Masonry Tips for Structural Engineers

*The following Masonry Tips originally appeared in **TMS Responds** by The Masonry Society (TMS). TMS is a professional, technical, and educational association dedicated to the advancement of knowledge on masonry. Members are design engineers, architects, builders, researchers, educators, building officials, material suppliers, manufacturers, and others who want to contribute to and benefit from the global pool of knowledge on masonry. Responses have been updated to include new information, and reference to updated standards.*

Q My house is over 80 years old and is made of some beautiful stone, much of which appears to be granite. But there are cracks in the mortar between the stones which I would like to repair. How can we fix the cracks and is there a strong mortar to use so they will not occur again?

(*Originally appeared in TMS Responds Vol. 1, No. 1, January, 2001*)
Response by Michael P. Schuller, Atkinson-Noland & Associates, Inc. (Former chair of The Masonry Society's Existing Masonry Committee)

A It is difficult to know why these cracks occurred without seeing the building, but they are likely due to normal building movement, along with long term settlement. While you may think that a stronger mortar is needed to repair the cracks, I would generally advise against this. The existing mortar appears to have performed well, since it is 80 years old and you have not indicated moisture penetration or significant structural problems. In fact, it is fortunate that the mortar was weaker than the stone, otherwise when this movement occurred, the stone would likely have cracked instead of the mortar, and repairs would have been more noticeable and difficult.

To repair these cracks I would first strongly recommend you contact a local mason to come take a look at the cracks. You may also wish to hire a consulting engineer or architect to ensure that the cracks are not an indication of more significant structural problems. They can advise you on proper repairs; but, assuming there are no significant structural problems, you will need to cut out the affected mortar joints and replace the mortar with a method called tuckpointing as described below.

To remove the existing mortar, you will need to cut out or chisel out the mortar to a depth of not less than ¾ inches (19 mm) or at least 2 times the joint width. If the mortar appears to be extremely soft, you should continue removing it until sound mortar is found. Be careful not to damage the surface of the stone when removing the mortar. Once sound mortar is found, remove any dust and debris from the mortar joint using a vacuum, air hose, brush, or water hose.

The mortar used should closely match the existing mortar in both color and properties. Since your house is over 80 years old, a mortar having proportions near that of a Type N or O mortar per ASTM C 270 was likely used. Common proportions for a similar lime-rich repair mortar are 1 part Portland cement, ½ to 1¼ parts hydrated lime, and 2¼ to 3 times the volume of the cement and lime in masonry sand. It is very important to measure these materials by volume, not weight, and when doing so, mix the mortar with full or half bags of the cement and lime to maintain consistency.

Mix the mortar with less water than you would typically consider appropriate for a masonry mortar. You want it damp enough so that you can press it into a small ball, but not wetter. Prior to placing the mortar, the surface of the masonry should be dampened, not soaked. There should be no standing water in the joints. Then the mortar is tightly pressed into the joint in layers not more than ¼-inch (6.4 mm) in thickness. The mortar joint is built up with these layers until the surface of the masonry is reached, at which point you will want to tool the mortar joint to match the existing mortar joint profile.

A common complaint with mortar joint repairs is that the mortar does not match the look of the existing mortar. Recognize that this is very difficult to do, since the existing mortar has been exposed for years to dirt, grime and staining. Certainly the entire building could be cleaned, but this is costly and the match will still be less than desired. Some masons will try samples of mortars to attempt to match the color and appearance of the existing mortar, but this is also difficult and time consuming. They can try pigments and varying proportions of the mortar, and then oven drying these samples to come up with a close match, but the new mortar may still vary somewhat from the existing. This is something we must accept.

Making minor repairs to mortar joints is a common practice that the mason and your local architects and engineers will be familiar with. Additionally, information on tuckpointing is commonly found in home improvement books that you can obtain from your local library.

Q I have heard that clumping steel in jambs of shear walls and in the bottoms and tops of lintels is not good practice. I understand that clumping the steel can cause congestion problems, but are there any other reasons why I should avoid clumping the steel? If I distribute the steel more, won't I decrease the moment capacity and thus need more steel reinforcement? Isn't this counterproductive?

(*Originally appeared in TMS Responds Vol. 1, No. 3, May/June, 2001*)
Response by Richard E. Klingner, University of Texas at Austin (Current Chairman of the Masonry Standards Joint Committee that oversees the development of ACI 530/ASCE 5/TMS 402)

Severe congestion of reinforcement required the faceshells of this concrete masonry wall to be cut to accommodate the steel. Such congestion should be avoided for economy, and to ensure proper placement of grout around the reinforcement. Photo courtesy of Phillip Samblanet.

A Concentrating flexural reinforcement at the extreme fibers of flexural elements has one advantage, but several disadvantages.

• The advantage is that it can maximize the efficiency of use of the reinforcement, by placing it the greatest possible distance apart. This increases flexural capacity for a given amount of steel, and also slightly increases flexural ductility.

