TMS Direct Design Handbook for Masonry Structures

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On any given night, there are countless Structural Engineers across the country sweating bullets as they scramble to complete their designs on schedule after numerous changes to the building have been made at the last minute by others, such as the Owner or Architect. This is when efficiency counts.

Yet, masonry wall systems sometimes require a rather complex analysis because they typically resist all forces in all directions at once, unlike simple beam and column systems that are often constructed with other materials. Furthermore, the building codes have become such a tangled web of cross-referenced provisions that, even with interaction diagrams or software programs, a great deal of time is required to design even the simplest of masonry elements.

For large, multi-story masonry projects, there is generally enough leeway in design fees to justify a full 3D analysis using software that incorporates a masonry design module, such as RAM. However, what about projects that cannot cover these costs?

TMS is the lead society of the Masonry Standards Joint Committee (TMS 402-08/ ACI 530-08/ASCE 5-08). In 2009, The Masonry Society (TMS) intends to publish the first *TMS Direct Design Handbook for Masonry Structures*.

Proposed Cover of the 1st Edition of the TMS Direct Design Handbook for Masonry Structures.

What is Direct Design?

The Direct Design Handbook is a structural design document that:

- Provides masonry designs that comply with 2006 IBC, ASCE 7-05, and 2005 MSJC Strength Design provisions.
- Provides a step-by-step procedure leading to a complete final design for all the masonry elements in the building.
- Intermediate calculations are included as part of the methodology and the included Tables. The handbook takes you from what you know, directly to what you need to know.

Who Should be Interested?

Virtually all calculations were performed in developing the Tables, using the established conditions of the Handbook which are written in terms non-Engineers would understand:

- Architects can use the Handbook to create preliminary designs that they can know with confidence will work.
- Structural Engineers can use the Handbook to reduce the time required for relatively simple construction so as to focus on complex issues that demand attention. In addition, the Handbook illustrates what should be economical and safe construction in any given area of the Country, when reviewing standards.
- Code Enforcement Officers can use the Handbook to efficiently review Structural drawings by comparing results.
- Masonry Contractors can use the Handbook to submit alternate designs to Structural Engineers for consideration.
- Educators can use the Handbook to teach the design process and give students the tools to design basic masonry buildings.

Where Does Direct Design Apply?

Direct Design applies to the vast majority of projects in the United States, for single-story, reinforced or unreinforced, concrete masonry structures with rectangular subdiaphragms.

The Handbook provides designs for various levels of each mapped parameter. This includes, for example, Basic Wind Speeds from 0 mph to 90 mph, 90 mph to 110 mph, 110 mph to 130 mph, and 130 mph to 150 mph. The Handbook also provides designs for various levels of seismic design parameters and ground snow loads.

The following is an Executive Summary of the conditions that must be met if the Direct Design Handbook is used:

Site Conditions

- Mapped Ground Snow Loads up to 60 psf.
- Mapped Basic Wind Speeds up to 150 mph.
- Mapped S_s up to 3.0g and Mapped S_1 up to 1.25g.

Architectural Conditions:

- Only single-story buildings.
- Simple, rectangular sub-diaphragms, bound by masonry on all sides.
- 200-foot maximum building dimension.
- Joist lengths up to 60 feet.
- Enclosed Building Classification.

Loading Conditions:

- Only Roof Dead, Roof Live, Snow, Wind, Seismic, Rain and Ice. No other loads.
- Dead Load: 2 psf minimum and 30 psf maximum.

Construction Conditions:

- Flexible Diaphragms.
- 8x8x16 CMU in running bond.
- #5 rebar only (if reinforced).

Modifications:

There are modifications provided in Chapter 4 of the Handbook to address many common specific conditions that do not meet the above criteria, providing alternate tables for those conditions.

Providing these alternate tables in a separate Chapter maintained as much simplicity as possible when using the basic procedure for the most common structures.

