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Assessment and Retrofit of Masonry Structures

Introduction to Ancient and Modern Masonry

College of Continuing and Professional Studies
Structural Engineering Webinar
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University of Minnesota
Driven to Discover®

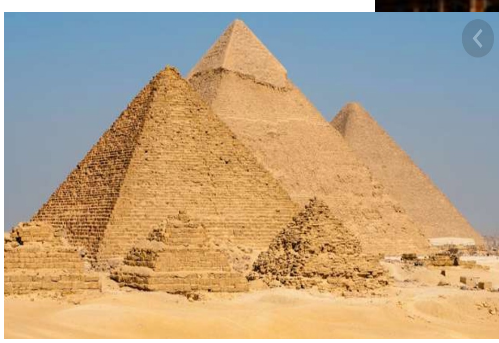
CHAPTER 1

INTRODUCTION TO ANCIENT MASONRY

Ribbed masonry vault

Examples of Ancient Masonry Structures

From ancient times to the present, there are spectacular examples of masonry structures that would very difficult and extremely expensive to duplicate today even with our advanced skills, modern machines and modern materials.



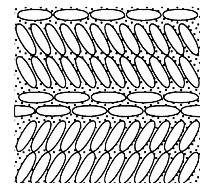
Masonry Materials for Ancient Masonry - Units

- Materials have been used for the construction of ancient masonry, with those locally available being most common.

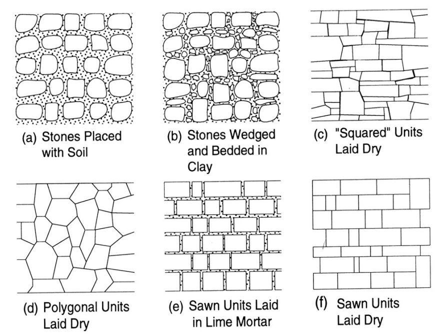
- Where civilizations existed in the vicinity of mountains, **stone** was used.

When civilizations developed in river plains, Alluvial deposits were used to create **brick**

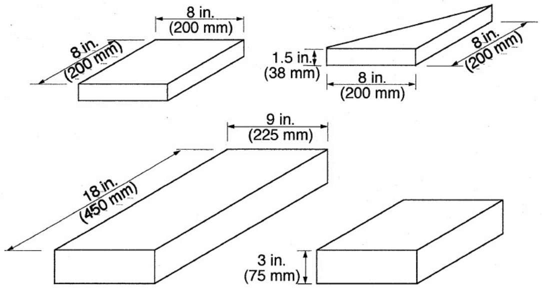
Ancient Masonry Materials- Stone



- The first masonry was a crude stack of selected natural stone. The mortar, if any, was earth that was packed between the stones.



As tools become available, stones were regularly trimmed , cut, stacked, wedged with smaller stones and bedded in clay



Ancient Masonry Material-Brick

- Clay brick has been used for at least 10,000 years. Sun-dried molded brick was widely used.

- Bricks varied greatly in shape from board flat bricks only 1 in. thick to those of roman size bricks

Ancient Masonry Materials - Mortar

- Early mortars were primarily used to fill cracks and provide uniform bedding for masonry units. Mortar joints also provide weathering resistance and improved durability

- Such mortars might have been
  - Clay
  - Bitumen
  - Clay-straw mixtures
  - Lime mortar

Compatibility of Restoration Mortar

ASTM C1713 provides a series of procedures to evaluate compatibility of restoration mortars and the following recommendations on compatibility limits for various properties.

- Water retention: ≥ 75 %
- Air content: ≤ 12 %
  ≤ 17 % (when using mortar cement)
  ≤ 21 % (when using masonry cement)
- Total porosity: between 75% and 125% of the target value
- Water vapor permeability: between 75% and 125% of the target value
- Compressive strength: between 100% and 125% of the target value
- Flexural bond strength (where bond is critical), for mortar containing hydraulic cement binders:
  ≥ 29 psi (0.2 MPa)

Fundamental Structural Problems

There are two fundamental structural problems when building:

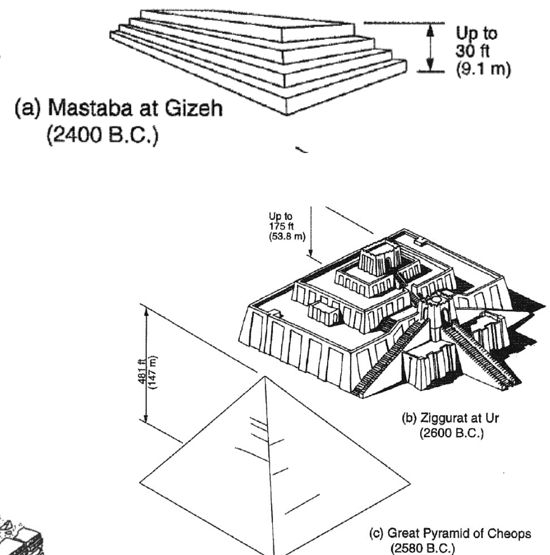
1- how to achieve height and

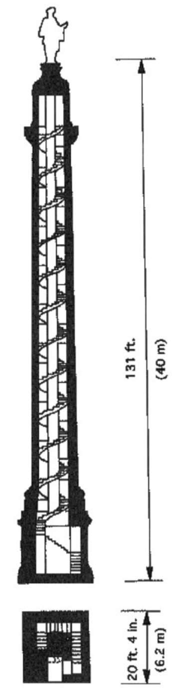
2- how to span an opening;

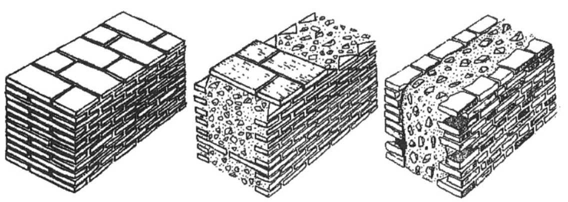
in a sense, *how to span vertical and horizontal spaces.* The former is achieved in masonry construction by using columns, towers, and walls and the latter by using lintels, beams, and arches. Some structural forms, such as vaults and domes, span vertically and horizontally at the same time.

Building Up

- The simplest way of building is stack masonry units one upon the other :
  - Mastaba/Pyramid
  - Walls
  - Columns and towers

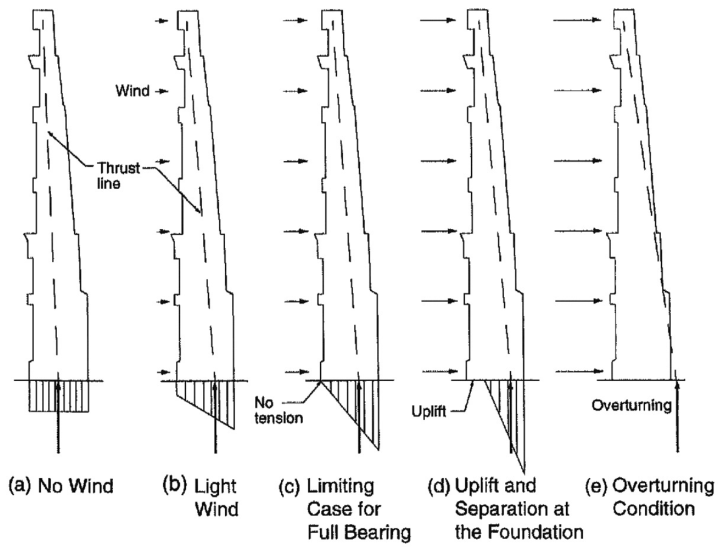






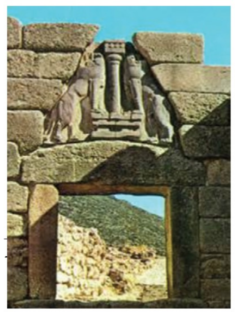
(a) Bonded Brick Wall (b) Brick Faced Wall with Header Courses (c) Brick Faced Wall

Building Up - Cantilever Uncoupled Walls

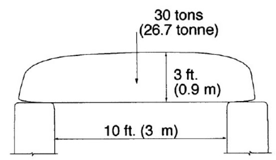


- Case of full bearing: e=M/p= t/6
- Case of uplift at base: e> t/6
- Case of only half base section in contact: e= t/3
- Case of overturning: e=t/2

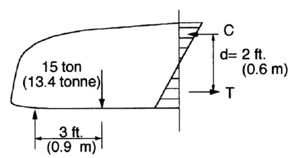
Spanning Across- Beams



(a) Lion Gate (c. 1250 B.C.)



(b) Sketch of Lion Gate Stone Lintel



(c) Free Body Diagram of Half of the Lintel

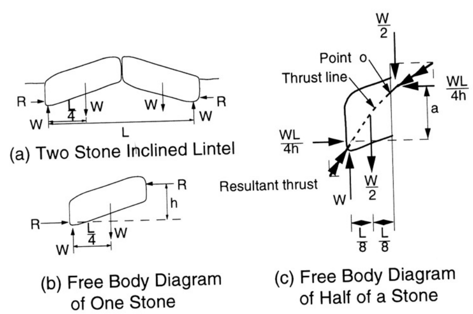
- Horizontal space is most easily spanned by placing a horizontal beam across an opening.

- The external couple produced by the weight of the beam is resisted by an equal and opposite internal couple equals

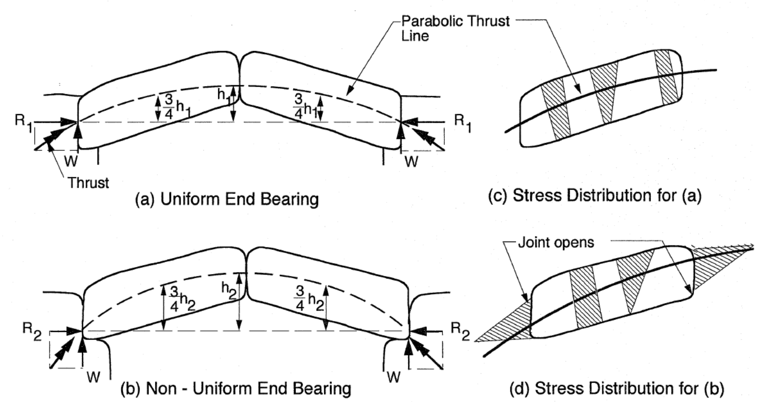
  $T d = Cd$

Spanning Across-Primitive Arch

A greater san is possible using two inclined stone slabs resting against each other to form a primitive arch. It is only possible if the horizontal reaction R can be developed.

