Overview of Masonry Codes

AIA Course:

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Richard Bennett
Professor, Civil and Environmental Engineering
The University of Tennessee, Knoxville

THE MASONRY SOCIETY

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Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

Course Description

This session will provide an overview of the TMS 402/602 code and specification. An overview of the organization of the code will be covered. The allowable stress design method will be compared to the strength design methods. The instructor will regale the participants with stories behind some of the code provisions. Notes and spreadsheets will be provided to participants for a complete structural masonry design course.

Learning Objectives

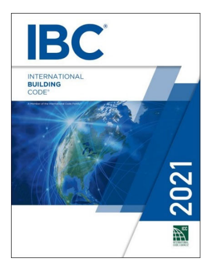
1. Understand the organization of TMS 402/602
2. Be informed on recent changes in the code
3. Understand the basic provisions of the TMS 402 Building Code Requirements for Masonry Construction
4. Understand structural masonry design using the TMS 402 code

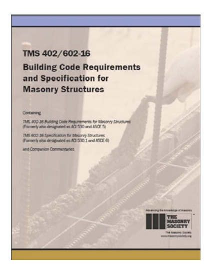
LazyDog Bennett's Course

- https://efcms.engr.utk.edu/ce576-2021-06/index.php
- Login: Netid: TMS402 Password: TMS602
- Many of powerpoints available by changing extension of .pdf to .pptx
- Notes based on 2016 code

Masonry Codes and Standards

- Almost the entire US now uses the IBC. We will focus on the 2021 IBC.
- https://codes.iccsafe.org/content/IBC2021P1
- The IBC extensively references "Consensus" Design and Material Standards:
  - ASTM Standards for Materials
  - ASCE 7 for Loads
  - ACI 318 for Concrete
  - TMS 402/602 for Masonry
    - Current is 2016
    - Will cover 2022





IBC Masonry Requirements

- Chapter 7 – Fire Ratings
- Chapter 14 – Veneer
- Chapter 17 – Quality Assurance
- Chapter 18 – Foundation Walls (includes prescriptive requirements based on TMS 402 Strength Design Procedures)
- Chapter 21 – Masonry

IBC Chapter 21

Section 2101 General
Section 2102 Notations
Section 2103 Masonry Construction Materials
Section 2104 Construction
Section 2105 Quality Assurance
Section 2106 Seismic Design
Section 2107 Allowable Stress Design
Section 2108 Strength Design of Masonry
Section 2109 Empirical Design of Adobe Masonry
Section 2110 Glass Unit Masonry
Section 2111 Masonry Fireplaces
Section 2112 Masonry Heaters
Section 2113 Masonry Chimneys
Section 2114 Dry-stack Masonry

IBC Section 2107: ASD

IBC Section 2107 requires compliance with TMS 402 Chapter 8, except for:

- Modifies splice lengths
  - $l_d = 0.002 d_b f_s \geq 12$ in.
  - f_s = computed stress in reinforcement due to design loads
  - Increase lap length by 50% when $f_s > 0.80 F_s$
  - Some cases is more conservative and in some cases less conservative than the TMS 402
- Has additional requirements for mechanical and welded splices
  - ASTM A706 steel required for welded lap splices.
  - Mechanical splices required for bars > No. 9

IBC Section 2108: SD

IBC Section 2108 requires compliance with TMS 402 Chapter 9, except:

- Development lengths capped at $72 d_b$
  - for No. 7 and larger bars, the $72 d_b$ cap generally governs and the IBC gives a shorter development lengths than the TMS 402.
- Has additional requirements for mechanical and welded splices
  - ASTM A706 steel required for welded lap splices. Welded splices not permitted in plastic hinge zones of intermediate or special shear walls.
  - ACI 318 Type 1 mechanical splices required in plastic hinge zones of intermediate and special shear walls.

TMS 402/602

- *TMS 402 “Code”*
  - Design provisions are given in Chapters 1 - 15 and Appendices C and D
  - Sections 1.2.4 and Chapter 3 require a QA program in accordance with the Specification
  - Section 1.4 invokes the Specification by reference.
- *TMS 602 “Specification”*
  - verify compliance with specified f'_m
  - comply with required level of quality assurance
  - comply with specified products and execution

History of TMS 402/602

1988: First edition

1995: Seismic requirements moved from Appendix to main body of code; chapter on veneers added; chapter on glass block added

1998: Major reorganization of code; prestressed masonry chapter added

2002: Strength design chapter added; definitions of shear walls added to correspond to IBC definitions; code moved to a three year revision cycle

2005: Changed lap splice requirements, requiring much longer lap lengths

2008: Major reorganization of seismic requirements; added AAC masonry in Appendix

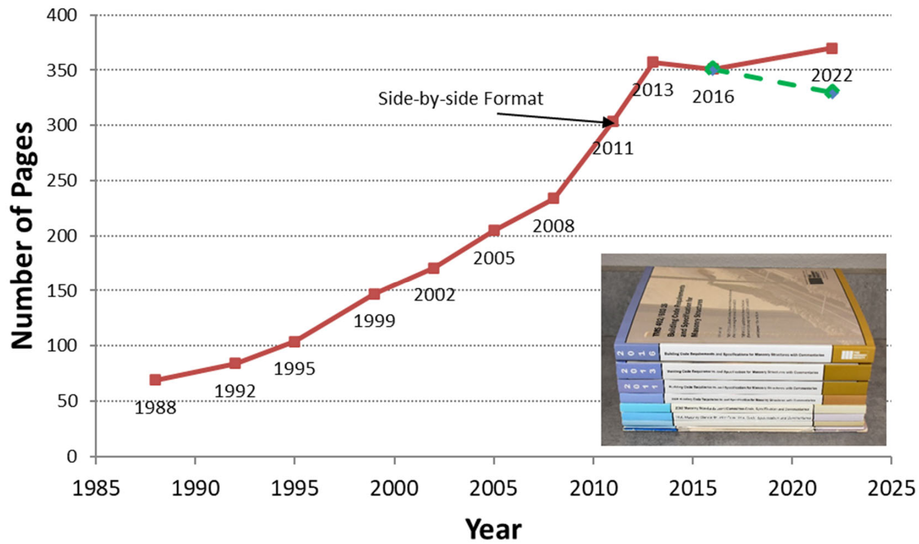
2011: Eliminated one-third stress increase and recalibrated allowable stresses; added infill provisions in Appendix

2013: Changes for partially grouted shear walls; updated unit strength table; limit states appendix

2016: Add shear friction provisions; increase cavity width; update anchor bolts

2022: Go to a six-year cycle

TMS 402 Pages



2022 TMS 402

Part 1: General
- Chapter 1: General requirements
- Chapter 2: Notation and Definitions
- Chapter 3: Quality and Construction

Part 2: Design Requirements
- Chapter 4: General Analysis and Design Considerations
- Chapter 5: Structural Elements
- Chapter 6: Reinforcement, Metal Accessories, and Anchor Bolts
- Chapter 7: Seismic Design Requirements

Part 3: Engineered Design Methods
- Chapter 8: Allowable Stress Design
- Chapter 9: Strength Design
- Chapter 10: Prestressed Masonry
- Chapter 11: AAC Masonry
- Chapter 12: Design of Masonry Infill

Part 4: Prescriptive Design Methods
- Chapter 13: Veneer
- Chapter 14: Glass Unit Masonry
- Chapter 15: Masonry Partition Walls

Part 5: Appendices
- Appendix C: Limit Design Method
- Appendix D: Glass Fiber Reinforced Polymer (GFRP) Reinforced Masonry

2022 TMS 602

- 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, Handling, and Storage
  - 1.8: Project conditions
- Part 2: Products
  - 2.1: Mortar Materials
  - 2.2: Grout Materials
  - 2.3: Masonry Unit Materials
  - 2.4: Reinforcement, Prestressing Tendons, and Metal Accessories
  - 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, Tie, and Anchor Installation
  - 3.5: Grout Placement
  - 3.6: Prestressing Installation
  - 3.7: Field Quality Control
  - 3.8: Cleaning
- Specifications Checklist
  - Mandatory Requirements Checklist
  - Optional Requirements Checklist

TMS 402 Part 1 General Requirements

- Ch. 1: Scope, Contract documents and calculations, Special Systems, Reference Standards
- Ch. 2: Notation, Definitions
- Ch. 3 Quality & Construction
  - Requires a quality assurance program in accordance with the Specification
  - Three levels of quality assurance (1, 2, 3)
  - Increasing levels of quality assurance require increasingly strict requirements for inspection, and for compliance with specified products and execution

TMS 402 Table 3.1: Quality Assurance

Designed in accordance with	Risk Category I, II, or III	Risk Category IV
Part 3 or Appendix C or Appendix D (Engineered Design)	Level 2	Level 3
Part 4 (Prescriptive Design)	Level 1	Level 2

TMS 602 Verification Requirements

Table 3 — Minimum Verification Requirements

Minimum Verification	Required for Quality Assurance[(a)]			Reference for Criteria
	Level 1	Level 2	Level 3	TMS 602
Prior to construction, verification of compliance of submittals.	R	R	R	Art. 1.5
Prior to construction, verification of f'_m and f'_{AAC}, except where specifically exempted by the Code.	NR	R	R	Art. 1.4 B
During construction, verification of Slump flow and Visual Stability Index (VSI) when self-consolidating grout is delivered to the project site.	NR	R	R	Art. 1.5 & 1.6.3
During construction, verification of f'_m and f'_{AAC} for every 5,000 sq. ft. (465 sq. m).	NR	NR	R	Art. 1.4 B
During construction, verification of proportions of materials as delivered to the project site for premixed or preblended mortar, prestressing grout, and grout other than self-consolidating grout.	NR	NR	R	Art. 1.4 B

(a) R=Required, NR=Not Required

TMS 602 Table 3: Minimum Verification Requirements

Minimum Verification	Required for Quality Assurance		
	Level 1	Level 2	Level 3
Prior to construction, verification of compliance of submittals	R	R	R
Prior to construction, verification of f'_m except where specifically exempted by the Code.	NR	R	R
During construction, verification of f'_m for every 5,000 sq ft.	NR	NR	R

