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Dating back to my first wood design class at Virginia Tech, I explained on day-one a simple fact: Wood is not only a renewable construction resource, it is also sustainable. Being one who has spent his entire career in wood engineering research, teaching, and continuing education, witnessing construction of large Mid-Rise Wood Frame multi-family or mixed-use projects is a beautiful site to see. In this issue of WDF, three authors with a 100-year combined experience in structural design of wood buildings share their experience in four articles.

In Mid-Rise Construction—A Call for Best Practices, Derek Hodgin addressed some of the more common in-service performance issues he has observed in the Southeast and offered “best practice” suggestions for design professionals to consider. In his summary, he concluded “…design professionals and contractors should be prepared to “raise the bar” when asked to participate in a mid-rise wood frame project.”

In ¼ in 12 Design Slope and Water Drainage (Part 1), Scott Coffman reviewed the code requirements for low-slope roof design and demonstrated by deflection analyses and drawings how the use of the common specification of “¼ per ft.” seen on building plans can lead to roof areas with near zero slope due to design loading and creep deflection. He concluded, “Members optimized to a code permitted deflection ratio further reduce the average slope and may create a negative slope or a “bowl” at the low end that limits or prevents free drainage.”

In Low Slope Roof and Deck Design Considerations (Part 2), Scott Coffman identified design and construction practices that limit or prevent free drainage and offered potential solutions to mitigate ponding that contributes to serviceability issues and structural framing damage. In his conclusions, he offered strong motivation for anticipating and acting on in-service water issues on the “front end” of a project having a low-slope roof: “Practices or conditions that inhibit or prevent the flow of water toward free drainage should be identified during the design phase and changed.”

In Resources for Guidance on Mid-Rise Wood Design, Terry Malone summarized key organizations and resources for Mid-Rise Design and listed a sample of resources specific to Mid-Rise: Design Example: Five-story Wood-Frame Structure over Podium Slab, Accommodating Shrinkage in Multi-Story Wood-Frame Structures, Options for Brick Veneer on Mid-Rise Wood-Frame Buildings, and Maximizing Value with Mid-Rise Construction. I was surprised to learn of the availability of the sample publications listed and encourage the reader to go to http://www.wood-works.org/ and search “mid-rise construction” in the top-right box.

It was indeed a pleasure to serve as the Mid-Rise Focus Editor and interact with the authors for this edition of WDF. I believe the reader will conclude the Mid-Rise articles are deserving of careful review and consideration.

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Mid-Rise Construction—
A Call for Best Practices

Derek A. Hodgin, P.E., RBEC, CCCA

Abstract
Over the past several years, the author 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 the wood framing and exterior cladding components can cause physical damages to building envelope components that increases the extent of water intrusion. Once the water reaches the wood framing components, significant damages such as decay, corrosion and mold can result. Additionally, once compromised, the effectiveness of products used to meet fire resistance requirements is unknown.

Introduction
Mid-rise wood-frame construction is now a designer’s choice for efficient and cost effective construction of mixed-use buildings. Most often, the buildings include retail and/or parking on the first couple floors and multi-family residential units on the upper 4-5 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 methods and materials (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 serve to 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 extent of future problems observed in the field.

KEYWORDS: wood, envelope, water, intrusion, damage
Limitations of wood framing
Practices that work well for 1 or 2 story residential are not necessarily adequate for 4 to 5 story wood frame structures. Specifically, the issues described below should be considered and addressed for mid-rise wood frame buildings.

Frame 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 4 to 5 stories.

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.

Frame 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 4 to 5 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 can cause water intrusion due to vertical movement.

A shrinkage analysis is now required by the building code for wood-frame buildings greater than 3 stories. According to the building code, the analysis must be provided to the satisfaction of the building official. However, experience thus far has indicated that shrinkage calculations are commonly not being performed, requested or reviewed on many mid-rise wood projects. In fact, out of approximately twenty-five (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 is most useful when considered by designers of electrical, plumbing and the building envelope, the components most impacted by building movement. Collectively, the combination of frame compression and shrinkage can cause vertical movements of nearly 1 inch per story.

In an effort to reduce frame shrinkage, hand held moisture meters should be used to check the moisture content (MC) of the lumber at the time of delivery to ensure the MC is consistent with the grade-marked maximum. Another suggestion is to return to the use of KD15 Southern Pine that was widely available prior to 1991; however, this change would require adoption by the southern pine lumber industry, as it is currently unavailable. Moreover, re-drying of KD19 lumber to KD15 MC is not recognized with respect to the validity of the marked grade on the piece when manufactured to the KD19 standard.

Deflection Design 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. The building code has long required a minimum slope of ¼ inch per foot 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 inch per foot (Figure 2). 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 wood framing that is susceptible...
Preliminary engineering analysis suggests that doubling the slope to ½ inch per foot 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.