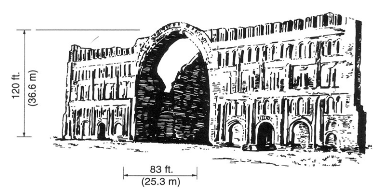


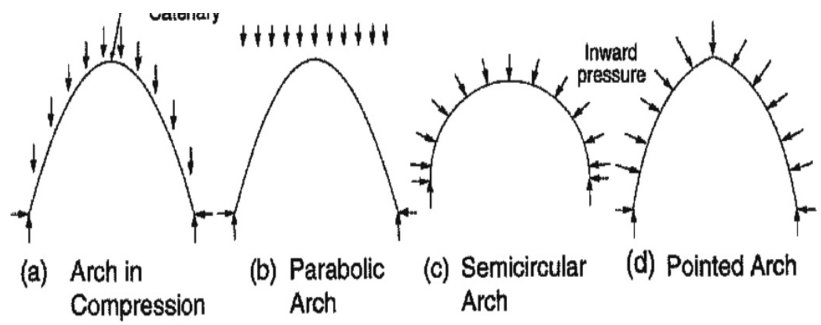
$$R = \frac{WL}{4h}$$

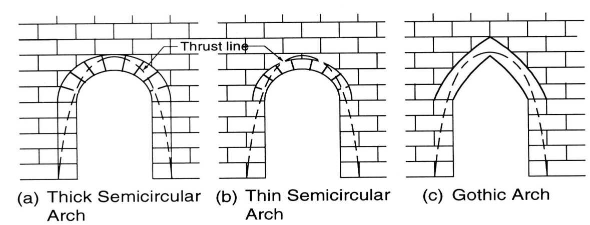


Spanning Across- True Arch

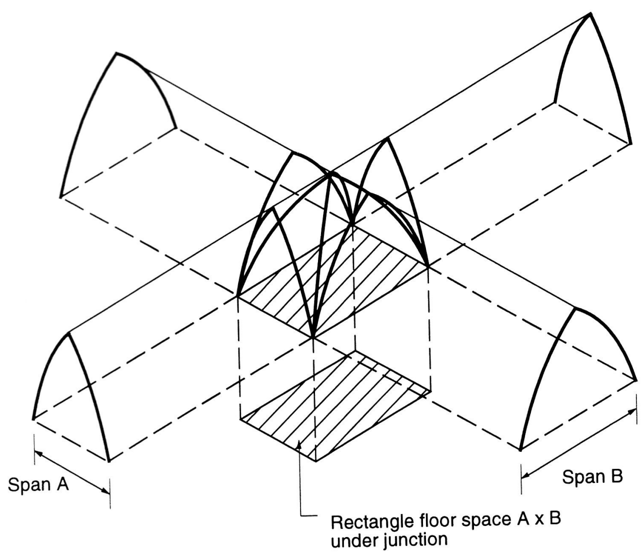
- A significant structural advance was made with the introduction of the first true arch in about 1400 B.C.
- In a true arch, the stone is hewn away so that only a narrow thickness, centered around the thrust line, remained, then arch is entirely in compression and uniformly stressed over its thickness.
- For a uniformly distributed load (like self weight), parabolic arch is a true arch.
- Under UDL, the thrust line in gothic or circular arch is not in the center. Gothic shape is closer to parabola than the semicircle. Therefore, it is more efficient.







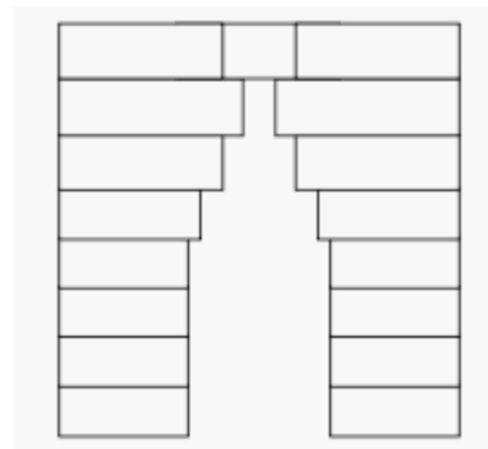
Spanning Across- Gothic Arch



- Under UDL, the thrust line in gothic or circular arch is not in the center. Gothic shape is closer to parabola than the semicircle. Therefore, it is more efficient.

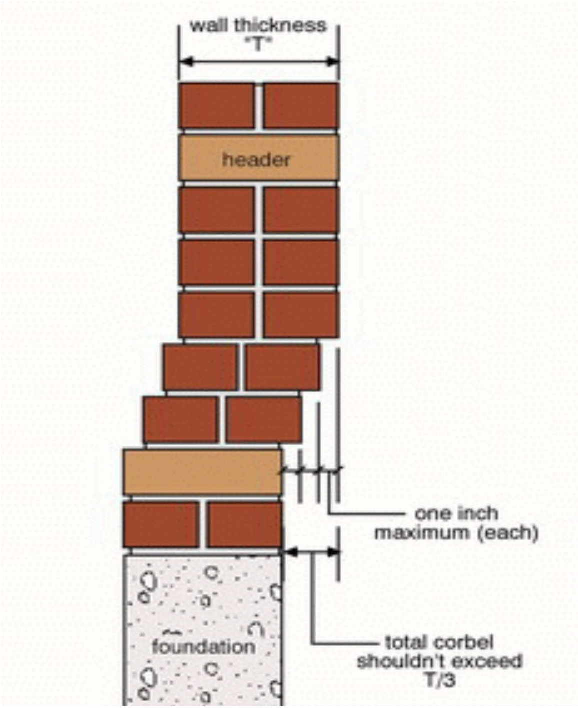
Spanning Across-Corbelled Arch

- Note that the horizontal component of the thrust force is resisted by the end piers.

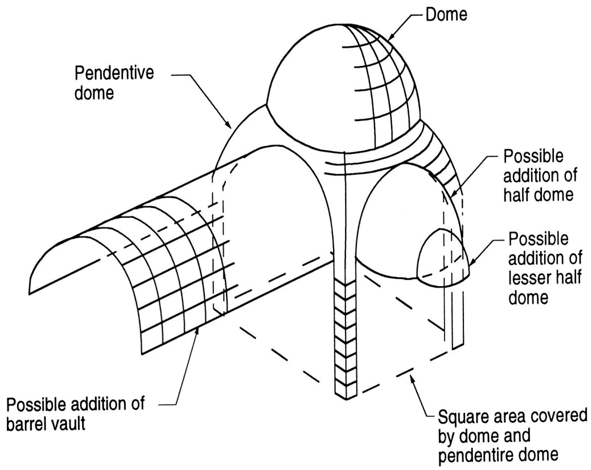


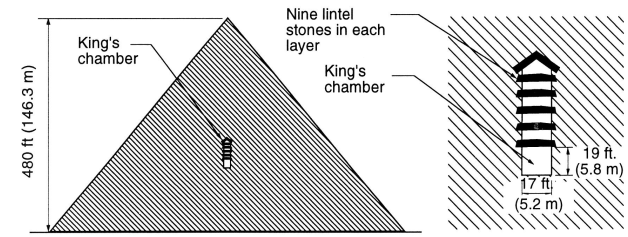
Spanning Across-Corbelling

- Masonry unit can be corbelled 1/3 to ½ of its height.
- At any section, e=M/p should be less than t/6. For a factor of safety of 2, e should not be more than t/12



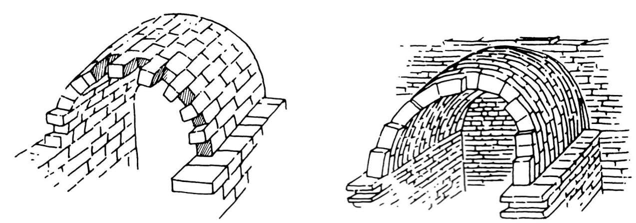
Enclosing Space : Pyramids, Domes, Vaults and Arches





(a) Location of King's Chamber

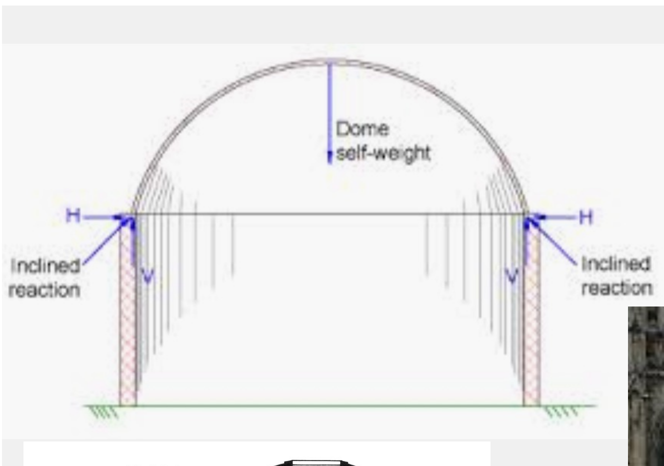
(b) Details of King's Chamber

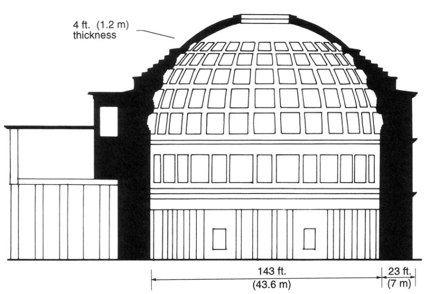


(a) Construction of Vaults Requiring Temporary Support

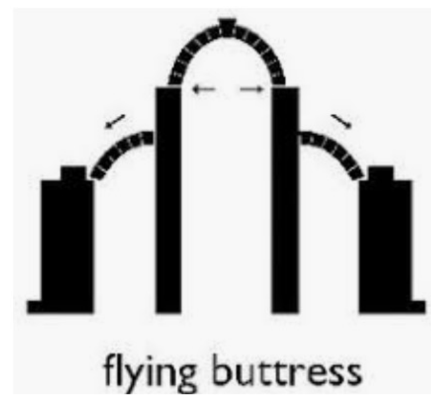
(b) Construction of Vaults Using End Walls and Previous Construction for Stability During Construction

Spanning Across (3-D) : Domes



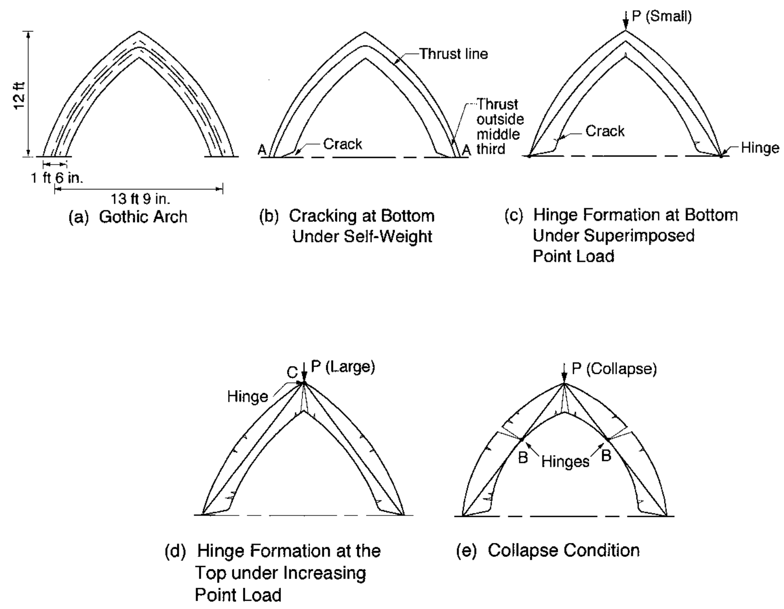


- The horizontal thrust force is resisted by buttresses or flying buttresses



Redundancy

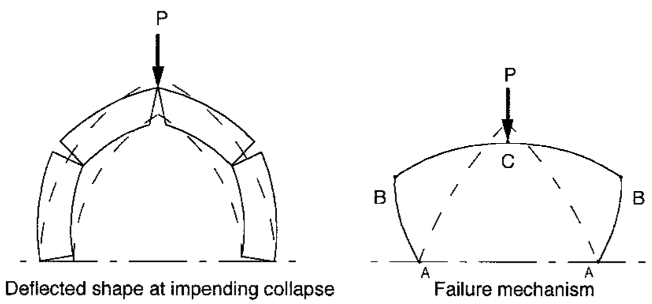
- With cracking at base (critical section with maximum moment), structure changes from 3-D (a) statically indeterminate to 1-D (b) statically indeterminate.
- With cracking of crown section (section of maximum positive moment), structure becomes statically determine (d)-3 hinged arch
- With further loading, cracks develop at B and the structure becomes unstable (goes to a mechanism because of the 5 hinges at the five cracked sections)



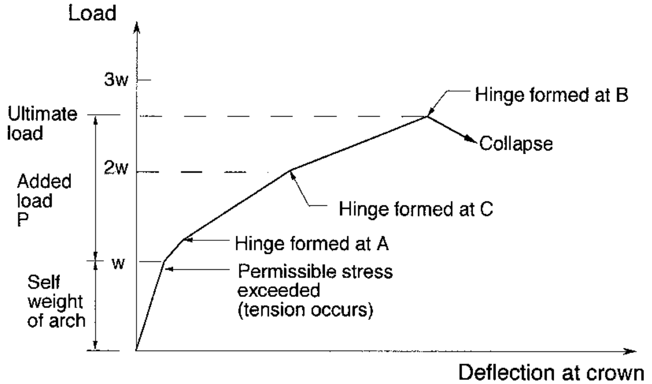
Effect of Cracking on Structural Response

Cracking does not mean necessarily that the structure is incapable of carrying the future loads and need to be retrofitted.

