BUILDING ENVELOPE TECHNOLOGY SYMPOSIUM

Mid-Rise Wood Frame Construction: A Call for Best Practices

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Abstract

Over the past several years, the speaker has observed an increasing number of water intrusion claims in relatively new mid-rise wood frame buildings. While the code requires the building envelope to provide protection from the weather, it does not provide the details necessary for designers and/or contractors to meet this requirement. More specifically, vertical and lateral movements caused by frame compression, shrinkage, external loads, and material incompatibility can compromise the function of flashing, drainage, and waterproofing details. Differential movements between wood framing and exterior cladding components can cause physical damages to building envelope components that increase the extent of water intrusion. Once the water reaches the wood framing components, significant damage, such as decay, corrosion, and mold can result. Additionally, once compromised, the effectiveness of products used to meet fire resistance requirements is unknown.

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DEREK A. HODGIN holds a bachelor of science degree in civil engineering from North Carolina State University. He has over 25 years of experience as an engineering consultant and is responsible for facility condition inspections, failure analysis, damage assessments, and forensic engineering investigations of all types of structures. His experience includes failure analysis of a wide variety of building envelope and roof systems. A large part of Hodgin's projects have included analysis of deficient construction cases, including roofs, exterior walls, windows, doors, structural framing, civil site work, and building code review. He has performed engineering assessments of hurricane-, flood-, tornado-, hail-, wind-, ice-, and fire-related damages for a wide variety of commercial and residential structures in the United States and the Caribbean.

Mid-Rise Wood Frame Construction: A Call for Best Practices

INTRODUCTION

Mid-rise wood frame construction has quickly become a designer's choice for perceived efficient and cost-effective construction of mixed-use buildings. Most often, the buildings include retail and/or parking on the first couple of floors and multifamily residential units on the upper four to five stories. Many of these projects are constructed as apartments located proximate to colleges with a significant student housing market. Student housing is being provided very quickly and most affordably by code-compliant wood frame construction (*Figure 1*). However, in very short order, some of these buildings are showing significant problems associated with building movement, water intrusion, cladding distress, and deflection, which all negatively impact the durability and long-term habitability of these buildings.

The purpose of this article is to address the most significant issues that can affect this type of construction and to serve as a notice to the construction industry of these issues. In addition to identifying the issues, the article provides suggestions for making design and/or construction-related changes to reduce the potential for future problems. Because these buildings are typically constructed in accordance with the International Building Code (IBC), a performance-based code, there are no prescriptive details that address these issues. Additionally, local authorities having jurisdiction (AHJ) typically have no requirements for building envelope inspections, where most of the problems develop.

CHALLENGES OF WOOD FRAMING

Practices that work well for one- or two-story residential structures are not necessarily adequate for four- to five-story wood frame structures. Specifically, the issues described below should be considered and addressed for mid-rise wood frame buildings in order to avoid problems.

Compression

When wood framing is assembled, minor gaps at joints will exist throughout the structure. As the wood framing receives load during construction (i.e., exterior cladding, interior drywall, flooring, etc.), the gaps will close as the frame assembly compresses. Depending on the framing system used, these gaps can add up to more than 1 inch of compression over four to five stories.[5]

Balloon framing should be considered as the number of gaps in the walls will be reduced, thus reducing the total frame compression. Additionally, prefabricated wall panels may serve to reduce the gaps that exist in the constructed assembly.

Shrinkage

Even if a building is well constructed, such that bulk water intrusion does not occur, changes in equilibrium moisture content will cause the solid-sawn lumber to typically shrink in service. Even minor changes can add up to be significant when they accumulate over four to five stories. A shrinkage analysis is necessary to avoid some of the performance problems within the finished buildings. Specifically, if not considered, framing shrinkage can cause damage to plumbing fixtures, damage to exterior cladding components, and water intrusion due to vertical movement.

