Architecture 509
Masonry Structures

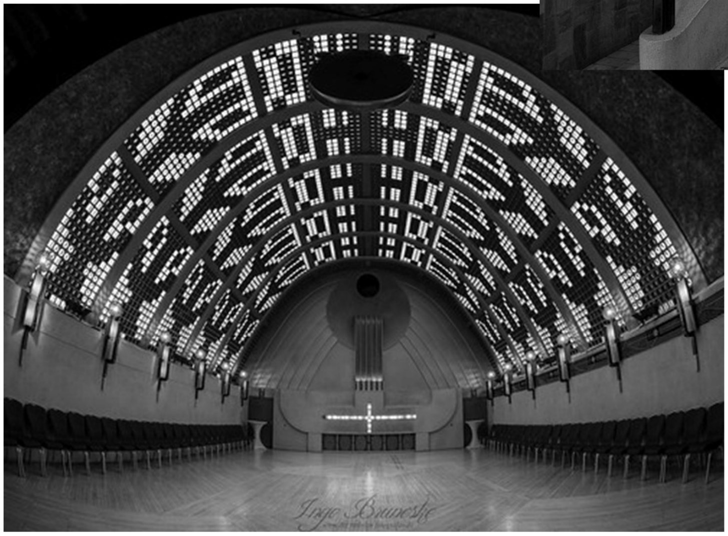
Masonry

- Mortar
- Grout
- Reinforcement

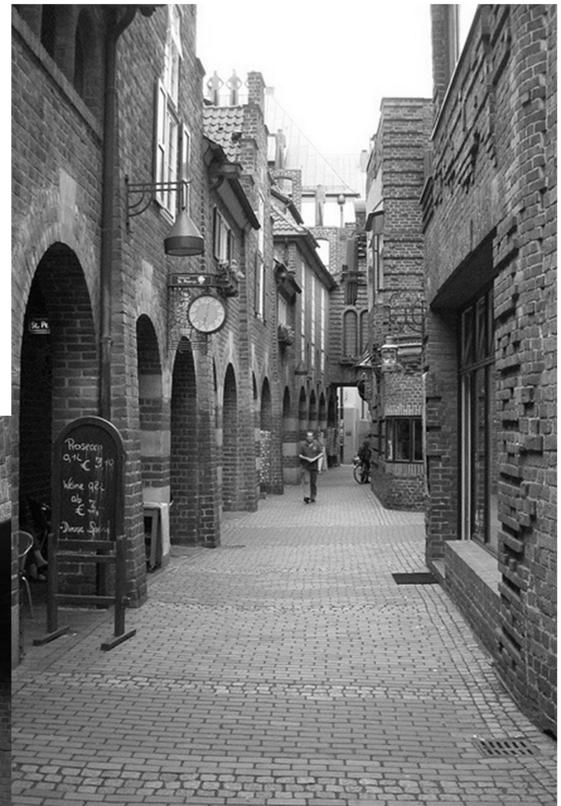
Haus Atlantis
Arch: Bernhard Hoetger
Böttcherstraße, Bremen

Böttcherstraße, Bremen

Haus Atlantis, Himmelssaal
Bernhard Hoetger, 1922 - 1931



Böttcherstraße, Bremen
Bernhard Hoetger, 1922 - 1931



Böttcherstraße, Bremen
Bernhard Hoetger, 1922 - 1931

Mortar Types

Types M, S, N, O

The following mortar designations took effect in the mid–1950's:

M a **S** o **N** w **O** r **K**

strongest weakest

Table 2-3. Guide to the Selection of Mortar Type*

Location	Building segment	Mortar type: Recommended	Mortar type: Alternative
Exterior, above grade	Load-bearing walls	N	S or M
	Non-load-bearing walls	O**	N or S
	Parapet walls	N	S
Exterior, at or below grade	Foundation walls, retaining walls, manholes, sewers, pavements, walks, and patios	S†	M or N†
Interior	Load-bearing walls	N	S or M
	Non-load-bearing partitions	O	N

*Adapted from ASTM C270. This table does not provide for specialized mortar uses, such as chimney, reinforced masonry, and acid-resistant mortars.

**Type O mortar is recommended for use where the masonry is unlikely to be frozen when saturated or unlikely to be subjected to high winds or other significant lateral loads. Type N or S mortar should be used in other cases.

†Masonry exposed to weather in a nominally horizontal surface is extremely vulnerable to weathering. Mortar for such masonry should be selected with due caution.

Note: For tuckpointing mortar, see "Tuckpointing," Chapter 9.

Portland cement – lime mortars

Relative Parts by Volume

mortar type	Portland cement	lime	sand
M	1	$\frac{1}{4}$	$3\frac{1}{2}$
S	1	$\frac{1}{2}$	$4\frac{1}{2}$
N	1	1	6
O	1	2	9

sum should equal 1/3 of sand volume
(assuming that sand has void ratio of 1 in 3)

Mortar Types

ASTM C91 Specification for Masonry Cement
ASTM C144 Specification for Aggregate for Masonry Mortar
ASTM C270 Specification for Mortar for Unit Masonry
ASTM C780 Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry
ASTM C1329 Specification for Mortar Cement
ASTM C1586 Standard Guide for Quality Assurance of Mortars

Portland Cement - Hydrated Lime (PCL)

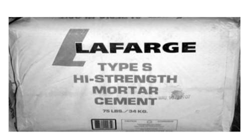
- Portland Cement + Lime

Masonry Cement

- Developed between 1918 – 1932
- Proprietary product – performance standards
- Portland Cement + fines (e.g. ground limestone)
- Additives – air entraining, water repellency
- Simple batching
- "fluffiness" due to air entrainment – easy to place
- Code limits in high seismic areas

Mortar Cement

- Proprietary product – performance standards
- Limitations on the amount of air entrainment
- Specified bond strength
- Codes recognize as equivalent to PCL mortar



Mortar Specifying
Physical properties

Table 2. Physical Properties of Mortar Cements (ASTM C 1329)

Mortar Cement Type	N	S	M
Fineness, residue on a 45-μm (No. 325) sieve, maximum %	24	24	24
Autoclave expansion, maximum, %	1.0	1.0	1.0
Time of Setting			
Initial Set, minimum, hr.	2	1½	1½
Final Set, maximum hr.	24	24	24
Compressive strength minimum, MPa (psi)			
7 days	3.4 (500)	9.0 (1300)	12.4 (1800)
28 day	6.2 (900)	14.5 (2100)	20.0 (2900)
Bond strength minimum, MPa (psi)			
28 days	0.5 (70)	0.7 (100)	0.8 (115)
Air content, volume, %			
Minimum	8	8	8
Maximum	17	15	15
Water retention, flow after suction as % of original flow			
Minimum	70	70	70

Table 3. Physical Properties of Mortar Cement Mortars (ASTM C 270)

Mortar Type	Compressive Strength Minimum, MPa (psi)	Water Retention Minimum, %	Air Content Maximum, %
M	17.2 (2500)	75	12
S	12.4 (1800)	75	12
N	5.2 (750)	75	14*
O	2.4 (350)	75	14*

*When structural reinforcement is incorporated in (cement-lime or) mortar cement mortar, the maximum air content shall be 12%.

Note: Physical properties listed in Table 2 and Table 3 are measured in accordance with prescribed laboratory test procedures. Conformance to compressive strength, bond strength, air content, and water retention requirements of Table 2 is determined using standard testing sand (ASTM C 778). Conformance to Table 3 requirements is established using a masonry sand (ASTM C144) that is intended to be used in construction. Mortar made using masonry sand typically has lower compressive strength, lower air content, and higher water retention as compared to that achieved using standard sand. This fact is reflected in the differences between Table 2 (ASTM C 1329) and Table 3 (ASTM C 270) requirements for these properties.

