Harmonization of Allowable Stress Design and Strength Design of Masonry

By Edwin T. Huston, P.E., S.E.

Edwin T. Huston, P.E., S.E., is a Principal with the structural engineering firm of Smith & Huston Inc. in Seattle, WA. He has received numerous awards for his work and is a Past President of NCSEA.

This article is provided by Ed Huston as the 2011 recipient of The Masonry Society's Haller Award. Named for Professor Paul Haller, the Haller Award recognizes an individual engineer or engineering firm that has enhanced the knowledge of masonry in practice. Ed has an extensive background in masonry design, research, and teaching that has resulted in advancements in masonry design practice and code development. He continues to advance masonry knowledge through his ongoing design and investigation practice, as well as disseminate that knowledge through his teaching activities. The Haller Award committee congratulates him on his achievements and selection.

History of Masonry Harmonization

Masonry structures have been built to endure; noteworthy masonry structures constructed hundreds, even thousands, of years ago, still exist. Masonry design and construction produces architecturally award-winning structures which are safe and durable. The main masonry materials in use today are brick, concrete masonry and glass block masonry. The primary masonry design methods in use today are allowable stress design (ASD), strength design (SD) and prestressed masonry design.

The masonry standards referenced in the *International Building Code* (IBC) are the *Building Code Requirements for Masonry Structures* (*Code*) and the *Specification for Masonry Structures* (*Specification*). These two documents, along with their respective commentaries are jointly known as the Masonry Standards Joint Committee documents, or the MSJC documents. (Starting with the 2008 edition, The Masonry Society became the lead organization and the documents are often referred to as the TMS 402 and TMS 602, respectively.) They are jointly published by The Masonry Society (TMS), The American Concrete Institute (ACI), and the American Society of Civil Engineers (ASCE). These three organizations formed the Masonry Standards Joint Committee.

The process of harmonization of design provisions in the MSJC documents dates back to the 1999 edition of the *Code* and *Specification*. The 1995 edition of the *Code* was comprised of twelve discrete chapters, which had almost no overlap. The 1999 edition of the *Code* and *Specification* reformatted the material into five chapters. Material common to different design methods, seismic design requirement, and quality assurance requirements were placed together in Chapter One. The 1999 edition of the *Code* and *Specification* had separate chapters for ASD and prestressed masonry design. There was a place holder for a future Limit States Design.

The 2000 *International Building Code* included masonry provisions in Chapter Twenty-one. Section 2108 was for the *Strength Design of Masonry*. Many MSJC members had serious concerns about the requirements in this section, and set aside the work on a Limit States Design procedure to revise these strength provisions. This allowed them to include a SD chapter for masonry in the 2002 MSJC, so that they could begin shaping a workable set of strength design provisions.

In keeping with seismic design changes in the *Minimum Design Loads for Buildings and Other Structures* (ASCE 7), the 2002 MSJC updated the seismic provisions for masonry and reorganized these provisions by Seismic Design Categories, rather than the Seismic Performance Categories used in previous editions of ASCE 7and the 1999 MSJC.

The major harmonization effort in the 2005 MSJC was to change the design equations for anchor bolts, so that a designer would get approximately the same bolt spacing using either the ASD procedures or the SD procedures.

The masonry modulus of rupture is used for the design of unreinforced masonry. It is also used in reinforced masonry to determine the cracking strength and the deflection of masonry elements just prior to cracking. The 2005 MSJC harmonized the modulus of rupture between the various design methods.

Since ancient times, masonry corbels have been used to help translate a wall out-of-plane. The 2002 MSJC ASD procedures had requirements for the design of corbels, but the SD procedures did not. The 2005 MSJC harmonized the requirements for the design of corbels, applied these requirements to both ASD and SD and moved them to Chapter One.

Medieval tower with masonry corbels.