For statically indeterminate structures, cracking of the critical section is not an ultimate limit state; it is a serviceability limit state.



(a) Hinge Location at Failure



(b) Load - Deflection Curve

Summary- Characteristics of Historic Masonry

- Thick, multi-wythe walls made of stone or molded clay
- Unreinforced
- Uncoupled-walls act as cantilever because of flexible wood diaphragms
- Gravity walls-rely on the compressive load to counter-balance tension

i.e. eccentricity does not exceed t/6 (kern eccentricity of rectangular sections). Thrust line is in the middle third.

Cracking does not represent an ultimate limit state because of redundancy/indeterminacy

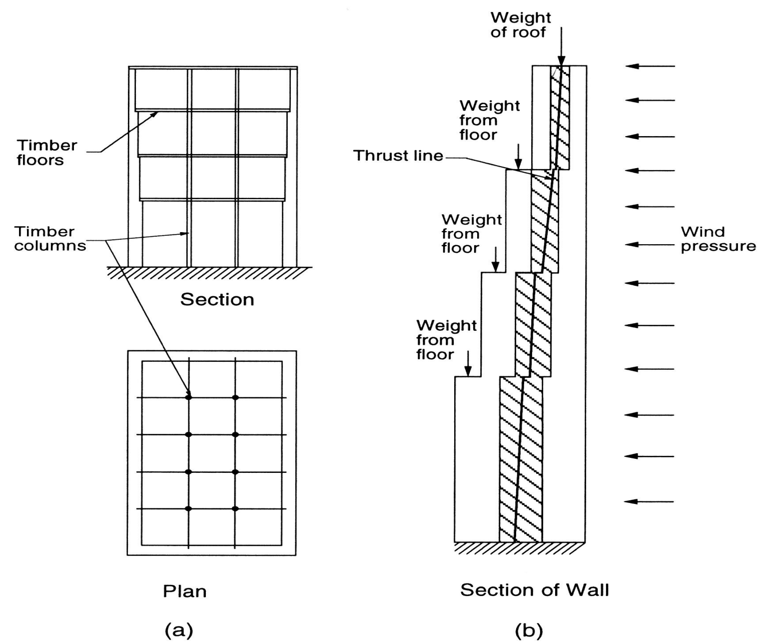


Figure 1.31 Traditional multistory loadbearing buildings.

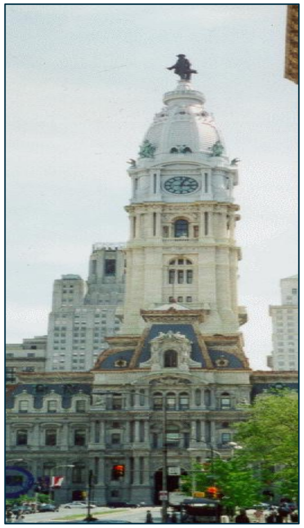
Transition from Ancient to Modern Masonry

Ancient masonry construction relied upon thick, multi-wythe walls to carry structural loads and resist moisture penetration. Massive masonry wall assemblies served the dual role of structure and environmental envelope, protecting interior spaces from external influences by their great mass: moisture penetration was resisted by the absorptive capacity of the multi-wythe masonry barrier, and thermal fluctuations were moderated by its thermal mass.

This type of construction is, from a modern approach, overbuilt, and minor flaws in their design or construction did not have a major effect on long-term performance.

...Transition from Ancient to Modern Masonry- Examples

This form perhaps reached its pinnacle in the 1890s with construction of the 16-story Monadnock Building in Chicago and the Philadelphia City Hall Tower, which (167 m) remains the tallest unreinforced masonry construction in the world. Its walls are 2.4 m thick in the tower and 6.7 m thick at the foundation.



…Transition from Ancient to Modern Masonry

Modern building design strives to optimize labor and material costs relative to structural performance and serviceability, while maintaining an attractive aesthetic.

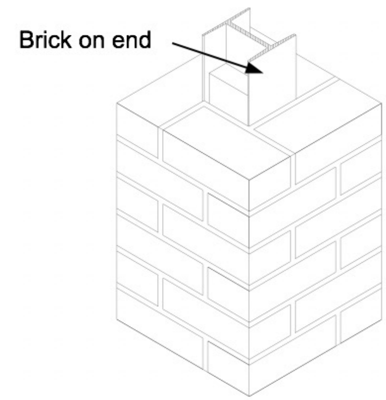
Development of more efficient, rational engineering design procedures have served to optimize the structure itself and reduce the mass of loadbearing walls.

....Transition from Ancient to Modern Masonry

Over the last 150 years the traditional usage of masonry has been adapted to meet modern design philosophy encompassing economy, function, and aesthetics. Technological developments led to the use of less expensive forms of stone, such as thin stone slab veneer, and new masonry products developed to simulate stone including terra cotta and textured concrete masonry.

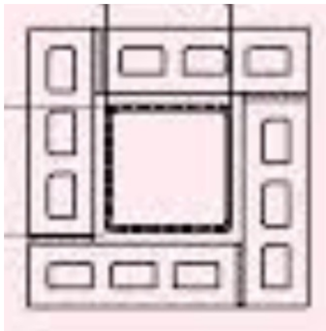
Improved procedures for manufacturing brick led to a transition from labor-intensive hand molded units to hydraulic-pressed brick and extruded brick forms. At the same time, advances in brick firing have given us highly durable units that are capable of being used as only a thin skin facing the structure without requiring massive wall systems for performance and durability.

....Transition from Ancient to Modern Masonry



Many different masonry systems were developed to act as fireproofing elements. Traditional load-bearing masonry walls continued to be used for low- to mid-rise construction. Masonry also fulfilled a role in protecting structural steel framing used for high-rise construction.

In its simplest form, brick and mortar was used to infill between flanges of steel beams and columns, with a 100 mm brick thickness considered as giving a 5-hour fire rating to structural steel members. Steel framing was typically surrounded by brick or masonry for fireproofing



CHAPTER 2

INTRODUCTION TO MODERN MASONRY

Modern masonry construction

Contents

- Introduction to contemporary masonry
- Masonry elements
- Masonry Systems
- Codes and Standards
- Sources of information

Introduction

Problems with Conventional Infilled RC Frame Construction

There is a significant need of efficient residential and institutional buildings in many parts of the world to meet the rapid growth of population.

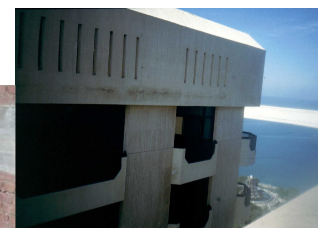
Conventional RC infill frame construction is unsustainable and has many problems

…Problems with RC Frame construction

Conventional skeleton infill RC frame buildings have problems of durability of the building envelope in form of

- spalling of plaster
- Delamination of face plaster or stone
- corrosion of reinforcing steel
- Cracking of masonry infill due to differential settlement



….Problems with RC Frame construction

- Slow construction with many trades on the job.
- RC frame construction goes from the bottom up and the finishing from the top down.
- Cast-in-place concrete requires formwork and waiting period for curing
- Plastering of walls slows construction significantly and requires formwork for exterior walls.
- There is an issue of quality of poured concrete

....Problems with RC Frame construction

Vulnerability to seismic attack :

B-C joints, punching shear of flat-plate, unconfined columns, cracking of infill masonry walls, torsional effect due to unsymmetrical distribution of infill walls, undesirable strong beam-weak column mechanism

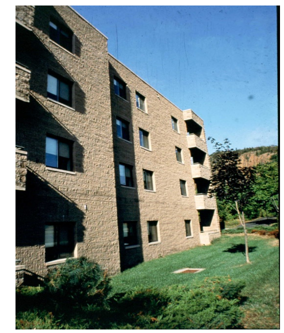
(e)

Proposed Solution

Use Loadbearing reinforced concrete masonry which consists of small precast units connected together to form a structural system.

Applications include:

- Apartments
- Schools
- Hotels
- Industrial and commercial buildings



Advantages of Loadbearing Masonry Wall System

Multifunctional Characteristics of loadbearing masonry buildings:

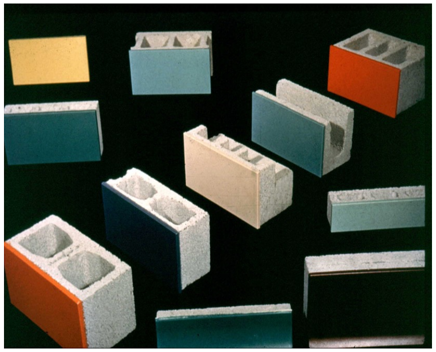
- 1- Structural framework
- 2- Define geometric space
- 3- Variety of architectural finishes
- 4-Waterproof enclosure
- 5- Thermal insulation
- 6- Acoustical enclosure
- 7- Fire proofing
- 8- Dimensional tolerance
- 9- Simple erection techniques

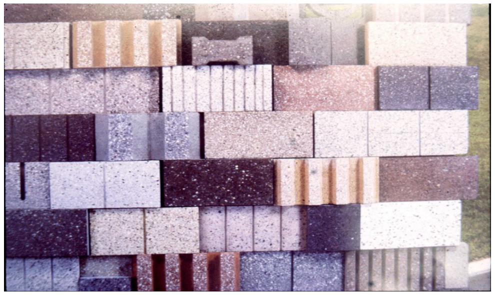
Contemporary Masonry Materials

Characteristics of Contemporary Masonry units

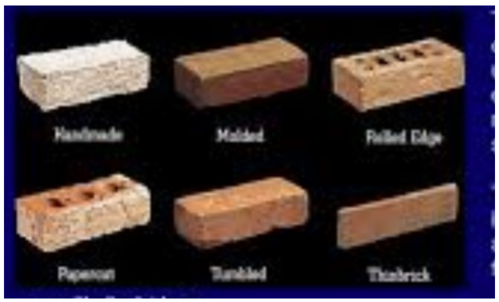
- Manufactured with high quality control.
- Variety of materials such as clay, concrete, calcium silicate, stone, glass, AAC
- Variety of shapes, colors and textures

Concrete Masonry Unit (CMU)



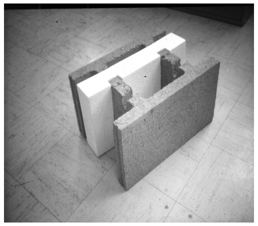


Clay Brick



Innovative CMU- Thermal Efficiency

- Insulated CMU



- AAC Blocks

Modern Mortar

- **Basic Ingredients:**

PC + Lime + masonry sand

- **Types:**

1- PCL mortar

2- Masonry cement

3- Mortar cement

Grout

- **Basic Ingredients**: PC + Lime + sand + Aggregate

- **Types- based on ingredients:**
  - Fine grout
  - Coarse grout

- **Types-based on workability**
  - Conventional grout-requires consolidation
  - Self-Consolidating Grout (SCG)

(a) Slump Test of Fluid Grout

(b) Water from the Fluid Grout is Absorbed into the Block and Results in Surface Wetness (Courtesy of Gary T. Suter)

Masonry Elements

Types of Masonry Elements

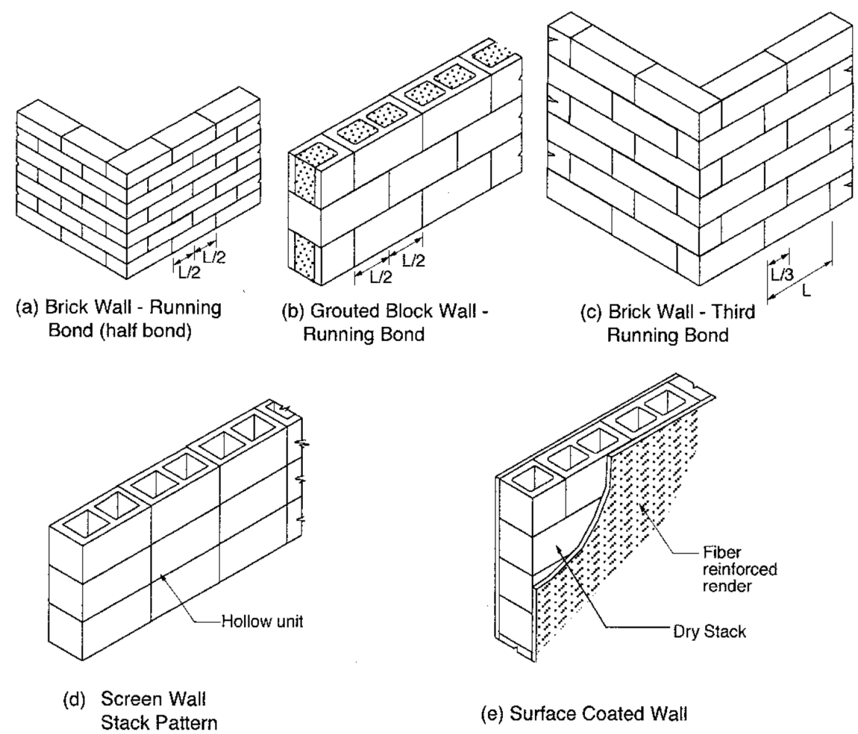
- Based on **geometry**:
  - Single wythe
  - Multi-wythe