Mortar Specifying

Proportion Specification

- A recipe for making mortar proportions cement - lime - sand
- It is simpler e.g. “All masonry mortar shall be Type N (or S or M,) in accordance with ASTM Specification C 270.”
- There is a recipe for each type
- This governs if none other is specified (default)

Mortar	Type	Proportion by Volume (Cementious Materials)					Aggregate Ratio (measured in damp, loose conditions)
		Portland Cement	Masonry or Mortar Cement			Hydrated Lime or Lime Putty	
			M	S	N		
Portland-Cement Lime	M	1				$^1/_4$	2 $^1/_4$ to 3 times the sum of the separate volumes of cementious materials
	S	1				$^1/_4$ - $^1/_2$	
	N	1				$^1/_2$ - $1^1/_4$	
	O	1				$1^1/_4$ - $2^1/_2$	
Masonry Cement and Mortar Cement	M	1			1		
	M		1				
	S	1/2			1		
	S			1			
	N				1		
	O				1		

Mortar Specifying

Property Specification

- Property spec. was developed using laboratory tests
- Not intended for field strength testing
- Requires test results - ASTM 270
  - — Compressive strength
  - — Water retention
  - — Air content
- Is intended for designing or checking a mix to be used
- This is more in line with "engineered masonry"
- ASTM C780 gives standards for field testing
  - — Consistency
  - — Board life
  - — Mortar-aggregate ratio
  - — Compressive strength

- Is intended for designing or checking a mix to be used
- This is more in line with "engineered masonry"
- ASTM C780 gives standards for field testing
  - — Consistency
  - — Board life
  - — Mortar-aggregate ratio
  - — Compressive strength

Table SC-2 — ASTM C270 property specification requirements for laboratory prepared mortar

Mortar	Type	Average compressive strength at 28 days, psi (MPa)	Water retention min, percent	Air content max, percent	Aggregate ratio (measured in damp, loose conditions)
Cement-lime	M	2500 (17.2)	75	12	Not less than 2¼ and not more than 3½ times the sum of the separate volumes of cementitious materials
	S	1800 (12.4)	75	12	
	N	750 (5.2)	75	14[1]	
	O	350 (2.4)	75	14[1]	
Mortar cement	M	2500 (17.2)	75	12	
	S	1800 (12.4)	75	12	
	N	750 (5.2)	75	14[1]	
	O	350 (2.4)	75	14[1]	
Masonry cement	M	2500 (17.2)	75	18	
	S	1800 (12.4)	75	18	
	N	750 (5.2)	75	20[2]	
	O	350 (2.4)	75	20[2]	

[1] When structural reinforcement is incorporated in cement-lime or mortar cement mortar, the maximum air content shall be 12 percent.

[2] When structural reinforcement is incorporated in masonry cement mortar, the maximum air content shall be 18 percent.

Plastic Properties of Mortar

Workability

- Spread easily with trowel into separations and crevices
- Support weight of masonry units when placed
- Adhere to vertical surfaces
- Readily extrude from mortar joints when mason applies pressure to bring unit into alignment
- Essential for good bond with masonry units

Measuring Workability

- The mason is the best judge by observing response of mortar to trowel
- A flow table will measure the percent increase in diameter of the base of a truncated cone when placed on the flow table and mechanically raised 1/2 in. and dropped 25 times in 15 seconds.
- Typical flow for construction mortars is in the range of 130 to 150%.

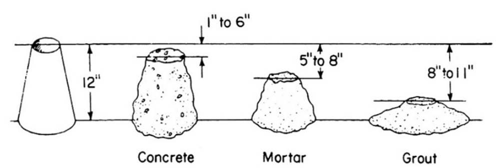


Fig. 2-27. Slump test comparison of concrete, mortar, and masonry grout.

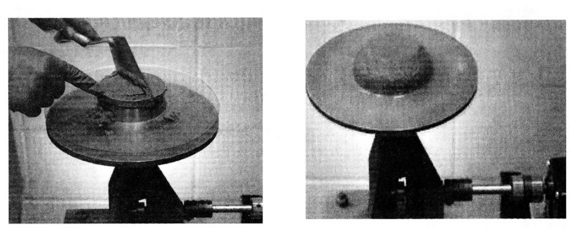


Figure 4.34 Flow table test.

Plastic Properties of Mortar

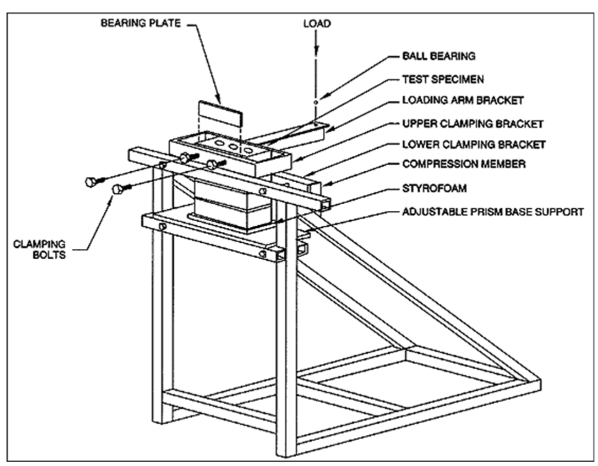
Water Retentivity

- Measure of ability of mortar under suction to retain its mixing water.
- Gives mason time to place and adjust unit without mortar stiffening.
- Increased through higher lime content, or addition of sand fines within allowable gradation limits.
- Determined by performing flow test after some water has been removed by a specific amount of vacuum.
  - Water retentivity is ratio of initial flow to flow after suction, expressed as a percent.
  - Typically, a water retentivity of 75% is required.

Properties of Hardened Mortar

Bond

- Most important property!
- Measure strength with a bond wrench
- Increases with cement content
- Because of workability criteria, Type S mortar generally gives maximum bond that can be achieved
- Bond can only be measured with units; thus not a property of mortar alone



Bond Extent

- The amount of surface bonded
- Lack of extent leads to serviceability problems
  - moisture penetration
  - increased air flow
  - increased sound transmission

Increased cement content increases bond strength but reduces bond extent due to loss of workability and increased shrinkage.

More serviceability problems with Type S and Type M mortars.

Properties of Hardened Mortar

Durability

- Increase in air content increases durability (good)
- Oversanding reduces durability
- Overtempering (adding water) reduces durability
  - Mortar should not be used beyond 2 ½ hours !
  - Use clean water – not from washing tools
- Use of highly absorbent masonry units reduces durability
- Do not over mix (by machine mixer)
- Use clean sand – no dirt or clay
- Reduce evaporation – place mortar tray in shade or cover
- Use clean tools – old mortar residue absorbs water

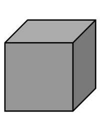
Extensibility

- The maximum tensile strain at rupture
- Low strength, low moduli mortars exhibit greater plastic tensile strains than high strength, high moduli mortars.
- Mortars with higher strength than necessary should not be used.

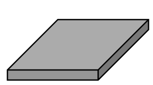
Properties of Hardened Mortar

Compressive Strength

- There is no ASTM standard for field tested mortar strength
  - It is sometimes mistakenly required
  - ASTM C270 only applies to lab samples
  - Field test samples differ in water content from lab samples so strength is not the same.
- Importance of compressive strength is overemphasized.
  - **Bond** is generally more important
  - **Extent** is generally more important
  - **Workability** is generally more important
  - **Water retentivity** is generally more important
- Increases with increase in cement content
- Decreases with increase in lime, sand, water, or air content
- Measured (in lab) using 2 inch cubes
- Mortar in practice (in masonry) is confined by units and in biaxial state of stress (different from lab samples)
- Strength of mortar has only a small effect on prism, or masonry wall strength
  - Tests on clay tile prisms which used an order of magnitude higher mortar compressive strength only doubled the prism strength.
  - Empirical relationship ~ prism strength is proportional to fourth root of mortar compressive strength.



2 inch test cube



Mortar joint in wall

Mortar test samples in lab

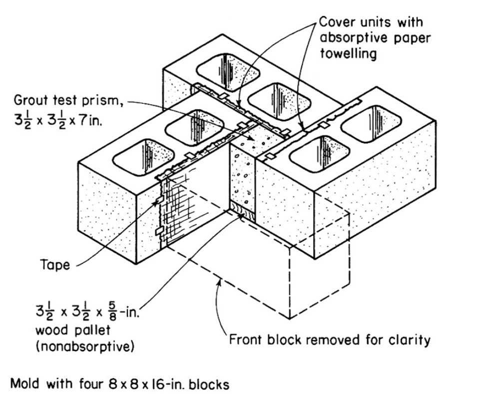


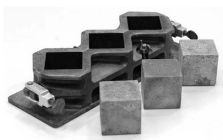
Fig. 2-29. ASTM C1019 method of using masonry units to form a prism for compression-testing of masonry grout.

