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Editorial

Mid-Rise Wood Design & Construction

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.woodworks.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.

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

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[1].

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[2]. 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[1].

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[3, 4]. 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

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

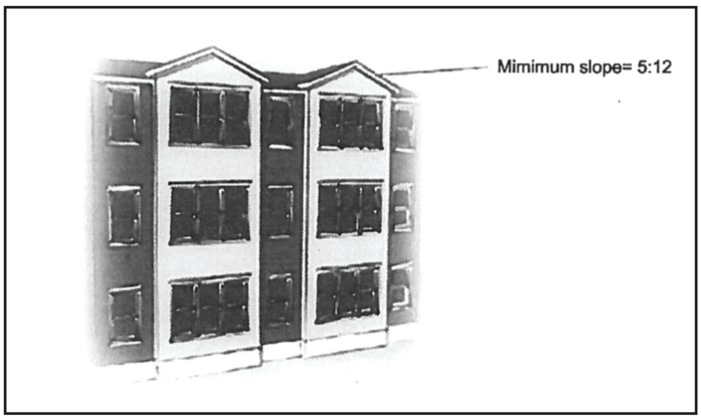

Figure 3: Typical ordinance-driven architectural details that require walls to have "reveals" in exterior walls, creating numerous inside/outside corners.

to deflection and creep. 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.

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.

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[5]. 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 done a good job addressing balcony drainage[6]. 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 for design options when using brick veneer.

Figure 4: Brick damage caused by differential building movement.

Figure 5: Moisture Damage behind stucco caused by improper integration of 2 layers of WRB.

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

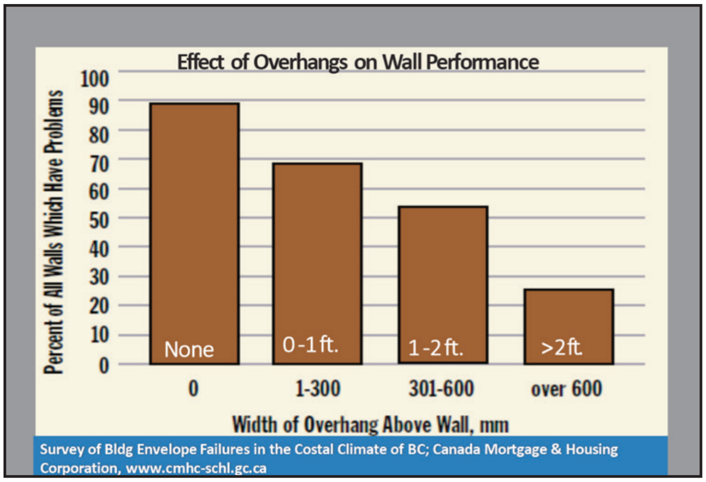

Figure 6: Correlation between roof overhang width and wall performance problems.

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[7]. 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.

Figure 7: Water intrusion/damage of a mid-rise wood frame building under construction.

Figure 8: A haphazard sequencing of multiple trades on the exterior wall of a building under construction.

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) Durable[8] (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

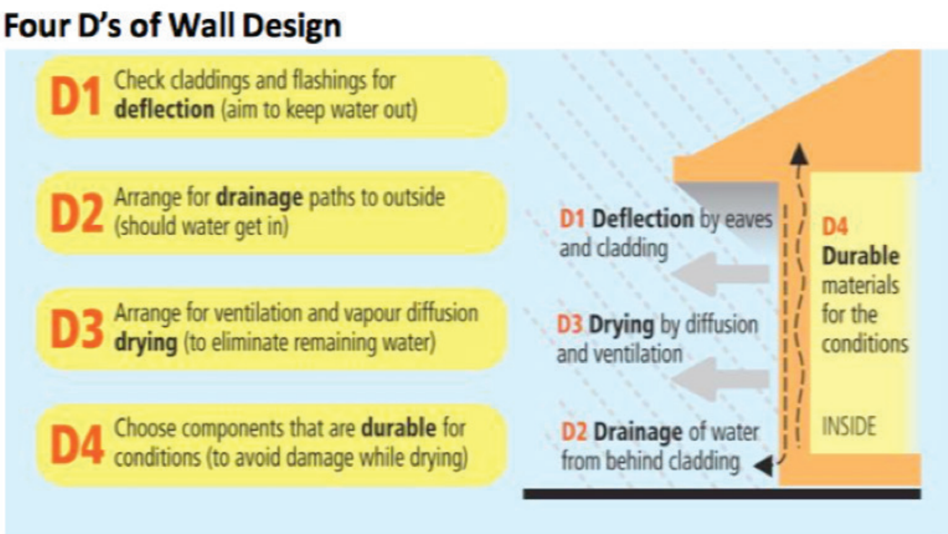

Figure 9: The Four D's of Wall Design.

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.

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¼ in 12 Design Slope and Water Drainage: Part 1[1]

Scott D. Coffman, P.E., SECB

Introduction

Construction Science and Engineering, Inc. an architectural and engineering firm, has investigated several low slope roof applications with water stains, ponding, framing damage on the lower side of the roof span, and structural collapse. Further examination typically reveals a relative level surface when compared to other roof locations (Figure 1). A similar occurrence is often found in exterior deck applications (Figure 2). In studying this potentially problematic issue, two building code parameters were identified that contribute to low slope roof and deck serviceability issues. This article examines susceptible bays with respect to the 1/4 in 12 design slope and code permitted deflection ratios. Part 2 will identify design and construction practices that contribute to serviceability issues.

Figure 1: Evidence of ponding on the roof.

Background

The *2015 International Building Code* (IBC) identifies ponding instability as a design consideration for snow and rain loads. The 2010 edition of the *Minimal Design Loads for Buildings and Other Structures* (ASCE 7-10), referenced by the IBC defines "ponding" as the "retention of water due solely to the deflection of relative flat roofs." The standard requires "susceptible bays" be investigated to ensure adequate member stiffness is present to prevent progressive deflection. Specifically, "Bays with a roof slope less than 1/4 in./ft. ...shall be designated as susceptible bays. Roof surfaces with a slope of at least 1/4 inch per foot (1.19°) toward points of free drainage need not be considered a susceptible bay." The phrase

Figure 2: Ponding water on the deck.

KEYWORDS: ponding, level, deflection, creep, balcony

[1] *Reprinted with permission,* STRUCTURE *magazine September 2017*

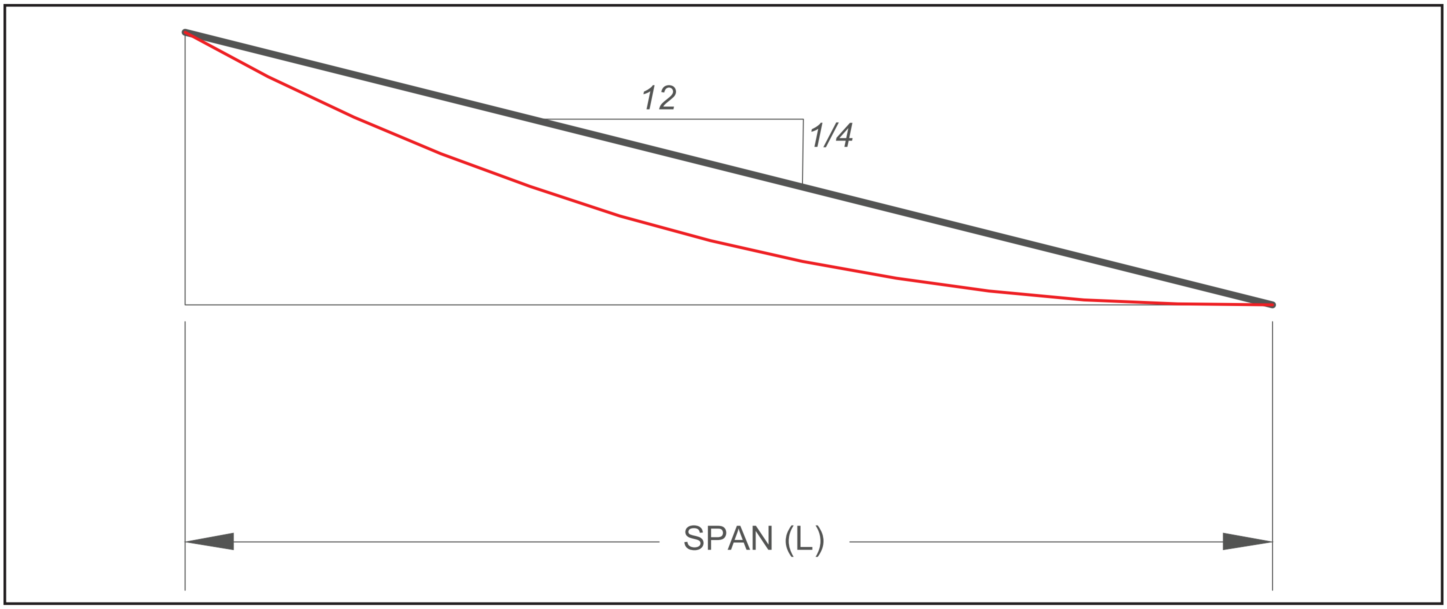

Figure 3: Deflected shape of beam with uniform load.

