Engineering Notes For Design With Concrete Block Masonry

MASONRY CHRONICLES

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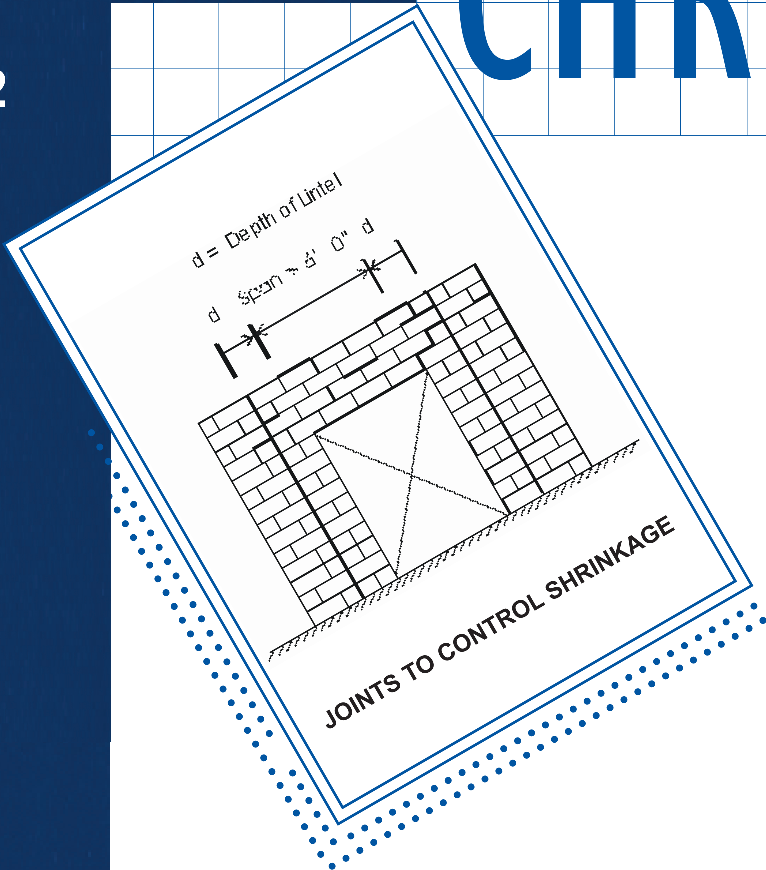

Shrinkage Cracks in Concrete Masonry

Introduction

Most engineers spend very little time detailing and specifying materials to reduce the effects of shrinkage in concrete masonry structures. Some may justify this approach by stating that the primary objective of structural design is to provide life safety protection. The current objective of most seismic codes and standards is to provide Life Safety and/or Collapse Prevention performance in the event of a major earthquake. This is in addition to the basic goal of providing a reasonable factor of safety against failure when buildings are subjected to dead, live, wind and other loads. It is therefore natural that most of the focus in the development of the 1997 Uniform Building Code (UBC) and the 2000 International Building Code (IBC) is on life safety issues.

However, while shrinkage cracks do not typically affect the structural integrity of masonry buildings, they may sometimes have a negative impact on the aesthetics of a building. In extreme instances, the cracking may diminish the serviceability of a structure by allowing moisture penetration and corrosion of reinforcing steel. These issues often have a severe financial impact on building owners.

This issue of "Masonry Chronicles" addresses some of the causes of cracking due to volumetric changes in concrete masonry. Cracking due to externally applied loads can be limited by providing adequate strength to keep the stresses below the masonry cracking stress. A discussion of such designs is not included here.

Volumetric Changes in Concrete Masonry Construction

Shrinkage cracks in concrete masonry construction occur when the volumetric changes that occur due to drying or temperature changes are restrained by relatively rigid elements such as foundations, cross walls or adjacent framing. Theoretically, stresses are induced not only by shrinkage when the masonry reduces in volume, but also when it expands as temperatures increase. However, cracks due to shrinkage, are much more common and so the term "shrinkage cracks" is generally used for all cracks due to dimensional changes in the masonry. When masonry shrinkage is restrained, tensile stresses are induced as shown in Figure 1. If the tensile stresses exceed the cracking stress of the masonry, cracking occurs.