TMS 602 QA Requirements

Table 4 — Minimum Special Inspection Requirements

MINIMUM SPECIAL INSPECTION					
Inspection Task	Frequency [(a)]			Reference for Criteria	
	Level 1	Level 2	Level 3	TMS 402	TMS 602
1. As masonry construction begins, verify that the following are in compliance:					
a. Proportions of site-prepared mortar	NR	P	P		Art. 2.1, 2.6 A, & 2.6 C
c. Grade and size of prestressing tendons and anchorages	NR	P	P		Art. 2.4 B & 2.4 H
c. Grade, type and size of reinforcement, connectors, anchor bolts,and prestressing tendons and anchorages	NR	P	P		Art. 3.4 & 3.6 A
d. Prestressing technique	NR	P	P		Art. 3.6 B
e. Properties of thin-bed mortar for AAC masonry	NR	C[(b)]/P[(c)]	C		Art. 2.1 C.1
f. Sample panel construction	NR	P	C		Art. 1.6 D
2. Prior to grouting, verify that the following are in compliance:					
a. Grout space	NR	P	C		Art. 3.2 D & 3.2 F
b. Placement of prestressing tendons and anchorages	NR	P	P		Art. 2.4 & 3.6
c. Placement of reinforcement, connectors, and anchor bolts	NR	P	C	Sec. 6.1, 6.3.1, 6.3.6, & 6.3.7	Art. 3.2 E & 3.4
d. Proportions of site-prepared grout and prestressing grout for bonded tendons	NR	P	P		Art. 2.6 B & 2.4 G.1.b

TMS 602 Table 4: Minimum Special Inspection Requirements

Inspection Task	Frequency		
	Level 1	Level 2	Level 3
1. As masonry construction begins:			
Proportions of site-prepared mortar	NR	P	P
2. Prior to grouting:			
Grout space	NR	P	C
Placement of reinforcement	NR	P	C
3. During construction:			
Placement of masonry units	NR	P	P
Placement of grout	NR	C	C
4. Observe preparation of grout specimens, mortar specimens, and/or prisms	NR	P	C

TMS 402 Part 2: Design Requirements

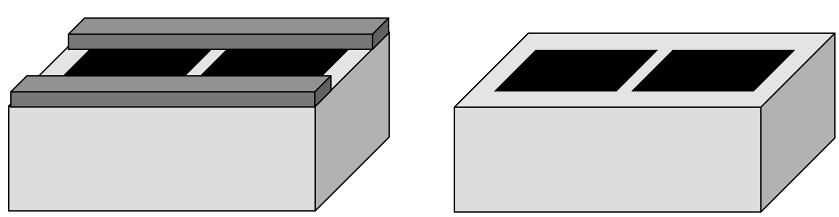
- Ch. 4: General Analysis & Design Considerations
  - 4.1 Loading
  - 4.2 Material properties
  - 4.3 Specified compressive strength
  - 4.4 Section properties
  - 4.5 Connections to structural frames
  - 4.6 Deflection of beam supporting unreinforced masonry
  - 4.7 Masonry not laid in running bond
  - 4.8 Embedded conduits, pipes, and sleeves
- Ch. 5: Structural Elements
- Ch. 6: Details of reinforcement, metal accessories & anchor bolts
- Ch. 7 Seismic design requirements

TMS 402 4.2 Material Properties

Property	CMU	Clay
Modulus of Elasticity	$900f'_m$	$700f'_m$
Modulus of rigidity (shear modulus)	$0.4E_m$	$0.4E_m$
Coefficient of thermal expansion	4.5 x 10^{-6} in./in./°F	4.0 x 10^{-6} in./in./°F
Coefficient of moisture expansion	N/A	3 x 10^{-4} in./in.
Coefficient of shrinkage	$k_m = 0.5s_l$ C90 limits shrinkage to 0.065%	N/A
Coefficient of creep	2.5 x 10^{-7} /psi	0.7 x 10^{-7} /psi

TMS 402 Section 4.4: Section Properties

- Use minimum (critical) net area for computing member stresses or capacities.
- Radius of gyration and member slenderness are better represented by the average section



TEK 14-01B: Section Properties of Concrete Masonry Walls

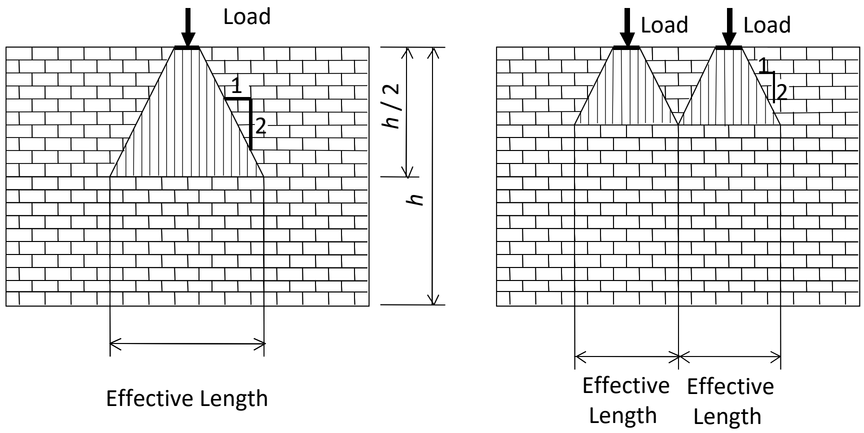
TMS 402 Section 4.4: Net Shear Area (Added in 2022)

Loading Direction / Member Type	Fully Grouted	Partially Grouted
Out-of-Plane / Wall	$A_{nv} = bd$; b = effective compression width (Section 5.1.2)	$A_{nv} = bd$
In-plane / Planar Shear Wall	$A_{nv} = t_{sp}d_v$	$A_{nv} = A_n$; A_n = net cross-sectional area
In-plane / Flanged Shear Wall	$A_{nv} = t_{sp}d_v$	$A_{nv} = A_n$ of segment of wall that lies parallel to the direction of applied shear
Beams	$A_{nv} = t_{sp}d$	$A_{nv} = 2t_{fs}d$

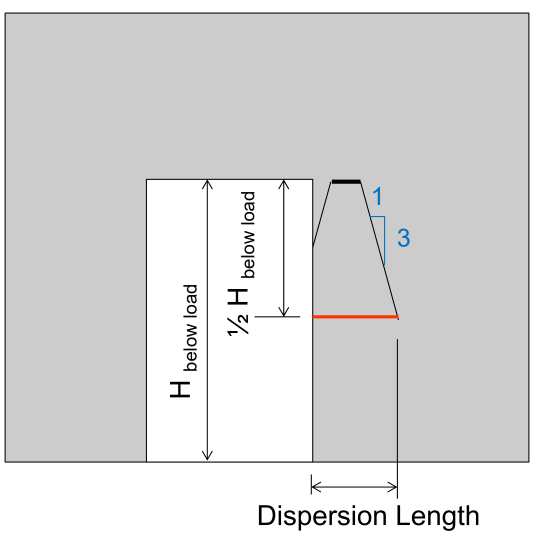
TMS 402 Part 2: Design Requirements

- Ch. 4: General Analysis & Design Considerations
- Ch. 5: Structural Elements (new section numbers in 2022)
  - 5.1 General
  - 5.2 Walls
  - 5.3 Beams
  - 5.4 Columns
  - 5.5 Pilasters
  - 5.6 Corbels
- Ch. 6: Details of reinforcement, metal accessories & anchor bolts
- Ch. 7 Seismic design requirements

TMS 402 5.1.1: Concentrated Load Dist.

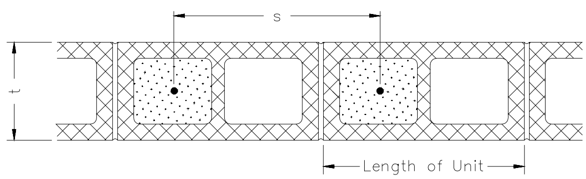


TMS 402 5.1.1: Concentrated Load Dist.



TMS 402 5.1.2: Effective Comp. Width

- For running - bond masonry, or masonry with bond beams spaced no more than 48 in. center – to – center:
  - Center - to - center bar spacing
  - Six times the wall thickness (nominal)
  - 72 in.

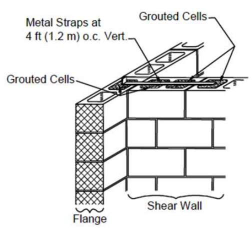


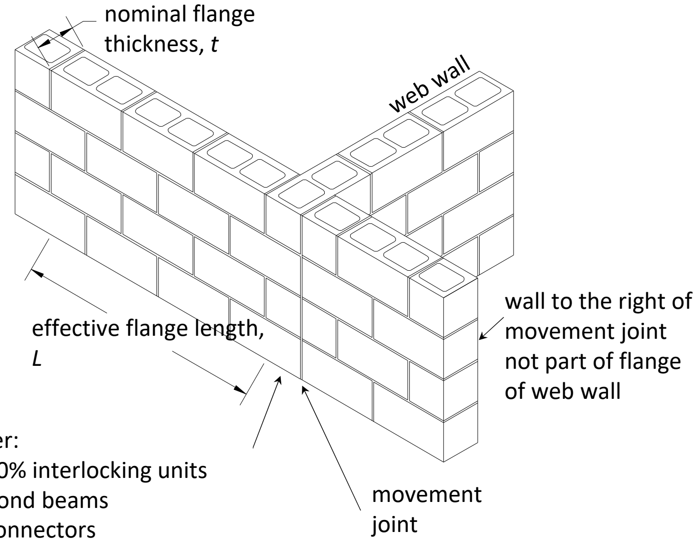
TMS 402 5.2: Walls (added in 2022)

- 5.2.1 Design of independent walls
- 5.2.2 Design of lateral supports of walls without composite action
- 5.2.3 Design of masonry wall and pilaster sections for composite action

TMS 402 5.2.3: Effective Flange Width

L = 6*t* for compression or unreinforced masonry in tension
L = 3/4 floor - to - floor wall height for reinforced masonry in tension

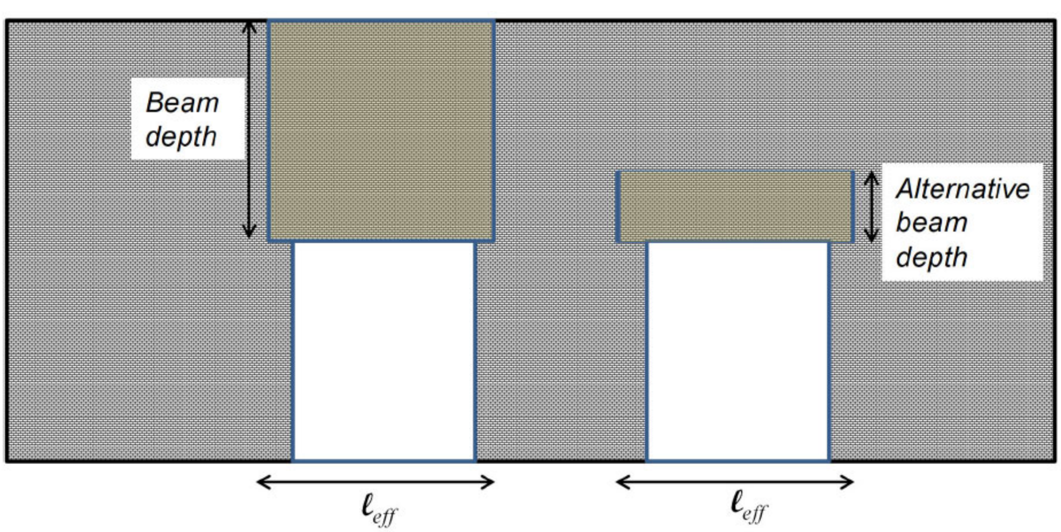




Either:

