J.B. SPEED SCHOOL OF ENGINEERING

Tips to Optimize Structural Masonry

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MASONRY SEMINAR
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From IMI Seminar

MIH

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Learning Objectives

- Understand interrelationship between masonry materials, architecture, engineering, and construction.
- Learn how a few simple decisions can lead to more efficient and economical structures.
- Discover some non-traditional structural masonry materials and systems.
- Apply code, specification and standards provisions appropriately.

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What is Structural Masonry?

Using masonry for the building's structural support

- Bearing walls
- Shear walls
- Combination bearing & shear
- Structural cores for stairs, shafts, etc.
- Hybrid

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Why Structural Masonry?

- Versatile structural system
- Fast, efficient & economical
- Masonry may be on the project already – use it structurally!

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Why Structural Masonry?

- Finish trade – so tighter tolerances are held
- No lead time for production, review and approval of shop drawings
- Adapts easily to field changes –

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Why Structural Masonry?

- Local materials, local employment
- Using material efficiently – one material for structure, finish, fire resistances, blast resistance, sheltering and more
- Masonry is ‘green’
- And it looks good too!

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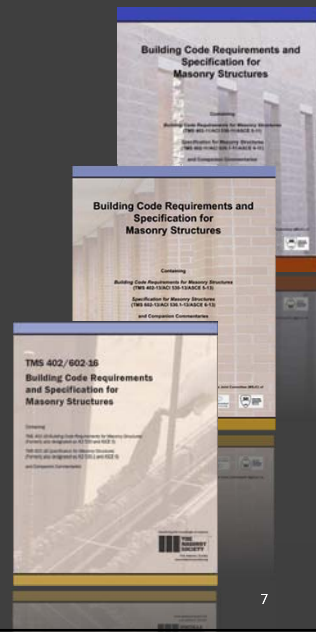
Tip – Select the correct Code edition

TMS 402-11 /ACI 530-11 /ASCE 5-11
TMS 402-13 /ACI 530-13 /ASCE 5-13
TMS 402-16
Building Code Requirements for Masonry Structures

TMS 602-11 /ACI 530.1-11/ASCE 6-11
TMS 602-13 /ACI 530.1-13/ASCE 6-13
TMS 602-16
Specification for Masonry Structures

Commentary for each
Non-mandatory



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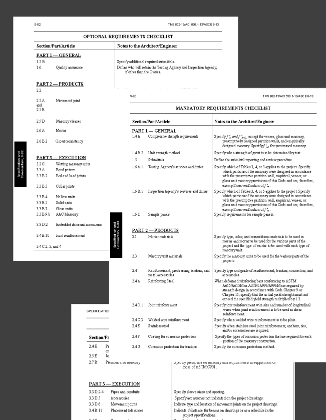
Tip – Use the TMS 402/602 Checklists

- TMS 402/602 Checklists
  - Look at the end of the Specification
  - Assistance to A/E in selecting and specifying project requirements in the Project Specification.
  - Identify areas where adjustments to the Specification must be made to meet the needs of a specific project.
- 2 Checklists
  - Mandatory Requirements Checklist
  - Optional Requirements Checklist



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Mandatory Requirements Checklist

- Items that MUST be included in Project Specifications.

Example:

The required compressive strength of masonry for the specific project must be specified by the architect/engineer for structural masonry.

MANDATORY REQUIREMENTS CHECKLIST

Section/Part/Article	Notes to the Architect/Engineer
PART 1 — GENERAL 1.4 A Compressive strength requirements	Specify f'_m and f'_{AAC}, except for veneer, glass unit masonry, prescriptively designed partition walls, and empirically designed masonry. Specify f'_{mi} for prestressed masonry.

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Optional Requirements Checklist

- Items that the A/E MAY WISH to include in Project Specifications.

Example:

Joint reinforcement may or may not be used as shear reinforcement – it is an option that the Engineer may have used on the project. The checklist reminds the Engineer to specify the lap length based on which option was used on the project.

3.4 B.10 Joint reinforcement	When joint reinforcement is used as shear reinforcement, specify a lap length of $48d_b$ instead of 6 inches.

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Codes.

Design Options:

- ASD
- SD
- Limit Design
- Partitions

Tip – Use the recent ASD Changes

- Major ASD changes started in the 2011 TMS 402/602
- Harmonization of ASD & SD shear provisions
- Stress recalibration extensive
  - Removal of 1/3 stress increase option that was formerly permitted for Allowable Stress Design (ASD) when considering wind or seismic loads
  - Some, but not all, Allowable Stresses increased through the recalibration work. Reduces impact of removal of 1/3 stress increase options
  - Conflict between the TMS 402/602 ASD loading provisions permitting the 1/3 stress increase and the ASCE 7-05 prohibition of the 1/3 stress increase has been eliminated.

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Example of the Benefits

- Building perimeter: 2(350’) + 2(525’) = 1,750 LF of wall
- **2009 IBC / TMS 402/602: #5 Rebar at 24” o.c. =**
  - 875 rebar = 19,250 LF + lap splices
  - 124 CY of grout
- **2012 IBC / TMS 402/602: #5 Rebar at 32” o.c. =**
  - 657 rebar = 14,438 LF + lap splices
    - 25% reduction / 2009 code = 33% increase!
    - 4,812 LF less
    - 5,053 lbs. less
  - 93 CY of grout
    - 25% reduction using new codes / 33% increase using the 2009 code
    - 31 CY less = 4 to 5 trucks!

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Tip – Is Limit Design for you?