"toward points of free drainage" is critical because it gives meaning to what is meant by a slope of 1/4 inch per foot. The same principle may be applied to exterior decks, although decks are not specifically identified within ASCE 7-10.

Building designers routinely stipulate within construction documents the well-known code minimum 1/4 in 12 design slope for low slope roofs and exterior deck applications. This practice, on the surface, appears to eliminate the code requirement to investigate a susceptible bay. Additionally, common practice is to specify or accept minimum building code deflection ratios for low slope applications. However, many building designers apparently fail to give due consideration to footnote "e" in IBC Table 1604.3 which states in part; "The above deflections do not ensure against ponding…"

A code defined deflection ratio is a function of span and is therefore not influenced by material characteristics and design load variables. Each deflection ratio defines the deflection limits that are commonly approached as structural members are optimized for cost. Bender and Woeste recognized this relationship and showed a beam member installed to a 1/4 in 12 slope that deflects to a code permitted deflection ratio results in an average slope less than 1/4 in 12. They also noted the average slope is further reduced when a long-term creep deflection component is introduced.

The Bender and Woeste (2011) study validates the author's field observations for serviceability complaints and water retention associated with low slope roof and deck applications. The deflection curve was approximated using the properties of a circle to verify the average slope was independent of the span and remained unchanged for a specified deflection ratio. Additionally, the lower end of the deflection curve was noted to be relatively flat, which explained potential causes of observed ponding. In the author's company's study, surfaces with a design slope of a least 1/4 in. per foot or less should be considered as a susceptible bay. Specifically:

1. The average slope of the deflected member is less than ¼ inch per foot; and,
2. At and near the lower reaction, the deflected member is relatively horizontal or flat.

Figure 3 visually depicts the downward movement of a beam member subject to load and vulnerability to ponding at the low end.

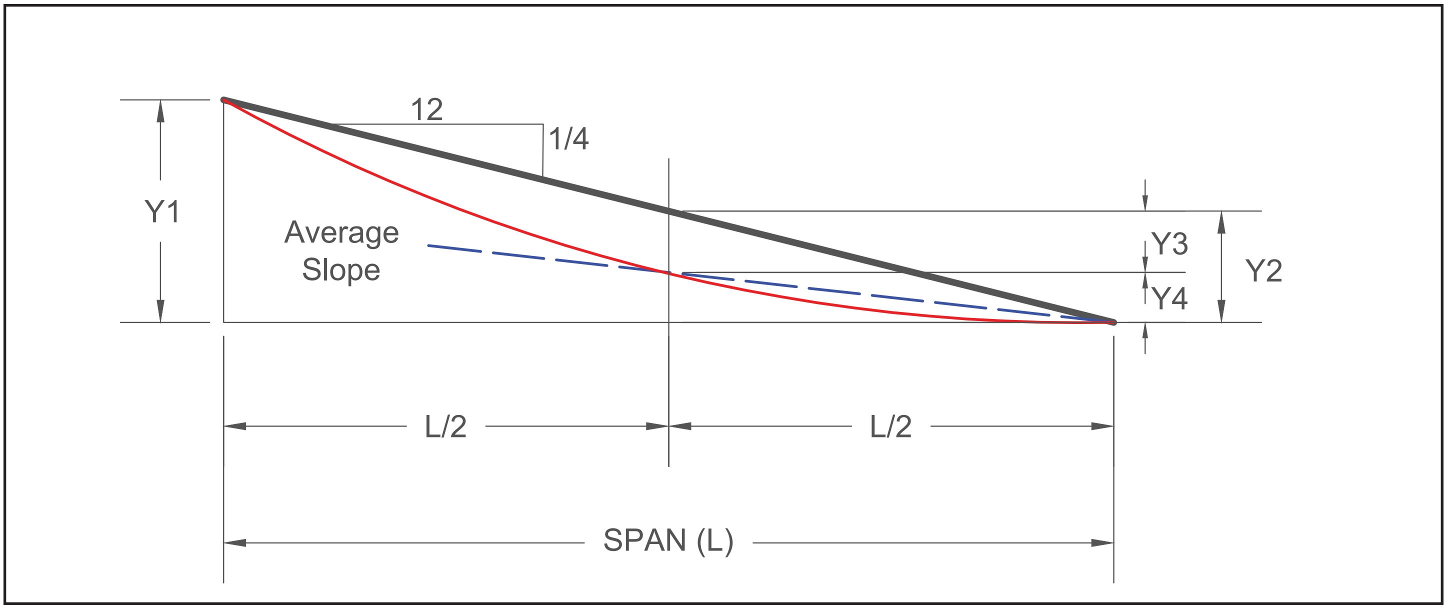

Figure 4: Average slope of deflected member.

Average Slope Example

The average slope for the performance of a member installed to a 1/4 in 12 design slope and permitted to deflect to a code permitted L/180 ratio is illustrated by the following example:

- Member Span: 25 feet
- Roof Total Load Deflection Limit: L / 180
- Right Support Datum Elevation: 0.00 inches
- Left Support Elevation: 6.25 inches (Y1)
- Midpoint Elevation: 3.13 inches (Y2)
- Member Total Load Deflection (L/180): 1.67 inches (Y3)
- Distance from datum to deflected member: 1.43 inches (Y4)

The "average slope" is the slope of a line from the low end support to the point of maximum deflection for a member. For a simply supported beam member subjected to a uniform load, the average slope is from the center of the span to the low end support. In this example, the right support is the low end and point of free drainage.

Figure 4 shows the original member slope and deflected shape. The distance from a level datum to the deflected member is 1-7/16 inches (Y4); the difference between the member's original position and code permitted deflection ratio at the mid-span. The average slope from the center of the member's deflected shape to the low end support is 0.117 inches per foot, a slope less than 1/8 in 12 or nearly flat. When a member initially installed to a ¼ in 12 design slope deflects and approaches the total load L/180 code permitted deflection ratio, the average slope becomes less than 1/8 in 12. The calculated 0.117 in 12 average slope is constant for any span designed to the L/180 deflection ratio.

ASCE 7-10 explicitly identifies member stiffness as a means to control progressive deflection of a susceptible bay. Design professionals typically specify a more limiting deflection ratio than required by the building code for the application to achieve a stiffer member. As expected, the average slope approaches the 1/4 in 12 design slope for a stiffer member or a higher deflection design ratio. However, a beam element subject to gravity load deflects and the average slope remains less than the designed 1/4 in 12 design slope. Therefore, a beam element installed with 1/4 in 12 slope requires a "susceptible bay" analysis based on ASCE 7-10 since all members deflect under load.

