Findings from a Survey on Current Practices for Masonry Beam Design & Construction

Ece Erdogmus & Laura Redmond
Clemson University

THE MASONRY SOCIETY

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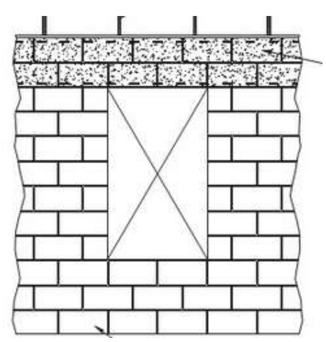
Motivation/Background

- Issues identified during Canada/US (CANUS) project: Harmonization of Canadian and American Masonry Structures Design Standards
  - Lack of masonry beam specific experimental data
    - Ex: Table 9.1.9.1
  - Lack of consistent design and construction practices for masonry beams
  - TMS 402 Code limitations/complexity
  - Common choice of other materials (e.g. precast or steel lintels) to span openings in masonry walls



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TMS 402/602 Definitions

Code Definitions

BEAM — A member designed primarily to resist flexure and shear induced by loads perpendicular to its longitudinal axis.

BOND BEAM — A horizontal, sloped, or stepped member that is fully grouted, has longitudinal reinforcement, and is constructed within a masonry wall.

LINTEL — See Beam.

Commentary to Code Definitions

BEAM — A beam usually spans horizontally, although it may have another orientation in space. For the gravity load resisting system, beams primarily resist flexural and shear loads. However, a beam may be required to resist axial loads.

LINTEL — The term “lintel” generally refers to a horizontal member over an opening, chase or recess. Masonry lintels are required to be designed in accordance with the beam provisions of this Code.

Setting and Participants

HOW- Participant Recruitment:

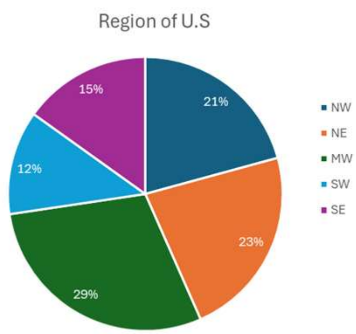
- Social media (LinkedIn)
- The masonry society (TMS)– particularly Structural Members Sub.
- Masonry Contractors Association of America (MCAA)
- Other masonry-related organizations and groups in the U.S.

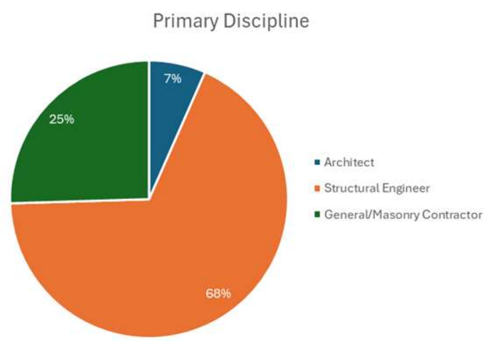
WHO:

- Structural Engineers, Architects, Contractors
  - Survey included common and branch-out questions

Setting and Participants

106 unique and complete responses





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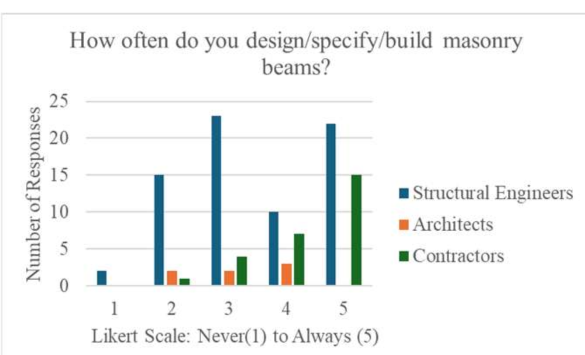
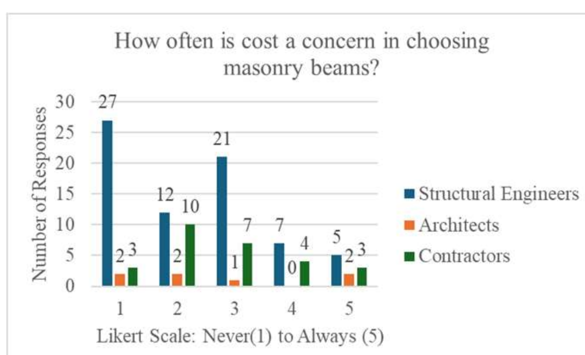
Discussion of Results-1: Choice of masonry beams in design/construction