- Appendix C in 2013 TMS 402/602
- Sophisticated Analysis Method
- Seismic design – optional method
- Perforated Walls

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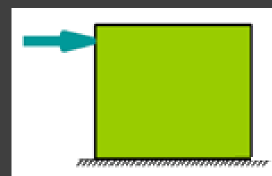
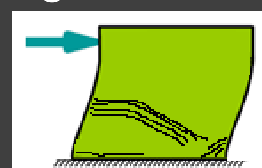
Limit Design: Seismic Design of Reinforced Masonry Structures

- Typical design methods:
  force - based design
  emphasizes strength



- Limit Design:
  displacement - based design
  emphasizes deformation



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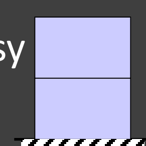
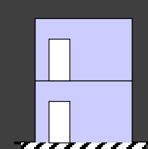
Force-based Seismic Design Limitations

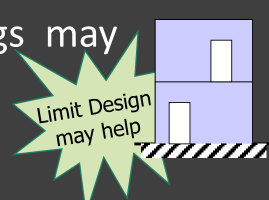
- uncoupled cantilever walls are easy to design



- coupled cantilever walls are more difficult to design



- walls with arbitrary openings may be impossible to design



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Tip – Design partitions with masonry

- TMS 402/602 Chapter 14: Masonry Partition Walls
  - Prescriptive tables for unreinforced masonry partitions
  - New in the 2013 TMS 402/602, but
  - Major improvements in 2016 TMS 402/602
- IMI Partitionwall Software
  - Code compliant, ASD design
  - Unreinforced and Reinforced walls
  - Free! www. Imiweb.org

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Partition wall design - 2016 TMS 402/602

Table 14.3.1 Partition Walls – Ungrouted or Partially Grouted

(See Table 14.3.2 for solidly grouted walls)

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

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

Example:

15 psf load. Partially grouted 8” wall. PCL mortar. Simple support.

h/t = 15 (from table) t = 8” (nominal dimension of an 8”CMU)

Solve for h: h = (15*8”)/12 = 10’ maximum height.

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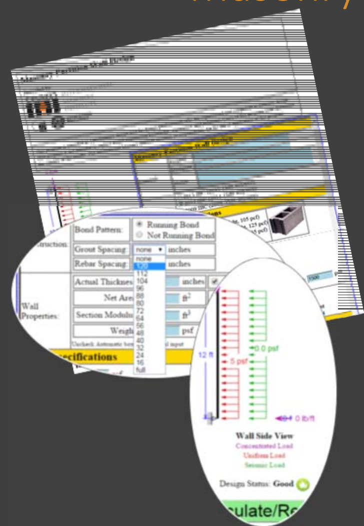
Masonry PartitionWall Software



New in Version 2:
- New Input sheet with scroll bar and pull downs
- 2015 IBC option added including new unit strength values for CMU
- Running Bond and Not Running Bond Options
- Reinforcement/Grout Options up to 120” c/c
- Calculate-As-You-Go feature with Structural Line Drawings

More Features:
- Codes Options: IBC 2009, IBC 2012, IBC 2015
- Allowable Stress Design for Masonry Partitions
- CMU - Unreinforced or Reinforced
- Clay Brick - Unreinforced
- 3 Support conditions – Vertical, Horizontal, Cantilever
- Loading options – Vertical, Horizontal Uniform, Horizontal Concentrated
- Seismic – All SDC with input options
- Option for Risk Category IV
- Option for Egress Stairways
- Complete documentation: Background, Reinforced Masonry Example, Unreinforced Masonry Example

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Codes.

Use the new unit strength tables

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Tip – Use updated Unit Strength Tables

Unit Strength Tables –

- Revised in the 2013 TMS 402/602
  - Format is more user friendly for both tables:
    - Table 1 – Clay masonry units
    - Table 2 – Concrete masonry units
- Recalibrated compressive strength values for Table 2
  - New research evaluated and incorporated
- 2016 TMS 402/602 revised Table 2
  - Reflects changes in ASTM C90 minimum unit compressive strength

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Tip – Use updated Unit Strength Tables

2016 TMS 402/602 Table 2: Compressive strength of masonry based on the compressive strength of concrete masonry units and type of mortar used in construction

Net area compressive strength of concrete masonry, psi (MPa)[1]	Net area compressive strength of ASTM C90 concrete masonry units, psi (MPa)	
	Type M or S mortar	Type N mortar
1,750 (12.07)	---	2,000 (13.79)
2,000 (13.79)	2,000 (13.79) 2800	2,650 (18.27) 3050
2,250 (15.51)	2,600 (17.93)	3,400 (23.44)
2,500 (17.24)	3,250 (22.41)	4,350 (28.96)
2,750 (18.96)	3,900 (26.89)	-----
3,000 (20.69)	4,500 (31.03) 4800	----- 5250

Examples: pre-2013 values

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

- Both unit strength tables reformatted in 2013 to be more user friendly
- Values in Table 2 were recalibrated in 2013 and revised in 2016
- Generally higher masonry compressive strength tailing off at higher unit strengths
- Prism testing still an option

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Codes.

Use tables not words

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Tip – Use the Table Formats in 2016 TMS 402/602

This:

TABLE 3.1 MINIMUM QUALITY ASSURANCE LEVEL

DESIGNED IN ACCORDANCE WITH	RISK CATEGORY I,II OR III	RISK CATEGORY IV
Part 3 or Appendix B or Appendix C	Level 2	Level 3
Part 4	Level 1	Level 2
Appendix A	Level 1	Not permitted

Not This:

~~**3.1.1** *Level 1 Quality Assurance*~~
~~The minimum quality assurance program for masonry in Risk Category I, II, or III structures and designed in accordance with Part 4 or Appendix A shall comply with the Level 1 requirements of TMS 602 Tables 3 and 4.~~

~~**3.1.2** *Level 2 Quality Assurance*~~
~~**3.1.2.1** The minimum quality assurance program for masonry in Risk Category IV structures and designed in accordance with Chapter 12 or 13 shall comply with the Level 2 requirements of TMS 602 Tables 3 and 4.~~
~~**3.1.2.2** The minimum quality assurance program for masonry in Risk Category I, II, or III structures and designed in accordance with chapters other than those in Part 4 or Appendix A shall comply with the~~
~~Level 2 requirements of TMS 602 Tables 3 and 4.~~