Deflection Curve at the Lower End

The lower end of the deflection curve is also a typical

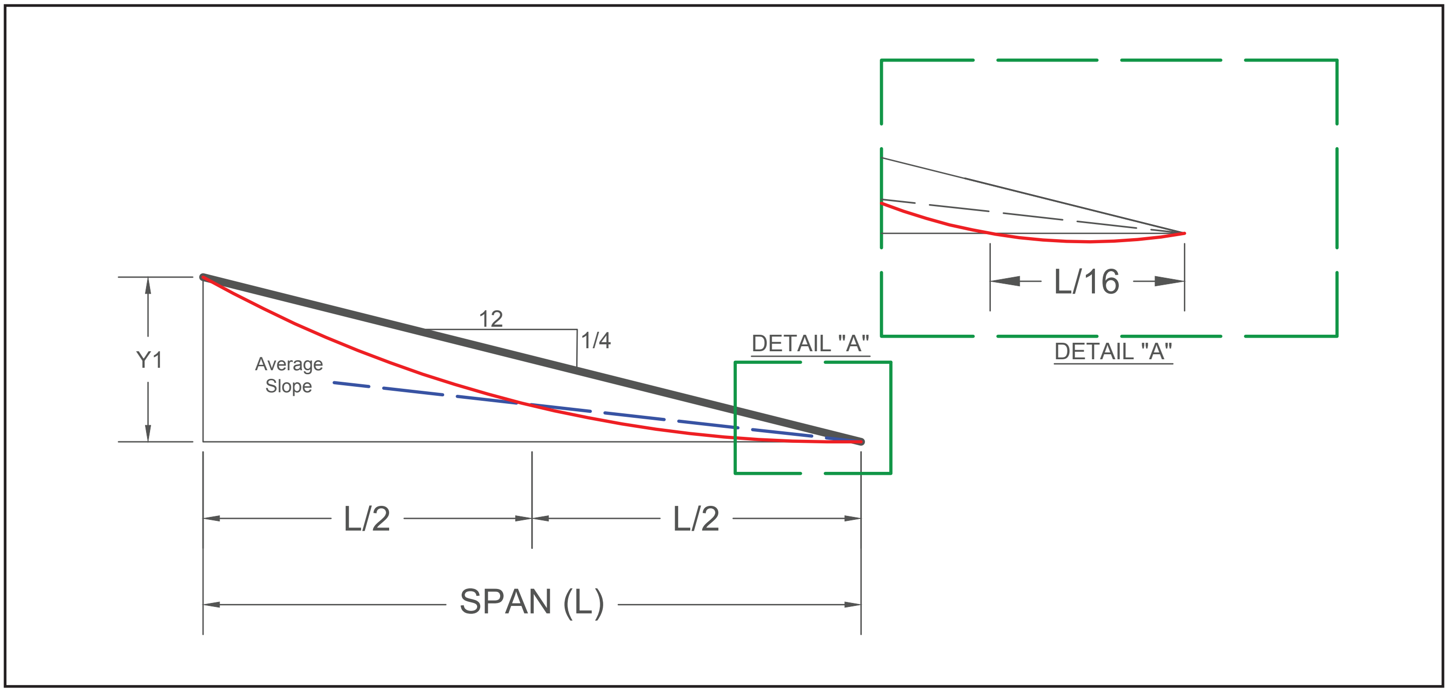

Figure 5: A typical location of ponding.

location for ponding, water stains, and damaged framing members (Figure 5). This opinion is based on observations made during forensic investigations. The vertical difference between a 1/4 in 12 plane and the L/180 deflection curve was calculated for spans of ten feet to forty feet in 2-foot increments. The deflected shape crosses the horizontal datum in the region of L/16 creating negative slope and a "bowl" at the low end. A "bowl" naturally retains water and restricts free drainage or water discharge. Ponding or water retention should be expected toward the low end of a plane designed to a 1/4 in 12 slope.

Long Term Creep Effects and Example

Structural materials susceptible to long-term creep intensify the deflection curve. The IBC estimates the creep component of long-term deflection to be half the immediate dead load deflection or a 1.5 factor. The creep deflection component may approach the initial dead load deflection, a 2.0 factor for wood products. The 2014 Truss Plate Institute Standard (TPI) recommends the 2.0 factor where the building designer does not specify adjustment factors for serviceability. The 1.5 building code factor was applied by the author for a "best case" scenario to study the effects of creep deflection.

Continuing the previous example, the initial dead load deflection is taken as the difference between the roof's total load (L/180) and roof's live load (L/240) deflection ratios. This calculates to 0.42 inches (1.67 – 1.25) for a 25-foot span. The long-term creep component is 0.21 inches (½ * 0.42). The center of the deflected member is 1.25 inches (Y4') above the right end support (3.13 – 1.67 – 0.21). The average slope from the center of the member deflection curve to the support is 0.10 inches or essentially no slope and remains constant for any span (Figure 6).

Although the average slope with a creep deflection component remains positive, albeit small, the low end of the member deflection curve remains of particular interest. The deflected shape crosses the horizontal datum in the region of L/6 creating a larger "bowl" area for ponding (Figure 7). As the dead load becomes a greater percentage of the total load, creep deflection increases and the "bowl" effect becomes more pronounced at the low end. It is imperative that deflection calculations include material long-term creep effects when compared to the ordinary live and total load code permitted deflection ratios.

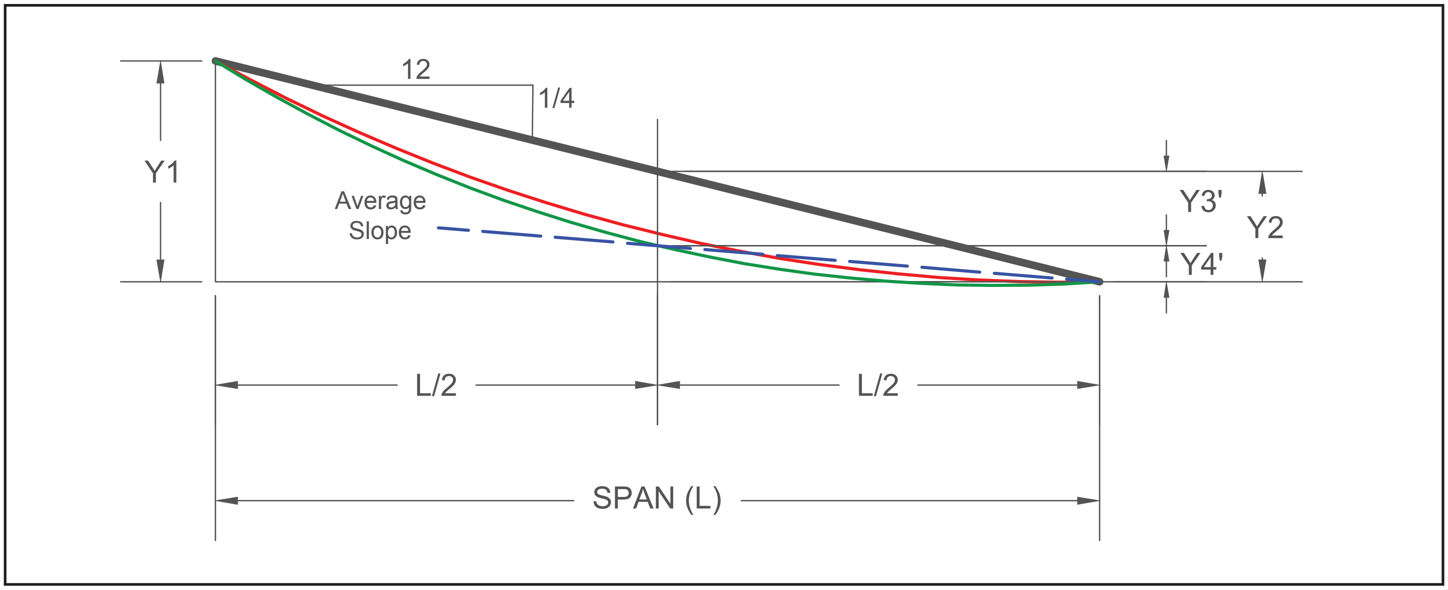

Figure 6: The average slope of the member with creep.

