MIH MASONRY INSTITUTE OF HAWAII
presents

MASONRY DETAILING AND CONSTRUCTION

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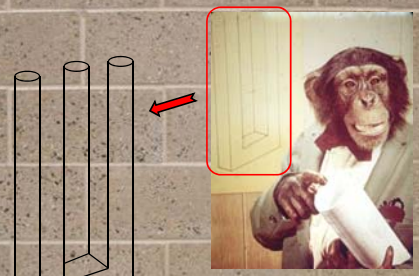
Masonry Institute of America
November 5, 2014

Masonry Detailing and Construction



Gentlemen, these plans might be confusing, so this simple graph on the wall should explain everything

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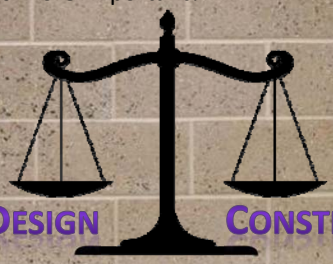
Masonry Detailing and Construction

- What's More Important?



Masonry Detailing and Construction

WHY???

- Designer Doesn't Understand Contractor Complaints
- Contractors Don't Understand the Design
- Codes Getting More Complicated
- Other Field Personnel (Inspectors, Suppliers) Caught in the Middle

WHAT HAPPENED TO COMMON SENSE?

Masonry Detailing and Construction

Outline

- Background-The Complicated Part
- The Players—Communication
- Vision to Reality
- ✓ Design Issues
- The Right Specification
- Moving Forward

Masonry Detailing and Construction

Outline-Design Issues

- Design Communication Issues
- What Needs to be in the Masonry Wall
  - Structural Integrity and Other Stuff
- Congestion
- Reinforcement and Splices
- Grouting
- When Things Go South
- Finding Help—Industry Resources

BACKGROUND

The Complicated Part

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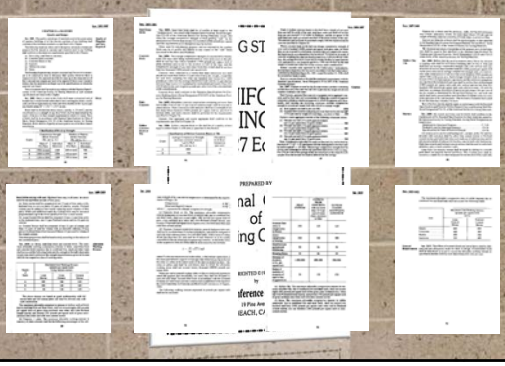
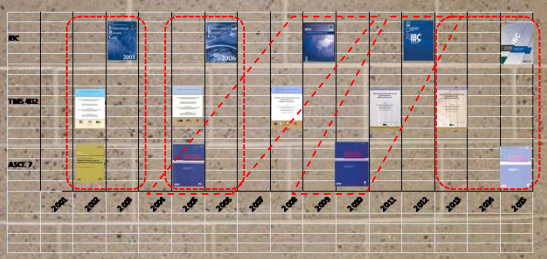


Masonry Detailing and Construction

Administration Design Material Standards

Masonry Detailing and Construction

Masonry Detailing and Construction



Masonry Detailing and Construction

- You Didn't Make This Stuff Up

$$l_d = \frac{0.13 d_b^2 f_y \gamma}{K\sqrt{f'_m}} \qquad \varepsilon = 1.0 - \frac{2.3 A_{sc}}{d_b^{2.5}} \qquad F_a = (1/4) f'_m \left[1 - \left(\frac{h}{140r}\right)^2\right]$$

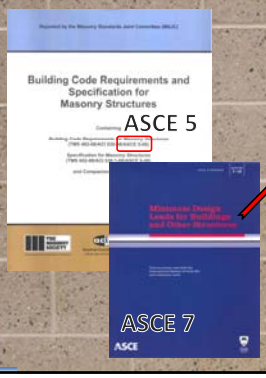
$$P_n = 0.80\left\{0.80 A_n f'_m \left[1 - \left(\frac{h}{140r}\right)^2\right]\right\} \qquad f_v = \frac{VQ}{I_n b} \qquad F_a = (1/4) f'_m \left(\frac{70r}{h}\right)^2$$

$$P_e = \frac{\pi^2 E_m I_n}{h^2}\left[1 - 0.577\frac{e}{r}\right]^3$$

$$P_n = 0.80\left[0.80 A_n f'_m \left(\frac{70r}{h}\right)^2\right] \qquad M_u = \varphi M_{u,0} \qquad \varphi = \frac{1}{1 - \frac{P_u}{A_n f'_m \left[\frac{70r}{h}\right]^2}}$$

$$V_{nm} = \left[4.0 - 1.75\left(\frac{M_u}{V_u d_v}\right)\right] A_{nv}\sqrt{f'_m} + 0.25 P_u$$

Masonry Detailing and Construction



14.4.3 Modifications to Chapter 1 of TMS 402/ACI 530/ASCE 5

14.4.4 Modifications to Chapter 2 of TMS 402/ACI 530/ASCE 5

14.4.5 Modifications to Chapter 3 of TMS 402/ACI 530/ASCE 5

14.4.6 Modifications to Chapter 6 of TMS 402/ACI 530/ASCE 5

14.4.7 Modifications TMS 602/ACI 530.1/ASCE 6

Masonry Detailing and Construction

2011 MSJC CODE . . .

- Chapter 1 - General Requirements
  - MSJC Specification
- Chapter 2 Allowable Stress Design
  - 2.1 - General ASD
  - 2.2 - URM
  - 2.3 - RM
- Chapter 3 Strength Design
  - 3.1 - General SD
  - 3.2 - URM
  - 3.3 - RM
- Chapter 4 Prestressed Masonry
- Ch. 5 Empirical Design
- Ch. 6 Veneer
  - 6.1 - General
  - 6.2 - Anchored
  - 6.3 - Adhered
- Ch. 7 Glass Block
- Appendix A - AAC

Masonry Detailing and Construction

2011 MSJC SPECIFICATION. . .

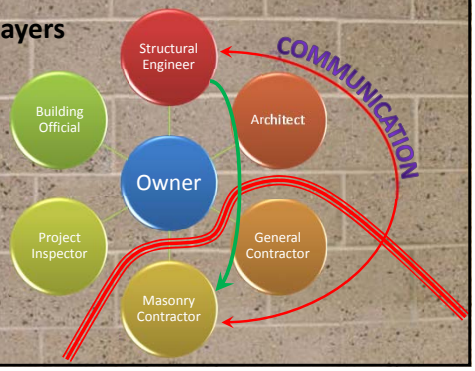
- MSJC Code
- MSJC Specification
  - Part 1 General
    - 1.1 Summary
    - 1.2 Definitions
    - 1.3 Reference standards
    - 1.4 System description
    - 1.5 Submittals
    - 1.6 Quality assurance
    - 1.7 Delivery, storage, handling
    - 1.8 Project conditions
  - Part 2 Products
    - 2.1 – Mortar
    - 2.2 – Grout
    - 2.3 – Masonry Units
    - 2.4 – Reinforcement
    - 2.5 – Accessories
    - 2.6 – Mixing
    - 2.7 – Fabrication
  - Part 3 Execution
    - 3.1 – Inspection
    - 3.2 – Preparation
    - 3.3 – Masonry erection
    - 3.4 – Reinforcement
    - 3.5 – Grout placement
    - 3.6 – Prestressing
    - 3.7 – Field quality control
    - 3.8 – Cleaning

THE PLAYERS

Communication = Working Together

Masonry Detailing and Construction

The Players



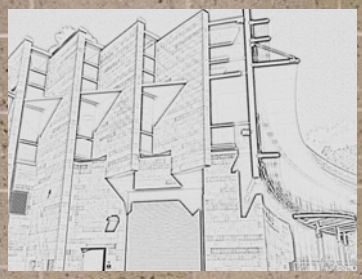
Masonry Detailing and Construction

Type of Arrangement

- Traditional Contract
- General Contractor = Project Manager
- Design-Build

Masonry Detailing and Construction

- I Can Design It.



