BRICK VENEER AND STRUCTURAL FRAMES: DIMENSIONAL TOLERANCES, DESIGN ERRORS AND CONSTRUCTION PROBLEMS

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ABSTRACT: The allowable dimensional tolerances for structural frames are greater than the tolerances acceptable for exposed brickwork. Design details usually do not have sufficient dimensional adjustment to account for these differences and those resulting from differential movement between materials. The masonry contractor is often forced to make field corrections to alleviate the problem.

INTRODUCTION

Any masonry contractor can cite examples of constructing masonry walls which cover up structural frame misalignment. Horror stories are told about buildings which have bricks cut in order to pass columns and beams on one elevation while extra length ties are required to attach the brick veneer to the frame on the opposite elevation. Concrete has been chipped so deep from the surface of beams and columns that reinforcing bars are exposed on some buildings. These are horror stories because brick veneer is seldom designed or analyzed. Typical details are repeated from job to job with little thought to the constructability of the drawing. Modifications are normally made by an agreement between the masonry contractor and the general contractor. Input by the design professional in these changes is minimal. The horror stories become reality when these veneer walls fall, do not perform as intended, or lead to a rapid deterioration of structural members.

Other problems related to structural frame and brick veneer construction show up during construction. The differential movement between the brick veneer and structural frame often causes cracks in the brickwork. Thermal movement and structural deflection are the primary causes of the cracking. Fortunately, this type of design error can be repaired while the masonry contractor is on the construction site. Thus the expense to correct the problem will be lower than when a crew must come back to the jobsite.

Brick is used almost exclusively as a cladding material in the United States. It is important for the masonry industry to address the problems inherent in combining structural frames with brick veneer. This paper summarized the results of a survey of masonry contractors on this subject (1).

FRAME/VENEER DIMENSIONAL TOLERANCES

Tolerance Determination

Construction tolerance requirements for each building material have been developed independently of those for other materials. The criteria for these construction tolerances are determined by several factors, factors which vary with the material's use on the project.

Materials used as structural elements normally have tolerances based on:

- fabrication tolerances
- structural performance of frames
- accidental eccentricities
- member to member connection methods

For materials used as a finish, the tolerances are primarily a function of:
.visual acceptance
.stability

In both cases the requirements published in industry standards (5,7,9,10) are promulgated with little input from the craftsmen involved in construction. The numbers chosen are usually compromises made in committee meetings attended by engineers, professors, architects, manufacturers, and staff members of associations representing these interests. One set of numbers is generated without regard to the set for other materials. Thus a construction problem occurs when the cladding or finish material rests on, is supported by, or is attached to structural materials. Obviously these conditions occur on every building. The connection detail must account for these differences.

Brick Masonry Tolerances

Most contract documents give little guidance to dimensional tolerances for brick veneer. A typical directive is to "Lay brick plumb and true to lines". This lack of allowable tolerances implies that perfection must be achieved.

Guidelines are provided in the SPECTEXT Section 04253-Brick Veneer Masonry, published by the Construction Specification Institute (9). A first stage of dimensional tolerances is given:

3.03 TOLERANCES
- B. Maximum variation from vertical and horizontal building lines is 1/4 inch (6.4 mm) in 10 ft. (3.048 m).
- D. Maintain flush face on exposed brick veneer surface.

Since there is no overall requirement these tolerances are open ended. The flush face could be 1/4 inch (6.4 mm) in 10 ft. (3.048 m) out of plumb for the entire building height.

The Brick Institute of America does not currently publish specific dimensional tolerances for brick veneer. The general statement above appears in their literature (7). Requirements are given for engineered brick masonry which have been applied to brick veneer (7). These are:

3.02 J. Construction Tolerances
1. Maximum variation from plumb in vertical lines and surfaces of columns, walls and arrises.
   - a. 1/4 inch (6.4 mm) in 10 ft. (3 m).
   - b. 3/8 inch (9.6 mm) in a story height not to exceed 20 ft. (6 m).
   - c. 1/2 inch (12.7 mm) in 40 ft. (12 m) or more.
2. Maximum variation from plumb for external corners, expansion joints and other conspicuous lines.
   - a. 1/4 inch (6.4 mm) in any bay or 20 ft. (6 m).
   - b. 1/2 inch (12.7 mm) in 40 ft. (12 m) or more.
3. Maximum variation from level of grades for exposed lintels, sills, parapets, horizontal grooves and other conspicuous lines.
   - a. 1/4 inch (6.4 mm) in any bay or 20 ft. (6 m).
   - b. 1/2 inch (12.7 mm) in 40 ft. (12 m) or more.
4. Maximum variation from plan location of related portions of columns, walls and partitions.
   - a. 1/2 inch (12.7 mm) in any bay or 20 ft. (6 m).
   - b. 3/4 inch (19 mm) in 40 ft. (12 m) or more.