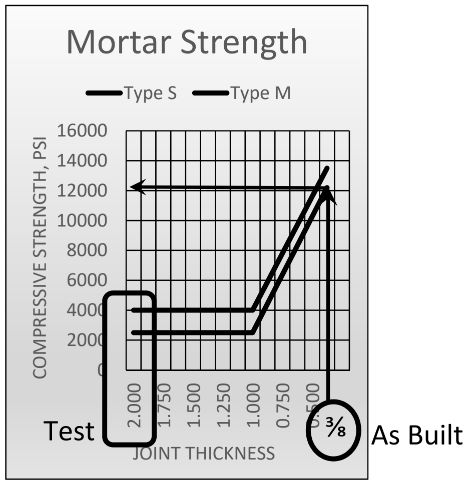
Grout test sample

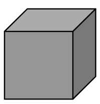
Properties of Hardened Mortar

Compressive Strength

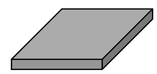
- Cube test strength is not the same as mortar bed strength.
- Masonry wall strength is measured with a prism test - ASTM C1314
  - Prisms are constructed by masons (not test engineers)
  - Prisms are to always be constructed in stack-bond configuration (not running bond)
  - Prisms have aspect rations between 1.3 and 5 with at lease one bed joint
  - Prisms shall always have a full mortar bed (not face-shell only)
  - Joints in prisms shall always be struck flush (not tooled)
  - Prisms should be made for all combinations of variables used – e.g. grouted and ungrouted
  - 3 prisms are required for testing
- Rather than measuring strength in the field, it is recommended to use ASTM C780 to evaluate field mortar.
  - Finds relative percentages of the materials used in the mortar (cement – sand)
  - Results can be compared with proportions specified







2 inch cube



Mortar joint

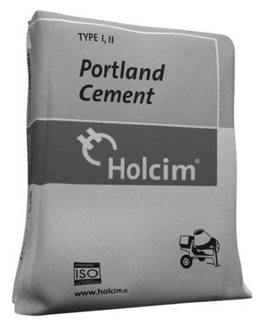
Ingredients of Mortar

Portland Cement

- Contributes to strength and durability of mortar.
- Provides early strength of mortar which is essential for speed of construction.
- Straight PC mortars are not used since they lack plasticity, have low water retentivity, and are harsh.
- PC mortars would give a strong wall, but the wall would be vulnerable to cracking and rain penetration.

Lime

- Provides workability, water retentivity, and elasticity
- Straight lime mortar would have low compressive strength and higher water retentivity
- Lime mortars would have a lower strength, but have a greater resistance to cracking and rain penetration.



Ingredients of Mortar

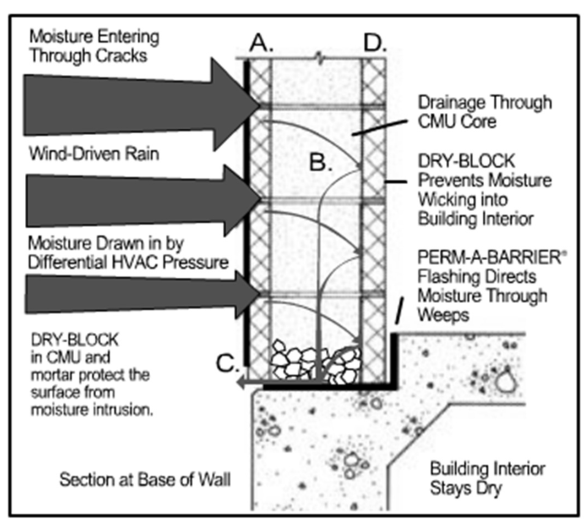
Sand

- Natural or manufactured sand can be used
- Void ratio of sand is about 1 in 3.
  - cementitious materials will fill voids in sand
  - Mortar mix is approximately volume of sand.
- Measured in damp loose condition.
  - Dry sand is 1.5-2 times as dense as damp, loose sand.
- Well-graded sands reduce separation of materials in plastic mortar, which improves workability.
  - Sands deficient in fines produce harsh mortars.
  - Sands with excess fines produce weak mortars; in extreme cases the mortar may not set up.
  - Sands that do not meet gradation requirements of C144 can be used provided resulting mortar can meet property specification.

Ingredients of Mortar

Admixtures

- Air entraining agents
  - Are generally not needed.
  - Masonry cement typically has air entraining agents.
  - Type A Portland cement is usually used, which has some air entraining additions.
- Coloring agents
  - require careful measuring and mixing
  - Mix with water
- Water repellents
  - Polymeric admixtures (e.g. DRY BLOCK from W.R. Grace).
  - One part is mixed throughout concrete during manufacture of masonry unit.
  - Other part is added to mortar during mixing.
  - Polymers cross link during curing to form resistance to water penetration.



Mixing Mortar

By machine mixer

- Mix 3-5 minutes in mechanical batch mixer.
- Let stand for 3 to 5 minutes.
- Workability is maintained by retempering (adding water)
  - Slightly reduces compressive strength
  - Increases bond strength
- Best results usually obtained if mortar is maintained at workable consistency.
- Discard mortar if it begins to stiffen or after 2.5 hours.

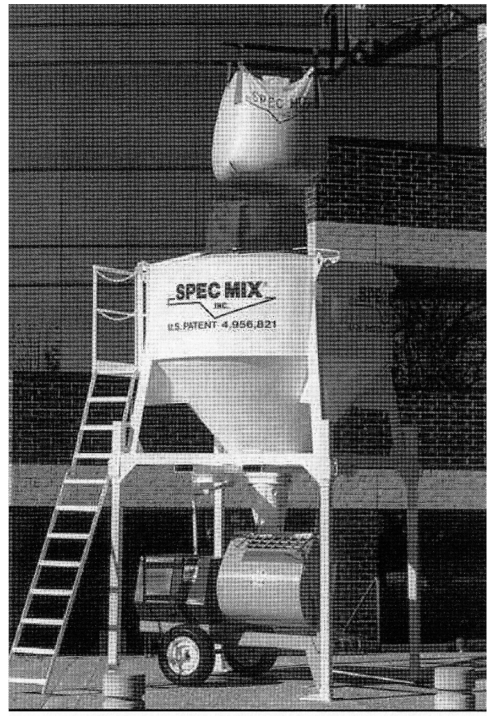
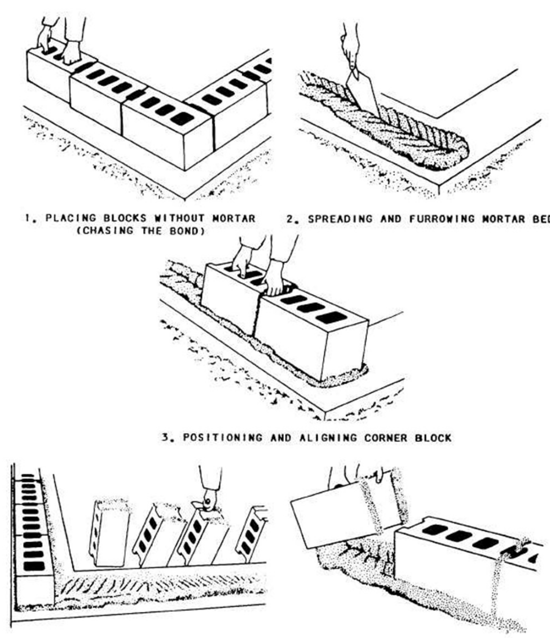


Figure 4.7 Pre-blended mortar silo setup.

Placing Mortar and Units

Bed Joints

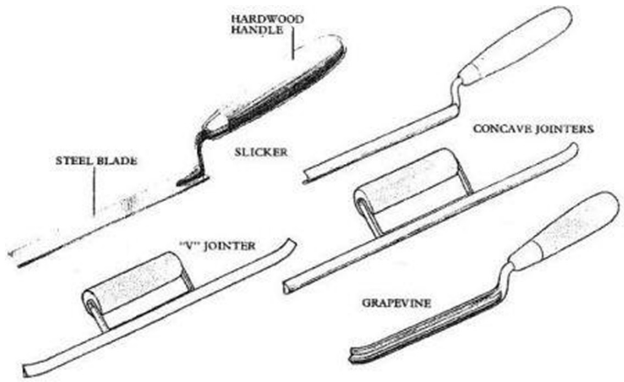
- Thickness
  - $3/8 \pm 1/8\ in.$
- Starting Course
  - at least $1/4\ in.$
  - Not more than $3/4\ in.$ when masonry is ungrouted or partially grouted
  - Not more than $1\,1/4\ in.$ when first course is solid grouted
- Thicker bed joints decrease compressive strength
- Solid units
  - Need solid bed joints
- Hollow units
  - Joints on width of face shell thickness



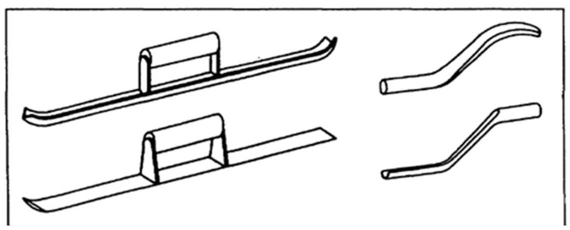
Placing Mortar and Units

Tooling

- Tool joints with round jointer to create a weather resistant surface.
- Do not disturb units after initially positioned; leads to reduced bond.
- Remove protrusions greater than 1/2 in. that will interfere with grouting.