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Discussion of Results-2: Choice - *continued*

*Q: Do you ever decide **against** using **masonry beams** due to any of the following considerations? Please check all that apply.*

Engineers' Concerns	No.	%
Torsion applied on the beam	26	41%
Contractor request/preference	26	41%
Constructability	22	34%
Architect request/preference	20	31%
Maximum reinforcement limits	16	25%
Detailing requirements	15	23%
Deflection limits	13	20%
Other (Use entered notes below)	9	14%
Lack of design guidance in the masonry code/standards in specific to	5	8%
Cost	4	6%
Familiarity with masonry codes/standards	1	2%
Total number of responses to this question	64	

Architects' Concerns	No.
Cost concerns	3
Strength concerns: I don't think they are possible for the longer span l	2
Aesthetic concerns	2
Concerns related to construction schedule	2
Detailing requirement are complex	2
Other (Use entered "none")	1
Total number of responses to this question	7

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Discussion of Results-3: Span Length vs. Choice

Q: Is there a span length limit, beyond which you typically do not specify masonry but instead choose another material for beams and lintels? (Please include units in your answer)

Architects' answers (N=7) **ranged between 3ft and 12ft.**
Specifically: 3ft (N=1), 6ft (N=1), 8 ft (N=3), 12ft (N=1), and defer to structural engineer (N=1)

Table 3: Engineers' Span-Length Limit Considerations for Masonry Beams

Engineers' Answers	No	%
Answered "No limit" or 20ft-84ft	34	54%
8ft-18ft	25	40%
Other responses (Noted considerations other than span length)	4	6%
Total responses	63	

"I don't necessarily have a span limit. The only reason I would go to a steel lintel if there is a complex architectural condition or there is torsion on the lintel (e.g. canopy attachment)"

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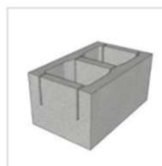
Discussion of Results-4: Unit choices

Concrete Masonry Unit Types

	Engineers		Architects	Contractors	
Concrete Masonry Type	**No**	**%**	**No**	**No**	**%**
Lintel units	54	76%	7	22	81%
Knock-out bond beam units	46	65%	4	19	70%
Precast concrete masonry lintels	22	31%	4	10	37%
Flush end 8"units	15	21%	2	4	15%
None- contractor prefeference	12	17%	0	2	7%
Manufactured concrete masonry lintels	11	15%	3	6	22%
Other types (entered by participant)	6	8%	0	3	11%
Total responses	**71**		**7**	**27**	


Lintel unit


Knock-out bond beam unit

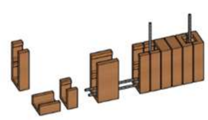

Flush end 8" unit

Discussion of Results-4: Unit choices

Clay Masonry Unit Types


Clay shapes with circular grout cells


Clay shapes with rectangular grout cells


Closed bottom 'lintel' units – with a limited length of 8".


Precut bond beam units

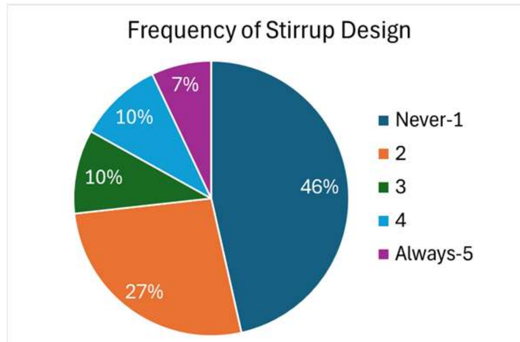
Clay Masonry Type	**No**	**%**	**No**	**No**	**%**
None-contractor preference	37	55%	4	14	52%
Clay shapes with rectangular grout cells	21	31%	3	7	26%
Closed bottom lintel units- with a limited length of 8"	17	25%	1	5	19%
Variations of "I do not work with structural clay"	15	22%	0	0	0%
Precut bond beam units	11	16%	0	2	7%
Clay shapes with circular grout cells	6	9%	0	1	4%
Other	0	0%	0	3	11%
Total responses*	**67**		**7**	**27**	
**Four engineers did not respond to this question. Implies lack of familiarity.*					

Discussion of Results-5: Beam Depth (Engineers)