A shrinkage analysis is required by the building code for wood frame buildings greater than three stories.[9] According to the building code, the analysis must be provided to the satisfaction of the building official. However, the author's experience thus far has indicated that shrinkage calculations are commonly not being performed, requested, or reviewed on most mid-rise wood projects. In fact, out of approximately 25 mid-rise projects investigated by the author to date, shrinkage calculations were not produced in any of the projects. This experience is limited to the southeastern United States. If a shrinkage analysis is performed, it would be most useful if considered by designers of electrical, plumbing, and building envelope components that are most impacted by building movement. Collectively, the combination of frame compression and shrinkage can cause vertical movements of nearly 1 inch per story.[4]

Deflection and Creep

Time-dependent deflection of a structural member under a sustained load (typically a dead load) is known as creep. This phenomenon can be particularly important for the long-term performance of low-slope roofs.[1, 2] The building code has long required a minimum slope of ¼ in. per ft. for low-slope roof coverings. Even when complying with this requirement, ponding can occur along the valleys of roof crickets that have a slope less than ¼ in. per ft. The slope can be further reduced when wood roof trusses deflect under the load of HVAC units when consideration for creep is not included in the design. The general issue is referred to as a ponding instability. Once the slope is lost and water begins to pond, the degree of overstress increases, producing additional creep.

In general, it is recommended to provide slope above and beyond code-required minimums, particularly when designing with

Figure 1 – Typical mid-rise wood frame building under construction.

wood framing that is susceptible to deflection and creep. Preliminary engineering analysis suggests that doubling the slope to ½ in. per ft. is typically sufficient for the deflected framing to provide "positive drainage" over an extended period of time (20 years or more). Positive drainage is considered to exist when water migrates off of a waterproofed surface (typically a roof, balcony, or walkway) in 48 hours or less following a rain event.

Reduced Strength

The wood used in construction today is not as strong as old-growth wood used in older construction. The wood used today is typically grown as a crop over a relatively short period of time (15 to 20 years, depending on the species). The fast growth results in wood that is less dense and has lower strength. The lower-strength properties of wood were recognized by the industry in 2013 when lower-strength values were published.[8] The lower values are now included in the National Design Specification (NDS) for Wood Construction, the code-referenced design standard.

ARCHITECTURE CHALLENGES

Developers and contractors are typically required to comply with local ordinances that are intended to protect the character of the community by setting architectural and zoning standards. Many ordinances have created detailing challenges that, if not properly handled, will be detrimental to the performance of the building. A few examples are presented below.

Inside/Outside Corners

In order for these larger buildings to have architectural appeal, many local ordinances require exterior walls to include setbacks or reveals, also referred to as modulation. By moving the walls in and out, numerous inside and outside corners are created. To detail properly, the corners require attention. Specifically, the drainage plane—typically consisting of components such as a weather-resistive barrier (WRB), self-adhered flashing (SAF), liquid-applied waterproofing, and metal flashing—needs to be constructed in a manner that provides continuity.[4] An open gap, joint, or unsealed or reverse lap can, and often does, lead to significant water-related damage (*Figure 2*).

Parapets

Many local ordinances require the top of the wall that extends above the roof (i.e., parapet) to move up and down. This requirement (similar to the walls) creates waterproofing challenges at transition points. Additionally, the general contractor needs to coordinate the work of the framer, the roofer, the sheet metal installer, and the exterior cladding installer to make sure that the work of each trade is properly integrated at these locations, particularly at areas where the work of multiple trades intersects.

Balconies

Balconies are a popular feature on many mid-rise buildings. Balconies may or may not be addressed by local ordinances. However, balconies require careful detailing to prevent water intrusion; this is true no matter how tall the building is. Balconies naturally require a positive slope to drain throughout the life of the structure. The design of balconies with cantilevered framing requires special attention since the deflection of the back span due to sustained live loads or non-uniform dead loads not included in the design could reduce or reverse the design slope of the balcony in service. Balcony surfaces can be more problematic than a roof, and while the code has done a good job requiring slope on roof surfaces, the code has not done a good job addressing balcony drainage.[7] Proposed changes to the 2018 IBC will provide balcony slope requirements that should serve to reduce the problems associated with these areas.

Proper detailing is critical where balconies intersect exterior walls, particularly when the balcony framing penetrates the exterior cladding and interrupts the

Figure 2 – Wall modulation with efflorescence.

Figure 3 – Window damage caused by differential building movement.