The Step-By-Step Procedure

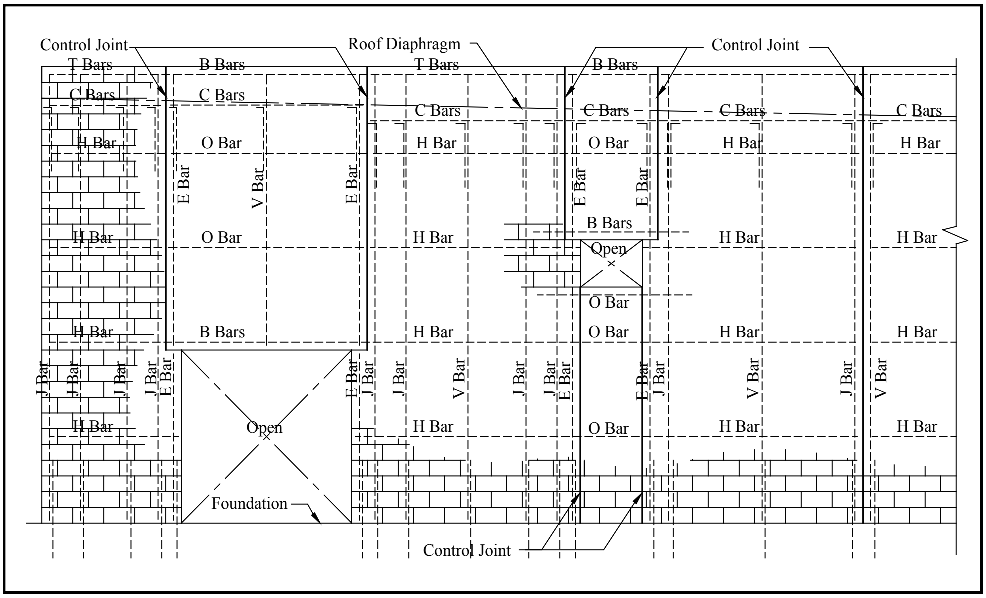
The following is an Executive Summary of the procedure in Chapter 3:

continued on next page

1) Gather information from IBC.
2) Create a preliminary layout, verifying Chapter 2 limitations.
3) Using Table A, Determine the Seismic Design Category.
4) Using Table B, determine which Lateral Force Resisting Systems are permitted.
5) In each principal plan direction, divide the roof into subdiaphragms and do the following:
   - 5a) Calculate the area of the building elevation.
   - 5b) Using Table C, obtain a Wind Response Coefficient, C_w.
   - 5c) Multiply C_w times A to determine the total lateral wind force.
   - 5d) Calculate the effective seismic weight per ASCE 7.
   - 5e) Using Table D, obtain a Seismic Response Coefficient, C_s.
   - 5f) Multiply C_s times W to determine the total lateral seismic force.
   - 5g) Determine the governing lateral load by comparing 5c & 5f, which account for the different load factors.
   - 5h) Using Tables E & F, determine the maximum spacing of vertical bars for axial and out of plane strength (wind and seismic.)
   - 5i) through k. Using Tables G & H, determine the maximum spacing of vertical and horizontal bars for each line of in-plane resistance. These Tables and Equations account for both flexural-based behavior and shear-based behavior.
   - 5l) Using Table I, determine the number of reinforced bond beams required for chord forces at the diaphragm boundaries.
6) Verify sufficient in-plane strengthat walls between multiple sub-diaphragms.
7 through 9) Using Tables J and K, detail header panels and sill panels.
10) Provide information on the plans that is required by the IBC.
11) Reference MSJC Specifications, providing mandatory requirements per Chapter 5.
12) Provide details from Chapter 6.

Example of Calculations

In the analyses used to develop Table E alone, to account for eccentric axial and out-of-plane wind loads, the following 16 steps were performed for each factored load combination, for the minimum and maximum values of each load case, to determine each critical value in the Table.



Reinforcement Legend referred to in the Handbook.

"V Bars" = Typical Vertical Bars
"H Bars" = Typical Horizontal Bars
"C Bars" = Horizontal Diaphragm Chord Bars
"J Bars" = Vertical Jamb Bars
"E Bars" = Vertical Edge Bars
"B Bars" = Horizontal Beam Bars
"O Bars" = Horizontal Opening Bars

This process includes a reinforced masonry model of arching action that relies on the horizontal reinforcement to act as a tension tie resisting the thrust of the flat arch, and vertical reinforcement to resist the combined thrust effect over the full height of the wall.

The tallest height was determined for the reinforced wall systems that satisfied the following 16 conditions.

