas: 40% of the load to the second-floor diaphragm, 40% of the load to the third-floor diaphragm, and 20% of the load to the roof diaphragm. This results in a relationship between shear and moment as follows: M_m=(18'-0")*V. Using this relationship, the calculated moment (M_m) is the maximum moment that can be applied to a given section before the concentrated shear flow stresses exceed the factored shear capacity of the masonry alone (i.e., without any horizontal shear reinforcing).
4. In the moment capacity tables (Tables 3.1A, 3.2A, and 3.3A), the moment capacities shown for a given geometry (ϕM_{nx} and ϕM_{ny}) are then compared to the corresponding values of M_m for the same geometry and direction of loading. If the moment capacity in the table exceeds M_m, horizontal shear reinforcing is required in order to resist concentrated shear flow stresses.

5. In order to calculate the amount of horizontal reinforcing required to resist shear flow stresses, the difference between the moment capacities in the table (ϕM_{nx} and ϕM_{ny}) and the moment limit for unreinforced masonry shear flow (M_m) is calculated. We will refer to this difference as M_s, and it is the additional moment capacity for which the shear flow must be resisted by horizontal shear reinforcing steel.
6. Since shear flow stresses are a function of shear force rather than bending moment, we convert this value to a shear force, V_s, using the same conservative building geometry equation, where $V_s=M_s/(18'-0")$. V_s corresponds to the additional shear force required to be resisted by horizontal shear reinforcing steel in order to use the maximum moment capacities provided in the table.
7. Using the geometry of the core, this value of shear, V_s, can be converted to a shear flow stress τ_s using the typical shear flow equation: $\tau_s=V_sQ/Ib$. This shear flow stress, τ_s, can be considered the unit shear stress demand that must be resisted by horizontal reinforcing steel.
8. For the given bar sizes and spacing in each horizontal reinforcing category (Categories 1 through 6 shown in Tables 3 and 4 of this guide), a corresponding shear capacity (in psi) associated with the minimum steel reinforcing in each category can be calculated. This was done by multiplying the cross-sectional area of each bar by the yield strength of the bar and a phi factor of 0.8 then dividing by the effective area associated with each bar (spacing x thickness). Therefore, $\phi\tau_{ns}=\phi A_s f_y/(s*t)$.
9. By comparing the shear stress reinforcing demand, τ_s, to the various options for shear reinforcing capacity, $\phi\tau_{ns}$, an appropriate minimum horizontal reinforcing category can be selected that will allow the full moment capacities in the tables (ϕM_{nx} and ϕM_{ny}) to be used without concentrated shear flow stress failure.
10. In cases where the highest category of shear reinforcing used in this guide cannot provide sufficient shear flow resistance to use the full calculated moment capacities, the moment capacities in the table are reduced to the maximum moment capacities achievable with the highest shear reinforcing ratio considered in this guide (Category 6). Where this limit controls design, the table is marked in bright green, corresponding with the limit state identified as... SHEAR FLOW

APPENDIX B: SAMPLE CALCULATIONS

ASD C-Shape

Force Applied Parallel to 1-wall Direction

Assumptions:

Fully grouted walls
Perpendicular walls are sufficiently connected to act together to resist bending
Linear compressive stress-strain relationship
No tensile strength contributed by masonry

Applicable Codes:

TMS 402-22 - allowable stress design

Geometry:

Length	96	in	
Width	96	in	
Open Side	Width		
L_1	96	in	*length of 1-wall direction*
L_2	96	in	*length of 2-wall direction*
t_{CMU_n}	8	in	*nominal CMU thickness*
t_{CMU_a}	7.625	in	*actual CMU thickness*
h_f	10	ft	*floor-to-floor wall height*

Materials:

Masonry

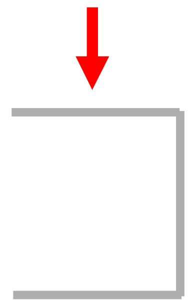
f'_m	2000	psi	
E_m	1800000	psi	*TMS 402 Table 4.2.2*
G	720000	psi	*TMS 402 Table 4.2.2*
γ_g	1.0		*grouted shear wall factor, TMS 402 Section 8.3.5.1.2*

Steel (Grade 60 reinforcement)

f_y	60	ksi	*yield stress*
E_s	29000	ksi	*modulus of elasticity*
e_{s_y}	0.0021		*yield strain*
f_{s_a}	32	ksi	*allowable stress, TMS 402 Section 8.3.3.1*
e_{s_a}	0.0011		*allowable strain*

