WoodWorks

CaseStudy

Wood Buildings Aim High

Benefits and Engineering Challenges of Podium Design

Worldwide, there is a trend toward the construction of taller wood buildings. At the high end of the scale are structures being made from cross-laminated timber, or CLT, such as the UK's Stadthaus building, which includes eight stories of wood over one story of concrete. While CLT is not yet widely used in North America[1], four-to-six-level wood buildings are common and the evolution upward seems inevitable.

The Rising Popularity of Podium Design

In North America, "podium" buildings, which include multiple stories of wood over an elevated concrete "podium deck," have become especially prevalent. With ever-increasing land costs and the rising cost of steel and concrete, developers are turning to wood designs that offer greater density and a higher percentage of rentable square footage than traditional garden-style apartments while also being cost-effective—both in terms of material and labor. Wood's other benefits, such as speed of construction, design flexibility, and reduced environmental impact add to the value proposition.

Rob Salkovitz is vice president of construction for Avalon Bay Communities, which developed the five-story Avalon Anaheim Stadium. Designed by Withee Malcolm Architects, the project includes 251 apartments and 13,000 square feet of retail and restaurant space over the podium deck and two levels of subterranean parking. Over the past five years, he says, podium design has increased in popularity to the point that it currently represents about 25 percent of Avalon's projects nationwide and 55 percent in Southern California. "The main advantage from our perspective is density. You can go right to the property line and end up with 140 units on an acre of land."

California-based engineer Tom VanDorpe, SE, whose company VanDorpe Chou Associates (VCA) worked on the Avalon Anaheim Stadium, says VCA's wood-framed podium structures average about 200 units but can be smaller or significantly larger. "The biggest we've been the engineer of record for was 1,500 units on two podiums connected by an underground tunnel that had about 1.4 million square feet of elevated deck."

What the Code Says

According to the *International Building Code* (IBC), the wood-framed portions of multi-family podium structures may be Type V or Type III Construction, both of which have basic limitations with regard to height, number of stories and square footage. For example, in the Residential Group R category, per IBC Table 503, a building with Type III-A Construction is permitted to be 65 feet and four stories, while a Type V-A building is permitted to be 50 feet and three stories. However, per IBC 504.2, the addition of an approved NFPA 13 automatic sprinkler system means designers have the option of another story and up to 20 extra feet in building height. On the structural side, ASCE 7-05 allows earthquake-resisting lateral systems of wood structural sheathing to a height of 65 feet, which may govern in areas of high seismicity.

One issue that can impact the height measurement is the elevation of the grade plane. For structural purposes, height can be determined beginning at the podium, but this is not true for the architectural height. Per section 502 Definitions, the IBC considers grade plane to be the average finished grade at exterior walls, and finished grade to be the lowest point between the building and the property line or 6 feet, whichever comes first. Local jurisdictions may also have their own requirements.

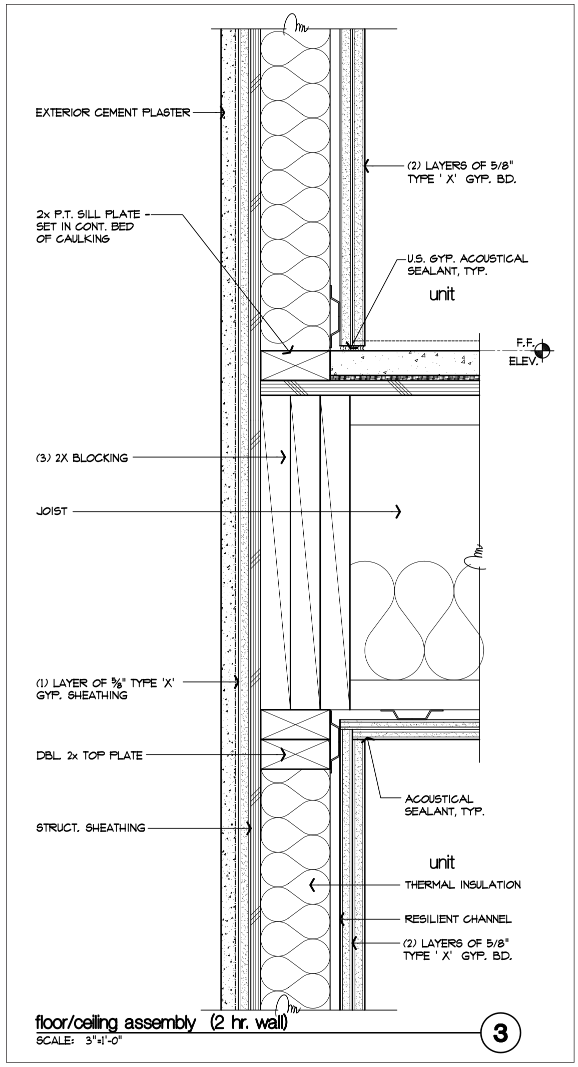

Photo: Arden Photography

For Avalon Bay Communities, which developed the Avalon Anaheim Stadium project, podium structures represent approximately 25 percent of projects nationwide and 55 percent in Southern California.

