and irreversible. Permanent moisture shrinkage affects all portland cement-based materials, including concrete, stucco, and concrete masonry. Permanent moisture expansion affects only clay masonry products.

Concrete masonry units shrink irreversibly as they lose the residual moisture from the manufacturing process. They subsequently expand and contract reversibly with changes in moisture content. The total amount of shrinkage varies with water–cement ratio, method of curing, aggregate type and gradation, cement type and content, service exposure, and carbonation. ASTM standards for concrete masonry units previously included a distinction between two types of units, based on moisture content and potential shrinkage. This distinction is no longer made, and the coefficients of linear moisture movement in *Fig. 9-4* for concrete masonry units made with different aggregates apply to all CMUs.

Steel reinforcement increases concrete masonry's resistance to the tensile stress of shrinkage. The most common method of shrinkage crack control is the use of horizontal joint reinforcement, which distributes the stress more evenly through the wall to minimize cracking. Control joints localize cracking to predetermined locations so that elastomeric sealants can be installed in the joint to prevent moisture penetration. Masonry that is reinforced to resist structural loads is also more resistant to shrinkage cracking.

The firing process removes virtually all moisture from clay masonry products. After they leave the kiln, reabsorption of moisture causes irreversible expansion. Total expansion depends primarily on the characteristics of the clay, but also on firing temperatures. For any given clay, the higher the firing temperature, the lower is the potential for expansion. Some minor reversible expansion occurs with subsequent changes in moisture content, but it is the initial permanent expansion in size which most affects building design. The majority of brick moisture expansion occurs during the first year after manufacture, but it continues at a much slower rate for years (*see Fig. 9-5*).

9.1.3 Elastic Deformation

Shortening of axially loaded masonry walls or columns is seldom critical. More often, problems arise from elastic deformation of horizontal masonry elements

Average Coefficient of Linear Moisture Movement (M_c)			
Material	Reversible Moisture Movement (%)	Coefficient (M_c) for Irreversible Moisture Movement (%)	Type of Movement
Concrete, gravel aggregate	0.02–0.06	0.03–0.08	shrinkage
Concrete, limestone aggregate	0.02–0.03	0.03–0.04	shrinkage
Concrete, lightweight aggregate	0.03–0.06	0.03–0.09	shrinkage
Concrete block, dense aggregate	0.02–0.04	0.02–0.06	shrinkage
Concrete block, lightweight aggregate	0.03–0.06	0.02–0.06	shrinkage
Brick, clay face	0.02	0.03–0.08	expansion
Limestone	0.01	unknown	n/a
Sandstone	0.07	unknown	n/a

Figure 9-4 Concrete masonry units shrink irreversibly with initial moisture loss and clay masonry units expand irreversibly with initial moisture absorption. (*From ASTM C1472,* Standard Guide for Calculating Movement and Other Effects When Establishing Sealant Joint Width. *Copyright ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428. Reprinted with permission.*)

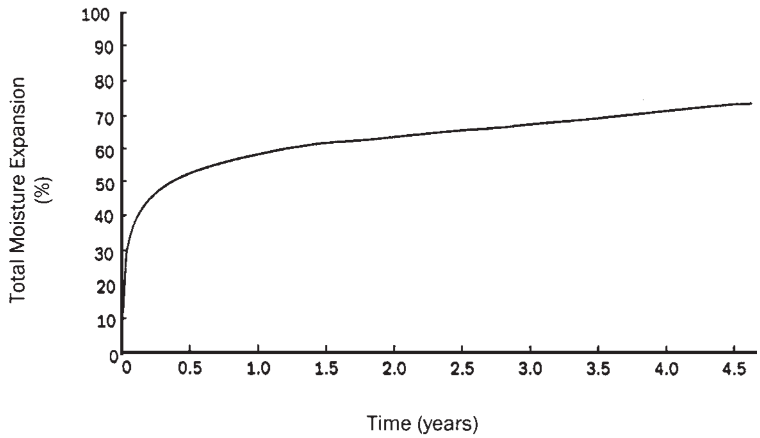

Figure 9-5 Graph showing permanent moisture expansion of clay brick over time. (*From BIA* Technical Note 18 Rev.)

such as beams and lintels. Standards limit deflection to $L/600$ or 0.3 in. under combined live and dead loads. In veneer construction, deformation of the structural frame to which the masonry is attached can also cause distress if loads are inadvertently transferred to the veneer.

9.1.4 Plastic Flow

When concrete or steel is continuously stressed, there is a gradual yielding of the material, resulting in permanent deformation equal to or greater than the elastic deformation. Under sustained stress this plastic flow, or creep, continues for years, but the rate decreases with time and eventually becomes so small as to be negligible. About one-fourth of the ultimate creep takes place within the first month or so, and one-half of the ultimate creep occurs within the first year. In clay masonry construction, the units themselves are not subject to plastic flow, but the mortar is. In concrete block construction, long-term deformations in the mortar and grout are relatively high compared to that of the unit. Joint reinforcement in CMU construction restrains the mortar and grout so that overall deformations of the wall are similar in magnitude to those for cast-in-place concrete. Plastic flow of the mortar in brick walls helps prevent joint separations by compensating to some degree for the moisture expansion of the units.

The creep deflection of a concrete or steel structural frame to which masonry is rigidly anchored is the most potentially damaging. Steel shelf angles and concrete ledges that sag over a period of time can exert unintended force on the masonry below. Without soft joints below such members, the masonry can buckle or spall under the eccentric load.

9.1.5 Effects of Differential Movement

Differential movement is the primary cause of cracking in masonry walls. In a cavity wall, for example, the moisture exposure and temperature variation in the outer wythe are much greater than in the inner wythe, especially if the wall contains insulation. Cracks can form at the external corners of brick walls because of the greater thermal and moisture expansion of the outer wythe which result. Long walls constructed without expansion joints also