Sled-runner jointers



S-shaped jointers

ASTM C1586 Standard for Quality Assurance of Mortars

Designation: C270 – 19a$^{\varepsilon 1}$

Standard Specification for Mortar for Unit Masonry[1]

Prior to Construction

- ASTM C 270
- Choose proportion or property specifications
- If property, make laboratory mortar specimens
  - Test mortar at a flow between 105% and 115%
  - Representative of moisture content after mortar placed in wall
    - Units will absorb some water
    - Drying of mortar from environment
  - Use recipe determined from laboratory property tests

During Construction

- ASTM C 780
- Tests for consistency of field produced mortar
- Strengths will be approximately 70% of lab tests
  - Field mortar has a flow between 130% and 150%
  - More water required for placement of units
- Better test is mortar aggregate ratio
  - Alcohol is used to retard hydration
  - Sieve analysis is performed (back in lab)

Grout

ASTM C476 Specification for Grout for Masonry
ASTM C1019 Sampling and Testing Grout

Grout is high-slump concrete (8-11 in.) made with small size aggregate (¼” – ½”)

- Bonds wythes together in composite masonry
- Bonds reinforcement to masonry
- Increases masonry volume for bearing and fire resistance

Specification

- Proportion
- Property

Grout

Proportion Specification

Type	Portland Cement	Hydrated Lime or Lime Putty	Aggregate Ratio (measured in damp, loose conditions)	
			Fine	Coarse
Fine	1	0 - $^{1}/_{10}$	2 $^{1}/_{4}$ to 3 times the sum of the volumes of cementitious materials	
Coarse	1	0 - $^{1}/_{10}$	2 $^{1}/_{4}$ to 3 times the sum of the volumes of cementitious materials	1 to 2 times the sum of the volumes of cementitious materials

Adapted from ASTM C476. Applicable other standards: Portland cement ASTM C150, blended hydraulic cement ASTM C595, Hydrated lime ASTM C207, lime putty ASTM C5, Aggregate ASTM C404

Coarse aggregate

- 85% pass 3/8 sieve
- 100% pass ½ sieve

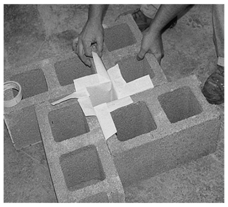
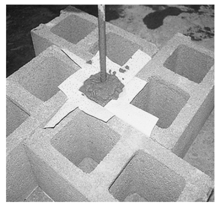
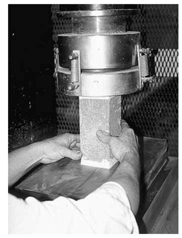
Good Qualities

- mix meets requirements of ASTM C476 (Standard Specification for Grout for Masonry)
- Slump between 8 and 11 inches
- W/C in the neighborhood of 0.65 to 0.80

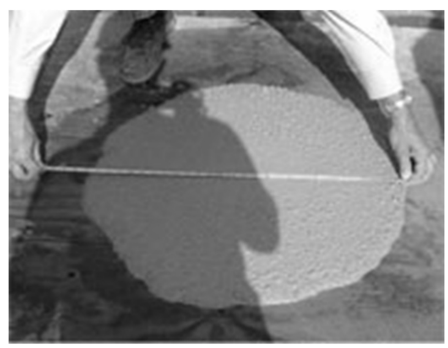
Grout

Properties

- Compressive Strength
  - 1000 psi to 2500 psi
  - Or equal to prism strength of masonry
  - Actual in place average ~ 4000 psi

Self-Consolidating Grout



Composition

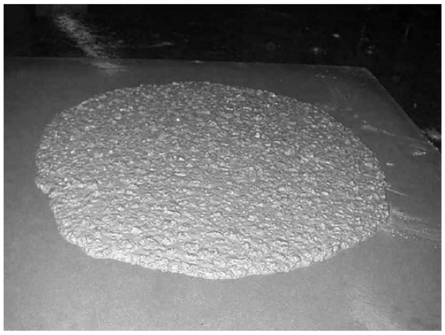
- contain a higher than normal cementitious content
- a high sand/aggregate ratio
- a polycarboxylate-based high-range water-reducing admixture
- an optional viscosity modifying admixture

Slump flow

- Spread of between 24 and 30 in. 1000 psi to 2500 psi
  - cone can be filled either upright or inverted
- Visual Stability Index ≤ 1

VSI Value	Criteria
0 = Highly Stable	No evidence of segregation or bleeding.
1 = Stable	No evidence of segregation and slight bleeding observed as sheen on the concrete mass.
2 = Unstable	A slight mortar halo ≤ 0.5 in. and/or aggregate pile in the center of the concrete mass.
3 = Highly unstable	Clearly segregating by the evidence of a large mortar halo > 0.5 in. and/or a large aggregate pile in the center of the concrete mass.

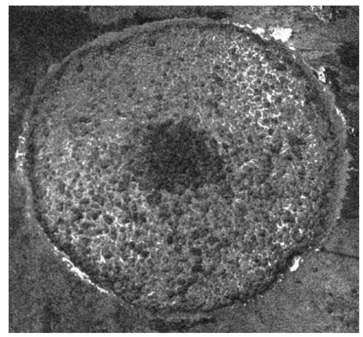
Self-Consolidating Grout Visual Stability Index



VSI = 0 – Concrete Mass is Homogeneous and No Evidence of Bleeding.

VSI = 1 – Concrete Shows Slight Bleeding Observed as a Sheen on the Surface.

VSI = 2 – Evidence of a Mortar Halo and Water Sheen.



VSI = 3 – Concentration of Coarse Aggregate at Center of Concrete Mass and Presence of a Mortar Halo.

Grout Pour and Lift Heights

Pour Height

- Total height of masonry to be grouted prior to erection of additional masonry.
- A pour can consist of several lifts.
- Maximum pour height is 24 ft. with cleanouts

Lift Height

- Height of grout placed in a single operation.
- Limited to 5.33 ft. (64 in. or 8 courses)
- OR 12.67 ft (152 in. or 19 courses) IF
  - masonry has cured 4 hrs
  - slump is between 10 and 11 in.
  - no intermediate bond beams between top and bottom of pour height

Consolidation

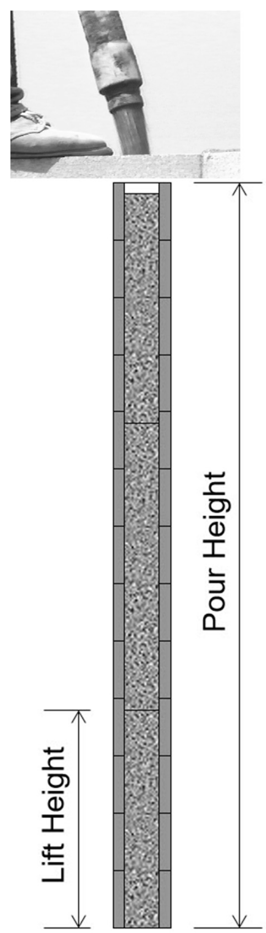
- Pour height < 12 in.
  - Puddling Stick (hard rubber tamper – 6” x 1” x1/2”)
- Pour height > 12 in.
  - Mechanical vibration
  - Reconsolidate after initial water loss

Placement of Reinforcement

- Place and secure rebar prior to grout placement.
- Typically secure rebar at every 200 bar diameters
  - about 8 ft. for a #4 bar

Cleanouts

- Required with high lift grouting.



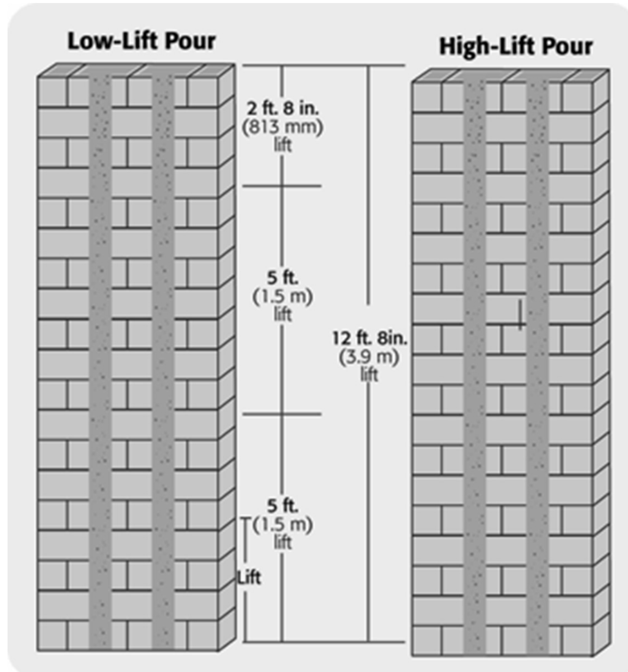
Grout Pour and Lift Heights

Pour Height

- Total height of masonry to be grouted prior to erection of additional masonry.
- A pour can consist of several lifts.
- Maximum pour height is 24 ft. with cleanouts

