

Volume Changes – Analysis and Effects of Movement

Abstract: This *Technical Note* describes the various movements that occur within buildings. Movements induced by changes in temperature, moisture, elastic deformations, creep and other factors develop stresses if the brickwork is restrained. Restraining of these movements may result in cracking of the masonry. Typical crack patterns are shown and their causes identified.

Key Words: corrosion, cracks, creep, differential movement, elastic deformation, moisture expansion, thermal expansion.

SUMMARY OF RECOMMENDATIONS:

- Use the following coefficients to calculate movement of brick veneer:
 - Thermal expansion: 4×10^{-6} in./in./°F (7.2×10^{-6} mm/mm/°C)
 - Moisture expansion: 3×10^{-4} in./in. (mm/mm)
 - Creep: 0.7×10^{-7} in./in. per psi (0.1×10^{-4} mm/mm per MPa)
- Creep of brick masonry is considered negligible; however, creep of backing or supporting material must be accommodated
- Consider coefficients of movement for other materials in contact with brickwork
- Consider elastic deformation and movement of structural elements supporting and connected to brickwork

INTRODUCTION

All building materials change in volume in response to variations in temperature or moisture content. All structural members deform under load; some also experience time-dependent and/or permanent deformations. These changes in volume, and elastic deformations due to loads, creep and other factors result in movement. Restraining of these movements may cause stresses within building elements that result in cracks.

To avoid cracks, masonry elements should be designed to minimize movement or accommodate differential movement between materials and assemblies. A system of movement joints can reduce the potential for cracks and the problems they cause. In brick masonry, this is accomplished by designing and inserting expansion joints. Estimating the magnitude of the different movements that occur in masonry and other building materials is useful in determining the size and spacing of expansion joints needed to accommodate movement.

This *Technical Note* describes volume changes in brick masonry and other building materials. It also describes the effects of volume change when materials are restrained. *Technical Note 18A* discusses the design and detailing of expansion joints and the types of anchorage that permit movement.

MOVEMENT OF CONSTRUCTION MATERIALS

The configuration and construction of most buildings does not allow exact prediction of building element movement. Volume changes are dependent on material properties and are highly variable. The age of the material and temperature at installation also influence expected movement. When mean values of material properties are used in design, the actual movement may be underestimated or overestimated. The designer should use discretion when selecting the applicable values. The types of movement experienced by various building materials are indicated in [Table 1](#).

TABLE 1
Types of Movement of Building Materials

Building Material	Thermal	Reversible Moisture	Irreversible Moisture	Elastic Deformation	Creep
Brick Masonry	✓	—	✓	✓	✓
Concrete Masonry	✓	✓	—	✓	✓
Concrete	✓	✓	—	✓	✓
Steel	✓	—	—	✓	—
Wood	✓	✓	—	✓	✓

Brickwork will generally increase in size over its service life. This expansion is the net effect of a variety of conditions that cause the size of brickwork to change, but it is influenced primarily by irreversible moisture expansion. Unrestrained elements or sections of brickwork will expand vertically from their supports and horizontally from their centers, as shown in Figure 1.

Temperature Movement

All building materials expand and contract with variations in temperature. For unrestrained conditions, these movements are theoretically reversible. Table 2 indicates the coefficients of thermal expansion for brick and other common building materials.

Unrestrained thermal movement is the product of temperature change multiplied by the coefficient of thermal expansion and the length of the element.

The stresses developed by restrained thermal movements are equal to the change in temperature multiplied by the coefficient of thermal expansion and by the modulus of elasticity of the material.

The temperature change used for estimating thermal movements should be based on mean temperatures in the component. For multi-wythe brick masonry walls, temperatures at the center of the wall should be used. In cavity walls and veneers, the temperature at the center of each wythe or component should be used. In discontinuous construction, the wythes will have different temperatures due to the separation of the wythes by an air space and perhaps insulation.

Surface temperatures of brick walls may be much higher than the ambient air temperature. Wall orientation, color, brick wall type, and presence and location of insulation are governing factors. It is possible for a dark, south-facing wall to reach surface temperatures as high as 140 °F (60 °C) while the ambient air temperature is well below 100 °F (38 °C). The mean temperature of a nominal 4 in. (102 mm) thick insulated brick veneer is very close to the surface temperature of the brick. A thicker or uninsulated wall may have a lower mean temperature than the outside surface. The temperature range experienced by brickwork is the difference of the high and low mean temperatures. In practice, this range is usually taken as 100 °F (38 °C) and is based on the annual high and low temperature of the exterior ambient air. Depending on the orientation of the wall, expansion of the temperature range may be necessary to address movement due to temperature.