Figure 4 – Moisture damage to wood-framed components behind stucco caused by improper integration of two layers of WRB.

drainage plane. Water intrusion at these intersections is not only a nuisance to the occupant, but over time can lead to life safety issues if fastener corrosion or decay of wood framing develop. Additionally, the guardrail details (material selection, attachment, and waterproofing) need to be carefully considered so that the guardrail integrity (and the integrity of the underlying wood substrate to which the guardrail is attached) is not compromised during the expected service life of the building, creating a life safety issue.

Multiple Exterior Claddings

Many ordinances require a mixture of exterior cladding types (i.e., brick veneer, stucco, cement board siding, metal panels, glass storefront, etc.) to create an attractive and interesting appearance. Some of the desired claddings can be particularly challenging when combined with wood framing (e.g., brick veneer), particularly if used on a four- to five-story building. Brick veneer grows due to wetting, while wood framing typically shrinks and/or compresses. Even if proper flashing details are provided to direct water away from the building at the time of construction, the differential movement between the brick veneer and wood framing could serve to damage the brick or adjacent wall components (e.g., windows) and/or reverse the slope of the flashing and direct water toward the building (*Figure 3*). Visit http://www.woodworks.org/wp-content/uploads/Options-for-Brick-Veneer-Wood-Solution-Paper-Oct-2015.pdf for design options when using brick veneer.

Other desired claddings, such as stucco, are brittle, and movements associated with mid-rise wood frame buildings can result in cracking of stucco façades. The cracking is typically more pronounced at higher elevations and building corners. It should be noted that building corners are also susceptible to water intrusion and building envelope issues. When the wood frame remains wet, decay may result. Another water intrusion area in stucco-clad buildings exists where the two layers of WRB are not integrated at a penetration (i.e., window or roof/wall intersection) and water is directed between the two layers. As such, the wall assembly and wood products are exposed to trapped water, resulting in decay of the wood sheathing and framing (*Figure 4*). This issue is not well understood, and problems frequently develop, even when following the building code, WRB manufacturer installation instructions, and well-known building envelope design references.

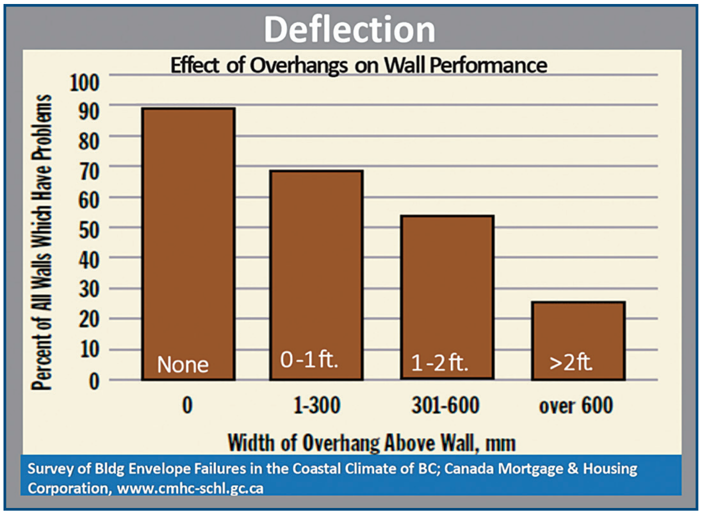

Figure 5 – Correlation between roof overhang width and wall performance problems.

Roof Overhangs

The benefits of a roof overhang are significant. A roof overhang can dramatically reduce an exterior wall's exposure to rain. As depicted in *Figure 5*, the percentage of walls that had reported problems in the coastal climate of British Columbia, Canada, decreased dramatically based on the width of the roof overhang above the wall.[4] While this condition is not unique to mid-rise wood frame buildings, there seems to be an architectural trend toward reducing or eliminating roof overhangs on mid-rise buildings. The absence of adequate roof overhangs serves to exacerbate the water intrusion problems that can be associated with these types of buildings.