- Based on **load-resisting** :
  - Loadbearing (**LB**) and
  - non-loadbearing (**NLB**) such as veneer, infill walls and partitions

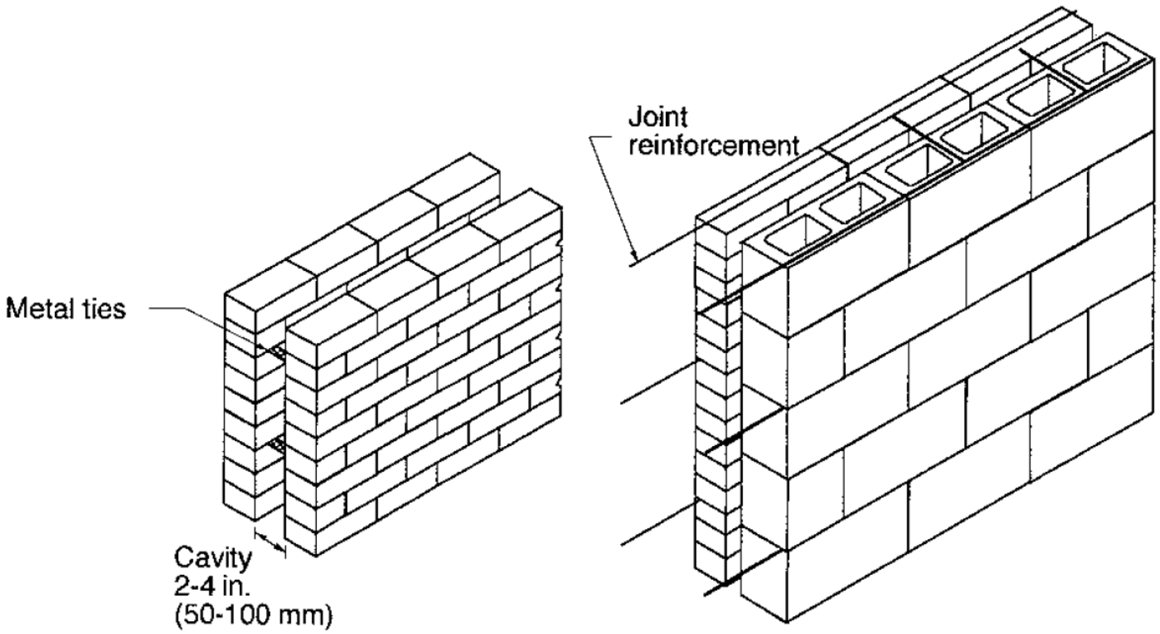
… Types of Masonry Elements

- Based on **how to resist structural loads**:
  - **URM-** tensile stresses are resisted by axial compression and also by limited tensile strength of mortar bond. Minimum reinforcement may be specified based on seismic design category (SDC)
  - **RM-** Tensile stresses are resisted by longitudinal (to carry flexure) and transverse (to carry shear) steel reinforcement. Tensile strength of masonry is ignored.
  - **PM-** Tensile stresses is resisted by axial compressive stresses from prestressing.

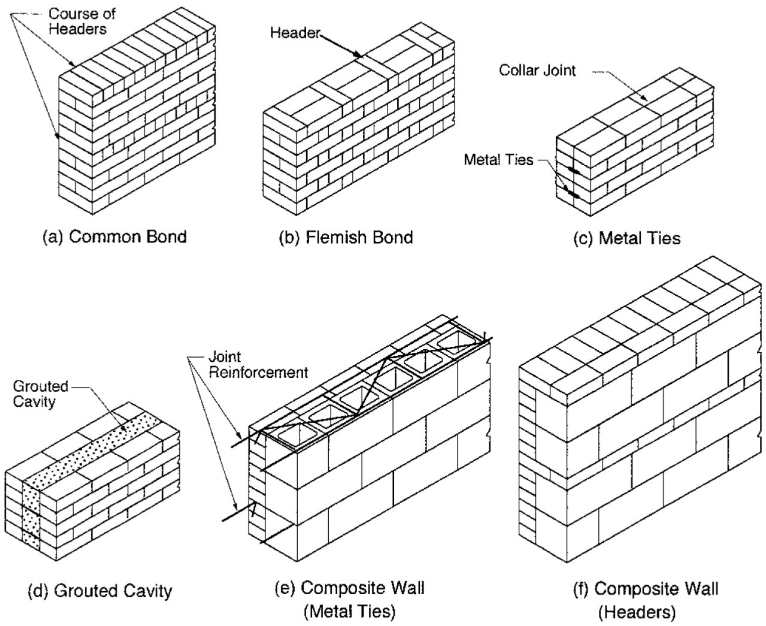
Single-Wythe URM Walls



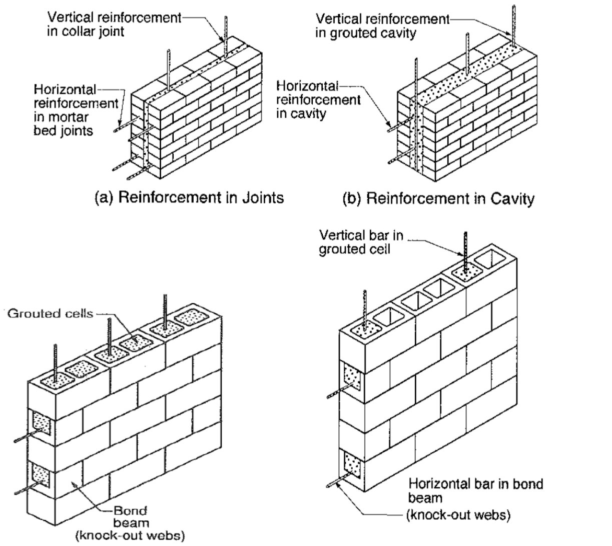
Cavity Walls



Multi-Wythe Solid URM Walls



RM Walls

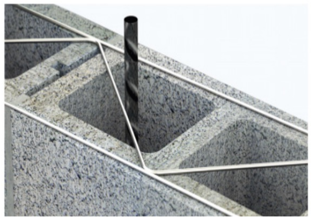


(c) Reinforcement in hollow units (fully and partially grouted masonry, L to R)

- Vertical (longitudinal) steel to carry flexure and horizontal (transverse) steel to carry shear.

- Reinforcement types:
  - Steel bars
  - Joint reinforcement

(a) Ladder Type



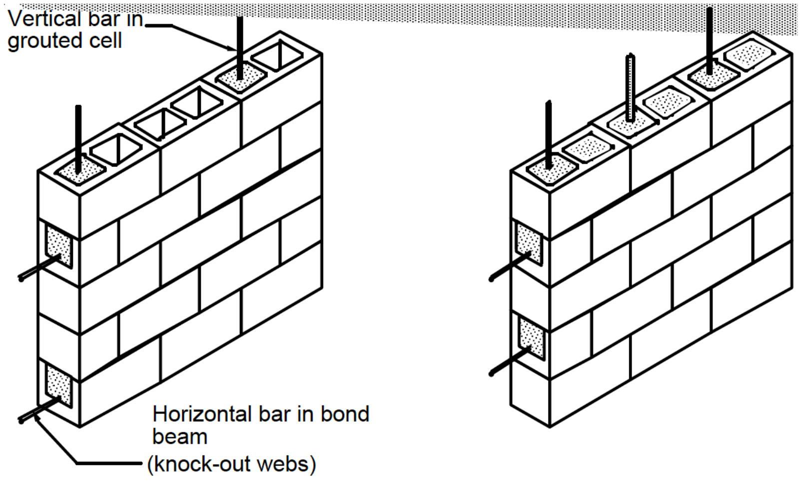
(b) Truss type

.....RM Walls

Extend of grouting

- Fully grouted (grouted solid) masonry (**FGM**) -Use gross section properties for stress calculation.

- Partially grouted masonry (**PGM**) – use net cross section properties for stress calculations.