Condition No. 1: The ratio of factored load to gross area, not the net area, is required by Section 3.3.5.4 of the 2005 MSJC Code to be less than 20% of the specified compressive strength of masonry, which as discussed in the Commentary for Section 2.4.2 was assumed to be 1500 lb/sq.in. (10.3 MPa).

Condition No. 2: The ratio of factored load to net area is required by Section 3.3.5.4 of the 2005 MSJC Code to be less than 5% of the specified compressive strength of masonry.

Condition No. 3: The factored axial load is required by Section 3.3.4.1.1 to be less than the nominal strength times a phi factor of 0.9.

Condition No. 4: The factored axial load and moment at the top of the wall are required to be within the permitted curve on a nominal moment-axial load capacity interaction diagram. This includes a tension check as well as compression check.

Condition No. 5: The factored axial load and moment at the middle of the wall, ignoring P-delta effects, are required to be within the permitted curve on a nominal moment-axial load capacity interaction diagram, accounting for phi.

Condition No. 6: A P-delta analysis was performed with 10 iterations, because the factored moment at the middle of the wall is required by Section 3.3.5 of the 2005 MSJC Code to be less than the nominal moment capacity times phi.

Condition No. 7: The out-of-plane deflection under service loads was determined based on service loads instead of factored loads by another P-delta analysis with 10 iterations, because the service deflection is required by Section 3.3.5.5 of the 2005 MSJC Code to be less than 0.007 times the vertical span of the wall.

Condition No. 8: The out-of-plane deflection under service load from the previous condition was also checked for cases with components and cladding wind loads to be less than 0.006 times the vertical span of the wall, because Section 1604.3.1 of the 2006 IBC requires that the out-of-plane deflection of such walls be limited to the vertical span divided by 240. Footnote (f) to Table 1604.3, referenced by Section 1604.3.1 of the 2006 IBC, permits determining the deflection by the components and cladding wind load times a 0.7 reduction factor. 1/240 further divided by 0.7 equals 0.006.

Condition No. 9: The factored shear at the top of the wall is required by Section 3.3.4.1.2.1 to be less than the nominal shear strength times a phi factor of 0.8. Note that the shear was checked at the top of the wall because there is less axial load, and less axial load will be associated with less nominal shear capacity. Note also that the value for P_u in Equation 3-21 was included regardless of whether this load was downward or upward (due to wind uplift). Also note that $M_u/(V_u d_v)$ in that same equation was taken as 1.0 as permitted by that section of the 2005 MSJC.

Condition No. 10: The area of reinforcement was compared to the maximum area of reinforcement permitted by Section 3.3.3.5.1 of the 2005 MSJC Code, which is also required for out-of-plane wall design by 3.3.3.5.2, 3.3.3.5.3, and 3.3.3.5.4. The lambda values for wind pressures in Exposure C Categories vary depending on building height according to Figure 6-2 and Figure 6-3 of ASCE 7. The above analyses were performed for each wall assuming they span 30 feet. Then, if the maximum span permitted was less than 30 feet, the analyses were re-performed with the lambda value associated with a building height equal to the maximum span permitted by the analysis. This process was based on the assumption that the bottom of the wall is at or very near the ground level. Structures where this is not the case, such as structures that are significantly elevated, should be evaluated independently.

Condition No. 11: For arching action between vertical bars, the tension was checked in the tie bars, assuming there is just one No. 5 taking 10 feet of tributary in-place thrust reaction, and assuming there are two discontinuous ends on each side of a panel that is as wide as the bar spacing (worst case).

Condition No. 12: For arching action, arch crushing of the masonry was checked.

Condition No. 13: With arching action taken into account, the tension in the vertical bars under biaxial bending and eccentric axial loading was checked using the conservative and simplifying interaction equation above.

Condition No. 14: The stability of the arch was checked to prevent snap-through buckling.

Condition No. 15: The out of plane deflection of the horizontal span (the flat arch) was checked against the 0.007 times the horizontal span. This is similar to the vertical span deflection check above.

Condition No. 16: If the wind is a components and cladding load, the out of plane deflection of the horizontal span (the flat arch) was checked against the serviceability check of 0.007 times the horizontal span. This is similar to the vertical span deflection check above.

Is This Referenced by Code?

