Josh Landis, May 2015

A Comparison of Reinforced Masonry and Reinforced Concrete Design

INTRODUCTION

In this paper, a general comparison will be presented between the strength design provisions found in the 2013 TMS 402/602 code and the provisions of ACI 318-11 for reinforced concrete design. The design methodologies presented in these two documents are similar in nature; if one is familiar with reinforced concrete design, then reinforced masonry design can be readily learned. It should be noted that allowable stress design is permitted in TMS 402/602-13; however, this approach will not be considered in this paper. This paper will focus on highlighting some of the different engineering design practices for these two building materials, primarily when evaluating the capacity of an element, so that an engineer who is familiar with reinforced concrete design can begin to learn reinforced masonry design.

MATERIAL PROPERTIES

First, it should be noted that the compressive strength of a given masonry assemblage (f'm) used in calculations is affected by the strength of the individual masonry units, the mortar bonding these units together, the grout that fills the cavities within the units, and the bond between the individual components. This composite action can be accounted for through prism testing or by using the unit strength method presented in TMS 602-13 1.4 B 2. Conventional grout used in reinforced masonry construction must have a higher slump and smaller aggregate size than that of conventional concrete to allow the grout to fill all of the voids within the masonry unit (MDG, 2013). Additionally, masonry units will absorb water from the grout, which reduces the high water content that is needed to achieve the necessary sump (Bennett, 2015). With all of these contributing factors at play, the compressive strength of a conventional concrete masonry unit assemblage will typically be less than half that of conventional concrete. Furthermore, engineers are limited to the dimensions of commonly used masonry units when proportioning beams, walls, pilasters, and columns.

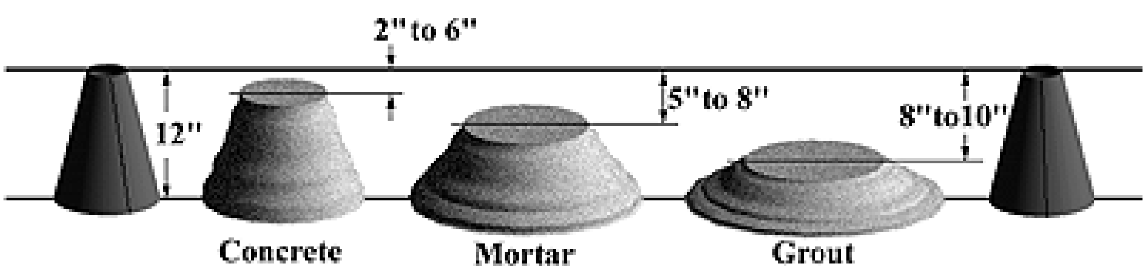

Figure 1: Typical Slumps for Concrete, Mortar, and Grout
(Source: http://www.maconline.org/tech/materials/grout.html)

STRENGTH REDUCTION FACTORS

The strength reduction factors specified by ACI 318-11 for reinforced concrete subjected to compression and flexure vary for different levels of extreme tensile reinforcement strain at ultimate loads, so that a lower strength reduction factor is applied when brittle compression-controlled failure governs design (Shahrooz, 2014). Figure 2 is a diagram of those strength reduction factors for reinforced concrete. Conversely, TMS 402/602-13 uses a constant strength reduction factor for both compression and flexure, but it limits the maximum flexural reinforcement ratio at different seismic strain demands. This maximum permitted longitudinal reinforcement is defined using the critical strain gradient when the maximum useful strain is reached in the extreme compression fiber, and the strain in the extreme tension fiber has reach a multiple of the specified yield strain (Klingner et. al., 2012). This provision is in place to avoid brittle compression-controlled limit states.