Concrete Tolerances

The American Concrete Institute sets the requirements for concrete frames. ACI 117-81 (10) contains the following:

2.0	General Building - Cast In Place	
2.1	Tolerances applying to concrete dimensions and locations only	
2.1.1	Plumb (allowable variation)	
2.1.1.1	In the lines and surfaces of columns, piers, walls and in arrises	
	in any 10 ft. (3 m)	1/4 inch (6.4 mm)
	maximum for the total height of the structure (less than 100 ft. (30.5 m))	1 inch (25.4 mm)
2.1.1.2	For exposed corner columns, control joint grooves and other conspicuous lines	
	in any 20 ft. (6 m)	1/4 inch (6.4 mm)
	maximum for the total height of the structure (less than 100 ft (30.5 m))	1 inch (2.54 mm)
2.1.2	Level or from the grades and elevations specified in the contract documents	
2.1.2.1	In slab soffits, ceilings, beam soffits and in arrises, measured before removal of supporting shores	
	in any 10 ft. (3 m)	± 1/4 inch (6.4 mm)
	in any bay or in 20 ft. (6 m)	± 3/8 inch (9.6 mm)
	maximum for the total length of structure	± 3/4 inch (19 mm)
2.1.2.2	In exposed lintels, sills, parapets, horizontal grooves and other conspicuous lines	
	in any bay or in 20 ft. (6 m)	± 1/4 inch (6.4 mm)
	maximum for the total length of structure	± 1/2 inch (12.7 mm)
2.1.3	Linear building lines from the basic dimensions in plan and related position of columns, walls, beams and partitions	
	in any bay or in 20 ft. (6 m)	± 1/2 inch (12.7 mm)
	in any 20 ft. (6 m)	± 1/2 inch (12.7 mm)
	maximum for the structure	± 1 inch (25.4 mm)
2.1.5	Cross-sectional dimensions of columns, beams, walls and slab thickness (including walls and columns constructed using slipforms)	
	up to 12 inches (304.8 mm)	+3/8 inch (9.6 mm), -1/4 inch (6.4 mm)
	more than 12 inches (304.8 mm)	+1/2 inch (12.7 mm), -3/8 inch (9.6mm)
2.1.6	Footings	
2.1.6.4	To receive masonry construction	
	alignment in 10 ft (3 m)	± 1/4 inch (6.4 mm)
	maximum for entire length in 50 ft. (15.2 m)	± 1/2 inch (12.7 mm)
	level in 10 ft (3 m)	± 1/4 inch (6.4 mm)
	maximum for entire length in 50 ft. (15.2 m)	± 1/2 inch (12.7 mm)

The differences between these two sets of requirements, in the vertical and horizontal directions, are depicted in Figure 1. The variation in cross-sectional dimensions permitted under ACI could be added to these differences. Contractor surveys and field measurements have shown that actual dimensions of concrete frames are in excess of the published standards (1). Thus, the dimensional variations which must be accommodated by construction