~~**3.1.3** *Level 3 Quality Assurance*~~
~~The minimum quality assurance program for masonry in Risk Category IV structures and designed in accordance with chapters other than those in Part 4 or Appendix A shall comply with the Level 3 requirements of TMS 602 Tables 3 and 4.~~

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Tip – Use the Table Formats in 2016 TMS 402/602

This:

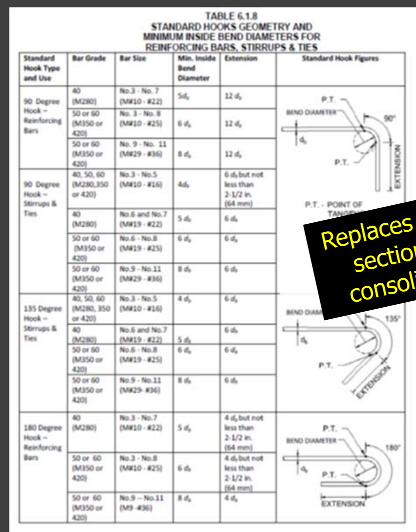

TABLE 6.1.8
STANDARD HOOKS GEOMETRY AND MINIMUM INSIDE BEND DIAMETERS FOR REINFORCING BARS, STIRRUPS & TIES

Standard Hook Type and Use	Bar Grade	Bar Size	Min. Inside Bend Diameter	Extension	Standard Hook Figures
90 Degree Hook – Reinforcing Bars	40 (M280)	No.3 - No. 7 (M#10 - #22)	$5d_b$	12 d_b	
	50 or 60 (M350 or 420)	No. 3 - No. 8 (M#10 - #25)	6 d_b	12 d_b	
	50 or 60 (M350 or 420)	No. 9 - No. 11 (M#29 - #36)	8 d_b	12 d_b	
90 Degree Hook – Stirrups & Ties	40, 50, 60 (M280,350 or 420)	No.3 - No.5 (M#10 - #16)	$4d_b$	6 d_b but not less than 2-1/2 in. (64 mm)	
	40 (M280)	No.6 and No.7 (M#19 - #22)	5 d_b	6 d_b	
	50 or 60 (M350 or 420)	No.6 - No.8 (M#19 - #25)	6 d_b	6 d_b	
	50 or 60 (M350 or 420)	No.9 - No.11 (M#29 - #36)	8 d_b	6 d_b	
135 Degree Hook – Stirrups & Ties	40, 50, 60 (M280, 350 or 420)	No.3 - No.5 (M#10 - #16)	4 d_b	6 d_b	
	40 (M280)	No.6 and No.7 (M#19 - #22)	5 d_b	6 d_b	
	50 or 60 (M350 or 420)	No.6 - No.8 (M#19 - #25)	6 d_b	6 d_b	
	50 or 60 (M350 or 420)	No.9 - No.11 (M#29- #36)	8 d_b	6 d_b	
180 Degree Hook – Reinforcing Bars	40 (M280)	No.3 - No.7 (M#10 - #22)	5 d_b	4 d_b but not less than 2-1/2 in. (64 mm)	
	50 or 60 (M350 or 420)	No.3 - No.8 (M#10 - #25)	6 d_b	4 d_b but not less than 2-1/2 in. (64 mm)	
	50 or 60 (M350 or 420)	No.9 -- No.11 (M9 -#36)	8 d_b	4 d_b	

Replaces language in multiple sections of the Code and consolidates into one table

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Materials.

Concrete Masonry Units

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Tip – Use the right ASTM Standard

ASTM C 90 Standard Specification for Loadbearing Concrete Masonry Units

- Use for projects requiring loadbearing CMU
- Sets **MINIMUM** requirements
- Include the edition
  - Example: ASTM C 90-16a
- Defaults to version referenced by local building code if not specified
- Starting with C90-11b – Equivalent web area replaces equivalent web thickness.

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Tip – Use the right ASTM Standard

Starting with C90-11b – Equivalent web area replaces equivalent web thickness

TABLE 1 Minimum ~~Thickness of~~ Face Shells and Webs Requirements[A]

Nominal Width (W) of Units, in. (mm)	Face Shell Thickness (t_{fs}), min, in. (mm)[B,C]	Webs ~~Thickness (t_w)~~	
		Web Thickness[C] (t_w), ~~Webs[B,D,C]~~ min, in. (mm)	~~Equivalent Web Thickness, min, in./linear ft[E] (mm/linear m)~~ Web Area (A_w), min, in.^{2}/ft^2 (mm^2/m^2)[D]
~~3 (76.2) and 4 (102)~~	~~¾ (19)~~	~~¾ (19)~~	~~1 5/8 (136)~~
~~6 (152)~~	~~1 (25)~~	~~1 (25)~~	~~2 ¼ (188)~~
~~8 (203)~~	~~1 ¼ (32)~~	~~1 (25)~~	~~2 ¼ (188)~~
~~10 (254) and greater~~	~~1 ¼ (32)~~	~~1 1/8 (29)~~	~~2 ½ (209)~~
3 (76.2) and 4 (102)	¾ (19)		
6 (152)	1 (25)	¾ (19)	6.5 (45,140)
8 (203) and greater	1 ¼ (32)		

Potential energy benefits, additional unit configuration options…design flexibility