Q: How do you determine the depth of a masonry beam?
N=71

a. I identify the depth/number of courses that will ensure **no shear reinforcement** will be required: **64%**
b. I use the entire depth of masonry wall above the opening to the next level as my beam depth and determine the required reinforcement accordingly: **7%**
c. I start with a fixed number of courses: **29%**

Q: Do you typically specify/require shear reinforcement (stirrups)?
N= 71
73%→ Never (1) or rarely (2)



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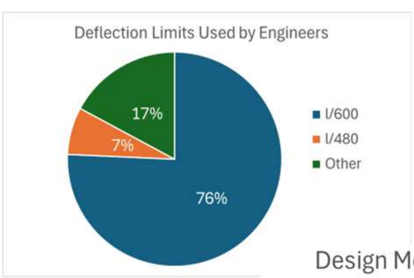
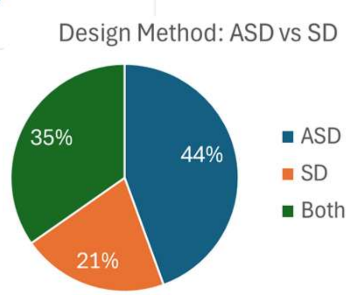
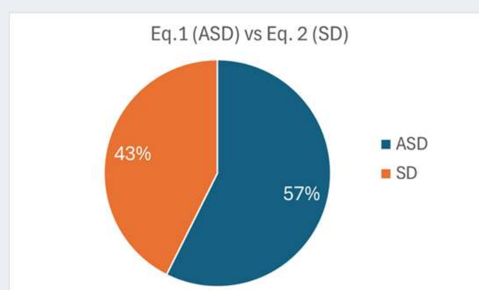
Discussion of Results-6: Design Methods





$$(1)\ I_{cr} = \left(\frac{b(kd)^3}{3} + nA_s[(d-kd)^2]\right)$$

$$(2)\ I_{cr} = \left(\frac{bc^3}{3} + nA_s[(d-c)^2]\right)$$



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Final Comments- Contractors

Q: Do you have any other general comments about masonry beam design?

Contractors

N=11 (out of 27, 41%)

Two common themes:

a) Lack of understanding or awareness by designers

b) Benefits of using masonry beams that are integral with masonry walls

"Building masonry beams in place is cost effective and allows the beam to be an integral part of the wall system. [Using] masonry beams are preferred to steel beams because it reduces unnecessary coordination with steel fabricator/iron worker.

"Faster and readily available. Less movement than when integrating steel and masonry together. Quicker to adapt to onsite changes of opening sizes.

"Get more engineers to learn about [masonry beams'] benefits.

Final Comments- Engineers

Q: Do you have any other general comments about masonry beam design?

Engineers

N=25 (out of 71, 35%)

Four common themes:

(a) Lack of code guidance on specific design considerations

(b) Lack of familiarity/education on structural masonry design

(c) (Perceived) Software Availability/Limitations

> *"I wish there was a software that was tailored toward CMU design that was not finite element. RAM elements and RISA 3d does CMU design, but since they are a FEA software, its hard to confirm the load with hand calculations."*
>
> *"I utilize RAM Elements as my primary lintel design tool. I do not manually calculate Icr; I utilize whatever RAM Elements uses."*

(d) Using masonry beams versus steel lintels: *"Don't be so quick!"*

Conclusions

- Even within this group of masonry-interested A-E-C practitioners, there is a **significant lack of knowledge/trust in structural clay products**.
- Reasons to design **with other materials than masonry for spanning openings**:
  - Engineers: complex loading situations (i.e. torsion) and contractor preference
  - Contractors: engineers and architects specifying other materials
  - Among the 7 architects, top concern was cost.
- **Span length** is a common reason **for not choosing masonry**: We need to educate architects and engineers!
- Lack of **clear code guidance on complex design issues** such as **torsion, deflection limits, and biaxial bending specific to beam design** should be addressed.

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Conclusions- *Continued*

- **Structural engineers favor ASD:**
  - 44% solely, 79% sometimes
- **Deflection limits set to l/600 common–** misunderstood, may result in overly conservative masonry designs.
- **Lack of awareness**:
  - **Benefits of masonry lintels,** especially in masonry walls
  - **Available design software:**
    - *Direct Design for Masonry Structures* (REVIT 2021 compatible)
    - *EleMasonry*
    - *Masonry iQ* (boosts REVIT LoD)
    - *MASS* (Canada)

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So, what's next Team Clemson?