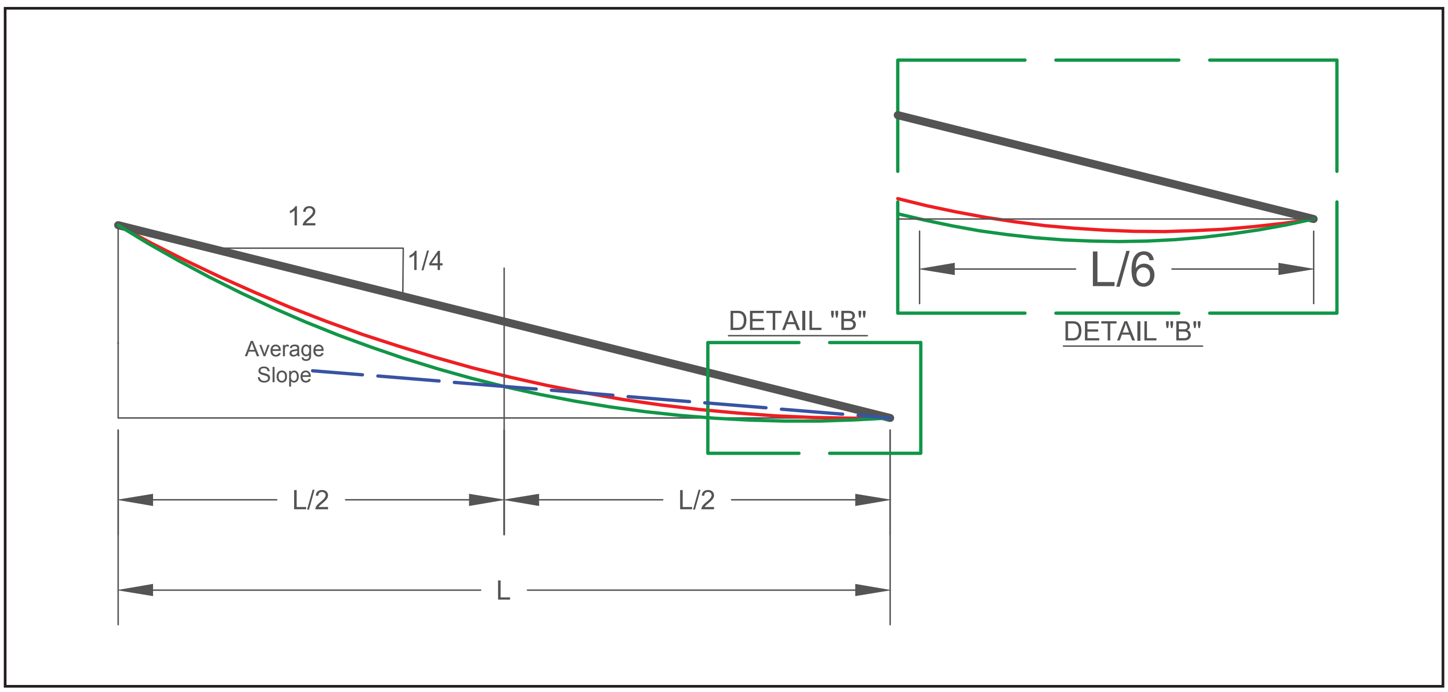

Figure 7: Increased "bowl" is caused by member creep.

Potential Design Solutions

Potential solutions to mitigate low slope serviceability issues are limited. ASCE 7-10 indirectly promotes a more stringent deflection ratio to prevent progressive deflection. The ASCE solution is imperfect because stiffer members increase the cost and the average slope remains less than 1/4 in 12. A member or plane designed to an "average slope" of 1/4 inch per foot is one method to mitigate ponding and resultant material damage. For a simply supported beam member subjected to a uniform load, the average slope line is from the point of maximum deflection at the center of the span to the low end support.

A more practical solution is a combination of increased slope and member stiffness. Design tools currently available afford a quick and efficient means for a designer to calculate the average slope of a member; the "average slope" being the slope of a line from the low end support to the point of maximum member deflection. A combination of increased member stiffness and design slope that results in a surface with an average slope of at least 1/4 inch per foot towards points of free drainage should eliminate susceptible bays.

Summary and Conclusions

The building code establishes the minimum parameters for building design. A member or system that satisfies each individual code parameter, may create a less than ideal condition when multiple minimum code parameters are combined. The combination of the 1/4 inch per foot design slope and a maximum permitted deflection ratio creates such a condition for free drainage. The code, however, does recognize this potential condition in IBC Table 1604.3 footnote "e" and instructs a building designer to investigate applications with insufficient slope or camber for ponding.

Building designers, contractors, and perhaps code officials have come to believe a roof or exterior deck surface designed to the 1/4 inch per foot slope is satisfactory because it meets building code intent. However, member deflection creates an average slope that limits free drainage and contributes to ponding toward the low end.

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. The condition is exacerbated for materials susceptible to creep deflection. Beam elements designed and/or installed to the 1/4 inch per foot slope should be considered a susceptible bay.

In the absence of code performance limits for low slope roofs, a building designer should consider implementing a more stringent total load deflection ratio, increase the minimum slope for positive drainage, design to an "average slope" of 1/4 in 12, or a combination of each. The practice should also be extended to decks.

Scott D. Coffman, P.E., SECB, has over 35 years in structural wood design, engineered wood building components and forensic engineering experience. This experience includes product testing, field investigations, FRT lumber, construction related problems, building envelope, expert testimony, and product application and serviceability. scottcoffman@constructionscience.org

Low-Slope Roof and Deck Design Considerations to Mitigate Ponding and Water Intrusion: Part 2[1]

Scott D. Coffman, P.E., SECB

INTRODUCTION

The author's company, a forensic engineering and architect firm, has investigated hundreds of low-slope roof and exterior deck applications with water stains, ponding, framing damage, and structural collapse. The first article, Part 1: *1/4 in 12 Design Slope and Water Drainage* (page 11), examined two building code parameters that contribute to low-slope roof and deck serviceability issues. This article identifies design and construction practices that limit or prevent free drainage. Potential solutions are presented to mitigate ponding that contributes to serviceability issues and structural framing damage. The goal is to raise awareness in the construction industry of typical practices that may cause harm to structural members and the building envelope.

Background

The 2015 *International Building Code* (IBC) establishes minimum parameters for building design and construction. A member or system that satisfies applicable individual code parameters may create a less than ideal condition when multiple minimum code parameters are combined. For example, the combination of the ¼-inch per foot design slope and a maximum permitted deflection ratio can create a condition that inhibits free drainage. The IBC, however, does recognize this potential condition in Table 1604.3 footnote "e" and instructs a building designer to investigate applications with insufficient slope or camber for ponding.

KEYWORDS: low-slope, valley, ponding, deflection, water intrusion

Design professionals, contractors, and perhaps code officials have come to believe a roof or exterior deck surface designed to the ¼-inch per foot slope is satisfactory because it meets building code intent. However, member deflection creates an average slope that limits free drainage and contributes to ponding toward the low end. The "average slope" is the slope of a line from the low end support to the point of maximum deflection for a member. Members optimized to a code permitted deflection ratio further reduce the average slope and may create a negative slope or a "bowl" condition at the low end that limits or prevents free drainage. The condition is exacerbated for materials susceptible to creep deflection, such as wood. Beam members designed and installed to the ¼-inch per foot slope should be considered a susceptible bay. Readers are encouraged to read the first article for additional information and potential solutions.

Field observations have identified common design practices that contribute to serviceability issues. These design blunders limit or prevent free drainage and result in unsatisfactory building envelope performance. Additionally, the absence of specific design details and reference to a "best practice" often result in typical construction practices that may meet the general intent of the building code, but limit free drainage.

Design Blunders

When design professionals specify framing members to minimum building code parameters alone, it is possible for the constructed roof to have in-service low-slope issues related to ponding or drainage of the system.