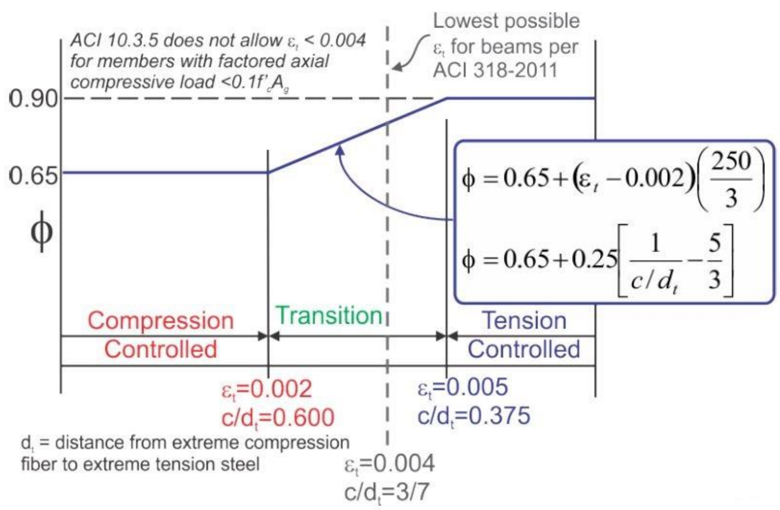

Figure 2: Strength Reduction Factors for Reinforced Concrete in Compression and Flexure
(Source: Shahrooz, 2014)

FLEXUAL CAPCACITY

Under design flexural loading, the actual stress distribution in both concrete and masonry is non-linear. In lieu of dealing with these actual stress distributions, an equivalent stress block is used in both reinforced masonry and reinforced concrete design. The value of the factor β_1 that is used in reinforced concrete design to determine the depth of the equivalent stress block varies with respect to f'c and can be between 0.85 – 0.65 when f'c is less than 8000 psi (Shahrooz, 2014). In reinforced masonry design, β_1 is taken as 0.8 for all possible values of f'm (MDG, 2013). Furthermore, the factor γ (see figure 3) that is applied to f'm/f'c to match the magnitude of the compressive force under actual stress distributions to that of the equivalent stress block is taken as 0.85 in reinforced concrete design and 0.8 in reinforced masonry design, regardless of the magnitude of f'm/f'c. These factors were developed to match experimental testing results to the theoretical equivalent stress blocks that are used in calculations (Bennett, 2015). In reinforced masonry design, the factor β_1 does not vary with f'm because the range of possible values for f'm is small and one factor can accurately model the experimental results (Bennett, 2015).

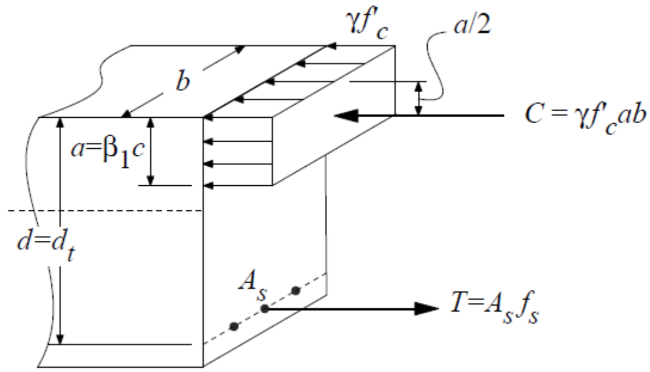

Figure 3: Equivalent Stress Block

(Source: Shahrooz, 2014)

Additionally, the maximum useable compressive strain for concrete masonry units is 0.0025 and for clay masonry units it is 0.0035, while the maximum usable compressive strain of concrete is 0.003. For both reinforced masonry and concrete design, the strain in the reinforcing steel under design loads is determined by assuming that strain is proportional to the distance from the neutral axis, and that the extreme compressive fiber has reached its maximum usable strain. The flexural capacity of a reinforced masonry element is then determined using the same principles as reinforced concrete, assuming plane sections, elasto-plastic behavior of reinforcement, and neglecting the tensile strength masonry.