- 50% interlocking units
- bond beams
- connectors

TMS 402 5.3: Beams

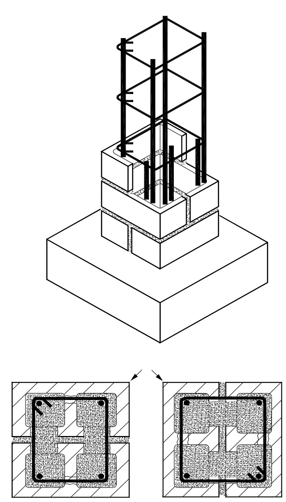


TMS 402 5.3: Beams

- Beams requiring shear reinforcement must be fully grouted
- Lateral support on compression face required
  - 32*b* (b = nominal beam thickness)
  - $120b^2/d$
- Shear can be taken at *d*/2 from face of support (applies to all beams in 2022)
- Deflections need not be checked when the span length does not exceed 8*d* in a masonry beam

TMS 402 5.4: Columns

- ISOLATED member that primarily resists compressive loads
- $h / r \leq 99$
- Minimum side dimension: 8 in.
- $0.25\% \leq \rho_g \leq 4.0\%$
- At least 4 longitudinal bars, laterally tied, except for lightly loaded columns



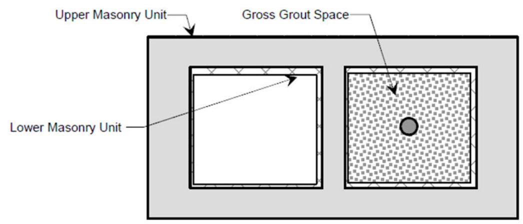
TMS 402 Part 2: Design Requirements

- Ch. 4: General Analysis & Design Considerations
- Ch. 5: Structural Elements
- Ch. 6: Details of reinforcement, metal accessories & anchor bolts
  - 6.1 Reinforcement
  - 6.2 Metal accessories
  - 6.3 Anchor bolts
- Ch. 7 Seismic design requirements

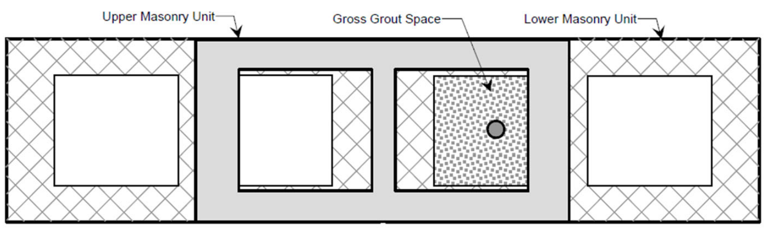
TMS 402 6.1: Reinforcement (harmonized in 2022)

Requirement	Provision	TMS 402 Ref.
Size of reinforcement	Maximum size: No. 11	6.1.3.2.1
	$d_b \leq 1/8$ least nominal dimension	6.1.3.2.3
	$d_b \leq 1/3$ of least clear dimension of gross grout space	6.1.3.2.4
	Area of vertical reinforcement ≤ 4% gross grout space 8% at lap splices	6.1.3.2.5
Placement of reinforcement	Clear distance between bars ≥ max{ d_b, 1 in. }	6.1.4.1
	Columns and pilasters: Clear distance between bars ≥ max{ 1.5d_b, 1.5 in. }	6.1.4.2
	Thickness of grout between reinforcement and masonry unit Coarse grout: ½ in. Fine grout: ¼ in.	6.1.4.5
Protection of reinforcement	Masonry exposed to earth or weather: No. 5 and smaller: 1½ in. cover larger than No. 5: 2 in. cover Masonry not exposed to earth or weather: 1.5 in. cover	6.1.5.1

TMS 402 6.1: Gross Grout Space (new in 2022)



Stack Bond



Running Bond

TMS 402 6.1: Maximum Vertical Reinforcement

Table CC-6.1.3.2.5.2.1 Maximum Vertical Reinforcement –
One-half Running Bond Two-cell Units

Nominal Unit Thickness	Maximum Vertical Reinforcement in Cell		
	Flanged Units	Jamb Units	Open-End Units
6 in.	1-#6 or 2-#4	1-#6 or 2-#5	1-#6 or 2-#5
8 in.	1-#7 or 2-#5	1-#8 or 2-#6	1-#8 or 2-#6
10 in.	1-#8 or 2-#6	1-#9 or 2-#6	1-#10 or 2-#7
12 in.	1-#9 or 2-#6	1-#10 or 2-#7	1-11 or 2-#8

TMS 402 6.1.6: Development Length

Condition	Provision	TMS 402 Ref.
Bars in grouted clay masonry and concrete masonry	$\max\left\{\frac{0.13 d_b^2 f_y \gamma}{K\sqrt{f'_m}}, 12\text{in.}\right\}$ K = min{masonry cover, clear spacing between adjacent splices, $9d_b$} $\gamma = \begin{cases} 1.0 & \text{for No. 3 through No. 5} \\ 1.3 & \text{for No. 6 and No. 7} \\ 1.5 & \text{for No. 8 through No. 11} \end{cases}$	6.1.6.3.1
Hooks in tension	$l_{dh} = l_d - \gamma_h d_b$ $\gamma = \begin{cases} 9.0 & \text{for No. 3 through No. 9} \\ 8.0 & \text{for No. 8 through No. 11} \end{cases}$	6.1.6.3.3
Wires in tension	$l_d = 48 d_b$	6.1.6.2.1.1
Epoxy-coated wires and bars	Development length increased by 150%	6.1.6.3.1

TMS 402 6.1: Splice Length

Condition	Provision	TMS 402 Ref.
Lap splices of bar reinforcement	$\max\left\{\frac{0.13 d_b^2 f_y \gamma}{K\sqrt{f'_m}}, 12\text{in.}\right\}$	6.1.7.1.1.2
Noncontact lap splices	Transverse spacing ≤ min{1/5 lap length, 8 in.}	6.1.7.1.2.3
Welded splices of bar reinforcement	Develop $1.25f_y$ Welding conforms to AWS 1.4 ASTM A706 bars or chemical analysis and carbon equivalent	6.1.7.3.1
Mechanical splices of bar reinforcement	Develop $1.25f_y$	6.1.7.2.1

TMS 402 6.3: Anchor Bolts

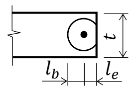
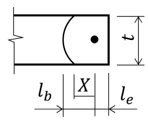
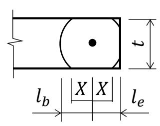
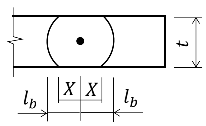
- Tensile capacity governed by
  - tensile breakout
  - tensile pullout
  - yield of anchor in tension
- Shear capacity governed by
  - shear breakout
  - masonry crushing
  - shear pryout
  - yield of anchor in shear

- Headed bolts, J - bolts or L - bolts
- Must be embedded in grout

TMS 402 6.3: Anchor Bolts - Tension

Failure Mode	Allowable Stress Design (8.1.3.3.1)	Strength Design (9.1.6.3.1)
Masonry breakout	$B_{ab} = 1.25A_{pt}\sqrt{f'_m}$	$B_{anb} = 4A_{pt}\sqrt{f'_m}$ $\phi = 0.5$
Steel strength (changed from f_y to f_u in 2022)	$B_{as} = 0.5A_b f_u$	$B_{ans} = A_b f_u$ $\phi = 0.75$
Anchor pullout (0nly bent bar)	$B_{ap} = 0.6f'_m e_b d_b$ $+120\pi(l_b + e_b + d_b)d_b$	$B_{anp} = 1.5f'_m e_b d_b$ $+300\pi(l_b + e_b + d_b)d_b$ $\phi = 0.65$

TMS 402 6.3: Anchor Bolts

Configuration	Geometry	Projected tension area, A_{pt}
	$l_b \le t/2$ $l_e \le l_b$	$A_{pt} = \pi l_b^2 - \frac{l_b^2}{2}\left(\frac{\pi\theta}{180} - \sin\theta\right)$ $\theta = 2\arccos(l_e/l_b)$
	$l_b > t/2$ $l_e \le l_b$ $l_e \le X$	$A_{pt} = (X + l_e)t - \frac{l_b^2}{2}\left(\frac{\pi\theta}{180} - \sin\theta\right)$ $\theta = 2\arcsin\left(\frac{t/2}{l_b}\right)$
	$l_b > t/2$ $l_e \le l_b$ $l_e > X$	$A_{pt} = 2Xt + l_b^2\left(\frac{\pi(\theta - \theta_1)}{180} - sin\theta + \sin\theta_1\right)$ $\theta = 2\arcsin\left(\frac{t/2}{l_b}\right)$ $\theta_1 = 2\arccos(l_e/l_b)$
	$l_b > t/2$ $l_e > l_b$	$A_{pt} = 2Xt + l_b^2\left(\frac{\pi\theta}{180} - \sin\theta\right)$ $\theta = 2\arcsin\left(\frac{t/2}{l_b}\right)$

TMS 402 6.3: Anchor Bolts - Shear

Failure Mode	Allowable Stress (8.1.3.3.2)	Strength (9.1.6.3.2)
Masonry breakout	$B_{vb} = 1.25A_{pv}\sqrt{f'_m}$	$B_{vnb} = 4A_{pv}\sqrt{f'_m}$ $\phi = 0.5$
Masonry crushing	$B_{vc} = 580\sqrt[4]{f'_m A_b}$	$B_{vnc} = 1750\sqrt[4]{f'_m A_b}$ $\phi = 0.5$
Anchor bolt pryout	$B_{vpry} = 2B_{ab} = 2.5A_{pv}\sqrt{f'_m}$	$B_{vnpry} = 8A_{pv}\sqrt{f'_m}$ $\phi = 0.5$
Steel yielding (changed from f_y to f_u in 2022)	$B_{vs} = 0.25A_b f_u$	$B_{vns} = 0.6A_b f_u$ $\phi = 0.65$

