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Masonry Beam Design and Construction in the U.S.: Findings from a Survey on Current Practices

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ABSTRACT

This paper aims to identify and discuss the current practices of masonry beam design and construction in the United States. An online survey was administered to identify professionals' design and construction choices for masonry beams, with particular interest in identifying structural design practices. The survey was distributed through social media (LinkedIn), the masonry society (TMS), Masonry Contractors Association of America (MCAA), and several other masonry-related organizations and groups in the U.S. The survey also aims to understand why designers might select materials other than masonry beams/lintels to span openings in masonry walls. 106 unique and complete responses are received including 7 architects, 72 structural engineers, and 27 contractors. After the analysis of the data, the results show that practices and opinions related to masonry beams vary between architects, engineers, contractors (A-E-C), and many of these relate to two fundamental issues: 1) lack of communication and coordination between A-E-C professionals, and 2) lack of consistent education specific to masonry design and construction at U.S. universities. Engineers' primary barriers to designing masonry beams are complex loading conditions and contractor preference. Contractors noted that architects and engineers often specify other materials for spanning openings in masonry walls, or they provide too few details and too much reinforcement, making them difficult to build. Architects noted their top concern was cost, even though contractors were not as concerned about cost of construction. It should be noted that the response rate from architects is too small to draw strong conclusions regarding any topic. Other key themes that emerged from the study included: a general lack of trust in masonry beams for large spans, limited use and awareness of structural clay masonry, and the lack of clear code guidance on complex design issues such as torsion, deflection limits, and biaxial bending specific to beam design in the United States. The survey results are valuable to shape future research and code development related to masonry beams.

KEYWORDS

Beam Design, Deflections, Masonry Beams, Masonry Design, Masonry Lintels

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INTRODUCTION

Recently, a significant project titled "*Canada/US (CANUS) collaborative project: Harmonization of Canadian and American Masonry Structures Design Standards"* was jointly funded by American and Canadian concrete masonry industry associations and provided a side-by-side comparison of US and Canadian masonry design standards [1-4]. This project, involving 14 structural engineers equally from each side of the border, identified several areas of future research related to masonry beam design for both countries' codes. For instance, the modulus of rupture (MOR) values included in TMS 402/602-16 and 22 [5, 6] for tension parallel to bed joints are not based on experiments on beams. Instead, they are based on wallette tests [7] that have significantly different cracking and failure mechanisms than beams. The CANUS project also highlighted the differences in cracked *(I_{cr})* and effective (I_{eff}) moment of inertia calculations as well as significant inconsistencies to the approach to predict and limit masonry beam deflections between the U.S and Canadian masonry standards. Most notably, deflection limits for masonry beams are ambiguously discussed in the U.S. code, likely due to lack of related and recent research. To respond to some of these research needs, the authors commenced a new project funded by National Concrete Masonry Association Education and Research foundation (NCMA FDN). This project aims at improved masonry beam design guidance in the future editions of TMS 402/602 through experimental and numerical studies on masonry beams. As part of this project, the team conducted a national survey to better understand the masonry beam design and construction approaches by architects (A), structural engineers (E), and contractors (C), which is presented here. This paper summarizes the results of the survey. First, an overview of the participant data is provided. Then, the responses to individual survey questions are presented examining the similarities and differences in responses among the A-E-C professionals. Finally, conclusions are drawn where possible.

Definitions

The survey participants were given the following definitions from TMS 402/602-22 [6] at the beginning of the survey to ensure the results were aligned with the authors' assumptions. After this, in the survey and in this paper, the expressions "masonry beam" and "masonry lintel" are used interchangeably.

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

The survey was distributed through masonry-related professional organizations. 106 unique and complete responses were received: 7 Architects, 72 Structural Engineers (this includes one responder who entered Architect and Structural Engineer but selected the branch-out questions for structural engineers), and 27 General or Masonry Contractors. It was identified that most of the 27 contractors were specialized in masonry, as opposed to general contractors. It should be noted that the participants had the option to skip any question in the survey, so, the number of participants noted in each discussion is unique to that question.

Survey included two questions regarding the geographic regions of the participants, one asking for their primary region of practice (northwest, southwest, midwest, northeast, and southeast), and a follow-up asking whether they occasionally practice in other regions of the U.S. Participants were from each of the geographic regions of the United States, with the least representation coming from the Southwest (13 participants) and most from Midwest (31 participants).