Masonry Detailing and Construction

- Can You Build It?

Masonry Detailing and Construction

- I Can Design It.

Masonry Detailing and Construction

- Can You Build It?

UNDERSTAND THE DESIGN

A MESSAGE TO THE CONTRACTOR

Masonry Detailing and Construction

- How about the 'plastic hinge zone'?

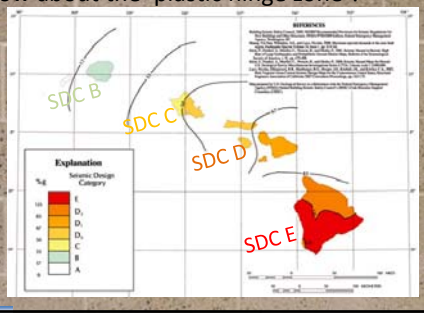
ASCE 7 Section 14.4, Masonry Detailing Requirements

Lap splices shall not be used in plastic hinge zones of special reinforced masonry shear walls. The length of the plastic hinge zone shall be taken as at least 0.15 times the distance between the point of zero moment to the point of maximum moment.

  - Applies to Special Reinforced Masonry Shear Walls
  - SDC D-Participating Element

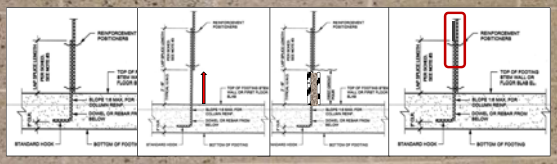
Masonry Detailing and Construction

- How about the 'plastic hinge zone'?



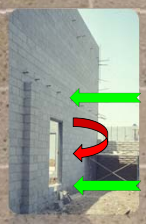
Masonry Detailing and Construction

- How about the 'plastic hinge zone'?
  - TMS 402-11, Sec 1.18.4.4.2 → Sec. 1.18.3.2.6
  - ASCE 7-10 Modification Sec. 18.4.4.2.2



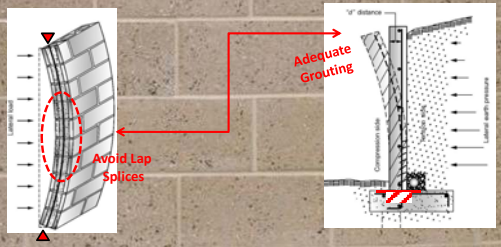
Masonry Detailing and Construction

- Maximum Design Moment



Masonry Detailing and Construction

- Maximum Design Moment



Masonry Detailing and Construction

- RFI from Masonry Contractor to SE

Really Happened!

Requirement For Block Strength of 3,750 PSI. Which is Classified Ultra High Strength by CMU Manufacturer, whom has Supplied CMU for A Dozen or so CVS's This Year and This Would Be the First One Using U.H.S. Masonry Units . I think The Question is Worth asking Because the Block Production time will be reduced with normal strength Units . The reason is that Once the Block is Manufactured they must cure and reach design strength before they Leave CMU Manufacturer and Obviously the Curing time Is reduced with Normal strength Units. We may need to Consult an Engineer as the overall Masonry assembly Design Strength is Stated At F'M = 2,500 PSI. (Page S-0.1 masonry note # 4) Request Reduction to Typical F'M = 1,500 PSI.

UNDERSTAND THE CONSTRUCTION

A MESSAGE TO THE DESIGNER

Masonry Detailing and Construction

- How much can fit into a small space?

Masonry Detailing and Construction

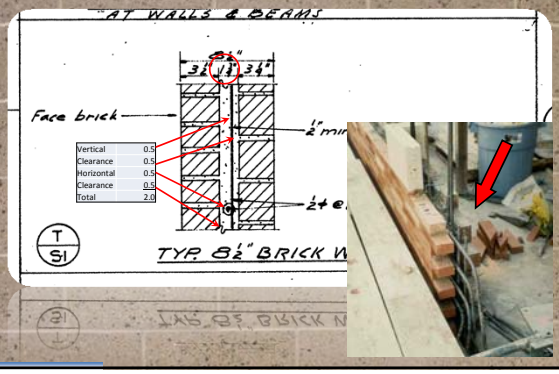
- How much can fit into a small space?

Masonry Detailing and Construction

CALIFORNIA BUILDING CODE
2114.6 Grouted masonry.
2114.6.1 General conditions…

Reinforcement and embedded items shall be clean properly positioned and securely anchored against moving prior to grouting. Bolts shall be accurately set with templates or by approved equivalent means and held in place to prevent dislocation during grouting. Reinforcement, embedded items and bolts shall be solidly embedded in grout. …

Masonry Detailing and Construction



CRITICAL COMPONENTS

Masonry Detailing and Construction

- Critical Components
  - Acceptable Foundation
  - Grout Space at Base of Wall
  - Location of Reinforcement
  - Grout
  - Connections, Including Anchor Bolts

Masonry Detailing and Construction

Critical Components

- What's really important?

Preparation of Foundation

First Course Layout

Masonry Detailing and Construction

Critical Components

- What's really important?

Reinforcement Placement

Grouting

DESIGN ISSUES

INSIDE THE WALL

Masonry Detailing and Construction

Inside the Wall

- What's Inside the Masonry Wall?
  - Reinforcement
  - Grout
- But Don't Forget
  - Electrical
  - Plumbing
  - Penetrations (HVAC)
  - Embeds

Masonry Detailing and Construction

Inside the Wall

Masonry Detailing and Construction

Masonry Detailing and Construction

Inside the Wall

Masonry Detailing and Construction

Inside the Wall

Masonry Detailing and Construction

Inside the Wall

DESIGN ISSUES

CONGESTION

Masonry Detailing and Construction

- What the Code (TMS 402-11) Says:

CODE	COMMENTARY
1.20.2.1 Conduits, pipes, and sleeves shall not be considered to be structural replacements for the displaced masonry. The masonry design shall consider the structural effects of this displaced masonry.	**1.20.2.1** Conduits, pipes, and sleeves not harmful to mortar and grout may be embedded within the masonry, but the masonry member strength should not be less than that required by design. Effects of reduction in section properties in the areas of conduit, pipe, or sleeve embedment should be considered. For the integrity of the structure, conduit and pipe fittings within the masonry should be carefully positioned and assembled. The coupling size should be considered when determining sleeve size. Aluminum should not be used in masonry unless it is effectively coated or covered. Aluminum reacts with ions, and may also react electrolytically with steel, causing cracking and/or spalling of the masonry. Aluminum electrical conduits present a special problem since stray electric current accelerates the adverse reaction. Pipes and conduits placed in masonry, whether surrounded by mortar or grout or placed in unfilled spaces, need to allow unrestrained movement.