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Next Steps of Project:

Objectives:

- To expand the limited experimental database for masonry beams:
  - 1-course beams, bond wrench test, 3-course beams
- To compare the MOR values from beam test and bond wrench tests
- To determine to the extent which each parameters influences MOR for masonry beams.
- To numerically extrapolate test results with a parametric analysis and confirm relationships
- To propose new approach to determine MOR values for masonry beams to TMS 402
- To review the cracked and effective moment of inertia equations in TMS 402 based on the research findings.

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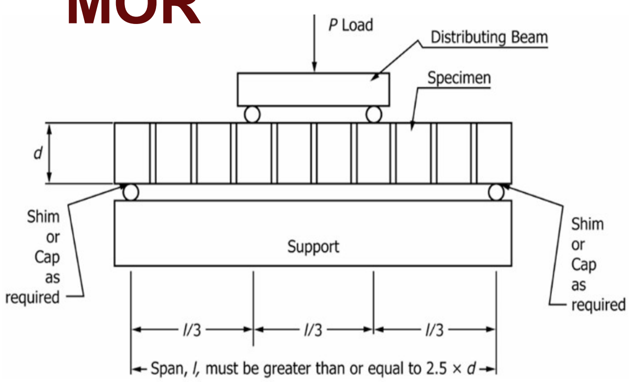
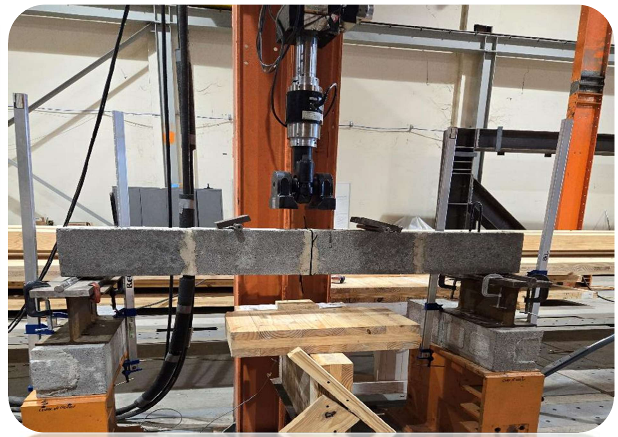
Third Point Loading Beam Test for MOR



Beam test schematic (ASTM E518)

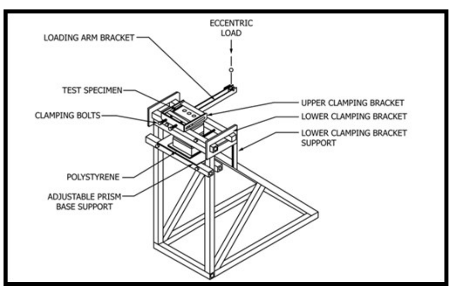
$$MOR = \frac{(P + 0.75P_s)l}{bd^2}$$



Test set up for beams

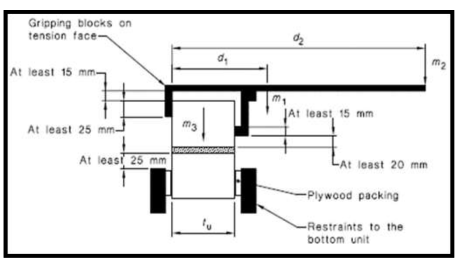
Continuous load-displacement(at mid-span) measured