DISCUSSION OF RESULTS

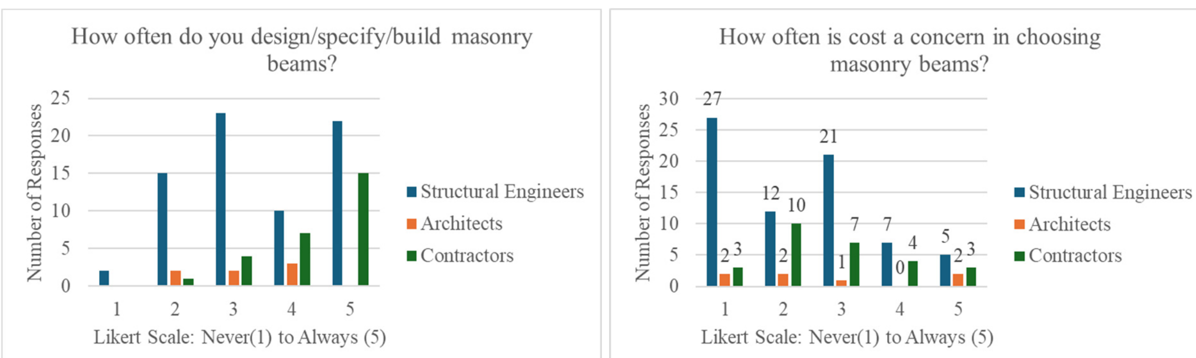
This section aims to provide the most informative results of the survey with an attention to comparison among A-E-C practitioners to identify alignment, or lack thereof, between the three subdisciplines on masonry beam design and construction as well as discipline-specific inquiries, when applicable.

Choice of masonry beams in design/construction

All three groups were asked to answer the following two questions using a Likert scale, where 1= never and 5= always.

- *How often do you [design/specify/build] masonry beams?*
- *How often is cost a concern in choosing masonry beams?*

Figure 1 shows the responses to these questions. The limited number of architects who participated (N=7), responded they *rarely-to-occasionally* (2-4) design masonry beams. In contrast, over 76% of the structural engineers, and over 96% of the contractors responded with scores 3-5. Large groups of structural engineers responded they are neutral to both questions, as noted in the peaks in Figures 1a and 1b.



(a) **(b)**

Figure 1: (a) Frequency of masonry beam design/construction by practitioners surveyed, (b) Participant opinions on whether cost is a deterrent on choice of masonry

The survey also queried engineers and architects on the reasons why they **decide against** masonry, or particularly masonry beams. The following question was asked in the survey:

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

Slightly different answer options were provided for engineers and architects. Tables 1 and 2 present these answer options along with the number and percentage of those options selected by engineers and architects, respectively. It should be noted that the participants could skip any question if they chose to, so the total number of participants is different than the number of survey participants (64 engineers). Further, given they could choose multiple answer options in this question, the sum of all responses is greater than the number of responses to the question. In Table 1, the percent response is the number of times an option was chosen divided by the total number of responses to the question to identify the popularity of that answer option.

Table 1: Engineers' Concerns for Using Masonry Beams in Design

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

Table 2: Architects' Concerns for Using Masonry Beams in Design

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

Note: Due to low number of architect responses, the data is not presented in percentage.

According to these results, while the engineers' top reasons for deciding against a masonry beam are complex design conditions (*i.e.* torsion) and contractor preference; the architects' most common concern is cost, along with an equal spread of the other concerns.

Architects were also asked about other beam design options: precast lintels, pre-assembled masonry, dry-cast lintels, and proprietary masonry precast lintels. Precast lintels were the most popular choice among these. Later, in open-ended questions, steel lintels emerged as a common option across A-E-C, which is aligned with the authors' observations.

To further study architects' and engineers' opinions around design decisions for or against masonry beams, both groups were asked the following question about span length:

- *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)

- Engineers’ answers (N= 64) ranged between 6ft and 84ft, a general breakdown is shown in Table 3 and further discussed below.