Lift Height

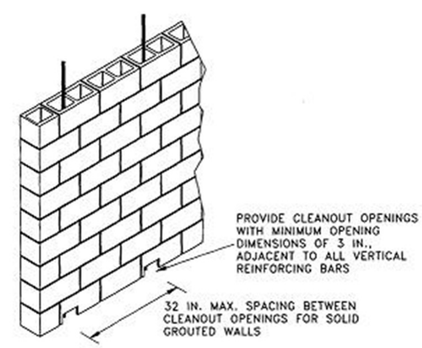
- Height of grout placed in a single operation.
- Limited to 5.33 ft. (64 in. or 8 courses)
- OR 12.67 ft (152 in. or 19 courses) IF
  - masonry has cured 4 hrs
  - slump is between 10 and 11 in.
  - no intermediate bond beams between top and bottom of pour height



Cleanouts

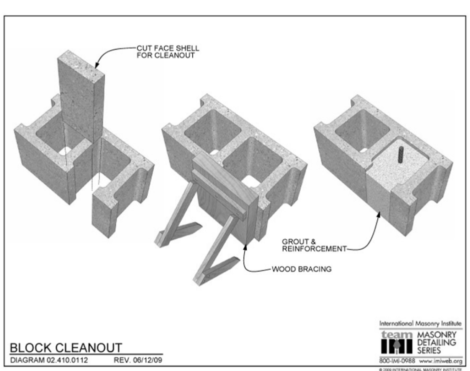
Requirements

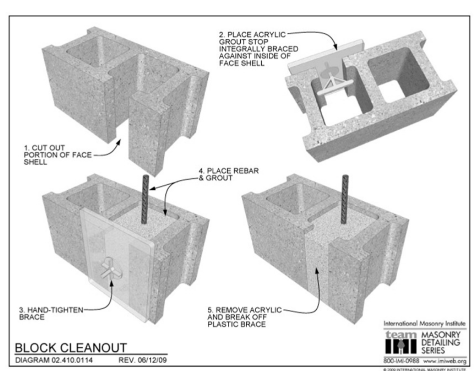
- Required when grout pour height exceeds 5 ft. – 4 in.
- Construct so space to be grouted can be cleaned and inspected.
- In solid grouted masonry, space cleanouts horizontally at a maximum of 32 inch on center.
- Minimum opening dimension is 3 inch
- After cleaning, close cleanouts with closures braced to resist grout pressure.



Fluid Pressure on Cleanout

- Grout exerts an equivalent fluid pressure of about 120 pcf.
- So, for example, the pressure at the base of a 5 foot pour is 600 psf.





Cleanouts

Fluid Pressure on Cleanout

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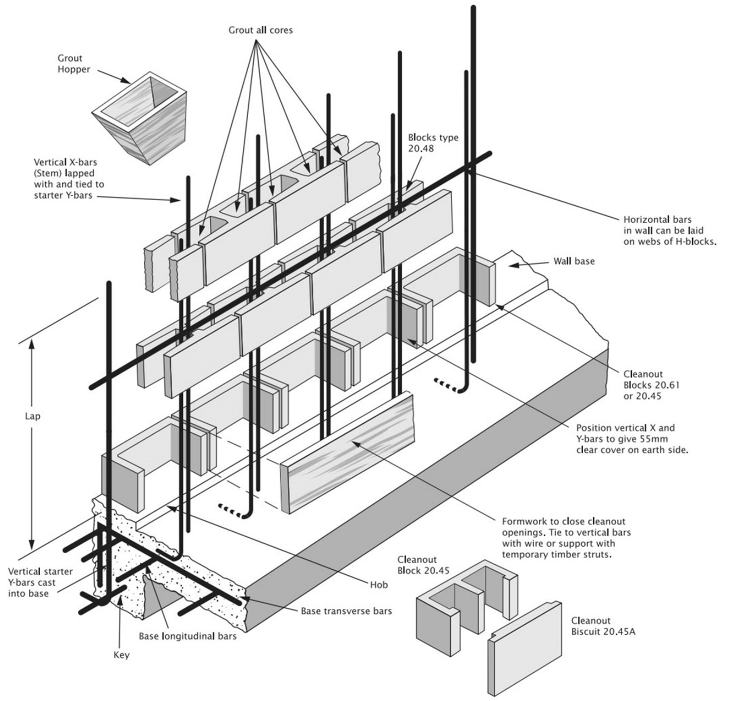


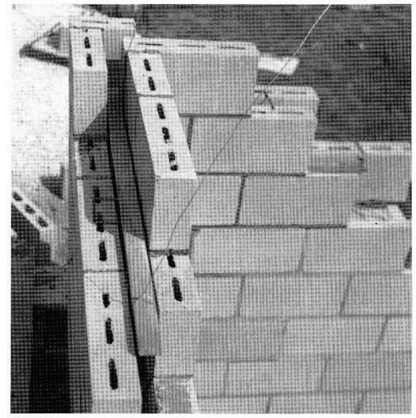
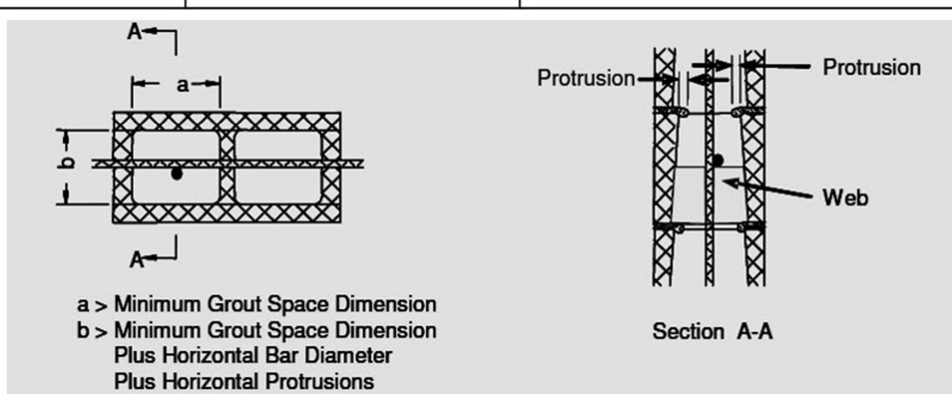


Fig. 6-47. To keep the cavity clean, a wood strip is laid across the ties in the cavity.

Fig. 6-48. The wood strip is lifted to remove mortar droppings.

Grout Space Requirements

Grout type	Maximum grout pour height (ft.)	Minimum clear grout space dimensions (in. x in.)
Fine	1 5.33 12.67 24	1 ½ x 2 2 x 3 2 ½ x 3 3 x 3
Coarse	1 5.33 12.67 24	1 ½ x 3 2 ½ x 3 3 x 3 3 x 4



Grout Space Requirements

Area of vertical reinforcement

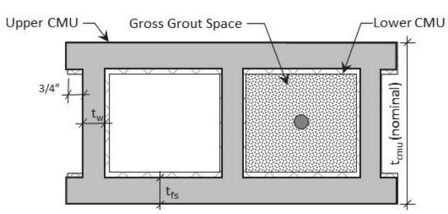
- ≤ 6% of grout space (TMS 402 - 6.1.2.4)
- UBC allowes 12% of area at splices.
- Strength design limits:
  - 4% of cell area (TMS 402 - 9.3.3.1)
  - ¼ least clear dimension
  - #9 max bar size
- IBC allows 8% at splices.
- Note the difference in above: grout space vs. cell area

Grout type	Maximum grout pour height (ft.)	Minimum clear grout space dimensions (in. x in.)
Fine	1 5.33 12.67 24	1 ½ x 2 2 x 3 2 ½ x 3 3 x 3
Coarse	1 5.33 12.67 24	1 ½ x 3 2 ½ x 3 3 x 3 3 x 4

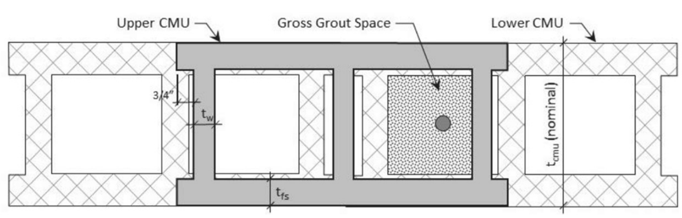
Grout Space Requirements example

8 in. CMU

- Thickness: assume 1.25 in. face shell and 0.25 in. taper
  - 7.625 - 2(1.25) - 2(0.25) = 4.625 in.
- Length: assume 1 in. webs
  - Stack bond: [15.625 - 2(0.75) - 3(1) - 3(0.25)]/2 = 5.1875 in.
  - Running bond: (0.5+0.25/2+5.1875) - (0.375/2+0.75+1) = 3.875 in.
- Stack bond: Area = 4.625(5.1875) = 23.99 in.2
  - 4% cell area = 0.04(23.99) = 0.96 in.2 (#8 bar)
- Running bond: Area = 4.625(3.875) = 17.92 in.2
  - 4% cell area = 0.04(17.92) = 0.72 in.2 (#7 bar)