It is partly because of the building height issue that the apartment complex at 870 Inman in Atlanta's upscale Inman Park has four stories instead of five as initially intended. "The building is on a hill with a steep grade change and there was some debate over where the grade plane for determining building height should be located," says Matthew Church, PE, principal with Davis & Church, LLC in Georgia. "In the end, the decision was made to make it a four-story Type V building, but to create as much height in each of the stories as possible."

"There are nuances to the application of number of stories versus building height," says VanDorpe, who recommends working with a specialist (e.g., an architect who specializes in this area or an expert in fire protection engineering). As was the case with the Avalon Anaheim Stadium project, structures may be Type III "modified," which means that building officials have allowed certain trade-offs to achieve the required level of performance. Examples may include more compartmentalization as an added measure of fire protection, increasing the fire protective capacity of walls and corridors, and pressurizing stairwells. These enhancements have been used to justify increases to allowable building height or area, or to lessen the requirements for fire protection in other areas of the building where it can be shown that the alternate results in equivalent overall performance.

"A Type III building can have six or even seven 'levels' of wood-frame construction providing the level qualifies as a mezzanine and not a story," he says, referring to section 505 of the 2006 IBC. "There's also the issue of different acceptability in different jurisdictions. It's complex, but there are tremendous possibilities with this type of structure."



Alternate detail example showing platform framing where the exterior wall is 2-hour rated and the floor is 1-hour rated. Under the IBC, FRT wood is required for exterior walls in Type III buildings.

ENGINEERING CONSIDERATIONS

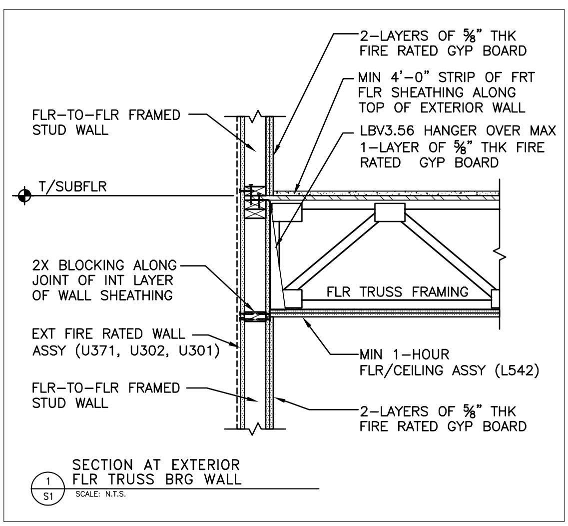
Framing Type

Platform framing, where the joists sit on top of the double top plates of the wall, is the most common type of framing for Type V wood-framed structures.

For Inman Park, Davis & Church used 11 7/8-inch engineered I-joists. "The design team chose a shallower engineered I-joist as a way of maximizing headroom without exceeding the local building height restrictions. This required fur downs along the perimeter of some of the rooms to accommodate mechanical duct runs but it also allowed for 10-foot ceilings, giving the owner the 'condominium feel' he was after."

Likewise, The Quarter in Towson, Maryland also featured platform construction. Comprised of three separate four-story wood buildings, two of which sit on a 50,000-square-foot post-tensioned concrete podium deck, the project used 18-inch deep open web trusses. "The ceilings were 9 feet with no fur downs since the open web truss system allowed for mechanical and exhaust ducts to run through the floor cavity," said Church.

In contrast, modified balloon framing—where the floor framing hangs off the double top plates—is often used as an alternate to platform-framed structures.



Credit: Davis & Church, LLC

Detail example for a Type III building where the exterior wall must be 2-hour rated and the floor is 1-hour rated.

As an example, the Avalon Anaheim Stadium project was framed with 16-inch open web wood joists at 24 inches o.c., with the top chord bearing on modified balloon framed walls and bottom chord bearing on walls at the interior of the units.