Dimensional changes in masonry occur because of three phenomena - contraction due to temperature changes, carbonation shrinkage, and drying shrinkage. The National

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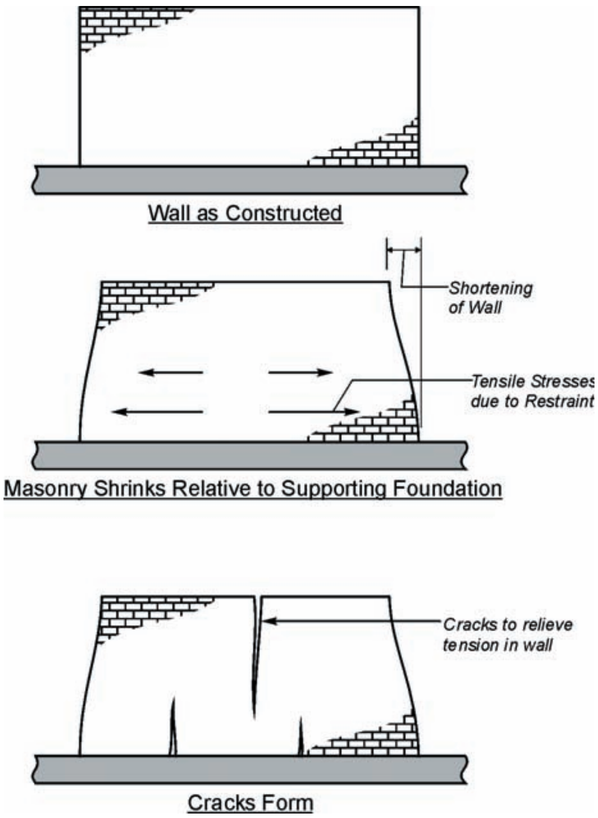

Figure 1 Exaggerated Illustration of Cracks In Masonry Due to Restraint of Dimensional Changes (Adapted from Masonry Structures by Drysdale et. al.)

Concrete Masonry Association (NCMA) has an excellent Technical Note on control joints in concrete masonry walls (TEK 10-2A) that provides a methodology for calculating shrinkage due to each of these effects. The coefficient of thermal expansion for concrete masonry ranges from 0.0000025 to 0.0000055 in/in/oF. Thus for a temperature variation of 70oF, and using a typical value of 0.0000045 in/in for the thermal coefficient, a 50 foot long concrete masonry wall would shrink about 0.2 inches due to temperature variations alone.

Carbonation shrinkage is a phenomenon that occurs due the reaction between the cementitious materials in the masonry and the carbon dioxide in the atmosphere. Carbonation shrinkage occurs over an extended period and is irreversible. Obviously, masonry with a high cement content, as is often required in units and grout to achieve higher compressive strengths, will experience more carbonation shrinkage over time. A coefficient of 0.00025in/in can be generally used for calculating the amount of shrinkage due to carbonation. This means that a 50-ft long wall will shrink about 0.15 inches due to carbonation alone.

The amount of drying shrinkage depends on the properties of the materials used in constructing the masonry, as well as the weather conditions at the jobsite. Drying shrinkage takes place during the early curing and drying of the masonry. As the grout hydrates and the masonry units dry out, the loss of moisture leads to a reduction in volume. In addition to this overall change in volume, there is a component of drying shrinkage that occurs due to the difference in moisture content between the grout and the concrete masonry units. The masonry units absorb moisture from the grout when it is placed in the cells. Since the moisture evaporates more quickly from the exterior surface of the wall, the face shells of the masonry attempt to shrink and are restrained by the interior of the wall, which still contains moisture. This results in tensile stresses on the exterior of the masonry as shown in Figure 2. Cracking occurs if the induced stresses exceed the cracking stress of the concrete masonry units.