Stack bond

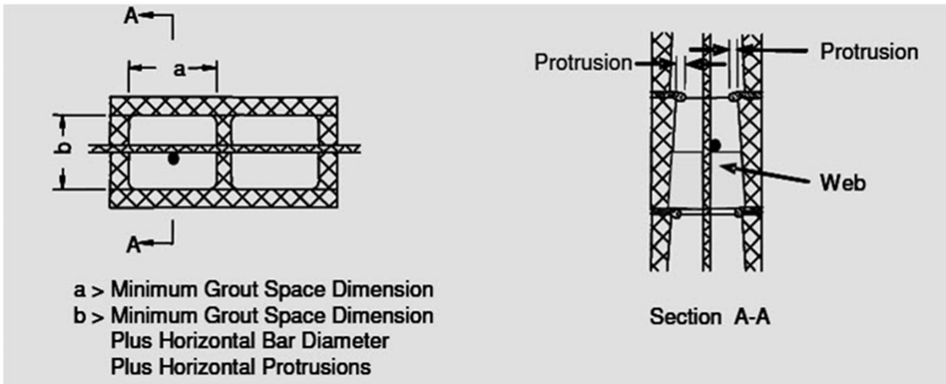


Running bond

Grout Space Requirements

Required grout thickness between bars and masonry
(TMS 402 - 6.1.3.5)

- 1/4 in. for fine grout
- 1/2 in. for coarse grout.
- Cross webs of hollow units can support horizontal reinforcement.



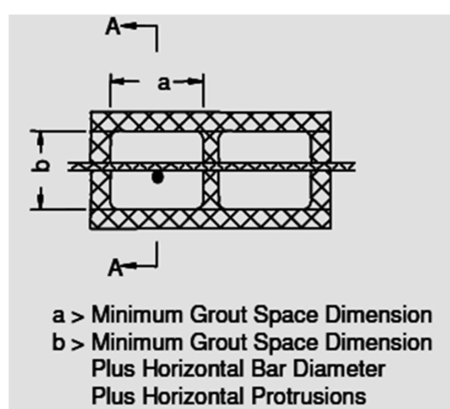
Grout Space Requirements

Bond beam Reinforcement - for 8 in. CMU (a = 5.8175 in.)

Bond beam bars	'b' (in.)	Area (in.^{2})	6% Area (in.^{2})	Max pour height (ft)
1 - #4	3 ⅛	18.18	1.09 (#9)	24
2 - #4	2 ⅝	15.27	0.92 (#8)	5.33
1 - #5	3	17.45	1.05 (#9)	24
2 - #5	2 ⅜	13.82	0.83 (#8)	1

<u>Example:</u> calculation of b

Block width	7.625
Face Shell	2(1.25) = 2.5
Taper	2(0.25) = 0.5
Protrusions	2(0.5) = 1.0
Bar diameter (1 - #4)	0.5
TOTAL	7.625-2.5-0.5-1.0-0.5 = 3.125



Grout Keys

Form grout keys between pours.

Form grout keys between lifts if the first lift is permitted to set prior to placement of subsequent lifts.

Form a grout key by terminating grout a minimum of 1½ inch below a mortar joint.

Do not form grout keys within beams.

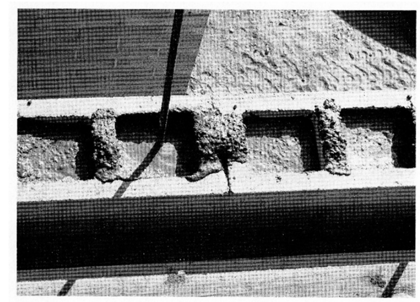
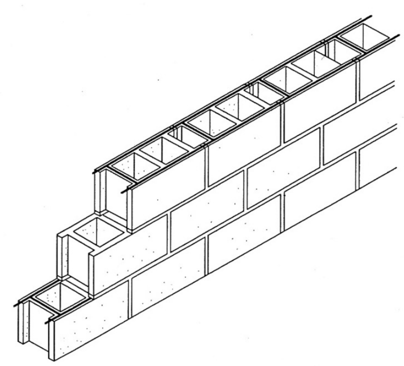


Fig. 6-60. Grouting is stopped about 1 in. below the top of the block to form a key with the next lift.

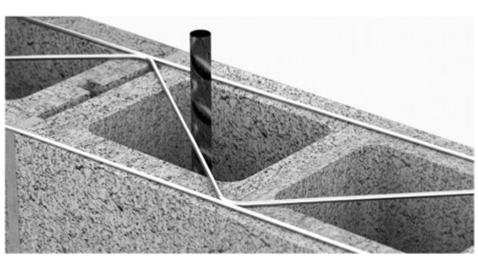
Reinforcement

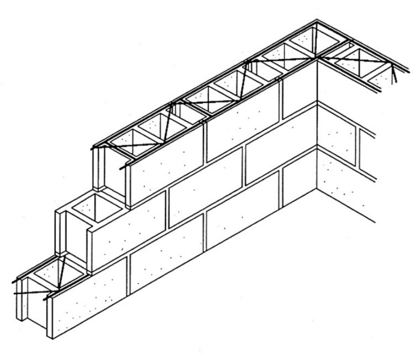
Joint Reinforcement – single wythe

- Ladder type
- Truss type



(a) Ladder type joint reinforcement for single-wythe wall



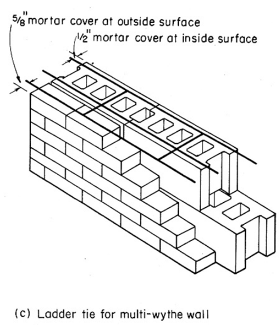


(b) Truss type joint reinforcement for single-wythe wall

Reinforcement

Joint Reinforcement – multi wythe

- Single piece
- Adjustable



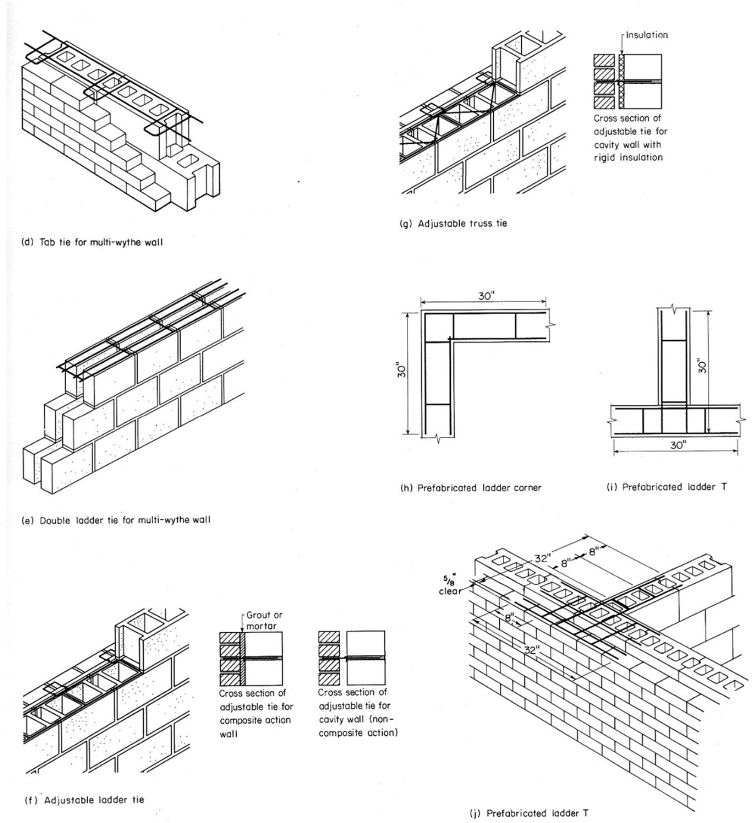


Fig. 4-12. Continuous metal ties or joint reinforcement.