Other building materials expand and contract at rates different from that of brick masonry. These differences are important when elements such as window frames, railings or copings are attached to brick masonry. Distress may occur in either material. Bowing may occur in composite walls that have concrete masonry interior wythes.

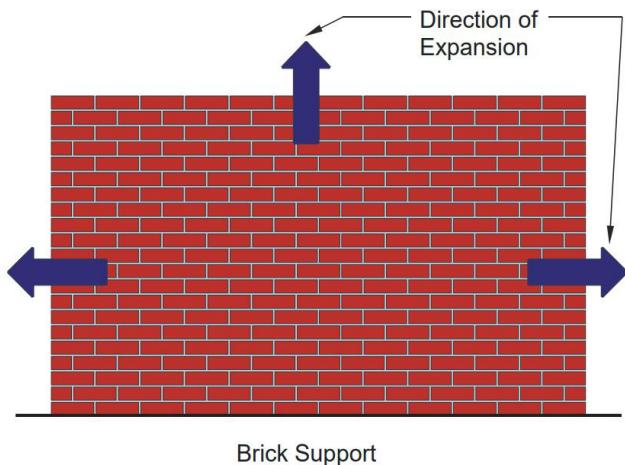


Figure 1
Direction of Brick Expansion

TABLE 2
Types of Movement of Building Materials

Material	Design Coefficients of Linear Thermal Expansion	
	$\times 10^{-6}$ in./in. per °F	$\times 10^{-6}$ in./in. per °C
Brickwork	4.0	7.2
Concrete Masonry	4.5	8.1
Stone		
Granite	4.4	7.9
Limestone	4.4	7.9
Marble	7.3	13.1
Concrete	5.5	9.9
Metal		
Aluminum	12.8	23.1
Bronze	10.1	18.1
Stainless Steel	9.9	17.8
Structural Steel	6.5	11.7
Wood, Parallel to Fiber		
Fir	2.1	3.7
Oak	2.7	4.9
Pine	3.0	5.4
Wood, Perpendicular to Fiber		
Fir	32	58
Oak	30	54
Pine	19	34
Autoclaved Aerated Concrete	4.5	8.1

Moisture Movement

Many building materials tend to expand with an increase in moisture content and contract with a loss of moisture. For some building materials, these movements are reversible; while for others they are irreversible or only partially reversible.

Brick. As shown in Table 1, brick is the only building material that experiences irreversible moisture expansion. This expansion is the net effect of a variety of conditions that cause volume change in brickwork but is influenced primarily by exposure to moisture or humid air over time. A brick unit is smallest in size when it cools after exiting the kiln. It will draw moisture from its environment and increase in size from that time. Most of the expansion takes place over the first few weeks but will continue at a much lower rate for several years (see Figure 2). The amount of moisture expansion depends primarily on the raw materials and, to a lesser extent, the firing temperatures. Brick made from the same raw materials that are fired at lower temperatures will expand more than those fired at higher temperatures.

In brickwork, moisture expansion of the brick is somewhat offset by drying shrinkage of the mortar. As brick with larger face dimensions cover more wall area, the brickwork will experience more moisture expansion.

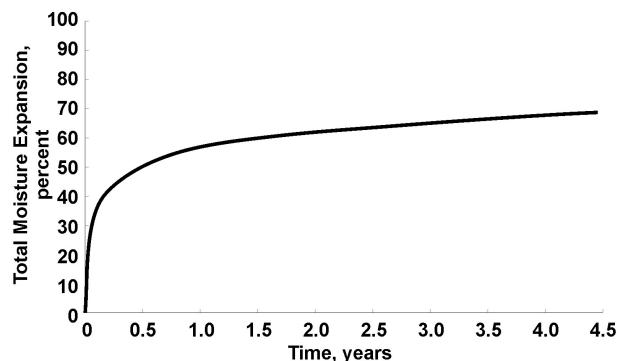


Figure 2
Projected Moisture Expansion of Fired Brick vs. Time

Predicting the total moisture expansion of brickwork is difficult; however, it can be estimated by multiplying the coefficient of moisture expansion by the length of the wall. The design coefficient of linear moisture expansion for brickwork in TMS 402, *Building Code Requirements for Masonry Structures* (TMS Code) [Ref. 15], is 3×10^{-4} in./in. (mm/mm). For brick veneer, a design coefficient of linear expansion of 5×10^{-4} in./in. (mm/mm) is recommended.