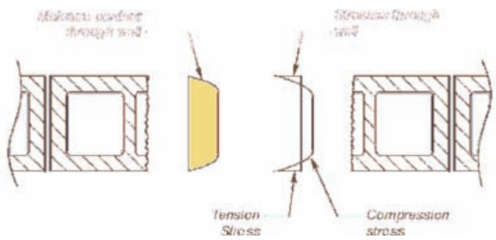

Figure 2 Moisture Content and Shrinkage Stresses Iin a Concrete Masonry Wall (Adapted from Reinforced Masonry Engineering Handbook by J.E. Amrhein)

The UBC Standard 21-4 and ASTM Specification C 90 provide requirements for the water absorption, moisture content and linear shrinkage of load bearing concrete masonry units. These requirements are designed to reduce the drying shrinkage in concrete masonry, particularly when using Type I moisture-controlled units. (In the latest C90-02 specification, Type I and Type II classifications have been eliminated.) In general, masonry units with normal weight aggregates tend to shrink less than units manufactured using lightweight aggregates. In addition, high strength units, with the corresponding high cement content, will shrink more. It is also important to ensure that the masonry units are not wet when they are placed since the loss of additional moisture will cause more drying shrinkage and additional cracking.

The properties of the grout also affect the amount of drying shrinkage in concrete masonry. As with concrete masonry units, high-strength grout tends to shrink more. This leads to a larger overall shrinkage in a masonry wall if there is good bond between the grout and the units. Additives are often used to aid the grout by improving the shrinkage characteristics and bond to the concrete masonry units.

The weather conditions at the job site also contribute to the dimensional changes in concrete masonry. Clearly, there will be more shrinkage in hot, arid climates as the amount of moisture lost to the atmosphere is greater than in cooler, humid climates.

Crack Control in Concrete Masonry

Three common methods of controlling shrinkage cracking in concrete masonry are as listed below. To achieve best results, a combination of all three methods should be used as permitted by the specific project.

- Provide reinforcing steel to resist the tension stresses caused by shrinkage and thus limit the size of the cracks.
- Use control joints that permit movement and thereby reduce the tension stresses introduced as the masonry changes volume.
- Use materials (Units, grout and mortar) that have a low shrinkage potential

Horizontal reinforcing steel resists the tension stress induced by the volumetric changes in the masonry. The shrinkage stresses and deformations are not eliminated but distributed more evenly by the resisting steel. Thus, the tendency is to have many small cracks instead of a few large, visible cracks. TEK Report 10-2A by the NCMA provides directives for using horizontal steel to limit the crack widths to 0.02 inches since waterproofing coatings can effectively resist water penetrations for cracks of this size. The report recommends the use of horizontal reinforcing steel equal to 0.002 times the net cross-sectional area of the masonry. This is probably the most cost-effective way to reduce cracking if the aesthetics of the wall are not critical or if the wall is to be covered by a finish material. In seismic regions, horizontal steel is already required to resist lateral shear loads on the wall.

Another method of crack control is to use control joints that permit movement of the masonry without the introduction of crack-inducing tensile stresses. The 1997 UBC and the 2000 IBC do not address control joints. Historically, these are left to the structural engineer doing the design. Unfortunately, this often results in cracking that not only affects the specific project but the future selection of masonry when it is in competition with an all-concrete structure.

To begin a discussion of control joints it is important to recall the intended function of a control joint. Control joints are intended to relieve tension stresses due to shrinkage of the concrete masonry units and grout. They are separations built into the structure at locations where stress concentrations are expected to occur. Examples of such locations where control joints should be located are shown in Figure 3. In addition to being placed at critical locations, control joints should also be placed closely enough to ensure that the tensile stresses that build up over the length of a wall do not exceed the cracking stress of the masonry. It should also be noted that for control joints to be fully effective in permitting movement, all materials should be terminated at the joint, including reinforcing steel. However, reinforcing steel required to resist structural loads such as chord steel or lintel reinforcing needs to continue through the joint.