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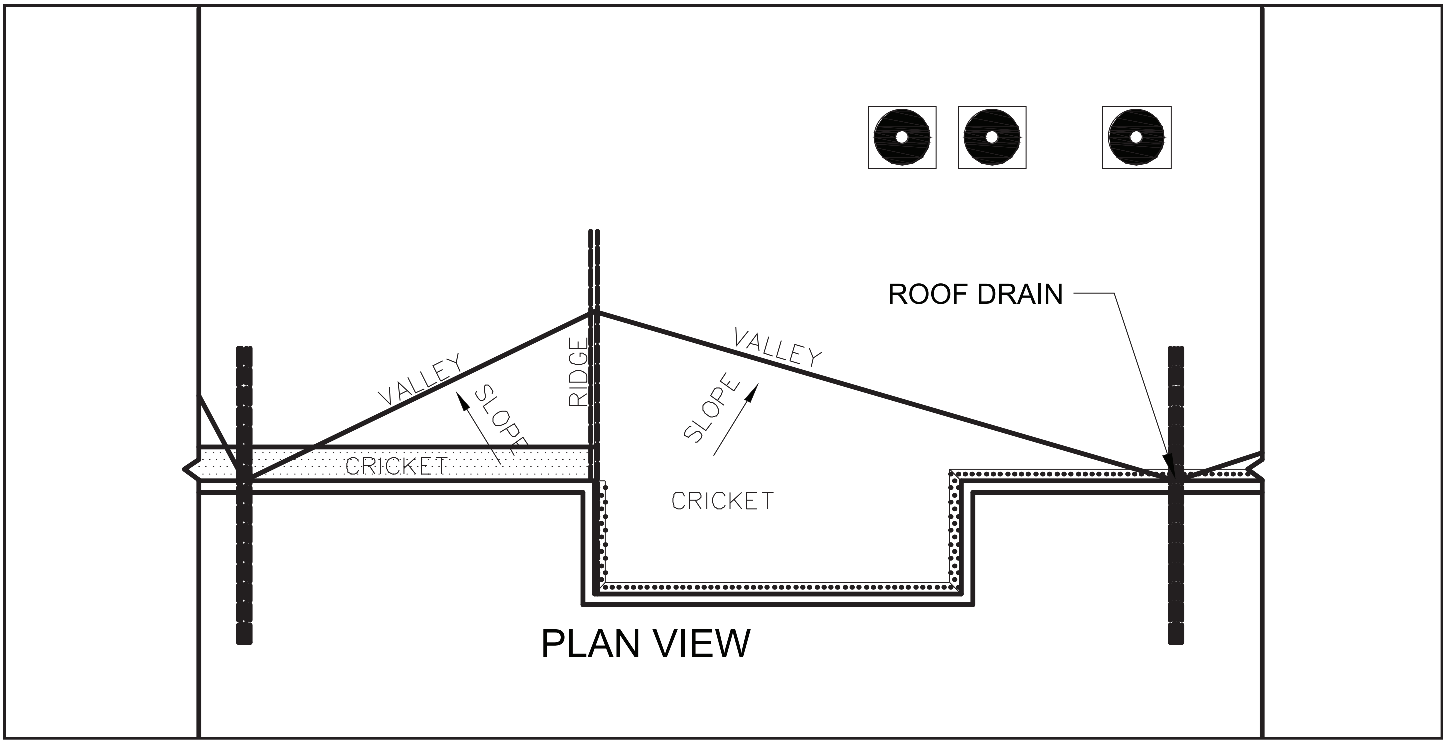

Figure 1: Common minimum roof slope plan with valley.

Five common design blunders that contribute to low-slope issues and potential solutions are summarized below.

1. Intersecting Planes

Building offsets are common and create intersecting planes that contribute to drainage issues for low-slope applications. Design professionals frequently specify the minimum code-permitted slope with little, if any, consideration of the resultant valley slope created by the intersecting planes (Figure 1). Ponding water is commonly observed at valley intersections for low-slope roof and deck (balcony) applications.

The diagonal distance between two fixed elevation points is less than the design slope. This principle can be illustrated by two sloped planes that intersect at a right angle (Figure 2). The eight-foot wide balcony with a specified 1/4 in 12 slope has a two-inch elevation drop from the wall to the free drainage edge. The diagonal distance denoted in red has the same two-inch elevation change. However, the elevation change occurs over a distance of approximately eleven feet four inches, creating a slope less than the 1/4 in 12 minimum slope.

The 2010 edition of the *Minimum Design Loads for Buildings and Other Structures (ASCE 7)* published by the American Society of Civil Engineers (ASCE) and referenced by IBC states in part "surfaces with a slope of at least ¼-inch per foot toward points of free drainage need not be considered a susceptible bay." Therefore, roof and balcony surface areas designed to a 1/4 in 12 slope that intentionally direct water to a valley should be considered a susceptible bay. A potential solution is to assign the 1/4 in 12 slope to the valley and calculate the associated roof or balcony slope to be shown on the construction documents.

2. Integrated Columns

Building codes and accepted design practice incorporate "crickets" to divert water for effective drainage. Balcony support columns present conditions that are rarely detailed within the

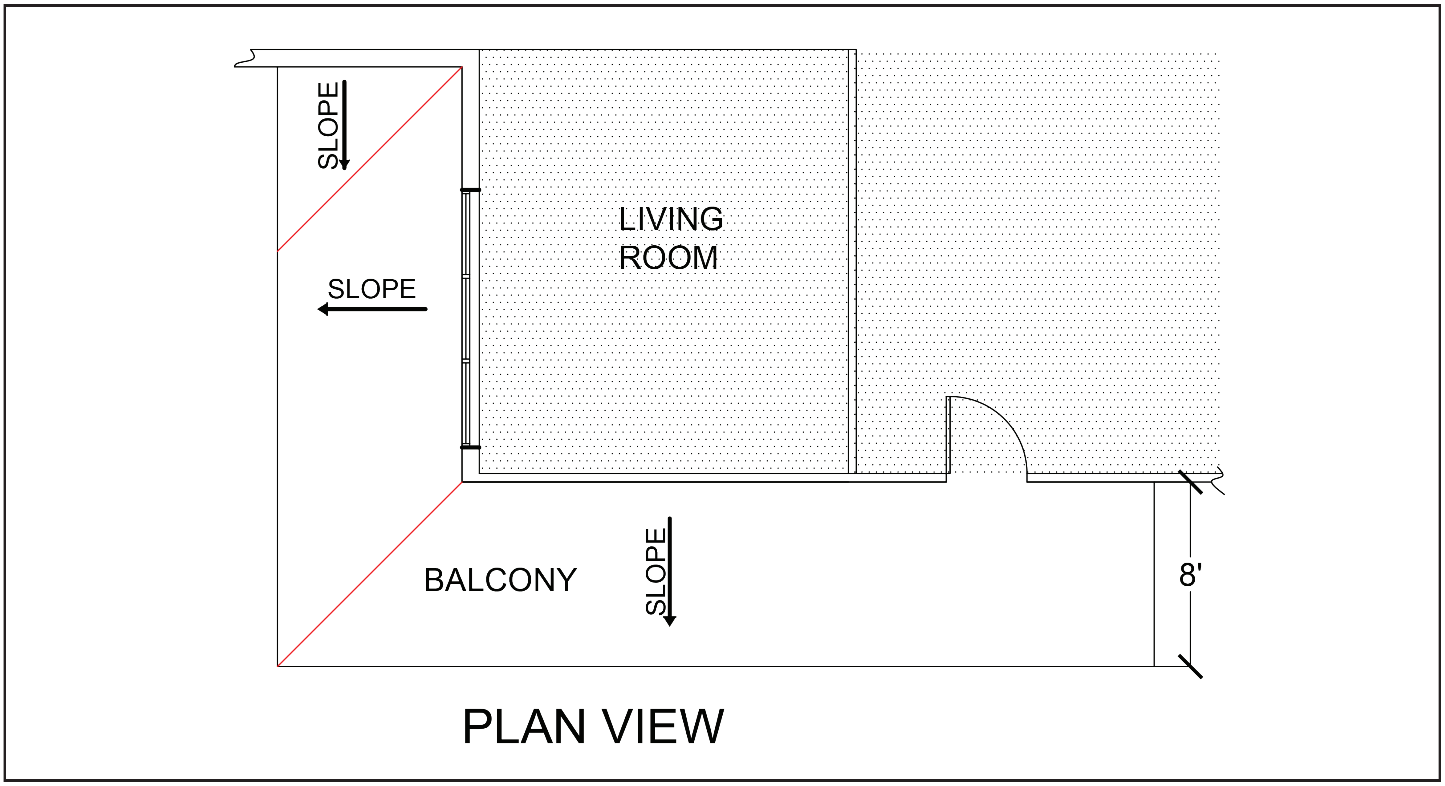

Figure 2: The design slope is reduced at slope plane intersections.

Figure 3: Integrated balcony columns without drainage provisions.

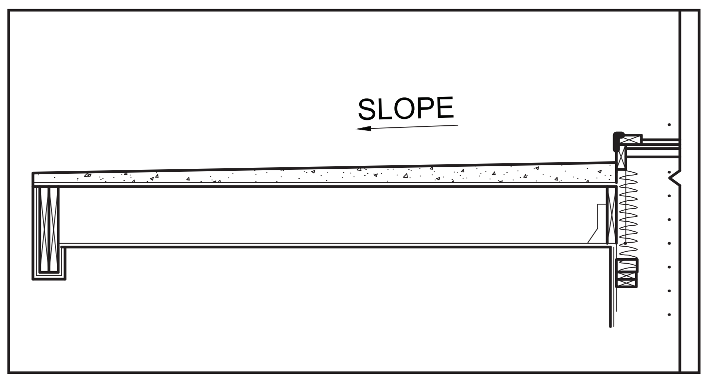

Figure 4: Slope obtained with finish topping.

construction documents. Design professionals routinely design integrated exterior balcony columns that serve as "dams" that inhibit water from flowing toward points of free drainage (Figure 3). Columns are frequently located at the balcony perimeter and contain interior edges or corners. Water becomes trapped at the interior edges and often contributes to damage. Design professionals should provide clear details that divert or allow free drainage at these locations throughout the life of the building.