Analysis:

Moment *Tension assumed to govern, no axial load*



<Tension

<Compression

Calculate effective compressive width

$6t_{CMU\_a}$	45.75	in	*TMS 402 Table 5.2.3*
$0.75h_f$	90	in	
$b_f = L_2 - t_{CMU\_n}/2$	92	in	*actual flange width*
$b_{f\_comp} = \min(6t_{CMU\_a}, b_f)$	45.75	in	effective compressive flange width
$b_{f\_tens} = \min(0.75h_f, b_f)$	90	in	effective tensile flange width
$b_{comp} = b_{f\_comp} + t_{CMU\_a}/2$	49.5625	in	*compressive zone width*
$b_{tens} = b_{f\_tens} + t_{CMU\_n}/2$	94	in	*tensile zone width*

Input vertical reinforcement spacing and bar size

Vertical reinforcement spacing	32	in	
Vertical reinforcing bar size (No.)	5		*area of 0.31 in^2*

Calculate number of bars in each wall

# bars in 1-wall direction	2	*excluding corner bars*
# bars in 2-wall direction	2	*excluding corner bars*

Vertical reinforcement calculations table

Number of Tension Level	Depth (in)*	# of Bars	Area of Steel (in^2)
1	92	3	0.93
2	60	1	0.31
3	28	1	0.31

*Tension bar depths minimized for most critical scenario

Vertical reinforcement calculations table

			Case A‡		
Number of Tension Level	Depth (in)*	# of Bars	Depth (in)†	Strain in bar (in/in)§	Force in level (kip)
1	92	3	92	0.0011	29.8
2	60	1	60	0.0007	6.1
3	28	1	28	0.0003	2.4

*Tension bar depths minimized for most critical scenario

†0 if in compressive zone

‡Case A is when the neutral axis depth is less than the block depth

§Maximum steel strain set to maximum allowable strain

$$e_{sn} = e_{s1}\frac{d_n - kd}{d_1 - kd} \qquad T_n = A_s E_s e_s$$

Calculate neutral axis depth

Case A				
n_{TL-1}		2		*number of tension levels minus one*
$\left(\sum d_n\right) - d_1$		88.0	in	*sum of bar depths minus the first*
$kd = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$	*a*	1.5		*NOTE: quadratic determined by equating C and T*
	b	1.6		
	c	-112.8		
kd		8.08	in	*neutral axis depth*
e_{m_max}		0.000106		*check maximum masonry strain*
C		38.25	kip	*compressive force*

If compressive depth exceeds actual CMU size

kd > actual CMU size?	Yes	*checks if the compressive depth is greater than the block depth*

Vertical reinforcement calculations table

Number of Tension Level	Depth (in)*	# of Bars	Case B[‡] Depth (in)[†]	Case B[‡] Strain in bar (in/in)[§]	Case B[‡] Force in level (kip)
1	92	3	92	0.0011	29.8
2	60	1	60	0.0007	6.1
3	28	1	28	0.0003	2.4

*Tension bar depths minimized for most critical scenario

[†]0 if in compressive zone

[‡]Case B is when the neutral axis depth is greater than the block depth

[§]Maximum steel strain set to maximum allowable strain

$$e_{sn} = e_{s1}\frac{d_n - kd}{d_1 - kd} \qquad T_n = A_s E_s e_s$$

Case B				
n_{TL-1}		2		*number of tension levels minus one*
$\left(\sum d_n\right) - d_1$		88.0	in	*sum of bar depths minus the first*
$kd = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$	*a*	6862500.0		*NOTE: quadratic determined by equating C and T*
	b	620542187.5		
	c	-5466805214.8		
kd		8.09	in	*neutral axis depth*
e_{m_max}		0.000106		*check maximum masonry strain*
C		38.25	kip	*compressive force*

Check masonry strain

Maximum allowable masonry strain	0.00050	*Section 8.3.4.2.2 of TMS 402-22*
Allowable > Calculated?	Yes	*therefore, tension governs*

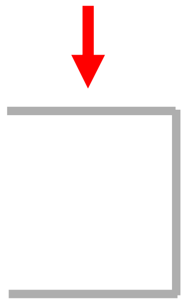
Check if compressive force is equal to tensile force

Total Compressive Force	38.3	kip
Total Tensile Force	38.3	kip

Calculate allowable moment

Correct Case	Case B		
Correct Neutral Axis Depth	8.09	in	
Moment Arm	80.2	in	*between centroids of tensile and compressive forces*
$M_{a1} = Tensile\ Force\ x\ Moment\ Arm$	**255.7**	**kip-ft**	***GOVERNS***