The behavior of brick in freezing conditions is dependent on the amount of moisture present within the brick itself. In cold, dry environments, the length of the brick will generally shrink in accordance with thermal contraction. In saturated conditions, the brick will behave similarly until temperatures are near or below 14 °F (-10 °C), at which point the moisture present in the brick pores will freeze, creating an increase in volume. In some cases, residual expansion will remain after the brick thaws. However, proper detailing of brick masonry should “minimize saturation or near-saturation of the units in freezing conditions” [Ref. 2], which would leave sufficient room within the brick pores/matrix to accommodate freezing expansion of water. In addition, in the case where freezing expansion occurs, the shrinkage due to thermal contraction offsets or partly offsets this expansion. In most cases, the extent of thermal and moisture expansion that occurs in normal temperatures will govern. Therefore, freezing expansion is typically considered negligible.

Concrete Masonry. Concrete masonry units experience shrinkage as a result of moisture loss and carbonation and will expand as moisture content increases. These combined movements typically result in a net shrinkage of concrete masonry that is affected by the method of curing, aggregate type, change in moisture content, cement content, temperature changes, and wetting and drying cycles. The total potential linear drying shrinkage due to changes in moisture content is determined using ASTM C426, *Test Method for Linear Drying Shrinkage of Concrete Masonry Units* [Ref. 3], which measures unit shrinkage from a saturated condition to a condition of equilibrium at a relative humidity of 17 percent. Typical linear shrinkage values for concrete masonry units range from 2×10^{-4} to 4.5×10^{-4} in./in. (mm/mm) or 0.24 to 0.54 in. (6.1 to 13.7 mm) in 100 ft (30.48 m). The coefficient of shrinkage for concrete masonry is assumed to be half the total linear shrinkage determined by ASTM C426.

Carbonation is the chemical combination of hydrated portland cement with carbon dioxide present in air. This reaction is irreversible and occurs slowly over time. Although there is currently no standard test method to measure carbonation shrinkage, the National Concrete Masonry Association recommends a value of 2.5×10^{-4} in./in. (mm/mm) be used to estimate carbonation shrinkage in concrete masonry walls. This results in a shortening of approximately 0.3 in. (7.6 mm) in a 100 ft (30.48 m) long wall [Ref. 5].

Concrete. Concrete shrinks as it cures or dries and expands when it is wet. Shrinkage of concrete is influenced by the water-cement ratio, composition of the cement, type of aggregate, size of concrete member, curing conditions, and amount and distribution of reinforcing steel. Shrinkage values for concrete generally range from 2×10^{-4} to 8×10^{-4} in./in. (mm/mm) depending on the factors listed above.

Wood. Wood shrinks during the natural seasoning process as the moisture content recedes from the fiber saturation point (28 to 30 percent) until it reaches equilibrium with the environment. Shrinkage occurs at different rates in the radial, tangential and longitudinal directions of the wood. Therefore, the American Softwood Lumber Standard PS 20 [Ref. 1] suggests using an average shrinkage value of 1 percent per each 4 percent reduction in moisture content (a coefficient of 0.0025 in./in. [mm/mm] per percent change in moisture content) for typical softwoods. Longitudinal shrinkage (0.5×10^{-4} in./in. [mm/mm] per percent change in moisture content) is usually small enough to be neglected in design. Moisture expansion and contraction continues with changes in moisture content of the wood.

Elastic Deformation

Elastic deformation is a reversible change in length, volume or shape produced by stress in a material. In the structural design of a building, the designer must consider all forces imposed on the structure. These include dead and live loads and such external lateral forces as wind, soil, snow loads, earthquake and blast. Each of these forces creates stresses in the building materials, which can result in deformations and deflections of the building elements. If a material remains within its elastic range, it will return to its original shape once the applied forces are removed.

There are several types of deformation to consider. Horizontal elements such as beams and lintels deflect vertically due to their own weight and dead and live loads. Axially loaded elements such as columns and bearing

walls shorten in length due to vertical dead and live loads. Walls, beams, columns and building frames deflect horizontally (laterally) from lateral loads such as wind and seismic events, as well as uneven gravity loads.