Bond Wrench Test for MOR



ASTM C1072 Bond wrench

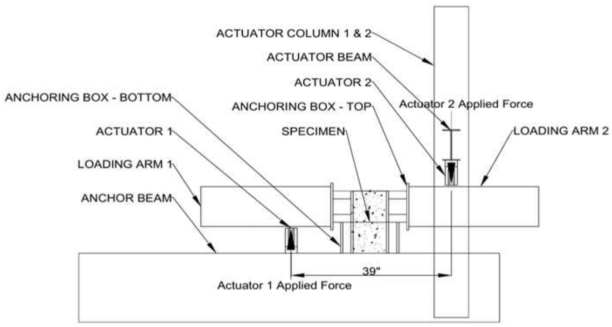
TAMU Unbalanced Bond Wrench



Australian Bond wrench AS 3700

Indian Balanced Bond wrench

Selected Setup: Modified Bond Wrench Test



Schematic Diagram for Modified Bond Wrench Test

$$MOR = \frac{-SW}{A} + \frac{M\frac{h}{2}}{I}$$

Test set up for modified bond-wrench

Continuous load-displacement(of loading arms) measured

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Test Matrix

Designation	Unit Type 200 mm (8 in.)	Mortar Type (Masonry Cement)	Grout Type	No. of test specimens	
				Beam	Bond Wrench
8-LU-MCM-LSG	Lintel Units (LU)	Type M	Low strength Grout (LSG)	4	5
8-LU-MCN-LSG	Lintel Units (LU)	Type N	Low strength Grout (LSG)	5	6
8-LU-MCN-HSG	Lintel Units (LU)	Type N	High strength Grout (HSG)	4	5
8-KOBB-MCN-LSG	Knock Out Bond Beam Units (KOBB)	Type N	Low strength Grout (LSG)	5	6

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Failure Modes

Beam

Bond Wrench

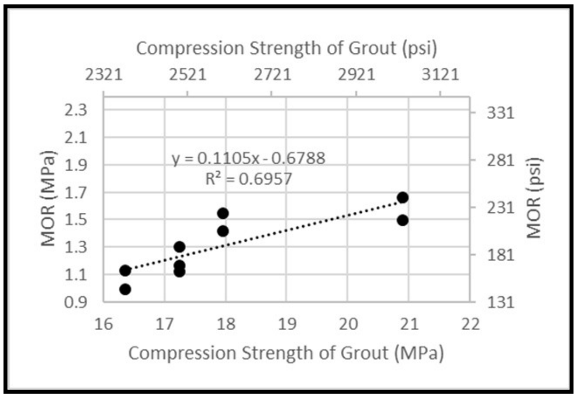
Tested MOR Values vs. Predicted Values

Batch	Mortar Type (Masonry Cement)	TMS 402/602-22 Predicted MOR (Table 9.1.9.1), f_{rp} kPa (psi)	Average Tested MOR values, f_r kPa (psi) *Standard Deviation in kPa (psi)*		Ratio f_r/f_{rp}	
			ASTM E518	Modified Bond Wrench	ASTM E518	Modified Bond Wrench
8-LU-MCM-LSG	Type S	1103 (160)	1239 (180) *41.20 (5.97)*	1970 (286) *323.71 (47)*	1.12	1.79
8-LU-MCN-LSG	Type N	689 (100)	1140 (165) *110 (16)*	1758 (255) *200 (29)*	1.64	2.55
8-LU-MCN-HSG	Type N	689 (100)	1530 (222) *103 (15)*	2108 (306) *160 (23.20)*	2.21	3.04
8-KOBB-MCN-LSG	Type N	689 (100)	1165 (169) *67.60 (9.80)*	1507 (219) *137(19.80)*	1.68	2.17

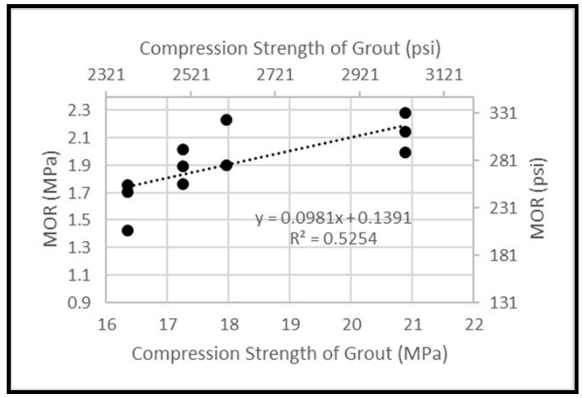
Average MOR values as well as the dispersion of the data **are higher** for bond wrench tests as compared to beam tests.