Masonry Detailing and Construction

Congestion

- For an 8 inch wall
  - Maximum Bar Area
    - 5 in. x 6 in. = 30 in^2 x 4% - 1.2 in^2
  - Maximum Bar Size
    - #8 bar = 0.78 in^2
  - Most Reinforcement in Cell
    - 2 - #7 bars = 1.20 in^2
    - 4 - #5 bars = 1.24 in^2

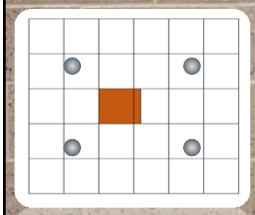
Masonry Detailing and Construction

- What the Code (TMS 402-11) Says:

CODE	COMMENTARY
3.3.3 *Reinforcement requirements and details* **3.3.3.1** *Reinforcing bar size limitations* — Reinforcing bars used in masonry shall not be larger than No. 9 (M#29). **The nominal bar diameter shall not exceed one-eighth of the nominal member thickness**, and shall not exceed one-quarter of the least clear dimension of the cell, course, or collar joint in which the bar is placed. The area of reinforcing bars placed in a cell or in a course of hollow unit construction **shall not exceed 4 percent of the cell area.**	**3.3.3** *Reinforcement requirements and details* **3.3.3.1** *Reinforcing bar size limitations* — The limit of using a No. 9 (M #29) bar is motivated by the goal of having a larger number of smaller diameter bars to transfer stresses rather than a fewer number of larger diameter bars. Some research investigations have concluded that in certain applications masonry reinforced with more uniformly distributed smaller diameter bars performs better than similarly configured masonry elements using fewer larger diameter bars. While not…

Masonry Detailing and Construction

Congestion



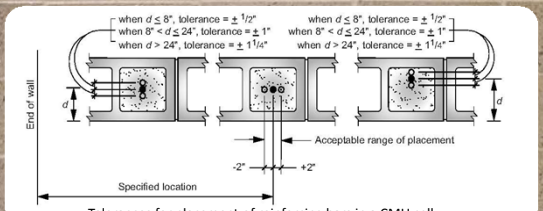
DESIGN ISSUES

REINFORCEMENT AND SPLICES

Masonry Detailing and Construction

Reinforcement

- Location



Tolerances for placement of reinforcing bars in a CMU cell

Masonry Detailing and Construction

Reinforcement

Masonry Detailing and Construction

Reinforcement

- Congestion

Masonry Detailing and Construction

Reinforcement

- Congestion

Masonry Detailing and Construction

Reinforcement

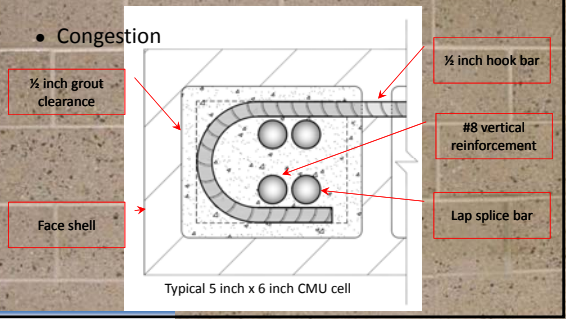
- TMS 402, Section 3.3.3 Reinforcement requirements and details

3.3.3.3.2.1 Except at wall intersections, the end of a horizontal reinforcing bar needed to satisfy shear strength requirements of Section 3.3.4.1.2 shall be bent around the edge vertical reinforcing bar with a 180-degree hook. The ends of single-leg or U-stirrups shall be anchored by one of the following means:…

Masonry Detailing and Construction

Reinforcement

- Congestion



Typical 5 inch x 6 inch CMU cell

Masonry Detailing and Construction

Lap Splices

- How Long Should a Lap Splice Be?
- $l_d = 0.002 d_b f_s$ (UBC ASD)
- $l_d = l_{de}/\emptyset, \quad l_{de} = \frac{0.15 d_b^2 f_y}{K\sqrt{f'_m}} \leq 52 d_b$ (UBC SD)
- $l_d = \frac{0.13 d_b^2 f_y \gamma}{K\sqrt{f'_m}}$ (TMS 402-08 ASD Override)
- $l_d = \frac{0.13 d_b^2 f_y \gamma}{K\sqrt{f'_m}}$, but $\varepsilon = 1.0 - \frac{2.3 A_c}{d_b^{2.5}}$ where $\frac{2.3 A_c}{d_b^{2.5}} \leq 1.0$ (TMS 402-11 ASD Override)

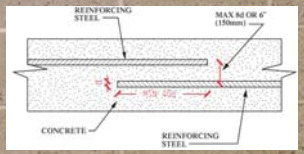
(ε is multiplier when transverse bars cross lap splice)

Masonry Detailing and Construction

Lap Splices

- How Much Contact is Required for a Lap Splice to be Effective?

Do the bars need to be tied?



…or can they just be in the neighborhood?

Masonry Detailing and Construction

Lap Splices

- How Much Contact is Required for a Lap Splice to be Effective?

Reinforced Concrete Design, K Leet (1991)…Although bars joined by a lap splice are usually wired together with their sides in direct contact, forces can also be transferred effectively between bars whose transverse spacing does not exceed one-fifth of the lap length l_s or 6 in (152 mm), whichever is smaller.

ACI 318-11 Building Code Requirements for Structural Concrete (2011) - 12.4.2.3 Bars spliced by noncontact lap splices in flexural members shall not be spaced transversely farther apart than the smaller of one-fifth the required lap splice length, and 6 in.

Masonry Detailing and Construction

Lap Splices

- How Much Contact is Required for a Lap Splice to be Effective?

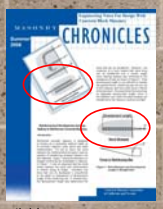
TMS 402-11 Building Code Requirements for Masonry Structures (2011) – Sections 2.1.7.7.1.3 and 3.3.3.3.1 Bars spliced by noncontact lap splices shall not be spaced transversely farther apart than one-fifth the required length of lap nor more than 8 in. (203 mm).

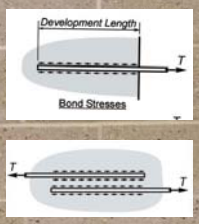
TMS 602-11 Specification for Masonry Structures (2011) – Article 3.4 B.9 *Noncontact lap splices* – Position bars spliced by noncontact lap splices no farther apart transversely than one-fifth the specified length of lap nor more than 8 in. (203 mm).

Masonry Detailing and Construction

Lap Splices

- How Much Contact is Required for a Lap Splice to be Effective?





Available at www.cmacn.org

Masonry Detailing and Construction

Lap Splices

- How Much Contact is Required for a Lap Splice to be Effective?

TMS 602-08 Specification for Masonry Structures (2008) – Article 3.4 B.1 Support and fasten reinforcement together to prevent displacement beyond the tolerances allowed by construction loads or by placement of grout or mortar,.

TMS 602-11 Specification for Masonry Structures (2011) – Article 3.4 B.1 Support reinforcement to prevent displacement caused by construction loads or by placement of grout or mortar, beyond the allowable tolerances.

Masonry Detailing and Construction

Lap Splices

- How Much Contact is Required for a Lap Splice to be Effective?

Masonry Detailing and Construction

Lap Splices

- Keep it simple and consistent
- Class of splice (ACI 318) NOT Required
- Try to Limit Congestion
- Tying Splices is Not a Code Requirement
- Consider Staggering Splices for Highest Seismic Applications

CRITICAL COMPONENTS

ANCHOR BOLTS

Masonry Detailing and Construction

Anchor Bolts

- A Real Dilemma
  - Anchor Bolts Should Be Embedded as Deep as Possible for Maximum Efficiency
  - There Isn't Much Room Inside the Cell

3.4 D. *Anchor bolts…*
3. For anchor bolts placed through the face shell of a hollow masonry unit… maintain a clear distance between the bolt and the face of masonry unit and between the head or bent leg of the bolt and the formed surface of grout of at least ¼ in. (6.4 mm) when using fine grout and at least ½ in. (12.7 mm) when using coarse grout.