TMS 402 6.3: Anchor Bolts

	Allowable Stress Design	Strength Design
Interaction	$\left(\frac{b_a}{B_a}\right)^{\frac{5}{3}} + \left(\frac{b_v}{B_v}\right)^{\frac{5}{3}} \leq 1$	$\left(\frac{b_{au}}{\phi B_{an}}\right)^{\frac{5}{3}} + \left(\frac{b_{vu}}{\phi B_{vn}}\right)^{\frac{5}{3}} \leq 1$

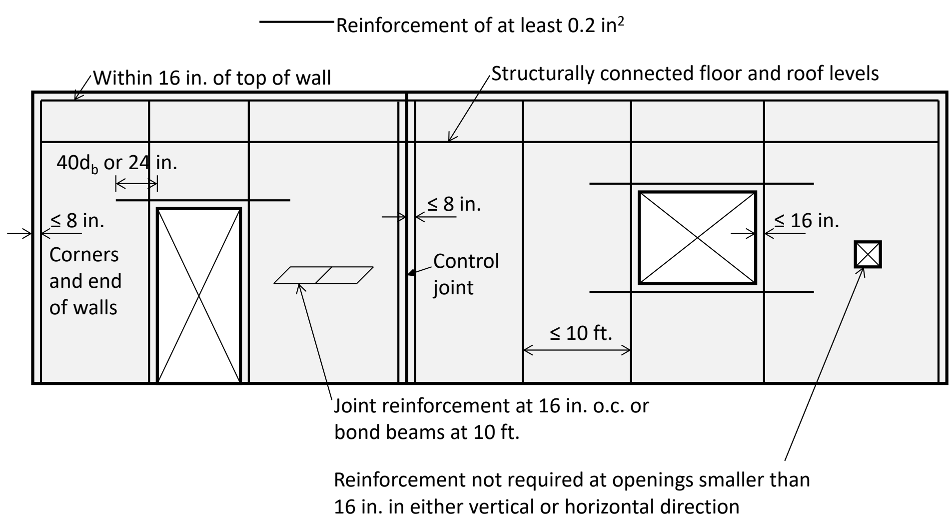
TMS 402 Part 2: Design Requirements

- Ch. 4: General Analysis & Design Considerations
- Ch. 5: Structural Elements
- Ch. 6: Details of reinforcement, metal accessories & anchor bolts
- Ch. 7 Seismic design requirements
  - 7.1 Scope
  - 7.2 General analysis
  - 7.3 Element classification
  - 7.4 Seismic Design Category Requirements

Shear Walls: Minimum Reinforcement

SW Type	Minimum Reinforcement	SDC
Empirically Designed	None	A
Ordinary Plain	None	A, B
Detailed Plain	Vertical reinforcement = 0.2 in.^{2} at corners, within 16 in. of openings, within 8 in. of movement joints, maximum spacing 10 ft; horizontal reinforcement W1.7 @ 16 in. or #4 in bond beams @ 10 ft	A, B
Ordinary Reinforced	same as above	A, B, C
Intermediate Reinforced	same as above, but vertical reinforcement @ 4 ft	A, B, C
Special Reinforced	same as above, but horizontal reinforcement @ 4 ft, and $\rho_v + \rho_h \geq 0.002$, and ρ_v and $\rho_h \geq 0.0007$	any

TMS 402 7.3.2.3: Ordinary Reinforced Walls



TMS 402 7.3.2.5: Special Reinforced Walls

- Maximum spacing of vertical and horizontal shear reinforcement smallest of:
  - one-third length of wall
  - one-third height of wall
  - 48 in. for running bond; 24 in. not laid in running bond
- Minimum reinforcement
  - 0.0007 in each direction
  - 0.002 total
- Hooks required for horizontal reinforcement when
  - $F_v/F_{vm} > 0.4$ or $V_u/\phi V_{nm} > 0.4$
  - new in 2022; not clear in 2016

Shear Capacity Design

- Allowable Stress Design
  - Calculated shear stress increased by 2.0
  - Changed from 1.5 in 2016 but no reduction in allowable masonry shear stress
- Strength Design
  - Design shear strength, ϕV_n, greater than shear corresponding to 1.25 times nominal flexural strength, M_n
  - Except ϕV_n need not be greater than $2.0V_u$.

Chapter 8 and 9

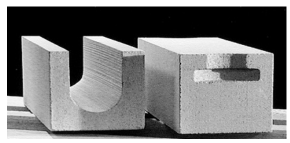
- Chapter 8: Allowable Stress Design
- Chapter 9: Strength Design
- Will cover later

TMS 402 Chapter 10: Prestressed

- Prestressed masonry provisions were introduced in the 1999 TMS 402, and extensively updated in the 2005 TMS 402
- Provisions address bonded and unbonded tendons
- Provisions address laterally restrained and laterally unrestrained tendons
- Provisions for prestressed masonry beams added in 2022

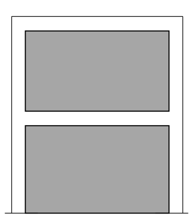
TMS 402 Chapter 11: AAC Masonry

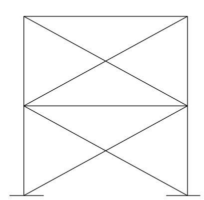
- Autoclaved Aerated Concrete (AAC) is a lightweight, concrete - like material
  - density from 25 to 50 pcf
  - compressive strength from 290 to 1100 psi
- Strength is specified by strength class of the AAC material alone (no prisms)
  - strength class is the specified compressive strength in MPa (for example, Strength Class 4 has a specified compressive strength of 4 MPa, or 580 psi)
- AAC masonry units are laid using thin - bed, polymer - modified mortar, which is stronger than the AAC material itself



TMS 402 Chapter 12: Infills

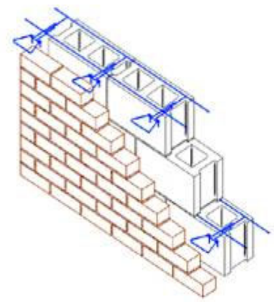
- Participating and Non-participating infills
- In-plane loading
  - Equivalent diagonal strut for stiffness
  - Strength based on shear, limiting deformation, or crushing
- Out-of-plane loading
  - Arching





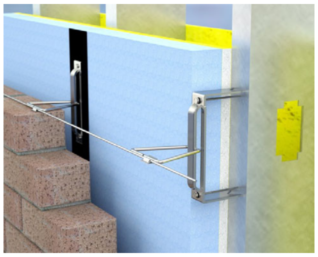
TMS 402 Chapter 13: Veneer (Completely new in 2022)

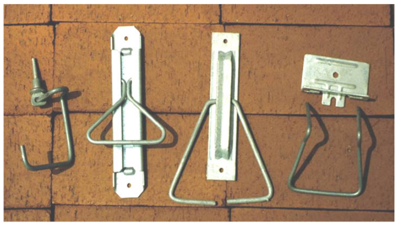
- 13.1 General
  - 13.1.1 Scope
  - 13.1.2 General design requirements
- 13.2 Anchored Veneer
  - 13.2.1 General requirements
  - 13.2.2 Prescriptive design
  - 13.2.3 Engineered design
- 13.3 Adhered Veneer
  - 13.3.1 General requirements
  - 13.3.2 Prescriptive design
  - 13.3.3 Engineered design



TMS 402 Chapter 13: Anchored Veneer

- Anchor requirements in TMS 402 Table 13.2.2.5
  - Corrugated sheet metal anchors
  - Sheet metal anchors
  - Wire anchors
  - Joint reinforcement
  - Adjustable anchors





TMS 402 Chapter 13: Prescriptive Anchored Veneer

p_{veneer}, psf	Permitted Design Method	
	Seismic Design Category A, B, and C	Seismic Design Category D and higher
≤ 50	Prescriptive (Basic) or Engineered	Prescriptive (Enhanced) or Engineered
>50 and ≤ 75	Prescriptive (Enhanced) or Engineered	
>75	Engineered	

	Basic	Enhanced
Maximum tributary area per tie	2.67 ft^2	1.78 ft^2
Maximum spacing	24 in.	16 in.

TMS 402 Chapter 13: Engineered Anchored Veneer

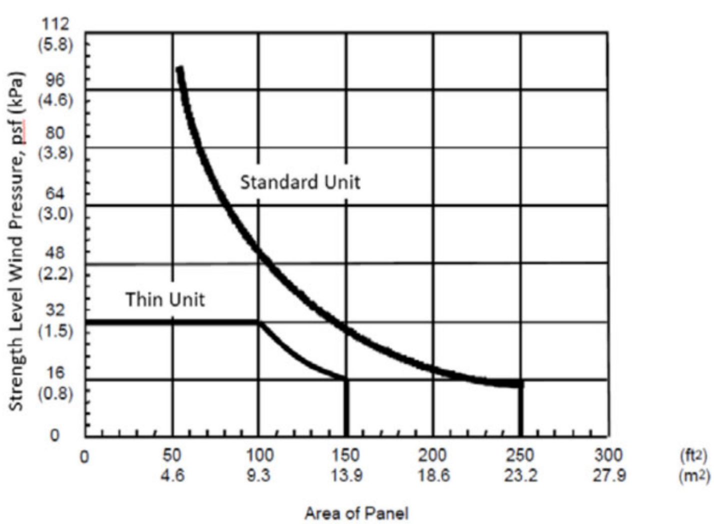
Tie stiffness (lb/inch)	Strength level force
$k_{tie} \leq 2500$	$2p_u A_t$
$2500 < k_{tie} \leq 5000$	$2.5p_u A_t$
$5000 < k_{tie} \leq 8000$	$3p_u A_t$
$k_{tie} > 8000$	$4p_u A_t$

Veneer Tie	Design Strength (lb)	Stiffness (lb/inch)
Corrugated	125	500
Adjustable – slotted	330	3000
Adjustable – two leg pintle	210	2500

TMS 402 Chapter 14: Glass Unit Masonry

- Prescriptive requirements for
  - interior and exterior panels
  - isolated panels and continuous bands
  - standard (3 ⅞ in.) or thin (3 ⅛ in.) units
  - f'_m not required for glass unit masonry designed by Chapter 13
  - Figure 13.2-1 sets maximum panel areas for different design wind pressures

TMS 402 Chapter 14: Glass Unit Masonry (includes thin units in 2022)



TMS 402 Chapter 15: Partition Walls

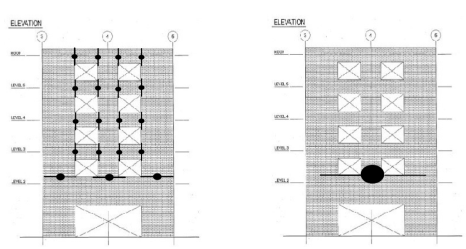
- Rationally based using engineering analysis