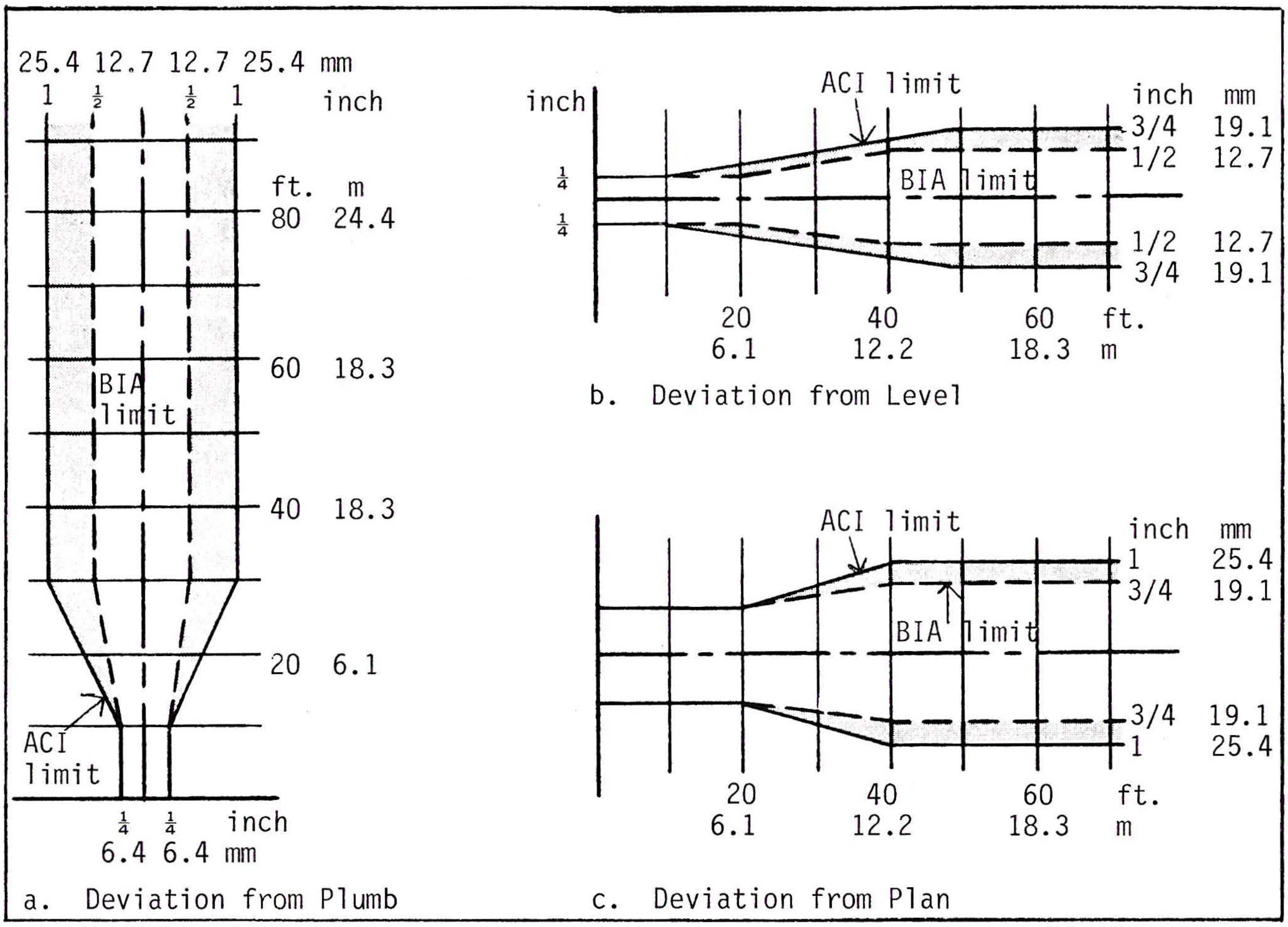


FIGURE 1. COMPARISON OF MASONRY AND CONCRETE ALLOWABLE TOLERANCES

details are greater than those predicted by comparing the tolerances themselves. It is interesting to note that ACI has more stringent requirements for exposed columns than for structural frames which are covered by other materials. These tolerances are closer to those of brick masonry. The tolerances for footings which receive masonry construction are significantly tighter than those for other footings.

Steel Frame Tolerances

The tolerances for the erection of steel frames are given by the American Institute of Steel Construction (AISC) (5). The pertinent requirements are:

7.5 Installation of Anchor Bolts and Embedded Items.

7.5.1 Anchor bolts and foundation bolts are set by the owner in accordance with an approved drawing. They must not vary from the dimensions shown on the erection drawings by more than the following:

(b) 1/4 inch (6.4 mm) center to center of adjacent anchor bolt groups.

(c) Maximum accumulation of 1/4 inch (6.4 mm) per hundred feet (30.4 m) along the established column line of multiple anchor bolt groups, but not to exceed a total of 1 inch (25.4 mm), where the established column line is the actual field line most representative of the centers of the as-built anchor bolt groups along a line of columns.

(d) 1/4 inch (25.4 mm) from the center of any anchor bolt group to the established column line through that group.

(e) The tolerances of paragraphs b,c, and d apply to offset dimensions shown on the plans, measured parallel and perpendicular to the nearest established column line for individual columns shown on the plans to be offset from established column lines.

7.11 Frame Tolerances

7.11.3 Position and Alignment

The tolerances on position and alignment of member working points and working lines are as follows:

7.11.3.1 Columns

Individual column shipping pieces are considered plumb if the deviation of the working line from a plumb line does not exceed 1:500, subject to the following limitations:

(b) The member working points of exterior column shipping pieces may be displaced from the established column line not more than 1 inch (25.4 mm) toward nor 2 inches (50.8 mm) away from the building line in the first 20 stories; above the 20th story, the displacement may be increased 1/16 inch 1.6 mm) for each additional story, but may not exceed a total displacement of 2 inches (50.8 mm) toward nor 3 inches (76.2 mm) away from the building line.

(d) The member working points of exterior column shipping pieces may be displaced from the established column line, in a direction parallel to the building line, no more than 2 inches (50.8 mm) in the first 20 stories; above the 20th story, the displacement may be increased 1/16 inch (1.6 mm) for each additional story, but may not exceed a total displacement of 3 inches (76.2 mm) parallel to the building line.

7.11.3.2 Members Connecting to Columns

(a) The horizontal alignment of members connecting to columns is considered acceptable if any error in alignment is caused solely by the variation in column alignment within permissible limits.