Masonry Detailing and Construction

Anchor Bolts

- A Real Dilemma

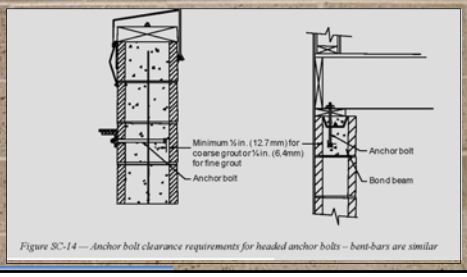
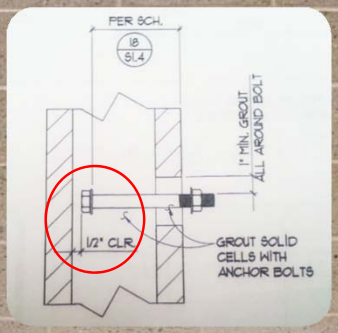
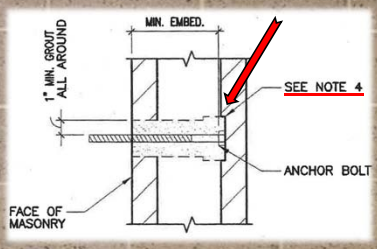


Figure SC-14 — Anchor bolt clearance requirements for headed anchor bolts – bent-bars are similar

Masonry Detailing and Construction

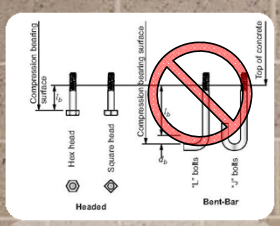


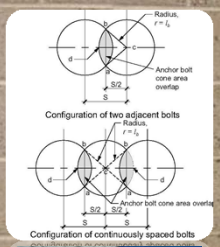
Masonry Detailing and Construction



NOTES:
1. MINIMUM BOLT SPACING SHALL BE 16 BOLT DIAMETERS WITH A MINIMUM EDGE DISTANCE OF 12 DIAMETERS, UNLESS NOTED OTHERWISE.
2. PROVIDE AN ADDITIONAL 2" OF EMBEDMENT FOR ANCHOR BOLTS LOCATED IN THE TOP OF COLUMNS.
3. ANCHOR BOLTS SHALL BE HEX HEADED WITH THE DIMENSIONS OF THE HEX CONFORMING TO ANSI/ ASME B18.2.1 BENT BAR ANCHORS SHALL NOT BE USED.
4. PARTIALLY CORE CMU FACE SHELLS AS REQUIRED TO ATTAIN PROPER ANCHOR BOLT EMBEDMENT.

Masonry Detailing and Construction





2013 CBC Section 2114.10 *Bent bar anchor bolts shall not be allowed.*

DESIGN ISSUES

GROUTING

Masonry Detailing and Construction

Grouting

- Cells should be reasonably clean

Unacceptable Cells

Ready for Grouting

Masonry Detailing and Construction

Grouting

- Placement of Grout

Masonry Detailing and Construction

Grouting

- Placement of Grout

Masonry Detailing and Construction

Grouting

- Consolidation and Reconsolidation

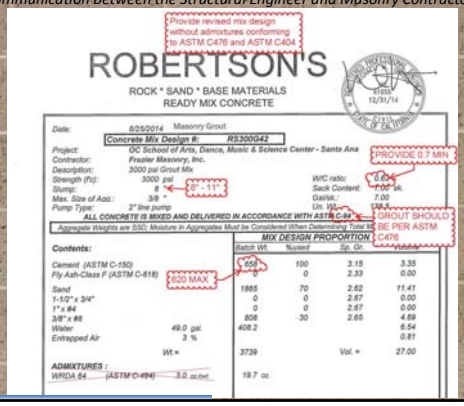
Communication Between the Structural Engineer and Masonry Contractor

- Masonry Grout is like Concrete, but…….
  - A lot of water is NOT a bad thing (up to 11" slump)
  - Aggregates must be smaller

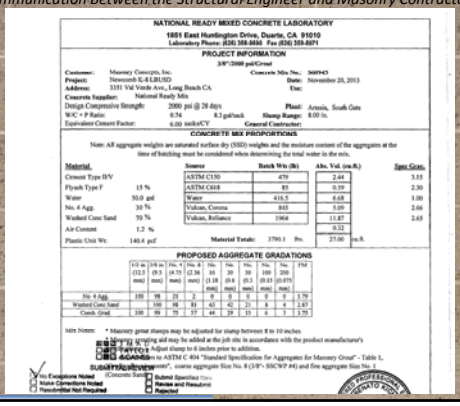
Communication Between the Structural Engineer and Masonry Contractor

- Masonry Grout is like Concrete, but…….
  - A lot of water is NOT a bad thing (up to 11" slump)
  - Aggregates must be smaller
  - Not Too Much Cement
  - Fly Ash and Slag are Good (Longer Strength Gain)
  - No Plasticizers as Water Replacement
  - Masonry Grout has a unique ASTM Standard

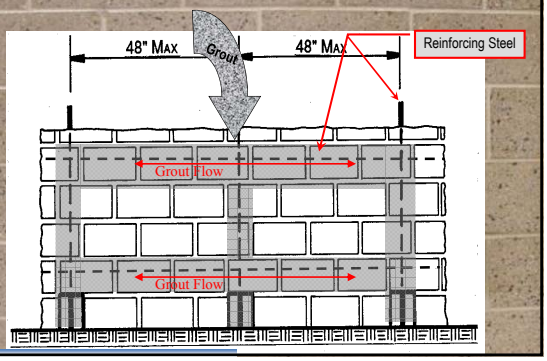
Communication Between the Structural Engineer and Masonry Contractor



Communication Between the Structural Engineer and Masonry Contractor

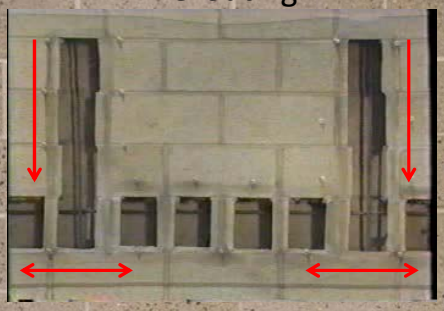


Masonry Detailing and Construction



Masonry Detailing and Construction

Grouting



DESIGN ISSUES

MORTAR – A THORN IN THE SIDE

Masonry Detailing and Construction

- The Root of the Problem
  - ASTM C270 - Standard Specification for Mortar for Unit Masonry
  - ASTM C780 - Standard Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry
  - ASTM C1586 - Standard Guide for Quality Assurance of Mortars

Masonry Detailing and Construction

- The Root of the Problem – ASTM C270

ASTM C 270 TABLE 1– PROPORTION SPECIFICATION REQUIREMENTS

MORTAR	TYPE	PROPORTIONS BY VOLUME (cementitious materials)							AGGREGATE MEASURED IN A DAMP, LOOSE CONDITION
		Portland cement or blended Cement	Masonry cement			Mortar cement			HYDRATED LIME OR LIME PUTTY
			M	S	N	M	S	N	
Cement-Lime	M	1	-	-	-	-	-	-	¼
	S	1	-	-	-	-	-	-	Over ¼ to ½
	N	1	-	-	-	-	-	-	Over ½ to 1¼
	O	1	-	-	-	-	-	-	Over 1¼ or 2½
Mortar cement	M	1	-	-	-	-	-	1	-
	M	-	-	-	-	1	-	-	-
	S	½	-	-	-	-	-	1	-
	S	-	-	-	-	-	1	-	-
	N	-	-	-	-	-	-	1	-
	O	-	-	-	-	-	-	1	-

Not less than 2¼ and not more than 3 times the sum of the separate volumes of cementitious materials

For Field Mortar

Masonry Detailing and Construction

- The Root of the Problem – ASTM C270

ASTM C270, TABLE 2, PROPERTY SPECIFICATION REQUIREMENTS[A]

Mortar	Type	Avg. Compressive Strength at 28 Days, min psi	Water Retention, Min. %	Air Content, Max %	Aggregate Ratio
Cement-Lime	M	2500 (17.2)	75	12	Not less than 2¼ and not more than 3½ times the sum of the separate volumes of cementitious materials
	S	1800 (12.4)	75	12	
	N	750 (5.2)	75	14	
	O	350 (2.4)	75	14	
Mortar Cement	M	2500 (17.2)	75	12	
	S	1800 (12.4)	75	12	
	N	750 (5.2)	75	14	
	O	350 (2.4)	75	14	
Masonry Cement	M	2500 (17.2)	75	18	
	S	1800 (12.4)	75	18	
	N	750 (5.2)	75	20	
	O	350 (2.4)	75	20	

[A] Laboratory prepared mortar only

Masonry Detailing and Construction

Laboratory Prepared Mortar Only!