3. Sloped Concrete Surface

Many design professionals specify horizontal framing members with a sloped topping surface for drainage (Figure 4). The topping surface is typically a lightweight concrete product installed in a semi-fluid state. Specifications for a "stiff" slump test or to install with a stipulated slope are difficult at best, rarely achieved,

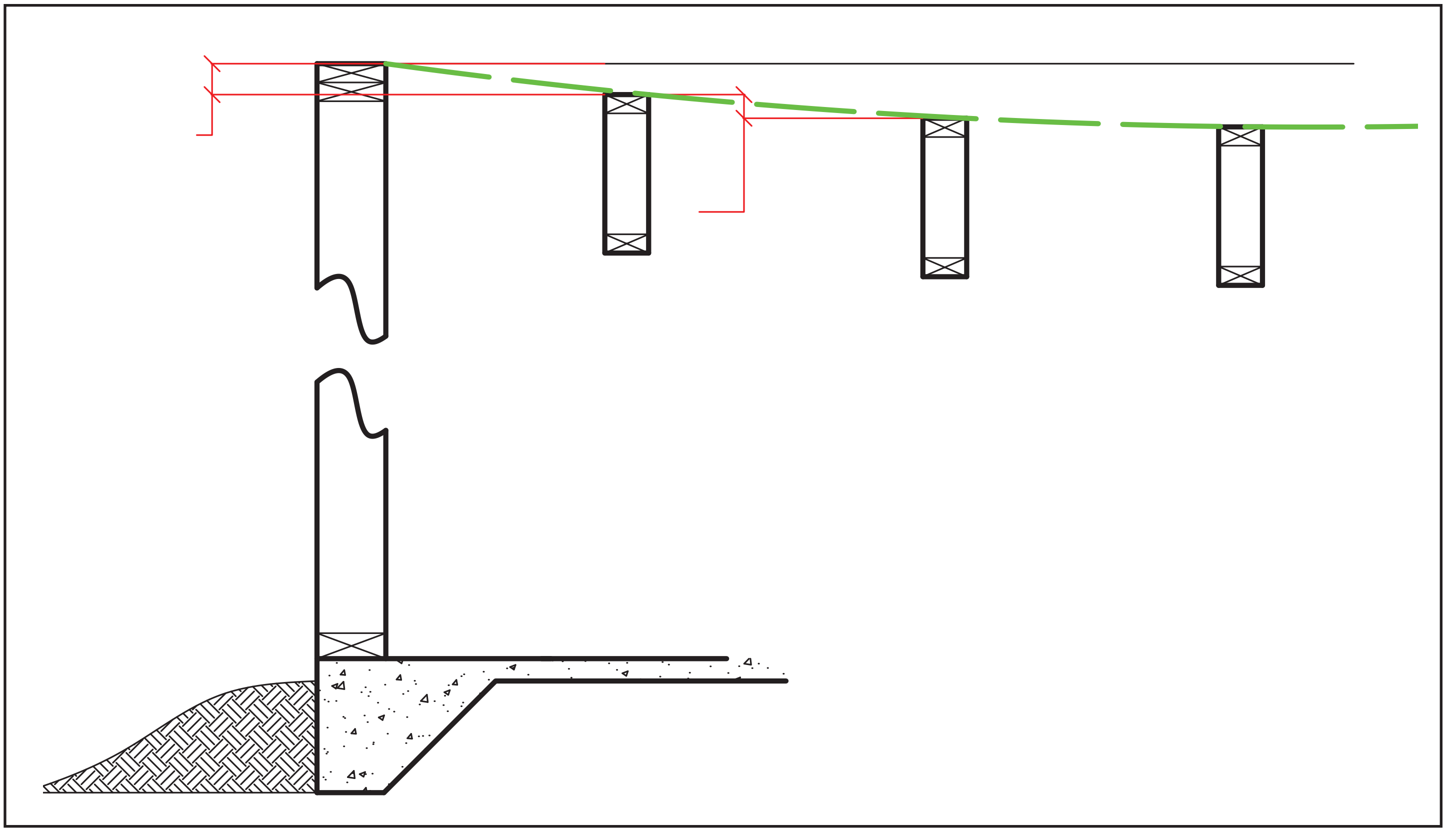

Figure 5: Differential deflection adjacent to wall.

and often result in a constructed level surface. Water percolates the permeable topping surface to the horizontal plane created by the support members. Free drainage rarely occurs since the support member is level or deflected vertically downward, allowing water to pond. Forensic investigations often encounter damage to support members when water finds a breach in the protective membrane between the topping surface and structural framing.

Structural members should be designed and oriented with a positive slope toward points of free drainage for water discharge. The topping surface should conform to the structural member slope to maintain positive drainage. Water that permeates the topping surface encounters the sloped surface and is directed toward the desired free drainage location.

4. Wood Framing Members

The use of ripped, solid sawn framing members is a common design and construction practice to achieve a desired slope. Lumber grade marks are assigned in accordance to criteria outlined in the code referenced *American Softwood Lumber Standard* (PS 20). The standard specifically states that the remanufacture (ripping) of a graded or grade marked wood member negates the mark and associated design values of the original product.

The "ripping" of lumber members can be eliminated by modifying the framing detail. One option is to install each end of the lumber member at two distinct elevations to achieve the desired slope. A ceiling joist or furring may be required to obtain a "flat" ceiling. A second option is to specify a truss with the desired top chord slope for drainage and horizontal bottom chord for ceiling attachment.

Another common framing technique orients the framing member perpendicular to the free drainage slope direction. Forensic investigation of this condition typically finds water accumulation toward

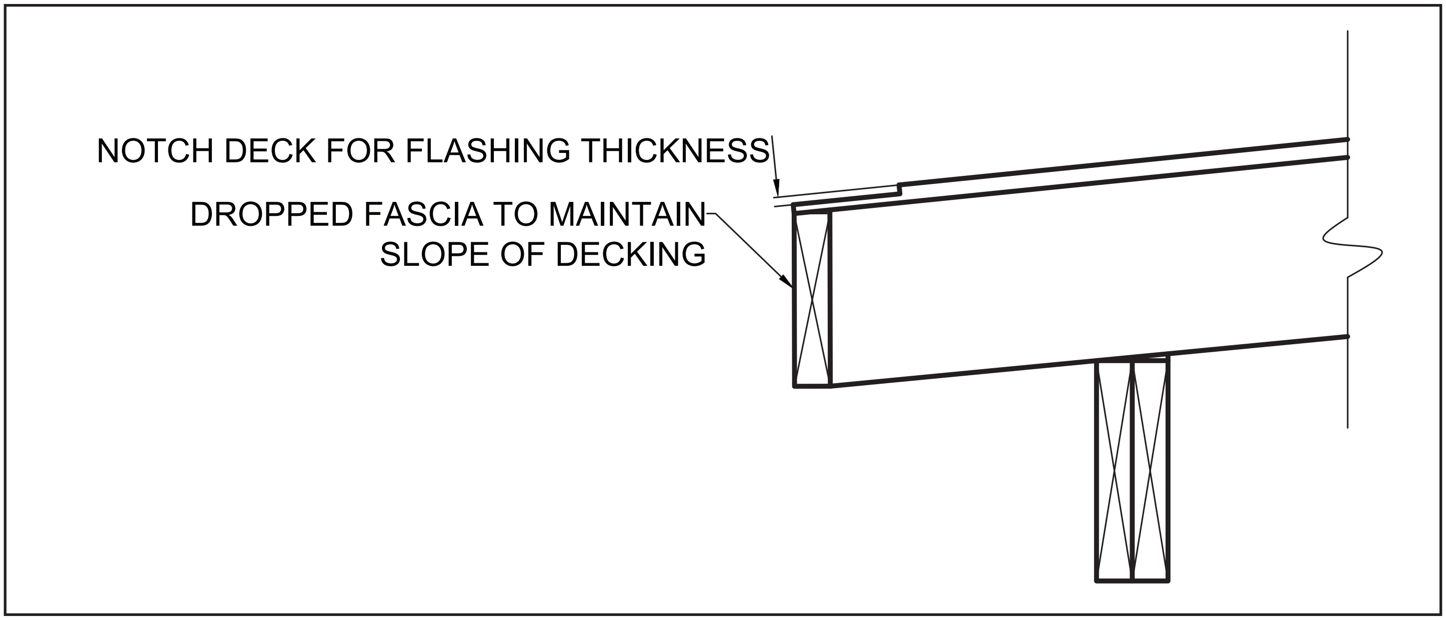

Figure 6: Fascia detail to maintain slope to free drainage edge.

the center as the member deflects downward. Framing members should be oriented and installed to promote water flow toward points of free drainage.