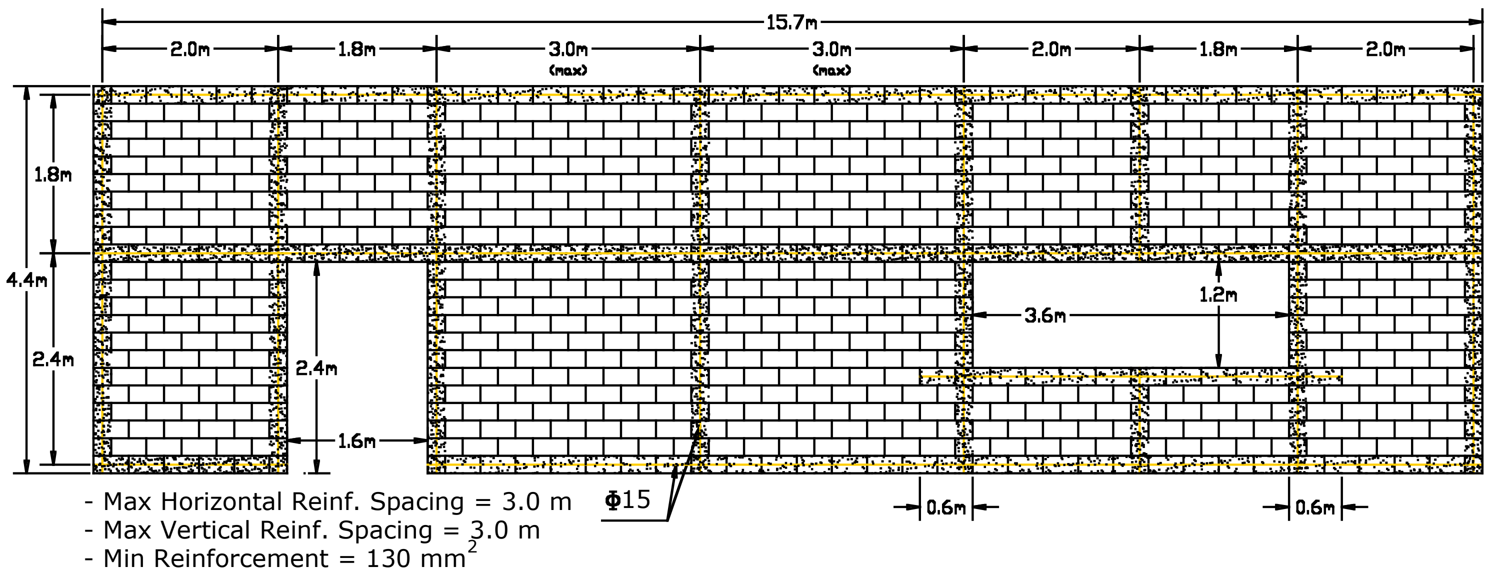


(a) Partially grouted concrete masonry
(b) Fully grouted concrete masonry

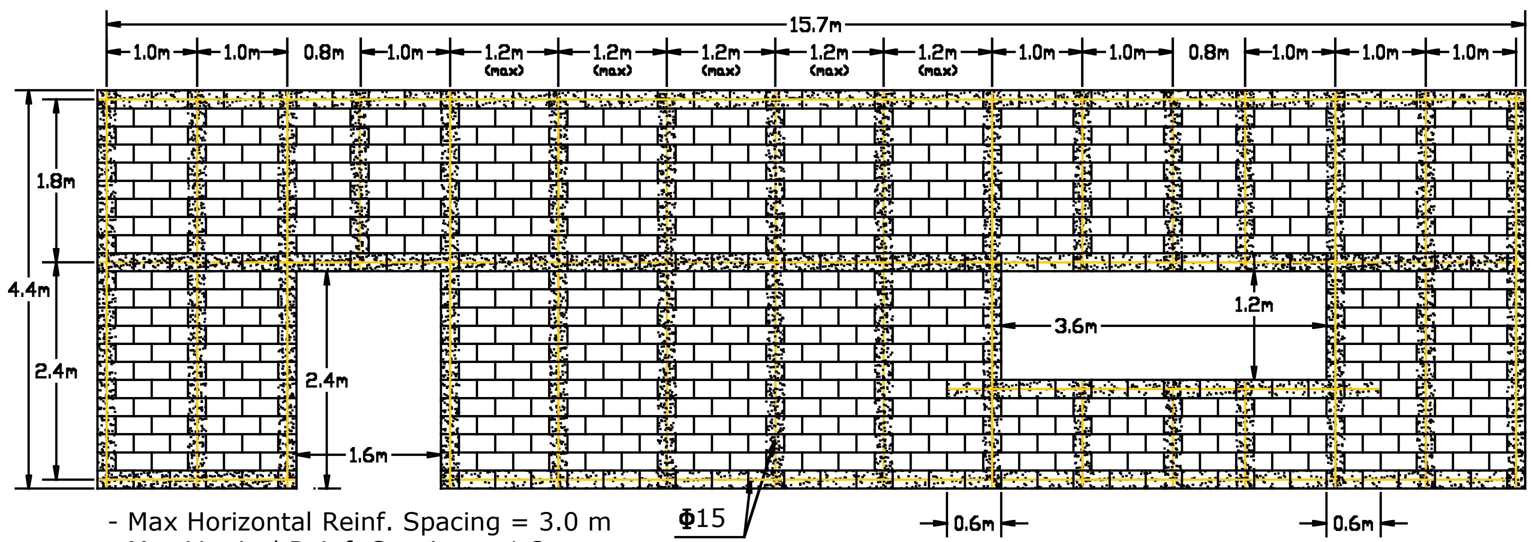
TMS 402 Code Minimum steel Reinforcement in Masonry walls

- Based on Seismic Design category:
  - Ordinary Reinforced Masonry (**ORM**)
  - Intermediate Reinforced Masonry (**IRM**)
  - Special Reinforced Masonry (**SRM**)

TMS 402 Reinforcement Requirements for ORM Walls

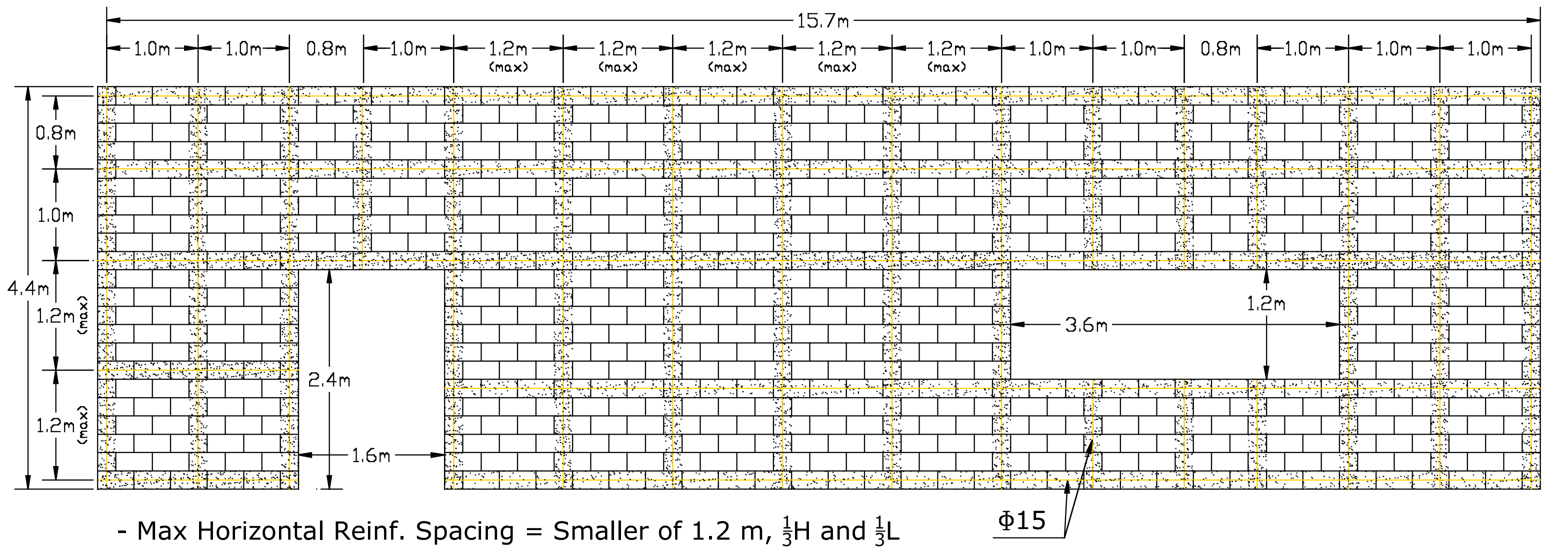


TMS 402 Reinforcement Requirements for IRM Walls



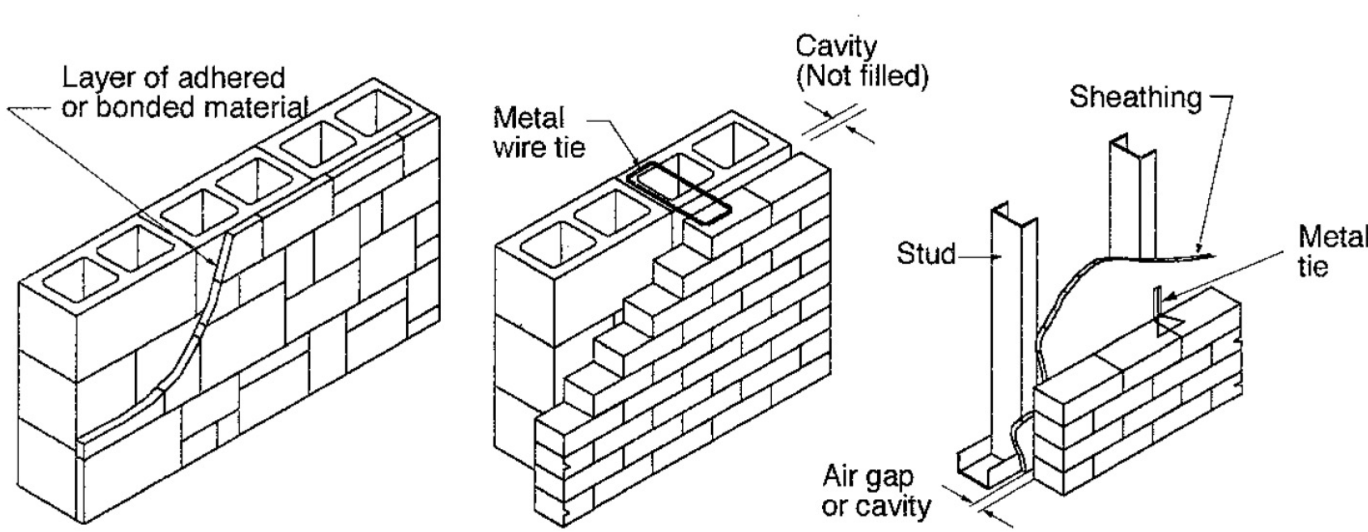
- Max Horizontal Reinf. Spacing = 3.0 m
- Max Vertical Reinf. Spacing = 1.2 m
- Min Reinforcement = 130 mm^2

TMS Reinforcement Requirements for SRM Walls



- Max Horizontal Reinf. Spacing = Smaller of 1.2 m, $\frac{1}{3}$H and $\frac{1}{3}$L
- Max Vertical Reinf. Spacing = Smaller of 1.2 m, $\frac{1}{3}$H and $\frac{1}{3}$L
- Min Reinforcement = 130 mm^2
- Min area of vertical reinf. shall be $\frac{1}{3}$ of required shear reinf.

Veneered Walls

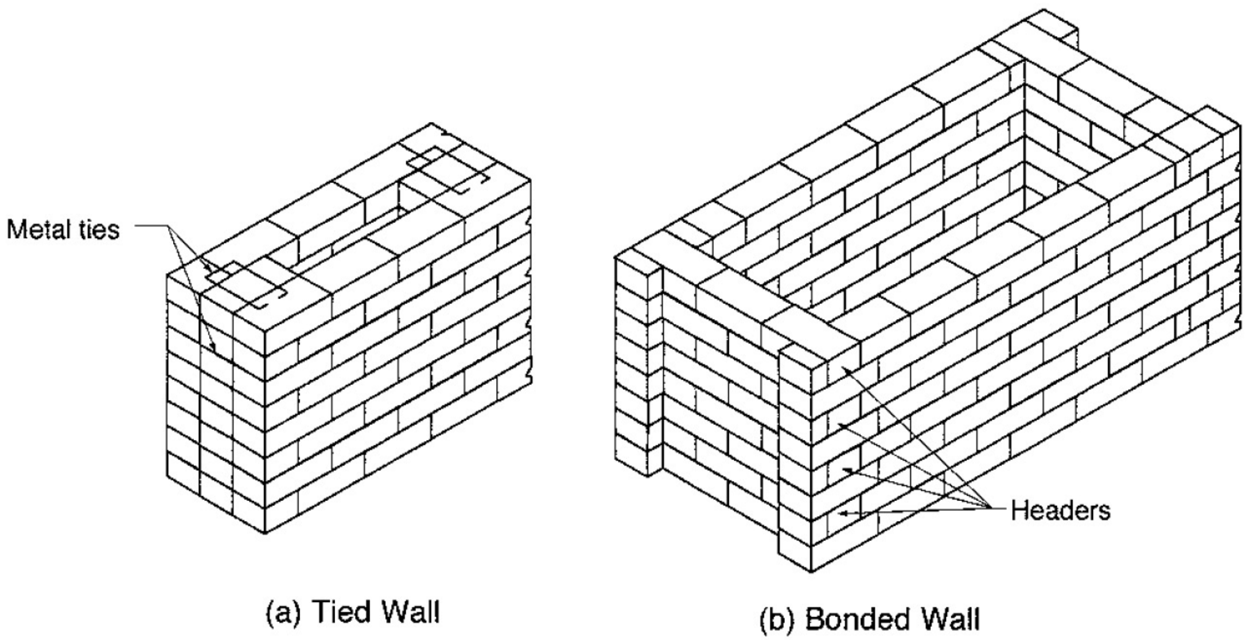


(a) Adhered Veneer

(b) Anchored Veneer (Masonry Backing)

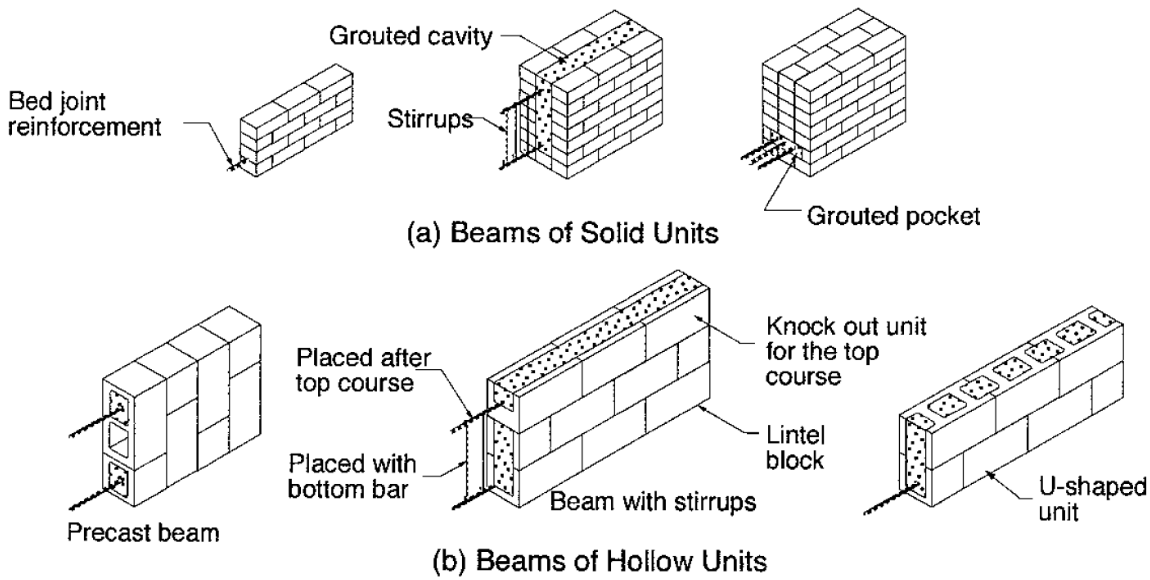
(c) Anchored Veneer (Stud Backing)

Diaphragm Walls (URM or PM)



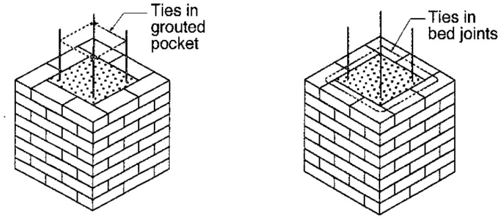
RM Beams

Beams and lintels
have to be reinforced.