"In a Type V-A building, both the wall and floor are typically 1-hour rated," says Church. "Therefore, the 1-hour envelope is easily maintained with the floor framing bearing directly on top of the wall. However, in a Type III building, if that exterior wall is load bearing, it must be 2-hour rated while the typical unit floor is still 1-hour rated. If the bottom chord of the truss/joist sits directly on the wall, it can be challenging to maintain the 2-hour vertical envelope across the depth of the floor. In addition, anything that penetrates the wall envelope must meet the building code definition of non-combustible material. To maintain this continuous 2-hour envelope and satisfy the code requirements, we pull the truss back off the wall, extend the wall and sheathing and support the floor framing off the double top plate using a hanger designed to span over one layer of 5/8-inch fire-rated gypsum sheathing. This single layer of gypsum maintains the 1-hour wall rating through the floor and when coupled with a 1-hour floor system yields a total of two hours of protection across the depth of the floor. This approach has been well received by building officials and plan reviewers on all of our Type III projects."

Species and Grade

The lateral design of any wood structure is impacted by the species and grade of wood used, so it's important to know early in the project if the contractor has certain preferences or limitations with regard to local availability.

As an example, Church highlighted a five-story Type III project his firm worked on in Chicago, where the contractor chose a mix of Douglas fir and Spruce-Pine-Fir (SPF). "In this case, the contractor was able to take advantage of efficiencies by mixing species that were locally available at a good price. We designed floors one and two in Douglas fir, because these stories carry significantly higher gravity loads, and floors three through five in the lighter and less dense SPF. When you're doing the initial calculations, it's important to know what's locally available and to understand local contractor preferences to avoid having to rethink elements of the design later. Also, when mixing species of wood, particularly stud material, inspection becomes critical to ensure that material with less strength or capacity doesn't end up in areas where a stronger and denser species and/or higher grade is required."

Concrete/Wood Interface

One of the challenging aspects of a podium structure is designing the interface between the upper portion of the building (wood superstructure) and the lower portion (podium slab).

In terms of load transfer, there is some confusion as the code may be interpreted as requiring podium slabs to have the design strength to resist the maximum axial force that can be delivered or per the load combinations with the overstrength factor in ASCE 7-05 section 12.4.3.2. However, commentary to ASCE 7-05 says the overstrength factor need not be applied where it can be shown that yielding of other elements (diaphragm, collector, etc.) will occur below the overstrength level forces. (For additional information, please see pages 48 and 49 of the WoodWorks design example, *Four-story Wood-frame Structure over Podium Slab*.[2])

Photo: Matt Church

A high degree of coordination is needed among the many trades involved in a podium structure.

There are also constructability considerations, especially in a post-tension poured-in-place design, because there is so much going on in the slab—including (among other things) the post-tension tendons, rebar, utilities, embed plates, additional steel at the top of columns, additional steel at raised curbs, block-outs and drainpipes.

"When you drill into a post-tensioned concrete slab, you have to know exactly where you are or you risk serious injury by cutting a tendon and suddenly releasing 15 tons of compressive force," says Church. "You have to find a way to isolate post-installed anchors from the tendons. One of the things we've had success with in the past is the use of wire cages. They're fastened to the bottom of the form to indicate where the shear wall end anchorage needs to go and the tendons are placed around them. This creates the necessary clearance for the anchor while providing full benefit of the concrete slab for uplift resistance." A similar technique was used on both the Inman Park project and The Quarter.

A related challenge, says VanDorpe, is ensuring coordination among the many trades involved in a podium structure. "Much of the complexity and needed coordination are due to the presence of the transfer slab, which is the interface for the architectural, structural, waterproofing, landscaping, mechanical, electrical and plumbing consultants, as well as the work of the concrete, framing, landscaping, mechanical, electrical and plumbing contractors. In the most successful projects there is a high degree of collaboration among these players, and it can also be helpful to combine some of these tasks."

Two-stage Design

Both Church and VanDorpe use two-stage analysis for lateral design, which enables them to treat the flexible upper portion of the structure (wood-frame) and rigid lower portion (concrete) as separate buildings. A widely used approach, two-stage analysis provides an alternative to having to design the entire structure for the same seismic response coefficient R, which would mean (among other things) designing the upper portion for a minimum of 30 percent higher forces.