Masonry Detailing and Construction

- The Root of the Problem – ASTM C270

ASTM C270, TABLE 2, PROPERTY SPECIFICATION REQUIREMENTS[A]

Mortar	Type	Avg. Compressive Strength at 28 Days, min psi	Water Retention, Min. %	Air Content, Max %	Aggregate Ratio
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	N	750 (5.2)	75	14	
	O	350 (2.4)	75	14	
Mortar Cement	M	2500 (17.2)	75	12	
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	N	750 (5.2)	75	14	
	O	350 (2.4)	75	14	
Masonry Cement	M	2500 (17.2)	75	18	
	S	1800 (12.4)	75	18	
	N	750 (5.2)	75	20	
	O	350 (2.4)	75	20	

[A] Laboratory prepared mortar only

Masonry Detailing and Construction

- The Root of the Problem – ASTM C270

1.2 The proportion or property specifications shall govern as specified.
1.3 When neither proportion or pro`perty specifications are specified, the proportion specifications shall govern,…

3.1 Specification C270 is not a specification to determine mortar strengths through field testing.

3.3 The compressive strength values resulting from field tested mortars do not represent the compressive strength of mortar as tested in the laboratory nor that of the mortar in the wall.

Masonry Detailing and Construction

- The Root of the Problem – ASTM C780

1.4 The test results obtained under this test method are not required to meet the minimum compressive values in accordance with the property specifications in Specification C270.

5.2.6 …Mortar compressive strength test values are not representative of the actual compressive strength of mortar in the assembly and are not appropriate for use in predicting the compressive strength that would be attained by the mortar in the masonry assembly.

A6.1.1 …Strength values for mortars obtained through these testing procedures are not required, nor expected, to meet strength requirements of laboratory Specification C270 mortars.

Masonry Detailing and Construction

- The Root of the Problem – ASTM C1586

4.1 Use Specification C270 to specify masonry mortar by either the Proportion or Property Specifications of that standard, but not both. If neither the Proportion nor Property specification is given, Specification C270 the Proportion specification to be used.

4.2 *Proportion Specifications*—These Specifications direct the mason to produce the masonry mortar using designated volumetric proportions of cementitious materials and aggregate as set forth in Table 1, Proportion Specifications, of Specification C270 for the Type of mortar specified. This procedure of specifying mortar requires no sampling and testing of mortar, and hence, no measurement of mortar properties in the laboratory or the field is required. All that is necessary is field confirmation of the proper proportions of the mixes used in construction.

Masonry Detailing and Construction

- The Root of the Problem – ASTM C1586

4.3.2 Do not use the Specification C270 Property Specifications requirements to evaluate construction site-produced mortars. Due to the higher amount of water necessary for actual masonry construction, mortar produced and sampled in the field will typically have lower compressive strength than that produced in the laboratory per Specification C270.

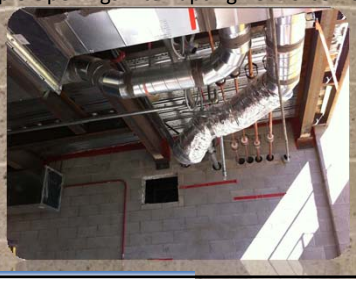
5.5.3 Measurement of construction site masonry mortar compressive strength using Test Method C780, Annex A7, is not the appropriate test method to determine the compliance of the mortar with the compressive strength requirements of Specification C270; however it may have some value in the determination of mortar uni

THE BAD STUFF

When Things Go South

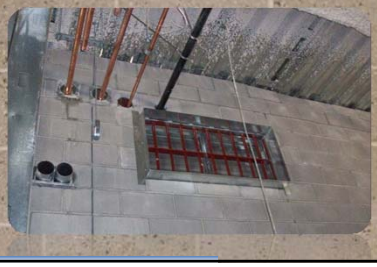
Masonry Detailing and Construction

- Coordination with Penetrations
  - Multiple Openings Interrupting Reinforcement



Masonry Detailing and Construction

- Coordination with Penetrations
  - Multiple Openings Interrupting Reinforcement



Masonry Detailing and Construction

- Coordination with Penetrations
  - Multiple Openings Interrupting Reinforcement

Masonry Detailing and Construction

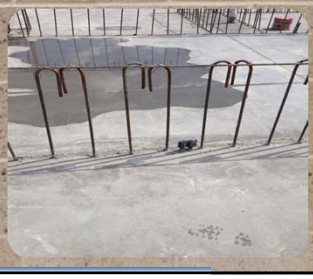
- Coordination with Penetrations
  - Penetrations at Beam Supports

Masonry Detailing and Construction

- Coordination with Penetrations
  - Penetrations at Beam Supports

Masonry Detailing and Construction

- Coordination with Underground
  - Base Wall Conditions

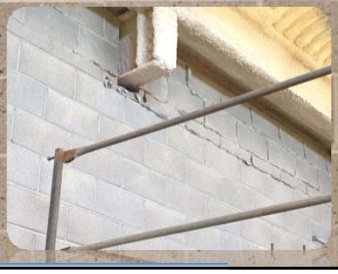


Masonry Detailing and Construction

- Coordination with Underground
  - Interface with Dowels, Conduits, Piping

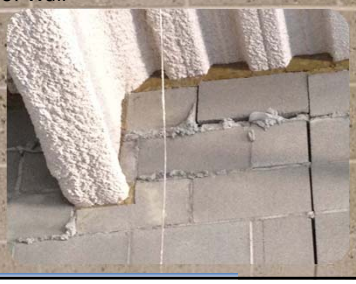
Masonry Detailing and Construction

- Difficult Grouting Conditions
  - Top of Wall



Masonry Detailing and Construction

- Difficult Grouting Conditions
  - Top of Wall



Masonry Detailing and Construction

- Difficult Grouting Conditions
  - Top of Wall

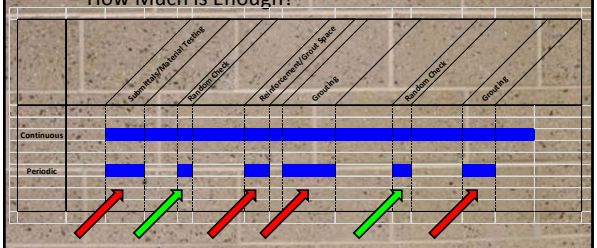
Masonry Detailing and Construction

- Difficult Grouting Conditions
  - Top of Wall

CONFUSION ON BOTH SIDES

Masonry Detailing and Construction

- Frequency of Inspection
  - How Much is Enough?



Masonry Detailing and Construction

Periodic Inspection—How Much?

- (2012 IBC) Code Definition

SPECIAL INSPECTION. Inspection of construction requiring the expertise of an *approved special inspector* in order to ensure compliance with this code and the *approved construction documents*.

Continuous special inspection. Special inspection by the *special inspector* who is present when and where the work to be inspected is being performed.

Periodic special inspection. Special inspection by the *special inspector* who is intermittently present where the work to be inspected has been or is being performed.

Not much help

Masonry Detailing and Construction

Periodic Inspection—How Much?

- Need to Quantify 'Periodic' – TMS 602 Commentary

3.1 — Quality Assurance program

…The level of required quality assurance depends on whether the masonry was designed in accordance with Part 3, Appendix B, or Appendix C (engineered) or in accordance with Part 4 or Appendix A (empirical or prescriptive).

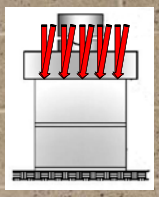
NEW-2016

Quality Assurance Tables 3.1.2 and 3.1.3 require inspection tasks to be performed on a continuous or periodic basis. The Architect/Engineer should define the required timing of periodic inspections so that they are sufficient to verify a representative sample of the materials and workmanship. The frequency of periodic inspection varies depending on the size and complexity of the project.

