Technical Advisory
Wood Frame Shrinkage and Associated Issues with Building Performance– 22-2021

TITLE: Wood Frame Shrinkage and Associated Issues with Building Performance

DESIGNATION: IIBEC TA-022-2021

OBJECTIVES:

- To acknowledge an apparent generalized absence of building code enforcement regarding wood shrinkage analysis,
- To describe the importance of analyzing and accommodating wood shrinkage in mid-rise wood frame construction pursuant to (and beyond) current building code requirements,
- To provide an understanding of why current building code requirements are not addressing all potential issues,
- To give an overview of the extent of published information and available resources that address wood shrinkage issues, and
- To provide recommendations for design details that would reduce the potential for adverse conditions to develop.

BACKGROUND

- Wood is hygroscopic, which means that wood absorbs and releases moisture in an effort to reach equilibrium with the surrounding environment.
- Wood is commonly used in construction of mid-rise buildings.
- A net decrease in moisture content from construction to in-service conditions causes shrinkage of wood framing components. When significant shrinkage occurs after construction, it can result in differential movement and stresses within a building unless properly accounted for in design.
- The most significant moisture-related movement occurs across the grain of wood (tangential and radial directions), which is typically across the width or thicknessof a wood member. Shrinkage in the longitudinal direction, typically along the length of the wood member, is significantly less.
- Moisture-related movement of wood depends on the species and grain density. Most softwood species commonly used for lumber in North America exhibit a maximum cross-grain shrinkage of about 6% when drying from the green condition to an equilibrium moisture content under typical interior conditions.
- Dry lumber has maximum moisture content of 19% at time of manufacture. While lumber moisture content will generally reduce over time when protected from wetting, actual moisture content at time of installation may be greater or less depending on environmental conditions and material handling

practices..In service (after the building is enclosed), wood members commonly dry to a moisture content of approximately 9% to 12%, depending on the environmental conditions, climate zone, and construction details. This change in moisture content results in shrinkage of wood members used in construction.

- While it depends on the framing details, most shrinkage in the vertical direction within a building typically occurs at floor lines. This is particularly true with platform construction because sill plates, rim joists and other members are installed with the grain perpendicular to the height of the building.
- If not properly accommodated, shrinkage of wood framing can impart stresses in the building enclosure components (i.e., cladding and fenestration elements) attached to the wood-framing, as well as components that extend through or are connected to the framing (i.e., mechanical, electrical, and plumbing). For example, windows installed in wood framed walls can experience compression, if shrinkage of the rough opening is not accommodated.
- Another example is the important consideration that should be given to constructing buildings on a slope; the downhill side of the building will have more lumber and can experience greater shrinkage than the uphill side.
- Of particular importance is clay masonry which expands irreversibly in service. The combination of wood shrinkage and masonry expansion can cause many issues with the building enclosure. Other cladding systems are also prone to experience issues related to wood shrinkage.
- The building code recognizes the importance of wood shrinkage and requires design professionals to perform an analysis to the satisfaction of the building official for buildings with wood walls supporting more than two floors and a roof.
- While wood shrinkage has been addressed in building codes for more than two decades, shrinkage analysis has been required since the 2003 Edition of the International Building Code (IBC), and each of the subsequent five editions[1].
- In many cases, local Building Officials do not require or enforce an analysis to be submitted as part of the permit process.
- The absence of enforcement of the shrinkage analysis requirement in some jurisdictions, combined with a lack of understanding regarding the potential effects of wood shrinkage, has resulted in significant issues on numerous projects.

It should be noted that in addition to shrinkage of wood resulting from drying, other movements in wood structures can adversely affect other building components and systems. These include long-term deflections induced by loads. This Technical Advisory does not address these additional movements in wood structures.

BUILDING CODE REQUIREMENTS

Section 2304.3.3 of the 2018 *International Building Code stipulates* when shrinkage consideration is required in wood-frame building design.