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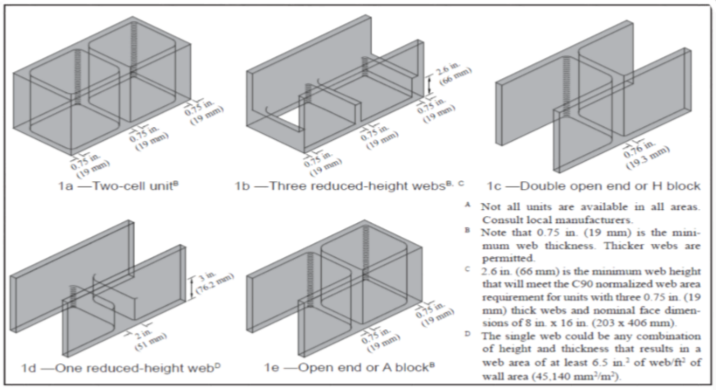
Tip – Use the right ASTM standard

Examples of unit configurations that comply with new ASTM C90 web area requirements



[A] Not all units are available in all areas. Consult local manufacturers.
[B] Note that 0.75 in. (19 mm) is the minimum web thickness. Thicker webs are permitted.
[C] 2.6 in. (66 mm) is the minimum web height that will meet the C90 normalized web area requirement for units with three 0.75 in. (19 mm) thick webs and nominal face dimensions of 8 in. x 16 in. (203 x 406 mm).
[D] The single web could be any combination of height and thickness that results in a web area of at least 6.5 in.^{2} of web/ft^2 of wall area (45,140 mm^2/m^2).

Figure 1—Examples of Web Configurations Permitted Under ASTM C90-11b[A]

NCMA TEK 2-5B

Tip – Understand Unit Compressive Strength & Density

ASTM C 90 Table 2

- Compressive strength requirements are independent of unit density

Example: Lightweight units are required to meet the same compressive strength minimum requirements as Medium weight and Normal weight units

C90 – 16a

TABLE 2 Strength, Absorption, and Density Classification Requirements[A]

Density Classification	Oven-Dry Density of Concrete, lb/ft^3 (kg/m^3)	Maximum Water Absorption, lb/ft^3 (kg/m^3)		Minimum Net Area Compressive Strength, lb/in^2 (MPa)	
	Average of 3 Units	Average of 3 Units	Individual Units	Average of 3 Units	Individual Units
Lightweight	Less than 105 (1680)	18 (288)	20 (320)	2000 (13.8)	1800 (12.4)
Medium Weight	105 to less than 125 (1680–2000)	15 (240)	17 (272)	2000 (13.8)	1800 (12.4)
Normal Weight	125 (2000) or more	13 (208)	15 (240)	2000 (13.8)	1800 (12.4)

[A]Compressive strength, absorption, and density determined in accordance with 8.2.

Tip – Remember, Minimum Requirements

- ASTM C 90
  - Minimum compressive strength requirements in Table 2
  - No maximum compressive strength limit
- Permissible (Advisable!) to specify higher unit strength which leads to higher compressive strength for the masonry wall
- Check local availability before specifying higher strength units

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Tip – Specify Above C-90 Minimum Strength

- If higher strength units are available, the effect on the structural design can be significant
- Often very little, if any cost penalty for units with strengths above the ASTM C 90 minimum
- May already be on the job – so use what you already have!

for example…

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Tip – Specify Above C90 Minimum Strength

Finding the average unit compressive strength

XXX TESTING LABORATORIES
Address
Address
Phone/fax/e-mail

Client name
Client address

Attn:

SUBJECT: Physical Analysis of 8" x 8
PROJECT: XXXXXX
SPECIFICATION: ASTM C 90, "Specificati
TEST METHOD: ASTM C 140, "Test Met Units and Related Units
DATE OF TESTS: January 4, 2012

TEST RESULTS

Physical Properties	A	B	C	Average
Weight Dry (lbs)	33.60	33.55	33.60	33.58
Absorption (%)	6.99	6.86	7.14	7.00
Absorption (lbs/cu.ft.)	9.08	8.91	9.27	9.09
Compressive Strength (PSI)	3025	3101	3075	3067
Density (lbs./cu.ft.)	119.82	120.03	119.82	119.89
Linear Shrinkage (%)	0.036	0.041	0.041	0.039

The tests show compliance with ASTM C 90, "Specification for Loadbearing Concrete Masonry Units".

Respectfully submitted,

XXX TESTING LABORATORIES

Principal

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Tip – Specify Above C 90 Minimum Strength

Unit Strength Method to determine Masonry Compressive Strength

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

Using ASTM C90 minimum unit strength

*2016 TMS 402/602

Net area compressive strength of concrete masonry, psi (MPa)	Net area compressive strength of ASTM C90 concrete masonry units, psi (MPa)	
	Type M or S Mortar	Type N Mortar
1,750 (12.07)	---	2,000 (13.79)
2,000 (13.79)	2,000 (13.79)	2,650 (18.27)
2,250 (15.51)	2,600 (17.93)	3,400 (23.44)
2,500 (17.24)	3,250 (22.41)	4,350 (28.96)
2,750 (18.96)	3,900 (26,89)	----
3,000 (20.69)	4,500 (31.03)	----

Taller, thinner walls can result!

Using Average unit compressive strength from testing report

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Materials.