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	

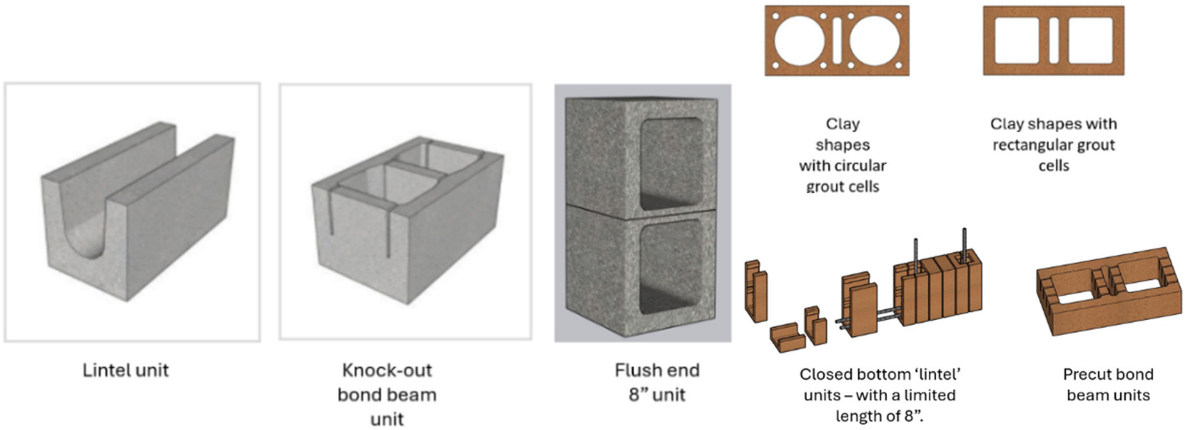
A couple of discussion-worthy comments (some lightly edited for grammar/clarity, indicated by [..]) entered in response to this question include:

- *No - I've engineered masonry beams up to 84 feet long.*
- *Around 40' I start to look at other options to see if they would be a better option- typically because of the out of plane [action].*
- *Not really if the available depth is adequate but around 30 feet would feel too long for just masonry.*
- *Depends on the height of wall above and the width of wall on either side available for arching action.*
- *18 feet with 8-inch block, 24 feet with 12-inch [block]*
- *No. If it's a CMU wall, the openings are spanned with CMU lintels*
- *Our office does not like designing CMU lintels/ beams that span over 12', which I was advocating against it. However, due to some reason issues in the field because of mason contractors, designing with CMU will not be my first choice, because I am very concerned about the quality of construction, QC/ QA, lack of shop drawings submittals, special inspections, etc…*
- *No official limit, but around 8'-0" is when our office would start to consider a structural steel lintel/beam*
- *No. As long as deflection and reinforcing work and the details make sense, I'll stick with masonry.*
- *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)*

As can be seen, structural engineers exhibit a wide variation in their confidence in masonry's ability to span over openings. It is interesting that some firms have pre-determined (and rather short, such as 8ft) limits without specific reasoning mentioned, while some engineers have successfully designed masonry beams up to 84ft in span length. This highlights the need for better education in structural masonry design in higher education and beyond. The concerns around complex loading conditions (e.g. torsion) and the issues around miscommunication between engineers and contractors, are aligned with responses to other questions.

Masonry unit choices in beam design/construction

All participants were asked to identify concrete masonry (Figure 2a) and clay masonry (Figure 2b) unit types they typically detail/specify in their designs or use in construction. Precast concrete masonry lintels, manufactured concrete masonry lintels, and none (contractor specified) were also options listed, along with an option for the participant to enter new items. The A-E-C responses for concrete and clay masonry are shown in Tables 4 and 5, respectively. Table 5 shows that while lintel units, knock-out bond beam units, and precast masonry lintels are frequently used (or recognized) by all groups, architects are the group that utilize precast or premanufactured lintels the most. While the sample size is small, it is noted that the architects never leave the choice to the contractor but both engineers and general contractors sometimes take this route.