"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 movement 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 alternative, such systems shall be designed to accommodate the differential shrinkage or movements."

PROBLEMS AND RECOMMENDED SOLUTIONS

The current building code requirement is not being consistently enforced and building design professionals may not have familiarity with details to accommodate wood shrinkage. Most Building Officials that do not require a shrinkage analysis indicate that they are relying on design professionals to know the building code requirements and to properly address shrinkage issues in their design. Although the building code requirements for wood shrinkage need to be enforced, it should be recognized that building officials and design professionals have independent duties regarding code compliance. Therefore, design professionals should recognize the importance of such an analysis, and perform it on a routine basis, regardless of enforcement. The issuance of a building permit does not provide a design professional with a waiver of meeting building code requirements. It is unreasonable for a design professional and/or a building official to rely on each other to "catch" building code violations.

The current building code requirement does not necessarily address all potential issues. Even if the shrinkage analysis requirement of the building code was performed by every designer, the analysis will vary depending on experience of the design professional and details incorporated into the building design to accommodate shrinkage. Specifically, the requirement for a shrinkage analysis "*satisfactory to the building official*" allows for evaluation of the system based on experience and project specific details and does not provide wood shrinkage details and analysis methods to be considered by the members of the project team. As an example, a designer may perform a shrinkage analysis on a specified maximum wood moisture content of 19%. However, under conditions of prolonged continuous exposure to water during construction, the moisture content of wood members may be greater than the specified 19%, rendering the analysis invalid. Therefore, to be effective and meaningful, the design documents should specify maximum wood moisture content of installed wood members during construction, so that the assumed values used in the analysis are not exceeded. In the event of prolonged exposure to moisture at the site, it may also be necessary to measure moisture content of installed wood members prior to the wood framing being enclosed to ensure the assumed moisture content values are not exceeded at any time during construction." The assumptions made during the analysis should also be checked and enforced by the construction team to ensure the calculations remain valid. The information from a shrinkage analysis should be incorporated into proper design and construction details that would reduce the potential for damage.

Significant damages can be caused by wood shrinkage. When wood shrinkage is not accounted for in mid-rise wood construction, the vertical movement can induce changes in the slope of flashings, balconies, and walkways, such that the flow of water is directed towards the building. This can result in water intrusion, rot, and mold. Damages to windows, doors, and brittle exterior claddings (i.e., brick veneer, fiber-cement and stucco) are commondue to unanticipated movement. Additionally, any components that penetrate the wood framing, such as mechanical, electrical, and plumbing (MEP), are susceptible to damage caused by frame shrinkage. For instance, there have been many cases reported of broken PVC plumbing components associated with mid-rise wood construction. Design professionals need to provide details that will reduce the extent of damages caused by wood shrinkage, as described in more detail below.

Design professionals may not be addressing wood shrinkage. Experience has shown that there are design professionals who are not independently performing the analysis needed to determine design details that would result in a functional building with reduced potential for damage related to moisture movement of wood construction. Design professionals need to provide details that adequately address wood shrinkage. Many industry standard details for cladding or window systems do not adequately address this issue. Design details should consider wood shrinkage and differential movements. The following recommendations should be considered when developing design details for wood frame buildings:

- Perform an analysis to determine maximum wood shrinkage at each floor and large openings. The analysis should assume practical wood moisture content during construction versus in-

service. For example, if the wood structure cannot be practically kept protected from rain, a higher initial wood moisture content should be used. Estimated in-service equilibrium moisture content should also consider the in-service use of the building.