Influence of Grout Strength

Beam Test



Bond Wrench Test



Definitive relationship between grout strength and MOR

Note that current TMS 402/602-22 tables do not acknowledge the impact of strength of grout

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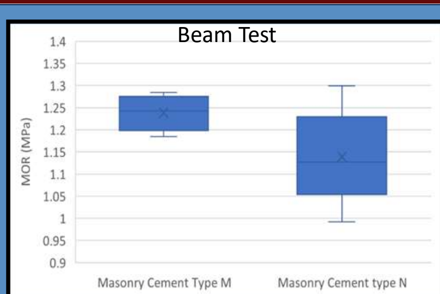
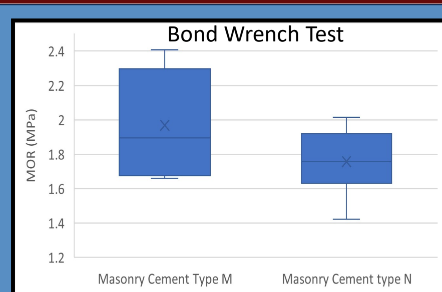
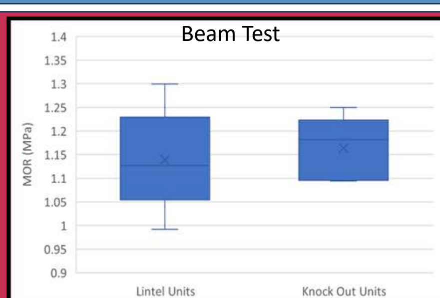
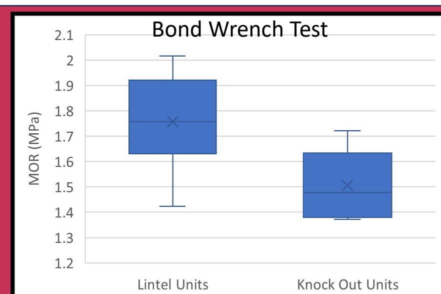
Influence of Mortar Type





Influence of Block Type





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Conclusions

MOR values from both tests are higher (1.48 times for beams and 2.17 times for bond wrench) than the values provided in TMS 402/602-22.

Grout strength has the largest and most significant impact on the MOR values of beams, which is not accounted for in current code TMS 402/602-22.

Mortar and block type are less influential in the impacting the MOR values of masonry as evident from both beam and bond-wrench tests.

MOR obtained from bond-wrench tests were significantly (30%-59%) and consistently higher than the beam tests.

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Acknowledgements

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  - **Southeast Concrete Masonry Association (SCMA)**
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THE MASONRY SOCIETY

ecee24@clemson.edu
lmredmo@clemson.edu

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Extra Info (For Q&A)

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Motivation

Direction of flexural tensile stress and masonry type	Mortar types			
	Portland cement/lime or mortar cement		Masonry cement or air entrained Portland cement/lime	
	M or S	N	M or S	N
Normal to bed joints				
Solid units	133 (919)	100 (690)	80 (552)	51 (349)
Hollow units				
Ungrouted	84 (579)	64 (441)	51(349)	31 (211)
Fully grouted	163 (1124)	158 (1089)	153 (1055)	145 (1000)
Parallel to bed joints in running bond				
Solid units	267 (1839)	200 (1379)	160 (1103)	100 (689)
Hollow units				
Ungrouted and partially grouted	167 (1149)	127 (873)	100 (689)	64 (441)
Fully grouted	267 (1839)	200 (1379)	160 (1103)	100 (689)
Parallel to bed joints in masonry not laid in running bond				
Continuous grout section parallel to bed joints	335 (2310)	335 (2310)	335 (2310)	335 (2310)
Other	0 (0)	0 (0)	0 (0)	0 (0)

Src: TMS 402/602-22 Table 9.1.9.1

Material Properties and ASTM Compliance

Batch	Compressive Strength of Mortar Cubes ASTM C109, MPa (psi) (28 Day)		Compressive Strength of Grout Specimens ASTM C1019, MPa (psi) (28 Day)		Compressive Strength of Masonry Prisms ASTM C1314, MPa (psi) (28 Day)	
	Average of 3	Std. Deviation	Average of 8	Std. Deviation	Average of 4	Std. Deviation
8-LU-MCM-LSG	13.40 (1942)	0.10 (12.50)	13.30 (1934)	1.72 (250)	17.40 (2526)	2.99 (434)
8-LU-MCN-LSG	8.16 (1184)	0.55 (80.30)	16.80 (2438)	1.19 (172)	18.80 (2721)	2.66 (386)
8-LU-MCN-HSG	8.26 (1199)	0.31 (44.80)	21.00 (3051)	3.49 (506)	21.60 (3136)	0.85 (122)
8-KOBB-MCN-LSG	5.62 (815)	0.34 (49.30)	13.50 (1958)	1.26 (182)	18.30 (2649)	0.72 (104)