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Table 1: Bar Size Limitations Recommended by Many and Required by Some Codes[1]

Nominal Wall Thickness, *t* (in.)	4[2]	6	8	10	12
⅛*t* (in.)	0.5	0.75	1.0	1.25	1.5
Bar Designation meeting ⅛*t* and other requirements	No. 4	No. 6	No. 8	No. 9[3,5]	No. 11[4,5]

1 Based on MSJC-02 Section 3.2.3.1, MSJC-05 Section 3.3.3.1, IBC-00 and IBC-03 Section 2107.2.4, IBC-00 Section 2108.9.2.1, and IBC-06 Section 2107.7

2 While 4-inch nominal hollow clay masonry units are available, most 4-inch nominal hollow concrete masonry is nearly solid, and thus cannot be reinforced and grouted. Check with local concrete masonry unit supplier on unit availability

3 A No. 9 is listed since the nominal diameter of a No. 10 bar is 1.27, which slightly exceeds ⅛*t*

4 Maximum bar size in masonry is No. 11

5 MSJC-02, 3.2.3.1 and MSJC-05 Section 3.3.3.1 limits maximum bar size to No. 9

• The disadvantages are that it can lead to congestion of reinforcement; that it can decrease resistance to shear failure along a section perpendicular to the axis of the member (for example, along the bed joints of walls; and that it can lead to more rapid deterioration of the compression toe of the wall.

The principal negative consequences of congestion are inadequate bond (because of the inability to get the grout to flow around congested bars), and an increased tendency toward longitudinal splitting because of the tensile forces produced around the bars, and the small cover around a zone of congested reinforcement.

Code Requirements to try to Prevent Reinforcement Congestion

Numerous general requirements and recommendations on ways to prevent reinforcement congestion have been used in the past, and some requirements are given in masonry codes. One rule-of-thumb recommendation given to many beginning designers is to limit bar designation (in US units only) to the nominal wall thickness (*t*) in inches, or the wall thickness minus one. Thus, the maximum bar size would be a No. 8 (or a No. 7 if you used *t* - 1) for an 8-inch masonry, a No. 6 (or a No. 5 for *t*-1) for a 6-inch wall, etc. These easy to apply rules-of-thumb generally limit congestion effectively, although they are not code requirements for all masonry. The following summarizes some of the main code requirements to limit reinforcement congestion. References sited are designated as the MSJC-99, MSJC-02, and MSJC-05 for the 1999, 2002, and 2005 editions of ACI 530/ASCE 5/TMS 402, *Building Code Requirements for Masonry Structures*, respectively, and the IBC-00, IBC-03, and IBC-06 for the 2000, 2003, and 2006 Editions of the International Building Code, respectively. While not logical, requirements in these codes and standards often differ for masonry designed by the Working Stress Design Method and the Strength Design Method. The reader should review the applicable requirements carefully to ensure the appropriate provisions are being applied to the job.

Maximum Bar Size

No. 11 (M #36) (1.12.2.1 of MSJC-99 and MSJC-02, and 1.13.2.1 of MSJC-05), but for Strength Design of Masonry the Maximum Bar Size is limited to No. 9 (M #29) (MSJC-02, 3.2.3.1 and MSJC-05, 3.3.3.1).

Maximum Bar Size per Wall Thickness (*Table 1*)

⅛ nominal wall thickness (IBC-00 and IBC-03 2107.2.4, IBC-00 2108.9.2.1, IBC-06 2107.7, MSJC-02 3.2.3.1 and MSJC-05 3.3.3.1 for Strength Design)

Maximum Bar Size per Cell Thickness (*Table 2*)

½ clear cell or collar joint thickness (MSJC-99 and MSJC-02, 1.12.2.2, MSJC-05 1.13.2.2)

¼ clear cell or collar joint thickness (IBC-00 and IBC-03 2107.2.4 and IBC-06 2107.7 for Allowable Stress Design, and IBC-00 2108.9.2.1, MSJC-02 3.2.3.1 and MSJC-05 3.3.3.1 for Strength Design)

Table 2: Bar Diameter Limitations Required by Various Codes for Hollow Masonry

Nominal Unit Thickness *t* (in.)	Probable Maximum Clear Cell Width[1] (in.)	Maximum Bar Diameter based on ½ clear cell requirement of MSJC, except for Strength Design[2] (in.)	Maximum Bar Diameter based on ¼ clear cell requirement of IBC and MSJC[3] For Strength Design (in.)
Hollow Clay Masonry			
4	1	0.5	0.25
5	1.5	0.75	0.38
6	2.5	1.25	0.63
8	4	3.0	1.0
10	5.75	2.88	1.44
12	7.5	3.75	1.88
Hollow Concrete Masonry			
4[4]	1.125	0.56	0.28
6	2.625	1.31	0.66
8	4.125	2.06	1.03
10	5.875	2.94	1.47
12	7.625	3.81	1.91

1 Based on minimum faceshell thickness from ASTM C 652 for hollow clay masonry and from ASTM C 90 for concrete masonry. In addition, the probable maximum clear cell width assumes ½-inch mortar protrusions are present on both sides of cell, thus reducing the "clear" cell width by a total of 1-inch. The ½-inch mortar protrusions are the maximum mortar protrusions permitted by Article 3.3B 1c of the MSJC Specification.