(b) The elevation of members connecting to columns is considered acceptable if the distance from the member working point to the upper milled splice line of the column does not deviate more than plus 3/16 inch (4.8 mm) or minus 5/16 inch (8.0 mm) from the distance specified on the drawings.

7.11.3.4 Adjustable Items

The alignment of lintels, wall supports, curb angles, mullions, and similar supporting members for the use of other trades, requiring limits closer than the foregoing tolerances, cannot be assured unless the owner's plans call for adjustable connections of these members to the supporting structural frame. When adjustable connections are specified, the owner's plans must provide for the total adjustment required to accommodate the tolerances on the steel frame for the proper alignment of these supports for other trades. The tolerances on position and alignment of such adustable items are as follows:

(a) Adjustable items are considered to be properly located in their vertical position when their location is within 3/8 inch (9.6 mm) of the location established from the upper milled splice line of the nearest column to the support location as specified on the drawings.

(b) Adjustable items are considered to be properly located in their horizontal position when their location is within 3/8 inch (9.6 mm) of the proper location relative to the established finish line at any particular floor.

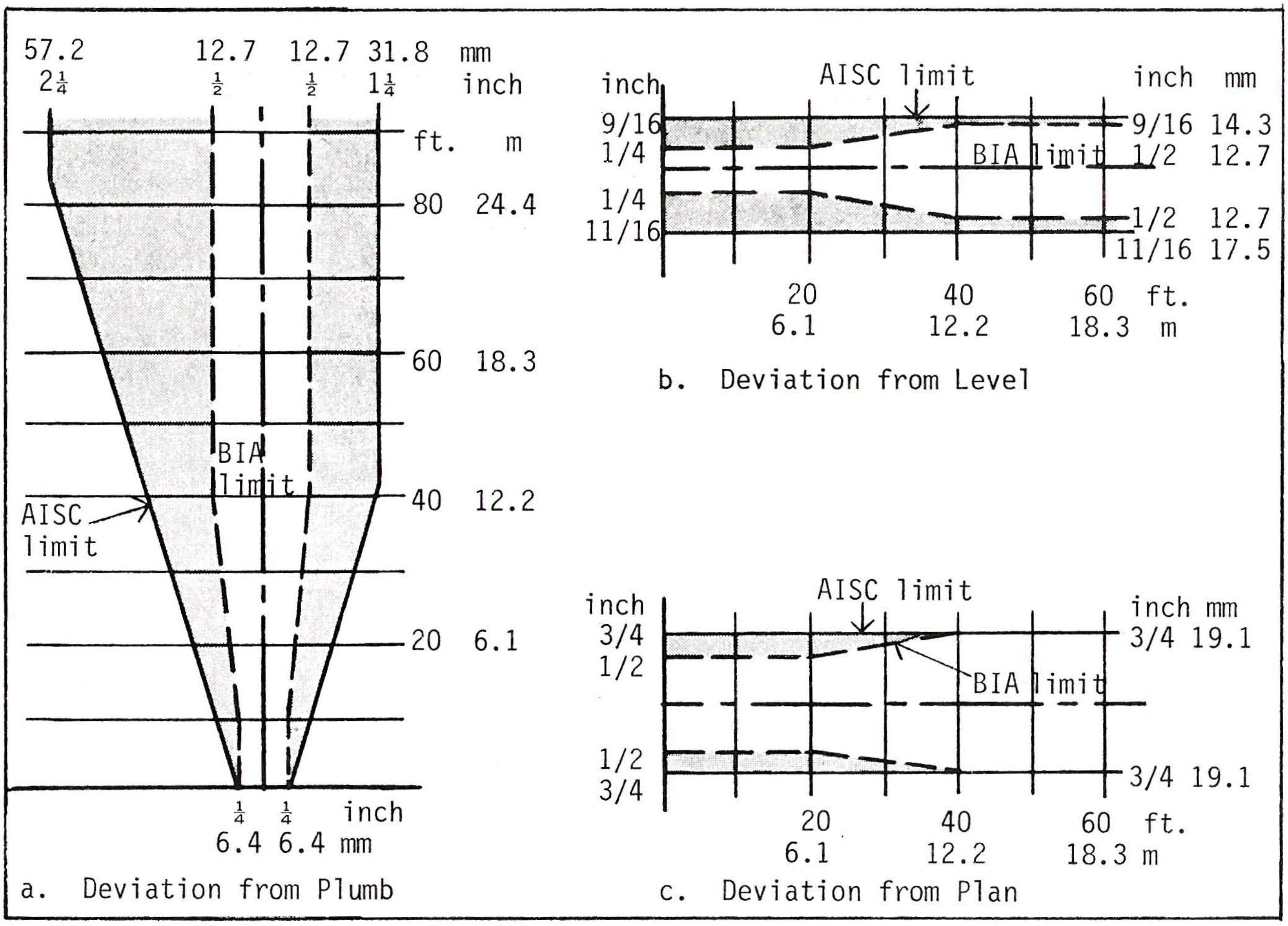


FIGURE 2. COMPARISON OF MASONRY AND STEEL ALLOWABLE TOLERANCES

The above requirements refer only to location and erection tolerances. Steel members are also subject to mill and fabrication tolerances. Thus, the total dimensional tolerance for steel frames is the accumulation of all of these components. Mill tolerances are established by the American Society for Testing and Materials (8). AISC sets the fabrication tolerances (5). Both are relatively small, less than 5/16 inch (9.6mm) each.