5. Differential Deflection

A system of members with the same span are anticipated to deflect a similar amount. Adjacent members with different spans, however, deflect a different amount; the longer span member deflects more, relative to a shorter span member, and creates a "bowl" that retains water.

The Truss Plate Institute (TPI) recognized this phenomenon and identified differential deflection as a design parameter for metal plate connected wood trusses. TPI Section 2.3.2.4 (g) (4) specifically requires the building designer to specify differential deflection design limits. Differential deflections, however, are not limited to wood trusses and this practice should be adopted to other building components. The design professional should consider material properties of the cover, framing, and ceiling when evaluating an acceptable limit to evaluate differential deflections.

A similar condition exists for structural members installed parallel to a wall supported by a foundation. The design intent is for the wall to be a free drainage location; however, the wall is "rigid" and does not displace downward under load (Figure 5). The structural member adjacent to the wall deflects downward creating a "bowl." For low-slope members adjacent to a "rigid" member, water may begin to accumulate inward of the intended free drainage point.

Construction Practices

Construction practices also contribute to ponding for minimum slope applications. Fascia members are often installed flush to the top edge of the framing member to create a horizontal surface. Detailed fascia members should be shown "dropped" to maintain the slope of the plane (Figure 6).

Flashing is often installed at the boundary with one leg placed on top of the roof or deck substrate. The material thickness at the boundary impedes water discharge (Figure 7). The substrate should be notched to receive flashing members and accommodate material thickness.

These are two examples of a common framing practice that may be found within construction standards and implemented in the field. Material installation or

Figure 7: Component thickness prevents free drainage.

thickness impact low-slope drainage and are often neglected at the time of design or during construction. A design professional should recognize the limits of building code requirements, standard details or practices; in these cases, it is important to provide "best practice" details within the construction documents to mitigate potential ponding and serviceability issues.

Conclusion

Accepted design and framing practices often contribute to serviceability issues with low-slope roof and deck applications. Practices or conditions that inhibit or prevent the flow of water toward free drainage should be identified during the design phase and changed.

Design professionals have the ability to create in-service conditions that diminish ponding and promote free drainage. Slopes should be increased to maintain a sufficient slope to drain at intersecting planes. Framing members should provide the drainage plane and not rely completely on the slope of the topping or finish surface. Additionally, differential deflection of adjacent structural members should be investigated and the appropriate limit assigned to mitigate low areas for water retention.

Framing practices and standard construction details often create high points that inhibit water drainage in low-slope applications. The design professional is encouraged to detail boundary conditions to promote drainage.

Scott D. Coffman, P.E., SECB, has over 35 years in structural wood design, engineered wood building components and forensic engineering experience. This experience includes product testing, field investigations, FRT lumber, construction related problems, building envelope, expert testimony, and product application and serviceability. scottcoffman@constructionscience.org

Resources for Guidance on Mid-Rise Wood Design

Terry Malone, P.E., S.E., WoodWorks – Wood Products Council

Introduction

It's interesting to consider the connecting thread that leads from growing urban populations to policies that favor density while maintaining a 'neighborhood' feel to the architectural response—which has been to design increasingly complex mid-rise buildings. More advanced building shapes and footprints are causing research, full-scale testing, and refinements in methods of analysis to evolve—and this is driving the evolution of design procedures and code requirements for lateral force-resisting systems and materials. Wood is no exception.

Figure 1. The Stella is a luxury mixed-use development in Marina del Rey, California. Designed by Los Angeles-based DesignARC, it includes two wood-frame residential buildings—one with four stories of Type VB construction; the other with five stories of Type IIIA—on a shared concrete podium. The 650,466-square-foot project includes 244 units above 9,000 square feet of ground floor retail space and 578 parking stalls. Photos Lawrence Anderson, www.lawrenceanderson.net.

Engineers of mid-rise wood buildings now commonly face challenges that include increased building heights, fewer opportunities for shear walls at exterior wall lines (e.g., more glass and larger openings), multiple horizontal and vertical offsets, and multi-story shear wall effects. In addition, mid-rise wood buildings frequently require the consideration of a corridor-only shear wall approach to address the lack of capable exterior shear walls.

Among the knowledge that structural engineers must now possess, implementation of a well-considered design requires the understanding of diaphragm and shear wall flexibility and their effects on the horizontal distribution of forces through the structure. It also requires awareness of new methods of analysis, such as that for open-front structures.

Recognizing the pace at which new information is being developed, the goal of this paper is to provide guidance on where to find the best and most current resources available to assist in the design of mid-rise wood structures.

KEYWORDS: Mid-rise, wood design, mass timber, resources

New Territory Even for Experienced Designers

Beyond the engineering challenges associated with more complex geometries is the fact that demand for taller wood-frame buildings is increasing.

Five-story wood buildings have long been permitted in the International Building Code (IBC) for residential occupancies (the IBC allows six stories for offices). However, broad awareness of wood's performance capabilities for taller buildings, along with its sustainability attributes, is relatively new.

Meanwhile, many firms have never designed a wood building over three stories. They may have lacked opportunity or experience, or they may simply have defaulted to other materials out of preference or habit.

It is also common for engineers new to the field to lack wood design expertise. One hundred percent of university architecture and engineering programs teach students how to design buildings in steel and concrete. Just 55% offer curricula related to timber design, and it's typically packaged as an elective. After graduation, this can lead to a deficiency in the ability to perform on projects in a well-rounded firm.

The fact is, designing a five-story wood building is very different than designing a three-story wood building. The differences are easily surmountable—with the right information—but finding the information can be a challenge. Searching the internet without direction can yield more frustration than results.

Key Organizations and Resources

Following is a summary of key organizations and resources.

WoodWorks – Wood Products Council:
http://www.woodworks.org/

WoodWorks provides free project assistance as well as education and resources related to the code-compliant design, engineering and construction of non-residential and multi-family (mid-rise) wood buildings (everything other than single-family homes). Technical staff have expertise in a wide range of subjects, all of which can relate to mid-rise construction, including but not limited to:

- Allowable heights and areas and construction types
- Structural design and detailing of wood-frame and hybrid material systems
- Fire resistance and acoustical-rated assemblies
- Efficient and code-compliant lateral system design
- Alternate means of code compliance
- Energy-efficient detailing
- Application of advanced building systems and technologies
- General product availability

WoodWorks offers project support from design through construction on building types that include multi-family/mixed use (mid-rise), education, office, commercial, industrial, institutional, and public.

Online Resources

There is no specific category or tab assigned to mid-rise construction; rather, most topics on the website can be relevant to this type of structure (e.g. mass timber, timber-frame, fire resistance, shaft walls, etc.). There are six pull-down tabs, three of which provide opportunities for education—Education, Design & Tools, and Publications & Media. The topics listed under these pull-downs are self-explanatory.

- Education – These sub-sections are particularly relevant:
  - o Upcoming Events includes a regularly updated list of events offered nationwide, including webinars, with many focused on mid-rise wood design.
    - Examples include Shaft Wall Solutions for Wood-Frame Structures, Mid-Rise and Taller Wood Buildings, and Designing Wood-Frame Structures for High Winds.
    - Participants can earn AIA/CES, PDH or ICC credits for attending events or webinars.
    - To be alerted to events in your region, sign up for e-blasts via the "Stay Informed" button on the home page.

- o Webinar Archive includes past webinars, which can be watched for free (though not for credit).
  - Examples related to mid-rise as well as other structures include Code-Compliant Fire-Resistance Design for Wood Construction, Practical Design Methods for Diaphragms with Openings, and High-Performance Wood Structures: An Example of Increased Efficiency in Multi-Family Construction.
- o Presentation Slides Archive features PDFs (slides only) of presentations by in-house and third-party experts. These can be extremely useful as a reference. Scrolling through the list will show a large number of mid-rise-specific titles and other related topics.
- o CEUs (video and print) can be watched or read for credit.