2 Represents ½ clear cell or collar joint thickness (MSJC-99 MSJC-02, 1.12.2.2 and MSJC-05 1.13.2.2)

3 Represents ¼ clear cell or collar joint thickness (IBC-00 and IBC-03 2107.2.4, and IBC-06 2107.7, for allowable Stress Design, and IBC-00 2108.9.2.1, MSJC-02 3.2.3.1 and MSJC-05 3.3.3.1 for Strength Design)

4 While 4-inch nominal hollow clay masonry units are available, most 4-inch nominal hollow concrete masonry is nearly solid, and thus cannot be reinforced and grouted. Check with local concrete masonry unit supplier on unit availability.

Table 3: Area of Steel Limitations Required by Various Codes for Typical Concrete Masonry (CMU) Walls

Nominal CMU Wall Thickness, *t* (in.)	Approximate Area of CMU Cell[1]	Maximum Area of Vertical Reinforcement based on 6% Limit[2]	Maximum Area of Reinforcement based on 4% Limit[3]
4[4]	12.5	0.75	0.50
6	21	1.26	0.84
8	30	1.80	1.20
10	42	2.52	1.68
12	54	3.24	2.16

[1] Cell area listed is approximate, and varies based on units used (thickness of faceshells and webs of units, core shape, etc.).
[2] Based on Footnote 4 of MSJC-99 Table 1.15.2, MSJC-02 Table 1.15.1, and MSJC-05 Table 1.16.1- applies to vertical reinforcement.
[3] Based on MSJC-02 Section 3.2.3.1, MSJC-05 Section 3.3.3.1 and IBC-00 Section 2108.9.2.1
[4] Many nominal 4 in. concrete masonry units cannot be reinforced and grouted because they are nearly solid. Check with local concrete masonry unit supplier on unit availability

Maximum Bar Area Per Grout Space Area (*Table 3*)

6% of Grout Space Area (Footnote 4 of MSJC-99 Table 1.15.2, MSJC-02 Table 1.15.1 and MSJC-05 Table 1.16.1) Applies to Vertical Reinforcement

4% of Grout Space Area (IBC-00 2108.9.2.1, MSJC-02 3.2.3.1 and MSJC-05 3.3.3.1 for Strength Design)

Q We have very dense architectural concrete masonry units (CMU) on a large construction project that are required to be grouted. The units tend to absorb moisture very slowly. The contractor repeatedly wants to supply a grout with a slump of 6-8 inches, but our inspector has required the slump to be increased to at least 8 inches that she says is a code requirement. The contractor has complied, but notes that such a high slump is not needed, and may in fact cause problems related to efflorescence, freezing, low grout strengths, etc.

Who is right? I know grout needs more water than concrete because of the absorption of the units, but if, as the contractor says, when the units have low absorption, can we permit low slump grouts? If we use low slump grout, will it still flow appropriately? (*Originally appeared in TMS Responds Vol. 4, No. 2, September, 2004*)

Response by David T. Biggs, Ryan-Biggs Associates PC (Member of the Masonry Standards Joint Committee, and chair of their Prestressed Masonry Subcommittee)

A Your inspector is correct that, *unless otherwise required*, a minimum grout slump of 8 inches (203 mm) is currently required by Article 2.6 B2 of the Masonry Standards Joint Committee's (MSJC) *Specification for Masonry Structures* (ACI 530.1-05/ASCE 6-05/TMS 602-05). This criterion has been part of earlier versions of the MSJC also. However, the contractor has an excellent point. Using high slump grouts with low-absorption CMU has created field problems in certain circumstances and, accordingly, this may be one of those "unless otherwise required" cases. I have requested that the Masonry Standards Joint Committee consider this issue as they make future revisions to the MSJC *Specification.*

Current practice is to use high slump grout (8 to 11 inches (203 – 279 mm)) to increase flow, so that the grout will readily flow into confined spaces. With typical masonry units, much of the mix water is absorbed by the surrounding masonry, lowering the apparently high water-cement ratios of the grout. Adequate grout compressive strengths and bond are achieved, provided the grout is adequately consolidated.

When high slump grouts are used with low-absorption units, either clay or CMU, the mix water is not readily absorbed by the units and several conditions are possible. In some cases, mix water is forced through the mortar joints resulting in increased efflorescence. In addition, the excess water reduces the grout strength somewhat, since the water cement ratio at the time of hydration is higher than for more traditional masonry. In cold weather, that excess water produces a greater chance of freeze damage.

For these reasons, I question whether an 8-inch (203 mm) grout slump is appropriate for low absorption units. Low absorption units are clay units with a low IRA (initial rate of absorption less than 5 g/min x 30 in.^{2}) or concrete masonry units manufactured with integral water repellent admixtures.

When using low absorptive units, I recommend that you reduce the grout slump to 5 to 6 inches (127 to 152 mm) as permitted by the "unless otherwise required" exception in the MSJC *Specification*. In addition, in cold weather, provide protection for 48 hours to prevent freezing. If grout flow is a concern, have the contractor construct a demonstration panel to verify complete filling of the cavities and adjust the maximum lift height accordingly. Grout admixtures are also available to improve the flow of low slump grouts.▪

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