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

Appendix C: Limit Design Method

- Alternative for Special Reinforced Shear Walls
  - Avoids maximum reinforcement requirements
- Useful for design of complex, perforated wall configurations
  - Performance-based option
  - Global look at the wall rather than just the segments
  - Distribute shear according to the plastic capacities, rather than according to elastic stiffness
  - Code and Commentary is two pages



Appendix D: GFRP Reinforced Masonry (new in 2022)

- Scope limited to non-bearing walls and lintels in such walls
- Compression and tension-controlled sections
- Reduced masonry compressive strength for compression-controlled lintels

Comparison with Steel-Reinforced Masonry

4 - #4 GFRP Bars

3 - #4 Steel Bars

TMS 602: Verification of f'_m

- Prism test
- Unit strength table

Net area compressive strength of concrete masonry, psi	Net area compressive strength of ASTM C90 concrete masonry units, psi (MPa)	
	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	2,600	3,400
2,500	3,250	4,350
2,750	3,900	----

Allowable Stress Design: Chapter 8

TMS 402 Chapter 8: ASD

- 8.1.1 Scope
- 8.1.2 Calculated stresses
- 8.1.3 Design stress
- 8.1.4 Anchor bolts embedded in grout
- 8.1.5 Shear stress in composite masonry
- 8.1.6 Bearing stress
  - $0.33f'_m$

TMS 402 8.2: ASD Unreinforced Masonry

- 8.2.1 Scope
- 8.2.2 Design criteria
- 8.2.3 Design assumptions
- 8.2.4 Axial compression and flexure
- 8.2.5 Axial tension
- 8.2.6 Shear

Key design equation: $$f_t = \frac{Mc}{I} - \frac{P}{A}$$

TMS 402 8.3: ASD Reinforced

- 8.3.1 Scope
- 8.3.2 Design assumptions
- 8.3.3 Steel reinforcement
- 8.3.4 Axial compression and flexure
- 8.3.5 Shear
- 8.3.6 Shear-friction

TMS 402 8.3: Allowable Stresses

- Steel reinforcement (8.3.3)
  - Grade 60 32,000 psi
  - Wire joint reinforcement 30,000 psi
- Stress in masonry from axial load plus bending:
  - $0.45f'_m$ (8.3.4.2.2)
- Axial (8.3.4.2.1) (0.25 increased to 0.30 in 2022)
  - $P_a = (0.30f'_m A_n + 0.65A_{st}F_s)\left[1 - \left(\frac{h}{140r}\right)^2\right]$ for $\frac{h}{r} \leq 99$
  - $P_a = (0.30f'_m A_n + 0.65A_{st}F_s)\left(\frac{70r}{h}\right)^2$ for $\frac{h}{r} > 99$

TMS 402 8.3.5: Shear

- Shear stress is computed as: (8.3.5.1.1)
  - $f_v = \frac{V}{A_{nv}}$
- Allowable shear stress (8.3.5.1.2)
  - $F_v = (F_{vm} + F_{vs})\gamma_g$
  - γ_g = 0.70 for partially grouted shear walls, 1.0 otherwise (decreased from 0.75 in 2022)

TMS 402 8.3.5: Shear

- Allowable stress limit (8.3.5.1.2)
  - $M/(Vd_v) \leq 0.25$ $\quad F_v = \left(3\sqrt{f'_m}\right)\gamma_g$
  - $M/(Vd_v) \geq 1.0$ $\quad F_v = \left(2\sqrt{f'_m}\right)\gamma_g$
  - $0.25 < M/(Vd_v) < 1.0$ $\quad F_v = \left(\frac{2}{3}\left(5 - 2\frac{M}{Vd_v}\right)\right)\gamma_g$
- Allowable masonry shear stress (8.3.5.1.3)
  - $F_{vm} = \frac{1}{2}\left[4 - 1.75\left(\frac{M}{Vd_v}\right)\right]\sqrt{f'_m} + 0.20\frac{P}{A_n}$

$M/(Vd_V)$ is positive and need not exceed 1.0.

TMS 402 8.3.5: Shear

- Allowable reinforcement shear stress (8.3.5.1.4)
  - $F_{vs} = 0.5\left(\frac{A_v F_s d_v}{A_{nv} s}\right)$
  - Shear reinforcement is placed parallel the direction of the applied force at a maximum spacing of $d/2$ or 48 in.
  - One - third of A_v is required perpendicular to the applied force at a spacing of no more than 8 ft.

TMS 402 8.3.6: Shear Friction

Shear Span Ratio	Allowable Shear Friction	
$\frac{M}{Vd_v} \leq 0.5$	$F_f = \frac{\mu(A_{sp}F_s + P)}{A_{nv}}$	
$0.5 < \frac{M}{Vd_v} < 1.0$ Linear interpolation	$F_f = \frac{\left(0.488 + \frac{\mu - 0.488}{0.5}\left(1 - \frac{M}{Vd_v}\right)\right)A_{sp}F_s + \left(0.65 + \frac{\mu - 0.65}{0.5}\left(1 - \frac{M}{Vd_v}\right)\right)P}{A_{nv}}$	
$\frac{M}{Vd_v} \geq 1.0$	$F_f = \frac{0.65(0.75A_{sp}F_s + P)}{A_{nv}}$	0.60 increased to 0.75 in 2022

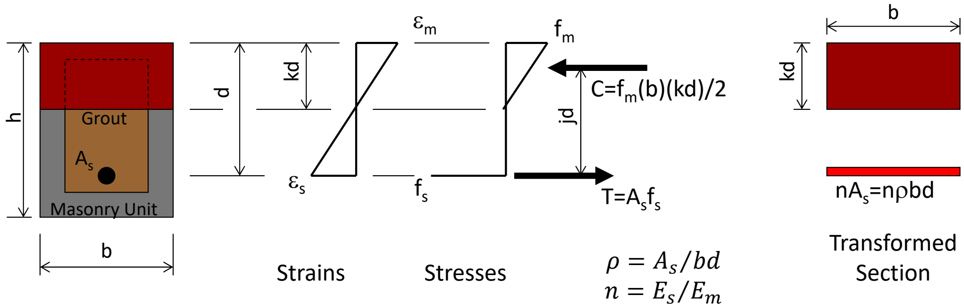
A_{sp} = cross-sectional area of reinforcement within the net shear area, perpendicular to and crossing the horizontal shear plane

TMS 402 8.3.6: Shear Friction

- μ = 1.0 for masonry on concrete with unfinished surface, or concrete with a surface that has been intentionally roughened
- μ = 0.70 for all other conditions
- UBC (1997) required concrete abutting structural masonry to be roughened to a full amplitude of 1/16 inch.
- For $0.5 < \frac{M}{Vd_v} < 1.0$
  - $\mu = 1.0 \quad F_f = \frac{\left(0.488+1.024\left(1-\frac{M}{Vd_v}\right)\right)A_{sp}F_s+\left(0.65+0.70\left(1-\frac{M}{Vd_v}\right)\right)P}{A_{nv}}$
  - $\mu = 0.7 \quad F_f = \frac{\left(0.488+0.424\left(1-\frac{M}{Vd_v}\right)\right)A_{sp}F_s+\left(0.65+0.10\left(1-\frac{M}{Vd_v}\right)\right)P}{A_{nv}}$

Special reinforced shear walls: The 2.0 multiplier should not be applied to V when calculating the $M/(Vd_v)$ ratio, or for shear friction design.

ASD: Flexure Formulas



- Distance to neutral axis, kd — $k = \sqrt{(n\rho)^2 + 2n\rho} - n\rho$
- Internal lever arm, jd — $j = 1 - k/3$
- Steel stress, f_s — $f_s = \frac{M}{A_s jd}$
- Masonry stress, f_m — $f_m = \frac{2M}{b(kd)(jd)}$

ASD Design: Flexure

- Assume value of *j* (or *k*). Typically 0.85 < *j* < 0.95.
- Determine a trial value of $A_{s,reqd}$.
  - $A_{s,reqd} = M/(F_s jd)$
  - Choose reinforcement.
- Determine *k* and *j*; steel stress and masonry stress.
- Compare calculated stresses to allowable stresses.
- If masonry stress controls design, consider other options (such as change of member size, or change of f'_m). Reinforcement is not being used efficiently.

ASD Design: Flexure and Axial

Set $k \geq k_{bal}$=$k = k_{bal} = \frac{F_b}{F_b+F\_s/n}$

For Grade 60 steel,

CMU k_{bal} = 0.312; Clay k_{bal} = 0.368

Iterate using k_2 as new guess

Allowable steel stress controls

$$M' = P\left(\frac{d_v}{2} - \frac{kd}{3}\right)$$

$$A_{s,reqd} = \frac{M - M'}{F_s d\left(1 - \frac{k}{3}\right)}$$

$$\zeta = \frac{(P + A_{s,reqd}F_s)n}{F_s bd}$$

$$k_2 = \sqrt{\zeta^2 + 2\zeta} - \zeta$$

Is $k_2 \leq k_{bal}$

YES

NO

$$kd = 3\left[\frac{d}{2} - \sqrt{\left(\frac{d}{2}\right)^2 - \frac{2\left(P\left(d - \frac{d_v}{2}\right) + M\right)}{3F_b b}}\right]$$

$$A_{s,reqd} = \frac{\frac{F_b(kd)b}{2} - P}{nF_b\left(\frac{1}{k} - 1\right)}$$

Allowable masonry stress controls

ASD Design: Flexure and Axial

If $k < k_{bal}$ tension controls; determine kd from cubic equation.

$$\frac{t_{sp}F_s}{6n}[kd]^3 - \frac{t_{sp}dF_s}{2n}[kd]^2 - \left(P\left(d - \frac{d_v}{2}\right) + M\right)[kd] + \left(P\left(d - \frac{d_v}{2}\right) + M\right)d = 0$$

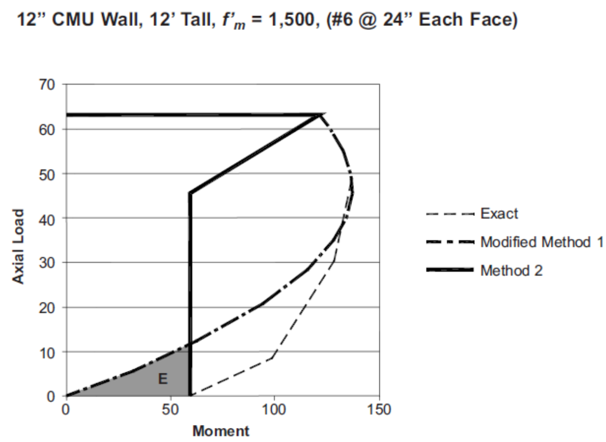
$$A_{s,reqd} = \frac{1}{2}(kd)t_{sp}\left(\frac{1}{n}\frac{kd}{d - kd}\right) - \frac{P}{F_s}$$