Moment *Compression assumed to govern, no axial load*



<Tension

<Compression

Calculate effective compressive width

$6t_{CMU\_a}$	45.75	in	*TMS 402 Table 5.2.3*
$0.75h_f$	90	in	
$b_f = L_2 - t_{CMU\_n}/2$	92	in	*actual flange width*
$b_{f\_comp} = \min(6t_{CMU\_a}, b_f)$	45.75	in	effective compressive flange width
$b_{f\_tens} = \min(0.75h_f, b_f)$	90	in	effective tensile flange width
$b_{comp} = b_{f\_comp} + t_{CMU\_a}/2$	49.5625	in	*compressive zone width*
$b_{tens} = b_{f\_tens} + t_{CMU\_n}/2$	94	in	*tensile zone width*

Input vertical reinforcement spacing and bar size

Vertical reinforcement spacing	32	in	
Vertical reinforcing bar size (No.)	5		*area of 0.31 in ^{2}*

Calculate number of bars in each wall

# bars in 1-wall direction	2	*excluding corner bars*
# bars in 2-wall direction	2	*excluding corner bars*

Vertical reinforcement calculations table

Number of Tension Level	Depth (in)*	# of Bars	Area of Steel (in^2)
1	92	3	0.93
2	60	1	0.31
3	28	1	0.31

*Tension bar depths minimized for most critical scenario

Vertical reinforcement calculations table

			Case A‡		
Number of Tension Level	Depth (in)*	# of Bars	Depth (in)†	Strain in bar (in/in)	Force in level (kip)
1	92	3	92	0.0052	140.1
2	60	1	60	0.0032	28.9
3	28	1	28	0.0012	11.1

*Tension bar depths minimized for most critical scenario

†0 if in compressive zone

‡Case A is when the neutral axis depth is less than the block depth

$$e_{sn} = e_{sm}\frac{d_n - kd}{kd} \qquad T_n = A_s E_s e_s$$

Calculate neutral axis depth

Case A			
n_{TL-1}	2		*number of tension levels minus one*
$\left(\sum d_n\right) - d_1$	88.0	in	*sum of bar depths minus the first*
$kd = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$	a 44606250.0		*NOTE: quadratic determined by equating C and T*
	b 44950000.0		
	c -3272360000.0		
kd	8.08	in	*neutral axis depth*
e_{s_max}	0.0052		*maximum steel strain*
C	180.12	kip	*compressive force*
T	180.12	kip	*tensile force*
Centroid of compressive force	5.38	in	*distance from neutral axis*

If compressive depth exceeds actual CMU size

kd > actual CMU size?	Yes	*checks if the compressive depth is greater than the block depth*

Vertical reinforcement calculations table

Number of Tension Level	Depth (in)*	# of Bars	Case B[‡] Depth (in)[†]	Case B[‡] Strain in bar (in/in)	Case B[‡] Force in level (kip)
1	92	3	92	0.0052	139.9
2	60	1	60	0.0032	28.9
3	28	1	28	0.0012	11.1

*Tension bar depths minimized for most critical scenario

[†]0 if in compressive zone

[‡]Case B is when the neutral axis depth is greater than the block depth

$$e_{sn} = e_{sm}\frac{d_n - kd}{kd} \qquad T_n = A_s E_s e_s$$

Case B				
n_{TL-1}		2		*number of tension levels minus one*
$\left(\sum d_n\right) - d_1$		88.0	in	*sum of bar depths minus the first*
$kd = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$	a	6862500.0		*NOTE: quadratic determined by equating C and T*
	b	620542187.5		
	c	-5466805214.8		
kd		8.09	in	*neutral axis depth*
e_{s_max}		0.0052		*maximum steel strain*
C		179.86	kip	*compressive force*
T		179.86	kip	*tension force*
Centroid of compressive force		3.07	in	*distance from neutral axis*

Maximum masonry strain

Maximum allowable masonry strain	0.00050	*Section 8.3.4.2.2 of TMS 402-22*

Check if compressive force is equal to tensile force

Total Compressive Force	179.9	kip
Total Tensile Force	179.9	kip

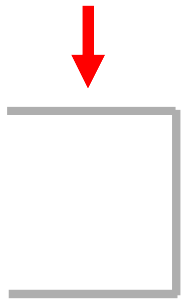
Check steel strain

Maximum allowable steel strain	0.0011	
Calculated steel strain at tension level 1	0.0052	
Calculated > Allowable?	Yes	*therefore, tension governs*