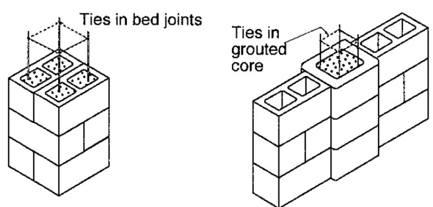


RM Columns and Pilasters

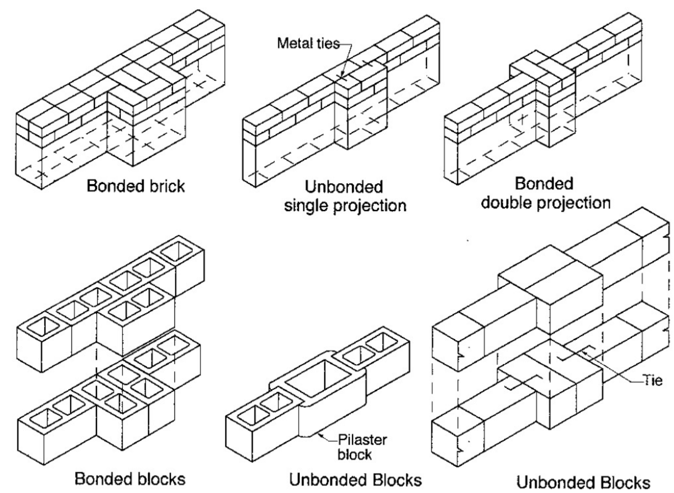
Masonry Columns have to be reinforced whereas masonry pilasters do not have to be reinforced.



(a) Solid or Cored Units



(b) Hollow Units



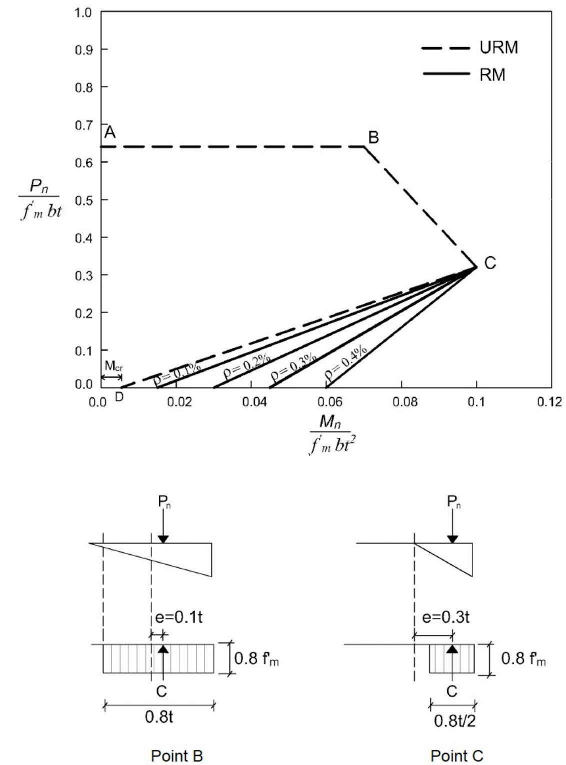
Masonry Elements

Behavior

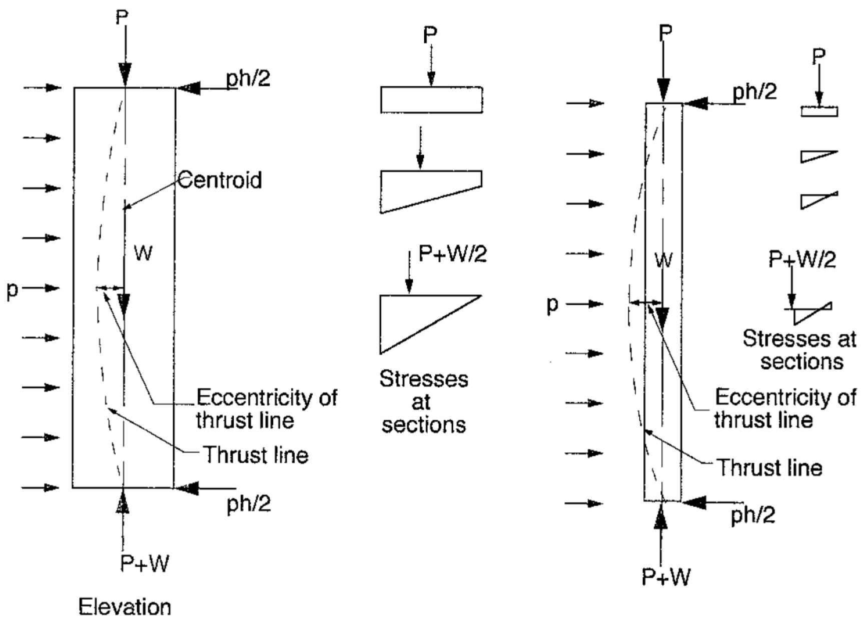
Out-of-Plane Behavior of Walls under Axial Load and Bending

- If eccentricity e is equal to or less than t/3, no need of steel reinforcement.

- If eccentricity e is greater than t/3 wall has to be reinforced.



Behavior of Walls under Axial Load and Bending- Location of Thrust Line



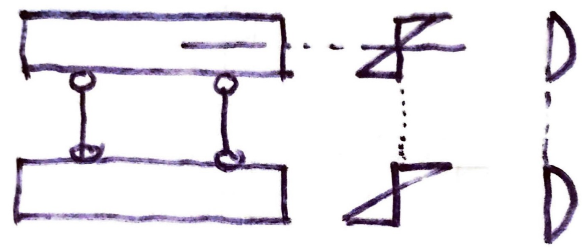
(a) Thick Wall

(b) Thin Wall

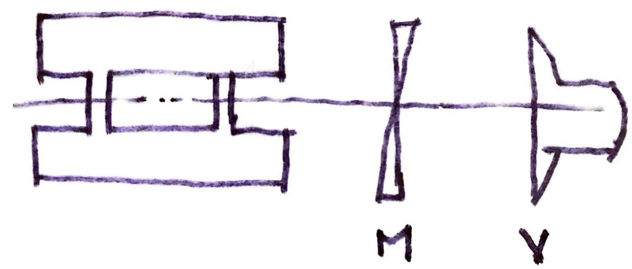
- If e is equal to or less than t/6, all section is under compression and no cracking
- If e exceeds t/6 cracking occurs (assume no tension capacity)
- For e=t/3 have the section is cracked
- For e greater than t/2 , the thrust line is outside the section and the wall has to be reinforced

Relative Flexural Strength and Stiffness of Cavity and Diaphragm Walls

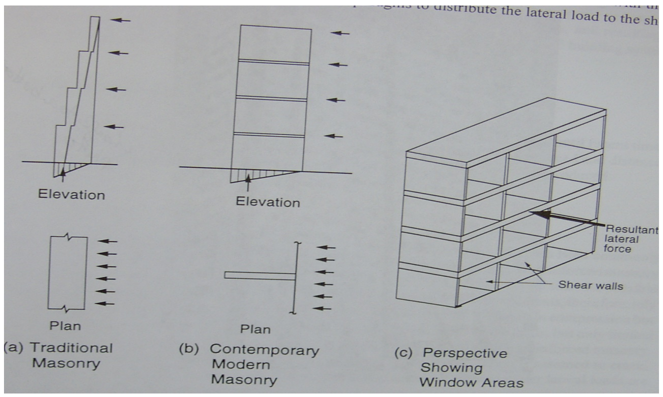
- Cavity wall strength (moment-carrying capacity) and stiffness are based on simple addition of individual wythes (uncoupled), each bend about its own axis.

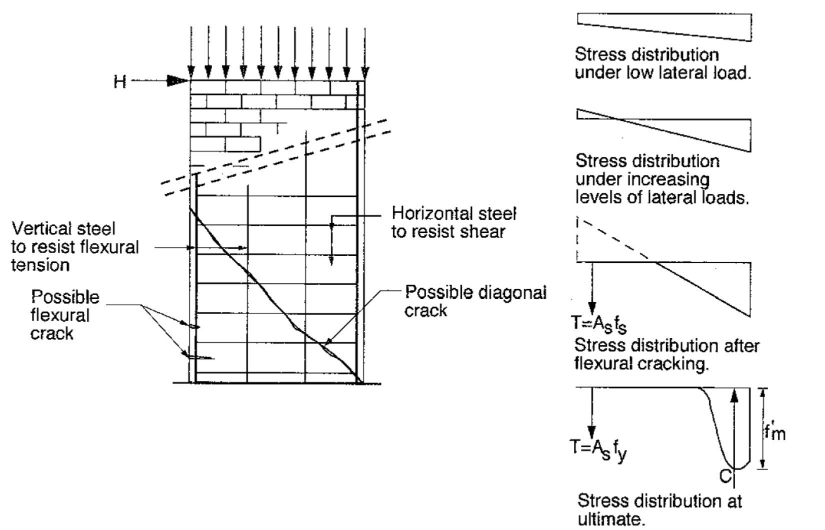


- In diaphragm wall, the two wythes are coupled by the cross rigid links that are capable of transferring shear. Therefore, the strength and stiffness are calculated based on net combined flanged cross section (with common centroidal axis).



Behavior of Reinforced Masonry Shear Walls

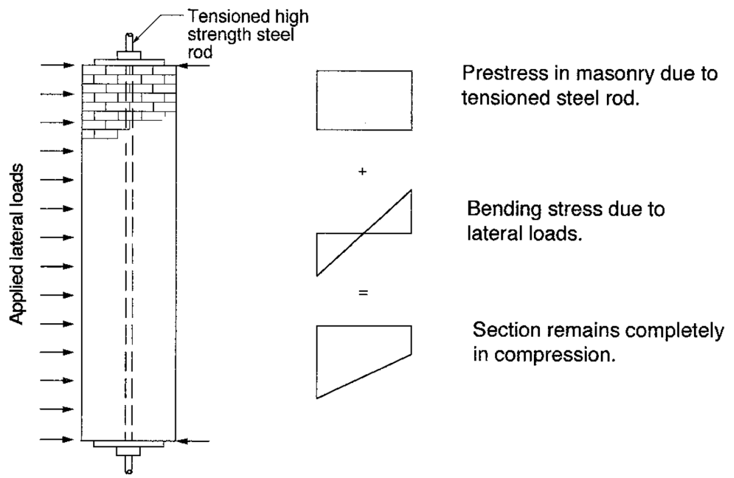




(a) Wall under combined axial and lateral loads.