INDUSTRY CHALLENGES

Misguided Budgets

Because the construction costs of mid-rise wood frame structures can be initially lower than other framing systems, such as concrete and/or steel, these projects can sometimes be associated with owners/developers who are driven more by profit than quality of construction. This is not intended to be an unfavorable comment toward wood frame construction; it is simply a fact that lower-cost construction attracts owners/developers who may not be investing for the long-term. For instance, based on the author's experience with mid-rise wood frame litigation, these projects generally have not included: 1) a design team that includes a building envelope consultant, 2) preconstruction mock-up walls, 3) flood testing of balconies, or 4) water penetration testing of windows and/or doors. That is not to say that these conditions apply to all mid-rise wood frame projects; these conditions have simply been common to projects that have experienced performance issues.

Unreasonable Schedules

Since many mid-rise wood frame buildings are constructed as student housing, there is a general rush to complete projects by August of a given year, corresponding to the return of students to school. While rushed schedules are not unique to wood frame buildings, the consequences of poor sequencing can be more dramatic and costly. For instance, several cases investigated by (or known to) the author have experienced water intrusion during construction to the extent that significant repairs were required to address mold and structural compromise before the buildings were completed (*Figure 6*).

When contractors are rushed to complete projects without meticulous coordination, sequencing issues typically result. On mid-rise wood frame projects, the performance of exterior walls is more sensitive to the order in which components are installed. For instance, when rain falls on a wood frame wall that is only partially protected by a weather resistant barrier (WRB), the water collects between the wood framing and WRB (*Figure 7*). Good construction practices would require the wall to be dried out before proceeding; however, the author has directly observed numerous projects that were subjected to water intrusion, and the construction continued uninterrupted. In these cases, it was the belief of the design professional and contractor that the exterior walls were "breathable," and the water would exit naturally on its own. Unfortunately, in some instances, water can

Figure 6 – Water intrusion/damage of a mid-rise wood frame building under construction.

be trapped. Bulk water intrusion issues must be dealt with immediately in wood frame construction if problems are to be avoided.

Figure 7 – A haphazard sequencing of multiple trades on the exterior wall of a building under construction.

BUILDING ENVELOPE CHALLENGES

The 4 Ds of Exterior Wall Design

A durable building envelope must be able to receive water, manage water, and shed water. The construction materials that encounter rainwater along their drainage path, driven by gravity (and capillary action) must be durable and not degraded by moisture. The entire path that water follows must be protected and free from "alternate paths" created by gaps, openings, reverse laps, etc., that could allow water to penetrate to deeper (often hidden), unprotected locations within the structure. In general, shorter flow paths are better. Residence time of water on building surfaces is critical in preventing absorption. The basic exterior wall design concepts for improved durability are often referred to as the Four Ds: 1) Deflection, 2) Drainage, 3) Drying, and 4) Durable[3] (*Figure 8*). In order to reduce water-related damages, these concepts are needed on all buildings, not just mid-rise wood frame buildings.

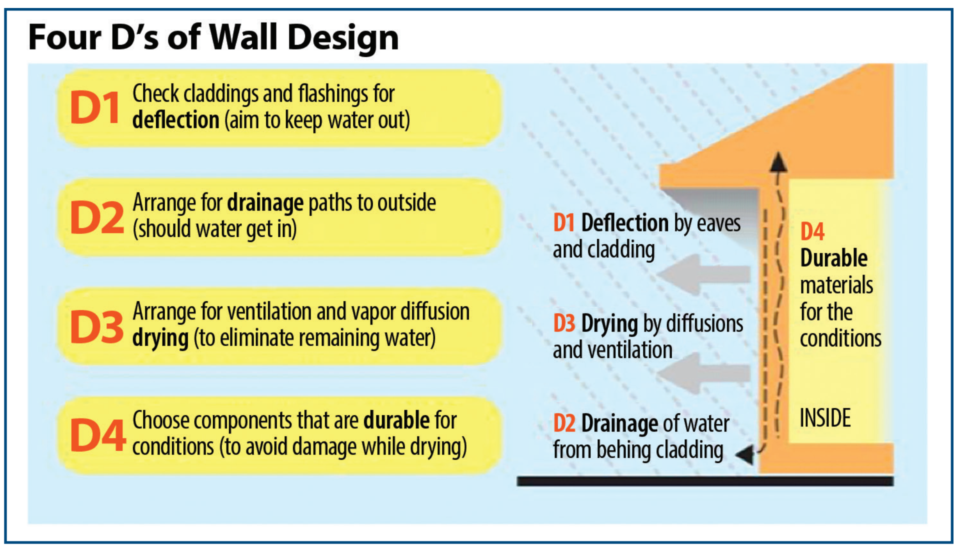

Figure 8 – The 4 Ds of wall design.