The masonry contractor survey indicates that the AISC requirements are more easily achieved than those of ACI. Unfortunately, this does not lessen the problem for the masonry contractor, only that these requirements can be obtained. Once again, compatibility envelopes with masonry have been prepared and are shown in Figure 2.

Results of Frame/Veneer Tolerances Differences

The masonry contractor has adapted construction practices over the years which deal with these tolerance differences. Most obvious changes are visually distracting but not usually a threat to the performance of the brick veneer. Most mortar joints on concrete grade beams and slabs vary considerably in size (Figure 3). The floor to floor alignment of exposed concrete slabs is not as accurate as the masonry walls built on them. The contractor has a story height to make adjustments in the wall location and usually can move the wall in or out as required. If the out of plane difference is greater than the one third of the unit thickness stability problems arise.

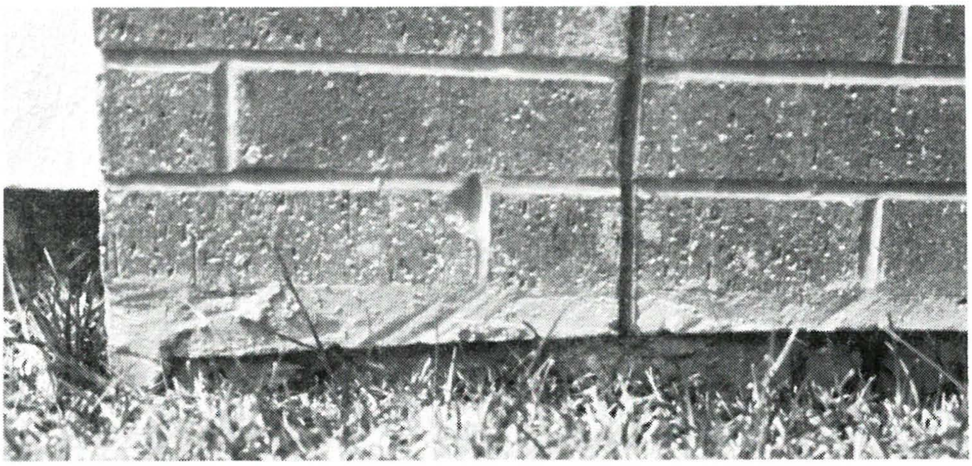


Figure 3
Thick mortar joint
on concrete slab

More troubling, however, are the changes made which are not visible in the completed wall. Many brick are cut (Figure 4) in order for the brick wall to pass beams, columns and floor slabs and remain plumb. The cut section is obviously weaker and a prime location for cracks to develop. If the brick are cut to accommodate beams or floor edges the stability of the wall above the cut become questionable. Veneer ties are also hidden items with performance modified by dimensional variations between the materials they tie. The air space between the sheathing and brick veneer may be detailed as 1 inch (25.4 mm) but it is seldom constructed at that dimension, often varying along the length of the wall. (Figure 5). Fortunately, ties come in a variety of sizes which allow the use of ties with different lengths for proper embedment in the mortar joint. Unfortunately, they are not always used. (Figure 6). Ties are often bent to fit the actual situation. Thus, the lateral support of veneer walls will be reduced. Brick walls constructed with these types of changes will fail at loads lower than expected.

DIFFERENTIAL MOVEMENT

The causes of differential movement between structural frames and brick veneers are well known. (2,4,6) Failures documented as a result of ignoring differential movement in design and construction have filled construction journals and courtrooms for many years. Published procedures and technically correct details have been around for decades. However brick walls still crack as a result of differential movement. The trend to refine design through the use of computers results in smaller structural members, making the deflection of members supporting masonry more important but often overlooked. The masonry contractors surveyed all agreed that differential movement of unlike materials is still a primary problem (1).