Masonry Detailing and Construction

Bad Test Reports? – Don't Panic

- Case where prisms were capped out-of-tolerance



Masonry Detailing and Construction

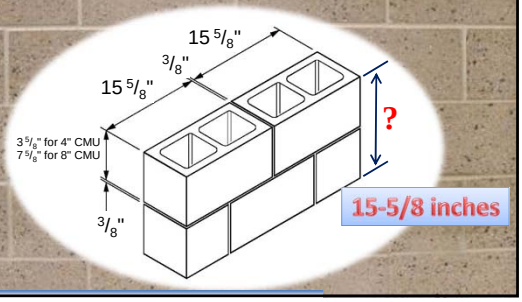
Bad Test Reports? – Don't Panic

- Testing procedure done incorrectly

THE GOOD STUFF

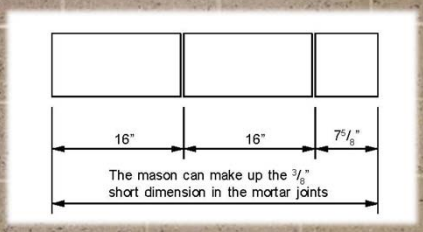
Masonry Detailing and Construction

- Masonry Dimensioning



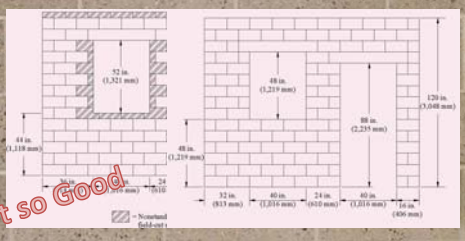
Masonry Detailing and Construction

- Masonry Dimensioning



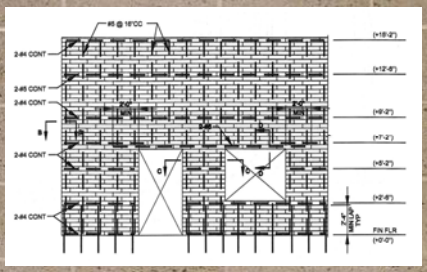
Masonry Detailing and Construction

- Masonry Dimensioning



Masonry Detailing and Construction

- Masonry Dimensioning



Masonry Detailing and Construction

- Masonry Dimensioning
  - Reinforcing Steel Must be Spaced in 8 inch increments
    - Vertically and Horizontally
  - Any wall dimension is possible, but…
    - Things look best when designed in 8 inch modules
  - You can hide stuff (electrical, plumbing) inside wall, but..
    - Be careful not to compromise the structural integrity
- When All is Said and Done
  - ASTM C90 says look at the wall from 20 feet away

FINDING HELP

Industry Resources

Masonry Detailing and Construction

- Industry Resources
  - NCMA TEK Notes
  - MasonrySystems.org
    - Google Sketchup
  - BIM-M
  - Local Resources

Masonry Detailing and Construction

- National Concrete Masonry Association www.ncma.org
  - TEK Notes

National Concrete Masonry Association — Association Website.mhtml

Masonry Detailing and Construction

- www.MasonrySystems.org

MasonrySystems.org - Masonry wall systems, technical notes, masonry resources, project galleries and more.mhtml

single-wythe-reinforced-concrete-block.skp

Masonry Detailing and Construction

- BIM-M www.BIMforMasonry.org

Building Information Modeling for Masonry (BIM-M)_org-.mht

BIM-M Benefits.mht

Masonry Detailing and Construction

- Local Resources
  - Masonry Institute of Hawaii
    www.masonryhawaii.com

Masonry Institute of Hawaii.mht

  - Cement and Concrete Products Institute
    www.ccpihawaii.org

Cement & Concrete Products Industry of Hawaii - Non Profit I Honolulu.mht

Masonry Detailing and Construction

- Other Valuable Resources
  - Masonry Institute of America
    www.masonryinstitute.org

MasonryInstitute.org.mhtml

  - Concrete Masonry Association of CA and NV
    www.cmacn.org

Concrete Masonry Association of California and Nevada.mhtml

Masonry Detailing and Construction

- Reinforced Masonry Engineering Handbook
- Design of Reinforced Masonry Structures
- Masonry Designers Guide
- Direct Design Handbook




THE RIGHT SPECIFICATION

Masonry Detailing and Construction

- Common on Structural Notes
  - Specifying Mortar by Properties and Proportion
  - Listing Grades and Types for CMU
  - Confusion about f'_m
  - Not Understanding the Difference Between Grout Lift and Grout Pour
  - Conflicts Between Architectural Specifications and Structural Notes

Masonry Detailing and Construction

- One Example

SECTION 5: MASONRY

5-1 BLOCK MASONY UNITS SHALL BE SINGLE OR DOUBLE OPEN-END BOND BEAM UNITS CONFORMING TO ASTM C90, LATEST REVISION, TYPE I.

5-2 MINIMUM f'_m UNO: 8" CMU = 1500 psi
12" CMU = 2000 psi

(2012 IBC) Code Definition
$f'm$ = Specified compressive strength of masonry at age of 28 days, psi (MPa).

Masonry Detailing and Construction

- One Example

SECTION 5: MASONRY

5-3 f'_m SHALL BE DETERMINED PER THE CBC (IBC), SECTION 2105. PROVIDE SUBMITTALS, TESTING AND INSPECTIONS AS REQUIRED BY CBC (IBC) SECTION 1704.5.2.

5-4 IN NO CASE SHALL COMPRESSIVE STRENGTH OF BLOCK UNITS BE LESS THAN 125% OF SPECIFIED f'_m. IN NO CASE SHALL GROUT FOR THE BLOCK UNITS HAVE A COMPRESSIVE STRENGTH LESS THAN 2000 psi AND 125% OF SPECIFIED f'_m AT 28 DAYS. MORTAR SHALL BE TYPE "S" OR "M".

Masonry Detailing and Construction

- One Example

SECTION 5: MASONRY

5-5 MINIMUM LAP OF REINFORCING STEEL SHALL BE PER C/5.03.

5-6 THE FIRST COURSE OF BLOCK FOR BLOCK LIFTS EXCEEDING 5'-0' SHALL HAVE CLEANOUTS CONSISTING OF DOUBLE OPEN END BOND BEAM BLOCK. SEE DETAIL N5.03.

(2011 TMS 402) Definition
Grout lift — An increment of grout height within a total grout pour. A grout pour consists of one or more grout lifts.
Grout pour — The total height of masonry to be grouted prior to erection of additional masonry. A grout pourconsists of one or more grout lifts.

Masonry Detailing and Construction

- One Example

SECTION 5: MASONRY

5-7 GROUT POURS SHALL BE TO THE FULL HEIGHT OF THE BLOCK LIFT. MAXIMUM GROUT POUR HEIGHT SHALL COMPLY WITH TABLE 1.19.1 OF ACI 530-08. GROUT POURS EXCEEDING 5'-0" IN HEIGHT SHALL CONSIST OF MULTIPLE GROUT LIFTS OF 5'-0" OR LESS IN HEIGHT. CONSOLIDATE AND RECONSOLIDATE EACH GROUT LIFT BY MEANS OF MECHANICAL VIBRATION IN COMPLIANCE WITH ACI 530. I SECTION 3.5.E. A GROUT LIFT SHALL NOT BE PERMITTED TO SET PRIOR TO PLACEMENT AND CONSOLIDATION OF SUBSEQUENT GROUT LIFT.

Masonry Detailing and Construction

- Common on Structural Notes

SECTION 5: MASONRY

5-8 HORIZONTAL CONSTRUCTION JOINTS BETWEEN GROUT POURS SHALL BE LOCATED 1" ± 1/2" BELOW A MORTAR JOINT.

5-9 MINIMUM GROUTING: FILL ALL CELLS.

5-10 ALL BOLTS IN MASONRY SHALL BE CENTERED IN CELLS ± 2 INCHES.

(2011 TMS 602)
3.5 F. *Grout key —…..*
1. Form a grout key by terminating the grout a minimum of 1½ in. (38.1 mm) below a mortar joint.

Masonry Detailing and Construction

The Right Specification

Structural Notes Said

Block masonry units shall be single or double open-end bond beam units conforming to ASTM C90, latest revision, ~~Type 1.~~

Should Have Been

Block masonry units shall be single or double open-end bond beam units conforming to ASTM C90, latest revision.