(a) (b)

Figure 2: (a) Concrete Masonry Unit Types (b) Right: Clay Masonry Unit Types

Table 4: Concrete Masonry Types Used for Beams

	Engineers		Architects		Contractors	
Concrete Masonry Type	**No.**	**%**	**No.**	**%**	**No.**	**%**
Lintel units	54	76%	7	100%	22	81%
Knock-out bond beam units	46	65%	4	57%	19	70%
Flush end 8" units	15	21%	2	29%	4	15%
Precast concrete masonry lintels	22	31%	4	57%	10	37%
Manufactured concrete masonry lintels	11	15%	3	43%	6	22%
None- contractor preference	12	17%	0	0%	2	7%
Other types (entered by participant)	6	8%	0	0%	3	11%
Total responses	**71***		**7**		**27**	
One engineer, who primarily represents the clay masonry industry, did not respond.						

Table 5: Clay Masonry Types Used for Beams

	Engineers *		Architects		Contractors	
Clay Masonry Type	**No.**	**%**	**No.**	**%**	**No.**	**%**
Clay shapes with circular grout cells	6	9%	0	0%	1	4%
Clay shapes with rectangular grout cells	21	31%	3	43%	7	26%
Closed bottom lintel units- with a limited length of 8"	17	25%	1	14%	5	19%
Precut bond beam units	11	16%	0	0%	2	7%
None-contractor preference	37	55%	4	57%	14	52%
Variations of "I do not work with structural clay"	15	22%	0	0%	0	0%
Other	0	0%	0	0%	3	11%
Total responses	**67***		**7**		**27**	
Four engineers did not respond to this question, which implies lack of familiarity/frequency of use.						

Results presented in Table 5 in general prove the authors' impression that in the U.S. clay masonry is not used as frequently for structural purposes, and based on this survey, this includes beams. It is also to be noted that if clay masonry is to be used for structural purposes, the type of unit is left to the contractor's choice more readily than for concrete masonry. This was indeed the most popular choice across the board, with more than half of each category of respondents, including architects. The authors hypothesize that because the concrete masonry industry in the U.S. has invested more in research and education compared to the clay masonry industry, this has contributed to the lack of awareness around structural clay products.

Depth of masonry beams and shear reinforcement

The survey asked "*What is the most common beam depth (in terms of number of masonry courses) you design/build? (pick up to 3 options, referring to your most common designs)*" to engineers and contractors. The question was deemed irrelevant to architects, and therefore, not asked. The purpose of this question was to gather a general approach to beam design and construction practices as well as to inform the author team's upcoming full-scale beam test matrix. As shown in Table 6, there is general alignment between the engineers and the contractors in that masonry beams are typically one to three courses deep, with two-course beams being most common for engineers and one-course for contractors.

Table 6: Commonly Designed Beam Depth/Number of Courses in Masonry Beams

	Engineers		**Contractors**	
What is the most common number of courses you design/specify?	**No.**	**%**	**No.**	**%**
Single course	25	35%	19	73%
Two courses	51	72%	18	69%
Three courses	44	62%	8	31%
Four courses	10	14%	1	4%
Five or more courses	5	7%	1	4%
Total responses	**71**		**26**	

The above observation is further validated by the responses to the question "*how often do you design deep beams*?" directed only to the engineers. 90% of the structural engineers selected 1-3 on a Likert scale of five. Only 4% (N=3) responded that they *always* design deep beams.

Engineers were also asked "*how do you determine the depth of a masonry beam*?" with 3 answer options:

a. I identify the depth/number of courses that will ensure no shear reinforcement will be required: 64% chose this option
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% chose this option
c. I start with a fixed number of courses: 29% chose this option

It should be noted here that the best approach, in the authors' opinion, is the first one above (when possible), which ensures a masonry beam design that is structurally safe and easier to construct.

A related question is also asked "Do you typically specify/require shear reinforcement (stirrups)? Out of the 71 responses, majority (73%) responded Never/rarely (scales 1-2) and 27% responded neutral-often-always (scales 3-5). This best practice, at least by the participating engineers is encouraging; and is aligned with the responses above to beam depth designation.