Design & Tools

This pull-down menu has four topics—Building Types, Building Systems, Design Topics and Design Tools.

- Sub-sections within each topic relate to mid-rise wood buildings (e.g., Mid-Rise/Multi-Family within Building Types).
- Each subsection includes a page of links to relevant publications, videos, webinars, and other resources.
- Within Design Topics, the Ask an Expert section is a technical Q&A with detailed answers on specific aspects of wood design. A new Q&A is announced each month on the home page (and via social media), and a high percentage of questions have to do with wood-frame structural design.
  - o Examples include: Can live load reduction be used on wood-frame bearing walls? Can wood structural panels be added to an acoustically-tested wall assembly? What are the design considerations where a shear wall requires multiple layers of shear resistance?
- Design Tools is worth exploring as it includes links to online calculators (such as the Heights & Areas Calculator App developed in partnership with the American Wood Council), span tables, and CAD/REVIT details.

Publications & Media

This is where you'll find case studies, design examples, wood solution papers, and research papers. Examples related to mid-rise design include:

- Design Example: Five-story Wood-Frame Structure over Podium Slab – This 80-page publication provides guidance on how to structurally design a five-story wood-frame building. It includes discussions of code related requirements, vertical shrinkage, and seismic and wind design.
- Solution Paper: Accommodating Shrinkage in Multi-Story Wood-Frame Structures – This paper describes procedures for estimating wood shrinkage and provides detailing options that minimize its effect on building performance.
- Solution Paper: Options for Brick Veneer on Mid-Rise Wood-Frame Buildings – This technical paper provides guidance and solutions for exceeding the prescriptive 30-foot height limitation for brick veneer.
- Solution Paper: Maximizing Value with Mid-rise Construction – This paper offers guidance for the selection of building configurations for mid-rise construction, and considers structural design challenges associated with fire safety, shrinkage, vibration and sound control.
- Case Studies – Case studies of five-story wood buildings currently include the Crescent Terminus project in Atlanta, GA, The Stella in Marina del Rey, CA, University of Washington Student Housing in Seattle, WA, and the Marselle Condominiums, also in Seattle. For a heavy timber contrast, there is a case study of the six-story Bullitt Center in Seattle, which has been described as the 'greenest commercial building in the world.'
- All downloads are free of charge.

Free Project Assistance

Visit the WoodWorks website to find a technical expert in your region. Contact information for the regional director nearest you can be found at: www.woodworks.org/project-assistance.

Ask a Question / Help Desk

WoodWorks' team of experts can answer your technical questions and provide solutions to issues that arise. This service is offered free of charge. Email: help@woodworks.org

American Wood Council (AWC): http://awc.org/

AWC is committed to ensuring a resilient, safe, and sustainable built environment. The organization contributes to the development of sound public policies, codes, and regulations which allow for the appropriate and responsible manufacture and use of wood products. AWC supports the utilization of wood products by developing and disseminating consensus standards, comprehensive technical guidelines, and tools for wood design and construction, as well as providing education regarding their application. Many of AWC's offerings are directly relevant to mid-rise construction.

Code-Referenced Standards

AWC develops ANSI standards that are adopted by reference in the International Building Code (IBC) and the International Residential Code (IRC):

- National Design Specification® (NDS®) for Wood Construction
- Special Design Provisions for Wind and Seismic (SDPWS)
- Wood Frame Construction Manual (WFCM) for One- and Two-family Dwellings

All are available in print or electronic format and include commentaries and other supporting documents.

Education

AWC provides online and live contact training to support implementation of building codes and standards through two avenues: independent eCourses and live presentations. AWC has partnered with the following organizations to provide continuing education credits:

- International Code Council (ICC) Education Preferred Provider Program
- American Institute of Architects (AIA) CES Program
- National Council of Structural Engineers Associations (NCSEA) Diamond Review Program

Online Resources

There are several areas of the AWC website applicable to mid-rise construction:

- Codes & Standards – Includes publications, calculators, building code information, and fire safety.
- Sustainability – Includes information on green building standards such as Green Globes and LEED, Environmental Product Declarations, and resiliency topics.
- Education – This tab directs visitors to additional links that provide information on upcoming webinar and live events, eCourses, and options for live presentations. On-demand eCourses are searchable by category such as those related to AWC standards, building codes, design considerations, and materials.
- FAQs – Includes topics such as AWC standards, building codes, green building, materials, and fire safety.
- Fire Safety – Includes information on designing for code acceptance, construction fire safety practices, mass timber, fire research, and firefighter resources.
- Tall Wood – Includes information on mass timber buildings that exceed current height limits of the IBC such as research, code developments, and educational offerings.
- Quick Links: This tab is located on the Home page, where calculators, publications, fire safety, code official connections and tall wood pages can be accessed.

Helpdesk

AWC's helpdesk provides support to the standards and related technical documents it develops. Contact: info@awc.org

Think Wood www.thinkwood.com

Think Wood, which represents North America's softwood lumber industry, offers resources from a wide variety of organizations, including but not limited to Woodworks and AWC. Although not focused on wood-frame construction, designers of mid-rise wood buildings may be interested in the organization's Mass Timber Research Library, which is continually updated to provide the latest information on mass timber products and building systems.

USDA Forest Service Forest Products Lab (FPL)
www.fpl.fs.fed.us/
FPL is world renowned among forest products research organizations and an unbiased source of information. Areas of research range from fiber and chemical science to composites, and research of significance to designers of wood buildings is often available via the WoodWorks education program. Of particular interest to designers of mid-rise buildings is the Wood Handbook – Wood as an Engineering Material, available on the FPL website.

FPInnovations (FPI): https://fpinnovations.ca/Pages/index.aspx
FPInnovations is a not-for-profit organization specializing in the creation of innovative scientific solutions in support of the Canadian forest sector's global competitiveness. It performs state-of-the-art research, develops advanced technologies, and delivers innovative solutions to complex problems for every area of the sector's value chain, from forest operations to consumer and industrial products.

In the context of this paper, FPInnovations offers publications on shear walls with multi-story effects, an important method of analysis that is expected to be added to the IBC. Research papers and reports can be found on the website under Research/Advanced Building Systems tab.

Other References and Resources

If you have questions regarding a specific topic area (e.g., fire resistance/protection, lumber shrinkage, fastener durability, insects and decay, water intrusion, fabrication best practices, etc.), the WoodWorks help desk can suggest relevant resources.

An abundance of information on wood design can also be found in the following publications:

1. International Building Code. 2012 and 2015. International Code Council, Washington, DC

2. The Analysis of Irregular Shaped Structures: Diaphragms and Shear Walls: Malone, Rice-McGraw-Hill/ICC

3. Design of Wood Structures ASD/LRFD.-D.E. Breyer, J.F. Fridley, D.G. Pollock, and K.E. Cobeen-McGraw-Hill, New York, NY.

4. American Wood Council (AWC). 2015. Special Design Provisions for Wind and Seismic with Commentary (SDPWS-15). 2015 ed., AWC, Leesburg, VA.

5. SEAOC/IBC Structural Design Manual, Volume 2. 2012. Structural Engineers Association of California. Sacramento, CA

6. American Wood Council (AWC). 2015. National Design Specification for Wood Construction and Supplement. 2015 ed., AWC, Leesburg, VA.

7. APA-The Engineered Wood Association. 1997. Plywood Design Specification, APA Form Y510T, APA-The Engineered Wood Association, Engineering Wood Systems. Tacoma, WA.

8. APA-The Engineered Wood Association. 2004. Design/Construction Guide-Diaphragms and Shear Walls., APA Form L350, APA-The Engineered Wood Association, Engineering Wood Systems. Tacoma, WA.

9. APA-The Engineered Wood Association. 2000. APA Research Report 138, Plywood Diaphragms., APA Form E315H, APA-The Engineered Wood Association, Engineering Wood Systems. Tacoma, WA.

Conclusion

For building designers new to wood design or seeking to expand their portfolio with taller wood-frame buildings, help is out there—in abundance. Most of the publications and resources presented above are free to download, and WoodWorks experts are available to answer questions and help resolve technical issues.

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