ASTM C90 for Concrete Block is published at least once a year. Grades (M, S) were dropped in 1991 and Types (I, II) were dropped in 2000, both in favor of the more stringent requirement.

Masonry Detailing and Construction

The Right Specification

Structural Notes Said

f'_m shall be determined per IBC Section 2105.

Should Have Been

Verification of f'_m shall be determined per IBC Section 2105.

The term f'_m is a design strength, not an actual strength. The designer needs a verification that the actual masonry strength meets or exceeds the design strength to assure that the installed product is safe.

Masonry Detailing and Construction

The Right Specification

Structural Notes Said

The first course of block for block lifts exceeding 5'-0" shall have cleanouts consisting of double open-end bond beam block.

Should Have Been

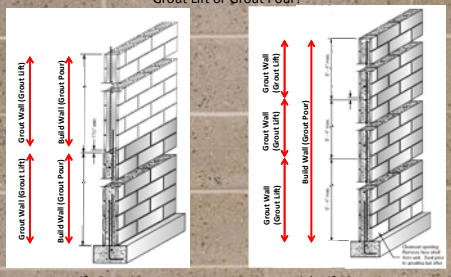
When grout pours exceed 5'-0", the first course of block shall consist of inverted double open-end bond beam block. Provide cleanouts for access to every cell with vertical reinforcement.

Assumption: Solidly grouted masonry – The most important concept is to invert the bond beams on the first course to provide access for cleaning the cells and to maximize grout contact with foundation. Technicality-the note is referring to grout pours, not grout lifts.

Masonry Detailing and Construction

The Right Specification

Grout Lift or Grout Pour?



Low Lift Grouting | High Lift Grouting

Masonry Detailing and Construction

The Right Specification

Structural Notes Said

A grout lift shall not be permitted to set prior to placement and consolidation of subsequent grout lift.

Should Have Been

When grout pours exceed 5'-0", a grout lift shall not be permitted to set prior to placement and consolidation of subsequent grout lift.

When grout pours do not exceed 5'-0" (low-lift grouting) the grout must set prior to the erection of additional masonry.

Masonry Detailing and Construction

The Right Specification

Structural Notes Said

Cleanouts at the bottom of all cells shall be used unless the lift is 4'-0" or less. Grout for each pour shall be stopped 1½" below the top of a block course except…

Should Have Been

Provide cleanouts for access to all cells when grout pours exceed 4'-0". Grout for each pour shall be stopped a minimum of 1½" below the top of a block course except…

Cleanouts relate to grout pours, not grout lifts. The grout key is intended to be a minimum dimension, not an exact dimension.

Masonry Detailing and Construction

The Right Specification

Structural Notes Said

Concrete masonry units (CMU) shall develop the following minimum 28 day prism compressive strengths in accordance with the building code.

MINIMUN 28 DAY COMPRESSIVE STRENGTHS			
Location	f'm	Type S Mortar	Grout
All CMU UNO	1500 psi	1900 psi	2000 psi

Should Have Been (without table)

Verify compliance with the masonry design strength, f'_m, by the prism test method.

The code is clear that verification of the compressive strength is to be by the prism test method or the unit strength method, not both.

MOVING FORWARD

Masonry Detailing and Construction

What is the Strength of Masonry?

- Methods of Determination
  - Prism Test Method *OR*
  - Unit Strength Method
  - Testing Prisms from Constructed Masonry
- What About Mortar?
  - (Implication) Stronger is Not Better
  - Less Cement = Better Bond = Better Performance

Masonry Detailing and Construction

Masonry Prism

Unit Strength

Masonry Detailing and Construction

Prism Test Method	**Unit Strength Method**
• CMU strength, 1,900 psi minimum	• CMU strength, 1,900 psi minimum
• Assume high strength unit = 3,750 psi	• Assume high strength unit = 3,750 psi
• Type S Mortar	• Type S Mortar
• Grout = 3,750 psi	• Grout = 3,750 psi
Will test between 3,200 and 3,500 psi	Table verifies 2,500 psi (≈ 30% less)

Masonry Detailing and Construction

Moving Forward

- Masonry Unit Strength Table Recalibration (2013 TMS 402)
- Based on Unrecognized Strength of Masonry
- ASTM C90-Standard Specification for Loadbearing Concrete Masonry Units
  - C90-13 – Compressive Strength 1,900 psi
  - C90-14 – Compressive Strength 2,000 psi

Masonry Detailing and Construction

Moving Forward

ASTM C90-13, Table 2 Strength, Absorption and Density Classification Requirements

Density Classification	Oven-Dry Density of Concrete, lb/ft³ (kg/m³)	Maximum Water Absorption lb/ft³ (kg/m³)		Minimum Net Area Compressive Strength, lb/in² (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)	1900 (13.1)	1700 (11.7)
Medium Weight	105 to less than 125 (1680-2000)	15 (240)	17 (272)	1900 (13.1)	1700 (11.7)
Normal Weight	125 (2000) or more	13 (208)	15 (240)	1900 (13.1)	1700 (11.7)

Masonry Detailing and Construction

Moving Forward

ASTM C90-14, Table 2 Strength, Absorption and Density Classification Requirements

Density Classification	Oven-Dry Density of Concrete, lb/ft³ (kg/m³)	Maximum Water Absorption lb/ft³ (kg/m³)		Minimum Net Area Compressive Strength, lb/in² (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)

Masonry Detailing and Construction

Masonry Unit Strength Recalibration

- Verification of masonry compressive strength
  - Prism test method
  - Unit strength method
  - Testing prisms from constructed masonry
  - (Masonry prism test record—No longer available)
    - Uniform Building Code exclusive
    - At least 30 historic prisms required
    - Test record results required to be at least 1.33 f'_m

Masonry Detailing and Construction

1973 Uniform Building Code

1973 UBC Table 24-J ASSUMED COMPRESSIVE STRENGTH I N BRICK MASONRY

COMPRESSIVE STRENGTH OF MASONRY UNITS, (psi)	ASSUMED COMPRESSIVE STRENGTH OF BRICK MASONRY, f'_m, psi		
	TYPE M MORTAR	TYPE S MORTAR	TYPE N MORTAR
Special Inspection Required→	Yes / No	Yes/No	Yes/No
14,000 plus	4600 / 2300	3900 / 1950	3200 / 1600
10,000	3400 / 1700	2900 / 1450	2400 / 1200
6,000	2200 / 1100	1900 / 950	1600 / 800
2,000	1000 / 500	900 / 450	800 / 400

- **Section 2404 (c).2.d.3 Assumed ultimate compressive strength**
  Hollow Concrete Units—Grade N.....f'_m = 1350 psi

Masonry Detailing and Construction

1988 Uniform Building Code (thru 1997)

1988 UBC Table 24-C SPECIFIED COMPRESSIVE STRENGTH OF MASONRY, f'm, (psi) BASED ON SPECIFYING THE COMPRESSIVE STRENGTH OF MASONRY UNITS

Specified Strength of Clay Masonry Units (psi)	Specified Compressive Strength of Masonry, f'_m	
	Type M or S Mortar (psi)	Type N Mortar (psi)
14,000 or more	5,300	4,400
12,000	4,700	3,800
10,000	4,000	3,300
8,000	3,350	2,700
6,000	2,700	1,100
4,000	2,000	1,600

Specified Strength of Concrete Masonry Units (psi)	Specified Compressive Strength of Masonry, f'_m	
	Type M or S Mortar (psi)	Type N Mortar (psi)
4,800 or more	3,000	2,800
3,750	2,500	2,350
2,800	2,000	1,850
1,900	1,500	1,350
1,250	1,000	950

Masonry Detailing and Construction

2011 TMS 602, Specification for Masonry Structures

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

Net area compressive strength of concrete masonry units, psi		Net area compressive strength of masonry, psi
Type M or S mortar	Type N mortar	
---	1,900	1,350
1,900	2,150	1,500
2,800	3,050	2,000
3,750	4,050	2,500
4,800	5,250	3,000