- Perform an analysis to estimate the irreversible expansion of clay masonry (also required by IBC) in order to determine the total differential movement, combining the shrinkage of the wood and the expansion of the masonry.
- Design all interfaces between enclosure and framing to accommodate the maximum differential movements.
- Design fenestration rough openings to accommodate differential movements between the fenestration and rough opening. Keep in mind that some window and door materials such as vinyl have a high coefficient of thermal expansion that can exacerbate differential movements.
- Provide expansion joints in cladding materials at each floor line and where structural changes occur.
- Consider differential movement between the frame and the cladding when detailing cladding attachment to the frame. In some cases, attachment devices capable of accommodating in-plane movements should be used.
- Consider wood shrinkage in longitudinal direction as well, particularly in long or tall buildings. Provide building expansion joints to accommodate such movements.
- Consider differential shortening of floor-to-floor heights when support materials vary. For example, wood framed exterior walls will shrink more than a concrete staircase enclosure.
- Specify provisions for protection of wood materials and structures during construction so that the initial moisture content of the wood can be maintained at levels considered by the initial analysis. Also consider including procedures during construction for random moisture content readings and documentation of those readings.

SUMMARY

There is now a significant body of published work that addresses the importance of shrinkage analysis for multi-story wood construction. A summary of some of these references is provided below. Many of these references provide design guidance and recommendations for details that would reduce the potential for damage. Design professionals should familiarize themselves with such standards, and perform wood shrinkage analysis regardless of enforcement of such requirements by the Building Officials.

- The Western Wood Products Association (WWPA) published Report No. 10, "*Shrinkage Calculations for Multistory Wood Frame Construction",* in November of 2002[2]. This report identifies prior building code references regarding wood shrinkage in the 2000 IBC and the 1997 Uniform Building Code. This report specifically recommends designing for relative dimensional change.
- In the 2003 textbook "Design of Wood Structures – ASD," the authors provide step-by-step methods, as well as example calculations for wood shrinkage for mid-rise wood-framed structures. They cite several types of problems that could occur due to wood frame shrinkage in multistory structures.
- In 2010, WoodWorks – Wood Products Council, an education and technical support group for wood construction, published a 52-page Design Example, titled: "*Four-story Wood-frame Structure over Podium Slab"*, that addressed wood shrinkage issues[3]. This document indicates that: "*Vertical displacement can be a significant problem in multi-level wood framing unless special considerations are accounted for during design and construction.*"
- The Fall 2010 Issue of Wood Design Focus, published by the Forest Products Society, included an article by Richard W. Howe, P.E. titled: *Accommodating Movement in High-Rise Wood-Frame Building Construction*.[4] This article correctly indicates that: "*The most effective way to avoid distress to finishes arising from cumulative differential movement of wood frames 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." No such awareness has been demonstrated on numerous projects constructed to date in the United States. The extent that wood shrinkage is problematic in other jurisdictions is not known.

- The Fall 2010 article: "*Accommodating Movement in High-Rise Wood-Frame Building Construction*."[5] that was previously published in Wood Design Focus was reprinted in the June 2011 issue of STRUCTURE magazine.
- In 2015, WoodWorks – Wood Products Council published "*Options for Brick Veneer on Mid-Rise Wood-Frame Buildings*" that addressed wood shrinkage issues[6]. This document discusses relevant design issues and provides recommended details to accommodate vertical framing movements and brick growth, which typically undergo dimensional changes in opposite directions.
- The 2015 "*Manual for Engineered Wood Construction*" is a detailed guide that provides the equations necessary to accurately calculate wood shrinkage potential within a wall frame. This manual provides all explanation necessary to understand the components required for the analysis.
- A presentation was provided at the 2016 IIBEC (formerly RCI) conference called: "*Avoiding Common Oversights in Design and Construction of Mid-Rise Wood-Framed Buildings*".[7] The presentation and associated proceedings identify the potential significance of vertical movement in a mid-rise wood-framed building, particularly when combining the effects of wood shrinkage and frame compression.
- In 2017, Woodworks published: "*Accommodating Shrinkage in Multi-Story Wood-Frame Structures*".[8] This comprehensive design guide provides designers with a basic understanding of wood shrinkage issues and provides recommendations for details to reduce adverse impacts.
- An article: "*Mid-Rise Wood Frame Construction: A Good Idea or Are We Asking for Trouble?*"[9] was published in the September 2017 issue of *Interface*, the technical journal of IIBEC. This article identifies wood shrinkage as one of several issues that can be problematic for mid-rise wood construction if not properly accounted for in design.
- The Winter 2017 issue of Wood Design Focus, published by the Forest Products Society, included an article by Derek A. Hodgin, P.E. titled: "*Mid-Rise Construction: A Call for Best Practices*".[10] This article recommends a series of "best practice" details that are needed to overcome performance issues associated with mid-rise wood construction.
- In June of 2018, Burgess Construction Consultants, Inc. published: "*Shrinkage is a Real Problem…for Multi-story Wood Frame Construction*" on their company website. This informative article clearly identifies the most common issues that are dealt with when shrinkage is not properly considered, as required by the building code.
- Chpater 4 of the 2021 book "Wood Handbook – Wood as an Engineering Material" by United States Department of Agriculture Forest Service. This chapter discusses the moisture relations and physical properties of wood.
- Canadian Wood Council Wood Dimensional Calculator: https://cwc.ca/dimensioncalc/