Masonry Beam Construction and TMS 402/602 Terminology

In further exploring the survey results, it was noted that a specific question related to what units are specified within upper (unreinforced) courses of a masonry beam may be helpful in future studies. Both recent editions, TMS 402/602-16 and 22 [5, 6], are silent on the unit configurations expected for a masonry beam. Both editions state that beams must be fully grouted (TMS 402-16 9.3.4.2.4). However, the provisions leave it ambiguous whether constructing upper courses with typical CMU block (leading to continuous vertical columns of grout within the cells but leaving out the head joints that interrupt the horizontal flow of grout) is permitted. In a follow up discussion with three engineers from across the U.S. who are masonry design experts, it was noted that current practice includes both a) the construction of upper courses using typical CMU block, which would impede the horizontal flow of grout, and b) using knock-out units or special H-units to permit horizontal flow of grout. All three agreed with the authors that the best practice would be to ensure continuous grout flow (vertically and horizontally) within the beam. Because of the formulation of this survey, we are unable to draw definitive conclusions about typical practice for block type used within the upper courses of masonry beams, but the initial discussion with the three engineers interviewed indicates the need for future research and improved guidance in future editions of TMS 402/602 around masonry beam construction.

Specific Inquiries on the Structural Design of Masonry Beams

Structural engineers were asked a few technical questions to better understand various design approaches to masonry beam design across the U.S. These questions were:

- *TMS 402/602 requires the deflection of beams supporting unreinforced masonry to be limited to L/600 under allowable stress level dead and live loads but is silent on deflection limits for beams supporting reinforced masonry. Do you routinely check beam deflections when supporting reinforced masonry, and if so, what are the limits applied?* [Options included l/600, l/480, other]
- *Do you use allowable stress design (ASD) method or strength design (SD)method?* [Options included ASD, SD, Both (I go back and forth)]
- *Which of the following equations for cracked moment of inertia do you use when you calculate deflections in masonry beams?* [Options included Equation (1) is an ASD-based and Equation (2) is SD-based.]

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

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

Responses to these three questions are provided in Figure 3.

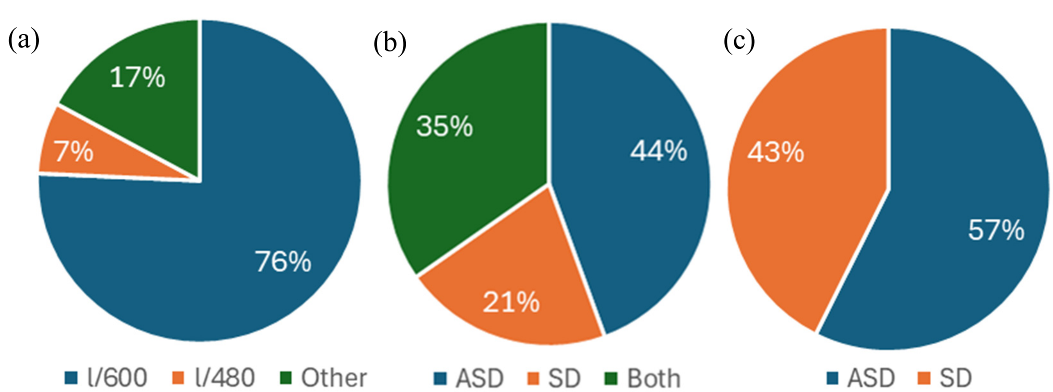


Figure 3: Structural Design Specifics (a) Deflection limits used by engineers, (b) Overall choice of design method, (c) I_{cr} equation choice

As can be seen, structural engineers predominantly use ASD (44% use it solely and 79% use it sometimes), and limit masonry beam deflections to l/600. Both design approaches may lead to overly conservative designs alone, but especially when used together.

Final Notes and Unique Perspective of Participants

Every survey (A-E-C specific questions) included the open-ended question "*do you have any other general comments about masonry beam design?*" None of the seven participating architects had any further comments. Contractors and engineers provided some valuable comments, as follows. Comments are edited for clarity/grammar/brevity when indicated by [..].

Contractors

Eleven out of 27 (41%) contractors entered in open-ended comments. These comments' center on two main points, which are presented through the select contractor comments given below.

a) Lack of understanding or awareness by designers: Specific responses are not included for brevity, but included the use of out-of-date codes, a perception that engineers do not understand masonry lintels, and excessive reinforcement being specified in bond beams.

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.*

Structural Engineers

25 out of 71 structural engineers entered in open-ended comments. These comments focus on a variety of topics, all valuable. Unfortunately, there is not enough space on the paper to include them. A few key areas of interest are noted here.