There is a saying that success begets success. Encouraged by the positive harmonization results of the 2002 and 2005 editions of the MSJC, the 2008 MSJC committee harmonized bearing requirements; effective compression width and provisions for concentrated loads, and moved all of these provisions to Chapter One. The 2008 committee also gathered most of the provisions for beams and columns and moved them to Chapter One. Many of the requirements for anchor bolts, such as placement, effective area and embedment length, were consolidated and moved to Chapter One. The anchor bolt provisions related to the design equations were left in the respective design chapters.

The MSJC, and its industry partners also began the process of moving requirements out of the IBC and placing them in the masonry standard. Much effort had been spent in previous code cycles, trying to maintain provisions in the IBC and the MSJC which were exactly the same in the two documents. For example, both documents had hot and cold weather requirements. If the provisions were not exactly aligned, users were left to wonder why and whether one provision was deliberately different from the other. Removing these "transcribed" provisions from the IBC reduced the work load and the confusion factor. The seismic provisions for prestressed shear walls and for the maximum reinforcement provisions for Special Reinforced Masonry Shear Walls designed by ASD were moved from the 2009 IBC into the 2008 MSJC.

For several decades, the IBC, and one of the predecessor legacy codes, required a 1.5 factor to increase the seismic shear forces on shear walls designed by ASD in areas of high seismicity, or, more recently, for Special Reinforced Masonry Shear Walls. The MSJC had a parallel design requirement in SD for capacity design for shear in Special Reinforced Masonry Shear Walls. The 2008 MSJC moved the ASD requirement from the IBC and the capacity design for shear requirement from the SD chapter of the MSJC and placed them side by side in the seismic requirements portion of Chapter One, so that designers could see that these requirements were focused on the same issue.

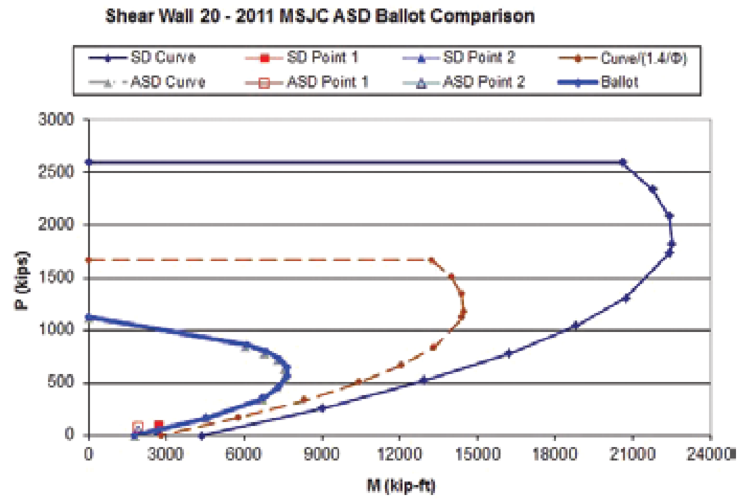
Harmonization in the 2011 MSJC – Allowable Stresses

The 2011 MSJC added a set of design assumptions at the beginning of the reinforced masonry portion of the ASD chapter to mirror the design assumptions which previously existed at the beginning of the reinforced masonry portion of the SD chapter.

With the availability of robust SD provisions, which have been substantiated by many laboratory test programs, the 2011 MSJC continued the harmonization process by reviewing these research results and by performing numerous trial designs comparing the results of the reinforcement requirements of elements designed by both the ASD and the SD procedures. We also reviewed historical code design provisions.

The trial designs included both brick and concrete masonry; walls with a large variation of aspect ratio, walls with both very low and moderately high axial loads and a wide range of strengths. The goal was to encompass the gamut of designs that structural engineers encounter.