REFERENCES

1. 2003 IBC: *International Building Code.* Country Club Hills, IL: ICC, International Code Council, 2003. Section 2304.3.3.
2. 2006 IBC: *International Building Code.* Country Club Hills, IL: ICC, International Code Council, 2006. Section 2304.3.3.
3. 2009 IBC: *International Building Code.* Country Club Hills, IL: ICC, International Code Council, 2009. Section 2304.3.3.

4. 2012 IBC: *International Building Code.* Country Club Hills, IL: ICC, International Code Council, 2012. Section 2304.3.3.
5. 2015 IBC: *International Building Code.* Country Club Hills, IL: ICC, International Code Council, 2015. Section 2304.3.3.
6. 2018 IBC: *International Building Code.* Country Club Hills, IL: ICC, International Code Council, 2018. Section 2304.3.3.
7. WWPA Tech Notes. Report Number 10, November 2002. Western Wood Products Association. Portland, OR.
8. Breyer, D. E., Fridley, K. J., Pollock, D. G., Jr., &Cobeen, K. E. (2003). *Design of Wood Structures - ASD* (Fifth ed.). New York, NY: Mcgraw-Hill.
9. Thompson, Douglas S., "Four-story Wood-frame Structure over Podium Slab." Woodworks Design Example.
10. Howe, Richard W., "Accommodating Movement in High-Rise Wood-Frame Building Construction" Wood Design Focus. 2010.
11. Howe, Richard W., "Accommodating Movement in High-Rise Wood-Frame Building Construction" Structure Magazine. June 2011.
12. Malone, R. Terry, "Options for Brick Veneer on Mid-Rise Wood-Frame Buildings" WoodWorks Wood Products Council. 2015
13. *American Wood Council Manual for Engineered Wood Construction* (2015).
14. Mayhew, S. A., Pashina, B.J. "Avoiding Common Oversights In Design And Construction of Mid-Rise Wood-Framed Buildings" Proceedings 31st RCI International Convention and Trade Show. 2016.
15. McLain, Richard., "Accommodating Shrinkage in Multi-Story Wood-Frame Structures" WoodWorks Wood Products Council. 2017.
16. Hodgin, Derek A., "Mid-Rise Wood-Frame Construction: A Good Idea, or Are We Asking for Trouble?" *Interface*. September 2017.
17. Hodgin, Derek A., "Mid-Rise Construction – A Call for Best Practices" Wood Design Focus. Winter 2017.
18. Burgess Inc., *"Shrinkage is a Real Problem…for Multi-story Wood Frame Construction."* June 2018. https://www.burgess-inc.com/post/2018/06/20/shrinkage-is-a-real-problem-for-multi-story-wood-frame-construction" https://www.burgess-inc.com/post/2018/06/20/shrinkage-is-a-real-problem-for-multi-story-wood-frame-construction