Masonry Mortar

Tip – Mortar Type Matters

Specify Type S vs Type N Mortar

Using Unit Strength Method to determine f'_m
ASTM C90 CMU minimum compressive strength of 2000psi

Using Type N mortar

Net area compressive strength of concrete masonry, psi (MPa)	Net area compressive strength of ASTM C90 concrete masonry units, psi (MPa)	
	Type M or S Mortar	Type N Mortar
1,750 (12.07)	----	2,000 (13.79)
2,000 (13.79)	2,000 (13.79)	2,650 (18.27)
2,250 (15.51)	2,600 (17.93)	3,400 (23.44)
2,500 (17.24)	3,250 (22.41)	4,350 (28.96)
2,750 (18.96)	3,900 (26,89)	----
3,000 (20.69)	4,500 (31.03)	----

Using Type S mortar

Tip – Mortar Type Matters

Specify Type S vs Type N Mortar

Using Unit Strength Method to determine f'_m
CMU compressive strength of 3900 psi

Using Type N mortar

Net area compressive strength of concrete masonry, psi (MPa)	Net area compressive strength of ASTM C90 concrete masonry units, psi (MPa)	
	Type M or S Mortar	Type N Mortar
1,750 (12.07)	---	2,000 (13.79)
2,000 (13.79)	2,000 (13.79)	2,650 (18.27)
2,250 (15.51)	2,600 (17.93)	3,400 (23.44)
2389 2,500 (17.24)	3,250 (22.41)	3900 4,350 (28.96)
2,750 (18.96)	3,900 (26,89)	----
3,000 (20.69)	4,500 (31.03)	----

Using Type S mortar

Tip – Get the Mortar QA Right

Is field sampling/testing of mortar needed?

- *Best indicator of good mortar is a good mason.*

If so, specify: *ASTM C 780 Standard Test Method for Pre-construction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry*

- Note "Pre-construction" and "Construction"
- Must specify which test(s) to be done
- Annex format

Compliance to ASTM C270 is verified by:

- Proportions
- Annex 4: Mortar Aggregate Ratio Test

Tip – Get Familiar with ASTM C1586

ASTM C 1586 *Standard Guide for Quality Assurance of Mortars*

- Discusses the proper use and relationship of
  - ASTM C 270 Standard Specification for Mortar for Unit Masonry

    and
  - ASTM C 780 S*tandard Test Method for Pre-construction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry*

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Materials.

Masonry
Grout

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Tip – Specify Grout Strength Appropriately

TMS 402/602 Specification for Masonry Structures

- *"Grout compressive strength equals or exceeds f'_m but not less than 2000 psi."*
- *"unless otherwise required, provide grout that conforms to the requirements of ASTM C 476, or "*
- *"…attains the specified compressive strength or 2000 psi, whichever is greater, at 28 days when tested…"*)

ASTM C 476 Standard Specification for Grout for Masonry

- *"…and shall have a minimum compressive strength of 2000 psi at 28 days."* (Conventional grout)
- …*"The grout shall have a minimum compressive strength of 2000 psi at 28 days."* (Self-consolidating grout)

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Tip – Specify Grout Strength Appropriately

Question: Is there a minimum grout strength and what is it?

Answer: Yes. The minimum is 2000 psi at 28 days.

Question: Does the minimum compressive strength of 2000 psi apply to grouted clay brick?

Answer: Yes. This minimum applies to CMU, Brick and AAC.

Question: So does this minimum apply to only conventional grout?

Answer: No. it applies to both Conventional and SCG.

Question: So for all projects, grout strength should be specified as 2000 psi at 28 days.

Answer: NO! And that leads us to our next slide….

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Tip – Specify Grout Strength Appropriately

- For many projects 2000 psi at 28 days is appropriate.
- Note however, the part of the provision:

"Grout compressive strength equals or exceeds f'_m"

- When f'_m is specified as greater than 2000 psi, then the grout compressive strength should be specified to equal or exceed the specified f'_m value.

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Tip – Understand Grout Pours and Lifts

Often confused or used interchangeably. TMS 402/602 Definitions:

- Grout Pour – The total height of masonry to be grouted prior to erection of additional masonry. A grout pour consists of one or more grout lifts.
- Grout lift – An increment of grout height within a total grout pour. A grout pour consists of one or more grout lifts.
- Maximum pour height – function of grout type (fine or coarse), minimum grout space dimensions, use of cleanouts, conventional grout or SCG. Maximum pour heights are established by TMS 402/602.
- Maximum lift height – default is 5'-4", may increase to 12'-8" under some circumstances. SCG may be increased to pour height under some circumstances.

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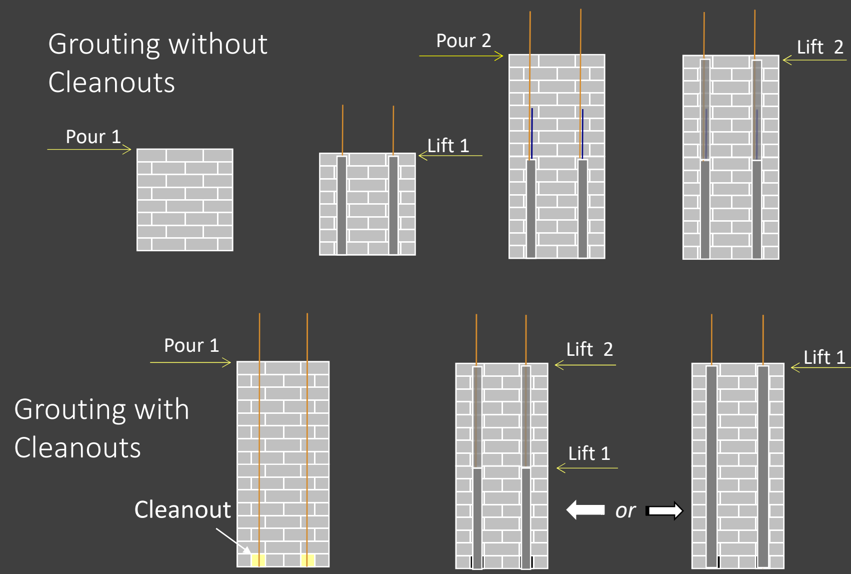
Pours and Lifts – Examples



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Tip – Give the Contractor Some Latitude

Give the contractor some latitude in the….

- *Selection of Fine or Coarse Grout*
  - *Technical considerations*
  - Grout space dimensions
  - Pour height limitations
  - Compressive strength independent of type

Fine Grout might be better suited here

Coarse or Fine Grout here

- *Constructability considerations*
  - Ease of use/Personal preference
  - Cost implications – material, placement
  - Issues related to pour height (next slide)

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Tip – Give the Contractor Some Latitude

Give the contractor some latitude in the….