Calculate allowable moment

Correct Case	Case B		
Correct Neutral Axis Depth	8.09	in	
Moment Arm	77.9	in	*between centroids of tensile and compressive forces*
$M_{a1} = Tensile\ Force\ x\ Moment\ Arm$	**1167.8**	**kip-ft**	

Moment *Compression assumed to govern, with added axial load*



<Tension

<Compression

Compressive axial load at base of walls

P_u	158.1	kip	*compressive axial load*

Calculate effective compressive width

$6t_{CMU\_a}$	45.75	in	*TMS 402 Table 5.2.3*
$0.75h_f$	90	in	
$b_f = L_2 - t_{CMU\_n}/2$	92	in	*actual flange width*
$b_{f\_comp} = \min(6t_{CMU\_a}, b_f)$	45.75	in	effective compressive flange width
$b_{f\_tens} = \min(0.75h_f, b_f)$	90	in	effective tensile flange width
$b_{comp} = b_{f\_comp} + t_{CMU\_a}/2$	49.5625	in	*compressive zone width*
$b_{tens} = b_{f\_tens} + t_{CMU\_n}/2$	94	in	*tensile zone width*

Input vertical reinforcement spacing and bar size

Vertical reinforcement spacing	32	in	
Vertical reinforcing bar size (No.)	5		*area of 0.31 in ^{2}*

Calculate number of bars in each wall

# bars in 1-wall direction	2	*excluding corner bars*
# bars in 2-wall direction	2	*excluding corner bars*

Vertical reinforcement calculations table

Number of Tension Level	Depth (in)*	# of Bars	Area of Steel (in^2)
1	92	3	0.93
2	60	1	0.31
3	28	1	0.31

*Tension bar depths minimized for most critical scenario

Vertical reinforcement calculations table

			Case A‡		
Number of Tension Level	Depth (in)*	# of Bars	Depth (in)†	Strain in bar (in/in)	Force in level (kip)
1	92	3	92	0.0033	88.8
2	60	1	60	0.0020	17.7
3	28	1	28	0.0007	5.9

*Tension bar depths minimized for most critical scenario

†0 if in compressive zone

‡Case A is when the neutral axis depth is less than the block depth

$$e_{sn} = e_{sm}\frac{d_n - kd}{kd} \qquad T_n = A_s E_s e_s$$

Calculate neutral axis depth

Case A				
n_{TL-1}		2		*number of tension levels minus one*
$\left(\sum d_n\right) - d_1$		88.0	in	*sum of bar depths minus the first*
$kd = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$	a	44606250.0		*NOTE: quadratic determined by equating C and T*
	b	-271210000.0		
	c	-3272360000.0		
kd		12.13	in	*neutral axis depth*
e_{s_max}		0.0033		*maximum steel strain*
C		270.51	kip	*compressive force*
T+P		270.51	kip	*tension force plus axial load*
Centroid of compressive force		8.09	in	*distance from neutral axis*

If compressive depth exceeds actual CMU size

kd > actual CMU size?	Yes	*checks if the compressive depth is greater than the block depth*

Vertical reinforcement calculations table

			Case B‡		
Number of Tension Level	Depth (in)*	# of Bars	Depth (in)†	Strain in bar (in/in)	Force in level (kip)
1	92	3	92	0.0029	77.0
2	60	1	60	0.0017	15.2
3	28	1	28	0.0005	4.7

*Tension bar depths minimized for most critical scenario

†0 if in compressive zone

‡Case B is when the neutral axis depth is greater than the block depth

$$e_{sn} = e_{sm}\frac{d_n - kd}{kd} \qquad T_n = A_s E_s e_s$$

Case B				
n_{TL-1}		2		*number of tension levels minus one*
$\left(\sum d_n\right) - d_1$		88.0	in	*sum of bar depths minus the first*
$kd = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$	a	6862500.0		*NOTE: quadratic determined by equating C and T*
	b	304382187.5		
	c	-5466805214.8		
kd		13.72	in	*neutral axis depth*
e_{s_max}		0.0029		*maximum steel strain*
C		254.88	kip	*compressive force*
T+P		254.88	kip	*tension force plus axial load*
Centroid of compressive force		8.52	in	*distance from neutral axis*

Maximum masonry strain

Maximum allowable masonry strain	0.00050	*Section 8.3.4.2.2 of TMS 402-22*

Check if compressive force is equal to tensile force

Compressive Force	254.9	kip
T+P	254.9	kip

Check steel strain

Maximum allowable steel strain	0.0011	
Calculated steel strain at tension level 1	0.0029	
Calculated > Allowable?	Yes	therefore, tension governs