(a) Lack of code guidance on specific design considerations:
  - Specific responses are not listed for brevity, but concerns included: lack of guidance for torsion, biaxial bending conditions, lack of clarity on head joint conditions, and issues with beam placement and movement/control joints.

(b) Lack of familiarity/education on structural masonry design
  - *Lack of familiarity with masonry codes seems to be the major issue as most designers have never had formal masonry education.*

(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
  - *I think engineers are too quick to use steel lintels and [they] don't consider the thermal effects of dissimilar materials*

- *Typical opinion we get from mason contractor is that they would rather use steel at 8ft and larger. They need steel to shore anyway, so preference is to have a steel lintel/beam. Sometimes this works better with supporting the veneer as well (due to large air/insulation space)*

Authors agree with many of the items provided in comment group (a) and (b) above, which further confirms the goals and potential impact of the ongoing project. Group (c) comments relate to group (b) in a particular way, because there are in fact software options tailored toward structural masonry design, as follows:

- Direct Design Software for Masonry Structures [8] – compatible with REVIT 2021
- EleMasonry Design Software [9]

Finally, group (d) comments show both a need for better communication between engineers and contractors (as there are comments from either side about the other group dictating the use of steel lintels) as well as a better education on the benefits of using masonry lintels in masonry walls compared to steel lintels.

CONCLUSIONS

A survey on beam design and construction practices was disseminated through masonry-related organizations. 106 unique responses were received from 7 architects, 72 structural engineers, and 27 contractors. The following key conclusions can be drawn from the analysis of the survey results:

- It was identified that most of the 27 contractors were specialized in masonry, as opposed to general contractors. This was deduced from their affiliation but also was evident in their response to the question regarding the frequency of building masonry buildings. Over 96% of the contractors selected scores of 3-5. Similarly, the 76% of the structural engineers selected scores of 3-5. This result points out to a level of familiarity and expertise with masonry design and construction among the participants.
- The results on the reasons to design other materials than masonry for spanning openings was interesting. Engineers' top concerns were complex loading situations (i.e. torsion) and contractor preference. Interestingly, contractors mentioned engineers and architects specifying other materials in the open-ended question. Among the 7 architects, top concern was cost.
- Even within this group of masonry-interested A-E-C practitioners, there is a significant lack of knowledge/trust in structural clay products. This is an indicator of lack of investment in education and research from the clay masonry industry as opposed to concrete masonry industry.
- One of the more interesting responses was to the question of span length limits informing the decision on choosing masonry or other materials for beams/lintels. The architects' responses ranged between 3-12ft, while the engineers' responses ranged between 8-84ft. While the response rate from architects is low (which is also an indicator of a lack of trust and familiarity); it is noted that the structural engineers' confidence in masonry construction is much higher than those of the architects. This could be improved through education efforts in architecture schools and firms.
- Lack of clear code guidance on complex design issues such as torsion, deflection limits, and biaxial bending specific to beam design should be addressed.
- Structural engineers predominantly use ASD (44% use it solely and 79% use it sometimes), and limit masonry beam deflections to l/600. Both design approaches may lead to conservative designs.

Overall, most alarming and yet most solvable issue that emerged from the study are the lack of knowledge around the benefits (over steel lintels), better communication between A-E-C practitioners, and proper design, specification, and construction of masonry lintels. This can be addressed with continued efforts in making masonry design a part of architecture, structural engineering, and construction curricula across higher education institutions and investing in research and marketing of masonry.

Limitations and Recommendations for Future Work

Many of the engineers who responded are members of the Masonry Society (TMS) and they are actively involved in masonry research, practice, education, and code/standard development. Many of these engineers also serve on TMS 402/602 committee, thereby having in-depth knowledge of the code's content and inherent limitations. Therefore, it is the authors' opinion that engineering responses reported herein are credible, and meaningful conclusions can be drawn from this data. While the contractor response was notable (27 responses), it is likely not representative of the national perspectives, especially that of large general contractors. Finally, the architects' participation was very low (7 responses), and while results are presented and discussed in the paper, care is taken not to draw any strong conclusions from this data. Further research could be conducted by reaching out to organizations for general contractors (ABC, AGC, CMAA, etc…), engineers (ASCE), and architects (AIA). Another future work option is to follow up with the many respondents (81 %) who stated they would participate in a focus group to further discuss the topic.

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