- *Determination of Pour and Lift height*
  - *Technical considerations*
    - Code/Spec compliance
    - Inspection options
    - Other
  - *Constructability considerations*
    - Cleanouts
    - Bracing
    - Site constraints
    - Coordination of trades
    - Placement procedures
    - Other

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Tip – Give the Contractor Some Latitude

Give the contractor some latitude in the….

- *Use of self-consolidating grout*
  - *Technical considerations*
    - New material comfort level
    - Grout spaces and pour heights
    - Inspection and testing capabilities
    - Local supplier experience
  - *Constructability considerations*
    - Cost
    - Availability
    - Experience with the product
    - Grout space/height

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Tip – Give the Contractor Some Latitude

Give the contractor some latitude...

- *But specify proper training in Grouting and Reinforced Masonry:*

"**Grouting and Reinforcing:** All masonry and grouting and reinforcing work shall be performed by masonry craftworkers who have successfully completed the International Masonry Institute (1-800-IMI-0988) training course for Grouting and Reinforced Masonry Construction, or equal."

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Rebar.

Lap lengths
Splice options

50

Tip – Use Current Code Requirements

2 changes in the 2011 TMS 402/602

- The beneficial effect of larger cover (K- factor) for computation of development length has been changed from $5d_b$ to $9d_b$
- Transverse reinforcement option to reduce lap lengths has been included based on new research

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Tip – Reduce Splice Length when Appropriate

Lap length INCREASES as:
- Bar size increases
- Cover or distance between bars decreases

Lap length DECREASES as:
- Bar size decreases
- Cover or distance between bars increases
- Masonry compressive strength increases

Options to avoid long lap lengths:
- Use smaller diameter bars at closer spacing
- Cover distance is key – maximize cover for minimum lap lengths
- Minimize laps by permitting higher grout lifts
- Use specified f'_m, not just minimum value…

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Tip – Use specified f'$_m$ not minimum

Example: *8" CMU, single bar centered, grade 60 steel, 2013 TMS 402/602 SD*

Bar size	f'$_m$ = 2000 psi	f'$_m$= 2750 psi
#4	12"	12"
#6	37"	32"
#8	79"	67"

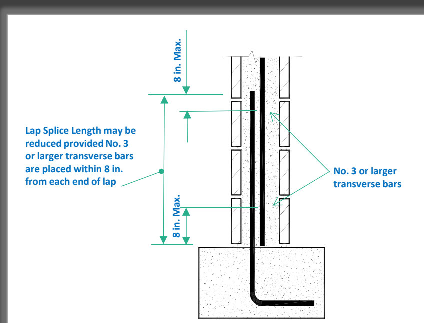
Options to avoid long lap lengths:

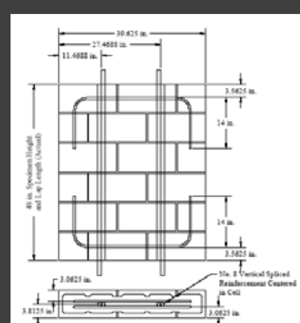
- Use smaller diameter bars at closer spacing.
- Cover distance is key – maximize cover for minimum lap lengths.
- Use specified *f'$_m$*, not just minimum value.
- Minimize laps by permitting higher grout lifts.

Note: Example only. Registered design professional should calculate based on specific project requirements

53

Tip – Consider transverse steel option





- ASD and SD
- Placed within 8" of the end of the splice and fully grouted
- Not more than 1.5" horizontally from vertical steel
- Horizontal bar must be 'fully developed' on each side of lap
- Bond beam steel option
- Minimum lap required of 36 bar diameters

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Tip - Consider transverse steel option

8" CMU. f'm = 2000psi. 2012 IBC. Rebar centered in wall.		
Bar Size	Lap Length, Unconfined (in.)	Lap Length, Confined (in.) (#4 confining bar)
No. 3	12	---**
No. 4	13	---**
No. 5	20	---**
No. 6	37	27
No. 7	52	32
No. 8	72	50

NCMA TEK 12-6A

* The IBC 2012 over writes to the TMS 402/602 lap lengths are used for this example
** 36 db min. lap is longer than unconfined lap

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Tip – Include Splice Lengths in Project Documents

Question: Why should the splice lengths and locations be included on the project drawings?

Answer: The design professional has the information necessary to calculate lap lengths, the contractor does not. Contractors cannot be expected to know which lap length equation is applicable nor the variables that are included in some lap splice equations.

Consider that laps may vary based on:

- Bar diameter
- Design method – this is changing
- Locally adopted building code
- Specified cover
- Specified f'_m
- and more…

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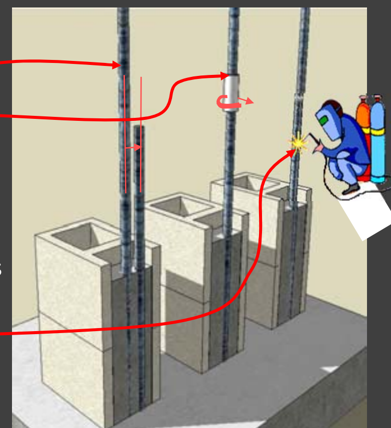
Tip – Consider other splicing options



- Lap splices
- Mechanical splices
  - Becoming more common
  - Develop 125% of specified bar yield strength.
  - IBC requires for some bar diameters
- Welded splices
  - Specify weldable reinforcement
  - Bars butted and must develop 125% specified bar yield strength.
  - Difficult, expensive, not recommended for most applications

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Rebar.