**Inside/Outside Corners**

In order for these larger buildings to have architectural appeal, many local ordinances require exterior walls to include setbacks or reveals (Figure 3). 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. An open gap, joint, unsealed or reverse lap can, and often does, lead to significant water-related damage.

**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 intersect.

**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 require 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. While the code has done a good job requiring slope on roof surfaces, the code has not

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**Figure 2: Typical ponding where the valley of a roof cricket is less than ¼ inch per foot.**

**Figure 3: Typical ordinance-driven architectural details that require walls to have "reveals" in exterior walls, creating numerous inside/outside corners.**

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**Ordinance-driven Architecture**

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.
done a good job addressing balcony drainage. However, balcony surfaces can be more problematic than a roof. Proposed changes to the 2018 International Building Code (IBC) will provide balcony slope and other important 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 drainage plane. Water intrusion at these intersections is not only a nuisance to the occupant, but can cause a life/safety issue if fastener corrosion or decay of wood framing develops. 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 incompatible with wood framing, particularly if used on a 4 to 5 story building. One example is brick veneer. Brick veneer grows due to absorption of moisture in-service. Wood framing will typically shrink and/or compress due to changes in moisture content and the application of dead and live loads during construction and in-service, respectively. 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, an adjacent wall component (such as a window) and/or reverse the slope of the flashing and direct water toward the building (Figure 4). Visit [http://www.woodworks.org/wp-content/uploads/Options-for-Brick-Veneer-Wood-Solution-Paper-Oct-2015.pdf](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 where water intrusion and building envelope issues may exist. When the wood frame gets wet, it is susceptible to decay. 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 related framing (Figure 5). 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.

Role of Roof Overhangs

The benefits of a roof overhang are significant. A roof overhang can dramatically reduce the extent that an exterior wall is exposed to rain. As depicted in Figure 6, the percent 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. 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.

Other Factors

Disconnected Occupants

Most mid-rise wood frame buildings are commonly being constructed to serve as apartments. These apartments typically provide temporary housing for younger occupants, such as college students. College students can be more abusive to a building than older, more mature, longer-term occupants. Therefore, less robust construction will likely show signs of distress earlier in the service life of these buildings, when compared to an owner-occupied single family home or condominium of similar construction. Additionally, water intrusion is simply a nuisance to the temporary occupant that may be overlooked and/or improperly addressed, such that more significant damages can develop.

When an apartment problem is reported, the symptom is often dealt with instead of the cause. If water intrusion is observed, the damaged area may be repaired and some exterior caulk applied to prolong the reporting of the next water intrusion event. If not properly corrected, structural integrity can be compromised and the interior building conditions (i.e. mold growth and air quality) can become a health risk to the occupant. This is not to suggest that owner-occupied mid-rise condominium buildings are not problematic; however, when the occupant has “skin in the game,” an appropriate and comprehensive response to a problem is more likely.

Misguided Construction/Design Budgets and Schedules

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 Owner/Developers that 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 that 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) mock-up walls being constructed and/or tested, 3) flood-testing of balconies, or 4) spray 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.
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 7).

When contractors are rushed to complete projects, 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 8). Proper construction 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, that is not the case. Bulk water intrusion issues must be dealt with immediately in wood frame construction for problems to be avoided.

Building Envelope Discussion
A durable building envelope must be able to receive water, manage water and shed water. The construction materials that encounter rainwater along its 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 4 Ds: 1) Deflection, 2) Drainage, 3) Drying, and 4) Durable⁸ (Figure 9). In order to reduce water-related damages, these concepts are needed on all buildings, not just mid-rise wood frame buildings.

Summary
The fundamentals of mid-rise wood-frame construction...
are clear and favorable—the application is both economical and the wood used in constructing the buildings is both renewable and sustainable. Based on the author’s forensic experience 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, at least in this area of practice, 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 of mid-rise projects, as the collective experience of the industry for protecting wood in 1 & 2-story applications does not directly transfer to mid-rise wood structures.

The discussion and recommendations presented in this article are based on the author’s experience as a forensic engineer investigating mid-rise wood construction 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 to design and construct buildings above and beyond minimum building code requirements so that reasonable durability can be achieved. For designers, this would include things like: providing more slope on roof, balcony and walkway surfaces; exaggerating the joints and flashing details at cladding transitions to accommodate frame compression/shrinkage; specifying WRB products that are not vulnerable to installation errors; and, providing reasonable roof overhangs to keep water off of exterior walls. For contractors, this would include things like: negotiating a reasonable schedule to complete the project properly; sequencing the subcontractors in an orderly and proper fashion that does not make the building vulnerable to damage; enlisting the assistance of a design professional and/or specialty consultant when needed; being familiar with building envelope design concepts so that the building is continuously being surveyed for potential issues and they are dealt with in a timely fashion.
References


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