Calculate allowable moment

Correct Case	Case B		
Correct Neutral Axis Depth	13.72	in	
Moment Arm	78.7	in	*between centroids of tensile and compressive forces*
$M_{a1} = Tensile\ Force\ x\ Moment\ Arm$	**1671.5**	**kip-ft**	

Shear *(according to TMS 402-22)*

Calculate net shear area

b	7.625	in	*wall thickness*
d_v	96.0	in	*actual depth of wall in direction of shear*
A_{nv}	732	in^2	*net shear area*

Calculate maximum allowable shear stress

2*sqrt(f'$_m$)*γ_g	89.4	psi	*TMS 402 Section 8.3.5.1.2, for M/V*d_v > 1*

Calculate allowable shear stress resisted by masonry

h	10	ft	*height of masonry above section being analyzed*
w_m	75	psf	*ASCE 7-22, self-weight of fully grouted 8" thick llightweight CMU*
P	6.00	kip	*compressive axial force*
$F_{vm} = \frac{1}{2}\left[\left(4.0 - 1.75\left(\frac{M}{Vd_v}\right)\right)\sqrt{f'_m}\right] + 0.20\frac{P}{A_n} \geq 0$	52.0	psi	*TMS 402 Equation 8-23, assuming M/Vd_v = 1*

Calculate allowable shear stress resisted by steel

s	32	in	*vertical spacing of shear reinforcement*
Horizontal reinforcing bar size (No.)	5		
A_v	0.31	in^2	*Area of single reinforcing bar*
$F_{vs} = \frac{1}{2}\left[\frac{A_v F_s d_v}{A_{nv} s}\right]$	20.3	psi	*TMS 402 Equation 8-24*

Calculate allowable shear stress

Allowable masonry and steel shear stress	72.3	psi	
F_v	72.3	psi	

Check torsion for case with shear reinforcement

V_2	105.8	kip	shear resistance in two wall direction
$V_2/2$	52.9	kip	shear resistance of single wall in 2 wall direction
$\tau_{max} = 0.5V_2(0.5L_1 - 4\ in)$	2328.0	kip-in	moment from torsion that 2 wall direction can withstand
$e = 0.5L_1$	48	in	eccentricity of uniformly distributed load
$V_{1\_max} = 2\tau_{max}/e$	97.0	kip	maximum applied shear in 1 wall direction

Calculate allowable shear with reinforcement

number of walls in direction of shear	1	
$V_{a1} = \min(F_v A_{nv}, V_{1\_max})$	**52.9**	**kip**

Check torsion for case with no shear reinforcement

V_2	58.6	kip	shear resistance in two wall direction
$V_2/2$	29.3	kip	shear resistance of single wall in 2 wall direction
$\tau_{max} = 0.5V_2(0.5L_1 - 4\ in)$	1288.4	kip-in	moment from torsion that 2 wall direction can withstand
$e = 0.5L_1$	48	in	eccentricity of uniformly distributed load
$V_{1\_max} = 2\tau_{max}/e$	53.7	kip	maximum applied shear in 1 wall direction

Calculate maximum allowable shear stress with no reinforcement

1.5*sqrt(f'm)	67.1	psi	*TMS 402 Section 8.2.6.2(a)*
	120	psi	*TMS 402 Section 8.2.6.2(b)*
60+0.45*P/An	63.7	psi	*TMS 402 Section 8.2.6.2(c)*
F_{vm_un}	63.7	psi	*unreinforced masonry strength*

Calculate allowable shear with no reinforcement

$V_{a1} = \min((2/3)F_{vm\_un} A_{nv}, V_{1\_max})$	**31.1**	**kip**

Shear Flow Check

Geometric Properties (using effective flanges)

	Q_{max}	30418	in^3	*maximum first area moment of inertia, at centroid of section*
	I_g	2434152	in^4	*gross moment of inertia of entire section*
Concenctrated Shear Stress, $\tau = 1.5\sqrt{f'_m}$				*TMS 402-22 Section 8.2.6.2*
	τ_m	67	psi	*allowable masonry shear strength*
Shear Force, $\tau = \frac{VQ}{It} \longrightarrow V = \frac{\tau It}{Q}$				
	V	40.9	kips	*shear force that results in* τ_m
Critical height of building				
	h	18	ft	*multiply this height by shear force to get moment*
Maximum allowable moment				
	M_a	736.8	kips	*maximum allowable moment resisted by masonry alone*
Moment Comparison				
	M_m	736.8	kips	*maximum allowable moment resisted by masonry alone*
	M_a	255.7	kips	allowable moment resistance of section
	M_s	0.0	kips	difference between M_a and M_m, taken as 0 if $M_a < M_m$
		GOOD		no shear rein. required to resist concentrated shear stresses