The 4 Ds of Exterior Wall Failure

Based on the author's investigation of hundreds of water-damaged walls over many years, it seems that there are also 4 Ds of wall failure that need to be understood and avoided. The 4 Ds of wall failure are as follows:

Direction (vs. Deflection): concentrated flow of water into the building envelope at roof/wall intersections, windows, balconies, transitions, etc.

Unlike deflection that keeps water off of exterior walls, direction concentrates water intrusion at locations where the building envelope is interrupted. The most common areas of water intrusion are roof/wall intersections, windows and doors, and balcony intersections. These are locations with potential for concentrated water intrusion.

While roof/wall intersections, windows, and doors have been known areas of water intrusion for years, balconies have become a more common problem since the introduction of mid-rise wood frame buildings that are susceptible to frame compression and shrinkage. Even when balconies are designed with a slope to drain water from the surface, this slope can quickly be eliminated or reversed as the wood frame wall compresses and shrinks. For this reason, many newer mid-rise wood frame building designs do not include balconies.

Dam (vs. Drainage): intimate wall cross sections that serve to trap water such as lapped siding, improper sealant joints, etc.

In the absence of clear and efficient drainage paths, water can get trapped in walls due to dams that are created in the wall assembly. The most common dams observed in wall failures are improperly installed sealant at window head flashing or the base of a wall, self-adhered flashing (SAF) tape over window sill nailing flanges, and tightly attached cladding components (typically cement board products) over a weather resistant barrier (WRB).

Damp (vs. Drying): absorptive materials that stay wet and cause migration of water into the wall assembly such as mortar droppings, conventional stucco, cement board products, etc.

If drying is not provided (typically by a drainage mat or an air cavity), dampness can develop in the wall assembly. Brick veneer cavities filled with mortar droppings are the most common areas for dampness to develop and stay in the wall. Similar conditions can develop in hard coat (aka conventional) portland cement stucco.

Distress (vs. Durable): the use of materials that are susceptible to damage caused by elevated moisture, such as wood, oriented strand board (OSB), medium-density fiberboard (MDF), steel fasteners, etc.

When building components are exposed to elevated moisture conditions, various types of distress can develop. Distress caused by elevated moisture conditions has been documented to range from corroded fasteners, to swelling and/or delamination of wall sheathing, to rotten wall framing and structural collapse. Of course, if water intrusion is significant enough, interior damages, including water-damaged finishes and mold, can develop, which can become a health concern for the occupants.

SUMMARY

The fundamentals of mid-rise wood frame construction can be favorable in the right circumstances. Wood used in constructing the buildings is both renewable and sustainable. However, based on forensic experience in investigating mid-rise wood frame buildings, the need for continuing education for designers and contractors in this area could not be greater, particularly as it relates to building movements and moisture management. Field evidence points to a lack of good design details necessary to prevent water intrusion into mid-rise structures, resulting in the premature failure of both structural and non-structural components. Publications of organizations such as the American Wood Council, WoodWorks™, and the U.S. Forest Products Laboratory are excellent for the science, requirements, and details for protection of wood products in buildings. However, while some organizations have been very active in continuing education, a need exists for education that specifically addresses "best practices" for design and construction to meet the challenges of mid-rise projects, as the collective experience of the industry for protecting wood in one- and two-story applications does not directly transfer to mid-rise wood structures.

The discussion and recommendations presented in this article are based on experience as a forensic engineer investigating mid-rise wood constructions with reported in-service performance issues. As such, the contents of the article may not be representative of the population of mid-rise wood construction throughout the U.S. However, because of the issues described above, design professionals and contractors should be prepared to "raise the bar" when asked to participate in a mid-rise wood frame project. Incorporating best practices means designing and constructing buildings above and beyond minimum building code requirements so that reasonable durability can be achieved.

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