Elastic deformation is most important when considering elements that support the gravity load from brickwork. The design of longer lintels and shelf angles are typically controlled by deflection. Such deflection should be limited or accommodated by the veneer design, or cracking of the veneer may result.

Lateral Drift. The drift or side-sway of a structural frame may cause distress to brick masonry used as infill walls or exterior cladding. Lateral loads from wind or earthquakes are transferred to brickwork if it is attached rigidly to the frame. The same is true for deflection of floor slabs or spandrel beams. Masonry intended to be non-load-bearing may become load-bearing if movements result in contact between these members and masonry elements.

Creep

Creep, or plastic flow, is the continuing, irreversible deformation of materials under load or stress. The magnitude of movement due to creep in masonry and concrete depends on the stress level, material age, duration of stress, material quality and environmental factors.

In frame structures, especially concrete frame buildings, vertical shortening due to creep or shrinkage of the structural frame may impose high stresses on the masonry. These stresses develop at window heads, shelf angles and other points where stresses are concentrated.

Brick. Creep in brick masonry occurs primarily in the mortar joints and is considered negligible. The TMS Code stipulates a design coefficient of creep for clay masonry of 0.7×10^{-7} in./in. per psi (0.1×10^{-4} mm/mm per MPa).

Concrete Masonry. Concrete masonry exhibits more creep than brick masonry because of the cement content in the units. The TMS Code stipulates a value of 2.5×10^{-7} in./in. per psi (0.36×10^{-4} mm/mm per MPa).

Concrete. Creep is most significant in concrete frame structures. Creep in concrete begins after load is applied and proceeds at a decreasing rate. High-strength concrete experiences less creep than low-strength concrete. Creep is slightly greater in concrete with lightweight aggregate than concrete with normal-weight aggregate. In high-rise buildings, the total elastic and inelastic shortening of columns and walls due to gravity loads and shrinkage may be as high as 1 in. (25 mm) for every 80 ft (24 m) of height.

Estimating Combined Movements

Equation 1 below combines the effects of movements above that affect brickwork, and can be used to estimate the amount of expansion that would be experienced by an unrestrained brick wythe. Although typically negligible, local conditions must be considered to determine if freezing expansion will occur.

$$m_u = (k_e + k_f + k_t \Delta T) L \quad \text{Eq. 1}$$

where:

m_u = total unrestrained movement of the brickwork, in. (mm)

k_e = coefficient of moisture expansion, in./in. (mm/mm)

k_f = coefficient of freezing expansion, in./in. (mm/mm)

k_t = coefficient of thermal expansion, in./in./°F (mm/mm/°C)

ΔT = temperature range experienced by brickwork, °F (°C)

L = length of wall, in. (mm)

Using the recommended values given previously for coefficients of expansion and temperature range experienced by brickwork, the equation becomes:

$$m_u = (0.0005 + 0 + (0.000004 \times 100)) L$$

$$m_u = 0.0009L$$

In addition to the expansion of brickwork, other movements of building materials described herein, restraint conditions, construction tolerances and wall orientation may affect the size and spacing of expansion joints.

Other Causes of Movement

Other causes of movement in building elements that may occur under given conditions include corrosion of steel, drift of the building frame, and the action of unstable soils. It is beyond the scope of this *Technical Note* to discuss these items in detail. However, they are briefly described below.

Corrosion of Steel. Excessive corrosion of steel confined in masonry can cause cracking or spalling of masonry. Corrosion is typically initiated when water penetrates masonry and comes in contact with embedded steel. The volume of corrosion by-products (rust) is significantly greater than that of the steel from which it is formed, up to 10 times greater [Ref. 13]. The forces exerted by rust as it develops increase the internal pressure on the surrounding masonry and will likely result in cracking or spalling. The resulting cracks in the masonry can increase the potential for more water ingress, which can lead to further corrosion.

Anchors, ties and joint reinforcement are only partially embedded in mortar and are partially exposed in an air space or cavity. Thus, they may be susceptible to corrosion. Other items in masonry assemblies that are susceptible to corrosion include steel lintels, steel shelf angles, anchor bolts and other metal fasteners in masonry. Most of these embedded steel elements are recommended to be galvanized or fabricated from stainless steel to provide corrosion protection. Items like lintels and shelf angles are typically carbon steel and must be protected by flashing and coatings. Metal items that are completely embedded within mortar or grout, such as reinforcing bars, are less susceptible to corrosion, since they are protected by the mortar/grout and are not exposed to the environment [Refs. 15 and 16]. To minimize corrosion, do not use additives in mortar that accelerate corrosion, such as calcium chloride, and minimize the amount of water within masonry through proper design, detailing and installation. See *Technical Note 44B* for more information on corrosion resistance of metal ties and anchors.