(b) Normal Stress distributions.

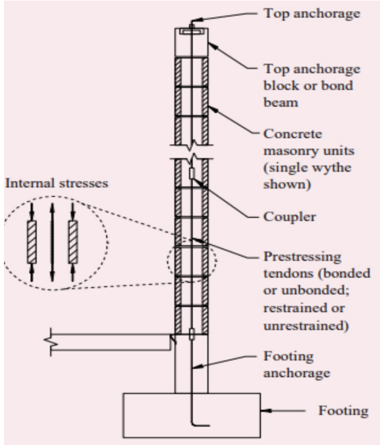
Prestressed Masonry Walls

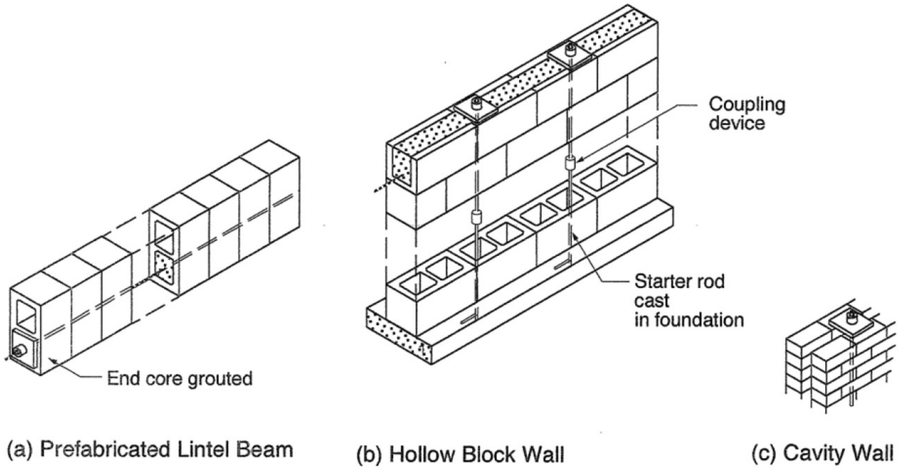


(a) Prestress Wall (b) Normal Stress Distribution at Midspan Section

- PM walls are typically designed to be free of tension (crack free) under service loads. This contrast with RM , which must crack for the reinforcement to become effective.
- If minor cracks do occur under service loads, the prestressed steel closes them again when the load is removed.
- The initial prestress has to be modified to account for long term deformation such as creep, shrinkage (for CMU).

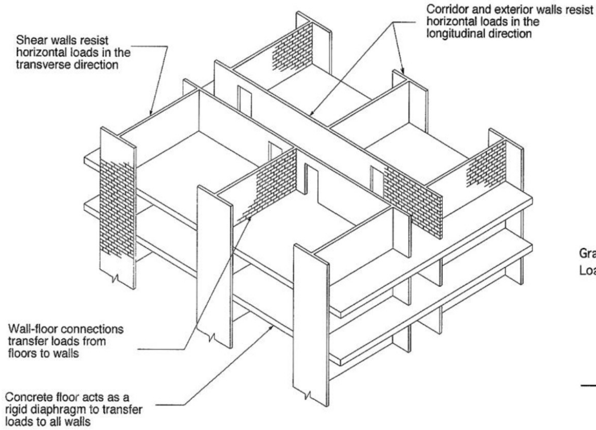
Post-tensioning



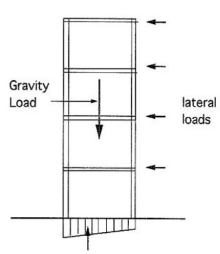


Masonry Systems

Multi-Story Reinforced Masonry Buildings



(a) Masonry Shear Wall Building



(b) Elevation of a Shear Wall

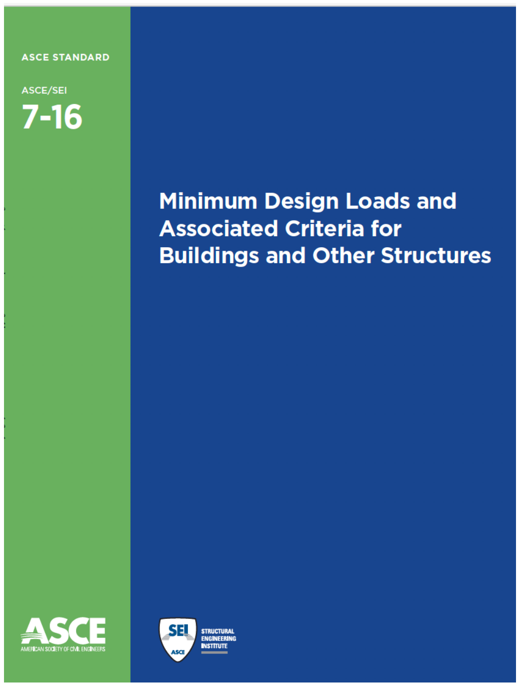
- Rigid diaphragms-loads are distributed to the lateral load resisting system (shear walls) based on relative stiffness.
- Accumulated In-plane action of shear walls under seismic loads controls the wall design
- Shear walls have to have adequate ductility capacity to reduce seismic demand (R factor)

Examples : Multi-Story Reinforced Masonry Buildings

- The 21 story Liberty Park East Towers in Pittsburgh were constructed using reinforced concrete masonry shear walls.
- The top 18 stories of the Excalibur Hotel I Las Vegas was Constructed using 12 in reinforced concrete masonry shear walls

Codes, Specifications and Materials Standards

Loading Standard



Covers load determination, serviceability requirements and ductility requirements for seismic design.

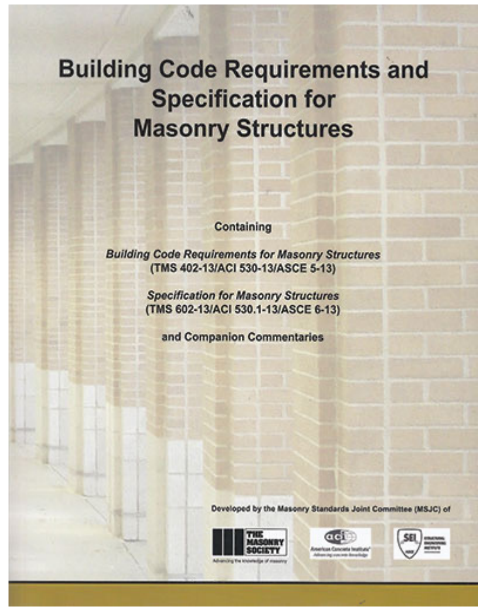
Gravity Loads: D, L, S, R

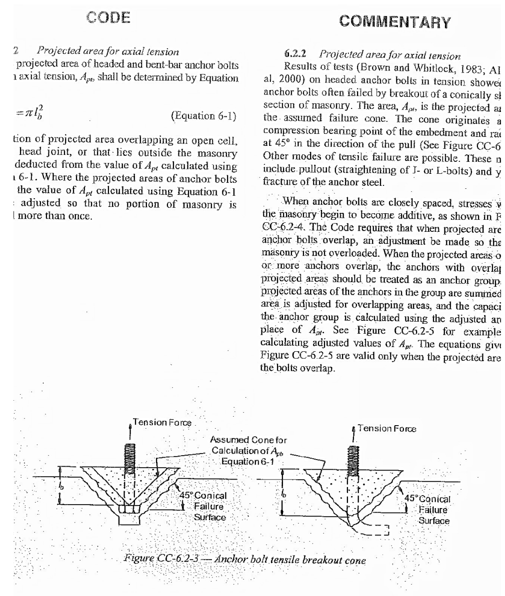
Lateral Loads: W, E

Load combinations

Design Standards

- Masonry Materials and assemblages- ASTM Specifications
- Design: TMS 402 Code-2016
- Construction: TMS 602 Specifications-2016





CODE

2 *Projected area for axial tension*
projected area of headed and bent-bar anchor bolts
ı axial tension, A_{pt}, shall be determined by Equation

$= \pi l_b^2$ (Equation 6-1)

tion of projected area overlapping an open cell,
head joint, or that lies outside the masonry
deducted from the value of A_{pt} calculated using
ı 6-1. Where the projected areas of anchor bolts
the value of A_{pt} calculated using Equation 6-1
adjusted so that no portion of masonry is
l more than once.

COMMENTARY

6.2.2 *Projected area for axial tension*
Results of tests (Brown and Whitlock, 1983; Al
al, 2000) on headed anchor bolts in tension showe
anchor bolts often failed by breakout of a conically s
section of masonry. The area, A_{pt}, is the projected a
the assumed failure cone. The cone originates a
compression bearing point of the embedment and ra
at 45° in the direction of the pull (See Figure CC-6
Other modes of tensile failure are possible. These n
include pullout (straightening of J- or L-bolts) and y
fracture of the anchor steel.

When anchor bolts are closely spaced, stresses w
the masonry begin to become additive, as shown in F
CC-6.2-4. The Code requires that when projected are
anchor bolts overlap, an adjustment be made so tha
masonry is not overloaded. When the projected areas o
or more anchors overlap, the anchors with overla
projected areas should be treated as an anchor group
projected areas of the anchors in the group are summed
area is adjusted for overlapping areas, and the capaci
the anchor group is calculated using the adjusted ar
place of A_{pt}. See Figure CC-6.2-5 for example
calculating adjusted values of A_{pt}. The equations giv
Figure CC-6.2-5 are valid only when the projected are
the bolts overlap.