Neither the 2009 IBC nor the 2009 IRC will reference the first edition of the TMS Direct Design Handbook for Masonry Structures.

However, TMS intends to submit the Standard as a deemed to comply manual for consideration for the 2012 IBC and the 2012 IRC, if it is completed in time.

When Can I Buy Direct Design?

The TMS Technical Activities Committee is currently reviewing this document. The document should be open for a Public Comment period in the summer of 2009.

The printed publication itself is scheduled to be available for purchase from TMS by the end of 2009. Watch TMS's website (**www.masonrysociety.org**) for details, updates, and availability.▪

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Wind V (mph)	Occupancy Category	Exposure Category	Maximum Ljoist (ft)	Unreinforced PCL Mortar				Unreinforced Masonry Cement Mortar				Vertical #5 at 120″ oc (S_{H1} = 120)		Vertical #5 at 96″ oc (S_{H1} = 120)		Vertical #5 at 72″ oc (S_{H1} = 120)		Vertical #5 at 48″ oc (S_{H1} = 120)		Vertical #5 at 32″ oc (S_{H1} = 120)		Vertical #5 at 24″ oc (S_{H1} = 120)		Vertical #5 at 16″ oc (S_{H1} = 120)		Vertical #5 at 8″ oc (S_{H1} = 120)	
				Ungrouted		Fully Grouted		Ungrouted		Fully Grouted		(S_{v1} = 120)		(S_{v1} = 96)		(S_{v1} = 72)		(S_{v1} = 48)		(S_{v1} = 32)		(S_{v1} = 24)		(S_{v1} = 16)		(S_{v1} = 8)	
				exterior	interior	exterior	interior	exterior	interior	exterior	interior	exterior	interior	exterior	interior	exterior	interior	exterior	interior	exterior	interior	exterior	interior	exterior	interior	exterior	interior
up to 90	I or II	B	no joist	9′4″	15′4″	18′0″	30′0″	7′4″	12′0″	17′4″	29′4″	10′0″	21′4″	10′0″	23′4″	16′8″	26′0″	20′8″	30′0″	22′8″	30′0″	24′8″	30′0″	27′4″	30′0″	NP	NP
			30	NP	NP	NP	NP	NP	NP	NP	NP	10′0″	11′4″	10′0″	12′8″	15′4″	14′8″	18′8″	20′0″	20′8″	20′0″	22′8″	20′0″	25′4″	24′0″	NP	NP
			60	NP	NP	NP	NP	NP	NP	NP	NP	10′0″	7′4″	10′0″	8′8″	14′0″	10′0″	16′8″	13′4″	19′4″	16′0″	20′0″	18′8″	NP	NP	NP	NP
		C	no joist	7′4″	15′4″	15′4″	30′0″	6′0″	12′0″	14′8″	29′4″	9′4″	21′4′	10′0″	23′4″	15′4″	26′0″	18′0″	30′0″	20′0″	30′0″	22′0″	30′0″	24′8″	30′0″	NP	NP
			30	NP	NP	NP	NP	NP	NP	NP	NP	9′4″	10′8″	10′0″	12′8″	14′8″	14′8″	17′4″	20′0″	19′4″	20′0″	20′8″	20′0″	23′4″	20′8″	NP	NP
			60	NP	NP	NP	NP	NP	NP	NP	NP	9′4″	NP	10′0″	8′8″	13′4″	10′0″	15′4″	13′4″	18′0″	16′0″	19′4″	18′8″	NP	NP	NP	NP
	III or IV	B	no joist	8′8″	15′4″	16′8″	30′0″	6′8″	12′0″	16′0″	29′4″	9′4″	21′4′	10′0″	23′4″	16′0″	26′0″	19′4″	30′0″	21′4″	30′0″	23′4″	30′0″	26′0″	30′0″	NP	NP