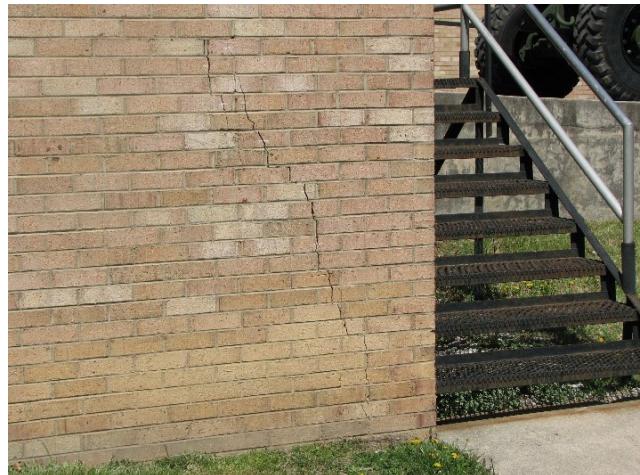


Photo 1
Foundation Settlement Cracking

Unstable Soils. Unstable or expansive soils often cause movement or differential settlement in foundations that support brick masonry. Foundation settlement may cause diagonal/stepped cracking in the brickwork and mortar joints directly above the foundation, as shown in **Photo 1**. Proper foundation design will help ensure stable support and allow uniform settlement within acceptable limits.

IDENTIFYING EFFECTS OF MOVEMENT

Changes in building materials and technology have affected the design and behavior of many building components, including masonry walls. The increased use of thinner walls and the tendency to specify high-compressive-strength mortars have become common. Although stronger units and mortars increase the compressive strength of the masonry, they do so at the expense of other important properties. Thus, masonry walls today tend to be thinner and more brittle than historic mass masonry walls. These thinner walls are more susceptible to cracking and spalling if differential movement is not addressed during design. *Technical Note 18A* includes recommendations for accommodating differential movement in new construction.

Proper design and construction of brickwork can help prevent the detrimental effects of movements. Cracking is perhaps the most frequent type of distress that affects masonry walls. The shape, location and magnitude of cracking will often indicate the cause. Examples of distress that can occur under specific conditions where movement is not accommodated are illustrated in the following photographs. *Technical Note 18A* recommends details that help prevent these conditions.

Long Walls. When expansion joints are too narrow or spaced too far apart, the expansion of the brickwork may not be adequately accommodated. This may force sealant material out of an expansion joint, as shown in