Referred to in ASCE 12.2.3.1, a two-stage approach is permitted in the IBC and *California Building Code* (CBC) providing certain criteria are met—e.g., stiffness of the lower portion is at least 10 times the stiffness of the upper portion, and the period of the entire structure is not greater than 1.1 times the period of the upper portion. A complete summary of criteria can be found in the WoodWorks design example.[2]

Rigid or Flexible Analysis

Another consideration is whether to use semi-rigid or flexible diaphragm analysis to determine shear distributions to the shear walls.

Explaining the pros and cons of each, Michelle Kam-Biron, SE, a technical director with WoodWorks in California, says—"The code has prescriptive and calculated requirements for classifying a wood diaphragm as semi-rigid or flexible. Flexible analysis is more straightforward. On the downside, it may not reflect the actual conditions—based on the span-to-depth ratios and shear walls—to consider diaphragms as flexible where they could behave more rigidly, which would result in an underestimation of the interior loading. Semi-rigid analysis, which includes consideration of both flexible and rigid analysis, allows designers to take advantage of rigid portions of the building and some engineers think it offers more leeway in laying out shear walls. But it's also a more complex procedure."

To meet the code requirements for a semi-rigid diaphragm assumption, many engineers combine the two approaches and design for worst-case loads. This approach is known as envelope design and is often recommended, though VanDorpe says it results in more shear walls than necessary because it combines the worst case results of both models. Both models have shortcomings based on assumptions that facilitate the calculation but don't indicate the real behavior of the building.

Although VanDorpe believes a well chosen shear wall scheme is essential to good seismic performance, he says it is equally true that a code-compliant shear wall scheme can result in poor performance. "Shear wall placement is an art as much as a science. Whatever

Photo: Matt Church

To make The Quarter compatible with the neighborhood architecture, the fourth floor was designed to give the illusion of a three-story building with mansard roofs and attic windows.

analysis you choose is an idealized mathematical representation required by the code and cannot replace the experience and judgement gained by following patterns of earthquake damage that occur."

Tie-down Systems

For multi-story wood structures, continuous tie-down systems offer several advantages over conventional

Credit: VanDorpe Chou Associates, Inc.

tie-downs, such as ease of installation and the achievement of higher uplift capacities. Both systems are discussed in the WoodWorks design example.[2]

While conventional straps and tie-down anchors were used for the Inman Park project, The Quarter featured a continuous tie-down system for both shear wall end anchorage and roof truss uplift due to wind. Church says this system is becoming increasingly popular among contractors because it avoids some of the traditional floor-to-floor connections. "Instead of using straps and hold-down connections at every floor, we're often able to design a single piece of high-strength steel threaded rod for multiple floors before anchoring the ends or installing additional anchorage. It is of particular benefit in moderate to low wind and seismic areas."

One disadvantage to the continuous tie-down system is that it is an in-wall system, whereas the conventional straps are applied to the outside of the wall. On taller buildings with lots of openings, says Church, the cavities along the sides of doors and windows can quickly disappear due to the increased number of jamb or king studs required, leaving little or no room to install the anchor.

Shrinkage

Where wood walls and bearing partitions support more than two floors and a roof, section 2304.3.3 of the IBC requires an analysis to ensure that shrinkage of the wood framing will not have adverse affects on the structure, plumbing, electrical or mechanical systems, or other equipment. The analysis must also show that the roof drainage system will either not be affected or be designed to accommodate the differential.

According to Church, a typical four-story wood building utilizing floor trusses and platform construction is teetering on "I need to do something about shrinkage territory," whereas, at five or six stories, shrinkage can definitely have an effect over time.

"The biggest impact we've experienced is at the interface between the structural elements and building finishes such as brick or stucco," he says. "If we don't provide for enough movement around windows and doors, we can end up with a multitude of problems as the structure shrinks and the finish either remains the same or expands due to heat and moisture exposure. Other areas of concern include horizontal duct runs, piping, non-wood fire wall separations, cementitious floor toppings, etc."

With the four-story Inman Park project, the engineered lumber used for the floor joists lessened the shrinkage value to the point that it was almost insignificant. However, The Quarter project included dimensional lumber chords for the floor trusses, which led to an increase of more than 50 percent of the estimated shrinkage potential.

"Shrinkage calculations aren't complex," says Kam-Biron, "but it's an area designers often overestimate, which makes it difficult to detail for differential movements. With sawn lumber, the majority of shrinkage occurs in the cross grain direction. Therefore, the majority of shrinkage will occur in the top plates, sill plate and sole plates, and possibly the floor joists—depending on how the floor framing members are framed to the wall. If the framing is modified balloon, then sawn lumber joists won't play a

Photo: VanDorpe Chou Associates, Inc.