SD C-Shape

Force Applied Parallel to 1-wall Direction

Assumptions:

Fully grouted walls
Perpendicular walls are sufficiently connected to act together to resist bending
No tensile strength contributed by masonry

Applicable Codes:

TMS 402-22 - strength design

Geometry:

Length	96	in	
Width	96	in	
Open Side	Width		
L_1	96	in	*length of 1-wall direction*
L_2	96	in	*length of 2-wall direction*
t_{CMU_n}	8	in	*nominal CMU thickness*
t_{CMU_a}	7.625	in	*actual CMU thickness*
h_f	10	ft	*floor-to-floor wall height*

Materials:

Masonry

f'_m	2000	psi	
$0.80f'_m$	1600	psi	*TMS 402 9.3.2, stress in flexural stress block*
e_{m_max}	0.0025		*TMS 402 9.3.2(c)*
E_m	1800000	psi	*TMS 402 Table 4.2.2*
G	720000	psi	*TMS 402 Table 4.2.2*
γ_g	1.0		*grouted shear wall factor, TMS 402 Section 9.3.3.1.2*

Steel (Grade 60 reinforcement)

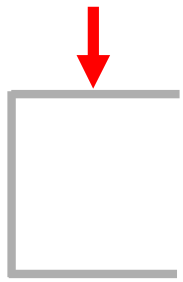
f_y	60	ksi	*yield stress*
E_s	29000	ksi	*modulus of elasticity*
e_{s_y}	0.0021		*yield strain*
e_{s_max}	0.0700		*From ACI deformed bar reference*

Analysis:

Strength Reduction Factors

Compression controlled failure	0.65	*TMS 402 Table 9.1.4*
Transition failure	$0.65 + 0.25\dfrac{\varepsilon_t - \varepsilon_{ty}}{0.003}$	*TMS 402 Table 9.1.4*
Tension-controlled failure	0.90	*TMS 402 Table 9.1.4*
Shear	0.80	*TMS 402 Section 9.1.4.5*

Moment *No axial load*



<Tension

<Compression

Calculate effective flange width

$6t_{CMU\_a}$	45.75	in	*TMS 402 Table 5.2.3*
$0.75h_f$	90	in	
$b_f = L_2 - t_{CMU\_n}/2$	92	in	*actual flange width*
$b_{f\_comp} = \min(6t_{CMU\_a}, b_f)$	45.75	in	effective compressive flange width
$b_{f\_tens} = \min(0.75h_f, b_f)$	90	in	effective tensile flange width
$b_{comp} = b_{f\_comp} + t_{CMU\_a}/2$	49.5625	in	*compressive zone width*
$b_{tens} = b_{f\_tens} + t_{CMU\_n}/2$	94	in	*tensile zone width*

Input vertical reinforcement spacing and bar size

Vertical reinforcement spacing	32	in	
Vertical reinforcing bar size (No.)	5		*area of 0.31 in^2*

Calculate number of bars in each wall

# bars in 1-wall direction	2	*excluding corner bars*
# bars in 2-wall direction	2	*excluding corner bars*

Vertical reinforcement calculations table

				c† (in) = 1.47	
Number of Tension Level	Depth (in)*	# of Bars	Area of Steel (in^2)	Strain in bar (in/in)	Force in level (kip)
1	92	3	0.93	0.1544	55.8
2	60	1	0.31	0.0998	18.6
3	28	1	0.31	0.0453	18.6

*Tension bar depths minimized for most critical scenario

†Iteration used to find neutral axis that corresponds with balancing forces

$$e_{sn} = e_{sm}\frac{d_n - kd}{kd}$$

$$T_n = A_s F_y$$

OR

$$T_n = A_s E_s e_s$$

T	93.0	kip	*total tensile force*
$a = 0.8c$	1.17	in	*depth of compressive block*
C	93.0	kip	*total compressive force*
T - C	0.0	kip	*tensile force minus compressive force*

Calculate ultimate moment

Centroid of Tensile Force	72.8	in	*from most compressive fiber*
Centroid of Compressive Force	0.6	in	*from most compressive fiber*
ε_{s_max}	15.4%		*maximum steel strain*
Ø	0.90		*TMS 402-22 Table 9.1.4, applicable phi factor*
$\emptyset M_{n1} = \emptyset\ x\ T\ x\ Moment\ Arm$	**503.7**	**kip-ft**	

If maximum steel strain is greater than 7% and, therefore, tensile rupture governs:

Note: Assume linear-elastic compressive behavior. Compressive and tensile strains, therefore, were found using similar triangles.