AXIALCAPACITY

When determining the pure axial capacity of a reinforced masonry element, the approach is similar to that taken when designing with reinforced concrete. One difference between these two approaches is that a stress equal to 80% of f'm is assumed to act over the effective area of masonry when evaluating pure axial compression for reinforced masonry (this is 85% for reinforced concrete). The pure axial capacity of reinforced masonry elements is then also reduced by a slenderness-dependent reduction factor (MDG, 2013). An interaction diagram for combined flexure and axial compression is constructed in similar fashion to that which would be constructed for reinforced concrete, using the principles presented above on flexural capacity and applying the pure axial capacity as the upper limit for compressive loading. Generic critical strain diagrams for intermediate points on the interaction diagram are shown in figure 4. The slenderness dependent reduction factor is applied only to the pure axial capacity of reinforced masonry elements, and is not applied when evaluating points of combined axial and flexural loading (MDG, 2013). Additionally, longitudinal steel in reinforced masonry is typically neglected when determining the axial capacity of a wall because it is placed in a single layer and cannot be laterally supported out of plane (Klingner et. al., 2012). In contrast, reinforced concrete walls typically have two curtains of longitudinal reinforcement which can be tied together so that the compressive reinforcement can be included in the capacity of the wall (Klingner et. al., 2012).

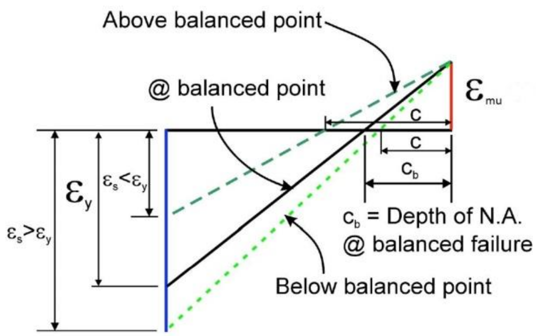

Figure 4: Critical Strains used to Evaluate Points on an Interaction Diagram
(Source: Shahrooz, 2014)

SHEAR CAPACITY

For both reinforced concrete and reinforced masonry, the shear capacity of an element is a combination of the shear capacity for that material being considered and the additional capacity gained by transverse reinforcement. When evaluating the contribution to shear capacity from masonry, there are four factors that come into play: the shear-related cross-sectional area, the square root of f'm (a measure of the diagonal tensile capacity of masonry), the ratio of shear span to depth, and the factored axial load applied to the element (Klingner et. al., 2012). Furthermore, when using the detailed expression given by ACI for the shear capacity of a reinforced concrete wall, these same four factors contribute to the one-way shear capacity of that wall (Klingner et. al., 2012). The equations used to evaluate the shear capacity of these two materials reflect the behavioral differences between these two materials, and therefore the numerical factors in these equations are quite different. However, these two materials are affected by very similar design parameters when evaluating shear capacity.

When transverse reinforcement is used in reinforced masonry (i.e. in a shear wall), the steel contribution is computed from the area of transverse reinforcement crossing a hypothetical 45-degree crack; this is the same way that transverse reinforcement is accounted for in reinforced concrete design (Klingner et. al., 2012). However, in reinforced masonry design, the contribution to shear strength provided by transverse reinforcement is multiplied by a factor of 0.5 to account for non-uniform yielding (Klingner et. al., 2012). Furthermore, when designing a reinforced concrete beam, it is typical to add additional transverse reinforcement instead of increasing the beam depth when additional shear capacity is needed. On the other hand, it is common practice to size a reinforced masonry bond beam to meet shear demands without the need for transverse reinforcement (MDG, 2013).

CONCLUSION

There are many similarities between reinforced masonry design and reinforced concrete design, and the principles that govern the behavior of these materials are analogous in many regards. The primary differences between these materials include construction practices, dimensional limitations, available strength ranges for concrete and masonry assemblages, and the composite action that governs the behavior masonry assemblages. This paper was not intended to exhaustively compare every aspect of reinforced concrete and reinforced masonry design; engineers should be careful to recognize other areas where these design methodologies differ.

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