To accommodate potential shrinkage, engineers must allow for adequate movement between the structural elements and building finishes such as masonry veneer.

Credit: Matt Church

In addition to its cost-effectiveness, wood's other benefits—such as speed of construction, design flexibility, and reduced environmental impact—add to the value proposition.

huge role in overall shrinkage."

For more information, a free shrinkage estimator is available from the Western Wood Products Association at www.wwpa.org.

Construction Types and Fire Resistance

In a Type III wood building, the IBC requires the use of fire-retardant treated (FRT) wood for exterior walls. In a Type V building, FRT wood is not required.

Fire-rated assemblies can be found in a number of sources including the IBC, the Underwriters Laboratories (UL) *Fire-resistance-rated Systems and Products*, the UL *Fire Resistance Directory*, the Gypsum Association's *Fire Resistance Design Manual*, and the American Wood Council's (AWC) *DCA 3: Fire-Rated Wood-Frame Wall and Floor/Ceiling Assemblies*.

Table 720.1(2) of the IBC lists fire ratings for various wall construction types. Both the architect and engineer should be aware that some of the wall construction types using wood construction reference footnote 'm.' Footnote 'm' of the table requires the reduction of F'_c to be 78 percent of the allowable with a maximum slenderness ratio l_e/d of 33.

AWC has also tested a number of wood-frame fire rated assemblies that do not require the reduction and are included in IBC Table 720.1(2). A description of these wall assemblies is contained in DCA 3.

According to VanDorpe, who used FRT wood on the Avalon Anaheim Stadium project, FRT products made by different manufacturers vary considerably in terms of their adjustment values, such as compression perpendicular to grain, sill plate crushing, fasteners, and connectors. He recommends that engineers be familiar both with their local suppliers and framing contractor preferences.

Engineering Support for Multi-story Wood Buildings

Through WoodWorks and its partner organizations, design professionals using wood for non-residential buildings have numerous avenues for free technical support. Visit woodworks.org for a list of technical directors available for one-on-one support as well as online resources such as design examples, case studies, webinars, CAD/REVIT details, and more.

[1] Efforts are underway to make cross-laminated timber widely available in the United States and Canada.

[2] Design example – *Four-story Wood-frame Structure over Podium Slab*, developed for WoodWorks by Douglas S. Thompson, PE, SE, SECB, STB Structural Engineers, Inc., 49 pages, available at http:// www.woodworks.org/Publications/caseStudies.aspx

Owner: Mech Properties
Architect: Brown Doane Architects, Inc.
Structural Engineer: Davis & Church, LLC

870 Inman Park Condominiums

Atlanta, GA

The Inman Park project features four stories of wood over two levels of post-tensioned concrete, which separate the residential units above from two levels of parking below. This upscale development includes 110 condominium units specially designed to fit into the eclectic Inman Park neighborhood, Atlanta's first in-town suburb. Additional features of this project included the design of a ground level restaurant, retail and office space that project out from the building.

Owner: Lane Northeast
Architect: Poole & Poole Architecture
Structural Engineer: Davis & Church, LLC

The Quarter Apartments

Towson, MD

The Quarter includes three separate four-story wood buildings. Two of the structures rest on a 50,000-square-foot post-tensioned concrete podium deck, which separates ground level parking from 150 high-end residential apartment units. To address concerns that four-story buildings would be incompatible with the adjacent single-family homes, the design team lowered the roof line from the attic space to the fourth floor and added a wall at a pitched angle along the outside of the fourth floor to match the line of roof trusses above. This created the illusion of three-story buildings with mansard roofs and attic windows, which not only satisfied the concerns of local residents but lowered costs thanks to reduced framing and the removal of false windows and dormers.

Owner: Avalon Bay Communities
Architect: Withee Malcolm Architects
Structural Engineer: VanDorpe Chou Associates, Inc.

Avalon Anaheim Stadium

Anaheim, CA

A mixed-use project, Avalon Anaheim Stadium includes 251 luxury apartment units and 13,000 square feet of retail and restaurant space over a 210,000-square-foot podium deck with two levels of subterranean parking. It is located in the heart of Anaheim's Platinum Triangle district.

Cover photos: Matt Church (large); VanDorpe Chou Associates, Inc. (small)
This page: Matt Church (top and center); Arden Photography (bottom)

WoodWorks is an initiative of the Wood Products Council, which includes all of the major North American wood associations.