

Accommodating Movement in High-Rise Wood-Frame Building Construction

Richard W. Howe, P.E.

Introduction

Ease of construction and favorable overall costs relative to other construction types are making high-rise (i.e., 4- and 5- story) wood-frame construction increasingly popular. With these buildings increasing in height, there is a greater impetus on designers to address frame and finishes movement in such construction. As we all know, buildings are dynamic creatures experiencing a variety of movements during construction and over their service life. In wood-frame construction, it is important to consider not only absolute movement but also differential movement between dissimilar materials. As the number of stories increases, paying attention to shrinkage of materials has increased importance. At the upper building stories, it is possible for allowable shrinkage to be exceeded resulting in distress to exterior finishes. Further, distress repaired during the construction period or early in the building's service life sometimes reappears each time it is remedied.

This article focuses on differential movement issues and how to recognize their potential and avoid problems by effective detailing. These problems are generally well-addressed in the literature; therefore, those who fail to address them are vulnerable to red faces and the repercussions of having to deal with them. This article does not address structural design and detailing for shear walls and connectors in typical wood-frame structures. Distress to finishes is seldom critical structurally but can be a major issue with owners, since the nature of the cause is ongoing (e.g., continued shrinkage of wood or growth of brick).

Shrinkage

An important issue is wood shrinkage and an appreciation of not only its magnitude but also its differential character relative to other common materials present in wood-frame construction. Construction types often using mixed materials include multi-

family residential, dormitories, hotels, etc. Hybrid materials also are seen often in mixed-use commercial and, especially, in the increasingly popular wood frame-over-podium construction.

Wood shrinkage is well-addressed in the literature. A great place to start is Chapter 4 of the *Wood Handbook*^[1]. Shrinkage is principally of interest in the cross-grain direction (radial or tangential). Longitudinal shrinkage along the length of typical dimensional lumber members is often negligible. An article by Joseph Lstiburek^[2] also provides a good overview of shrinkage and other sources for wood-frame movement noting “zones of (shrinkage) movement” focused at floor framing. Additional articles addressing primarily structural considerations but also detailing issues regarding movement accommodation include the following:

- *Multi-Storey Wood-Framed Structures: Requirements for Building Beyond Four Storeys* - Provides a good overview of literature addressing the issues^[3].
- *Four-story Wood-frame Structure over Podium Slab* - A Woodworks-sponsored case study addressing frame shrinkage in seismic design with numerous interesting references. See also the errata^{[4][5]}.
- A California-focused presentation entitled *5 over 1 Hi-Rise Podium Structures*^[6].
- *Hold Down Systems Key to Shear Wall Performance* - Provides a Wood Shrinkage Table for different classes of frame construction^[7].

The latter two articles refer to “settling” or “settlement of construction gaps,” which is the closing of gaps in dimensional lumber framing also known as “framing take-up” and an additional factor also contributing to frame shortening. The latter article also suggests consideration of axial creep shortening of wood framing, especially for lower level studs subjected to the relatively high loads of four- and five-story framing. Axial creep versus creep of flexural members has not been rigorously addressed in the literature. Intuition says that it may also contribute

1/8 inch or even 1/4 inch to the shortening of lower stories.

The *International Building Code* (IBC 2009 Section 2304.3.3) addresses shrinkage concerns for multi-story wood-frame construction:

2304.3.3 Shrinkage. Wood walls and bearing partitions shall not support more than two floors and a roof unless an analysis satisfactory to the *building official* shows that shrinkage of the wood framing will not have adverse effects on the structure or any plumbing, electrical or mechanical systems, or other equipment installed therein due to excessive shrinkage or differential movements caused by shrinkage. The analysis shall also show that the roof drainage system and the foregoing systems or equipment will not be adversely affected or, as an alternate, such systems shall be designed to accommodate the differential shrinkage or movements.

However, it is apparent that the emphasis is on performance of building structure and equipment and not architectural detailing issues impacting finishes or joints and joinery of materials, etc.