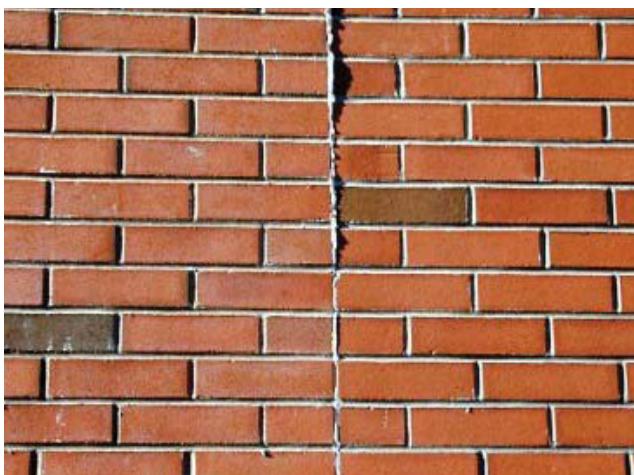


Photo 2
Sealant Forced Out of Expansion Joint Due to Expansion of Long Wall

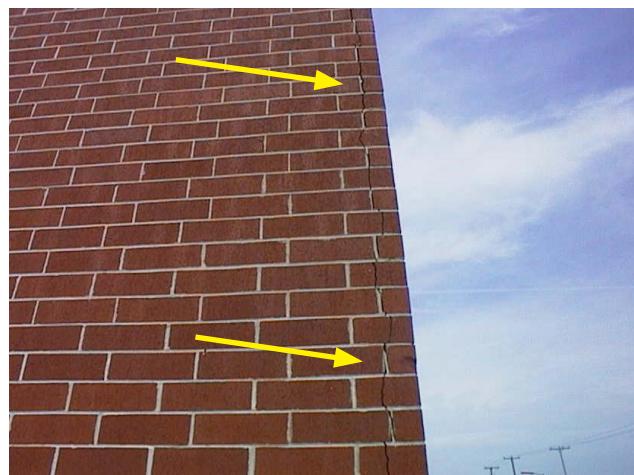


Photo 3
Crack at Corner Without Expansion Joint



Photo 4
Crack at Offset Without Expansion Joint

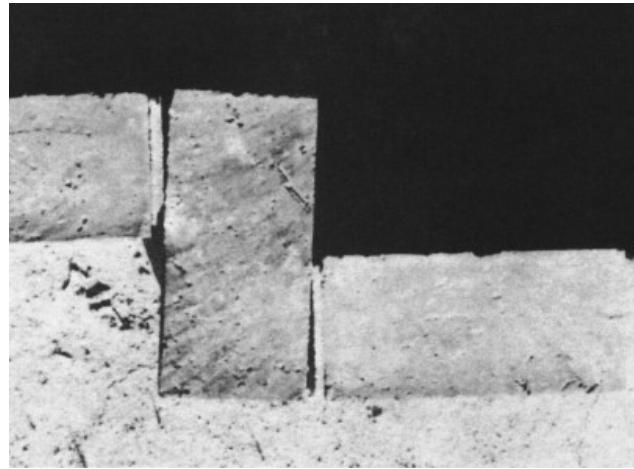


Photo 5
Rotation at Offset Without Expansion Joint

Photo 2. If expansion continues, then cracking occurs at other locations. In walls with openings, diagonal cracks may occur in brickwork between windows or doors. Such cracks usually extend from the head or sill at the jamb of the opening, depending upon the direction of movement and the path of least resistance. Because the effects of expansion are cumulative, dividing long walls into smaller segments reduces the amount of movement that the expansion joint has to accommodate.

Corners. Brickwork will expand in the plane of the wall. At a corner, the brickwork on each side will expand toward the corner. Absence of an expansion joint near a corner or an insufficient number of expansion joints in the wall can result in cracking at the corner, as shown in **Photo 3**. This typically occurs at the first head joint on one side of the corner.

Offsets and Setbacks. When parallel walls not in the same plane expand toward an inside corner without an expansion joint, the movement may produce rotation of the offset and vertical cracks, as shown in **Photo 4** and **Photo 5**. Installing an expansion joint at the inside corner can alleviate this condition.

Structural Frame Concerns. The brick veneer in **Photo 6** is supported by a steel shelf angle on a concrete frame. Over time, creep and shrinkage of the concrete frame, along with expansion of the brickwork, can cause the steel shelf angle to bear on the masonry below, causing spalling of the brick adjacent to the shelf angle. Since creep and shrinkage of the concrete frame will continue, this condition will induce axial load into the brickwork. This brickwork can bow if it is not adequately attached to the backing, or if the backing is not sufficiently rigid.



Photo 6
**Spalling Without Horizontal Expansion Joint
Due to Shortening of Structural Frame**



Photo 7
Movement of Parapet Away from Corner



Photo 8
**Crack at Foundation Due to Lack of Bond Break
Between Brickwork and Concrete**

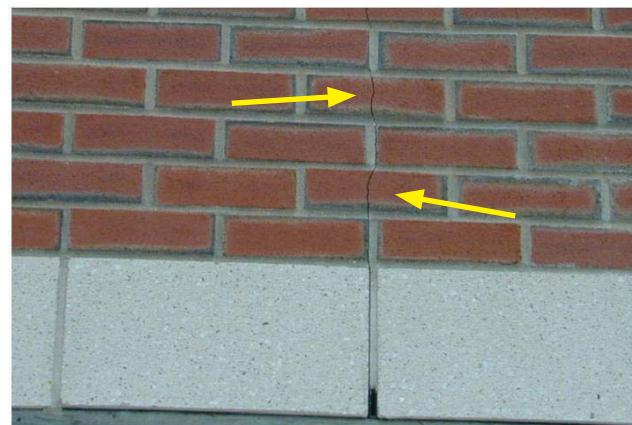


Photo 9
Crack Due to Deflection of Undersized Lintel

Steel frames typically have larger drifts and deflections than concrete frames. This movement generally becomes evident at shelf angles and may result in spalling if not accommodated. An expansion joint below each shelf angle alleviates this concern.