Thermal Movement

Thermal movement of materials accounts for most of the problem. References abound (3,6) for proper techniques but that is not always enough. Such a case is a shopping center in Houston, Texas. The continuous brick veneer spandrels, which are supported on continuous angles hung from the steel spandrel beams, were detailed and built with expansion joints at the recommended locations and spacing. Cracking occurred in the brick columns below the spandrel. The expansion joints were opening and closing at different times of the day as shown in Figures 7 and 8. The continuous steel beams and support angles grew from thermal expansion. The columns were cracking because

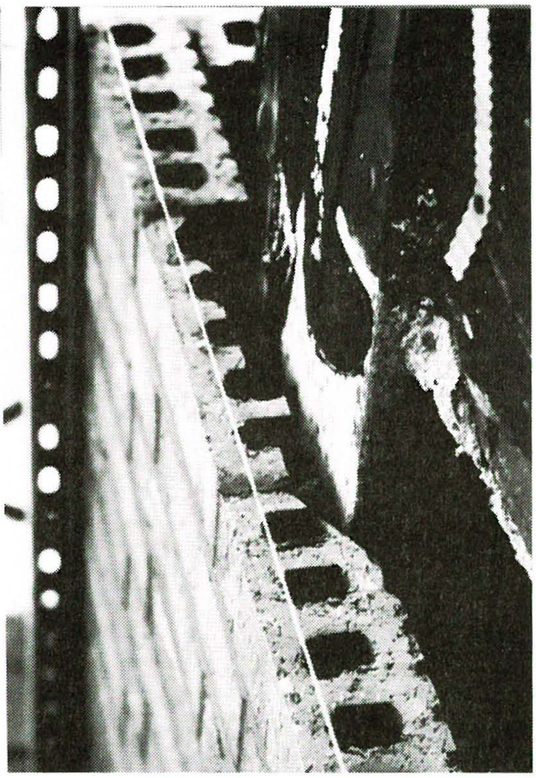


Figure 4.
Brick cut to
miss column

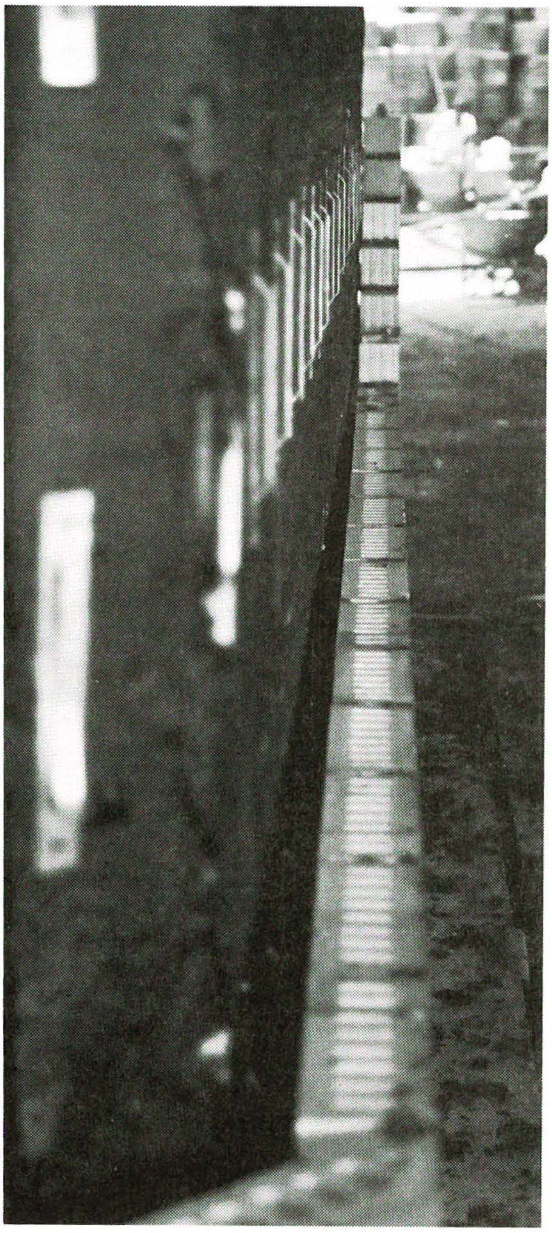
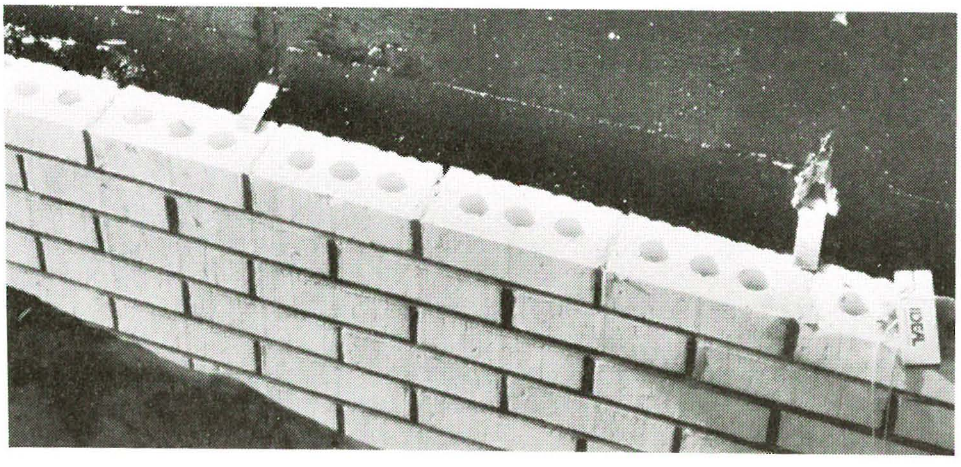