			30	NP	NP	NP	NP	NP	NP	NP	NP	9′4″	10′0″	10′0″	12′0″	14′8″	14′0″	17′4″	18′8″	20′0″	20′0″	21′4″	20′0″	24′0″	20′0″	NP	NP
			60	NP	NP	NP	NP	NP	NP	NP	NP	9′4″	NP	10′0″	8′0″	12′8″	9′4″	16′0″	12′0″	18′0″	14′8″	20′0″	16′8″	NP	NP	NP	NP
		C	no joist	8′0″	15′4″	14′0″	30′0″	5′4″	12′0″	13′4″	29′4″	8′8″	21′4″	10′0″	23′4″	14′8″	26′0″	17′4″	30′0″	19′4″	30′0″	20′8″	30′0″	23′4″	30′0″	NP	NP
			30	NP	NP	NP	NP	NP	NP	NP	NP	8′8″	10′0″	10′0″	11′4″	14′0″	14′0″	16′0″	18′8″	18′0″	20′0″	20′0″	20′0″	22′0″	20′0″	NP	NP
			60	NP	NP	NP	NP	NP	NP	NP	NP	8′8″	NP	10′0″	NP	12′0″	9′4″	14′8″	12′0″	16′8″	14′8″	18′8″	16′8″	NP	NP	NP	NP
91 to 110	I or II	B	no joist	7′4″	14′0″	14′8″	28′0″	6′0″	10′8″	14′0″	26′8″	8′8″	20′0″	10′0″	22′0″	10′0″	24′0″	17′4″	28′0″	19′4″	30′0″	21′4″	30′0″	24′0″	30′0″	NP	NP
			30	NP	NP	NP	NP	NP	NP	NP	NP	8′8″	10′8″	10′0″	12′8″	10′0″	14′8″	16′0″	18′8″	16′0″	18′8″	18′0″	20′0″	22′8″	20′0″	NP	NP
			60	NP	NP	NP	NP	NP	NP	NP	NP	8′0″	NP	10′0″	NP	10′0″	10′0″	14′8″	12′8″	17′4″	15′4″	18′8″	18′0″	NP	NP	NP	NP
		C	no joist	6′0″	14′0″	12′0″	28′0″	4′8″	10′8″	12′0″	26′8″	7′4″	20′0″	9′4″	22′0″	10′0″	24′0″	15′4″	28′0″	18′0″	30′0″	19′4″	30′0″	21′4″	30′0″	NP	NP
			30	NP	NP	NP	NP	NP	NP	NP	NP	7′4″	10′8″	9′4″	12′8″	10′0″	14′8″	15′4″	18′8″	16′8″	20′0″	18′0″	20′0″	20′0″	20′0″	NP	NP
			60	NP	NP	NP	NP	NP	NP	NP	NP	6′0″	NP	8′8″	NP	10′0″	NP	14′0″	12′8″	16′0″	15′4″	17′4″	18′0″	NP	NP	NP	NP
	III or IV	B	no joist	6′8″	14′0″	13′4″	28′0″	5′4″	10′8″	13′4″	26′8″	8′0″	20′0″	10′0″	22′0″	10′0″	24′0″	16′0″	28′0″	18′8″	30′0″	20′0″	30′0″	22′8″	30′0″	NP	NP
			30	NP	NP	NP	NP	NP	NP	NP	NP	8′0″	10′0″	10′0″	11′4″	10′0″	14′0″	15′4″	18′0″	17′4″	20′0″	18′8″	20′0″	21′4″	20′0″	NP	NP
			60	NP	NP	NP	NP	NP	NP	NP	NP	6′8″	NP	8′8″	NP	10′0″	NP	14′0″	11′4″	16′0″	14′8″	17′4″	16′8″	NP	NP	NP	NP
		C	no joist	6′0″	14′0″	11′4″	28′0″	4′8″	10′8″	11′4″	26′8″	7′4″	20′0″	8′8″	22′0″	10′0″	24′0″	14′8″	28′0″	16′8″	30′0″	18′0″	30′0″	20′0″	30′0″	NP	NP
			30	NP	NP	NP	NP	NP	NP	NP	NP	7′4″	NP	8′8″	11′4″	10′0″	14′0″	14′8″	18′0″	16′0″	20′0″	17′4″	20′0″	19′4″	20′0″	NP	NP
			60	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	6′8″	NP	10′0″	NP	13′4″	11′4″	14′8″	14′0″	16′0″	16′8″	NP	NP	NP	NP

An Example of one of the Tables in the Handbook. This is part of Table E, providing maximum vertical spans for walls without openings, accounting for axial and out-of-plane forces under all load combinations except seismic. The Seicmic combinations are addressed in Table F.