It is interesting to note that certain Canadian jurisdictions have codified consideration of wood-frame movement specifically for high-rise wood frame construction^[8]. Note that six stories are now permitted in some Canadian jurisdictions. British Columbia puts the issue of design to accommodate movement on the designer as opposed to the contractor^[9]. While generalized specification language deferring that responsibility on contractors might be legally enforceable, the end result is always a dog fight where all parties end up losers. The cited document also provides some sound recommendations for avoiding or minimizing shrinkage-related issues.

Wood Shrinkage Overview

Key factors influencing the magnitude of wood-frame shrinkage are:

- Pre-construction moisture content (MC), which will typically be higher than equilibrium (in-service) moisture content (EMC) whether due to pre-delivery MC (specifications and off-site storage) or on-site storage conditions, and the simple fact that typical buildings are tempered (typically by air conditioning). For example, lumber delivered to a job may be at a moisture content of 19 percent or 15 percent kiln-dried for commercial construction, or perhaps higher depending on storage conditions. As the completed air conditioned building reaches envi-

ronmental equilibrium, the in-service EMC in wood framing is generally assumed to be on the order of 8-10 percent, and hence, the wood framing is subject to inevitable shrinkage.

- Cumulative thickness of *cross-grain* wood contributing to shrinkage (plates, dimensional joists, fabricated open-web wood truss top chords, etc.). Wood species has relatively *little* impact since most species used in commercial construction have similar shrinkage properties.

As noted previously, a complete assessment also would consider wood framing connection “take-up” – as much as 1/8 inch per floor or cumulatively as much as 1/2 to 3/4 inch at the top floor of a high-rise wood framed building. Also, although not well documented, some would argue that “creep” (long term movement under sustained loading) contributes (albeit a small contribution for compressive creep – e.g., axial shortening of load-bearing wood studs – perhaps in range of 1/8 to 1/4 inch per story with magnitude progressively increasing from lower to upper stories). Flexural creep deflection may be of interest locally if the project features longer span wood flexural members supporting framing above, and then the magnitude varies with position of the concentrated load in the span. Flexural creep is not of interest where framing is not supported by beams or other flexural framing.

Mixed Materials

The important thing to recognize is that *cumulative shrinkage* is the issue - not absolute values per floor or story. This is especially of interest when considering differential movement between wood-frame elements and other materials, especially those that:

1. do not shrink at all (steel framing or steel/cast iron piping, such as plumbing stacks), or
2. shrink much less (concrete masonry, such as is often used in stair and elevator shafts), or
3. worst of all, materials that actually expand, such as brick commonly used in veneers for facility types for which high-rise wood-frame construction is often used. Like wood shrinkage, brick growth (and issues relative to differential movement with wood framing) is well addressed in the literature. See Brick Institute of America *Tek Note #18 Volume Changes – Analysis and Effects of Movement*^[10].

Brick detailing must be effectively addressed in high-rise wood-frame-over-podium construction where brick veneers can effectively extend two or even more stories below the supported wood-framed

superstructure. One method to address differential shrinkage is independently supported brick-on-shelf angles *with soft joints below them*. Otherwise, determination of *cumulative differential movement* between shrinking wood frame and growing brick veneer could be based on six, seven, or eight cumulative stories of uninterrupted brick subject to expansion.

Table 1 presents a *representative* analysis of story-by-story cumulative wood-frame shrinkage followed by a companion analysis of brick growth and the cumulative differential between the two. Time frames of 18 months post-installation and ultimate (long term) are considered. Needless to say, it is hard to accommodate two inches or more of differential movement between interior framing and brick veneer in the uppermost stories *unless the designer has provided effective details to accommodate it*. Better yet,

the designer should consider *effective material specs* to reduce movement.

Note that in Table 1, the third through sixth stories reflect a four-story wood-frame structure supported by a two-story podium (concrete parking structure). Detailing of the brick veneer without effective soft joints resulted in cumulative differential brick growth being assessed for a six-story stack of brick.