Masonry Detailing and Construction

2013 TMS 602, Specification for Masonry Structures - *Proposed*

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

Net area compressive strength of concrete masonry units, psi		Net area compressive strength of masonry, psi
Type M or S mortar	Type N mortar	
---	~~1,900~~	~~1,350~~
~~1,900~~	~~2,150~~	~~1,500~~
~~2,800~~ 2,000	~~3,050~~ 2,000	2,000
~~3,750~~ 2,500	~~4,050~~ 2,500	2,500
~~4,800~~ 3,835	~~5,250~~ ---	3,000
4,875	---	3,500
5,500	---	4,000

Masonry Detailing and Construction

2013 TMS 602, Specification for Masonry Structures - *Accepted*

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

Net area compressive strength of concrete masonry units, psi		Net area compressive strength of masonry, psi
Type M or S mortar	Type N mortar	
---	~~1,900~~ 1,900	~~1,350~~ 1,700
~~1,900~~ 1,900	~~2,150~~ 2,350	~~1,500~~ 1,900
~~2,800~~ ~~2,000~~ 2,000	~~3,050~~ ~~2,000~~ 2,650	2,000
~~3,750~~ ~~2,500~~ 3,250	~~4,050~~ ~~2,500~~ 4,350	2,500
~~4,800~~ ~~3,835~~ 4,500	~~5,250~~ ---	3,000
~~4,875~~	---	~~3,500~~
~~5,500~~	---	~~4,000~~

Masonry Detailing and Construction

2013 TMS 602, Specification for Masonry Structures

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

Net area compressive strength of concrete masonry units, psi		Net area compressive strength of masonry, psi
Type M or S mortar	Type N mortar	
---	1,900	1,700
1,900	2,350	1,900
2,000	2,650	2,000
3,250	4,350	2,500
4,500	---	3,000

Masonry Detailing and Construction

2013 TMS 602, Specification for Masonry Structures

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	Net area compressive strength of concrete masonry units, psi	
	Type M or S mortar	Type N mortar
1,700	---	1,900
1,900	1,900	2,350
2,000	2,000	2,650
2,250	2,660	3,400
2,500	3,250	4,350
2,750	3,900	---
3,000	4,500	---

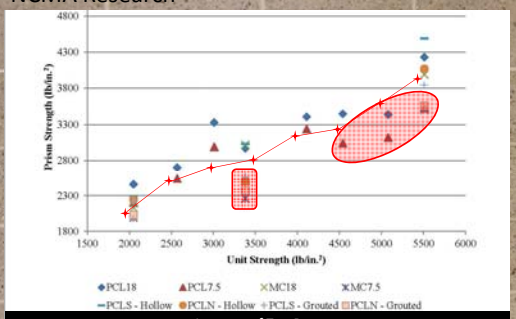
Masonry Detailing and Construction

Background

- How did we get there?
  - Research – NCMA
  - Proposal – TMS 602/MSJC Committee
  - Rejection – TMS 602/MSJC Committee
  - Task Group – Assigned by MSJC
    - Iteration
    - Compromise
  - Successful Ballot – TMS 602/MSJC Committee

Masonry Detailing and Construction

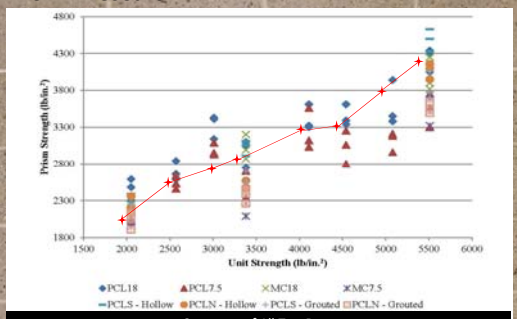
NCMA Research



Averages of Test Data

Masonry Detailing and Construction

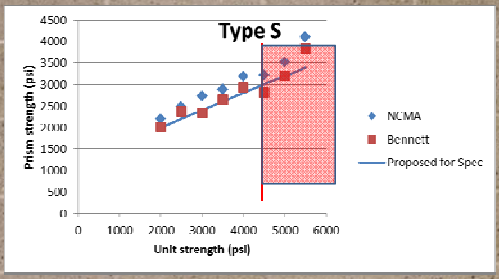
NCMA Research



Summary of All Test Data

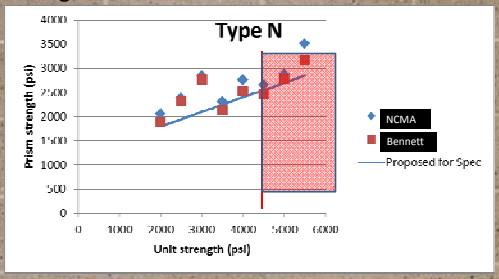
Masonry Detailing and Construction

Background



Masonry Detailing and Construction

Background



Masonry Detailing and Construction

ASTM C90 Modification

- In concert with ASTM C90
  - There is a new change in ASTM C90-14 - Raise minimum average CMU strength requirement from 1,900 psi to 2,000 psi
  - Original Unit Strength change proposal assumed ASTM C90 change would be published
  - Unit Strength Table accommodates both 1,900 psi and 2,000 psi block strength during transition

Masonry Detailing and Construction

Benefits

- **Design** – 2,000 psi, up from 1,500 psi
- **Material** – Recognized for improved manufacturing methods and increased quality control
- **Verification** – Moves results of two verification methods somewhat closer together while maintaining implied requirement for Prism Test Method on higher strength masonry

Masonry Detailing and Construction

Strength Verification Method

- **Unit Strength** Verification is easily applied for design strengths of up to 2,500 psi, maybe 3,000
- **Prism Test** Verification may be applied for any strength masonry, but is the reasonable choice for higher design strength and the only choice for very high design strength

Masonry Detailing and Construction

Unit Strength Task Group

Many thanks to our Task Group

Russ Brown, Chair
Dick Bennett
John Chrysler
Rich Klingner
Art Schultz
Jason Thompson
Diane Throop

Masonry Detailing and Construction

- Base design of masonry (*f'm*) has been 1,500 psi
  - Why? – Verification of design strength (*f'm*)
  - Low value on Unit Strength Table is 1,500 psi

(TMS 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 units, psi (MPa)		Net area compressive strength of masonry, psi (MPa)
Type M or S Mortar	Type N Mortar	
---	1,900 (13.10)	1,350 (9.31)
1,900 (13.10)	2,150 (14.82)	1,500 (10.34)
2,800 (19.31)	3,050 (21.03)	2,000 (13.79)
3,750 (25.86)	4,050 (27.92)	2,500 (17.24)
4,800 (33.10)	5,250 (36.20)	3,000 (20.69)

Masonry Detailing and Construction

- Changes coming – increase in CMU strength
  - ASTM C90-14 requires CMU to be 2,000 psi

(TMS 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)	Net area compressive strength of concrete masonry units, psi (MPa)	
	Type M or S Mortar	Type N Mortar
1,700 (11.72)	---	1,900 (13.10)
1,900 (13.10)	1,900 (13.10)	2,350 (16.20)
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)	---

Masonry Detailing and Construction

- Not so fast—not everything gets increased by ⅓rd
- For example-Reinforcement development length

$$l_d = \frac{0.13 d_b^2 f_y \gamma}{K\sqrt{f'_m}}$$ = 23 in. (for 2000 psi), 20 in for (1,500 psi)

+ 15%

- And ASD in-plane shear stress

$1.5\sqrt{f'_m} = 58$ psi (for 2000 psi), 67 psi for (1,500 psi)

+ 15.5%

Masonry Detailing and Construction

Moving Forward

- Some Thoughts to Ponder
  1. If a low bidder is <u>really</u> low, a higher level of QA verification may be required
  2. Many contractors are willing to go the extra mile if they know where that extra mile is
  3. Communication leads to Quality

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Thank You

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