Vertical reinforcement calculations table

Number of Tension Level	Depth (in)*	# of Bars	Area of Steel (in^2)	$c^{\dagger}$ (in) = 1.64	
				Strain in bar (in/in)	Force in level (kip)
1	92	3	0.93	0.0700	55.8
2	60	1	0.31	0.0452	18.6
3	28	1	0.31	0.0204	18.6

*Tension bar depths minimized for most critical scenario

†Iteration used to find neutral axis that corresponds with balancing forces

‡Maximum steel strain set to 7%

$$e_{sn} = e_{s1}\frac{d_n - kd}{d_1 - kd}$$

$$T_n = A_s F_y$$

OR

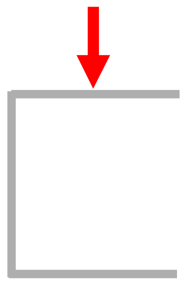
$$T_n = A_s E_s e_s$$

T	93.0	kip	*total tensile force*
ε_{m_max}	0.00127		*maximum compressive strain in masonry*
ε_{fs}	-0.00464		*compressive strain in face shell (positive is compression)*
C	93.0	kip	*total compressive force*
T - C	0.0	kip	*tensile force minus compressive force*

Calculate ultimate moment

Centroid of Tensile Force	72.8	in	*from most compressive fiber*
Centroid of Compressive Force	0.5	in	*from most compressive fiber*
Adjusted Centroid of Compressive Force	0.6	in	*from most compressive fiber*
ε_{s_max}	0.0700		*maximum steel strain*
Ø	0.90		*TMS 402-22 Table 9.1.4, applicable phi factor*
ε_{m_max}	0.0013		*check maximum masonry strain*
$\emptyset M_{n1} = \emptyset\ x\ T\ x\ Moment\ Arm$	**503.3**	**kip-ft**	***GOVERNS***

Moment *With added axial load*



<Tension

<Compression

Compressive axial load at base of walls

P_u	204.1	kip	*factored compressive axial load*

Calculate effective flange width

$6t_{CMU\_a}$	45.75	in	*TMS 402 Table 5.2.3*
$0.75h_f$	90	in	
$b_f = L_2 - t_{CMU\_n}/2$	92	in	*actual flange width*
$b_{f\_comp} = \min(6t_{CMU\_a}, b_f)$	45.75	in	effective compressive flange width
$b_{f\_tens} = \min(0.75h_f, b_f)$	90	in	effective tensile flange width
$b_{comp} = b_{f\_comp} + t_{CMU\_a}/2$	49.5625	in	*compressive zone width*
$b_{tens} = b_{f\_tens} + t_{CMU\_n}/2$	94	in	*tensile zone width*

Input vertical reinforcement spacing and bar size

Vertical reinforcement spacing	32	in	
Vertical reinforcing bar size (No.)	5		*area of 0.31 in^2*

Calculate number of bars in each wall

# bars in 1-wall direction	2	*excluding corner bars*
# bars in 2-wall direction	2	*excluding corner bars*

Vertical reinforcement calculations table

				c† (in) = 4.68	
Number of Tension Level	Depth (in)*	# of Bars	Area of Steel (in^2)	Strain in bar (in/in)	Force in level (kip)
1	92	3	0.93	0.0466	55.8
2	60	1	0.31	0.0295	18.6
3	28	1	0.31	0.0124	18.6

*Tension bar depths minimized for most critical scenario

†Iteration used to find neutral axis that corresponds with balancing forces

$$e_{sn} = e_{sm}\frac{d_n - kd}{kd}$$

$$T_n = A_s F_y$$

OR

$$T_n = A_s E_s e_s$$

T	297.1	kip	*total tensile force*
$a = 0.8c$	3.75	in	*depth of compressive block*
C	297.1	kip	*total compressive force*
T - C	0.0	kip	*tensile force minus compressive force*