Detailing Tips

The most effective way to *detail* the project to reduce cumulative shrinkage is to minimize the cumulative width/depth of wood framing members subject to (cross-grain) shrinkage or specify materials less subject to shrinkage where necessary:

	Shrinkage	Take-Up	Creep	Total per story	Cumulative at each story
6th story	0.2500	none	none	0.2500	1.8750
5th story	0.2500	0.0625	0.1250	0.4375	1.6250
4th story	0.2500	0.0625	0.1250	0.4375	1.1875
3rd story	0.2500	0.1250	0.2500	0.6250	0.7500
2nd story (conc)	0.0625	N/A	Negligible	0.0625	0.1250
1st story (conc)	0.0625	N/A	Negligible	0.0625	0.0625

Brick growth (at 5×10^{-4} per BIA recommendations)

	At 18 months (60%)		Ultimate	
	Growth in story	Cumulative	Growth in story	Cumulative
6th story	0.0360	0.1944	0.0600	0.3240
5th story	0.0360	0.1584	0.0600	0.2640
4th story	0.0360	0.1224	0.0600	0.2040
3rd story	0.0360	0.0864	0.0600	0.1440
2nd story (conc)	0.0216	0.0504	0.0360	0.0840
1st story (conc)	0.0288	0.0288	0.0480	0.0480

Per story differential - interior wall movement vs. brick growth

	At 18 months			Ultimate		
	Framing	Brick	Diff at each story	Framing	Brick	Diff at each story
6th story	-1.8750	0.1944	2.0694	-1.8750	0.3240	2.1990
5th story	-1.6250	0.1584	1.7834	-1.6250	0.2640	1.8890
4th story	-1.1875	0.1224	1.3099	-1.1875	0.2040	1.3915
3rd story	-0.7500	0.0864	0.8364	-0.7500	0.1440	0.8940
2nd story (conc)	-0.1250	0.0504	0.1754	-0.1250	0.0840	0.2090
1st story (conc)	-0.0625	0.0288	0.0913	-0.0625	0.0480	0.1105

Table 1. Wall movement summary of a four-story wood over two-story CIP concrete parking structure with aligning exterior walls (all units in inches).

- Avoid plates and fillers, especially stacked plates, except where absolutely necessary.
- Consider use of pressure-treated wood or engineered wood such as LVL at such locations, since the treatment process results in moisture contents at or below in-service EMC.
- Consider a single top plate (with appropriate structural design and detailing considerations).
- Consider floor framing with engineered wood framing such as I-joists or engineered open web trusses where only the thickness of the top and bottom chords contribute to shrinkage.
- Matteri suggests consideration of balloon framing with floor construction supported by hangers, thus avoiding plates and floor framing inserted into wall framing.

The above considerations can reduce cumulative wood-frame movement by a factor of 50 percent or more. Half the battle is won.

The most effective way to avoid distress to finishes arising from *cumulative differential movement* of wood frame relative to finishes is to be *acutely aware of the fact that there will be differential movement and conscientiously address detailing and specifications to minimize distress to finishes*. Consider where that is likely to occur and provide details to relieve it or avoid it.

Classic conditions to be addressed include the following:

- Windows in exterior walls - Such windows often serve as the bridge between shrinking wood frame and growing brick veneer. BIA Tek Note 18A Accommodating Expansion of Brickwork ^[11] also points to the need for expansion joints (soft joints) around windows (and doors) projecting into the veneer.

Brickwork Without Shelf Angles:

Accommodate brickwork movement by:

- placing expansion joints around elements that are rigidly attached to the frame and project into the veneer, such as windows and door frames.

- *Floor framing interfacing with unyielding materials or components* - Such materials and components include concrete or CMU stair or elevator shaft walls, steel framing, plumbing stacks, flues and chimneys, etc.