We discovered that the allowable flexural stress limit of $F_b = 0.33 f'_m$ was first codified in 1946, when normal masonry design strengths, f'_m, were about 800 psi. The trial designs indicated a very poor correlation between the flexural capacity of elements



Comparison of SD and ASD design with $F_b = 0.45 f'm$.

designed using SD and the same element designed using ASD and the 0.33 f 'm limit. The end result of this effort resulted in an increase of the flexural stress limit to $F_b = 0.45$ f 'm. The increase in the allowable flexural stress limit applies to all load combinations. Senior structural engineers will remember that the old working stress concrete design flexural limit was 0.45 f'_c. However, the 2011 MSJC was unwilling to increase the allowable flexural stress limit and to still allow a ⅓ stress increase. The trial designs confirmed that this could lead to unconservative designs. So masonry has now joined the other materials and eliminated this stress increase.

Other stresses were also increased, although not all allowable stresses have been increased in the 2011 edition of the code. Based on research and testing, the bearing stress limit has been increased in both ASD and in SD. The composite action shear stress limit has been increased in ASD. The allowable steel reinforcement stress for flexure, direct tension and shear has been increased to 32 ksi.

The allowable axial stress limit was not increased, because there was concern expressed between members of various subcommittees as to what effect this could have. For example, the prestress committee was unsure of the ramifications of this change on the design of prestress elements. This has been set aside as ongoing work for a future cycle.

The trial design efforts did not result in perfect correlation between ASD and SD. This is because masonry is a non-homogeneous anisotropic material. In ASD, the safety factor for reinforcement is 2.5, but the safety factor for masonry can be four or more. Because of these inconsistencies, ASD will still be slightly more conservative in almost all cases.

Harmonization in the 2011 MSJC – Shear Design

In the past, shear analysis in ASD of reinforced masonry has been treated very differently than in SD. In ASD, the shear stress on an element was calculated and compared to a lower level allowable stress which could be resisted by the masonry alone. If the shear stress on the element was less than the lower level allowable stress, the design was adequate, although reinforcement to meet prescriptive detailing requirements would still be required. If the shear stress on the element exceeded the lower level allowable stress, but was less than a higher level allowable (limit) stress, an amount of reinforcement was determined which could carry the entire shear. If the shear stress on the element exceeded the higher level allowable (limit) stress, the section was inadequate and had to be made stronger, thicker or longer.

In SD, the shear demand on an element was compared to the shear capacity of the masonry and the reinforcement working together.

In both design methods, the shear capacity was adjusted for the shear span of the element to promote ductility. This was analyzed by the M/Vd ratio of the element. Tall, narrow elements are flexurally dominated and have high M/Vd ratios. The shear capacity of such members was reduced to promote a ductile failure mode. Long squat elements are typically shear dominated, but generally have excess shear capacity. No reduction of the shear capacity of such members is required.

Recent research compared eight different design methodologies, used, or recommended for use, around the world, with the results of laboratory testing. This research concluded that, of the eight methodologies, the TMS 402-08 SD for shear was the best predictor of shear capacity and that the TMS 402-08 ASD for shear in reinforced masonry was the worst predictor of shear capacity.

Based on this research, the 2011 MSJC modified the SD methodology for shear capacity and converted it to an ASD methodology for shear stress, based on the stresses in both the masonry and the reinforcement. The modification kept the same terms in both methodologies, but modified (reduced) the constants which were applied to these terms. Trial designs were conducted to benchmark the ASD to the SD methodology. Particular attention was given to Special Reinforced Masonry Shear Walls, and these trial designs indicated that further reduction of the constants in the equations was required to achieve approximately the same results, regardless of the design method. In general, the amount of reinforcement required using ASD in the 2011 MSJC will be less than what was required using ASD in the 2008 MSJC. However, the amount of reinforcement required using ASD in the 2011 MSJC will typically be slightly more than the amount required using SD in the 2011 MSJC.

Future Harmonization Efforts

While much progress has been made, there is still room for additional harmonization efforts. As noted above, some allowable stresses have not yet been harmonized and additional harmonization between ASD, SD and prestressed design has been held over as the work of future code cycles. The work that has occurred to date sends a strong message to the users of the TMS 402 (MSJC) that we are committed to this process.■