Calculate ultimate moment

Centroid of Tensile Force	72.8	in	*from most compressive fiber*
Centroid of Compressive Force	1.9	in	*from most compressive fiber*
T+P	297.1	kip	
ε_{s_max}	0.0466		*maximum steel strain*
Ø	0.90		*TMS 402-22 Table 9.1.4, applicable phi factor*
$\emptyset M_{n1} = \emptyset\ x\ T\ x\ Moment\ Arm$	**1580.4**	**kip-ft**	

Shear *(according to TMS 402-22)*

Calculate net shear area

b	7.625	in	*wall thickness*
d_v	96.0	in	*actual depth of wall in direction of shear*
A_{nv}	732	in^2	*net shear area*

Calculate nominal masonry shear strength

h	10	ft	*height of masonry above section being analyzed*
w_m	75	psf	*ASCE 7-22, self-weight of fully grouted 8" thick llightweight CMU*
P	6.00	kip	*compressive axial force*
$V_{nm} = \left(4.0 - 1.75\left(\frac{M}{Vd_v}\right)\right)A_{nv}\sqrt{f'_m} + 0.25P_u \geq 0$	75156.1	lb	*TMS 402 Equation 9-18, assuming M/Vd_v = 1*

Calculate nominal shear strength provided by reinforcement

s	32	in	*vertical spacing of shear reinforcement*
Horizontal reinforcing bar size (No.)	5		
A_v	0.31	in2	*Area of single reinforcing bar*
$V_{ns} = 0.5\left[\frac{A_v}{s}\right]f_y d_v$	27900.0	lb	*TMS 402 Equation 9-19*

Check maximum spacing of shear reinforcement

8 feet	96	in	
Shear reinforcement spacing okay?	Yes		*If "No", then shear reinforcement spacing must be decreased*

Calculate nominal shear strength

$V_n = (V_{nm} + V_{ns})\gamma_g$	103056.1	lb	*TMS 402 Equation 9-15*
$V_n \leq \left(4A_{nv}\sqrt{f'_m}\right)\gamma_g$	130944.1	lb	*TMS 402 Equation 9-17, for M/Vd_v ≥ 1*

Check torsion for case with shear reinforcement

V_2	165.2	kip	shear resistance in two wall direction
$V_2/2$	82.6	kip	shear resistance of single wall in 2 wall direction
$\tau_{max} = 0.5V_2(0.5L_1 - 4\ in)$	3635.3	kip-in	moment from torsion that 2 wall direction can withstand
$e = 0.5L_1$	48	in	eccentricity of uniformly distributed load
$V_{1\_max} = 2\tau_{max}/e$	151.5	kip	maximum applied shear in 1 wall direction
number of walls in direction of shear	1		
$\text{Ø}V_{n1}$	**82.4**	**kip**	

Check torsion for case with no shear reinforcement

V_2	120.6	kip	shear resistance in two wall direction
$V_2/2$	60.3	kip	shear resistance of single wall in 2 wall direction
$\tau_{max} = 0.5V_2(0.5L_1 - 4\ in)$	2653.2	kip-in	moment from torsion that 2 wall direction can withstand
$e = 0.5L_1$	48	in	eccentricity of uniformly distributed load
$V_{1\_max} = 2\tau_{max}/e$	110.6	kip	maximum applied shear in 1 wall direction

Calculate allowable shear with no reinforcement

$\text{Ø}V_{n1}$	**60.1**	**kip**

Shear Flow Check

Geometric Properties (using effective flanges)

Q_{max}	30418	in^3	*maximum first area moment of inertia, at centroid of section*
I_g	2434152	in^4	*gross moment of inertia of entire section*

Concentrated Shear Stress, $\tau = 3.8\sqrt{f'_m}$ *TMS 402-22 Section 8.2.6.2*

τ_m	170	psi	*masonry shear strength*
Ø	0.80		*factor of safety for shear, TMS 402-22 Section 9.1.4.5*
$Ø\tau_m$	136		*factored masonry shear strength*

Shear Force, $\tau = \frac{VQ}{It} \longrightarrow V = \frac{\tau It}{Q}$

V	83.0	kips	*shear force that results in* $Ø\tau_m$

Critical height of building

h	18	ft	*multiply this height by shear force to get moment*

Maximum factored moment

M_m	1493.2	kips	*maximum factored moment resisted by masonry alone*

Moment Comparison

M_m	1493.2	kips	*maximum factored moment resisted by masonry alone*
$ØM_n$	503.3	kips	factored moment resistance of section
M_s	0.0	kips	difference between $ØM_n$ and M_m, taken as 0 if $ØM_n < M_m$
	GOOD		no shear rein. required to resist concentrated shear stresses