Determination of k_{bal}:

$$k_{bal} = \frac{F_b}{F_b + \frac{F_s}{n}} = \frac{F_b}{F_b + \frac{F_s}{\frac{E_s}{E_m}}} = \frac{0.45f'_m}{0.45f'_m + \frac{32\text{ksi}}{\frac{29000\text{ksi}}{900f'_m}}} = \frac{0.45}{0.45 + \frac{32}{\frac{29000}{900}}} = 0.312$$

For clay masonry, $E_m = 700f'_m$, $k_{bal} = 0.368$

ASD Design: Flexure and Axial



Method 2: $F_b' = F_b - f_a$

Reinforced Masonry Engineering Handbook, 7th edition

ASD Design: Distributed Reinforcement

- Design method similar to single layer of reinforcement
  - Based on uniformly distributed reinforcement, A_s^*
  - Tends to overestimate reinforcement by 10-15% for wider spaced reinforcement
  - Use specified thickness, even for partial grout
- Interaction diagram to check capacity
- Spacing of intermediate reinforcing bars often controlled by out-of-plane loading

ASD Design: Distributed Reinforcement

Calculate

$$k = \frac{M + P\frac{d_v}{6}}{\frac{1}{3}d_v^2 F_b t_{sp} - P\frac{d_v}{3}}$$

Is $k \geq k_{bal}$?

YES

$$A_{s,reqd}^{*} = \frac{\frac{1}{2}kd_v F_b t_{sp} - P}{\frac{1}{2}\frac{(1-k)^2}{k}d_v n F_b}$$

Compression controls

NO

Determine kd from the quadratic equation

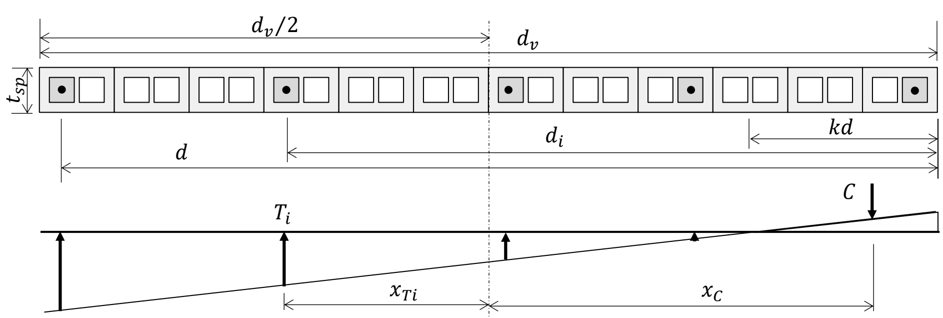
$$\left[\frac{1}{3}d_v^2 F_s \frac{t_{sp}}{n} + P\frac{d_v}{3}\right]k^2 + \left[M - P\frac{d_v}{6}\right]k - \left[M + P\frac{d_v}{6}\right] = 0$$

Solve for $A_{s,reqd}^{*}$

$$A_{s,reqd}^{*} = \frac{\frac{1}{2}kd_v t_{sp} F_s\left(\frac{k}{1-k}\right)\frac{1}{n} - P}{\frac{1}{2}(1-k)F_s d_v}$$

Tension controls

ASD: Interaction Diagram



$$P = C - \sum_{d_i > kd} T_i$$

$$M = Cx_C + \sum_{d_i > kd} T_i x_{Ti}$$

ASD: Interaction Diagram

Stress	Force	Moment Arm
If $k > k_{bal}$ $f_b = F_b$ $f_s = F_b n \frac{d - kd}{kd}$ If $k \leq k_{bal}$ $f_s = F_s$ $f_b = \frac{F_s}{n} \frac{kd}{d - kd}$ $f_{si} = f_s \frac{d_i - kd}{d - kd}$	$C = \frac{1}{2} f_b (kd) t_{eq}$ $T_i = A_{si} f_{si}$	$x_C = \frac{d_v}{2} - \frac{kd}{3}$ $x_{T_i} = d_i - \frac{d_v}{2}$

Strength Design:
Chapter 9

TMS 402 9.1: General

- 9.1.1 Scope
- 9.1.2 Required strength
- 9.1.3 Design strength
- 9.1.4 Strength-reduction factors
- 9.1.5 Deformation requirements
- 9.1.6 Anchor bolts embedded in grout
- 9.1.7 Shear strength in composite masonry
- 9.1.8 Nominal bearing strength
- 9.1.9 Material Properties

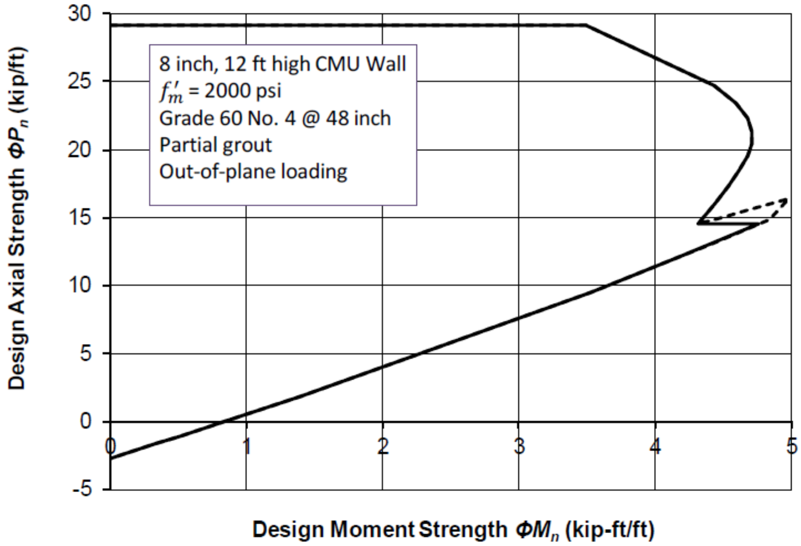
TMS 402 9.1.4: Strength-reduction Factors (Tension/Compression Sections New in 2022)

Action	Reinforced Masonry	Unreinforced Masonry
flexure and axial load	variable	0.60
shear	0.80	0.80
bearing	0.60	0.60

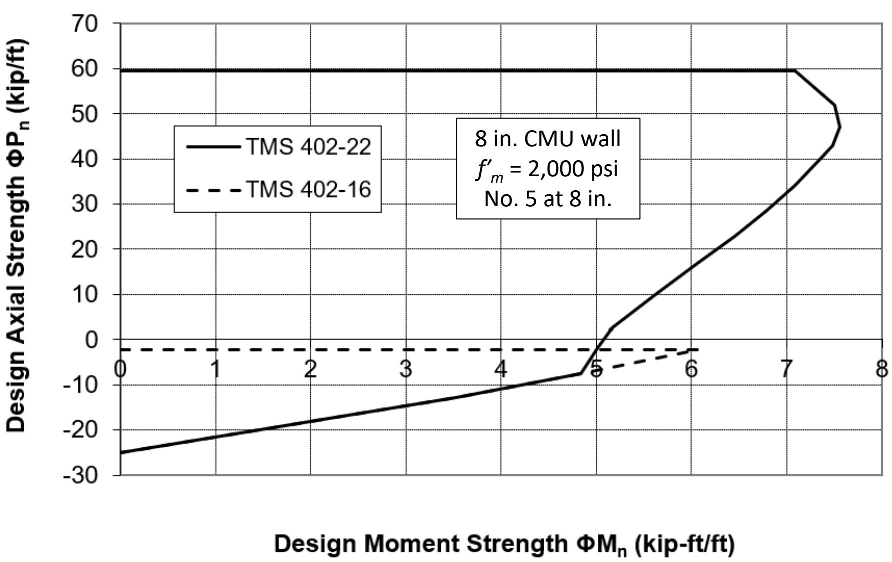
Net tensile strain, ε_t	Classification	ϕ
$\varepsilon_t \leq \varepsilon_{ty}$	Compression-controlled	0.65
$\varepsilon_{ty} < \varepsilon_t \leq 0.003 + \varepsilon_{ty}$	Transition	$0.65 + 0.25\frac{\varepsilon_t - \varepsilon_{ty}}{0.003}$
$\varepsilon_t \geq 0.003 + \varepsilon_{ty}$	Tension-controlled	0.90

Tension-controlled and transition regions:
ϕ for axial load shall be limited so that $\phi P_n \leq 0.65 P_{bal}$

TMS 402 9.1.4: Tension and Compression Controlled



TMS 402 9.1.4: Tension and Compression Controlled



TMS 402 9.2: SD Unreinforced Masonry

- 9.2.1 Scope
- 9.2.2 Design criteria
- 9.2.3 Design assumptions
- 9.2.4 Nominal axial compression and flexure
- 9.2.5 Axial tension
- 9.2.6 Nominal shear strength

Key design equation: $$f_t = \frac{Mc}{I} - \frac{P}{A}$$

TMS 402 9.3: Reinforced Masonry

- 9.3.1 Scope
- 9.3.2 Design assumptions
- 9.3.3 Design of beams and columns
  - nominal axial and flexural strength
  - nominal shear strength
- 9.3.4 Wall design for out – of – plane loads
- 9.3.5 Wall design for in – plane loads

TMS 402 9.3.2: Design assumptions

- continuity between reinforcement and grout
- equilibrium
- ε_{mu} = 0.0035 for clay masonry, ε_{mu} = 0.0025 for concrete masonry
- plane sections remain plane
- elasto–plastic stress–strain curve for reinforcement
- tensile strength of masonry is neglected
- equivalent rectangular compressive stress block of stress $0.80 f'_m$ and depth of $0.80c$

TMS 402 Chapter 9.3.3.1.1: Axial

$$P_n = 0.80\left[0.80 f'_m (A_n - A_{st}) + f_y A_{st}\right]\left[1 - \left(\frac{h}{140r}\right)^2\right] \quad \text{for } \frac{h}{r} \leq 99$$

$$P_n = 0.80[0.80 f'_m (A_n - A_{st}) + f_y A_{st}]\left(\frac{70r}{h}\right)^2 \quad \text{for } \frac{h}{r} > 99$$