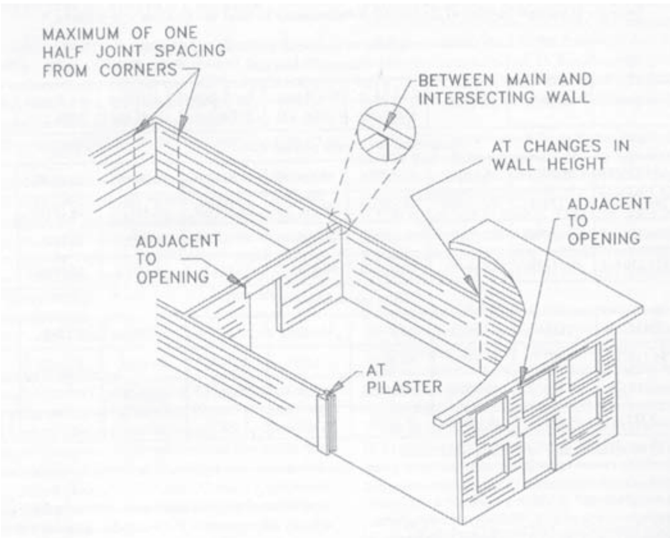

Figure 3 Typical Control Joint Locations (From NCMA TEK Report 10-2A, "Control Joints for Concrete Masonry Walls")

The materials use for construction of concrete masonry can be specified to minimize the amount of shrinkage and subsequent cracking that may occur. If limiting the amount of cracking is critical for a project, Type I, moisture-controlled units should be used. (Although moisture controlled units are not identified in the newest ASTM C90 specification, linear drying shrinkage requirements still remain.) It should be noted that the UBC and ASTM requirements are developed with a life-safety design goal in mind and may not satisfy the aesthetic performance requirements of many projects. Engineers should provide more stringent requirements for linear shrinkage in the project specifications if it is important to reduce the amount of shrinkage cracking.

The effect of masonry strength on the amount of shrinkage cracking has perhaps not been paid enough attention. The compressive strength of masonry is an important design parameter and the engineer can ensure that it exceeds the minimum design value by various methods outlined in Section 2105.3 of the 1997 UBC. Section 2108.2.3 of the UBC stipulates that the minimum compressive strength of masonry, fm' used in design of beams columns and piers is 1500 psi. The code also stipulates that a maximum compressive strength of 4000 psi can be used in design calculations. However, there is theoretically no limit on the compressive strength of the masonry, or its constituent parts that are delivered to the job site. The impression is that stronger is better. Since high strength units and grout tend to have more shrinkage and corresponding cracking than low-strength materials, supplying masonry that is significantly stronger than the specified strength could lead to more cracking than expected. Therefore, it makes sense for the engineer to provide limits on the strength of the masonry if cracking is a critical issue in a concrete masonry building. In a perfect world all engineers would recognize when their specific structural design requires special restrictions on fm' and grout strength. Alternately, the codes can place upper limits on the value of these parameters based on professional discussions.

Conclusions

The effect of shrinkage on concrete masonry structures can be reduced in a number of ways. We can minimize the size of the cracks by providing reinforcing steel to resist the tensile stresses that are induced by the volumetric changes that occur after construction. We can also attempt to eliminate the development of the tensile stresses by providing control joints that allow the masonry to move without restraint as it shrinks. A third method of minimizing shrinkage cracking is by selecting materials with a low potential for shrinkage. Engineers should utilize all of the above techniques to achieve the most effective form of crack control.

This issue of "Masonry Chronicles" was written by Dr Chukwuma Ekwueme and Dr Gary C. Hart of the Hart-Weidlinger Division of Weidlinger Associates.

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Please contact the Association Executive Director, Dr. Vilas Mujumdar, with any comments or suggestions for future issues.

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