Joint reinforcement vs Bond beam

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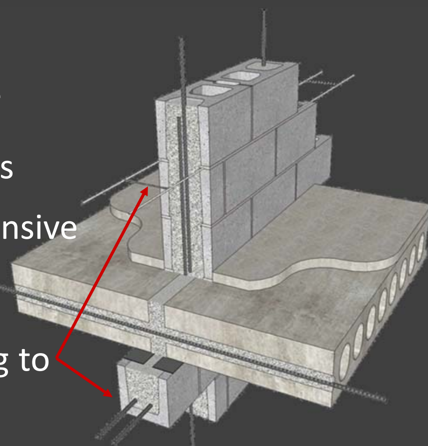
Tip – Think joint reinforcement not bond beams

- Joint reinforcement *may* be used to meet horizontal reinforcement requirements
- Bond beams are more expensive option but may offer more steel reinforcement area
- Can use both in the building to suit different needs



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Tip –Think engineered movement joints

- For crack control, joint reinforcement may not be needed with bond beams
- Using an engineered approach* can eliminate control joints and joint reinforcement

Example: 8” CMU partially grouted

Option 1

Use 9 ga. joint reinforcement at 16” o.c with control joints at 26’ o.c

Option 2

Use horizontal bond beams at 48” o.c. with a #6 bar and no control joints

** See NCMA TEK Notes 10-1 through10-3 for more information*

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Innovations.

Self-consolidating Grout

61

Tip – Consider Self-consolidating Grout

- First included in the 2008 TMS 402/602
- First included in ASTM C 476 in 2009
- No consolidation
- No job site proportioning
- Increased lift height potential
- Compliance and testing….

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SCG Quality Control

Slump test = Conventional Grout

ASTM C 143

8 - 11” slump

Slump flow & VSI = SCG

ASTM C1611

24” to 30”

VSI < 1

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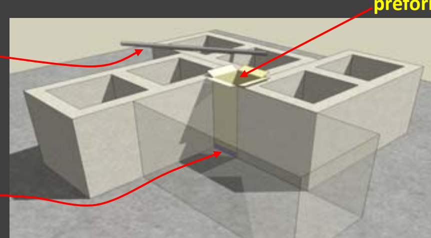
SCG Compressive strength testing

- Conventional grout and SCG
  - ASTM C1019 “Pinwheels”
    - Provisions same for SCG except:
      - Place in one lift
      - Do not rod



Ready to pour 3” x 3“ x 6” Grout test specimen

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Innovations.

Fly ash makes it Green

65

Tip – Green Your Grout with Fly Ash

- Mineral by-product of coal combustion – LEED
- Substitute for some of the portland cement
  - Included in blended cements or direct substitute
- ASTM C 618 - 2 classes for use in grout,
  - Class C
    - Some cementitious properties so may hydrate faster than Class F
  - Class F
    - Needs portland cement to kick off reaction
  - Some fly ashes may meet both Class C & F requirements

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Tip – Green Your Grout with Fly Ash

Grout with fly ash:

- Typically pumpability is enhanced.
- Often, but not always, there is slower early strength gain.
- Will reach approximately the same strength over time.
- Consider conditions early strength gain is critical:
  - Cold weather exposure
  - Construction of more masonry on grouted sections
  - Setting plank flooring, etc.
- Not all fly ash is the same so it is very important to know products being used.

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Innovations.

Structural Brick

68

Tip – Consider Structural Brick

- Reinforced hollow brick masonry
- Reinforced structural veneer

69

Innovations.

Internal Bracing

70

Tip – Consider Internal Bracing

- Two approaches to bracing:
  - External – traditional
  - Internal – well established but not as well known
- Both are engineered approaches
- Internal Bracing uses the constructed masonry's inherent strength to provide stability during wall construction.

Photo credit: Davenport Masonry

Photo credit: Koch Masonry

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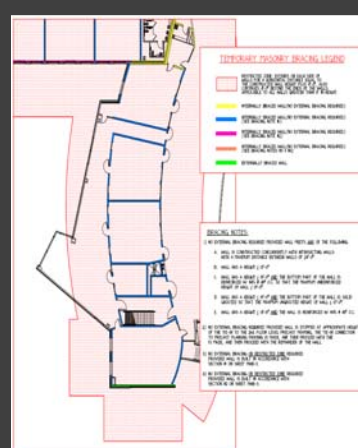
Tip – Consider Internal Bracing

- Internal bracing design requirements may require modifications to the design of record with increases in:
  - Dowel Length
  - Reinforcement size/spacing/lap length
  - Footing size
- However, it eliminates the need for external bracing and offers many additional benefits.
- Especially effective if considered during the building design.



Sample Bracing Plan Graphics, Notes and Legend

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Internal Bracing Guide

- Guide includes discussion of the method and how to use software to engineer
- Free download from IMI website: www.imiweb.org

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Sheltering.

Masonry
for
High wind
Sheltering.

74

Tip – Think Masonry for Sheltering

- IBC 2015 has adopted ICC 500 which mandates storm shelters for certain geographic areas and certain building uses:
  - Critical facilities – 911 call stations, emergency operation centers, fire, rescue, ambulance and police stations.
  - Group E occupancies (SCHOOLS!) with aggregate occupant load of 50 or more:
    - Must be capable of housing total occupant load of the Group E occupancy
    - Exceptions: Group E day cares, occupancies accessory to places of worship.

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Tip – Think Masonry for Sheltering

Structural for all tornado shelters

- Shelter enclosure must pass tornado missile test (published).
- Shelter walls must be engineered for 250 mph wind speed.
- Other structural requirements …

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Tornado Missile Tests on Masonry

Published masonry wall options that pass the tornado missile tests:

Single-wythe masonry.

- Solidly grouted and reinforced 6” CMU (min.) Veneer optional
- Solidly grouted and reinforced 6” Clay brick (min.) Veneer optional

Cavity wall masonry.