TMS 402 9.3.3.1.2: Shear

- Nominal shear strength
  - $V_n = (V_{nm} + V_{ns})\gamma_g$
  - γ_g = 0.70 for partially grouted shear walls, 1.0 otherwise
- Nominal strength limit
  - $M_u/(V_u d_v) \leq 0.25$ $\quad V_n = \left(6A_{nv}\sqrt{f'_m}\right)\gamma_g$
  - $M_u/(V_u d_v) \geq 1.0$ $\quad V_n = \left(4A_{nv}\sqrt{f'_m}\right)\gamma_g$
  - $0.25 < M_u/(V_u d_v) < 1.0$ $\quad V_n = \left(\frac{4}{3}\left(5 - 2\frac{M_u}{V_u d_v}\right)A_{nv}\right)\gamma_g$

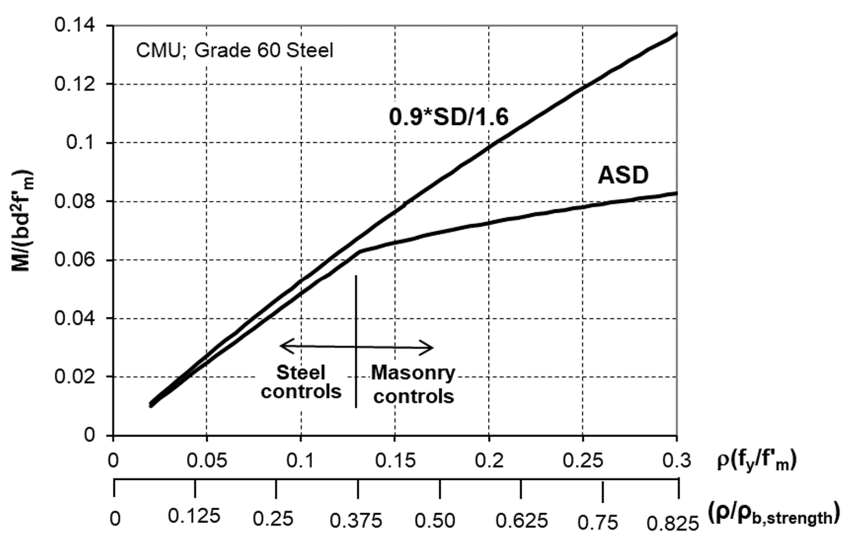
TMS 402 9.3.3.1.2: Shear

- Nominal masonry shear strength
  - $V_{nm} = \left[4 - 1.75\left(\frac{M_u}{V_u d_v}\right)\right]A_{nv}\sqrt{f'_m} + 0.25P_u$
  - $M_u/(V_u d_V)$ is positive and need not exceed 1.0.
- Nominal reinforcement shear strength:
  - $V_{ns} = 0.5\left(\frac{A_v}{s}\right)f_y d_v$
  - Shear reinforcement: Hooks only required for special shear walls.

TMS 402 Chapter 9.3.3.2: Beams

- $P_u \leq 0.05 A_n f'_m$
- Minimum reinforcement $M_n \geq 1.3 M_{cr}$
  - Unless A_s provided is at least 1/3 greater than required
- Maximum reinforcement: must be tension controlled
  - CMU, Grade 60, f'_m = 2 ksi, $\rho_{max} = 0.00711$ (61% of ρ_{bal})
  - Clay, Grade 60, f'_m = 3 ksi, $\rho_{max} = 0.01318$ (66% of ρ_{bal})
- Specific requirements for transverse reinforcement

Beams: ASD vs. SD



Design: Flexure plus Axial

Calculate

$$a = d - \sqrt{d^2 - \frac{2\left[P_u\left(d - t/2\right) + M_u\right]}{\phi\left(0.8 f'_m b\right)}} \qquad c = \frac{a}{0.8}$$

Is $c \geq c_{bal}$?
For Grade 60 steel
$c_{bal} = 0.547$

$$c_{bal} = \frac{\varepsilon_{mu}}{\varepsilon_{mu} + \varepsilon_y} d$$

YES

$$A_s = \frac{0.8 f'_m ba - P_u/\phi}{\varepsilon_{mu} E_s \left(\frac{d-c}{c}\right)}$$

Compression controls

NO

$$A_s = \frac{0.8 f'_m ba - P_u/\phi}{f_y}$$

Tension controls

TMS 402 Chapter 9.3.4: Out-of-Plane

- Capacity under combinations of flexure and axial load is based on the assumptions of TMS 402 Section 9.3.2 (interaction diagram)
- Single layer of steel, equivalent stress block in face shell or fully grouted.
  - $a = \frac{A_s f_y + P_u/\phi}{0.80 f'_m b}$
  - $M_n = (P_u/\phi + A_s f_y)\left(\frac{t_{sp} - a}{2}\right) + A_s f_y\left(d - \frac{t_{sp}}{2}\right)$
- For centered flexural reinforcement
  - $M_n = (P_u/\phi + A_s f_y)\left(d - \frac{a}{2}\right)$

TMS 402 9.3.4: Out-of-Plane

- Three procedures for computing out–of–plane moments and deflections
  - Complementary moment method, or slender wall method; additional moment from P – δ effects (9.3.4.4.2)
  - Second – order analysis (9.3.4.4.3)
  - Moment magnification method (9.3.4.4.3)
- Estimate reinforcement
  - Centered reinforcement: $A_{s,reqd} = \frac{M_u}{0.8 f_y d} - \frac{P_u}{f_y}$
  - Offset reinforcement: $A_{s,reqd} = \frac{M_u}{0.8 f_y d} - \frac{P_u}{2 f_y}$

Slender Wall Procedure

- Assumes simple support conditions.
- Assumes midheight moment is approximately maximum moment
- Assumes uniform load over entire height
- Valid only for the following conditions:
  - $\frac{P_u}{A_n} \leq 0.05 f'_m$ No height limit
  - $\frac{P_u}{A_g} \leq 0.20 f'_m$ height limited by $\frac{h}{t} \leq 30$

Moment:

$$M_u = \frac{w_u h^2}{8} + P_{uf}\frac{\varepsilon_u}{2} + P_u \delta_u$$

$$P_u = P_{uw} + P_{uf}$$

P_{uf} = factored floor load

P_{uw} = factored wall load

Deflection:

$M_u \leq M_{cr}$

$$\delta_u = \frac{5 M_u h^2}{48 E_m I_n}$$

$M_u > M_{cr}$

$$\delta_u = \frac{5 M_{cr} h^2}{48 E_m I_n} + \frac{5(M_u - M_{cr}) h^2}{48 E_m I_{cr}}$$

Slender Wall Procedure

Solve simultaneous linear equations:

$\boldsymbol{M_u > M_{cr}}$

$$M_u = \frac{\frac{w_u h^2}{8} + P_{uf}\frac{e_u}{2} + \frac{5 M_{cr} P_u h^2}{48 E_m}\left(\frac{1}{I_n} - \frac{1}{I_{cr}}\right)}{1 - \frac{5 P_u h^2}{48 E_m I_{cr}}}$$

$$\delta_u = \frac{\frac{5h^2}{48 E_m I_{cr}}\left[\frac{w_u h^2}{8} + P_{uf}\frac{e_u}{2} + M_{cr}\left(\frac{I_{cr}}{I_n} - 1\right)\right]}{1 - \frac{5 P_u h^2}{48 E_m I_{cr}}}$$

$\boldsymbol{M_u \le M_{cr}}$

$$M_u = \frac{\frac{w_u h^2}{8} + P_{uf}\frac{e_u}{2}}{1 - \frac{5 P_u h^2}{48 E_m I_n}}$$

$$\delta_u = \frac{\frac{5h^2}{48 E_m I_n}\left[\frac{w_u h^2}{8} + P_{uf}\frac{e_u}{2}\right]}{1 - \frac{5 P_u h^2}{48 E_m I_n}}$$

Slender Wall Procedure

Cracking Moment: $M_{cr} = \frac{(P_u/A_n + f_r) I_n}{t_{sp}/2}$

Cracked moment of inertia:

$$I_{cr} = n\left(A_s + \frac{P_u}{f_y}\frac{t_{sp}}{2d}\right)(d - c)^2 + \frac{bc^3}{3}$$

$$c = \frac{A_s f_y + P_u}{0.64 f'_m b}$$

Centered bars: $I_{cr} = n\left(A_s + \frac{P_u}{f_y}\right)(d - c)^2 + \frac{bc^3}{3}$

Second-Order Procedure

9.3.5.4 P-*delta effects*

9.3.5.4.1 Members shall be designed for the strength level axial load, P_u, and the moment magnified for the effects of member curvature, M_u. The magnified moment shall be determined either by Section 9.3.5.4.2 (slender wall procedure) or Section 9.3.5.4.3.

9.3.5.4.3 The strength level moment, M_u , shall be determined either by a second-order analysis, or by a first-order analysis and Equations 9-27 through 9-29 (moment magnification procedure).
Loophole: No axial stress or h/t limits

Moment Magnification Procedure

Complementary Moment

First Order Moment

$$M_u = \frac{\frac{w_u h^2}{8} + P_{uf}\frac{e_u}{2} + \frac{5M_{cr}P_u h^2}{48E_m}\left(\frac{1}{I_n} - \frac{1}{I_{cr}}\right)}{1 - \frac{5P_u h^2}{48E_m I_{cr}}}$$

Always Negative

$$\frac{5}{48} = 0.104 \sim \frac{1}{\pi^2} = 0.101$$

Magnified moment: $M_u = \psi M_{u,0}$

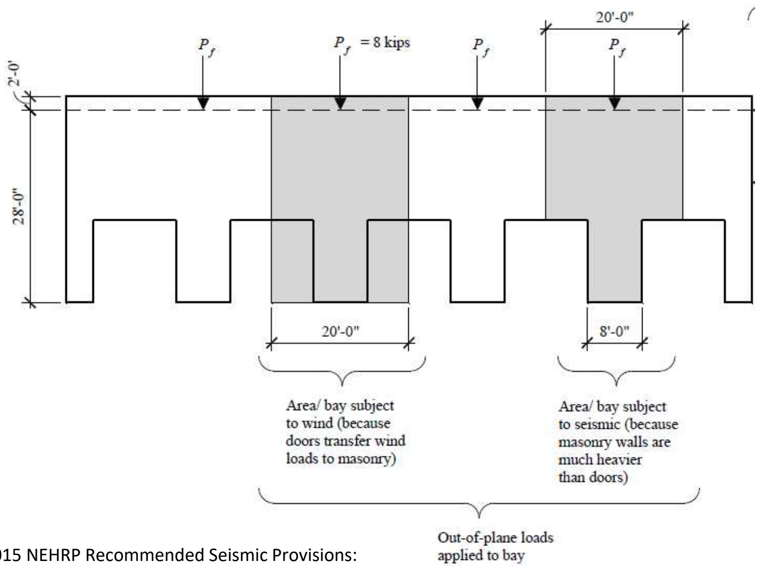
Moment magnifier: $\psi = \frac{1}{1 - \frac{P_u}{P_e}}$