Figure CC-6.2-3 — Anchor bolt tensile breakout cone

Sources of Information for Design and Construction of Modern Masonry Buildings

See Appendix A of the Masonry textbook by A. Hamid

A.1 Organizations

A.2 Books

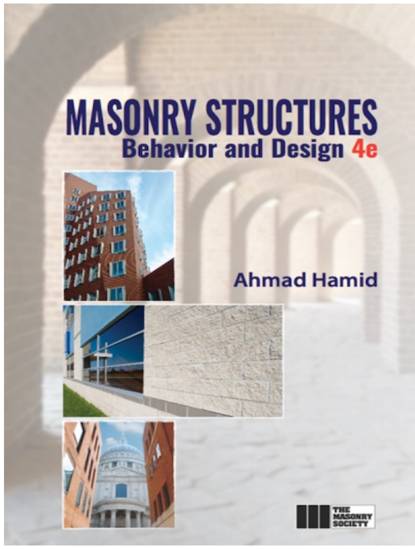
A.3 Special technical publications

A.4 Masonry journals

A.5 Technical notes

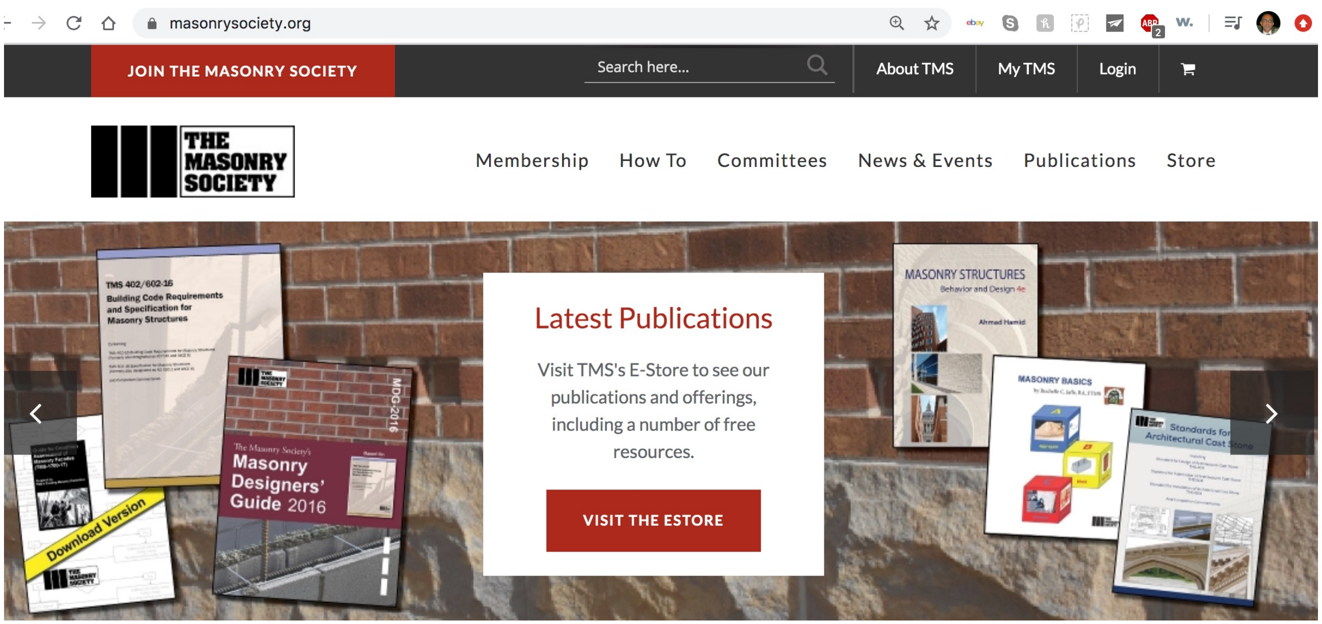
A.6 Conference proceedings

A.7 Magazines

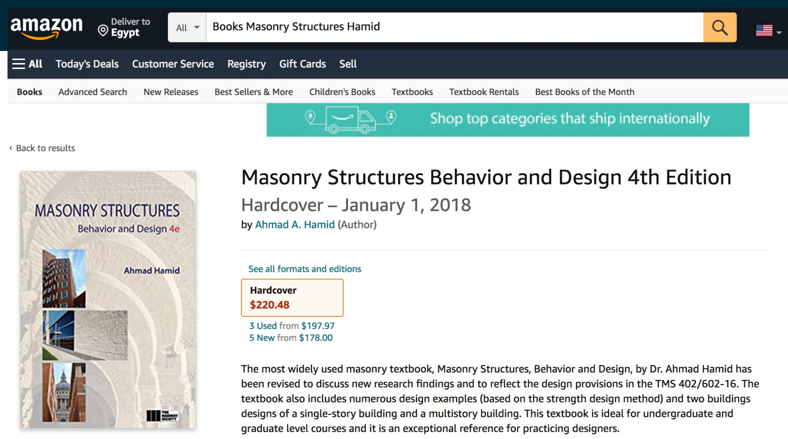


The Masonry Society

- The Masonry Society: www.themasonrysociety.org



Books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Shop top categories that ship internationally
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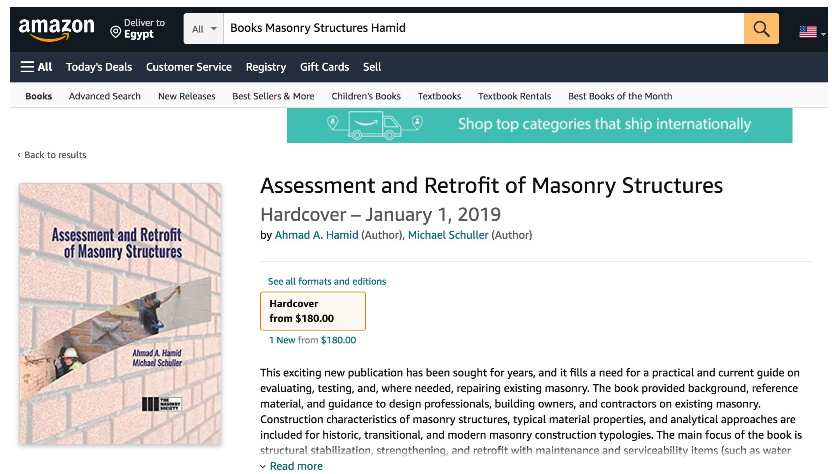
MASONRY STRUCTURES
Behavior and Design 4e
Ahmad Hamid
Masonry Structures Behavior and Design 4th Edition
Hardcover – January 1, 2018
by Ahmad A. Hamid (Author)
See all formats and editions
Hardcover
$220.48
3 Used from $197.97
5 New from $178.00
The most widely used masonry textbook, Masonry Structures, Behavior and Design, by Dr. Ahmad Hamid has been revised to discuss new research findings and to reflect the design provisions in the TMS 402/602-16. The textbook also includes numerous design examples (based on the strength design method) and two buildings designs of a single-story building and a multistory building. This textbook is ideal for undergraduate and graduate level courses and it is an exceptional reference for practicing designers.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Assessment and Retrofit of Masonry Structures
Ahmad A. Hamid
Michael Schuller
Assessment and Retrofit of Masonry Structures
Hardcover – January 1, 2019
by Ahmad A. Hamid (Author), Michael Schuller (Author)
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This exciting new publication has been sought for years, and it fills a need for a practical and current guide on evaluating, testing, and, where needed, repairing existing masonry. The book provided background, reference material, and guidance to design professionals, building owners, and contractors on existing masonry. Construction characteristics of masonry structures, typical material properties, and analytical approaches are included for historic, transitional, and modern masonry construction typologies. The main focus of the book is structural stabilization, strengthening, and retrofit with maintenance and serviceability items (such as water
Read more

Technical Notes

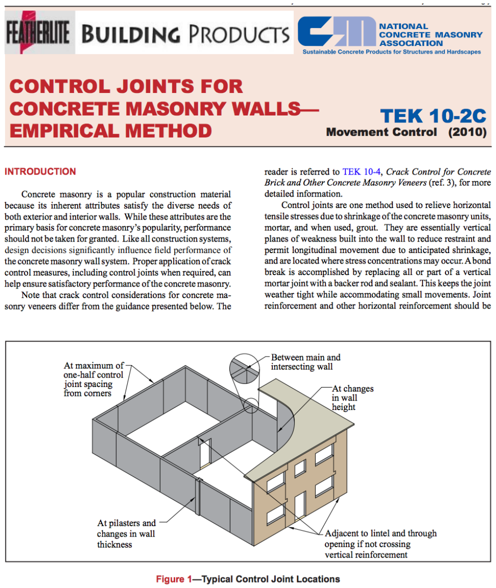
NCMA TEK notes available online : Go to NCMA website:

www.ncma.org

Cover materials, detailing, design, construction

Energy, water penetration resistance, fire

Resistance and noise control



FEATHERLITE BUILDING PRODUCTS — NATIONAL CONCRETE MASONRY ASSOCIATION — Sustainable Concrete Products for Structures and Hardscapes

CONTROL JOINTS FOR CONCRETE MASONRY WALLS— EMPIRICAL METHOD

TEK 10-2C
Movement Control (2010)

INTRODUCTION

Concrete masonry is a popular construction material because its inherent attributes satisfy the diverse needs of both exterior and interior walls. While these attributes are the primary basis for concrete masonry's popularity, performance should not be taken for granted. Like all construction systems, design decisions significantly influence field performance of the concrete masonry wall system. Proper application of crack control measures, including control joints when required, can help ensure satisfactory performance of the concrete masonry.

Note that crack control considerations for concrete masonry veneers differ from the guidance presented below. The reader is referred to TEK 10-4, *Crack Control for Concrete Brick and Other Concrete Masonry Veneers* (ref. 3), for more detailed information.

Control joints are one method used to relieve horizontal tensile stresses due to shrinkage of the concrete masonry units, mortar, and when used, grout. They are essentially vertical planes of weakness built into the wall to reduce restraint and permit longitudinal movement due to anticipated shrinkage, and are located where stress concentrations may occur. A bond break is accomplished by replacing all or part of a vertical mortar joint with a backer rod and sealant. This keeps the joint weather tight while accommodating small movements. Joint reinforcement and other horizontal reinforcement should be

Figure 1—Typical Control Joint Locations

…. Technical Notes

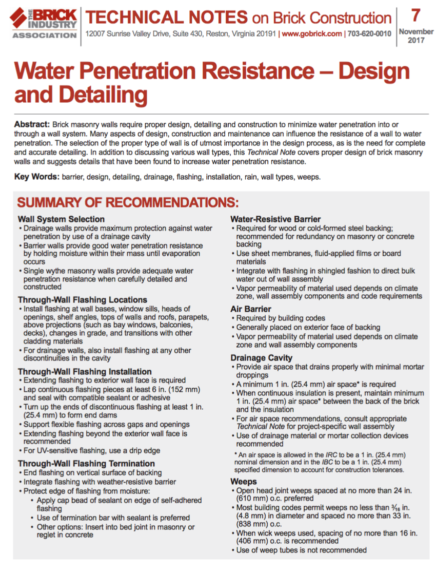
BIA Tech Notes-available online: Go to BIA website

www.bia.org

Cover materials, detailing, design, construction

Energy, water penetration resistance, fire

Resistance and noise control



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12007 Sunrise Valley Drive, Suite 430, Reston, Virginia 20191 | www.gobrick.com | 703-620-0010 | November 2017

Water Penetration Resistance – Design and Detailing

Abstract: Brick masonry walls require proper design, detailing and construction to minimize water penetration into or through a wall system. Many aspects of design, construction and maintenance can influence the resistance of a wall to water penetration. The selection of the proper type of wall is of utmost importance in the design process, as is the need for complete and accurate detailing. In addition to discussing various wall types, this *Technical Note* covers proper design of brick masonry walls and suggests details that have been found to increase water penetration resistance.

Key Words: barrier, design, detailing, drainage, flashing, installation, rain, wall types, weeps.

SUMMARY OF RECOMMENDATIONS:

Wall System Selection
- Drainage walls provide maximum protection against water penetration by use of a drainage cavity
- Barrier walls provide good water penetration resistance by holding moisture within their mass until evaporation occurs
- Single wythe masonry walls provide adequate water penetration resistance when carefully detailed and constructed

Through-Wall Flashing Locations
- Install flashing at wall bases, window sills, heads of openings, shelf angles, tops of walls and roofs, parapets, above projections (such as bay windows, balconies, decks), changes in grade, and transitions with other cladding materials
- For drainage walls, also install flashing at any other discontinuities in the cavity

Through-Wall Flashing Installation
- Extending flashing to exterior wall face is required
- Lap continuous flashing pieces at least 6 in. (152 mm) and seal with compatible sealant or adhesive
- Turn up the ends of discontinuous flashing at least 1 in. (25.4 mm) to form end dams
- Support flexible flashing across gaps and openings
- Extending flashing beyond the exterior wall face is recommended
- For UV-sensitive flashing, use a drip edge

Through-Wall Flashing Termination
- End flashing on vertical surface of backing
- Integrate flashing with weather-resistive barrier
- Protect edge of flashing from moisture:
  - Apply cap bead of sealant on edge of self-adhered flashing
  - Use of termination bar with sealant is preferred
  - Other options: Insert into bed joint in masonry or reglet in concrete

Water-Resistive Barrier
- Required for wood or cold-formed steel backing; recommended for redundancy on masonry or concrete backing
- Use sheet membranes, fluid-applied films or board materials
- Integrate with flashing in shingled fashion to direct bulk water out of wall assembly
- Vapor permeability of material used depends on climate zone, wall assembly components and code requirements

Air Barrier
- Required by building codes
- Generally placed on exterior face of backing
- Vapor permeability of material used depends on climate zone and wall assembly components

Drainage Cavity
- Provide air space that drains properly with minimal mortar droppings
- A minimum 1 in. (25.4 mm) air space* is required
- When continuous insulation is present, maintain minimum 1 in. (25.4 mm) air space* between the back of the brick and the insulation
- For air space recommendations, consult appropriate *Technical Note* for project-specific wall assembly
- Use of drainage material or mortar collection devices recommended

* An air space is allowed in the *IRC* to be a 1 in. (25.4 mm) nominal dimension and in the *IBC* to be a 1 in. (25.4 mm) specified dimension to account for construction tolerances.

Weeps
- Open head joint weeps spaced at no more than 24 in. (610 mm) o.c. preferred
- Most building codes permit weeps no less than $\frac{3}{16}$ in. (4.8 mm) in diameter and spaced no more than 33 in. (838 mm) o.c.
- When wick weeps used, spacing of no more than 16 in. (406 mm) o.c. is recommended
- Use of weep tubes is not recommended

The End