- Partially grouted and reinforced 8” CMU (min.) Clay brick veneer

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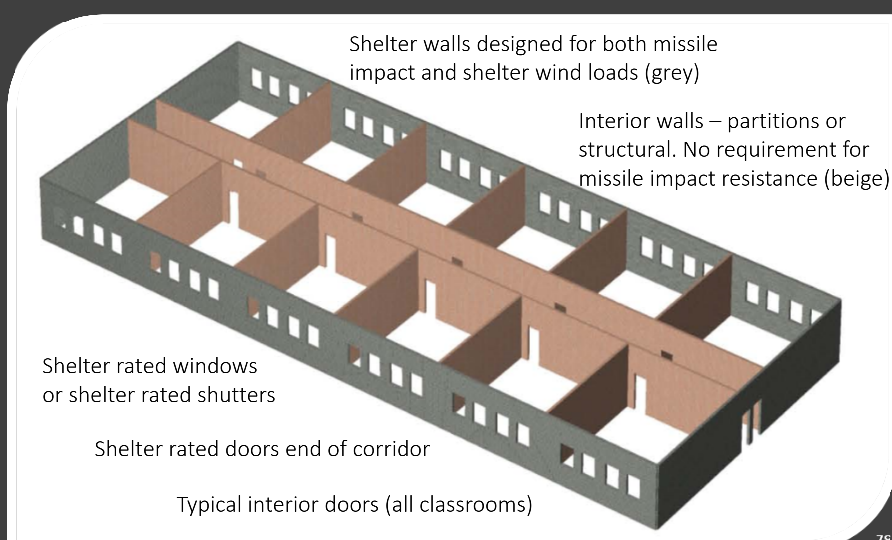
Example: Non-shelter & Shelter walls in Ohio

Classroom wing as Shelter



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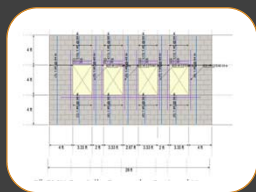
Example: Non-shelter & Shelter walls in Ohio

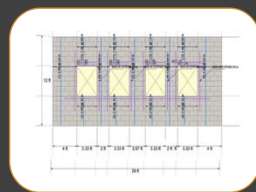
Non-shelter wall



8" CMU Partially Grouted.
Veneer optional.
#5 bar ea. jamb.
#5 bar @ 64" c/c
Joist roof option.

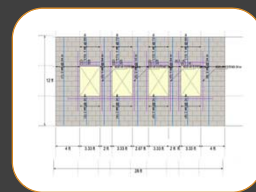
L-bar at top bond beam recommended.
Joint reinforcing 16" x 24"
Prescriptive veneer ties if veneer is used

Shelter – Single wythe



8" CMU Solidly Grouted.
Veneer optional.
#6 bar ea. jamb.
#6 bar @ 24" c/c
'Heavy roof' or second floor for uplift resistance.
Fully developed lap at foundation.
L-bar or fully developed bar detail at top bond beam required.
Joint reinforcing 16" x 24"
Prescriptive veneer ties if veneer is used

Shelter – Cavity wall



8" CMU Partially Grouted.
Veneer required.
#6 bar ea. jamb.
#6 bar @ 24" c/c
'Heavy roof' or second floor for uplift resistance.
Fully developed lap at foundation.
L-bar or fully developed bar detail at top bond beam required.
3/16" Joint reinforcement 16" x 16"
Engineered ties for veneer required

Example for illustration only, not for construction

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Why Masonry for Sheltering?

- Readily available materials
- Familiar construction methods
- Many structural & architectural sheltering options
- Load path requirements easily achieved
  - Foundation continuity
  - Roof connection continuity
- Component connections readily available
- History of proven performance

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Options.
Options.
Options.

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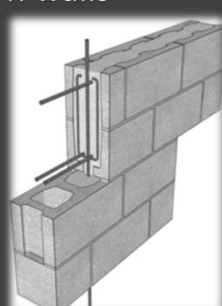
Options, options and more options!

Use masonry as:

- Lintels or Deep beams
- Shaft walls
- Structural cores
- Foundation walls



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Options, options and more options!

Prefabricated masonry

- Panels
- Rooms/Elements
- Lintels/beams
- Sound barriers
- Carbon fiber
- More

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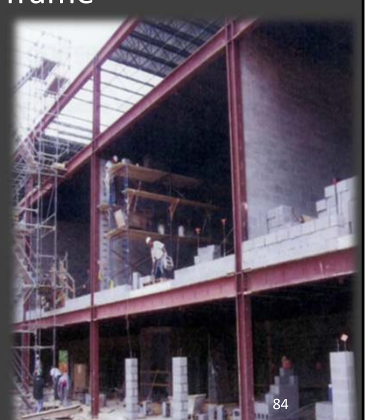
Options, options and more options!

Hybrid masonry/steel frame

- Reinforced Masonry infill
- Combined with structural steel frame
- Masonry acts as bracing
- Eliminates cutting infill around steel cross bracing



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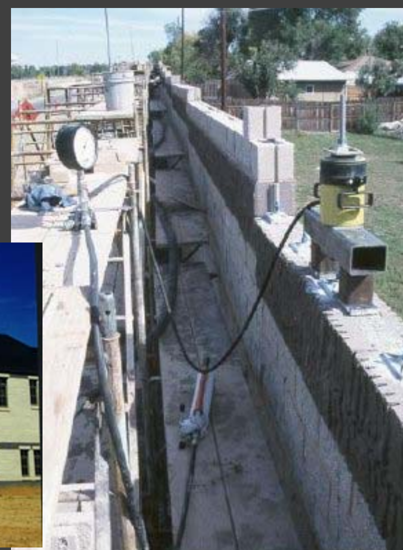
Options, options and more options!

Prestressed masonry



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THANK YOU !

QUESTIONS?

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