Buckling load: $P_e = \frac{\pi^2 E_m I_{eff}}{h^2}$

$M_u < M_{cr}$: $I_{eff} = 0.75 I_n$

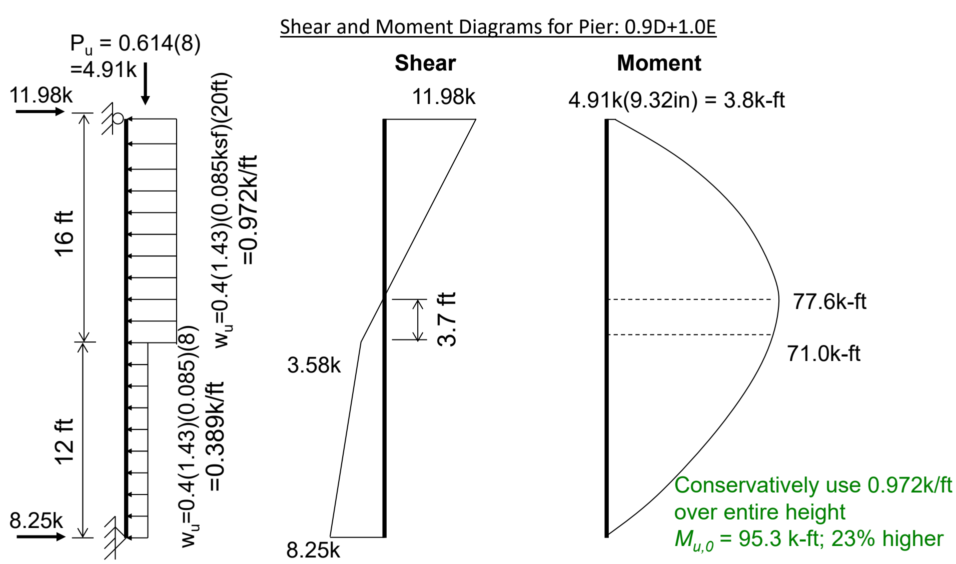
$M_u \geq M_{cr}$: $I_{eff} = I_{cr}$

Moment Magnification Application



After 2015 NEHRP Recommended Seismic Provisions:
Design Examples *FEMA P-1051 / July 2016*

Moment Magnification Application

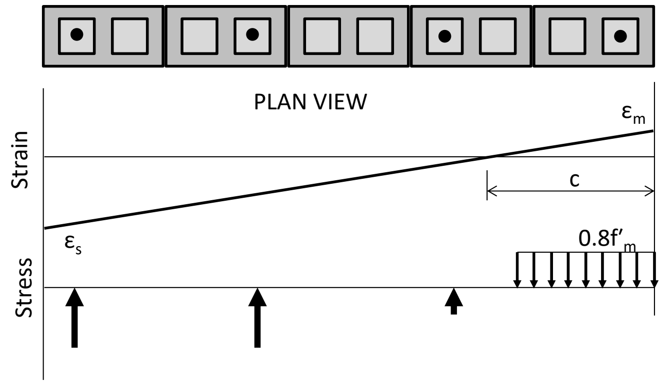


TMS 402 Chapter 9.3.4: Out-of-Plane

- Deflection limit: $\delta_s \leq 0.007h$
- δ_s calculated using ASD load combinations
- Effective moment of inertia for calculating deflections
- $I_e = \frac{I_{cr}}{1 - \frac{M_{cr}}{M}\left(1 - \frac{I_{cr}}{I_n}\right)}$

TMS 402 Chapter 9.3.5: In-Plane

Capacity under combinations of flexure and axial load is based on the assumptions of TMS 402 Section 9.3.2 (interaction diagram)



In-Plane: Design

Solve quadratic equation for depth of compression block, a:

$$a = \frac{-B + \sqrt{B^2 - 4AC}}{2A}$$

$$A = (\beta - 1)0.36f'_m t_{sp}$$

$$B = 0.36f'_m t_{sp} d_v - 0.5\beta P_u$$

$$C = -M_u$$

$$\beta = \frac{\varepsilon_y + \varepsilon_{mu}}{0.8\varepsilon_{mu}}$$

For Grade 60 steel:

$\beta = 2.3$ for concrete masonry

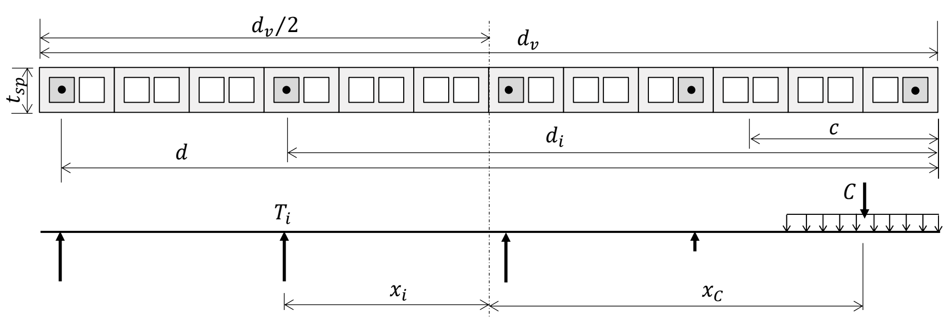
$\beta = 2.0$ for clay masonry

Solve for required area of steel per inch of wall length:

$$A^*_{s,req'd} = \frac{0.8f'_m a t_{sp} - P_u/\phi}{f_y(d_v - \beta a)}$$

- Tends to slightly overestimate $A^*_{s,req'd}$, particularly for wider spaced reinforcement.
- Spacing of bars often controlled by out-of-plane loading.

Interaction Diagram



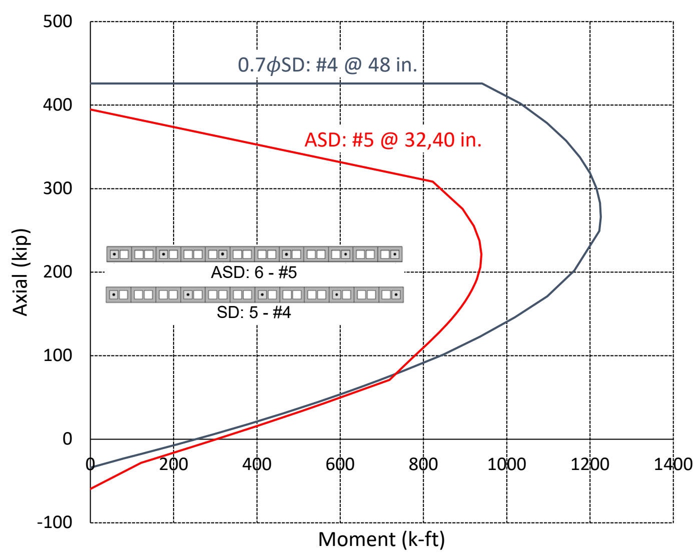
$$P_n = C - \sum_{d_i > kd} T_i$$

$$M_n = Cx_C + \sum_{d_i > kd} T_i x_i$$

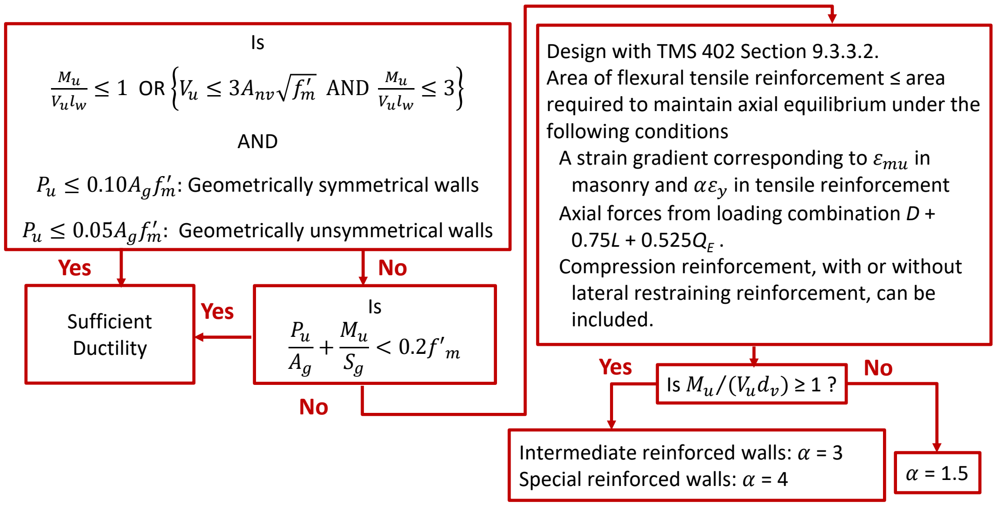
Interaction Diagram

Stress	Force	Moment Arm
$\varepsilon_s = \varepsilon_{mu}\dfrac{d-c}{c}$ $\varepsilon_{si} = \varepsilon_s\dfrac{d_i-c}{d-c}$ $f_{si} = \min\{E_s\varepsilon_{si}, f_y\}$	$C = 0.8f'_m(0.8c)t_{net}$ $T_i = A_{si}f_{si}$	$x_C = \dfrac{d_v}{2} - \dfrac{0.8c}{2}$ $x_{T_i} = d_i - \dfrac{d_v}{2}$

Shear Walls: ASD vs. SD (2016)



Ductility Requirements:
Intermediate and Special Reinforced



TMS 402 9.3.5.5: Shear Friction

Shear Span Ratio	Allowable Shear Friction
$\frac{M_u}{V_u d_v} \le 0.5$	$V_{nf} = \mu(A_{sp} f_y + P_u) \ge 0$
$0.5 < \frac{M_u}{V_u d_v} < 1.0$	Linear interpolation
$\frac{M_u}{V_u d_v} \ge 1.0$ Changed in 2022	$V_{nf} = 0.65(0.75A_{sp} f_y + P_u) \ge 0$

A_{sp} = cross-sectional area of reinforcement within the net shear area, perpendicular to and crossing the horizontal shear plane

A_{nc} = net cross-sectional area between the neutral axis of bending and the fiber of maximum compressive strain calculated at the nominal moment capacity of the section

This concludes The American Institute of Architects Continuing Education Systems Course

Richard Bennett
rmbennett@utk.edu
865-719-7859