Movement of structural elements that are rigidly attached to masonry may transfer load and cause cracks. These movements may be due to drift of the building frame or lateral expansion from creep. These cracks may occur on the exterior as well as the interior of the building. Space between the structural member and the brickwork and use of flexible anchors will reduce the likelihood of such cracking.

Parapet Walls. Parapets are exposed to the elements on three sides, as opposed to most walls, which are exposed on only one side. As a result, parapet walls are subjected to extremes of moisture and temperature that may be substantially different from those in the wall below. Parapets also lack the dead load of overlying masonry to help resist movement. Expansion can cause parapets to bow if restrained at both corners and move away from corners if restrained at only one end, as shown in Photo 7.

Foundations. Cracking of concrete foundations, as shown in Photo 8, or movement of above-grade brickwork away from the foundation corner is often the result of shear stress at the interface between the brick and concrete. Because brick walls expand and concrete foundations shrink, the differential movement between the two materials will cause shearing stresses to develop when these materials are bonded together. A bond break or flashing placed between the concrete and brickwork will permit movement to occur.

Deflection and Settlement. Deflection and settlement cracks are identified by a tapering shape. Photo 9 shows a deflection crack caused by supporting brickwork on an undersized lintel. The crack is wider at the steel angle

and tapers to nothing. *Technical Note 31B* details the proper design of steel lintels supporting masonry. Deflection cracks may also occur at steel shelf angles attached to spandrel beams that deflect.

Differential settlement may cause cracking when one portion of a structure settles more than an adjacent part, as shown in [Photo 10](#).

Curling of Concrete. Masonry that is supported by or bonded to cast-in-place concrete slabs may crack if curling of the slab lifts the adjacent masonry. In some cases, cracking of the brickwork can be prevented by separating it from the concrete slab with a bond break. Curling of concrete is most often the result of slab deflection and differences in moisture or temperature between the top and bottom of the slab. The American Concrete Institute or other concrete industry organizations should be consulted for recommended practices that minimize slab curling.

Embedded Items. Items embedded in masonry or attached to masonry may cause spalling or cracking when they move or expand. Joint reinforcement should not bridge expansion joints. If the joint reinforcing remains continuous, then when the joint closes, the reinforcing wire may buckle and spall adjacent mortar, as shown in [Photo 11](#). Joint reinforcement may also transfer load across the expansion joint, resulting in additional cracking.

Corrosion of metal elements within masonry causes volume increases of a magnitude that can crack or spall the masonry; however, mortar, masonry units and grout are considered to provide adequate protection against corrosion when the minimum cover and clearance requirements of *TMS 602 Specification for Masonry Structures (TMS Specification)* [Ref. 16] are met. Proper corrosion-resistant coatings on the steel item are also necessary.

SUMMARY

This *Technical Note* describes the various movements that occur within common building materials and constructions. It also explains the effects of these movements. Cracking in brickwork can be minimized if all factors are taken into consideration and the anticipated movement is accommodated.

The information and suggestions contained in this Technical Note are based on the available data and the combined experience of engineering staff and members of the Brick Industry Association. The information contained herein must be used in conjunction with good technical judgment and a basic understanding of the properties of brick masonry. Final decisions on the use of the information contained in this Technical Note are not within the purview of the Brick Industry Association and must rest with the project architect of record, engineer of record and owner.



Photo 10
Crack Due to Differential Settlement

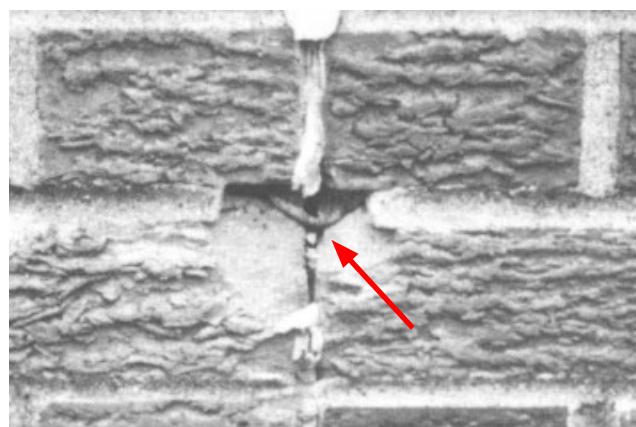


Photo 11
**Spalling Due to Buckling of Joint Reinforcement
Bridging an Expansion Joint**

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