Figure 5
Air space with
changing
dimension

Figure 6. Veneer ties of insufficient length



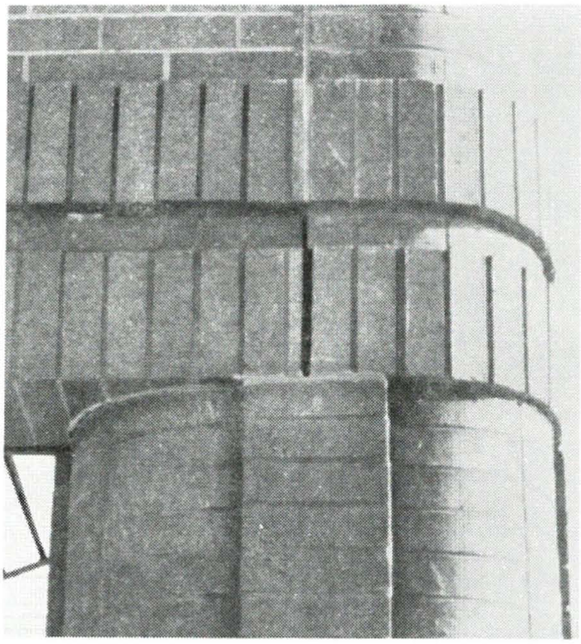


Figure 7. Cool condition, expansion joint open

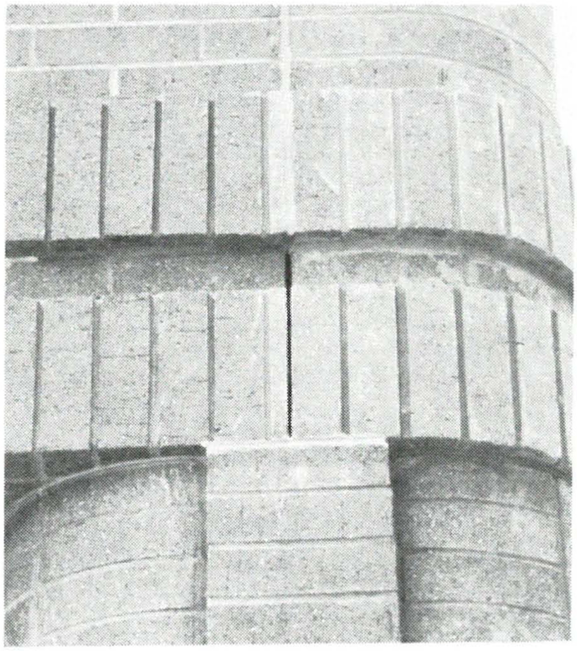


Figure 8. Hot condition, expansion joint closed due to steel expansion

they were not separated from the spandrel beam masonry. This occurred while the project was under construction. The masonry contractor cut the brick in the columns immediately under the support angle for the spandrel brickwork. This allowed the spandrel section to move with the expansion of the roof beams but did not transfer any force to the column brickwork.

Thermal movement is always going to occur and it is up to the designer to see that the movement of all materials is accommodated. With the advent of well insulated brick veneer walls, brick masonry is subjected to greater temperature differentials than before. As a result expansion joint placement is more critical. Of equal importance is the movement of the materials supporting the brick veneer. The designer should allow for expansion and contraction of these members as well as that of the brick.

Load Induced Movements

The criterion for limiting deflection of beams supporting masonry to span length divided by 600 was developed to prevent masonry cracking. This requirement has held up well over the years for in-plane bending. Most designers adhere to this precept. Steel frames will obviously undergo more load induced movement than concrete frames. The rigidity of reinforced concrete flexural members is normally higher than that of steel beams. Prestressed concrete members, however, must be given special attention when used to support brickwork. Loss of cable tension and smaller member size must be considered.

One part of load induced movement which is often overlooked is rotation of the member supporting masonry. The weight of the masonry is seldom placed over the centerline of the beam so a torsional moment is applied to the beam. A series of kickers is customarily applied to the spandrel beam or suspended angle to remove this torsion. When the masonry is supported at the floor level this precaution is not easily achieved.

On a multi-story office building in Dallas, Texas this off-center loading caused a brick cavity column cover to tilt away from the bulding. The inner wythe of brick was laid on a projection of about 24 inches (610 mm) from the floor slab edge. The exterior wythe of brick was laid on a shelf angle bolted to the edge of the projected slab. The concrete floor slab cracked at the cantilever support (Figure 9). Although the deflection of the concrete cantilever was relatively small, the rotation of the story high brick column resulted in the face of column moving up to 1-3/4 inches (44.5mm) out of plumb. (Figure 10).