Reinforcement

Unit ties for multi wythes

- Adjustable
- Allow vertical movement – differential expansion

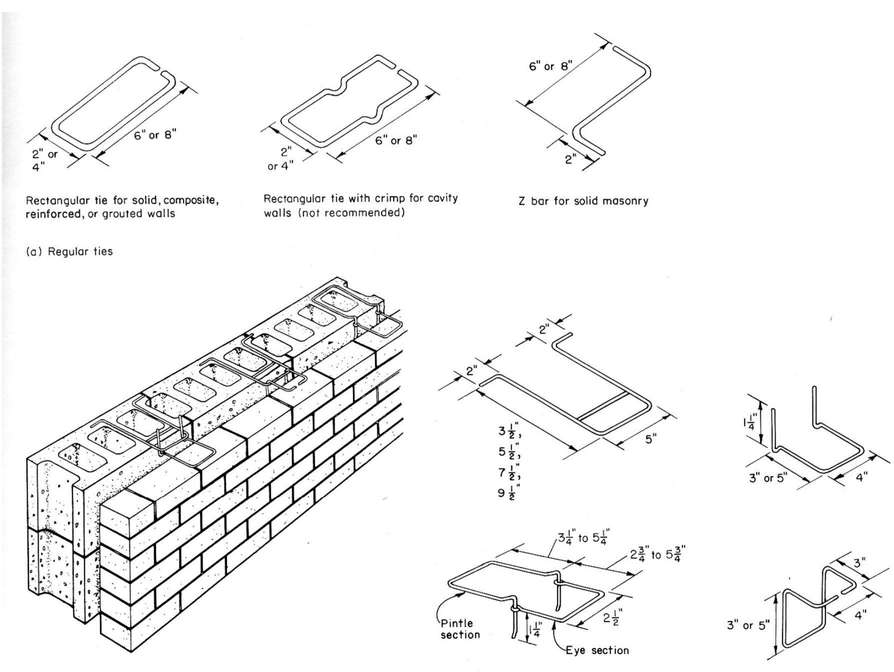


Fig. 4-11. Unit metal ties.

Reinforcement

Unit ties for wall bracing

- Provide rigid connection for intersecting walls

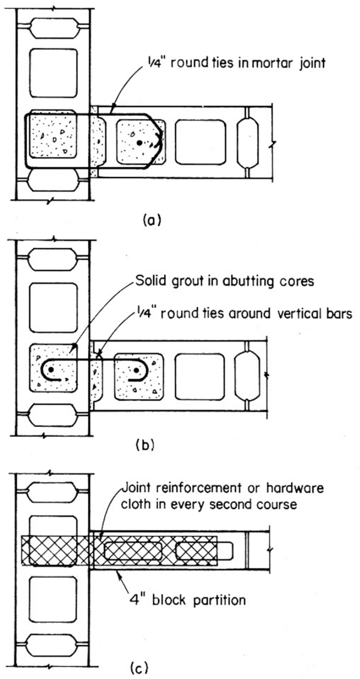


Fig. 4-45. Rigid connections for intersecting walls.

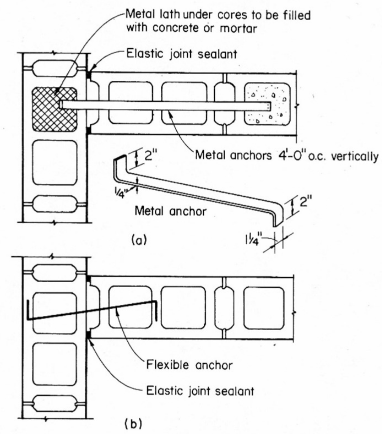


Fig. 4-46. Flexible connections for intersecting walls.

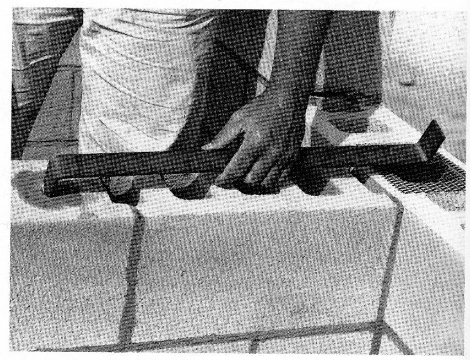


Fig. 4-47. Steel tiebar provides lateral support to wall at right.

Reinforcement

Beams

- Bars placed in bottom U-shaped unit, or knockout bond beam unit.
- Mesh or lash over open cores
- Cross webs of hollow units can support horizontal reinforcement.

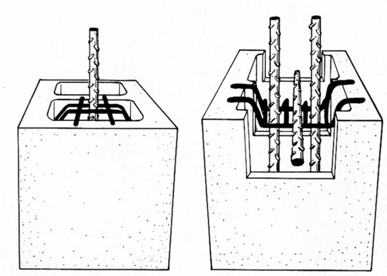


Fig. 6-52. Reinforcing bar spacers.

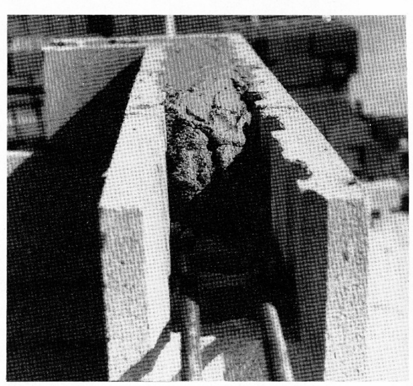
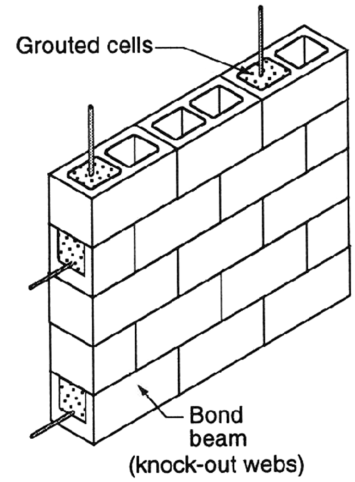


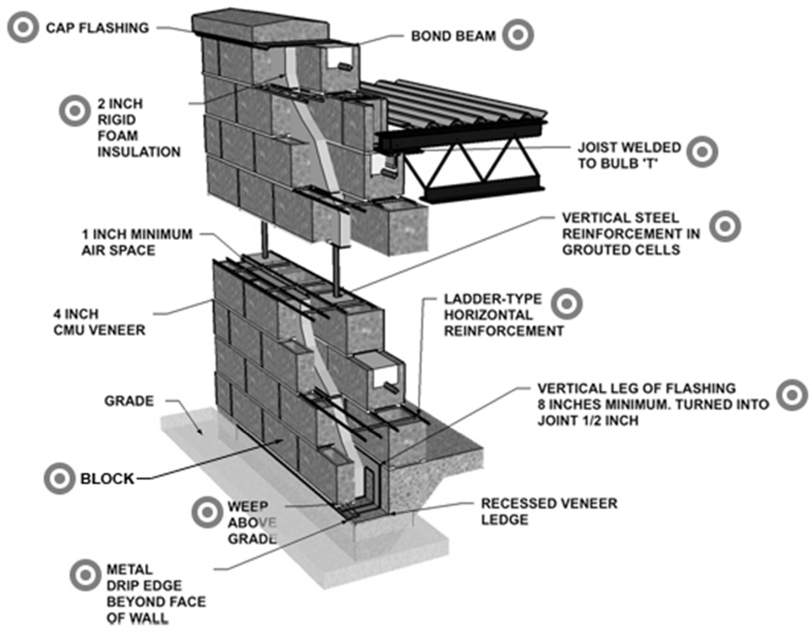
Fig. 6-54. Horizontal reinforcing bars positioned in a bond beam that will be solidly grouted.

Reinforcement

Walls

- Bars placed in grouted cores.
- Spacing of grouted or reinforced cores can vary
- Can also include horizontal bond beams

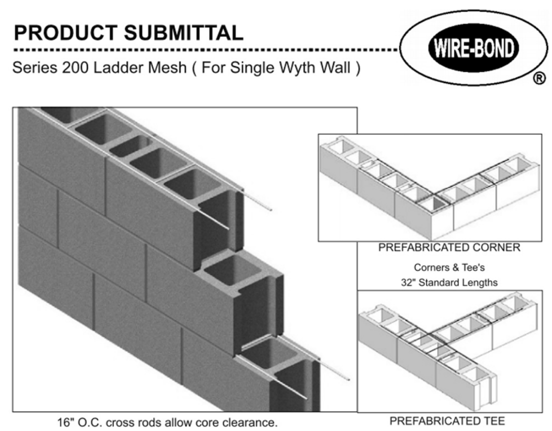




Reinforcement

Bar and wire sizes

Designation	Diameter (in.)	Area (in.^{2})
W1.1 (11 gage)	0.121	0.011
W1.7 (9 gage)	0.148	0.017
W2.1 (8 gage)	0.162	0.021
W2.8 (3/16 wire)	0.187	0.028
W4.9 (1/4 wire)	0.250	0.049
#3	0.375	0.11
#4	0.500	0.20
#5	0.625	0.31
#6	0.750	0.44
#7	0.875	0.60
#8	1.000	0.79
#9	1.128	1.00
#10	1.270	1.27
#11	1.410	1.56



Wire Size	Side Rods	Cross Rods
Standard	9 gauge	9 gauge
Heavy Duty	3/16 in.	9 gauge
Extra Heavy Duty	3/16 in.	3/16 in.