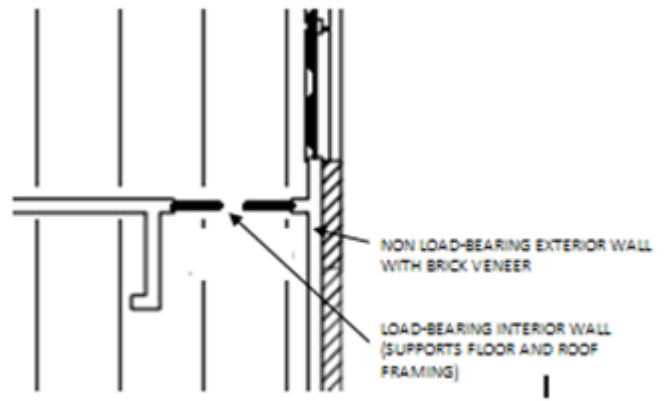


Figure 1. Interior load-bearing wood stud walls with doorways located immediately adjacent to intersecting exterior non-load bearing walls with brick veneer invites problems at header corners.

- *Interior load-bearing wood stud walls with doorways located immediately adjacent to intersecting exterior non-load bearing walls with brick veneer* - This unique condition invites never-ending distress to finishes at door header corners. An example of such a condition is shown in Figure 1.
- *Conditions where brick veneer wraps corners or parapet walls* - This condition often exists at exterior balconies or porches or similar conditions where the primary brick façade is supported on a non-yielding foundation (foundation wall or perhaps even prior existing brick as in a vertical expansion) and the brick façade at the porch or patio is supported on (shrinking) wood framing. Distress will likely occur unless effective detailing is provided to permit differential movement across the interface.

The importance of soft joints or details serving to “panelize” the exterior façade – especially if made of brick, masonry, or any finish not subject to shrinkage – to each story, hence shielding it from the effects of story shrinkage and especially cumulative shrinkage, cannot be overstated.

The literature is rife with recommendations for soft joints (see, for example, *Design and Detailing of Expansion Joints in Clay Brick Veneer* - an excellent treatise by G.A. Dalrymple^[12]). Dalrymple points to the use of lipped brick as an effective way to address soft joints (see Figure 2). This is perhaps the most effective, if not only, way to address the classic problem of typical 5/16- and 3/8-inch shelf angle out-

standing legs *while maintaining the standard 3/8-inch mortar joints* and achieving a soft joint. Even this detail calls for special attention to compressibility of sealants vs. anticipated movement.

Existing Construction

The preceding discussion has generally focused on new construction. Existing construction presents an obvious situation where *new wood framing* may be placed in the context of existing construction and juxtaposed against dimensionally stable materials. For example, new wood framing abutting an existing wall – whether wood or masonry – with finishes bridging the interface between the two. This is not unlike the classic architectural gaffe of floor, wall, or ceiling finishes crossing a structural building expansion joint. When buildings (or adjacent materials or components) move relative to one another, the finishes bridging the gap will show distress unless special details are provided.

Conclusion

In summary, the importance of architectural detailing to avoid distress to finishes cannot be overstated. The failure to recognize the potential for and to provide construction details to accommodate such movement can be a source of headaches, management overhead, and strained relationships with owners, contractors, and fellow design professionals.

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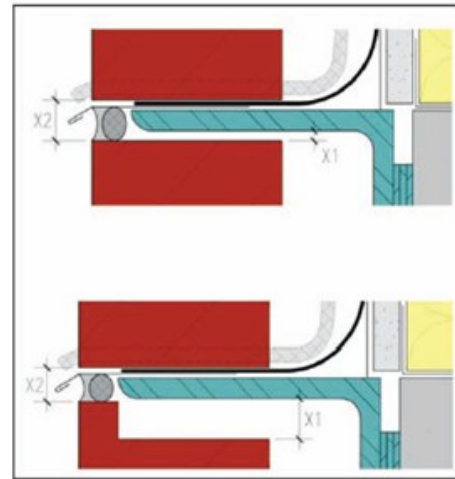


Figure 2. Lipped brick is an effective way to address soft joints.

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Richard W. Howe, P.E., is a licensed professional engineer in Memphis, Tennessee, with over 30 years experience performing forensic analysis of building performance issues. Contact him at rhowe@earthlink.net.