This movement occurred while the building was under construction. The problem was resolved in the unlaid masonry by placing ties from the steel column into the inner wythe of the cavity wall. The column covers which had been laid were pulled back to plumb. Horizontal angles were welded to the steel column. Clip angles were attached to the inner wythe of masonry with expansion bolts. A turnbuckle was attached from each end of the horizontal angle to the clip angle. The turnbuckles were simultaneously turned and the brick column cover drawn into alignment with the masonry above.

Other Considerations

Material properties produce dimensional changes which must also be considered. Changes in moisture content affect the volume of wood and concrete members. Brick units undergo longterm moisture expansion. Creep under sustained loads occurs in concrete. Fastening devices can shift or slip when loaded.

Figure 9. Crack in floor slab due to weight of masonry

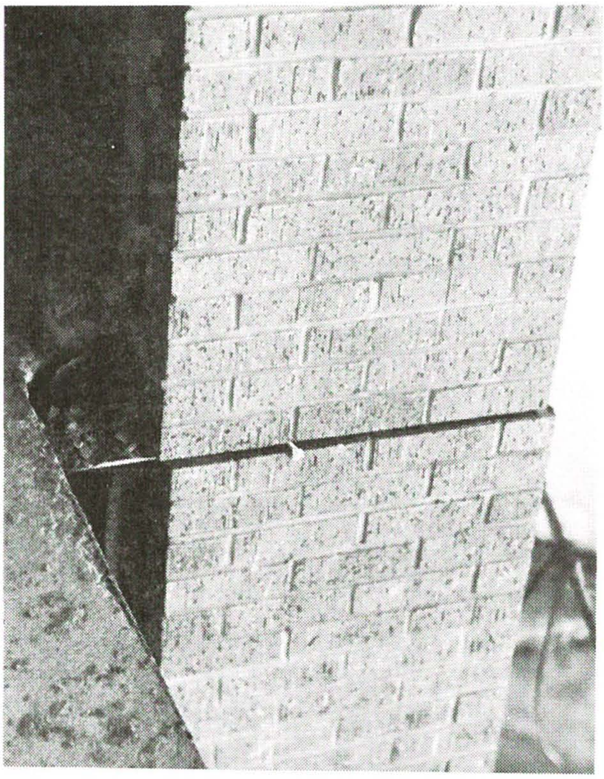


Figure 10. Displacement of masonry column due to floor slab rotation

SURVEY SUGGESTIONS FOR IMPROVEMENT

Construction Tolerances

Construction tolerances should be established which are both achievable and in line with those of other materials. The cladding material, whether brick, glass, or metal, should not be expected to cover the mistakes of the frame materials. Potential damage to both the structure and the cladding results. An industry wide standard for construction tolerances of all frames should be developed.

Standards for dimensional tolerances of construction should be enforced for all materials. Simply including allowable tolerances in the contract specifications is not enough. The frames must be built within the requirements. The survey indicates that this is not the case. Masonry contractors surveyed felt that more than 70% of the buildings on which they worked had excessive deviations which warranted corrective work. Responsibility for meeting the tolerances should be assigned to the architect.

Architectural and Engineering Details

Many problems of dimensional tolerance result from inflexible details in the construction drawings. All details should include sufficient adjustment to compensate for the dimensional tolerances which can be expected on the job. Permissible adjustment should be shown, with maximum and minimum amounts stated to prevent accidental loading of the support members. More adjustment is necessary with concrete frames than with steel frames since they have larger and more varied deviations. Adequate clearance for dimensional variations of the materials as well as differential movement between the materials should be shown on the design details.

Construction Practices

A major problem occurs when joining dissimilar materials because the necessary flexibility must be achieved. It does no good to detail sufficient dimensional adjustment and limited rotation if the constructed detail does not match the design. Ties and anchors of the proper size, shape, and dimension should be utilized to ensure sufficient embedment in mortar. Field modification of ties and anchors should be made only with the approval of the design professional. Shims should be the full height of smaller piece joined to limit rotation.

A system for rectifying construction problems, including compensation, should be a part of the contract documents. Problems should be identified as soon as possible in order to make the necessary changes.

SUMMARY

Brick masonry veneer and column covers will be used on structural frames. The difference between acceptable dimensional tolerances of frames and finish elements should be considered. Detail drawings which can be built and which allow for both the differential movement between materials and the construction tolerance differences should be shown. Standards of acceptability for dimensional tolerances should be enforced and construction should conform to the details. At the present time there are no adequate solutions to this problem of incompatible dimensional tolerances. It falls on the masonry contractor to correct these errors as best he can. After all, it is usually his work, the brickwork, which demonstrates the distress.

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