Tensile strength: 80,000 psi
Yield strength: 70,000 psi
(ASTM A1064/A1064M)

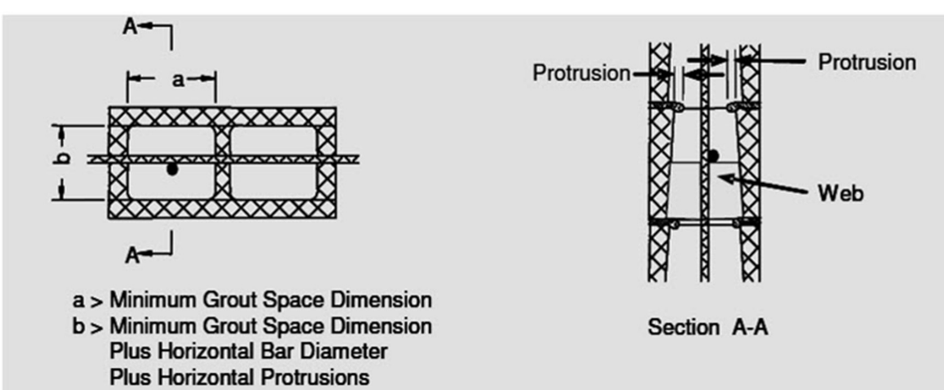
Reinforcement

Requirement	Provision	TMS 402 Reference
Size of reinforcement	Maximum size: #11 (Strength design: #9) d_b ≤ 1/2 of least clear dimension (Strength design: d_b ≤ 1/4 of least clear dimension) Area of vertical reinforcement ≤ 6% grout space (Strength design: ≤ 4% cell area) d_b ≤ 1/8 least nominal dimension	6.1.2.1, 9.3.3.1 6.1.2.2, 9.3.3.1 6.1.2.4, 9.3.3.1 6.1.2.5
Placement of reinforcement	Clear distance between bars ≥ max of { d_b, 1 in.} Columns and pilasters: Clear distance between bars ≥ max of { 1.5d_b, 1.5 in.} Thickness of grout between reinforcement and masonry Coarse grout: ½ in. Fine grout: ¼ in.	6.1.3.1 6.1.3.2 6.1.3.5
Protection of reinforcement: cover	Masonry exposed to earth or weather: #5 and smaller: 1½ in. larger than #5: 2 in. Masonry not exposed to weather: 1½ in.	6.1.4.1

Reinforcement - example

Determine the maximum size bar that can be placed in an 8 inch CMU.

- From cell area requirements (4%): face shells↓
  - 'b' : width is 7.625 – 2(1.25) = 5.125 in.
  - 'a' : length is 6.31 in.
  - Cell Area = 32.3 in.^{2}
  - 0.04(32.3in.^{2}) = 1.29in.^{2} 2-#7, 1-#9
- d_b ≤ 1/4 of least clear dimension: face shells↓ ↓protrusions
  - least clear dimension = 7.625 – 2(1.25) – 2(0.5) = 4.125 in.
  - ¼ (4.125 in.) = 1.03 in. #8 bar
- d_b ≤ 1/8 least nominal dimension: 1/8 (8 in.) = 1 in. #8 bar



Reinforcement

Wire Reinforcement

Requirement	Provision	TMS 402 Reference
Size of wire	Minimum size: W1.1 Maximum size: 1/2 joint thickness	6.1.2.3
Protection of wire	Cover: Exposed to weather: 5/8 in. Not exposed to weather: 1/2 in. Protection: Mean relative humidity > 75%: stainless steel, hot-dipped galvanized coating, or epoxy coating Mean relative humidity ≤ 75%: mill galvanized, hot-dip galvanized, or stainless steel	6.1.4.2

Reinforcement

Development Length

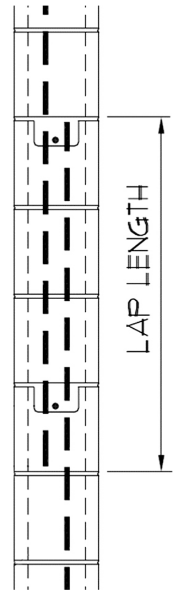
Condition	Provision	TMS 402 Reference
Bars in grouted clay masonry and concrete masonry	$l_d = \frac{0.13 d_b^2 f_y \gamma}{K\sqrt{f'_m}}$ Eq. (6-1) K = min of {masonry cover, clear spacing between adjacent splices, $9d_b$} $\gamma = \begin{cases} 1.0 \text{ for \#3 through \#5} \\ 1.3 \text{ for \#6 and \#7} \\ 1.5 \text{ for \#8 and greater} \end{cases}$	6.1.5.1.1
Hooks in tension	Equivalent embedment length: $l_d = 13d_b$ Eq. (6-2)	6.1.5.1.3
Wires in tension	$l_d = 48d_b$ Eq. (6-3)	6.1.5.2
Epoxy-coated wires and bars	Development length increased by 50%	6.1.5.1.1 6.1.5.2

l_d should be multiplied by 1.5 for epoxy coated bars

Reinforcement

Splice Length

Condition	Provision	TMS 402 Reference
Lap splices of bar reinforcement	max{ l_d (Eq. 6-1), 12 in.}	6.1.6.1.1.1
Noncontact lap splices	Transverse spacing ≤ min{1/5 lap length, 8 in.}	6.1.6.1.1.3
Welded splices of bar reinforcement	Develop $1.25f_y$ Welding conforms to AWS 1.4 ASTM A706 bars or chemical analysis and carbon equivalent	6.1.6.1.2
Mechanical splices of bar reinforcement	Develop $1.25f_y$	6.1.6.1.3
End-bearing splices (compression)	Bar ends within 1.5° to right angle of axis Fitted to within 3° after assembly	6.1.6.1.4
Lap splices of wire	max{ $48d_b$ (Eq. 6-3), 6 in.}	6.1.6.2.1
Welded splices of wire	Develop $1.25f_y$	6.1.6.2.2
Mechanical splices of wire	Develop $1.25f_y$	6.1.6.2.3



Reinforcement

Lap Splice Length

Bar Size	Required lap splice length (inches)								
	f'_m = 2000 psi			f'_m = 2500 psi			f'_m = 3000 psi		
	8 in. Center	12 in. Center	2 in. cover	8 in. Center	12 in. Center	2 in. cover	8 in. Center	12 in. Center	2 in. cover
#3	12	12	12	12	12	12	12	12	12
#4	12	12	22	12	12	20	12	12	18
#5	20	12	34	18	12	31	16	12	28
#6	37	24	64 [54]	33	21	57 [54]	30	19	52
#7	51	32	87 [63]	46	29	78 [63]	42	26	71 [63]
#8	79 [72]	49	131 [72]	71	44	117 [72]	65	40	107 [72]
#9	-	63	166 [81]	-	57	149 [81]	-	52	136 [81]
#10	-	82	211 [90]	-	73	189 [90]	-	67	172 [90]
#11	-	102 [99]	260 [99]	-	91	233 [99]	-	83	212 [99]

Values in square brackets are $72d_b$, the IBC requirement. Values only given if less than TMS 402.

Reinforcement

Lap Splice Length – example

Determine the required lap splice length for a #5 Grade 60 reinforcement bar placed in the center of an 8 in. CMU wall. Assume f'_m = 2000 psi.

- Masonry cover: $\frac{t_{sp}}{2} - \frac{d_b}{2} = \frac{7.625\ in.}{2} - \frac{0.625 in.}{2} = 3.50in.$
- Determine K: $K = \min\ of\ \{cover, 9d_b\} = \{3.50in., 9(0.625in.) = 5.625in.\}$
  $= 3.50in.$
- Determine γ: for a #5 bar, $\gamma = 1$
- Determine l_d: $l_d = \frac{0.13 d_b^2 f_y \gamma}{K\sqrt{f'_m}} = \frac{0.13(0.625in.)^2(60000psi)(1.0)}{3.50in.\sqrt{2000psi}} = 20in.$
- Splice length: $\max\ of\ \{l_d, 12in.\} = \max\ of\ \{20in., 12in.\} = 20\ in.$

Reinforcement

Mechanical Splices